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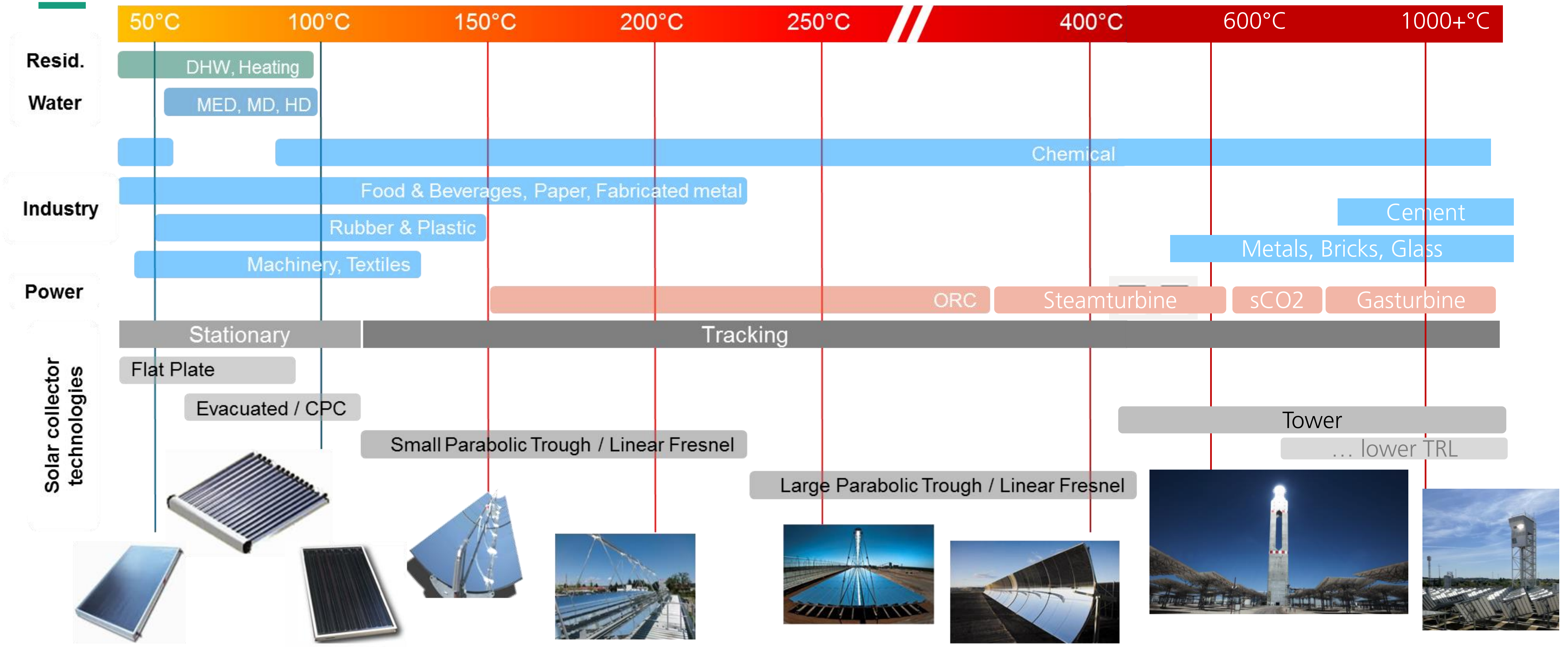
Gregor Bern

Freiburg, November 07, 2023

Optical Characterization of Collectors

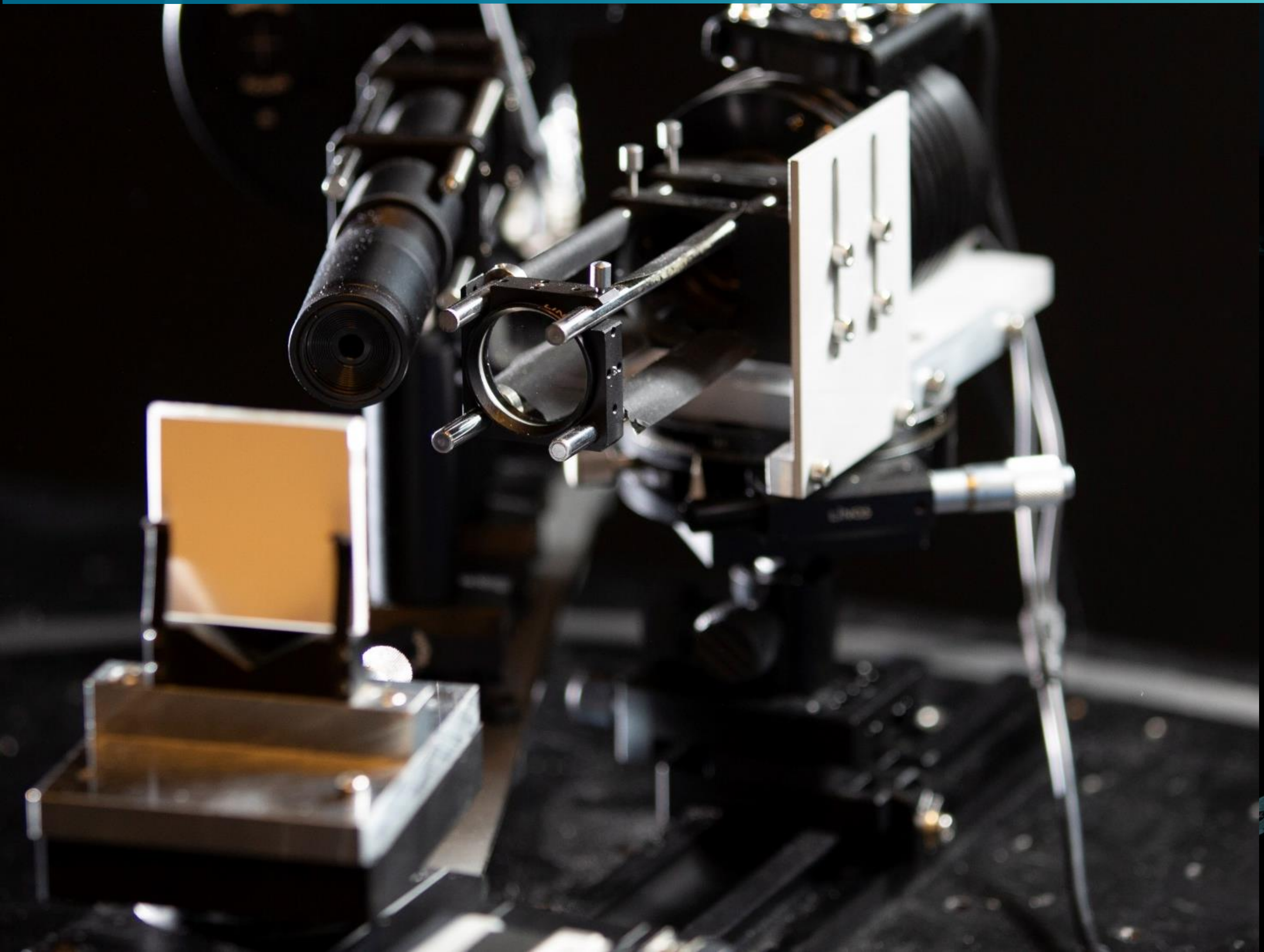
Solar Collector Solutions for Various Applications

Technology vs. Temperature

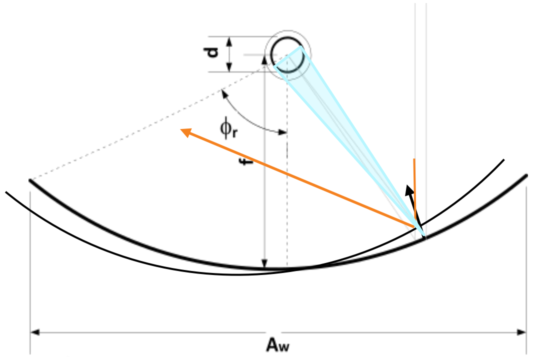


Concentrating Collectors and Optics

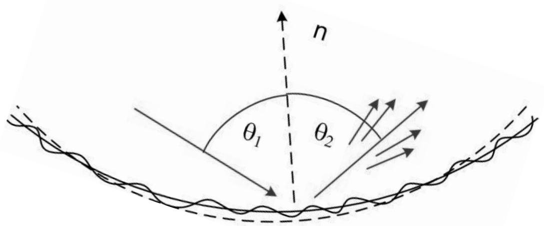
Measuring equipment and techniques



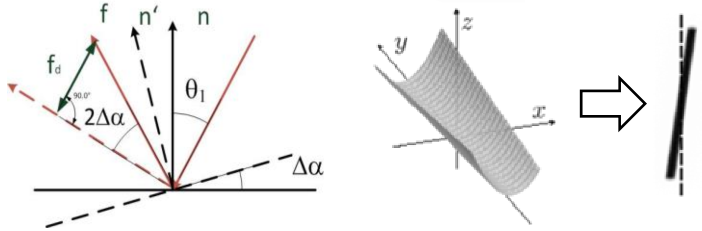
Macroskopic Shape Assessment



Canting + Tracking Deviations

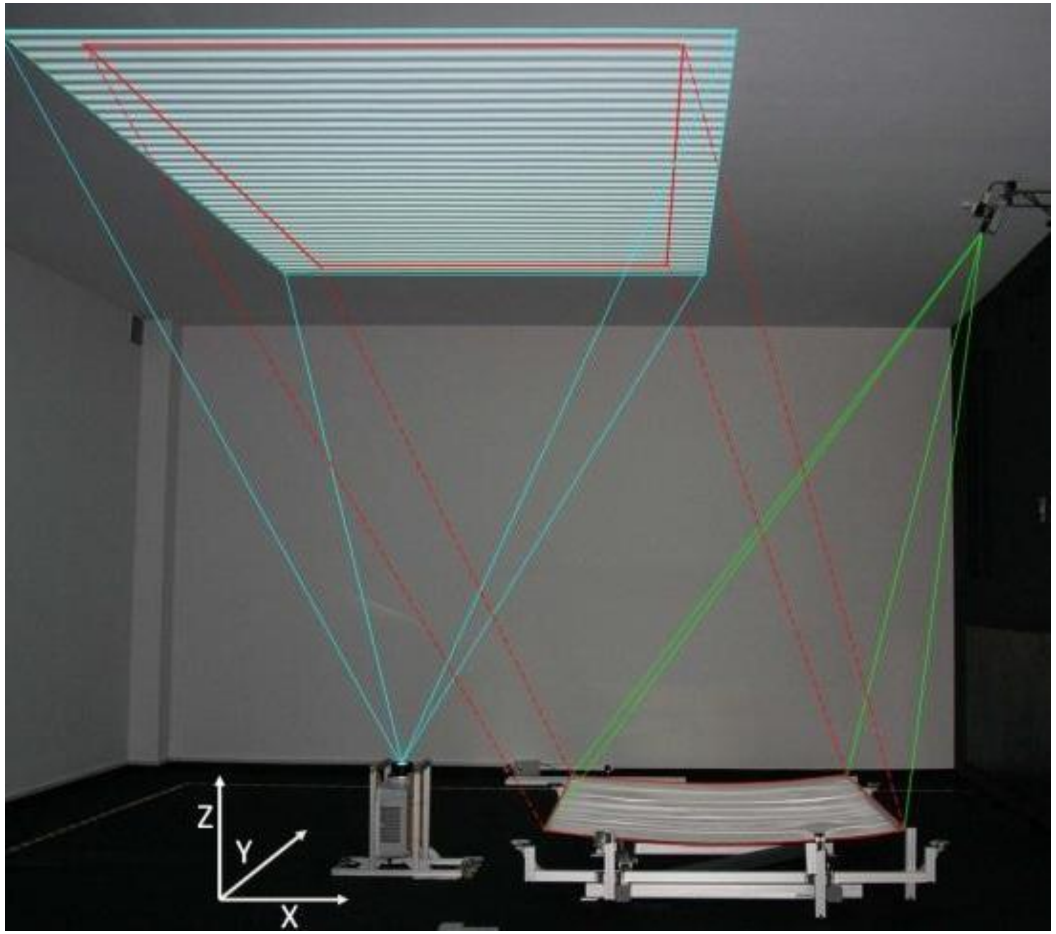


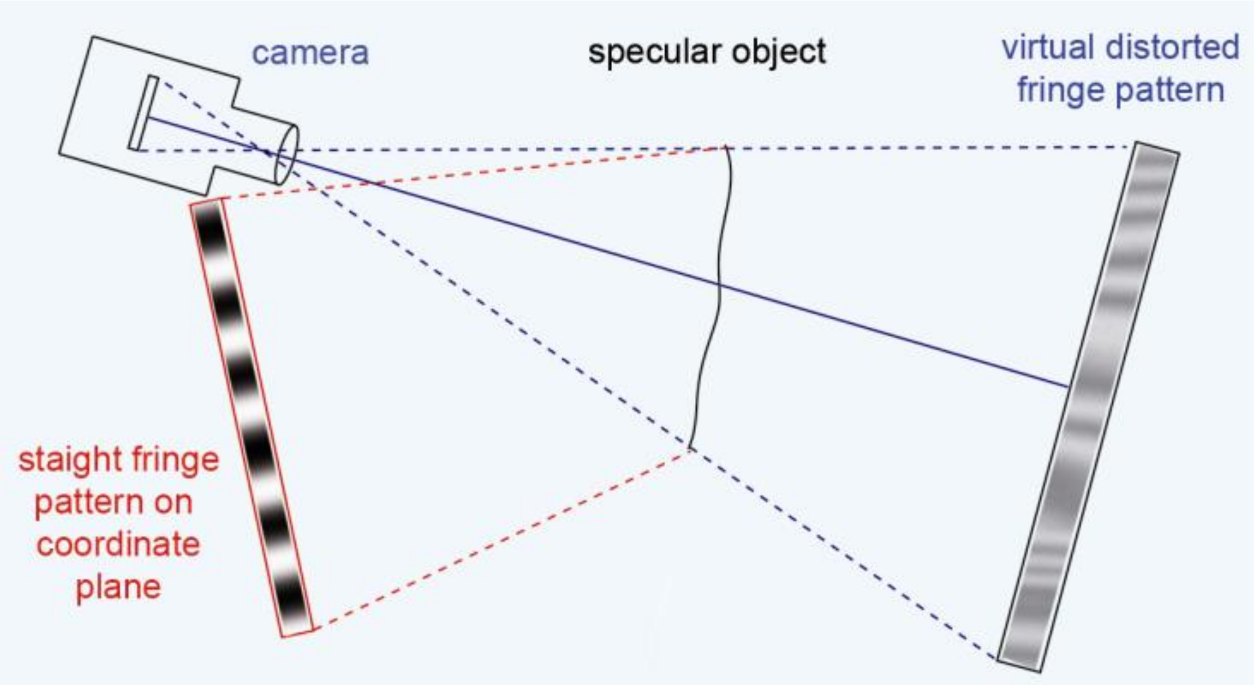
Surface Waviness



Slope deviations

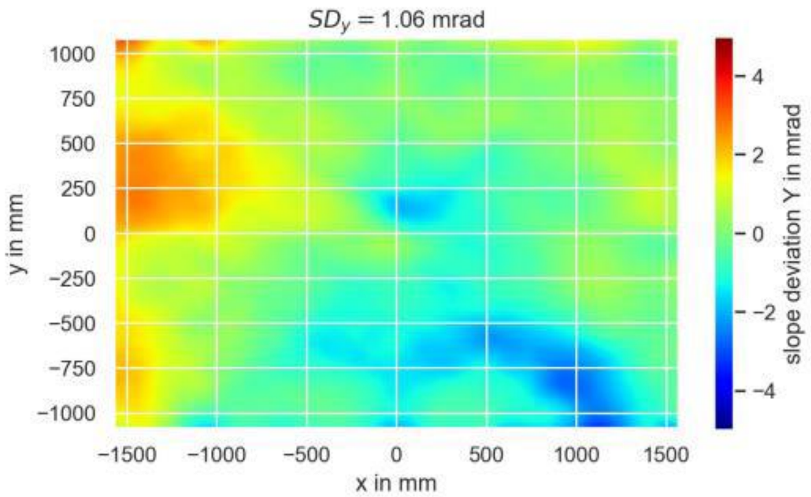
Deflectometry
Primary Reflector Assessment

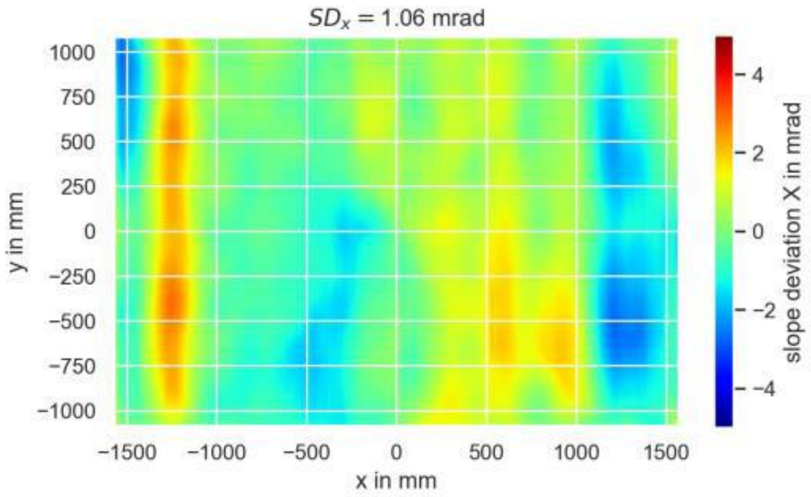


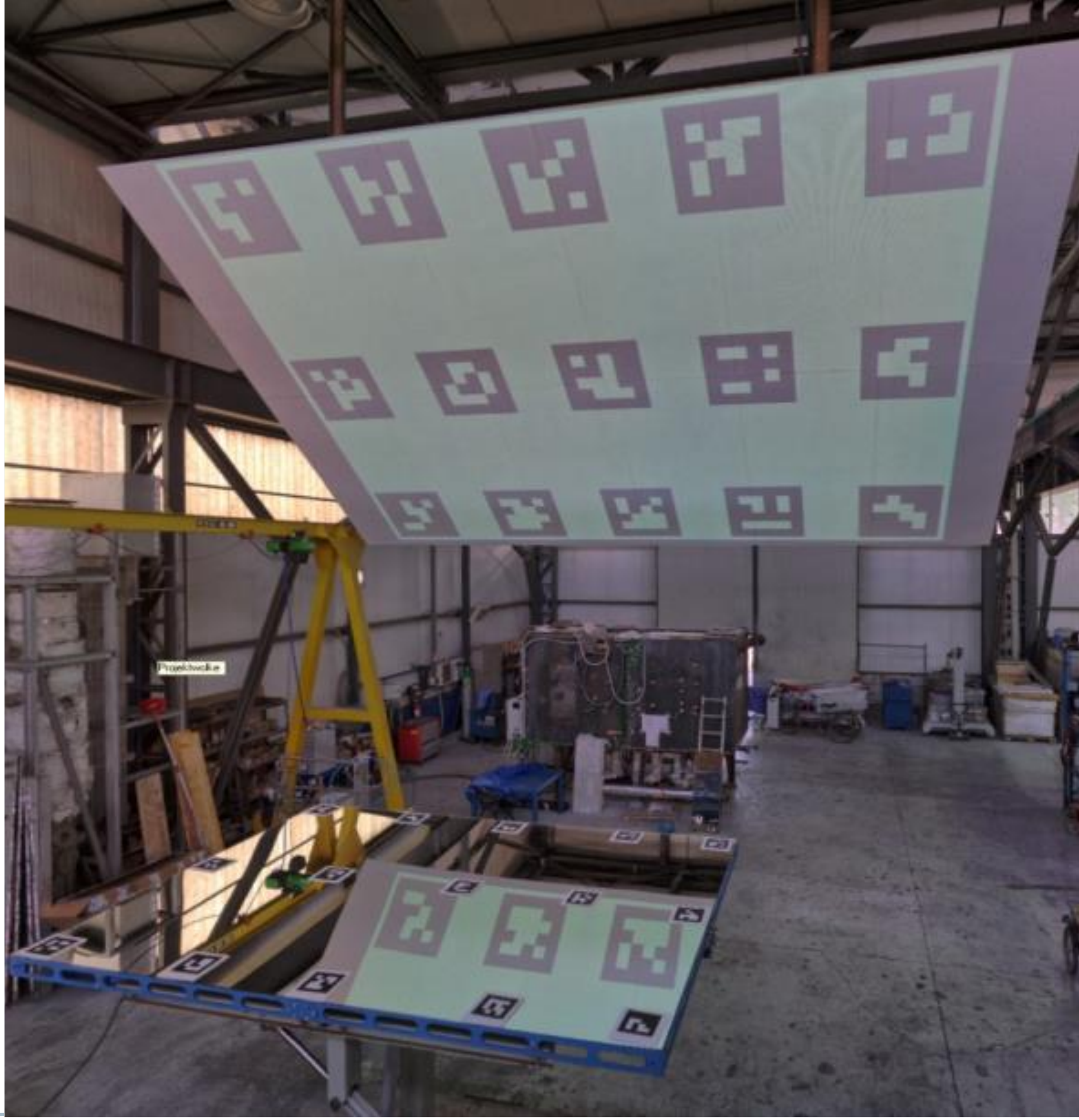

camera
specular object
virtual distorted fringe pattern
staight fringe pattern on coordinate plane

Deflectometry

Primary Reflector Assessment





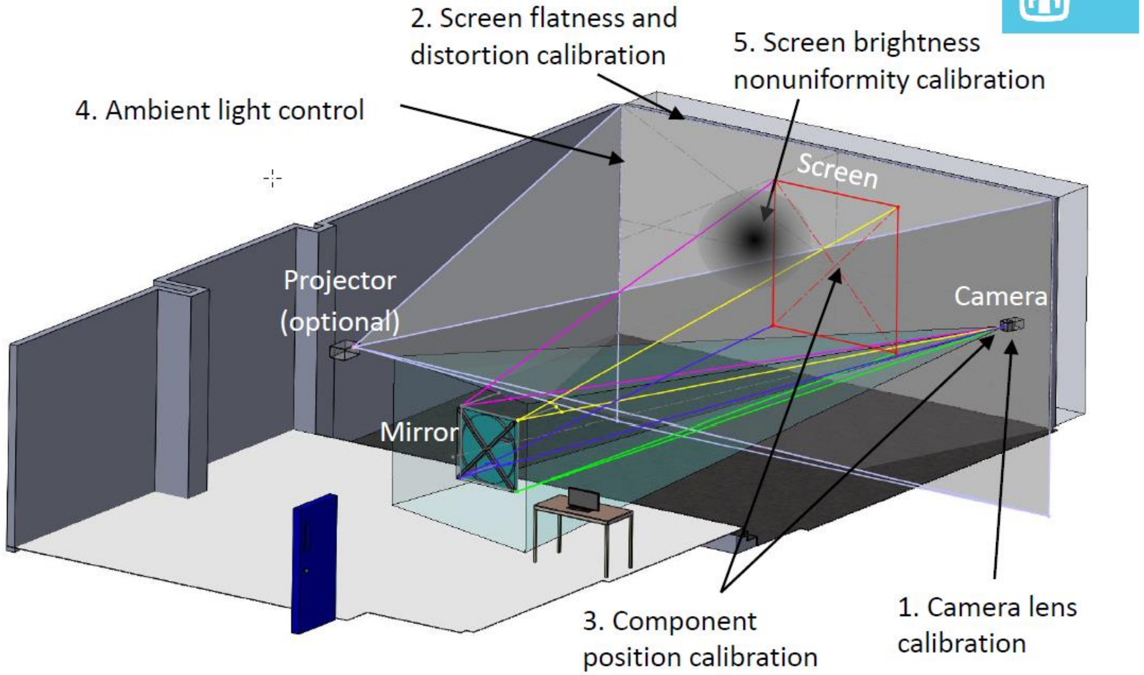


[1] F. Basetti et. Al, Long-term Performance Results of a Solid Particles Fluidized-bed Solar Receiver Coupled with a 2 MWt Beam-down Concentrator, Presentation at the SolarPACES Conference 2023 in Sydney

Deflectometry

Primary Reflector Assessment

Example SOFAST Setup



[1] B. Smith, R. Brost, Robust Deflectometry, Presentation at the SolarPACES Conference 2023 in Sydney
[2] CSP Services GmbH, Success Story – QDEC-M Helio, https://www.cspservices.de/wp-content/uploads/CSPS_QDecM_Helio.pdf

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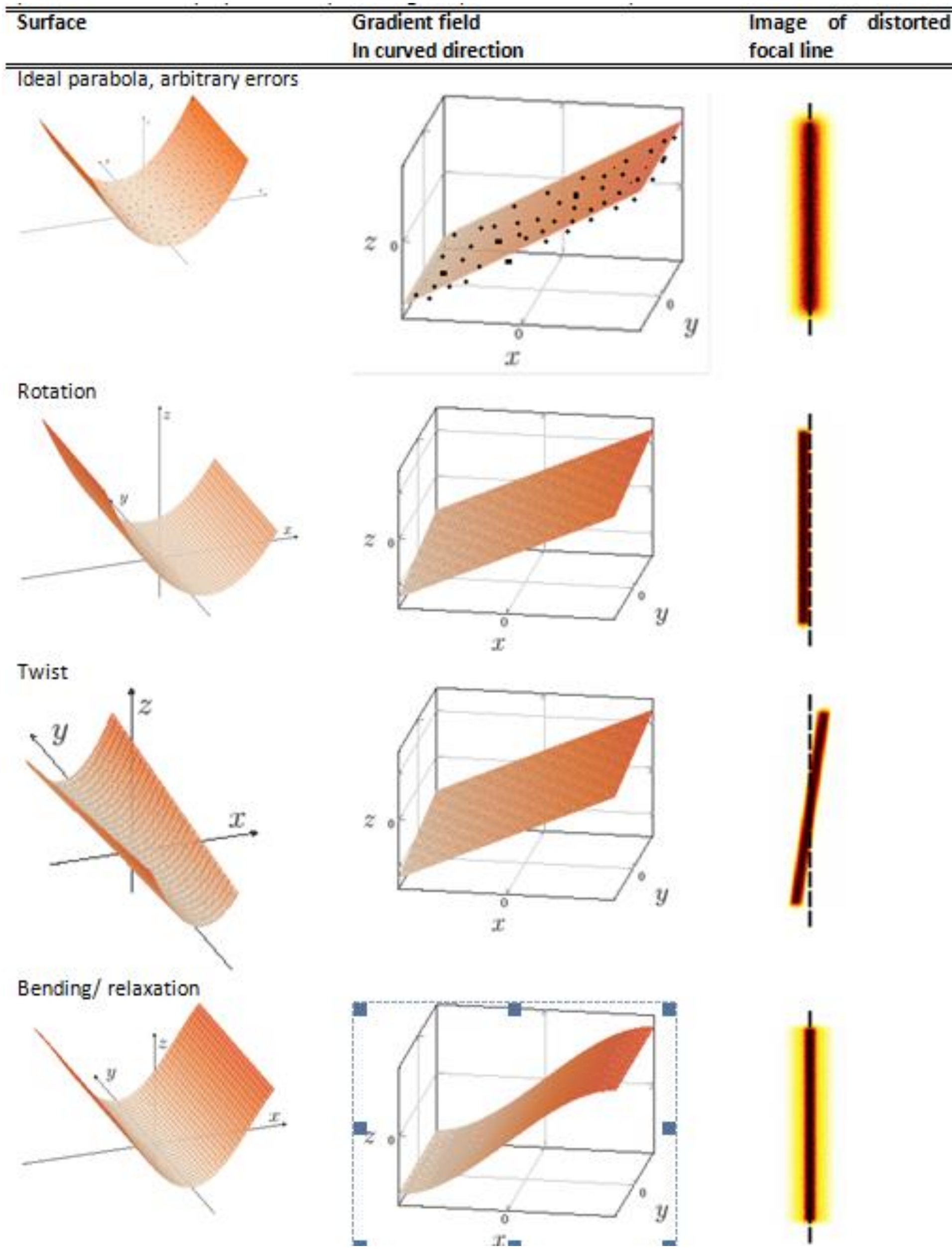
solar reflector form errors

- **arbitrary normally distributed errors**
- In curved direction
  - bending
    - sagging
    - relaxation
  - **rotation**
    - **tilt**
    - **twist**
- in longitudinal direction
  - bending
  - undulation



Heimsath, Schöttl et al., AIP Conf. Proc. 2126 (2019)

In-Situ Qualification and System Performance:

Parameter Identification

Performance validation on-site of systems under normal operation
Collector and system certification
Acceptance testing of sub-systems or complete solar field

+

No interference with regular operation

Statistical assessment of test results

In-Situ Qualification and System Performance:

Parameter Identification

Performance validation on-site of systems under normal operation
Collector and system certification
Acceptance testing of sub-systems or complete solar field

IN SITU

+

No interference with regular operation

DYNAMIC

Statistical assessment of test results

ENHANCED

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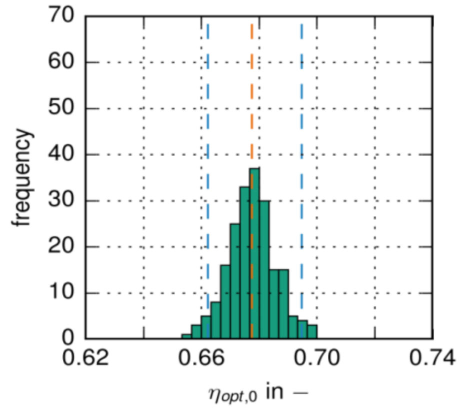
In-Situ Qualification and System Performance:

Parameter Identification



Performance validation on-site of systems under normal operation
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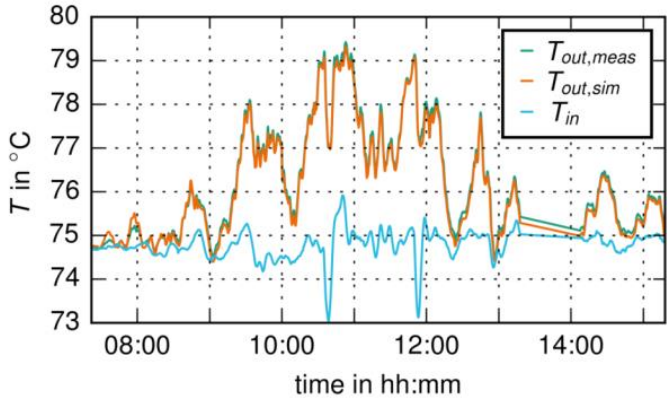
IN SITU



+

No interference with regular operation

DYNAMIC

Statistical assessment of test results

ENHANCED

=

information content & reliability of evaluation

effort, time, costs

Zirkel-Hofer et al., "Improved in situ performance testing of line-concentrating solar collectors. Comprehensive uncertainty analysis for the selection of measurement instrumentation," Applied Energy **184**, 298-312 (2016).
Zirkel-Hofer et al., "Confidence Interval Computation Method for Dynamic Performance Evaluations of Solar Thermal Collectors," Solar Energy (162), 58-596 (2018).

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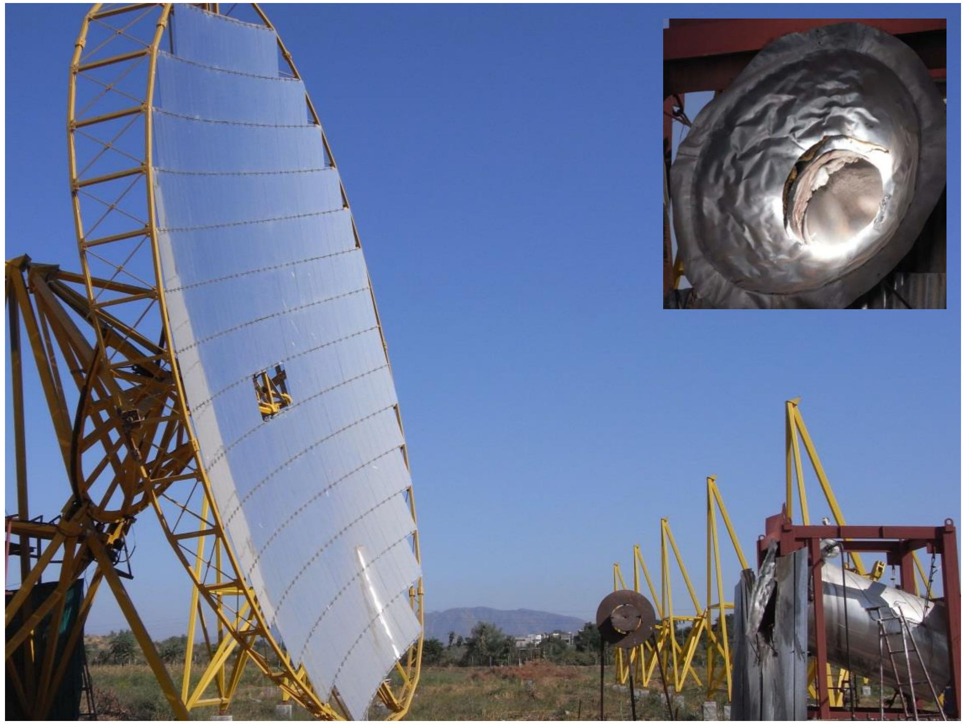
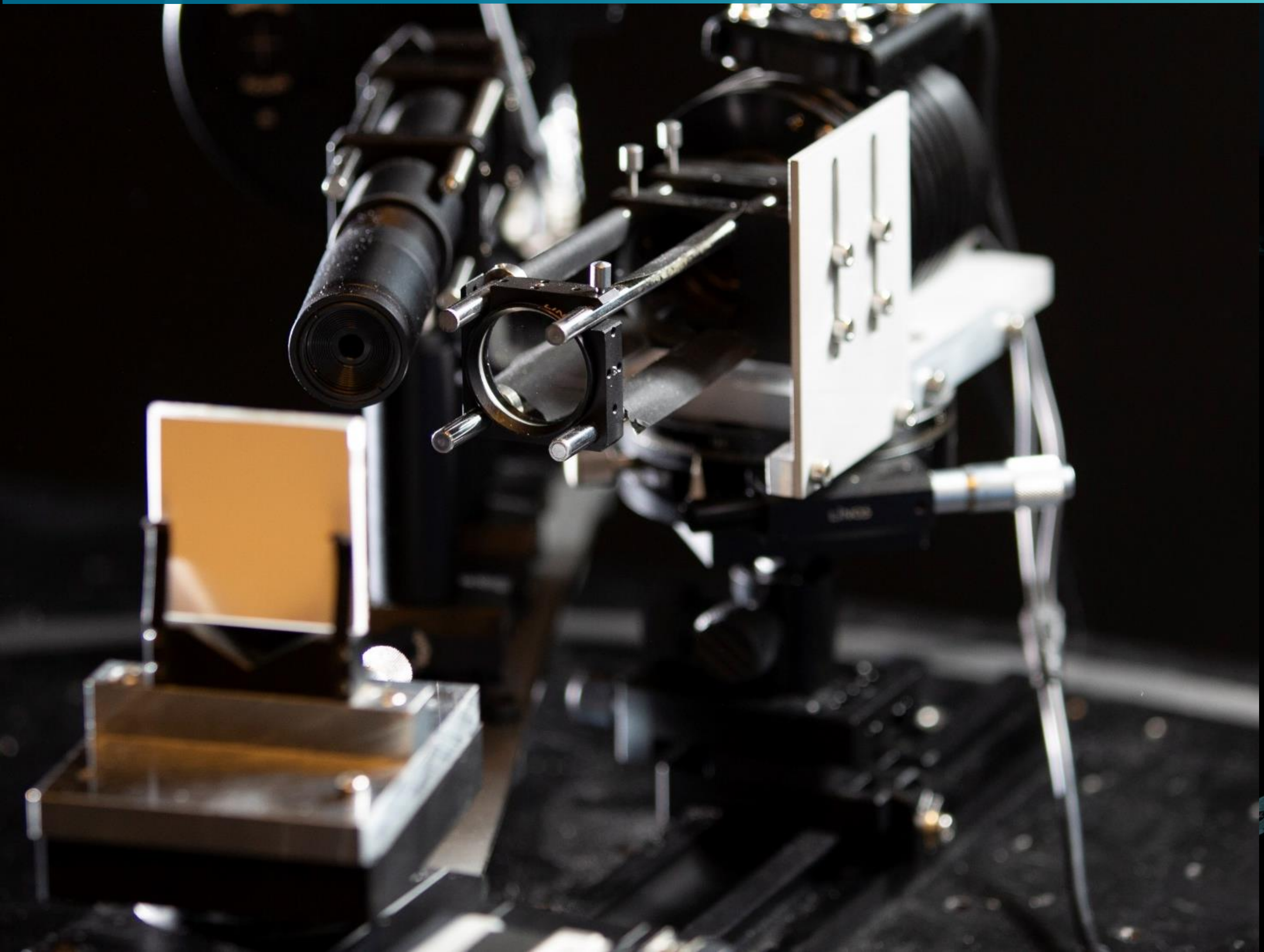
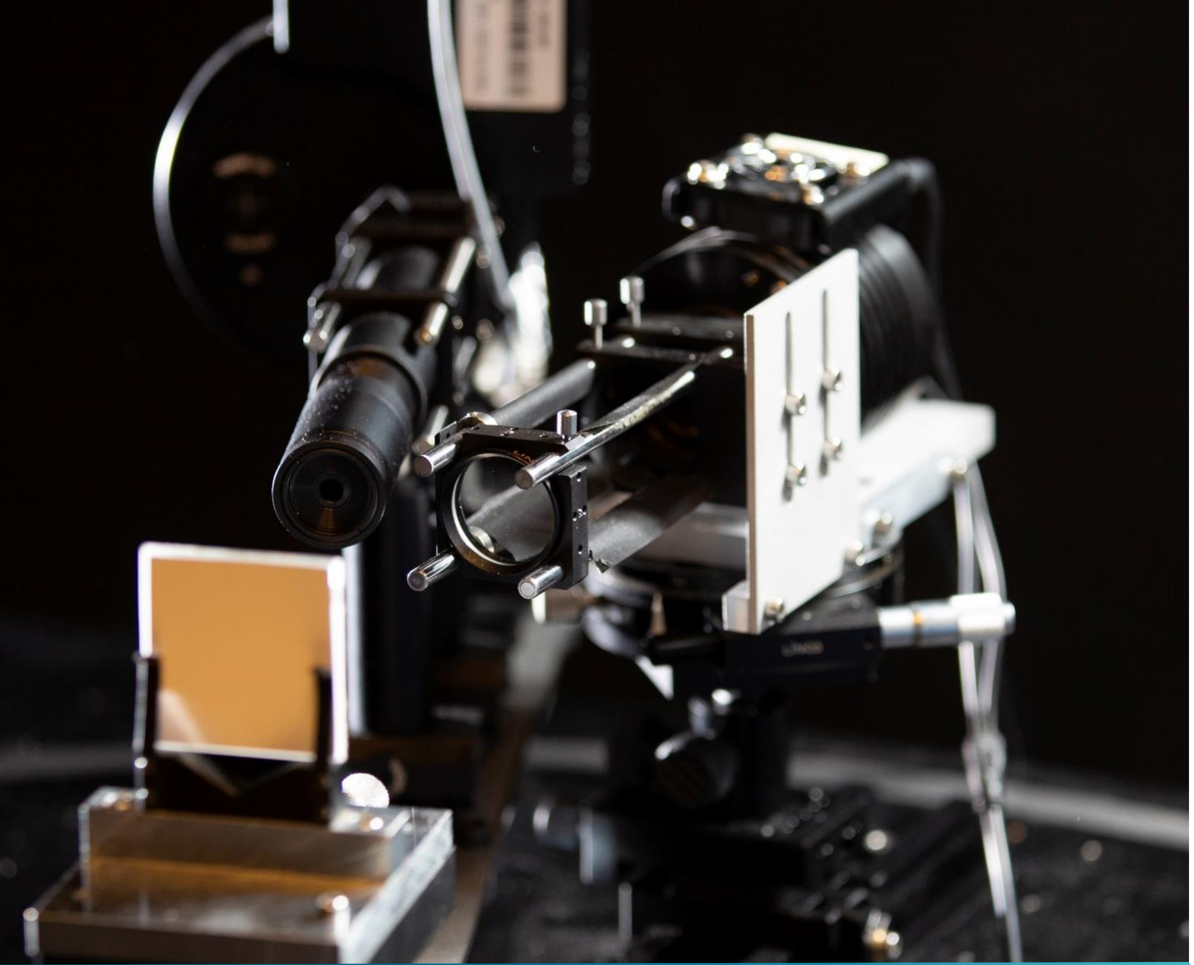
In-Situ Qualification and Precise Positioning:

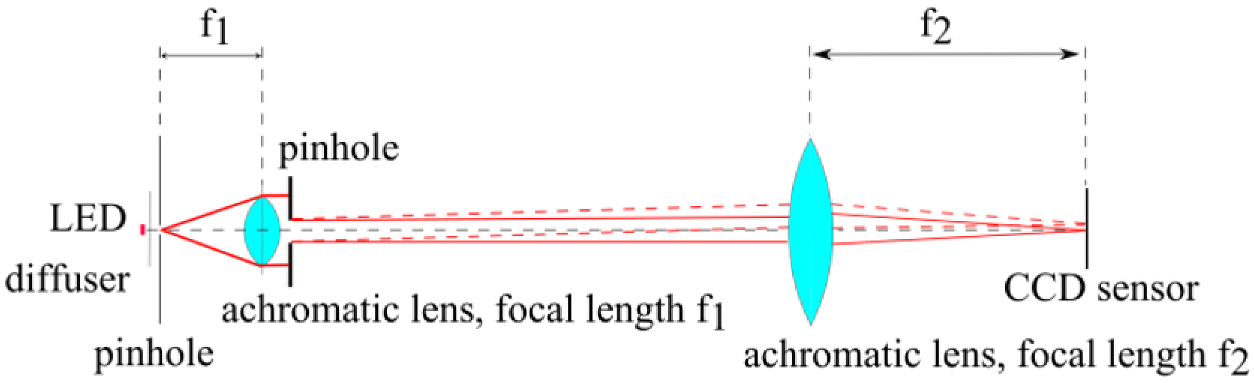


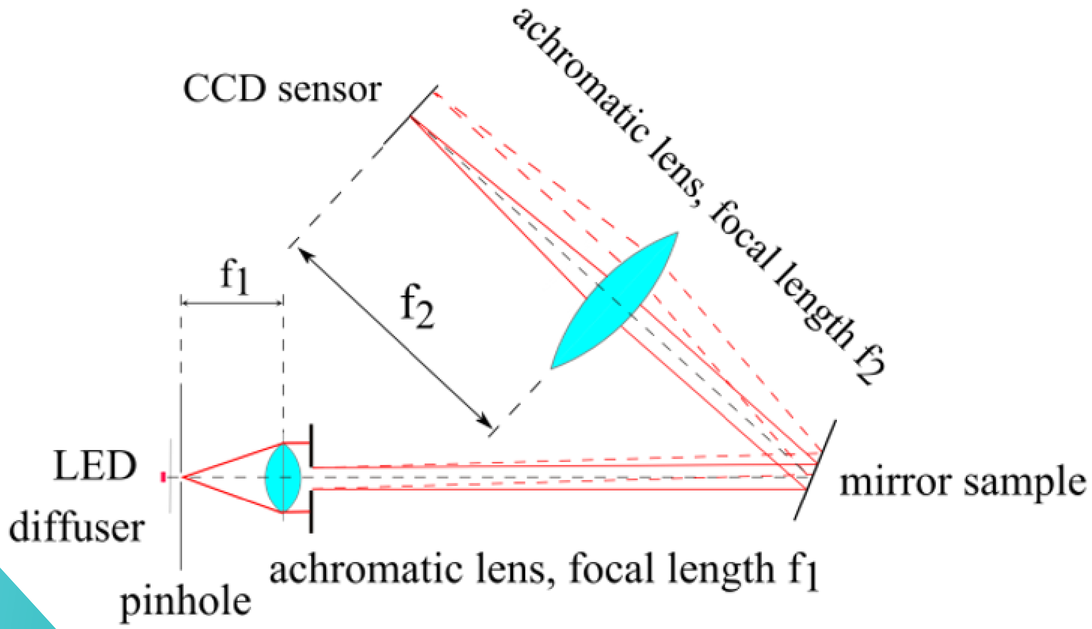
Concentrating Collectors and Optics

Measuring equipment and techniques









Laboratory Material and Dust Analysis

Measuring equipment and techniques

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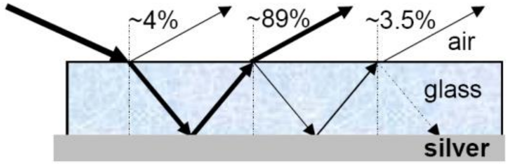
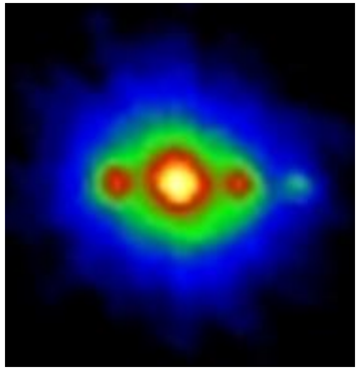
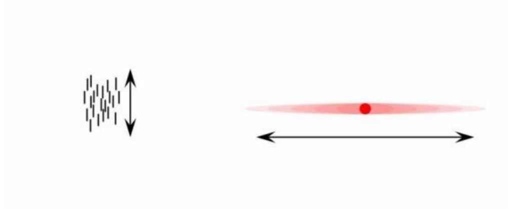
Laboratory Material Analysis

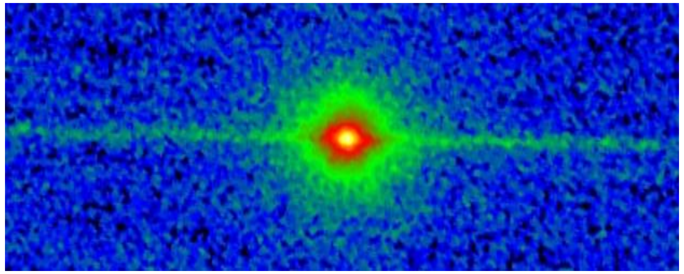
Glass mirrors



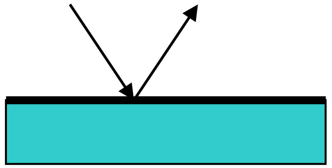


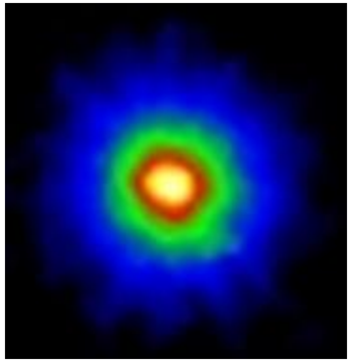
Aluminum sheets





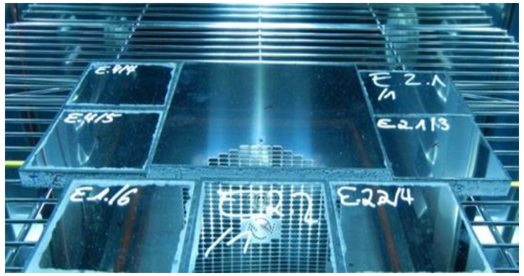
Polymer film





Durability: Environmental Impacts

Outdoor Exposure

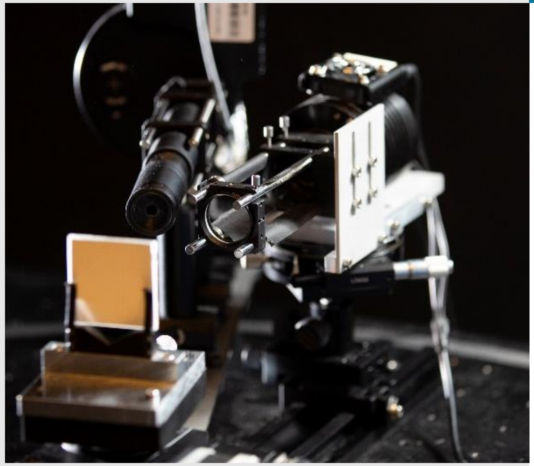


Accelerated Aging

Instruments for field measurements

Lab assessment, portable reflectometer, on-site monitoring, circum solar ratio camera

VLABS –
Laboratory Material and Dust Analysis



pFLEX –
Flexible Field Measurement

AVUS –
Remote Site Monitoring

CSR-Camera –
Ressource Analysis

Instruments for field measurements
Portable reflectometer and on-site monitoring

Assessing soiling rates and reflectance in the field:

Measurement of cleanliness with handheld mobile device in the field

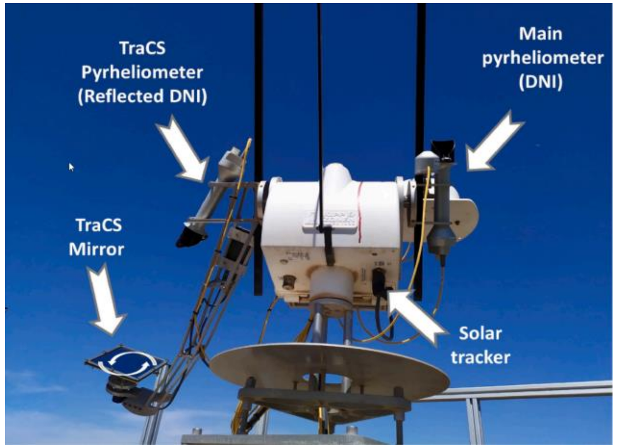
- ➢ pFLEX – handheld reflectometer
  - ✓ flexible and quick measurement with mobile phone integration

Automatic independent site monitoring

- ➢ AVUS – autonomous soiling assessment
  - ✓ AVUS monitors long-term cleanliness/ soiling rates with little maintenance
  - ✓ Evaluation of soiling impact during site monitoring, i.e. before installation of the plant possible

What is the soiling rate and what is the optimal cleaning cycle?

Instruments for field measurements
Portable reflectometer and on-site monitoring



Assessing soiling rates and reflectance in the field:

Measurement of cleanliness with handheld mobile device in the field

- pFLEX – handheld reflectometer
  - ✓ flexible and quick measurement with mobile phone integration

Automatic independent site monitoring

- AVUS – autonomous soiling assessment
- TraCS – Tracking Cleanliness Sensor
  - ✓ Automatic measurement of impact of soiling on solar ressource
  - ✓ Evaluation of soiling impact during site monitoring, i.e. before installation of the plant possible

What is the soiling rate and what is the optimal cleaning cycle?

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Introduction

Monitoring of Soiling: In Power Plants

Monitoring of the power plant and O&M optimization

Dust storm on May 23, 2022

Soiling Assessment for CSP

Recommendations for reflectance measurements on soiled mirrors

Optical Properties Working Group:

- ❖ First draft version of guideline for

  Recommendations for reflectance measurements on soiled mirrors

- ❖ Relevant effects of soiling on CSP

- ❖ Introduction and overview on measurement devices and procedures

Interpretation of measurement data for the application or comparison

- ➢ https://www.solarpaces.org/optical-properties-working-group/

SolarPACES
Solar Power & Chemical Energy Systems

Guidelines

Recommendations for reflectance measurements on soiled solar mirrors

Version 0.1

July 2022

Authors: F. Wolfertstetter (DLR), F. Sutter (DLR), E. Lüpfert (DLR), M. Montecchi (ENEA), C. Pelayo (UNIZAR), C. Heras (UNIZAR), G. Bern (Fraunhofer ISE), M. Bitterling (Fraunhofer ISE), A. Heimsath (Fraunhofer ISE), A. Fernández-García (CIEMAT), J. Wette (CIEMAT), C.-A. Asselineau (IMDEA Energy, ANU), Guangdong Zhu (NREL)

Interpreting Field Measurements

Acceptance Angle

Acceptance angle of the device

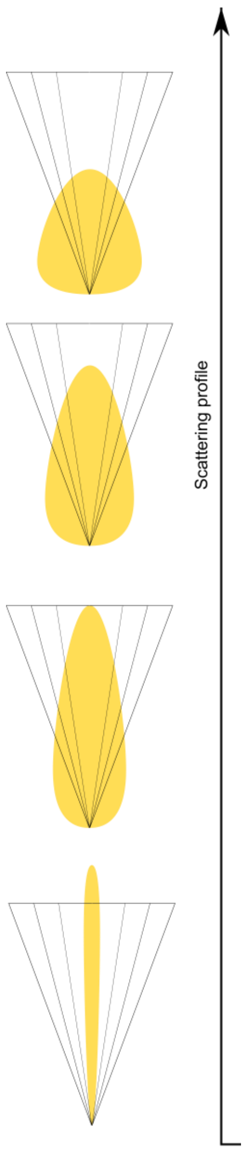
- D&S 15R-USB 3.5, 7.5, 12.5, 23.0 mrad
- pFlex 67 mrad
- Condor 145 mrad

Acceptance angle of the application

PTC: ~ 12.5 mrad

LFRR: ~ 30-60 mrad

CRS: ~ 3-20 mrad



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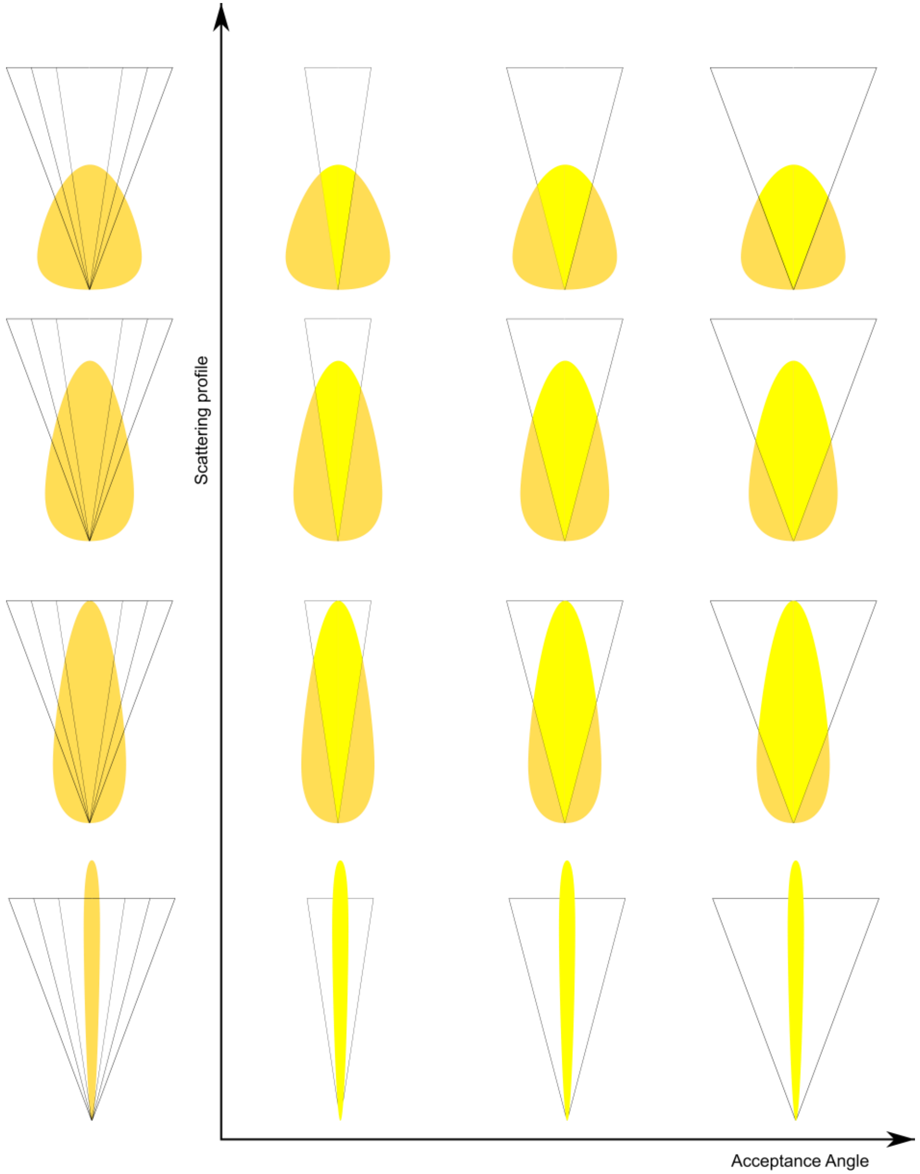

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Interpreting Field Measurements
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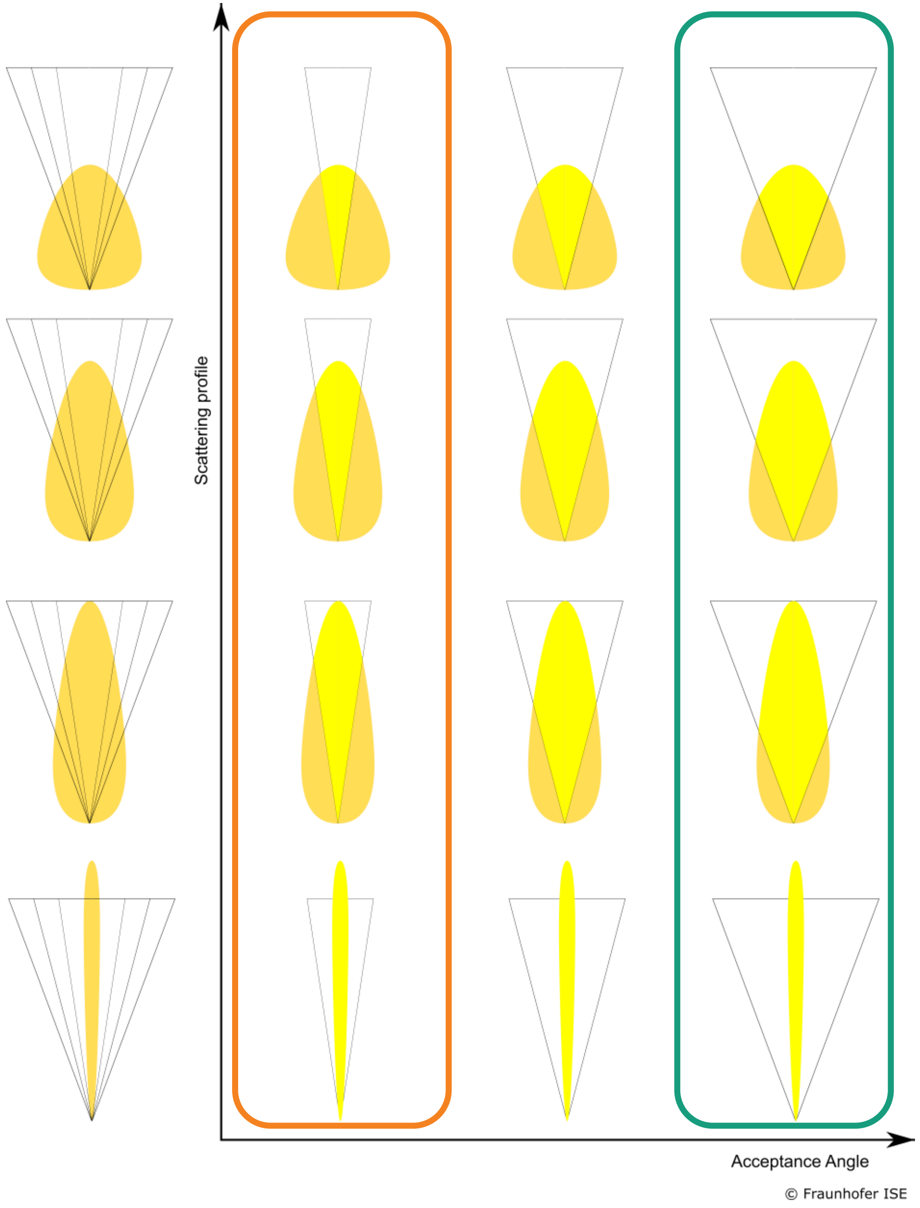

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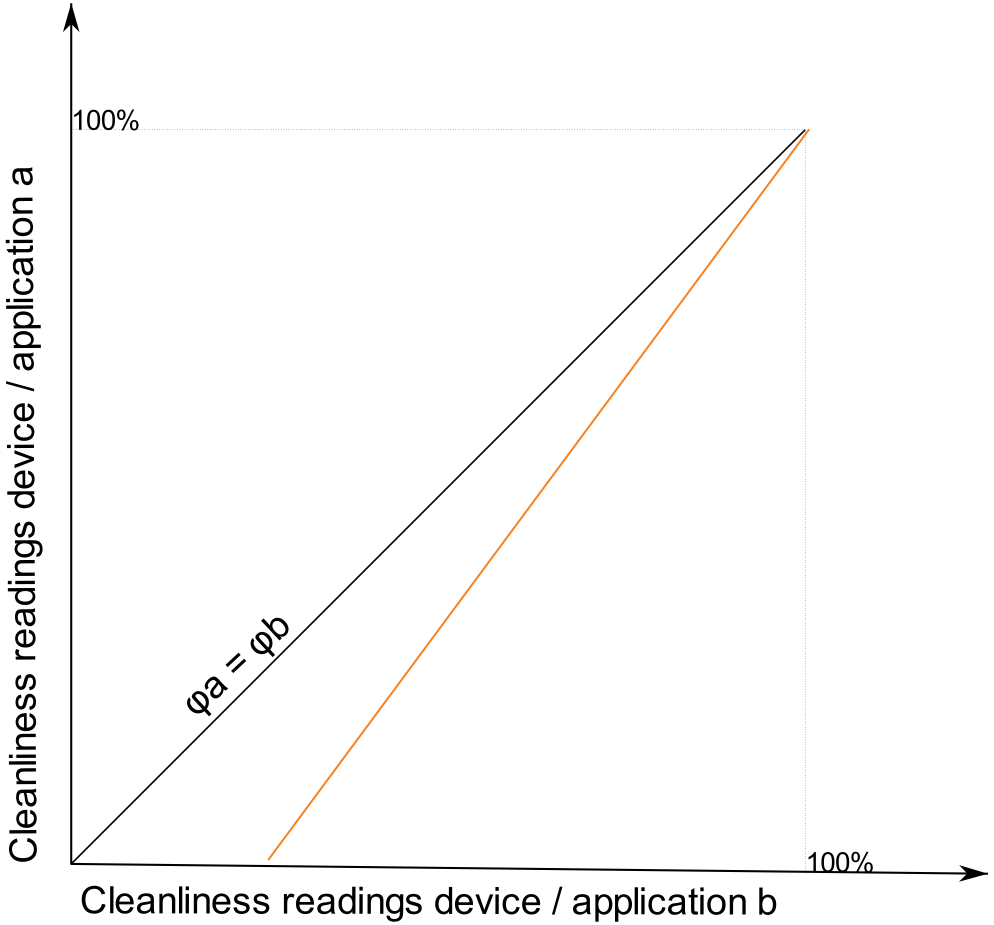
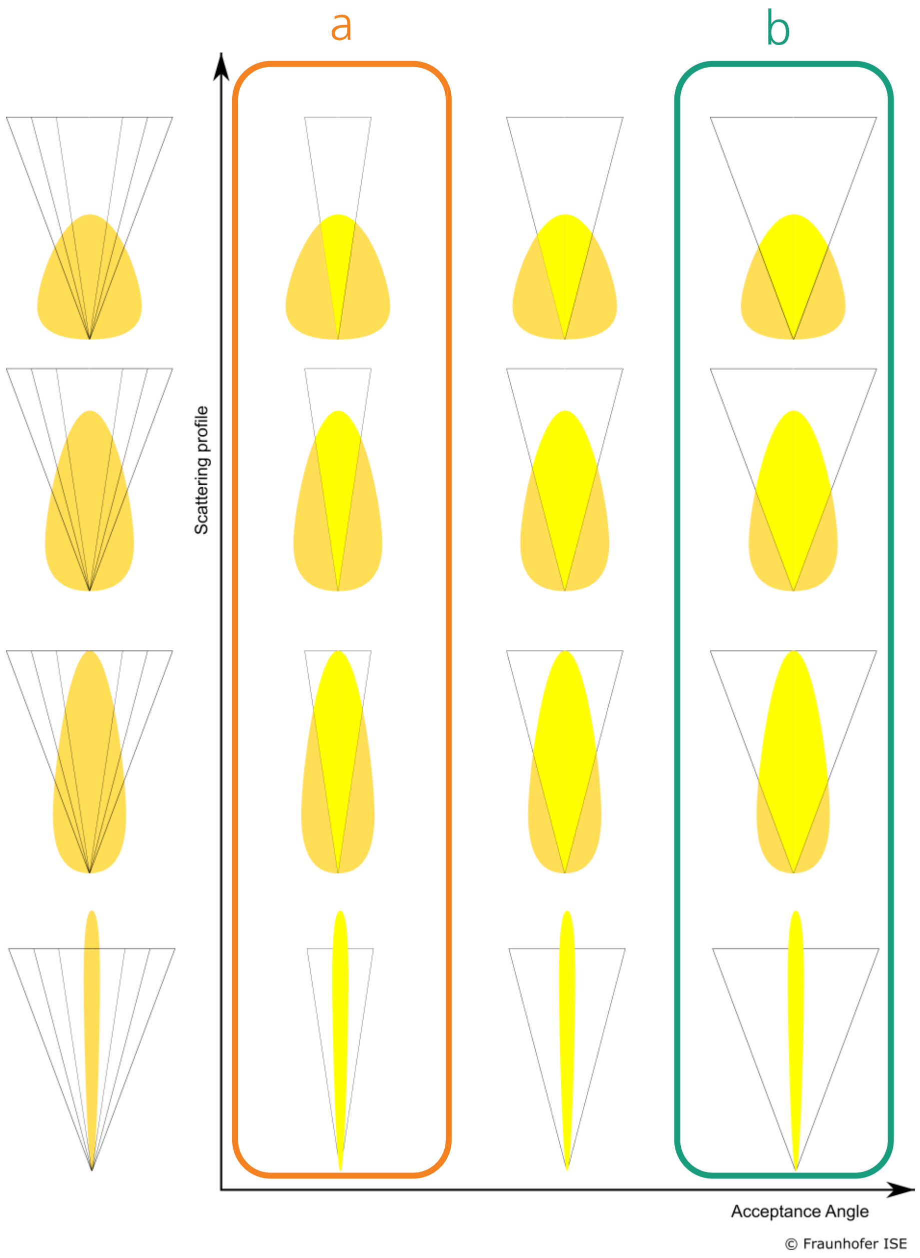
Interpreting Field Measurements

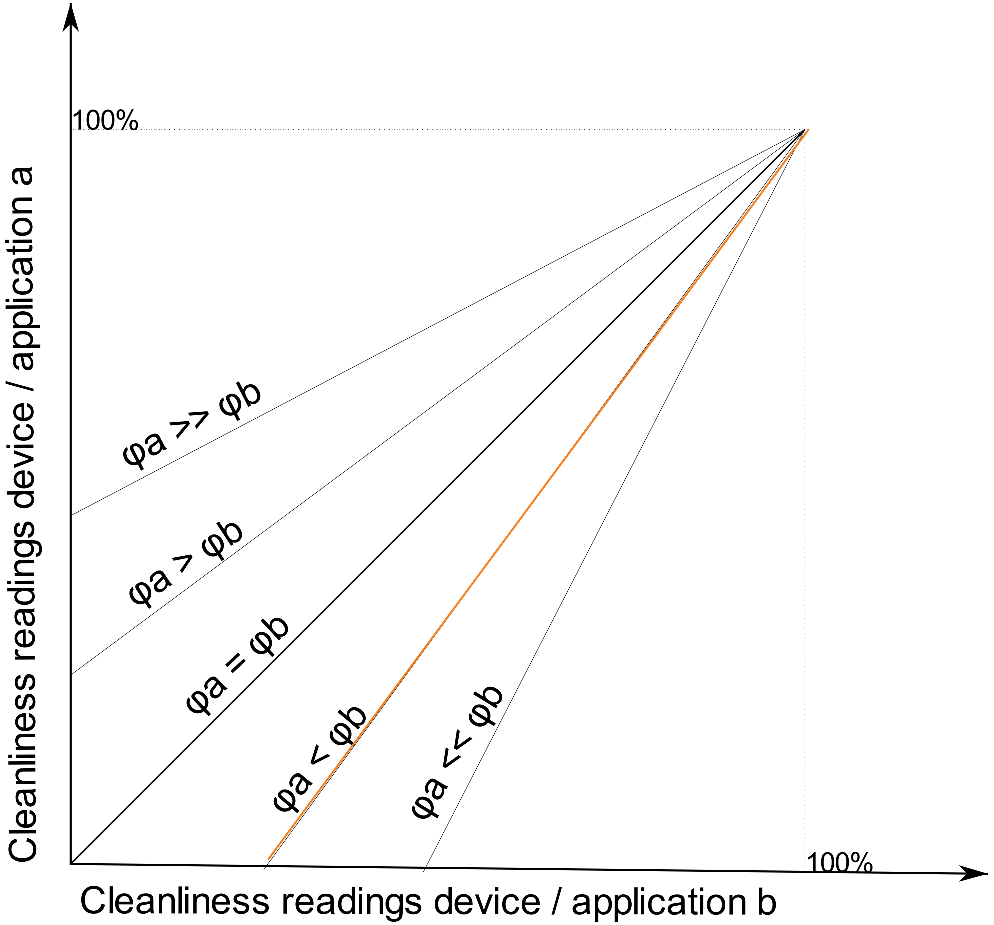
Acceptance Angle

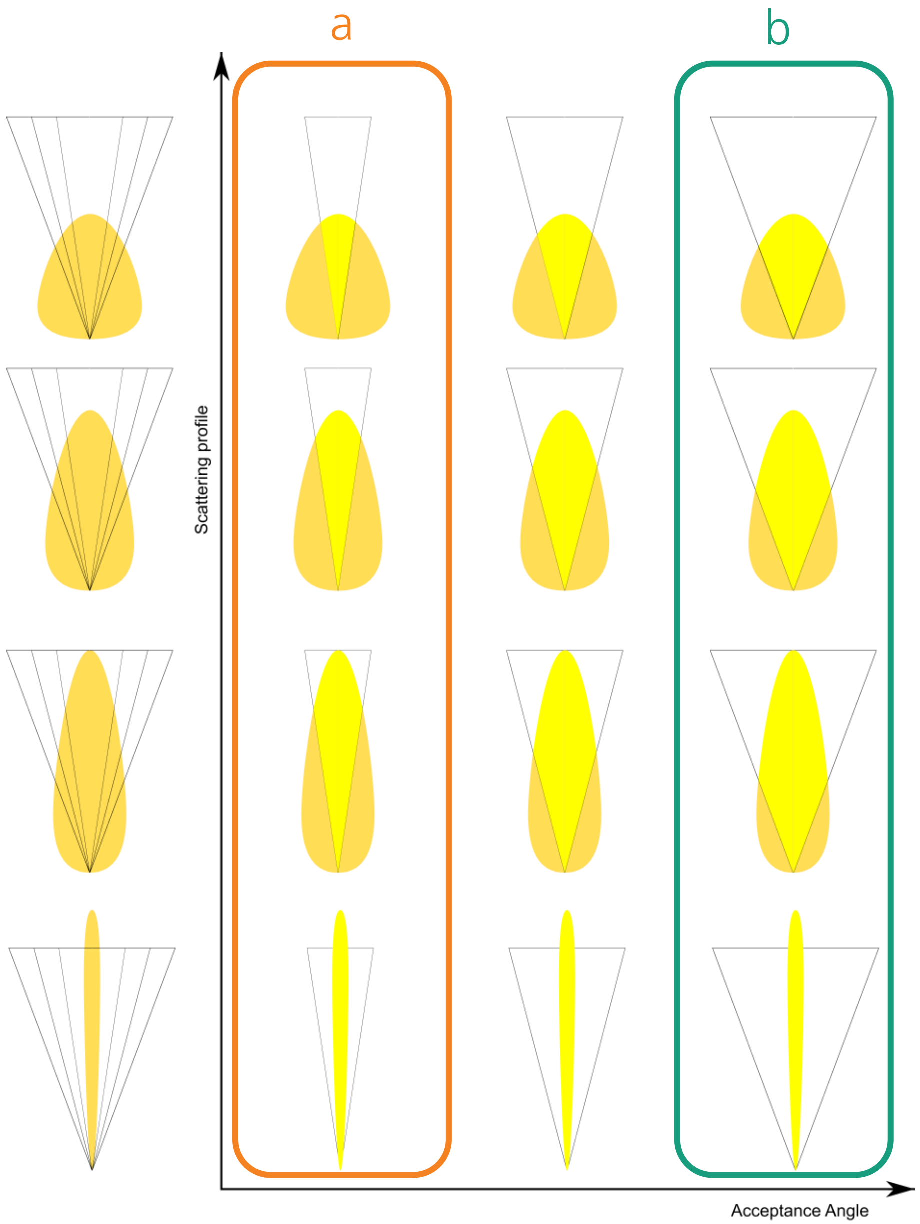




Interpreting Field Measurements

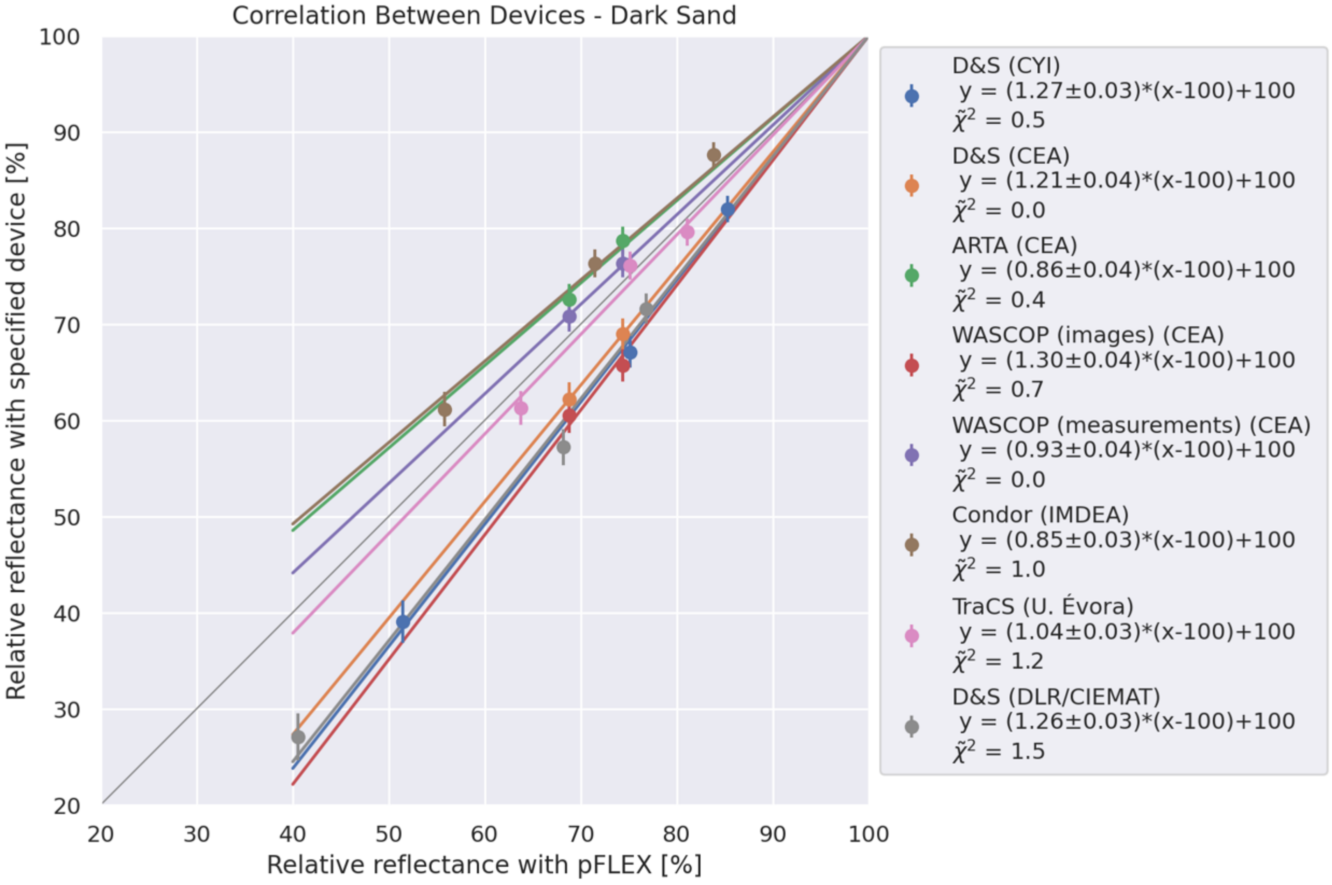
Acceptance Angle





MOTIVATION FOR OPTICAL MEASUREMENTS / APPLICATIONS

Transfer functions between different reflectometers



Results from the reflectometer round robin test in SFERA-III WP10

Measured reflectance depends on **acceptance angle, incidence angle, wavelength** of the reflectometer

Introduction

Soiling Measurement: Mobile Reflectometer

Introduction

Monitoring of Soiling : In remote areas

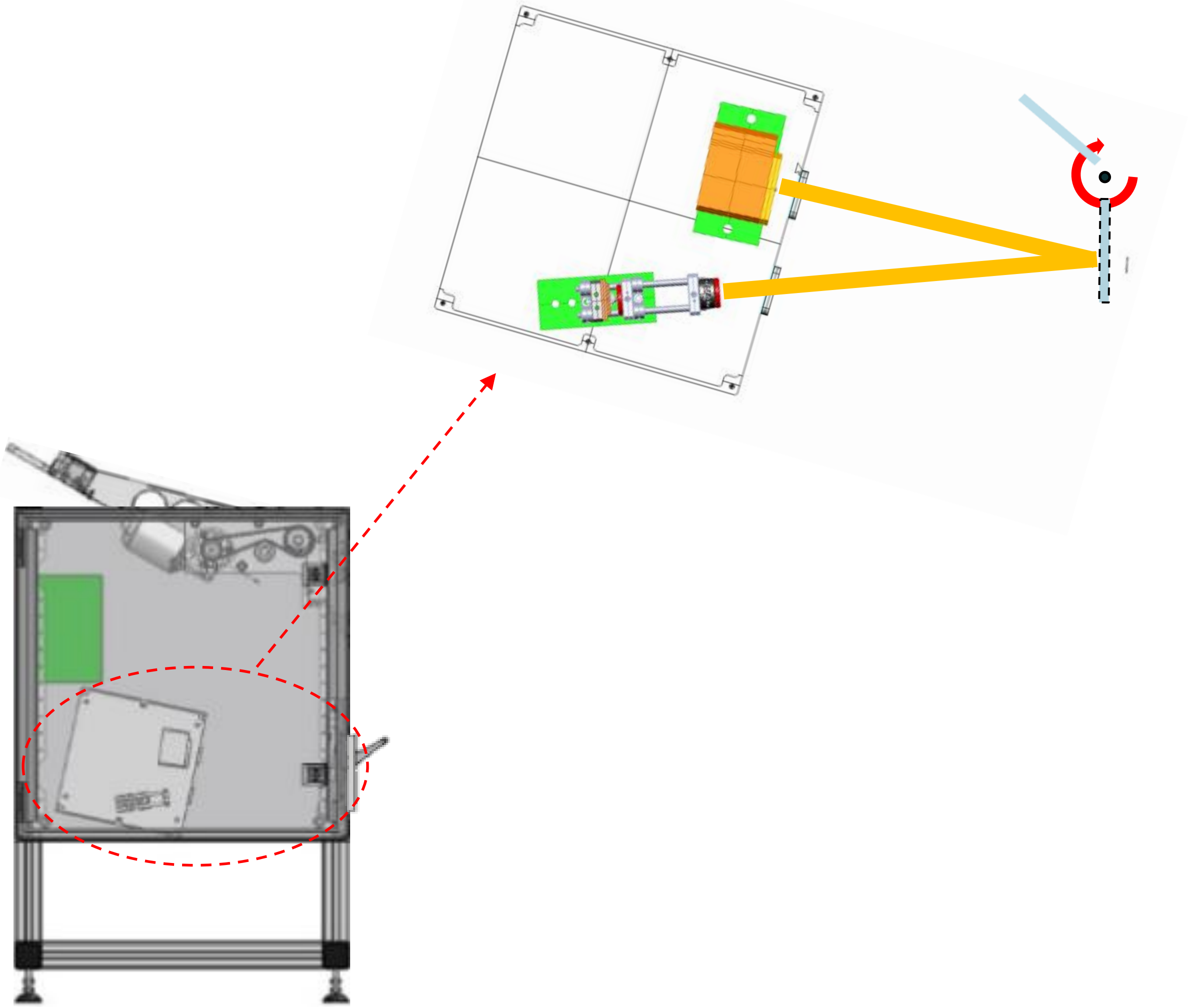
Data acquisition for forecast and site assessment

Meteostation owned and operated by Fraunhofer CSET, Atakama Desert, Chile

AVUS –
Remote Site Monitoring
Measurement of Soiling in CSP

Functional principle of the AVUSpro measurement system

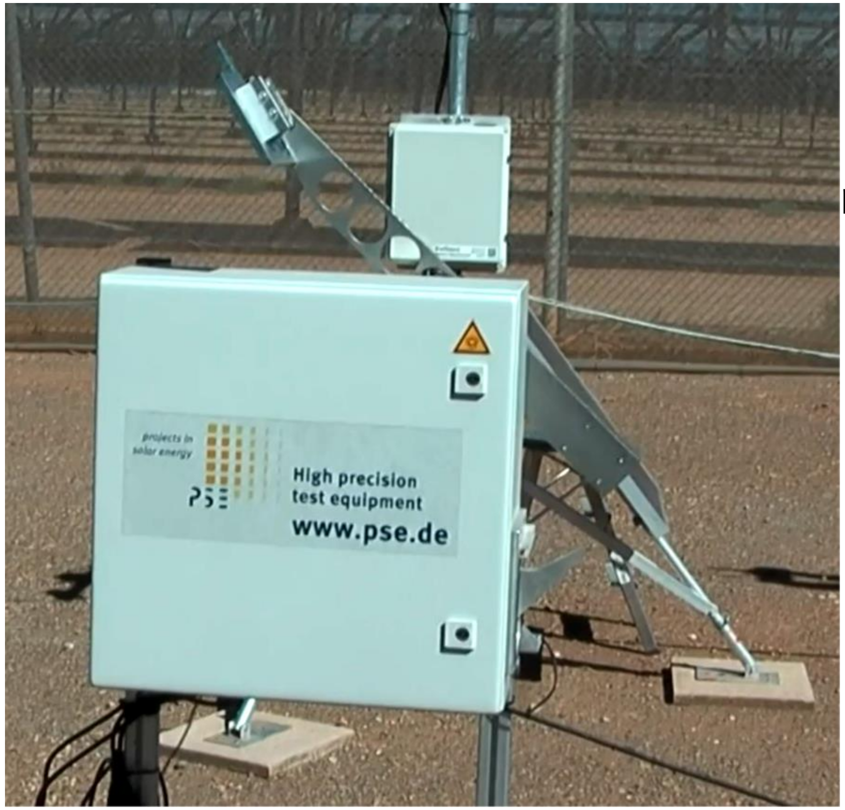
Automated measurements of soiling with low maintenance



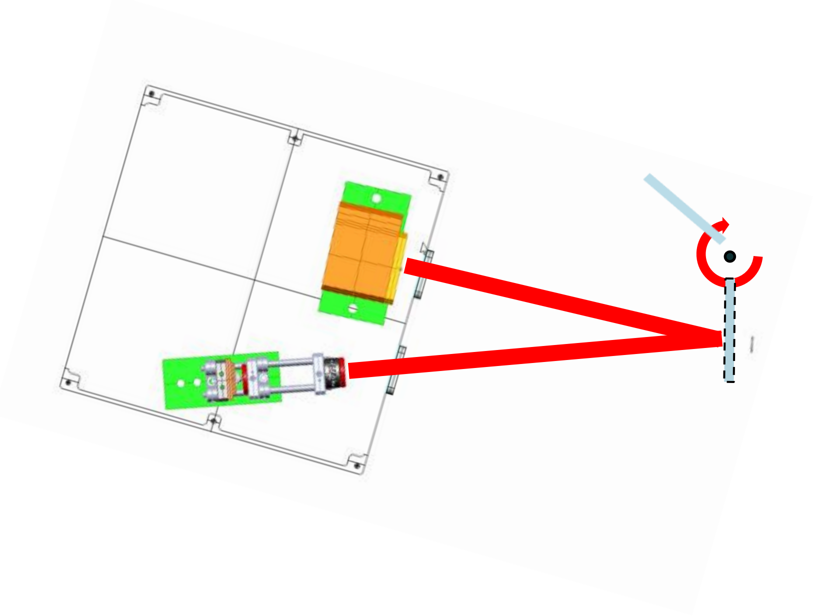
Functional principle of the AVUSpro measurement system

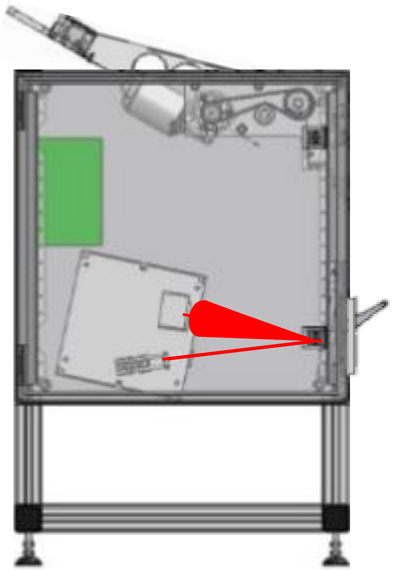
Automated measurements of Soiling with low maintenance

Functional principle



- nt position





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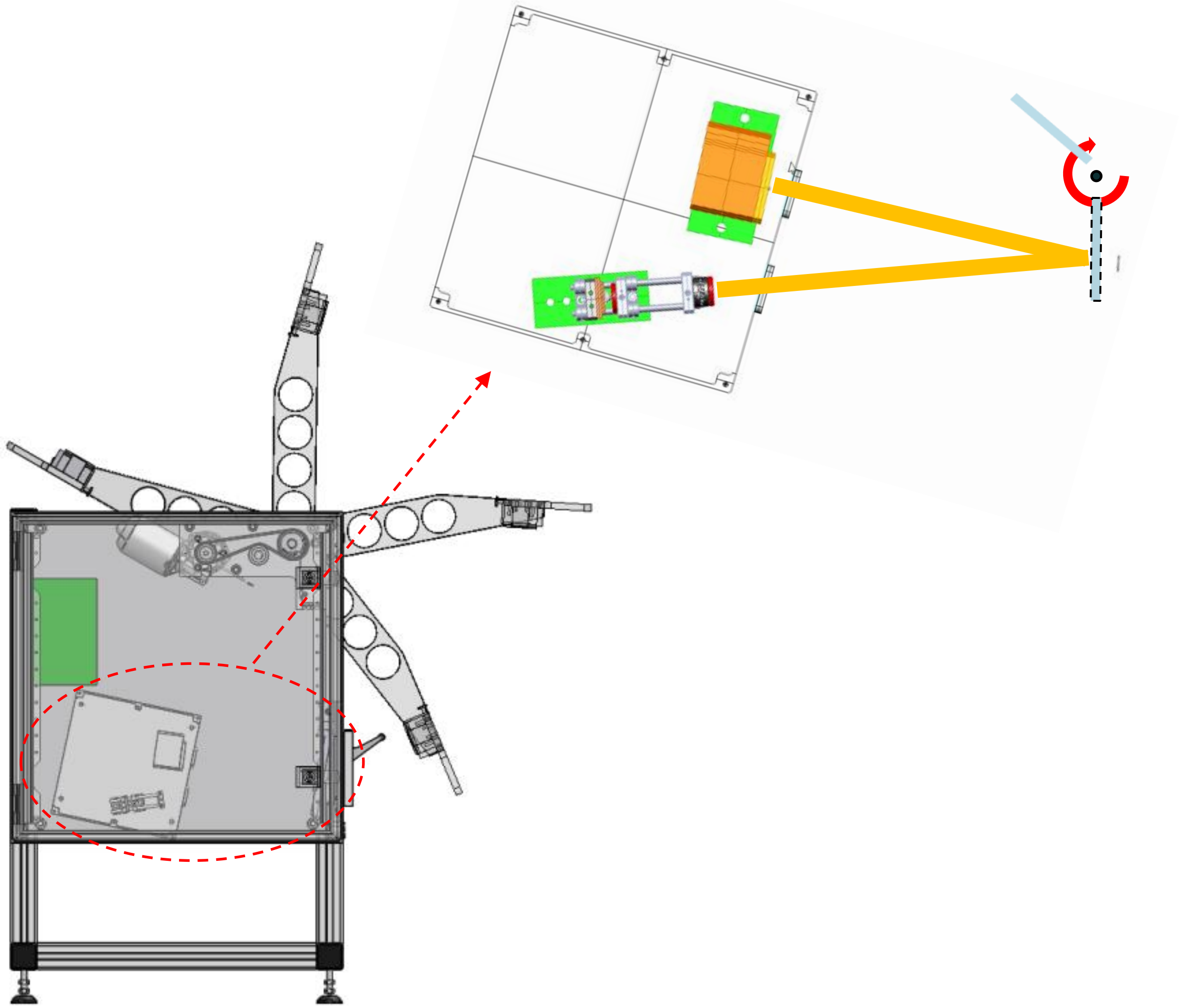
Functional principle of the AVUSpro measurement system

Automated measurements of Soiling with low maintenance

Functional principle

- Take a reference measurement
- Rotate the exposition arm to measurement position
- Aritize with electromagnet
- Measure the exposed specimen
- Move the arm to exposition position
- Autonomous measurement e.g. every hour



Instruments for field measurements

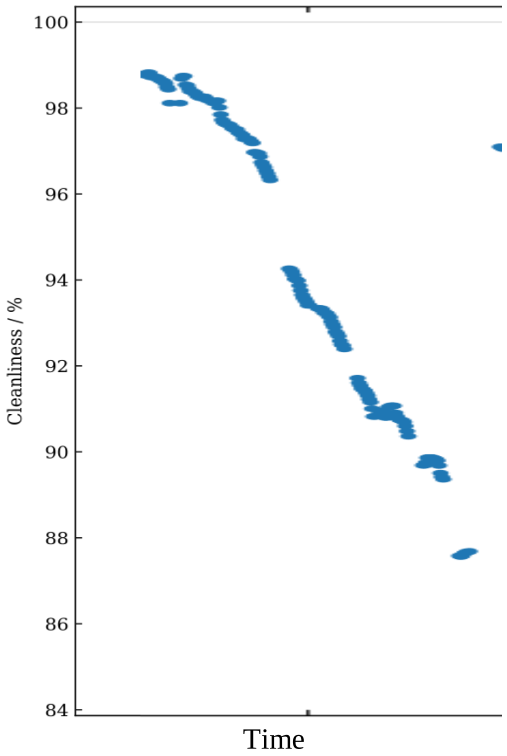
AVUSPro: on-site monitoring

Instruments for field measurements

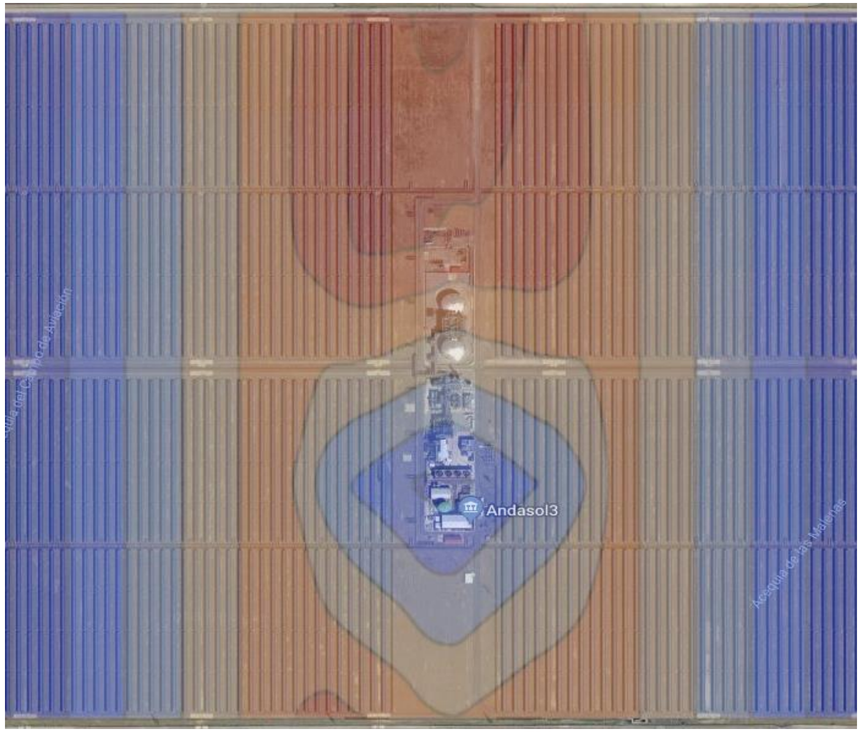
AVUSPro: on-site monitoring

Instrument

Daily Soiling Rate



Soiling distribution in PTC-Field



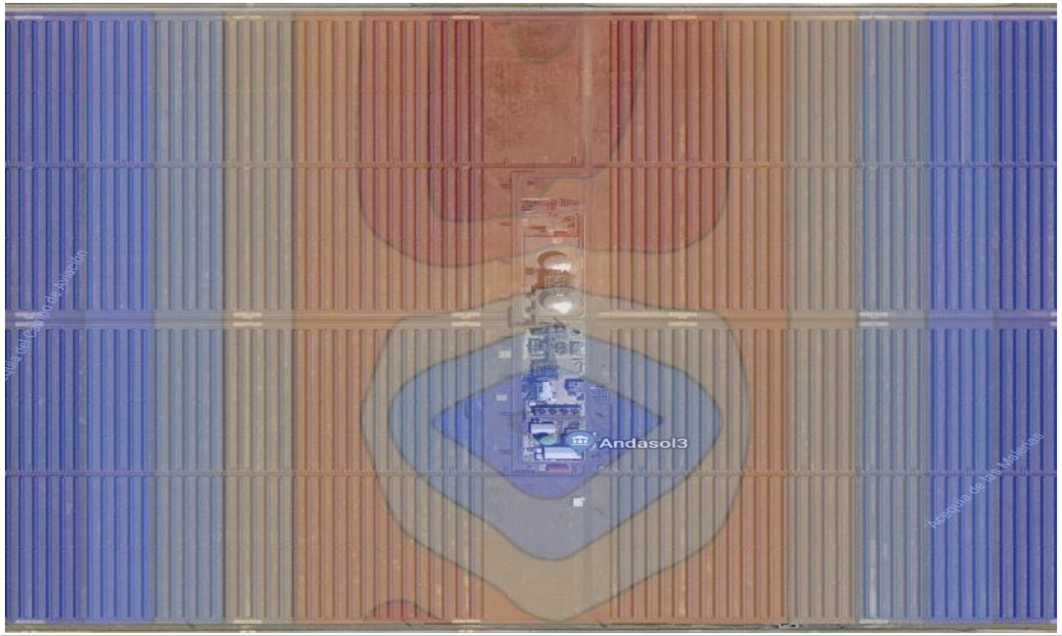
What is the soiling rate and what is the optimal cleaning cycle?

ColSim CSP

Dynamic system simulation

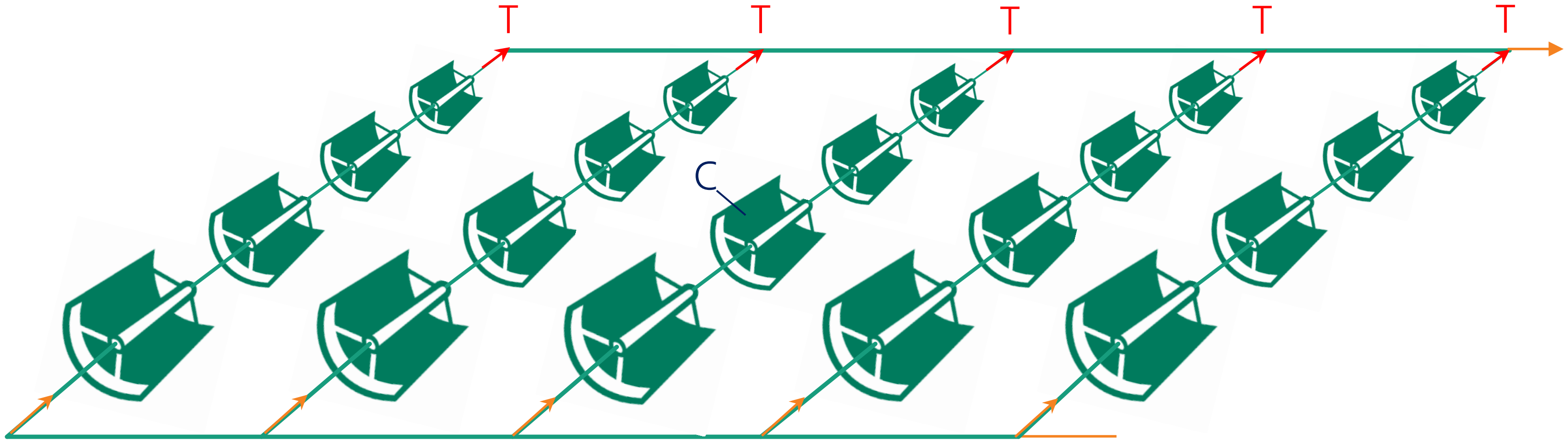
Modeling of individual Collector Modules and Loops in large-scale Parabolic Trough solar fields

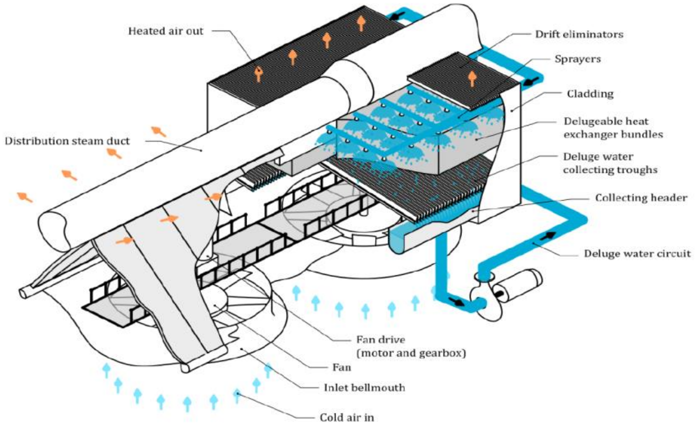
Local DNI and soiling maps based on measurements



Development and Evaluation of Water Wise Technologies

- Development of optimized mirror cleaning
- Improved cooling of steam cycle
- Improved operating strategy
- Development of water management plans for CSP plants
- Development of collectors combined with agricultural land use





Top: cleaning truck © ECILIMP
Bottom: Deluge ACC © ENEXIO

O&M Optimization
Advanced Cleaning Strategies

Fixed interval (Ref.)

- Cleaning is conducted in a fixed interval, e.g. 1 per week

Cleaning threshold – Fixed

- Loops with cleanliness below fixed threshold are prioritized

Cleaning threshold – Variable

- Loops are with cleanliness below variable threshold are prioritized

O&M Optimization

Advanced Cleaning Strategies

Fixed interval (Ref.)

Cleaning threshold – Fixed

Cleaning threshold – Variable

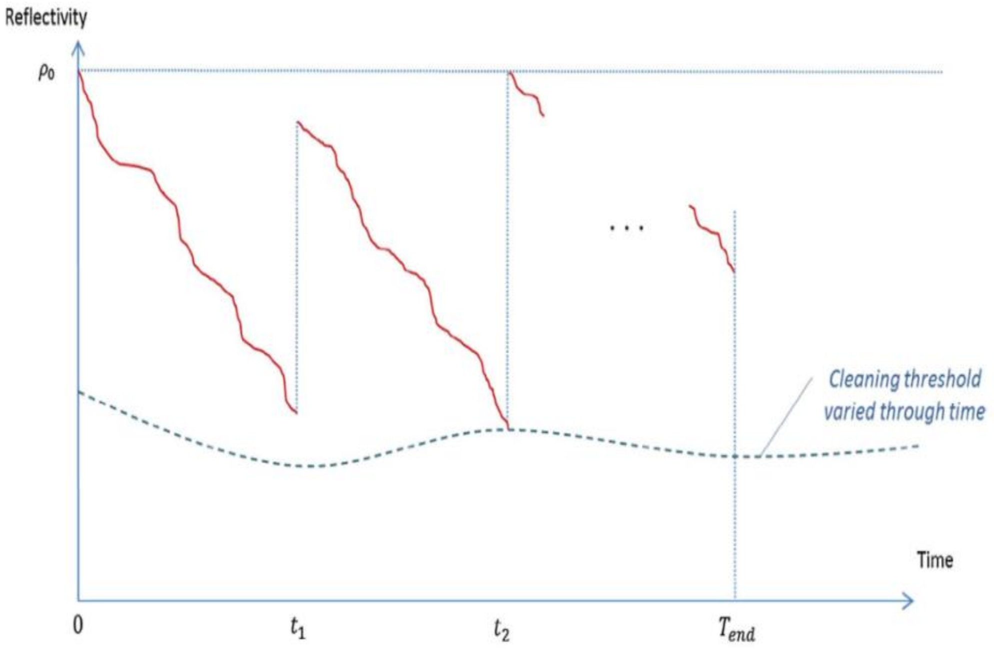
The cleaning threshold varies based on:

Radiation potential of next day

Rain forecast greater than 6 mm for next day

The loop with lowest cleanliness has priority to be cleaned.

Brush cleaning is employed after extreme reduction in cleanliness (soiling rate > 10 %).



 14.11.2023

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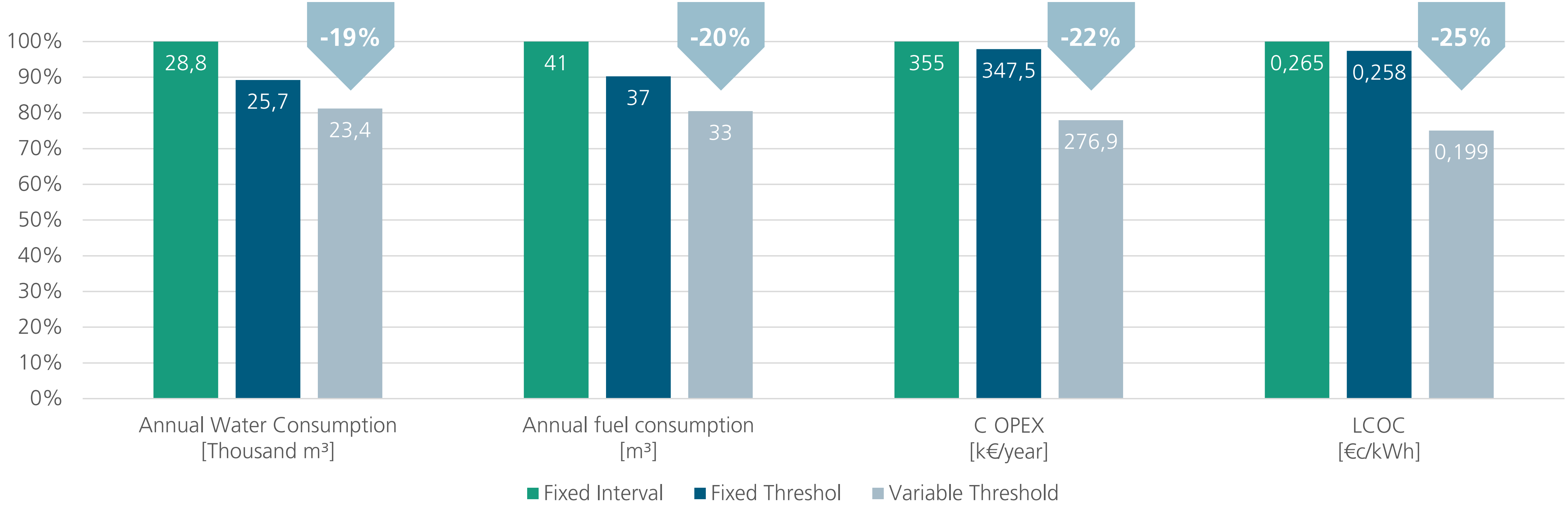
O&M Optimization

Advanced Cleaning Strategies



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Assessment of Soiling
Further Approaches

Camera Based Approaches

[1]

Particle Counting + Modell

[2]

Novel Approach: Terrestrial Laser Scanning Method

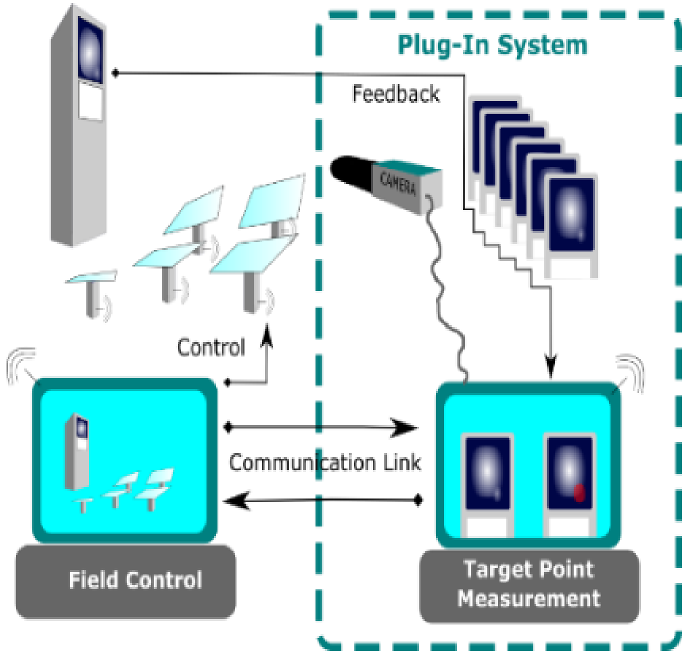
[3]

[1] R. Mahoni et. al, A Robotic Vision System for Rapid Inspection and Evaluation of Solar Plant Infrastructure, Final Project Report, ANU Canbera
[2] G. Picotti et. al, Development and experimental validation of a physical model for the soiling of mirrors for CSP industry applications, Solar Energy 173, 2018
[3] M. Ferreres et.al, Terrestrial Laser Scanning for Fast Spatially Resolved Cleanliness Assessment of Heliostat Fields, The SolarPACES Conference, 2022, Albuquerque

Camera Based Measurement Techniques

Computer Vision Applications in CSP

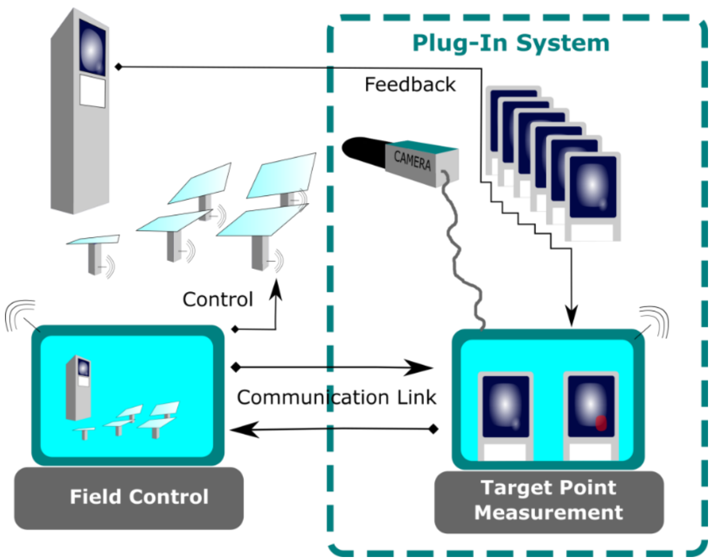
Heliostat Calibration & Closed Loop Control



HelioControl- Closed Loop Heliostat Control

Improved Heliostat Calibration and Control through Computer Vision

Theory → Lab Scale → Experimental



Fast Aim Point Detection During Commissioning & Operation

Instruments for field measurements

HelioControl – Calibration & Closed Loop

Technical specifications HelioControl – Plug In:

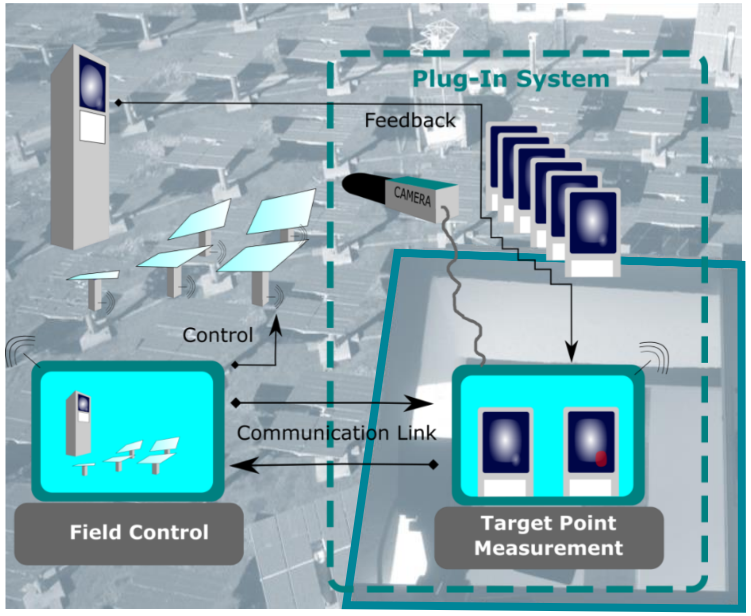
- *Smart:* Parallel calibration of heliostat's by identification of their aimpoints on focus at the receiver
- *Fast:* Measurement of up to 2 aim points / s in operation
- *Simple:* Plug-In System for minimal field control interference
- *Demo:* Tested in lab and experimentally in Themis plant
- *Next Step:* Demonstration in commercial scale

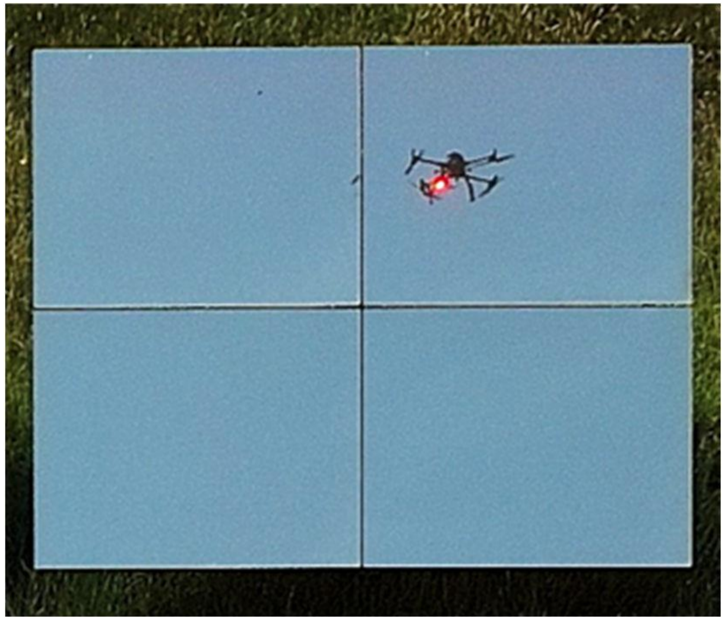
Quick Heliostat Field Commissioning & Improved Aim Point Control

Instruments for field measurements

HelioControl – Calibration & Closed Loop

Approaching Heliostat Calibration Techniques



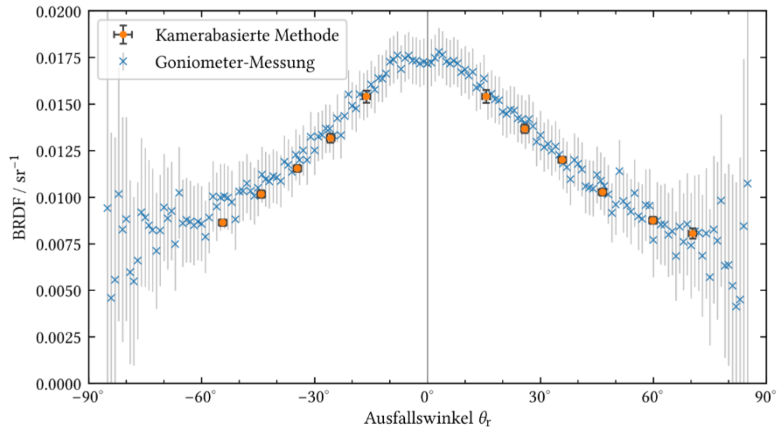


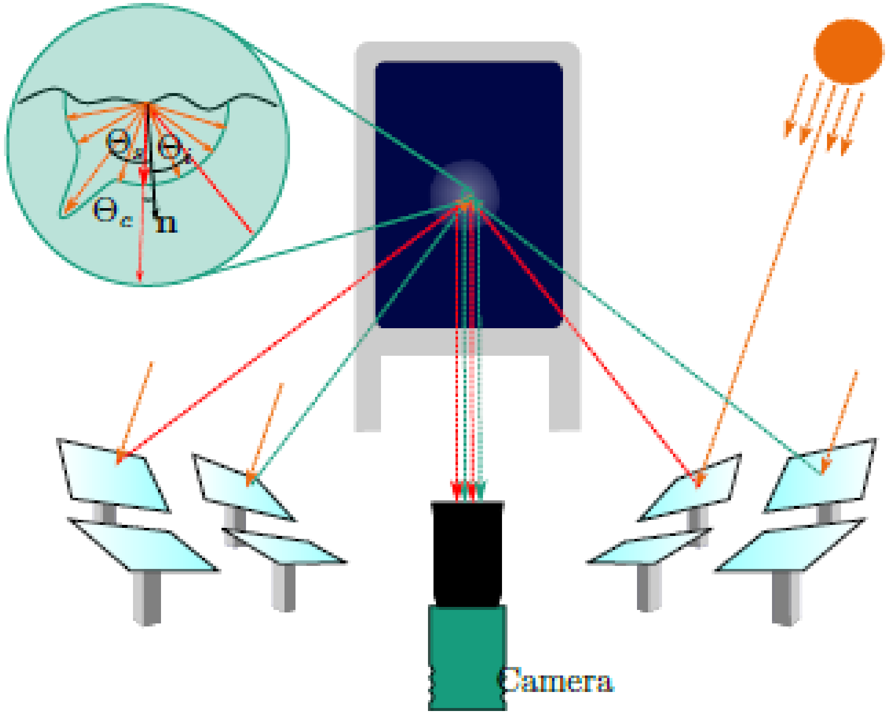
Quick Heliostat Field Commissioning & Improved Aim Point Control

[1] R. Brost et. al, Variation in Reflected Beam Shape and Pointing Accuracy Over Time and Heliostat Field Position, The SolarPACES Conference, 2023, Sydney
[2] G. Bern, Experimental Assessment of Simultanious In-Situ Heliostats Calibration Methodology HelioControl at Themis Facility, The SolarPACES Conference, 2019, Daegu
[3] J. Krauth, et.al, Fast Airborne Calibration of Entire Heliostat Fields of Heliostats, The SolarPACES Conference, 2023, Sydney

Receiver Material Evaluation

Example: Receiver Coating Evaluation

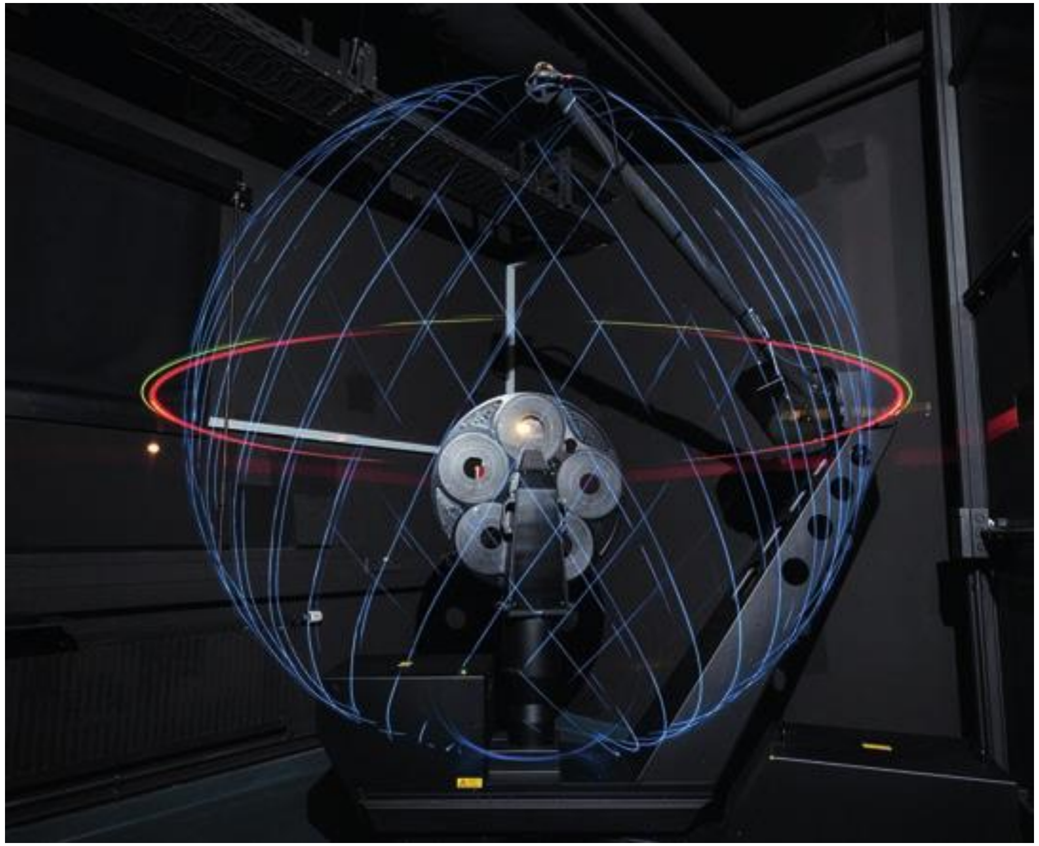


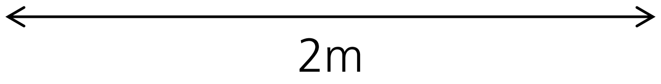


- Spatially varying bidirectional reflectance mapping
- Determination of directional absorptance
- Assessment of durability and quality of receiver coating

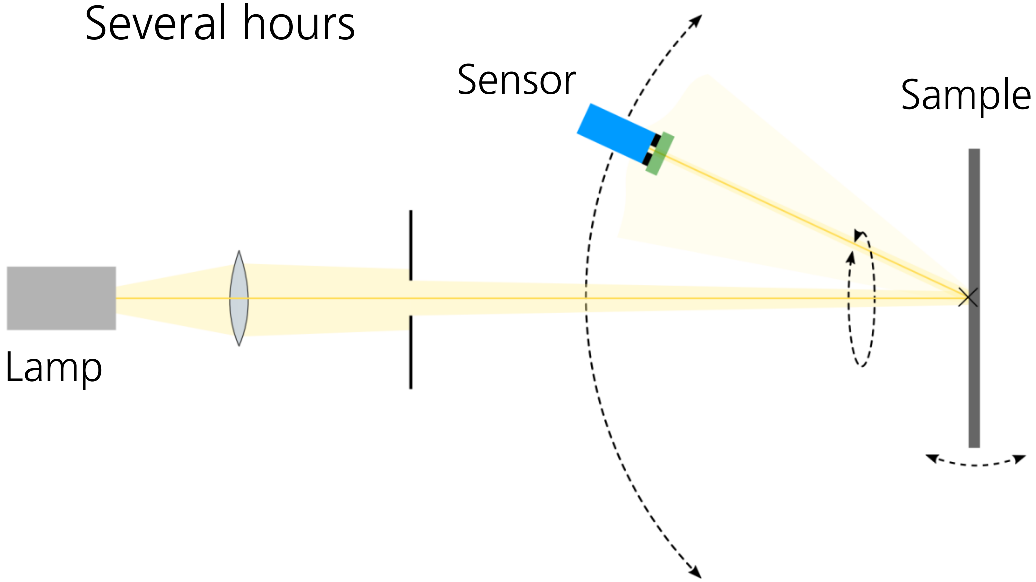
Fraunhofer ISE

BRDF Measurements with the 3-D gonio-photometer





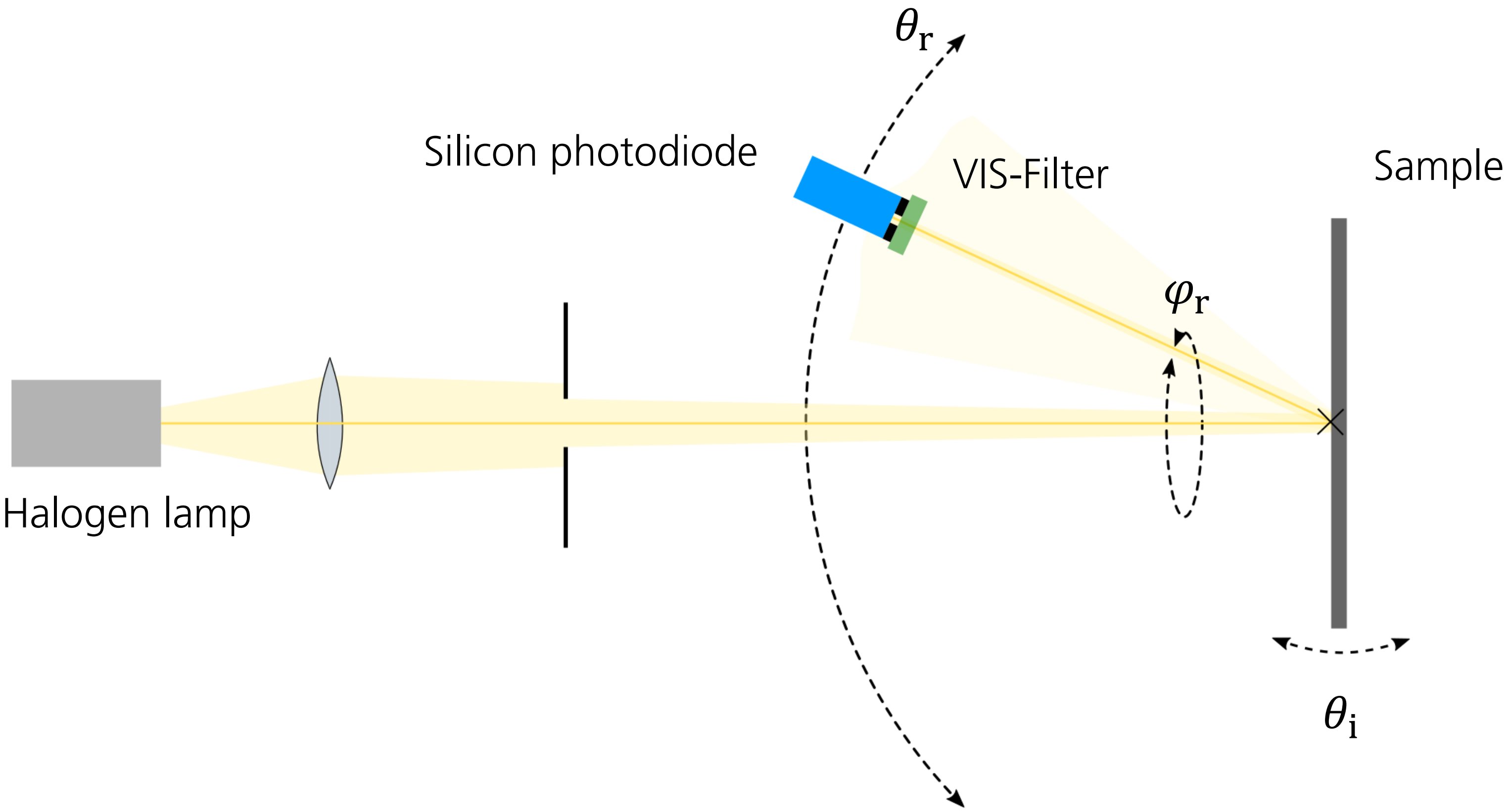
- Measurement of reflection properties on the hemisphere in the lab
- Samples: Soiled mirrors, Receiver coatings, refactory materials, etc…
- Duration of one measurement: Several hours



BRDF Measurements with the 3-D gonio-photometer

- θ_{i}: Polar angle of incidence
- θ_{r}: Polar angle of reflection
- φ_{r}: Azimuthal angle of reflection

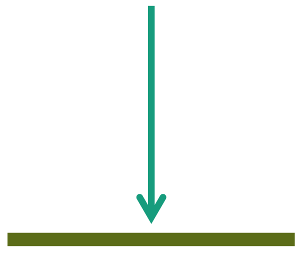
→ The measurement signal is a function of 3 parameters

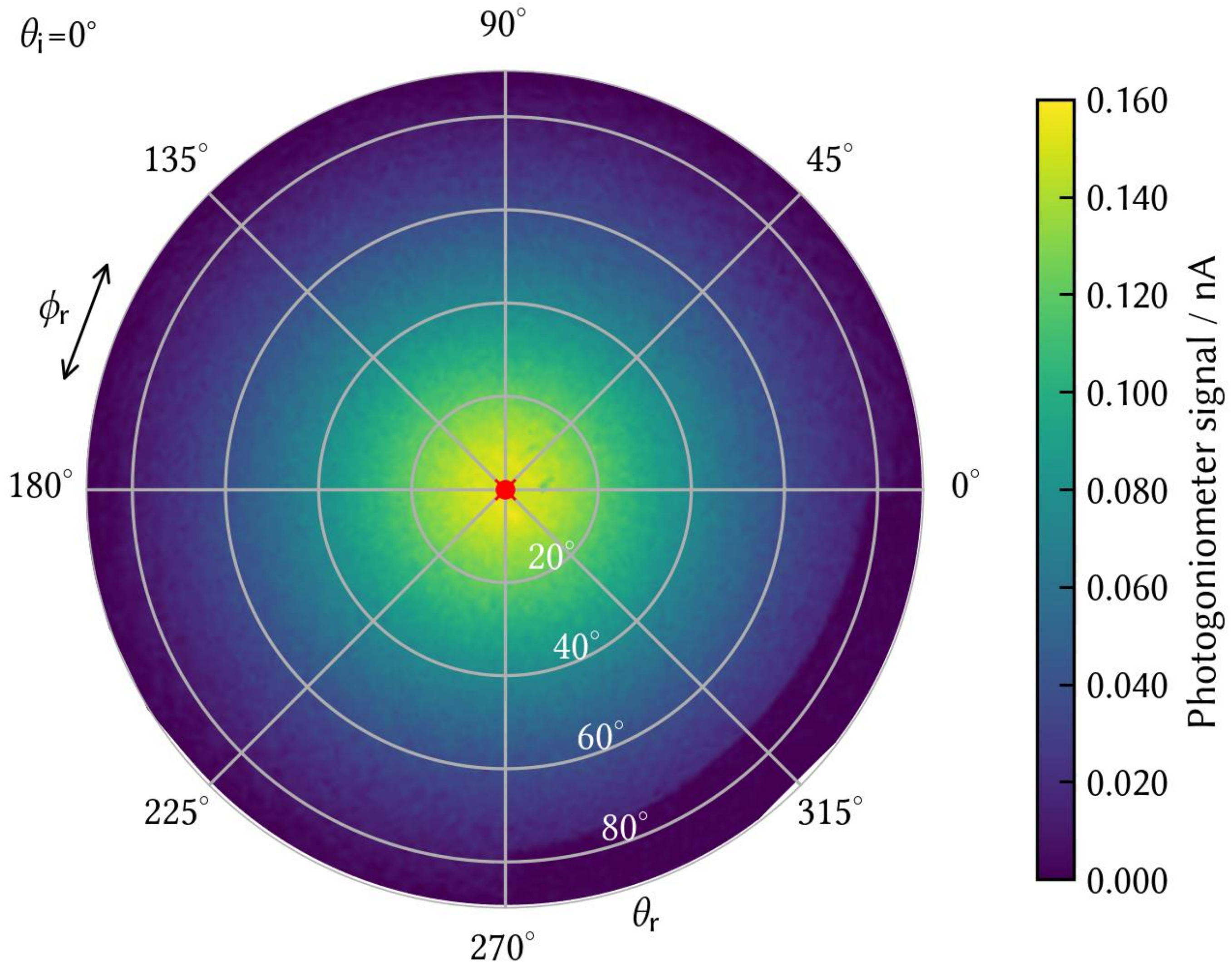


BRDF Measurements with the 3-D gonio-photometer

Pyromark

Measurement for perpendicular incidence



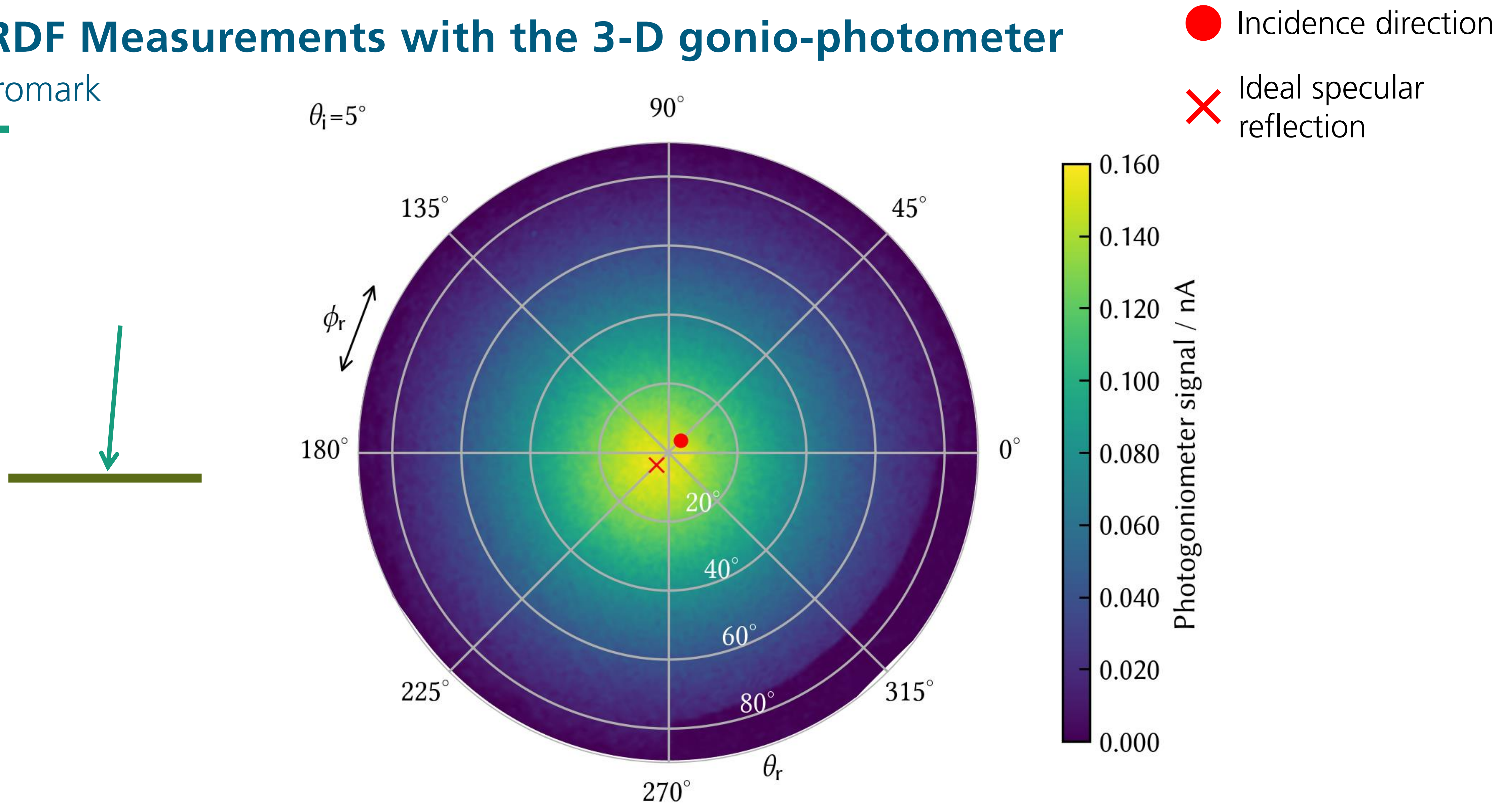


Current of photodiode

- Signal proportional to irradiance

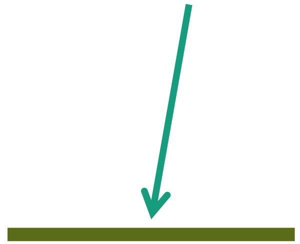
BRDF Measurements with the 3-D gonio-photometer

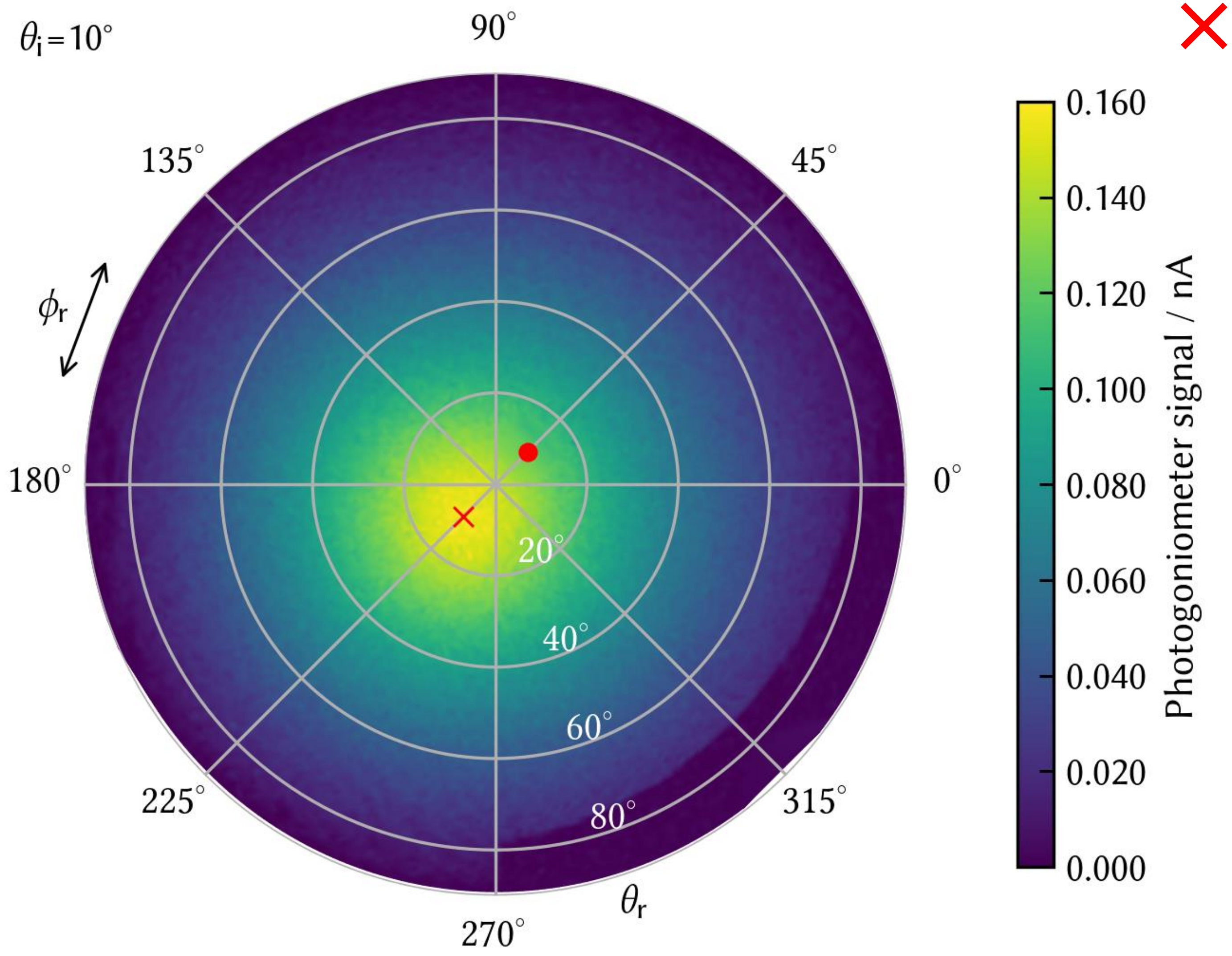
Pyromark



BRDF Measurements with the 3-D gonio-photometer

Pyromark



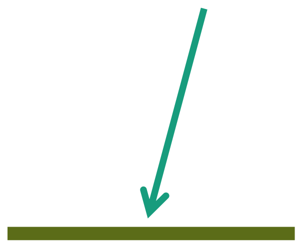


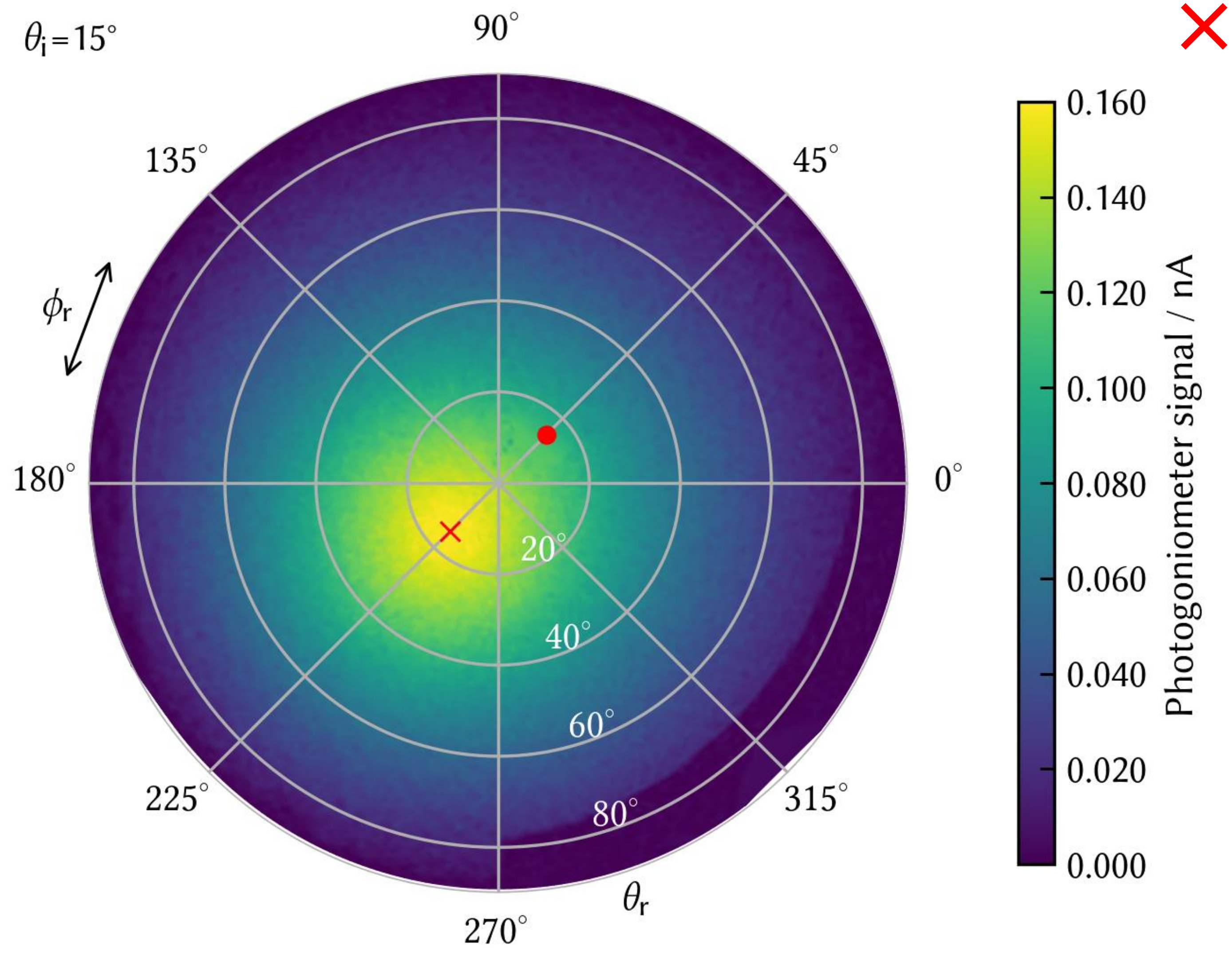
● Incidence direction

✕ Ideal specular reflection

BRDF Measurements with the 3-D gonio-photometer

Pyromark



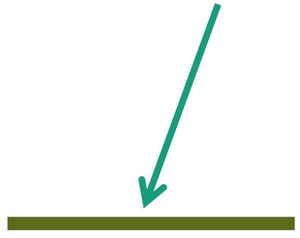


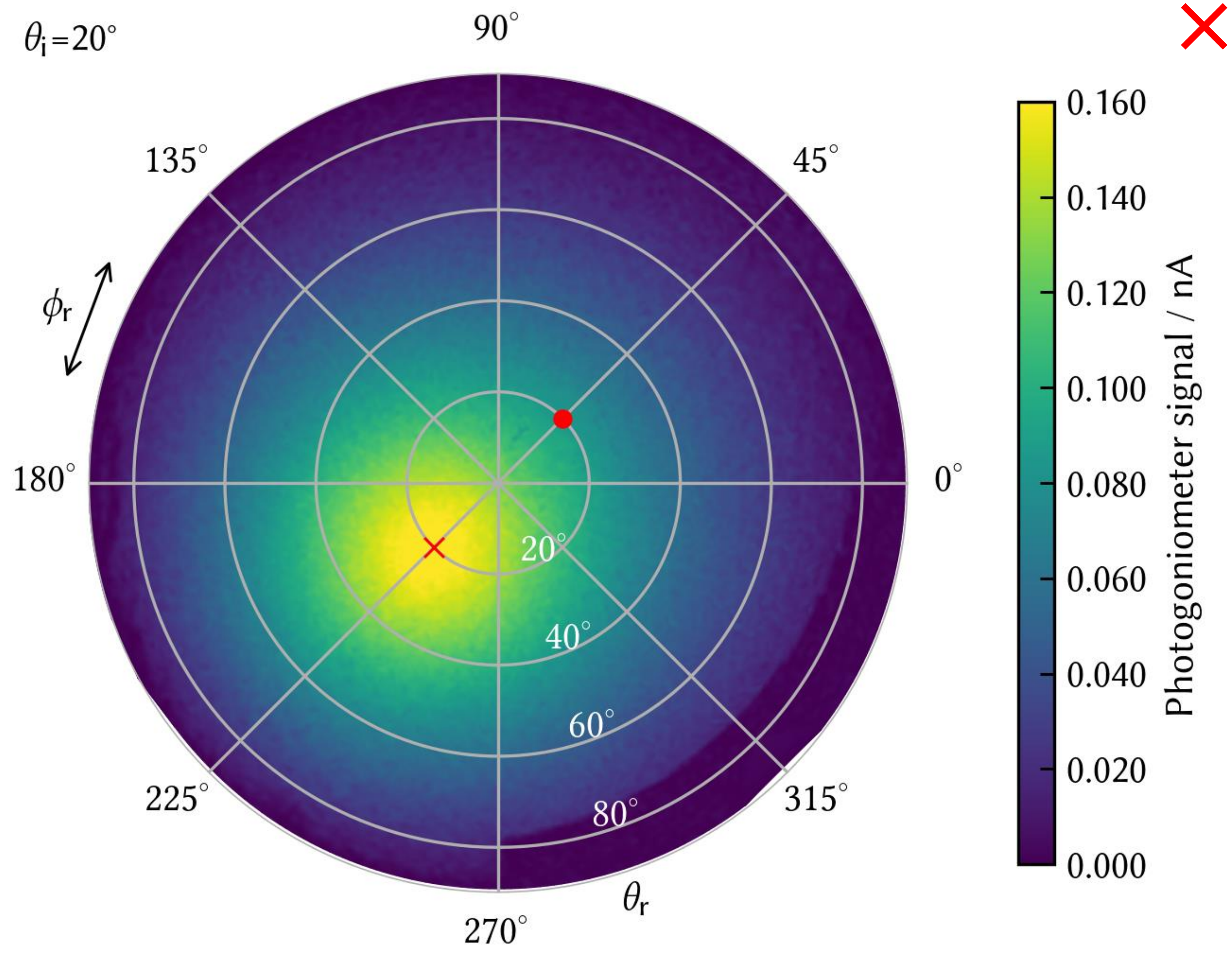
Incidence direction

Ideal specular reflection

BRDF Measurements with the 3-D gonio-photometer

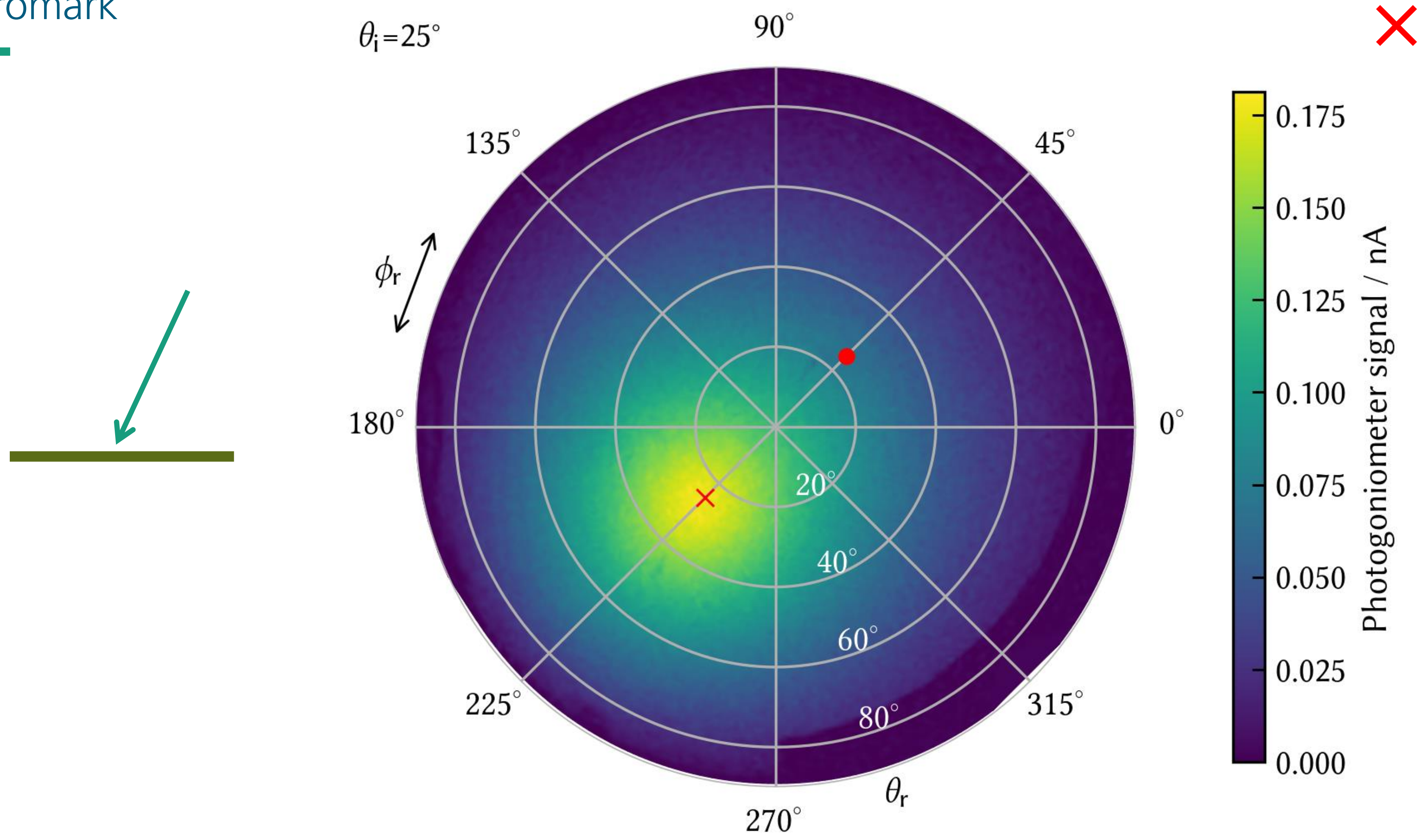
Pyromark





BRDF Measurements with the 3-D gonio-photometer

Pyromark

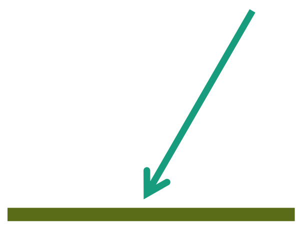


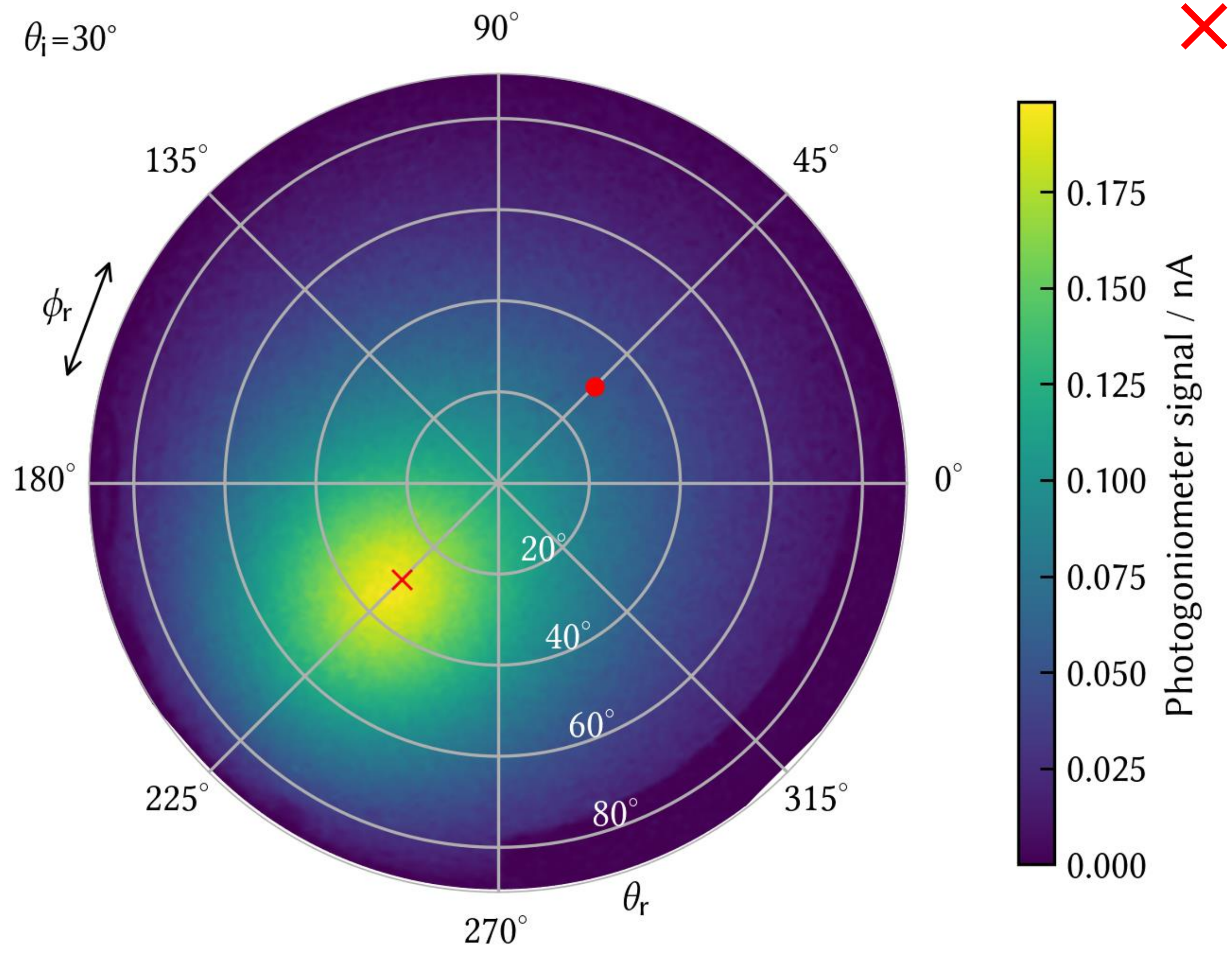
Incidence direction

Ideal specular reflection

BRDF Measurements with the 3-D gonio-photometer

Pyromark





Incidence direction

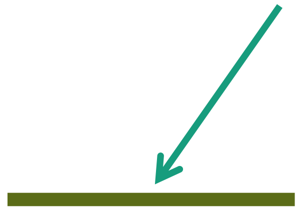
Ideal specular reflection

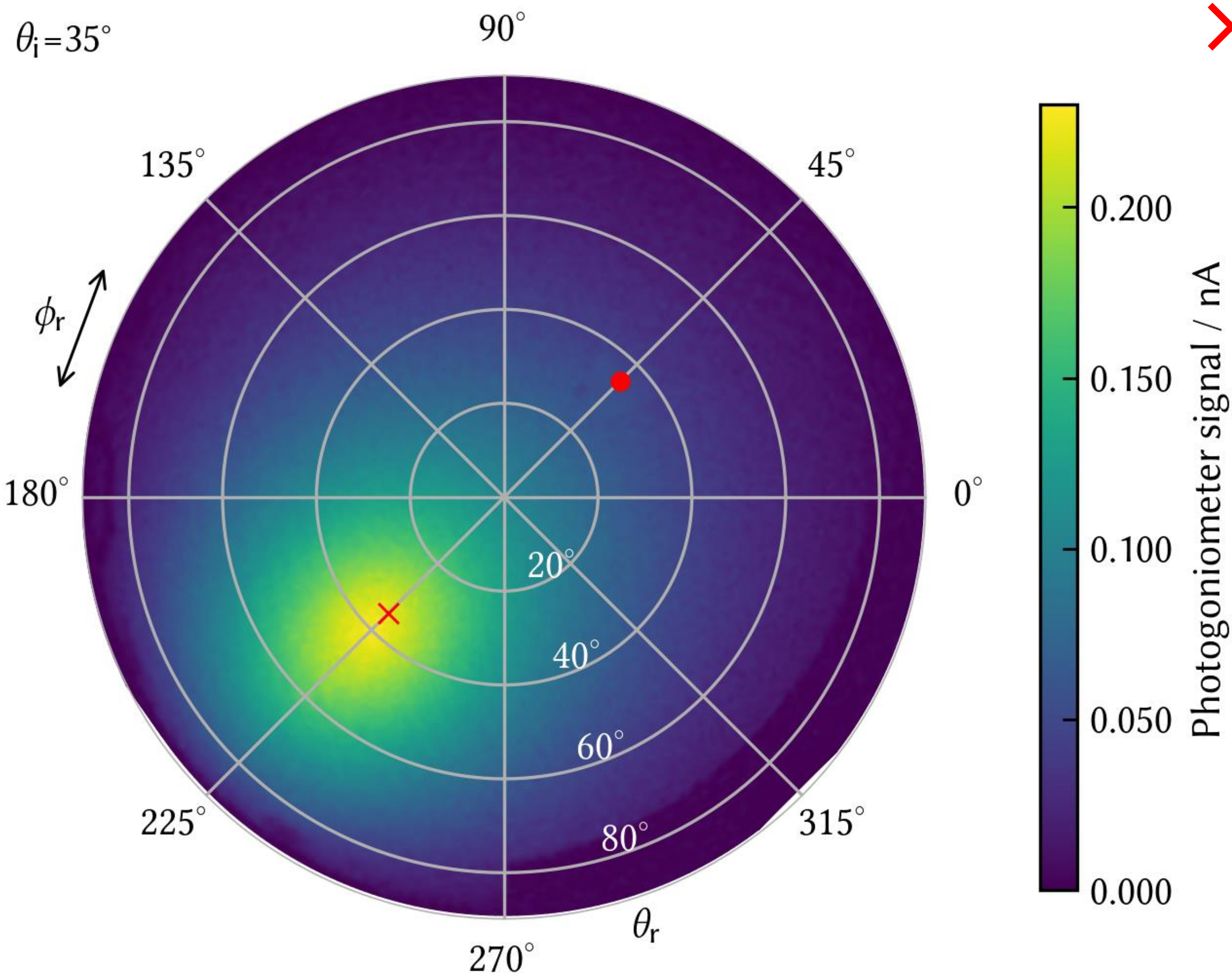
 14.11.2023 FHG-SK: ISE-INTERNAL

Fraunhofer ISE

BRDF Measurements with the 3-D gonio-photometer

Pyromark





Incidence direction

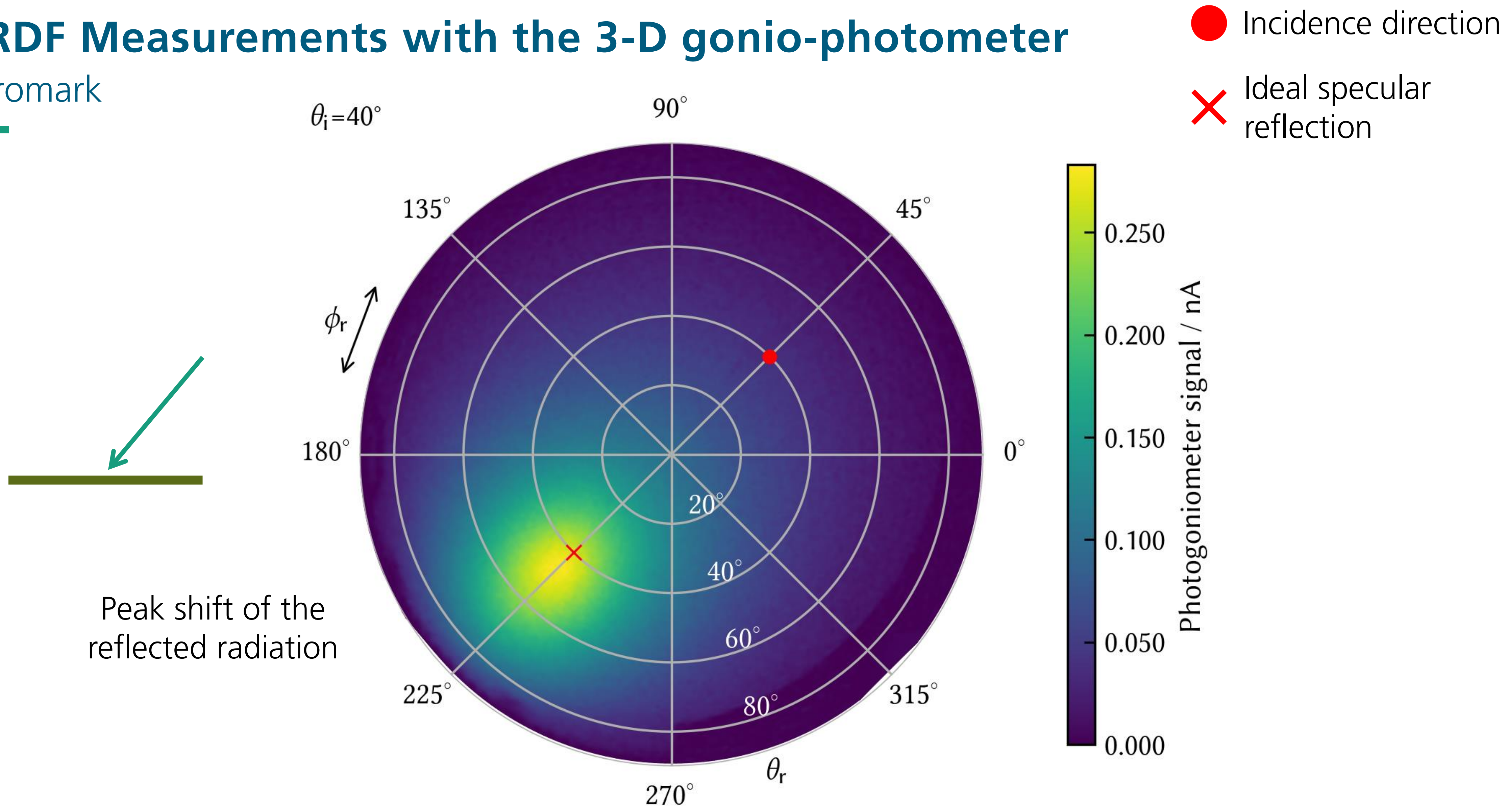
Ideal specular reflection

  FHG-SK: ISE-INTERNAL

Fraunhofer ISE

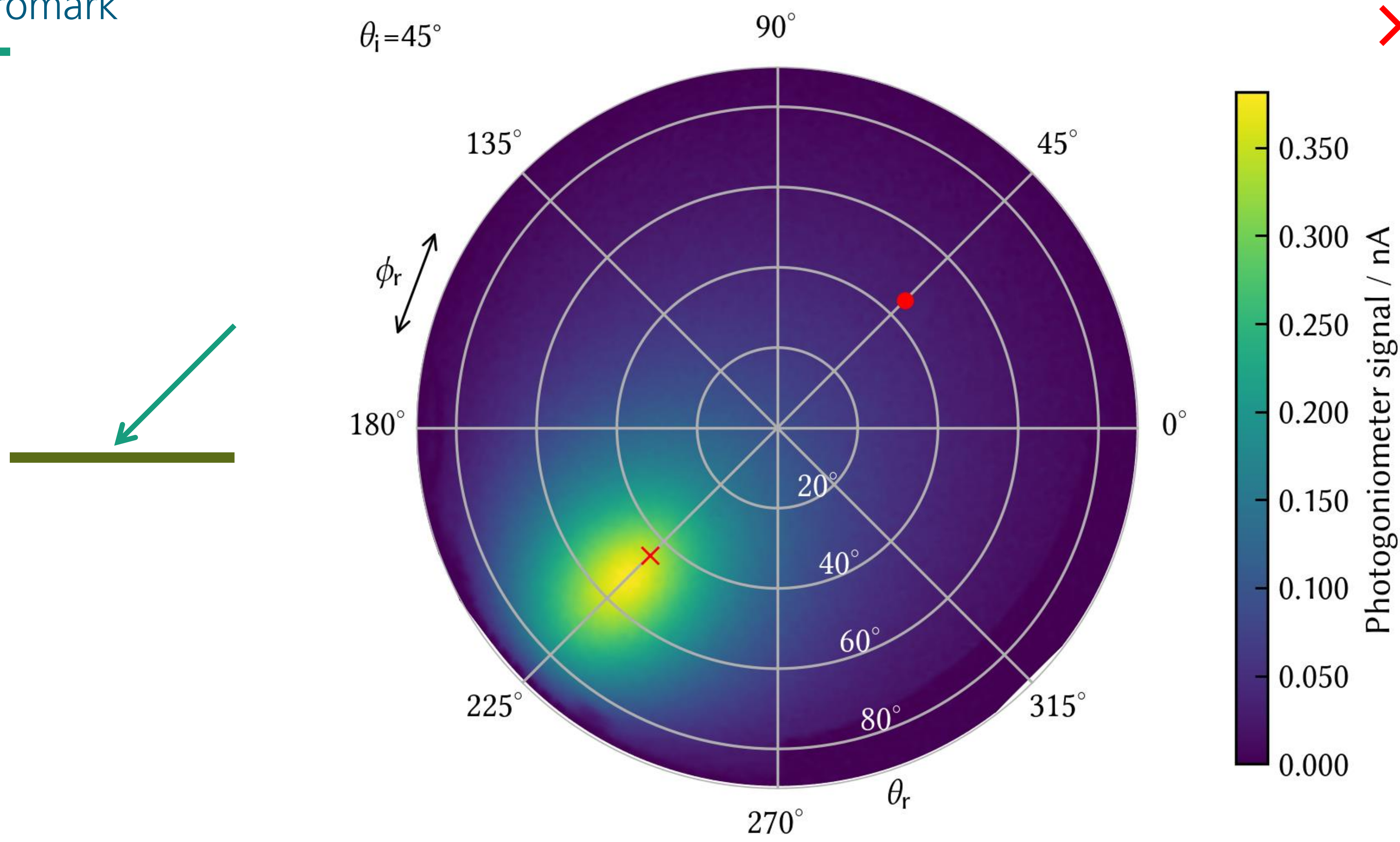
BRDF Measurements with the 3-D gonio-photometer

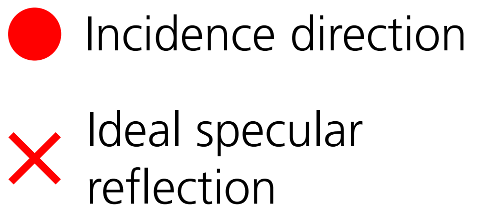
Pyromark



BRDF Measurements with the 3-D gonio-photometer

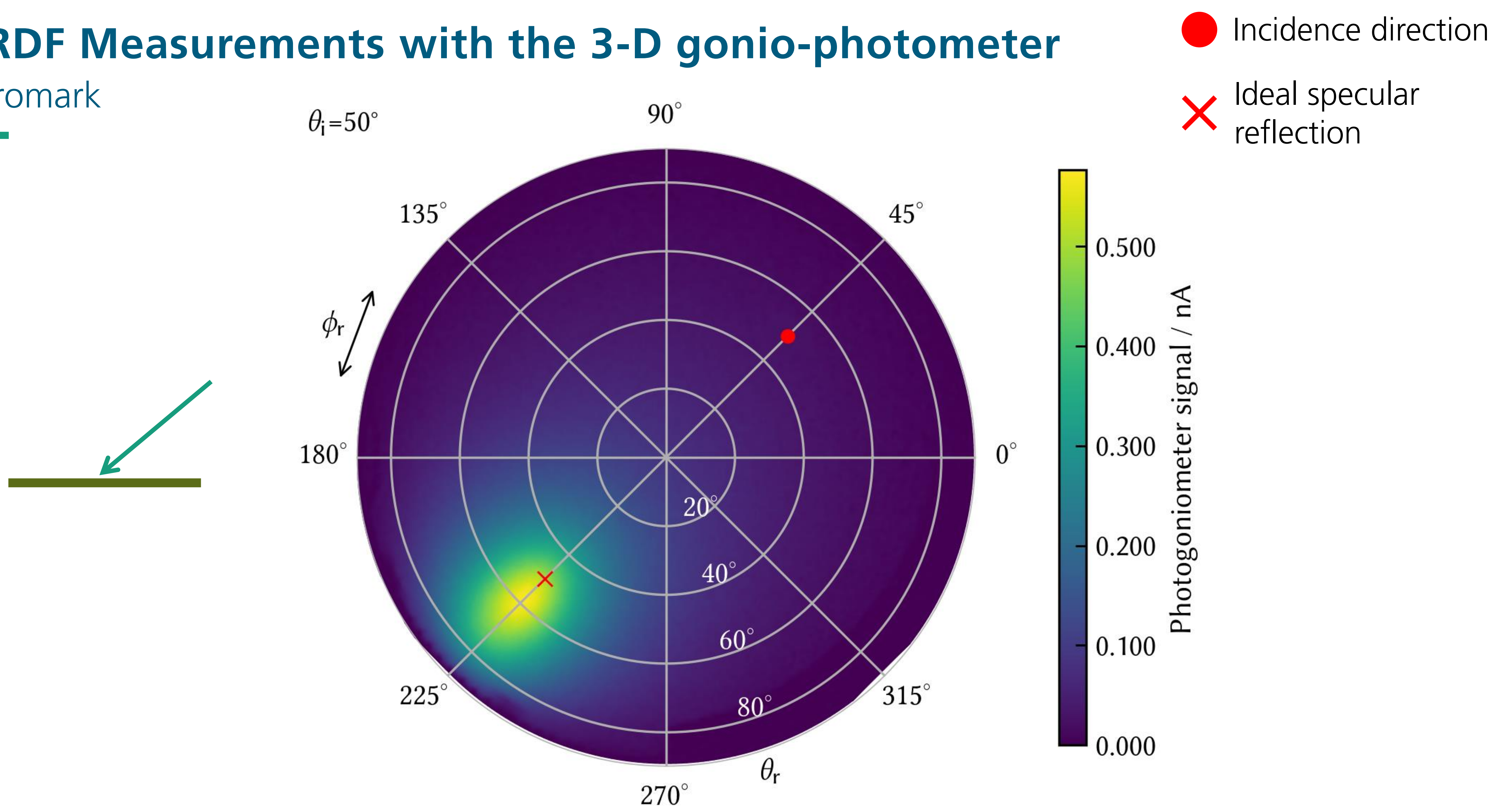
Pyromark





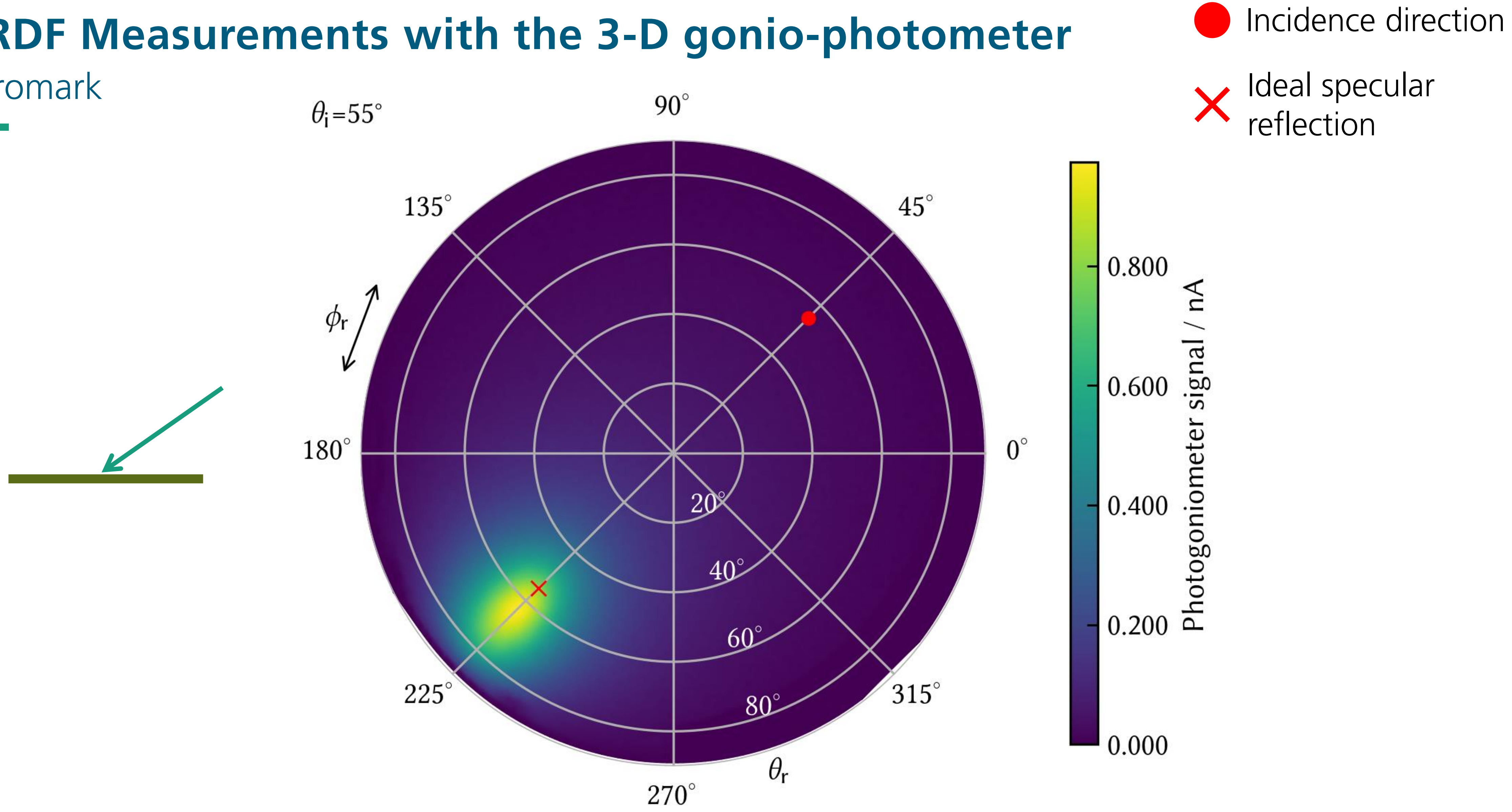
BRDF Measurements with the 3-D gonio-photometer

Pyromark



BRDF Measurements with the 3-D gonio-photometer

Pyromark



BRDF Measurements with the 3-D gonio-photometer

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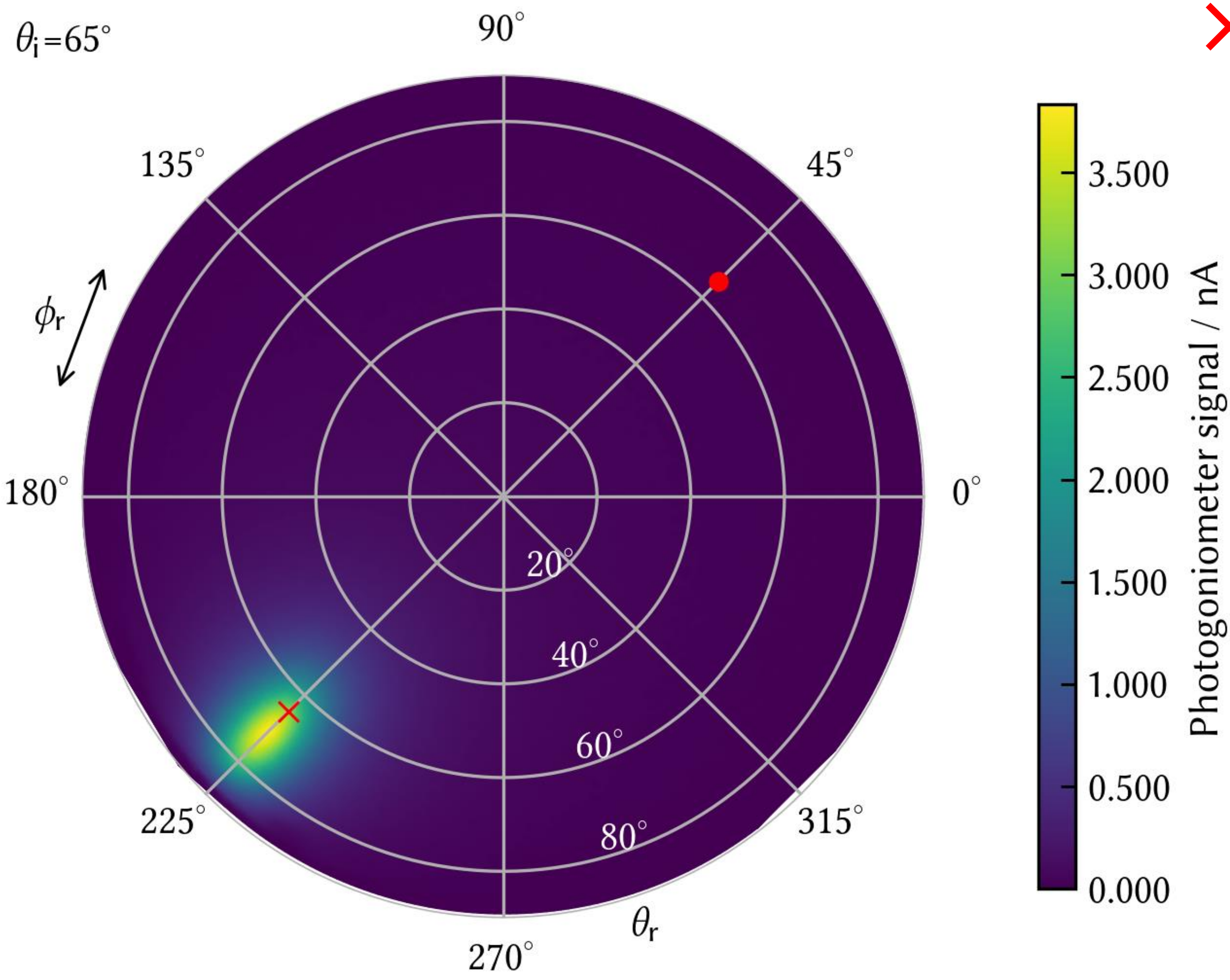
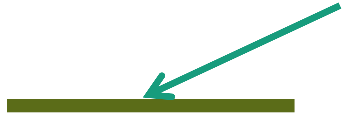


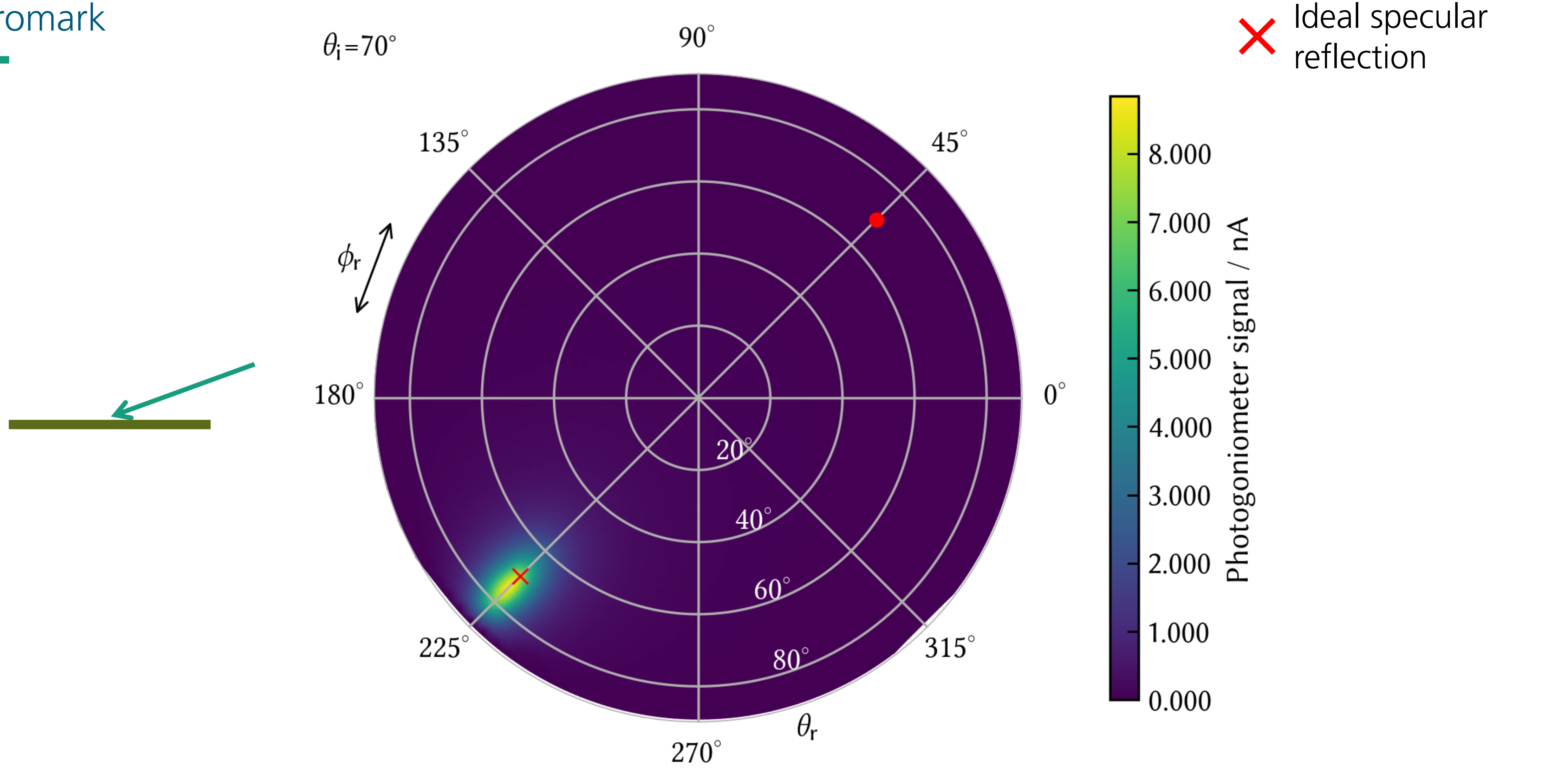


Incidence direction

Ideal specular reflection

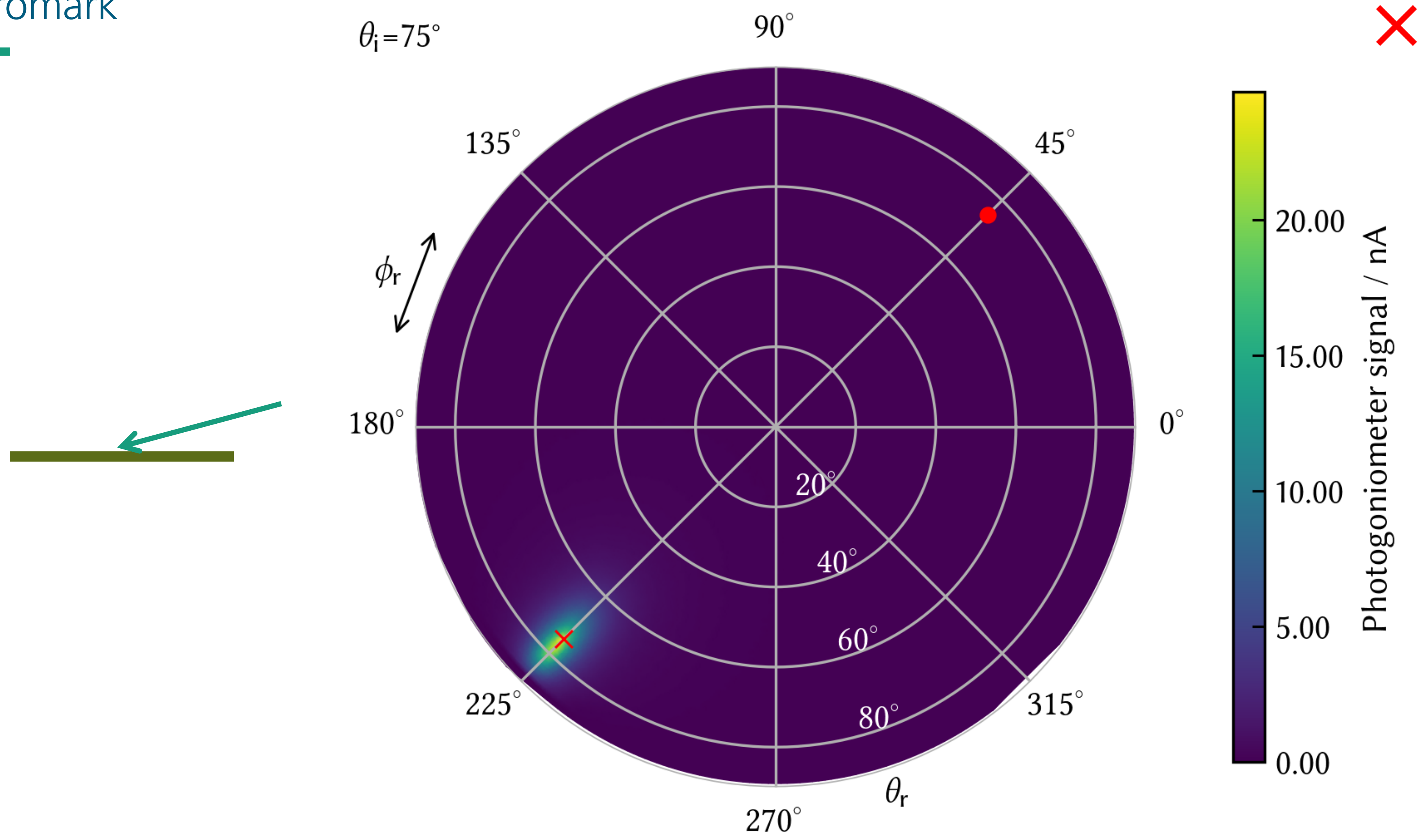
BRDF Measurements with the 3-D gonio-photometer

Pyromark



BRDF Measurements with the 3-D gonio-photometer

Pyromark

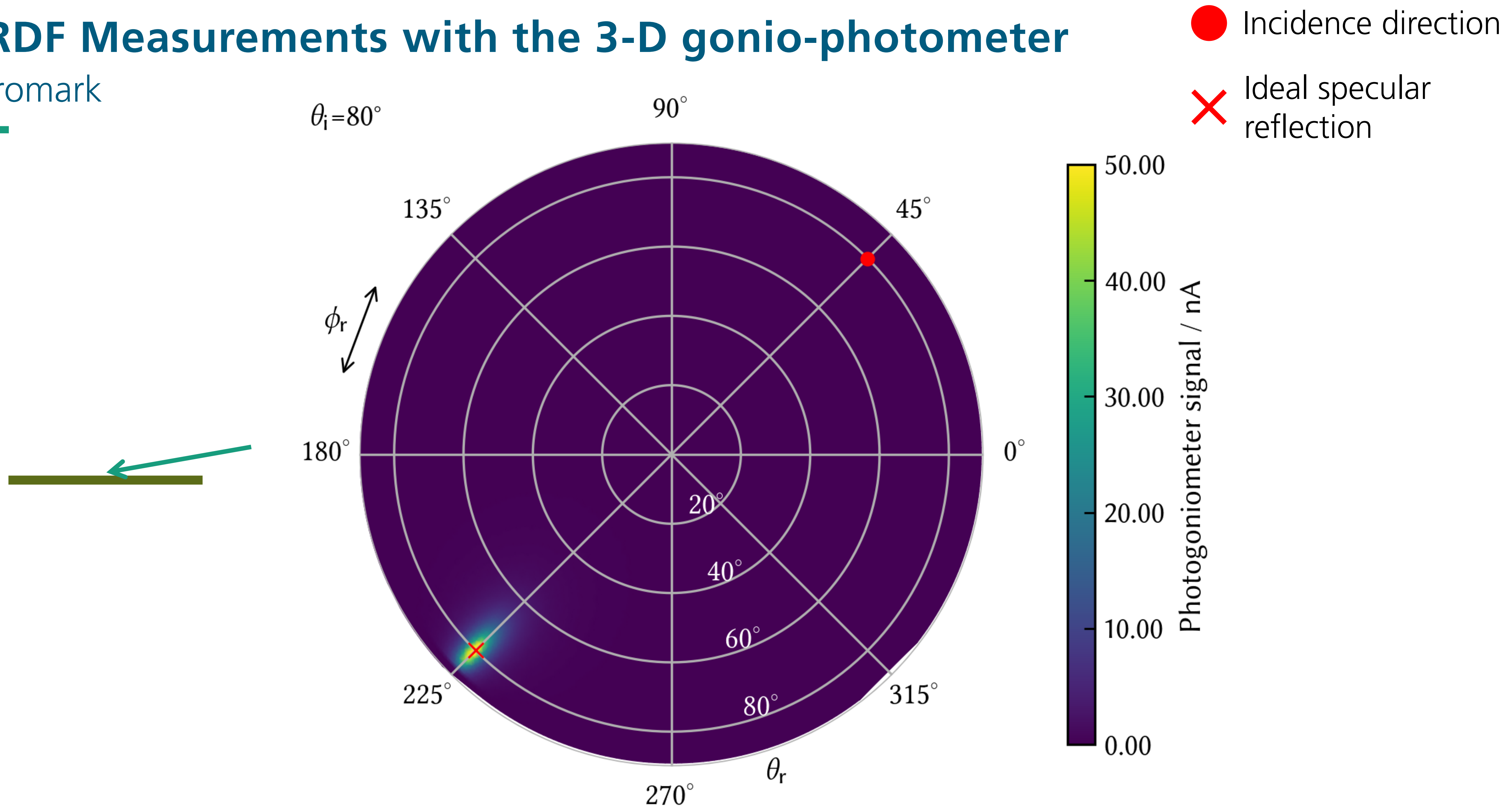


Incidence direction

Ideal specular reflection

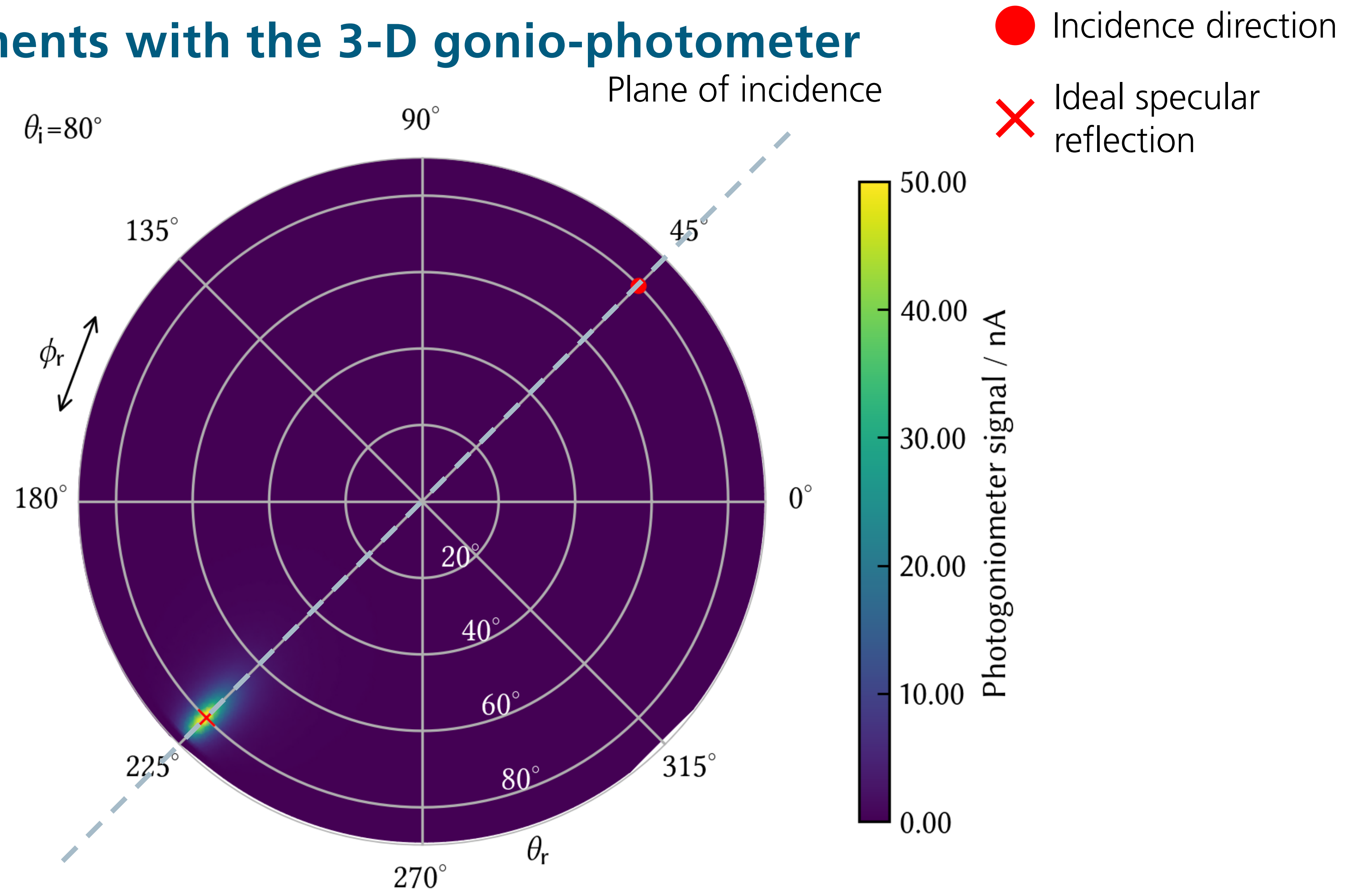
BRDF Measurements with the 3-D gonio-photometer

Pyromark



BRDF Measurements with the 3-D gonio-photometer

Pyromark



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BRDF Measurements with the 3-D gonio-photometer

Conversion of measurement data to BRDF values

- Derivation of the BRDF from measured current to calculate the different reflectance factors (directional-conical, directional-hemispherical, biconical, …):
  - Normalization with beam intensity
  - Division by $\cos\theta_{\mathrm{r}}$

Definition BRDF: $f_{\mathrm{r}} = \frac{\mathrm{d}L_{\mathrm{r}}}{\mathrm{d}E_{\mathrm{i}}}$ [sr^{-1}]

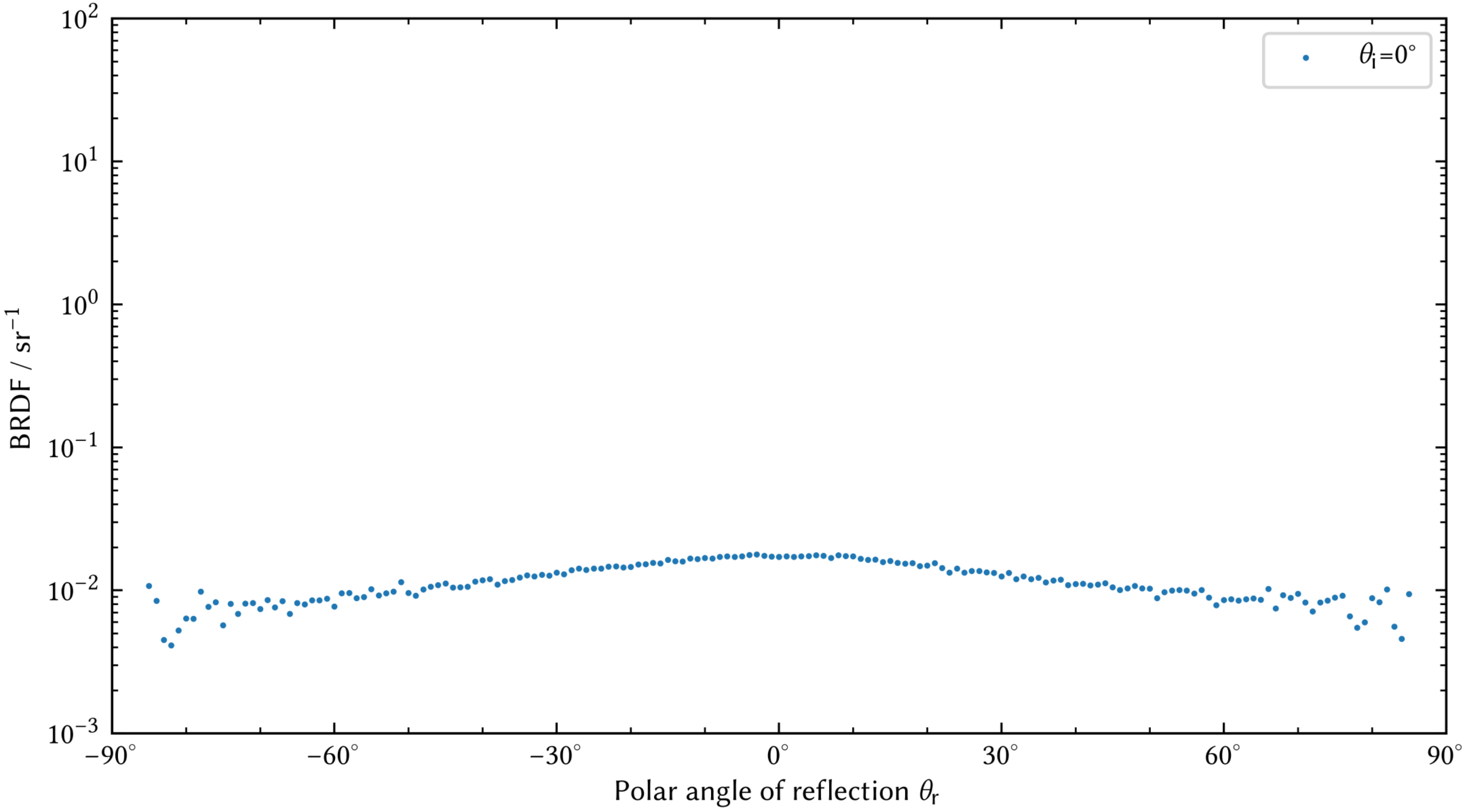
Reflected Radiance / Incident Irradiance

- Perfect Lambertian Reflector: $f_{\mathrm{r}} = \frac{1}{\pi}\ \mathrm{sr}^{-1} \approx 0.32\ \mathrm{sr}^{-1}$
- cBRDF (without division by cos) seems to be more intuitive for mirrors

F. E. Nicodemus, J. C. Richmond, J. J. Hsia, I. W. Ginsberg und T. Limperis. Geometri-cal Considerations and Nomenclature for Reflectance. National Bureau of Standards.Washington, D.C, 1977

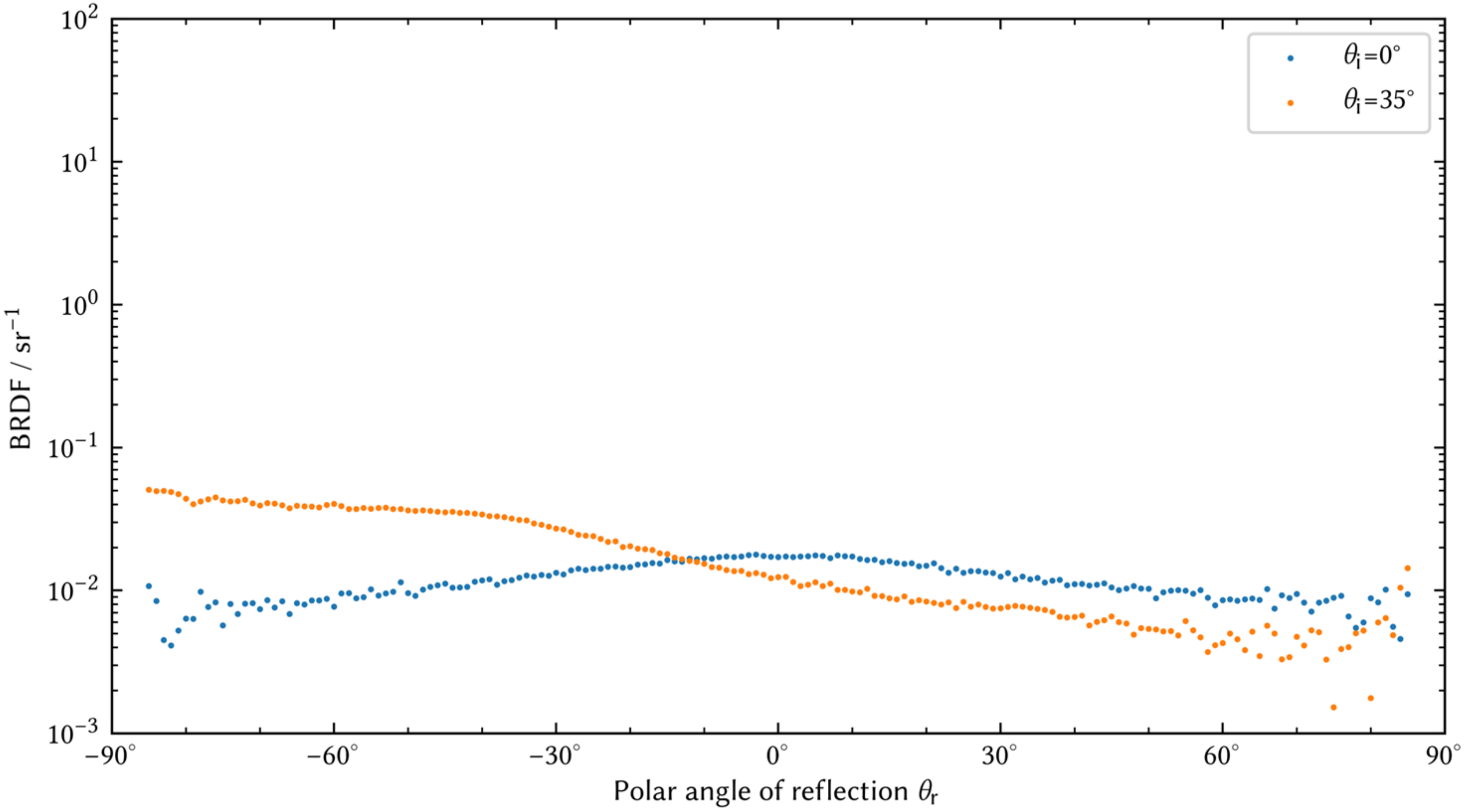
BRDF Measurements with the 3-D gonio-photometer

Measurement data in the plane of incidence for Pyromark



BRDF Measurements with the 3-D gonio-photometer

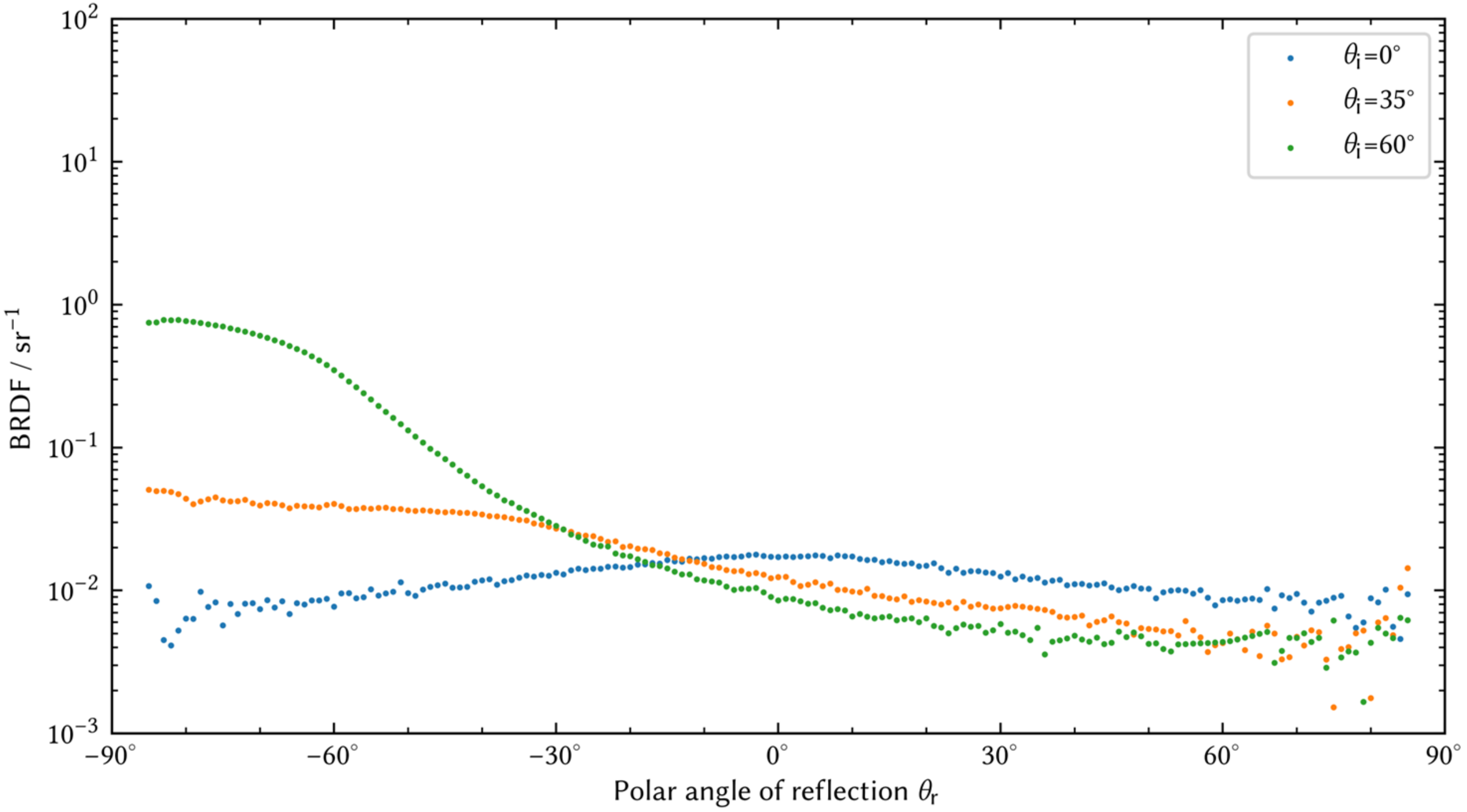
Measurement data in the plane of incidence for Pyromark



Fraunhofer ISE

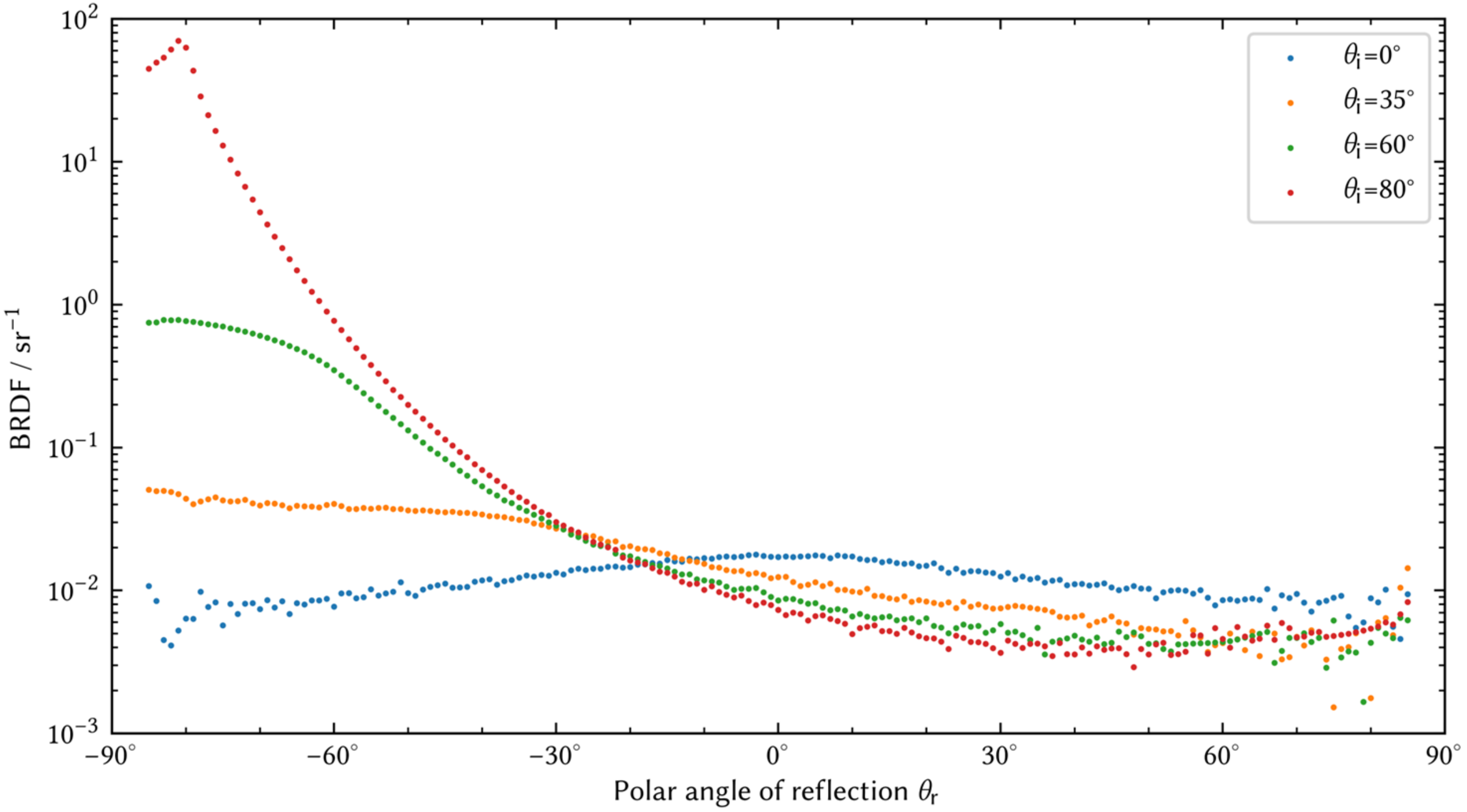
BRDF Measurements with the 3-D gonio-photometer

Measurement data in the plane of incidence for Pyromark



BRDF Measurements with the 3-D gonio-photometer

Measurement data in the plane of incidence for Pyromark



BRDF Measurements with the 3-D gonio-photometer

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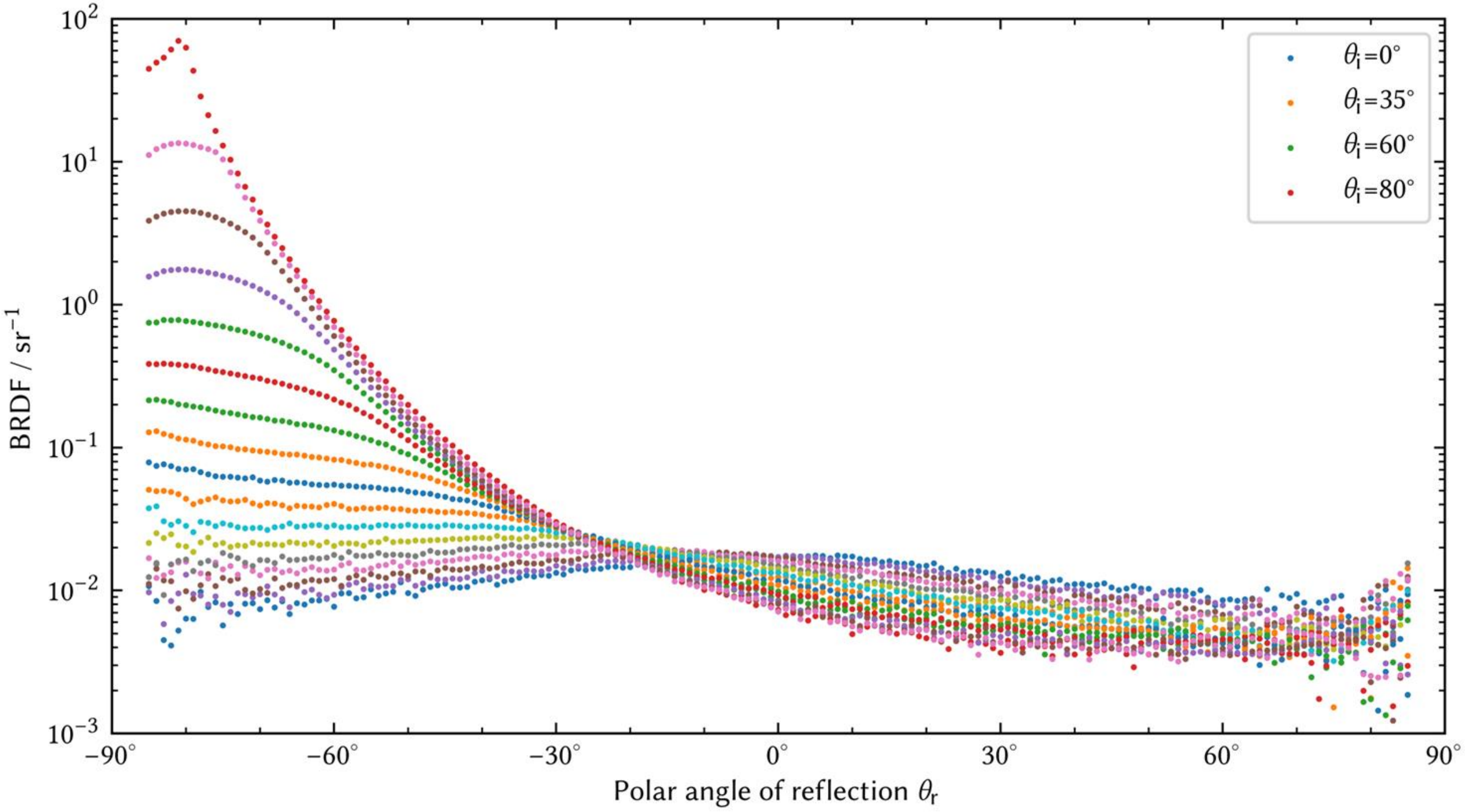
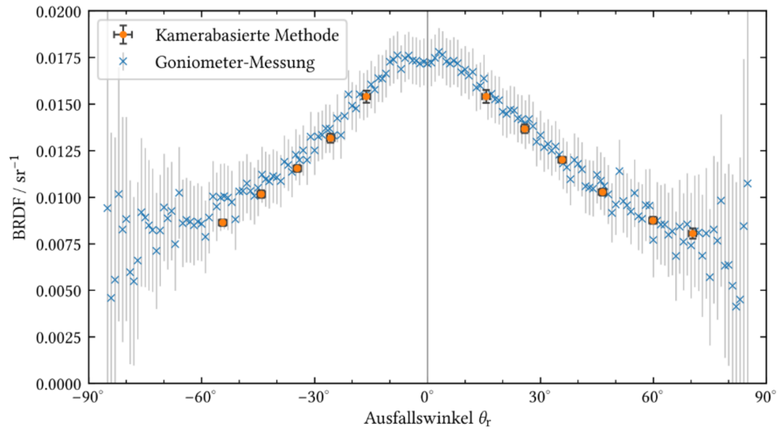
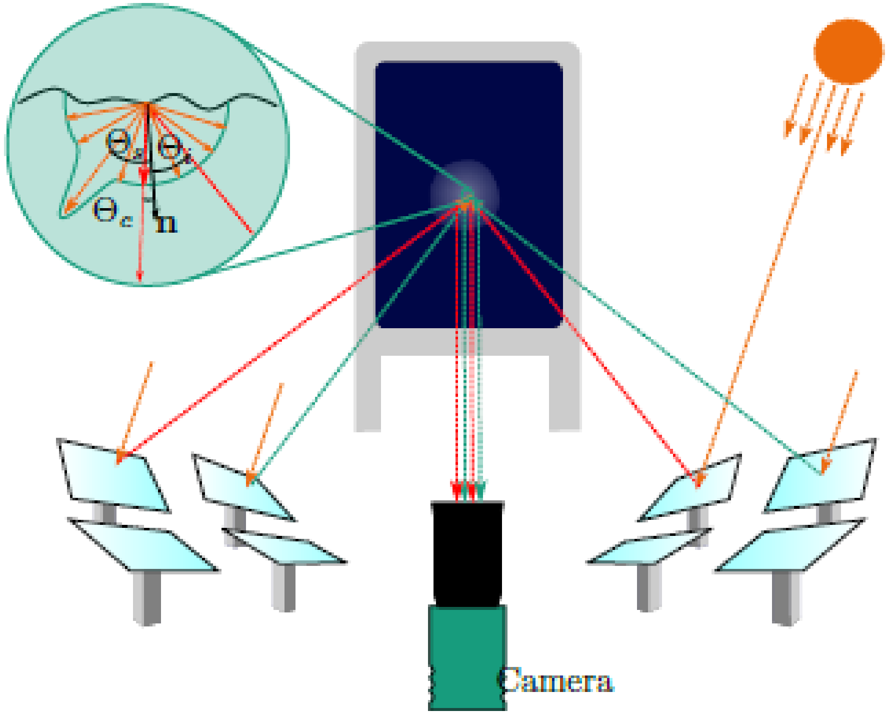


Instruments for field measurements

Remote Receiver Quality Assessment



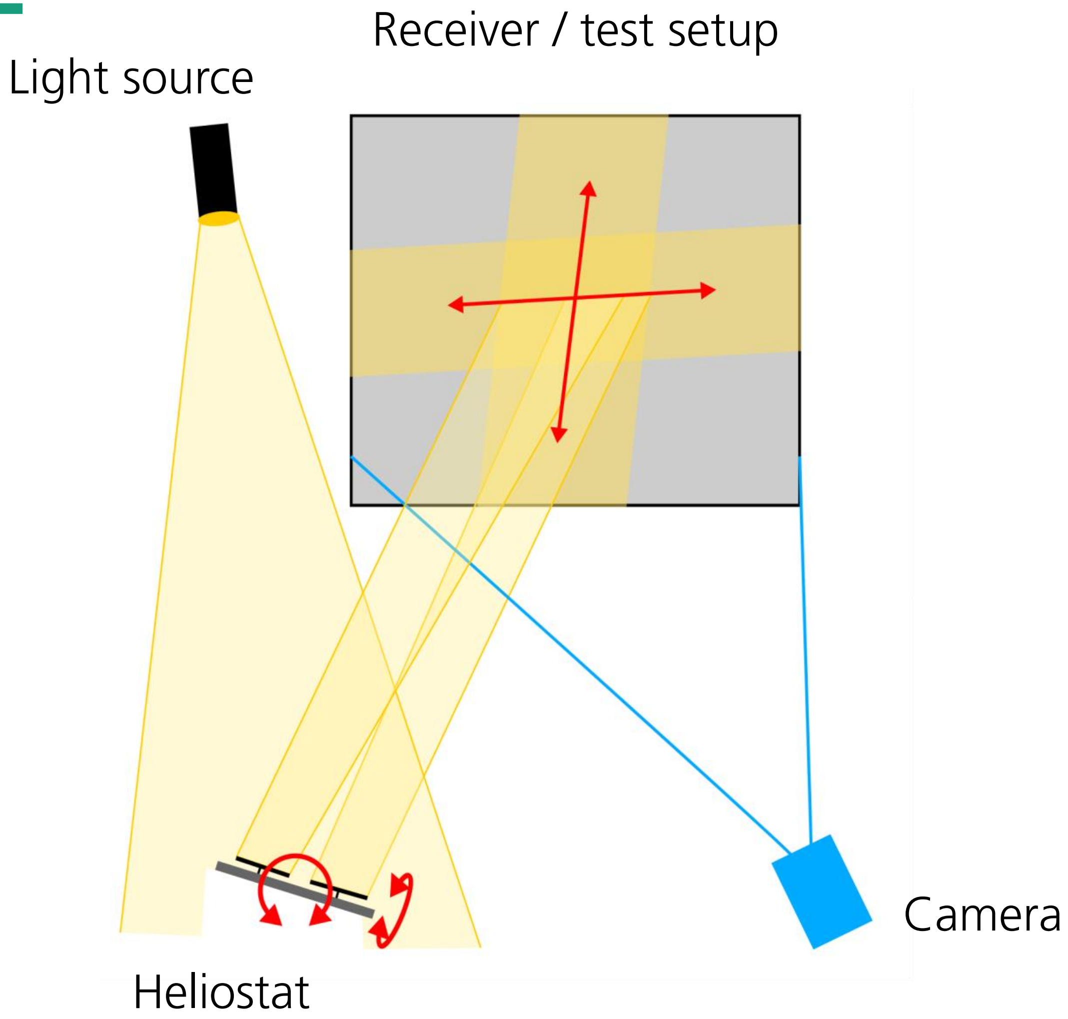
Validated Far Field SVBRDF with uncalibrated lightsource



- Camera based remote measurement from solar field
- Spatially varying bidirectional reflectance mapping
- Determination of directional absorptance
- Assessment of status and quality of receiver coating

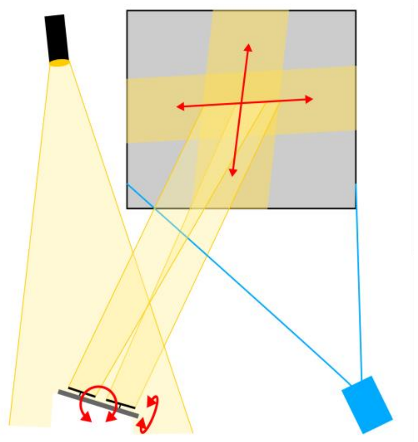
When is the best time to recoat? Was there a damaging event?

Measuring the SVBRDF



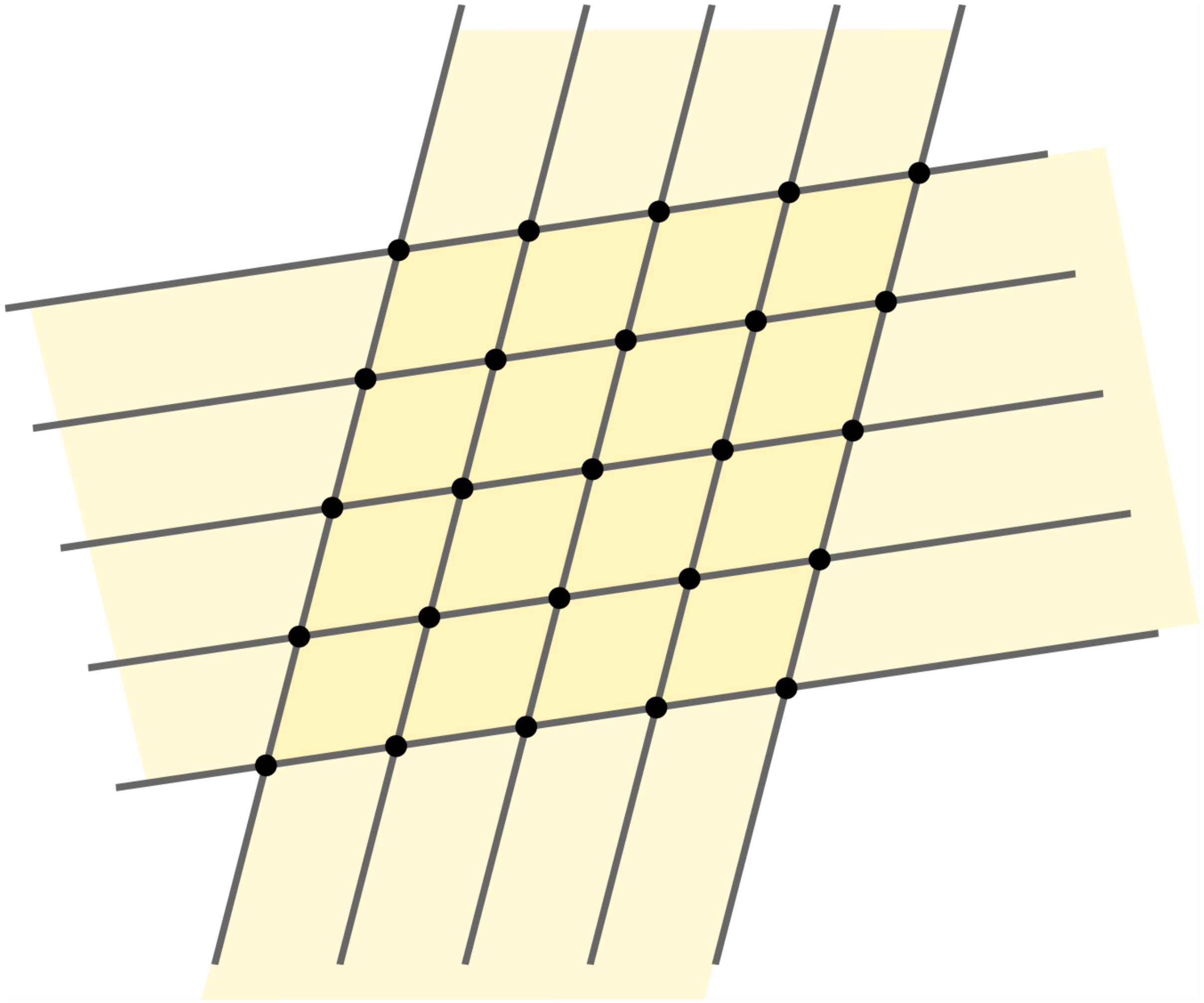
- Light source + heliostat: Unknown and inhomogeneous intensity distribution
- Acquisition of two image sequences with movement of the light distribution over absorber
- Calculation of the relative reflectance of the absorber from the image sequences

Measuring the SVBRDF

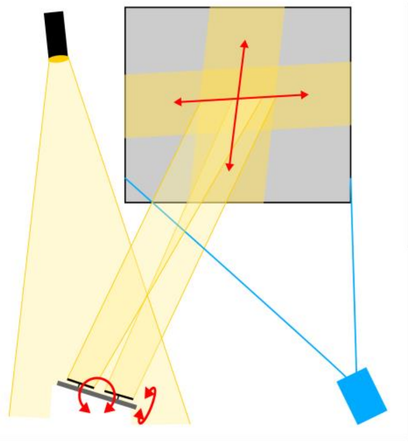


- Lines of constant intensity in the direction of motion
- Analysis of the intensity maxima of the individual pixels
- Overdetermined system of equations in the overlapping area
- Numerical minimization

→ Relative reflectance



Measuring the SVBRDF



Images of the horizontal sequence (600 single images)

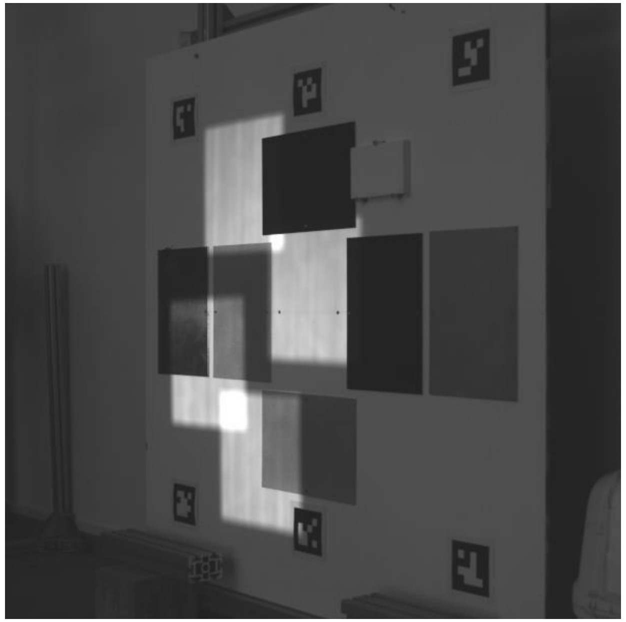


image 240

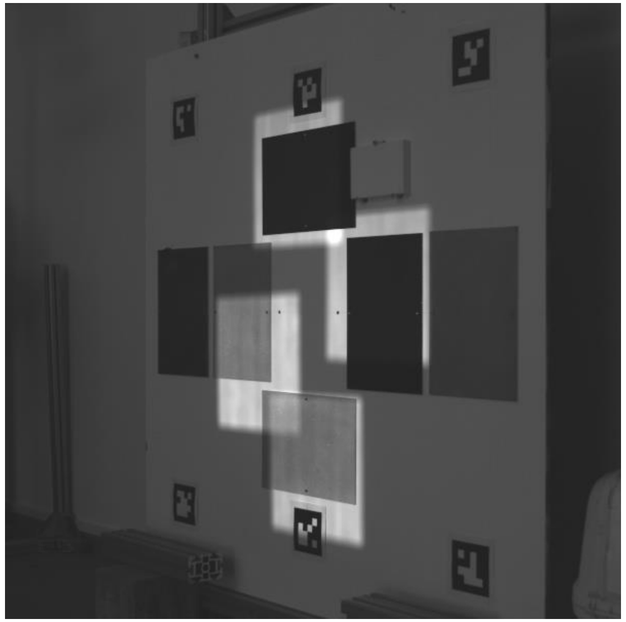


image 290

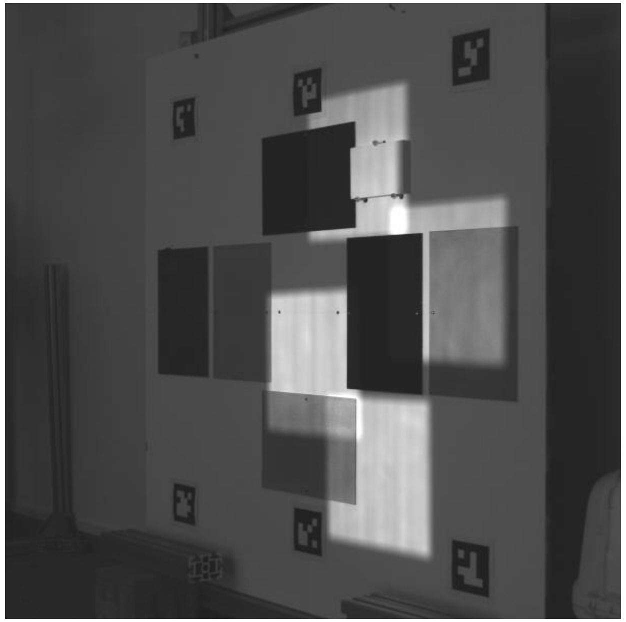
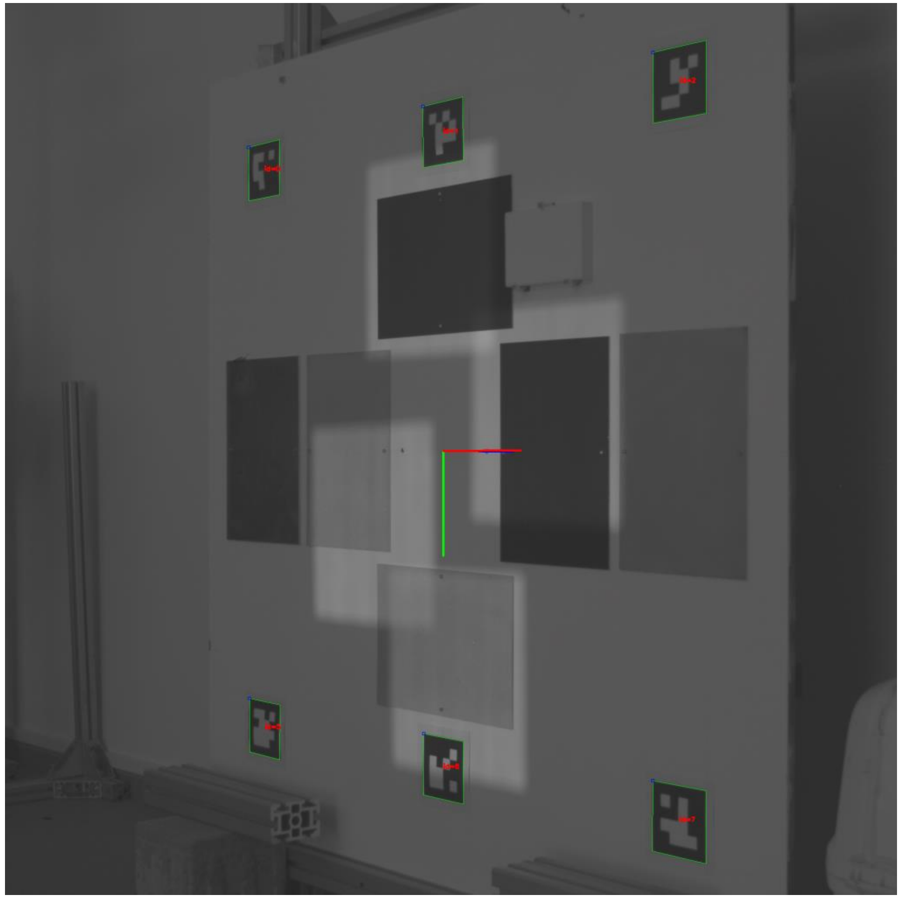
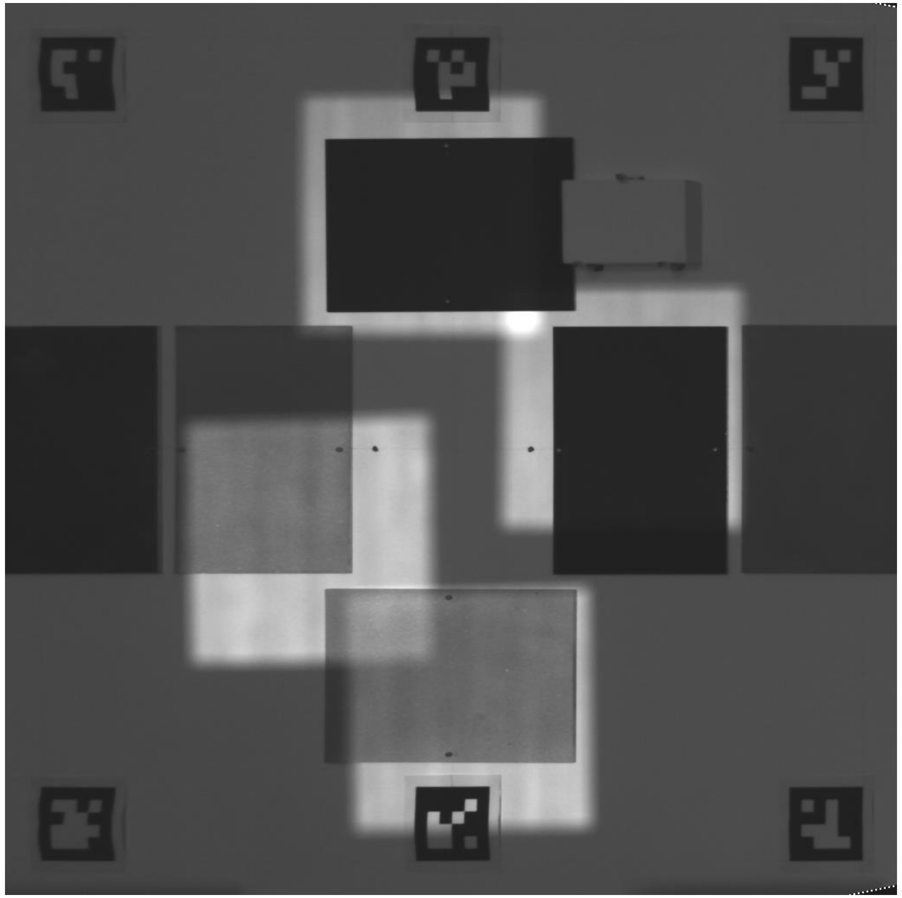


image 340

Measuring the SVBRDF

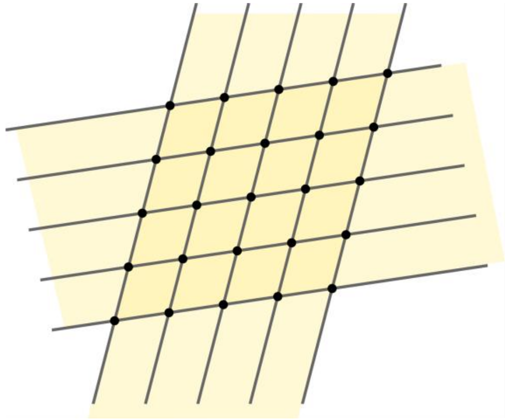
- Transformation of camera images into vertical perspective with markers

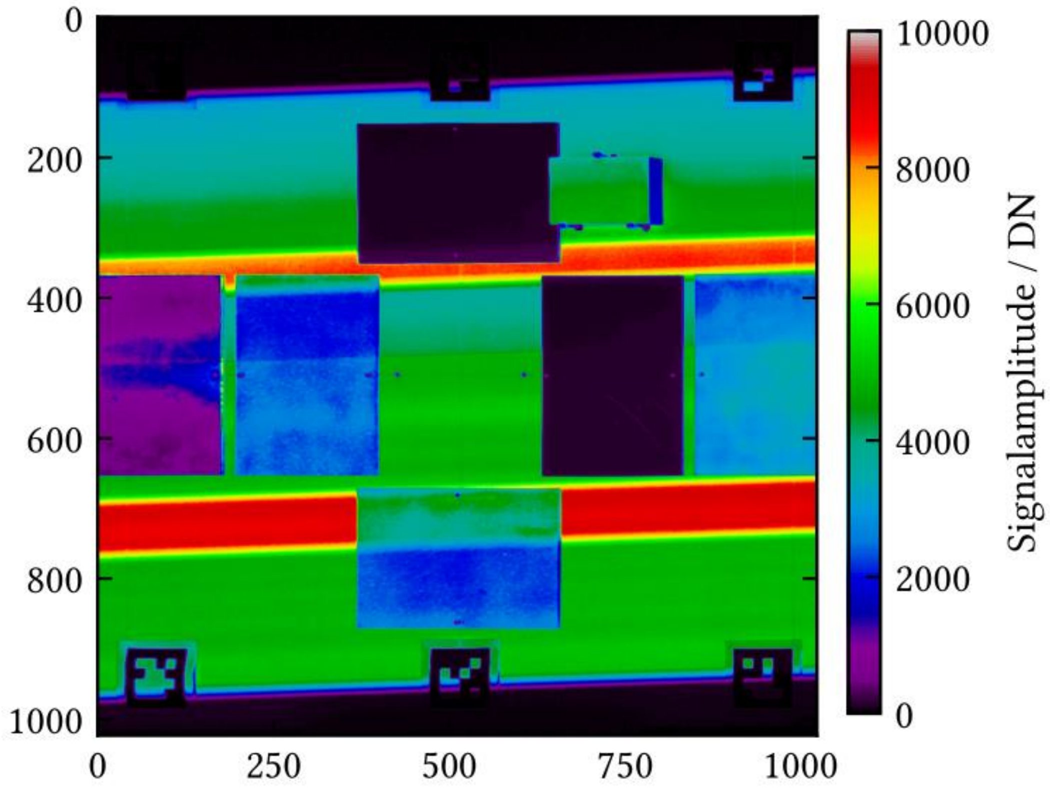


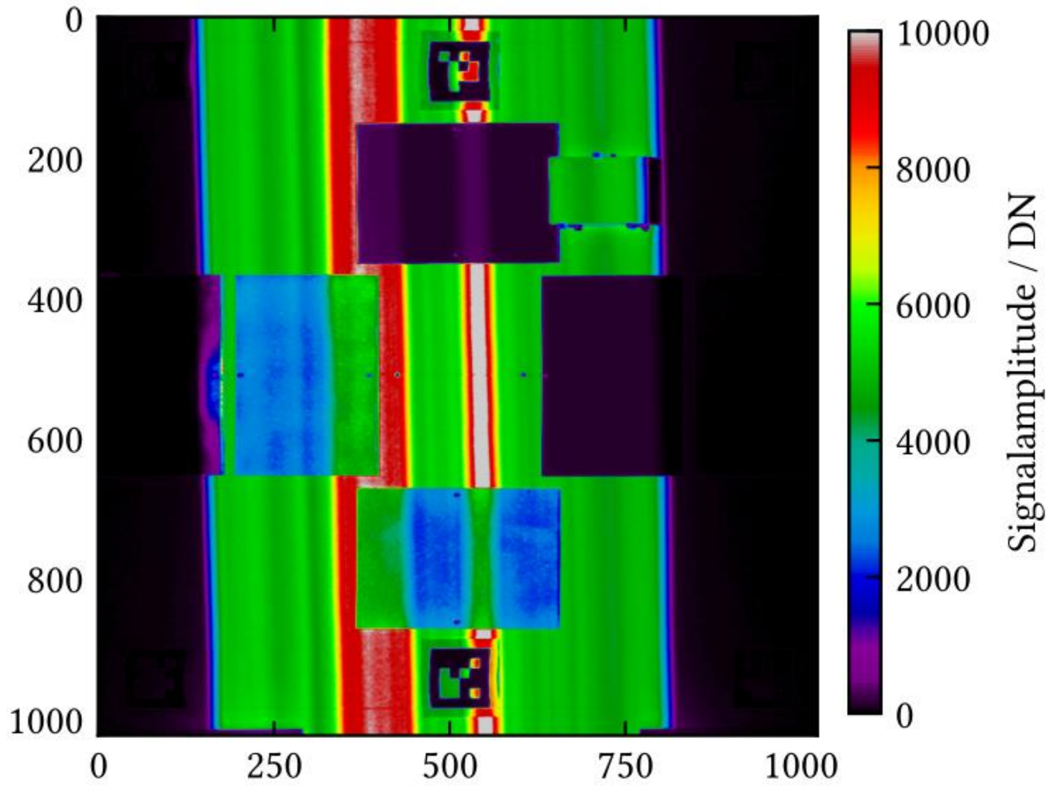


Measuring the SVBRDF

- Analysis of intensity maxima of horizontal and vertical image sequence



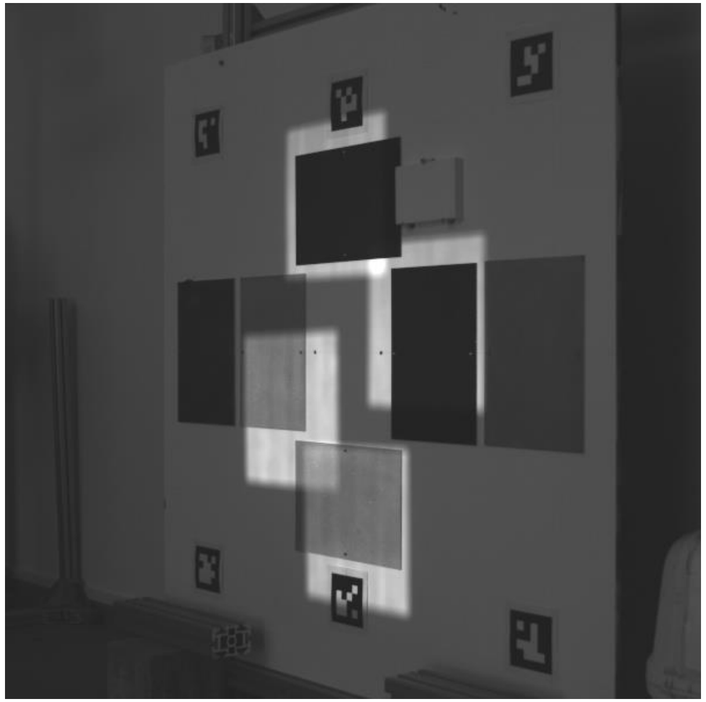




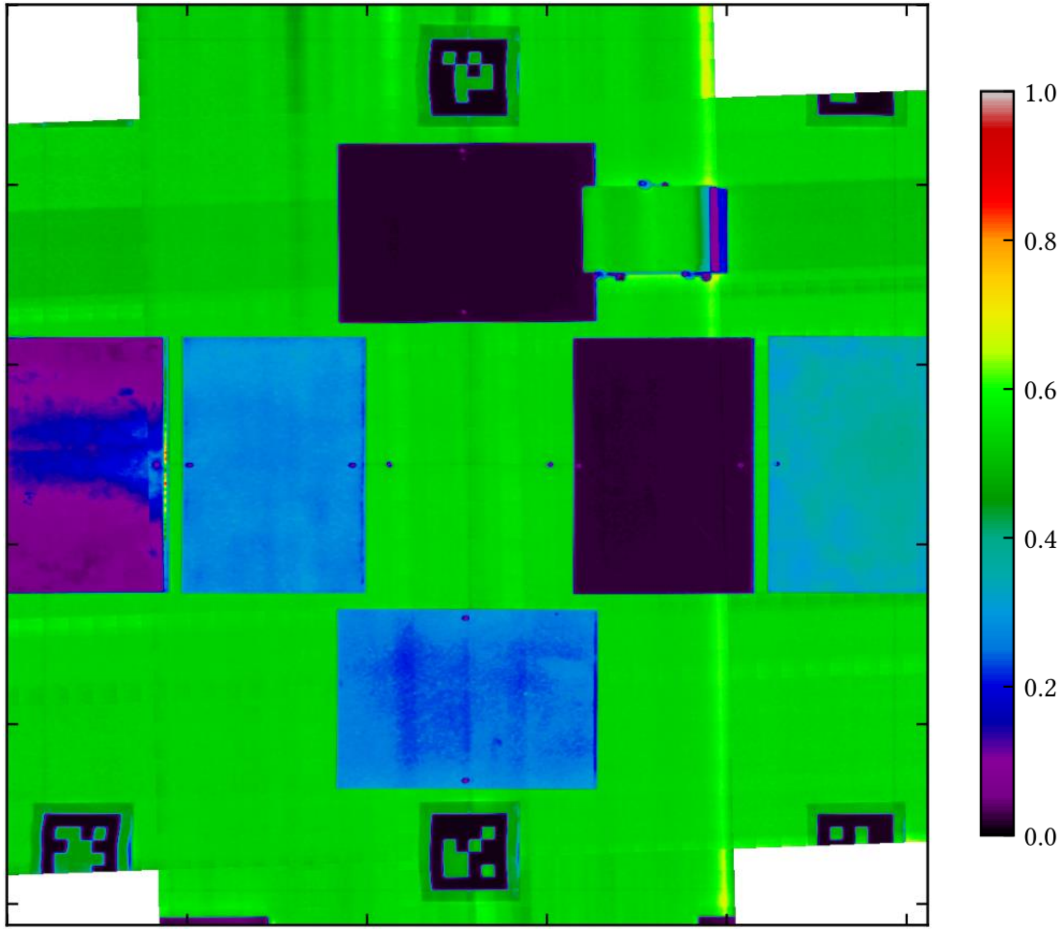
Fraunhofer ISE

Measuring the SVBRDF

Result of the evaluation



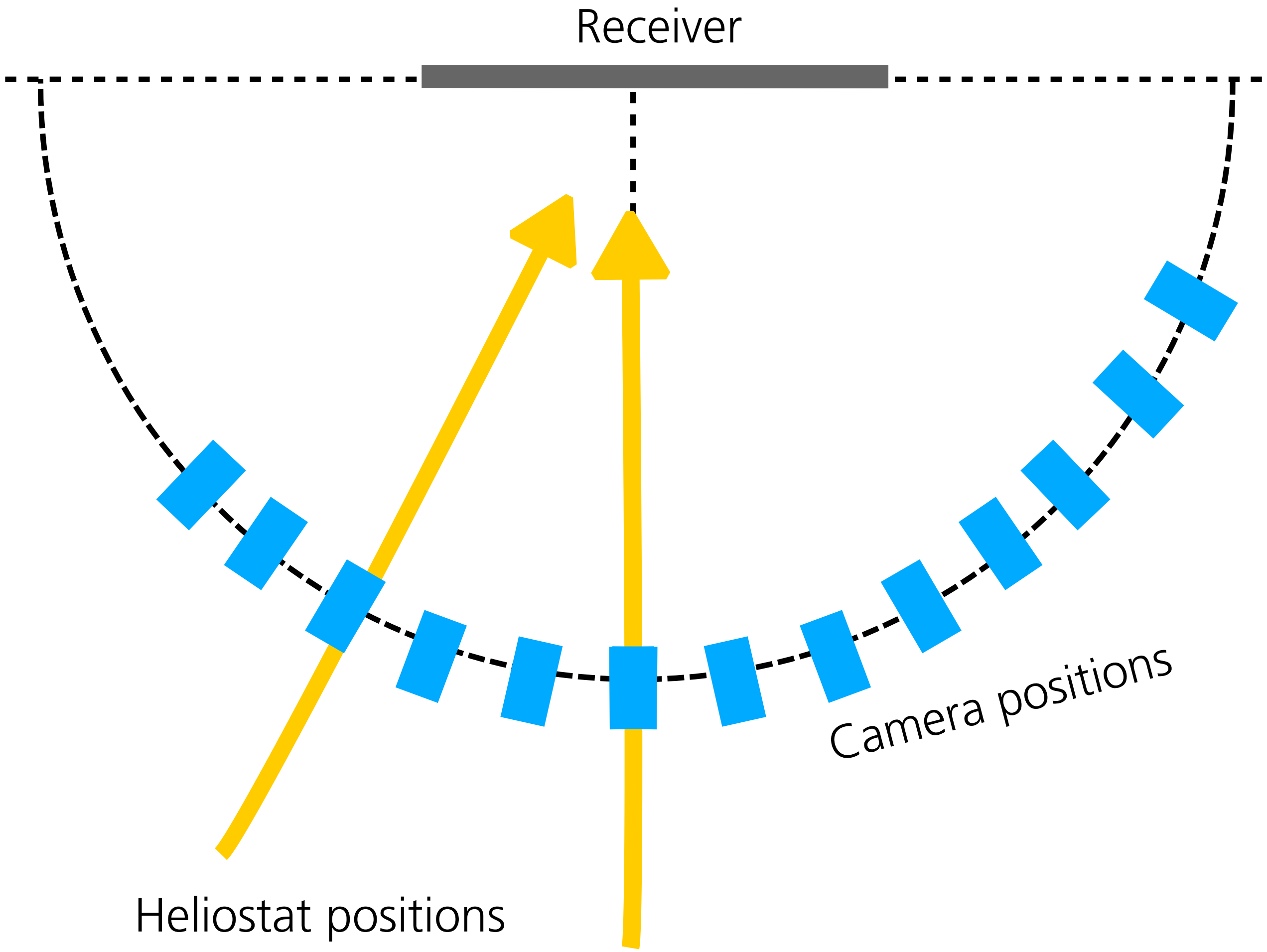
Measurement data



Relative reflectance of the surface
(for one position of light source and camera)

Measuring the SVBRDF

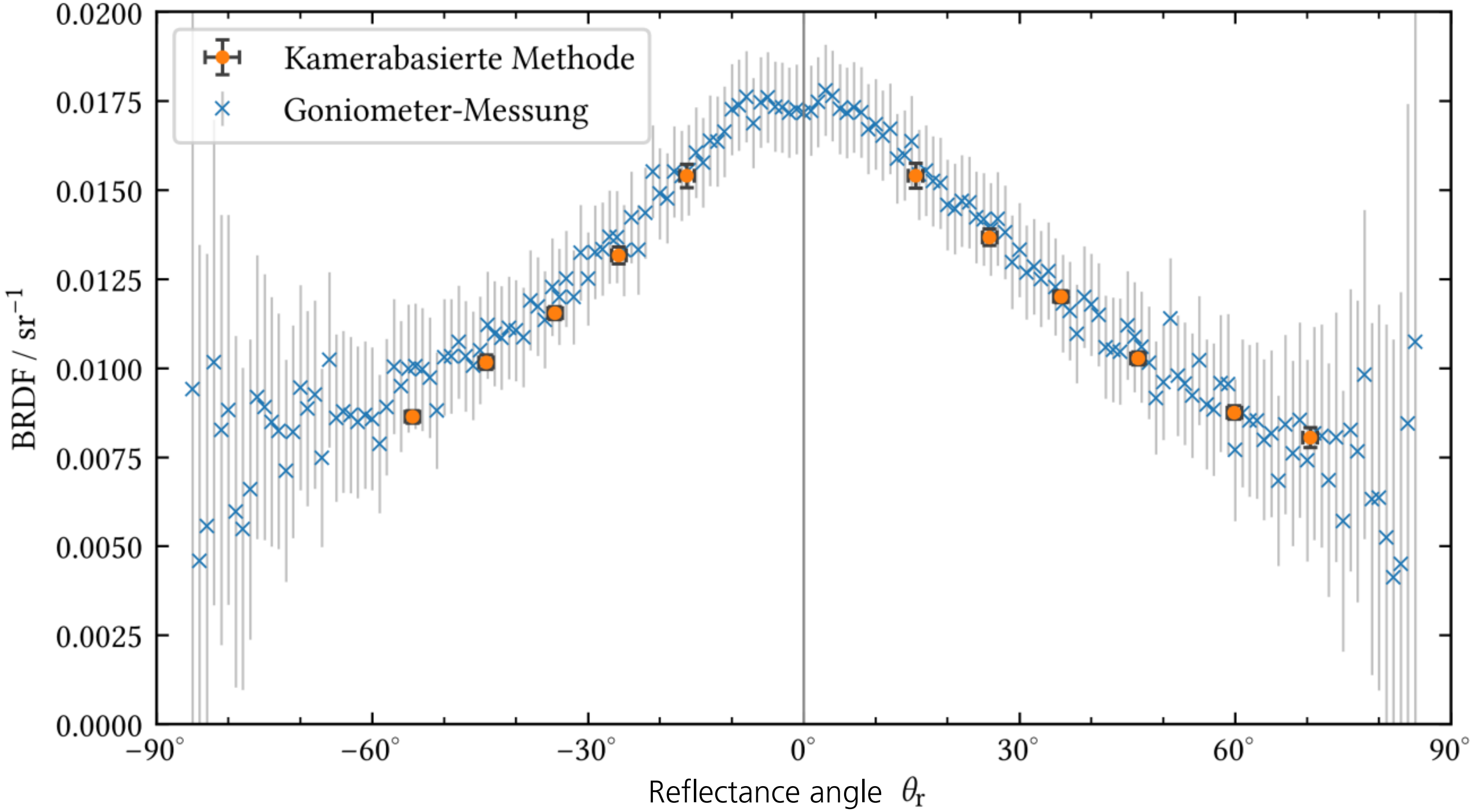
Measuring a 'full' SVBRDF…



Measuring the SVBRDF

Comparison with the goniometer measurement

Incidence angle
$\theta_\mathrm{i} = 0°$



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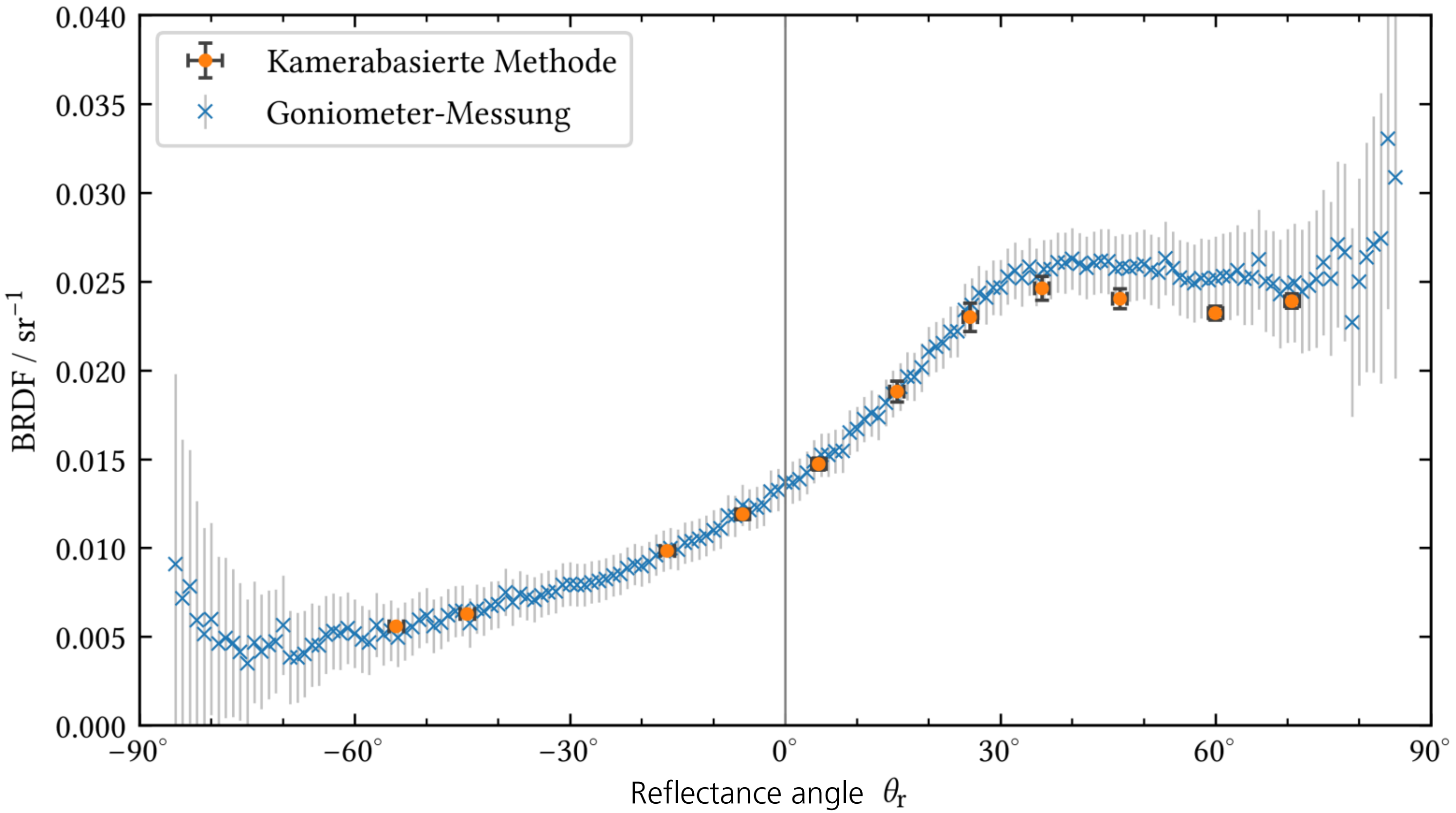
Measuring the SVBRDF

Comparison with the goniometer measurement

Incidence angle
$\theta_i = -28°$



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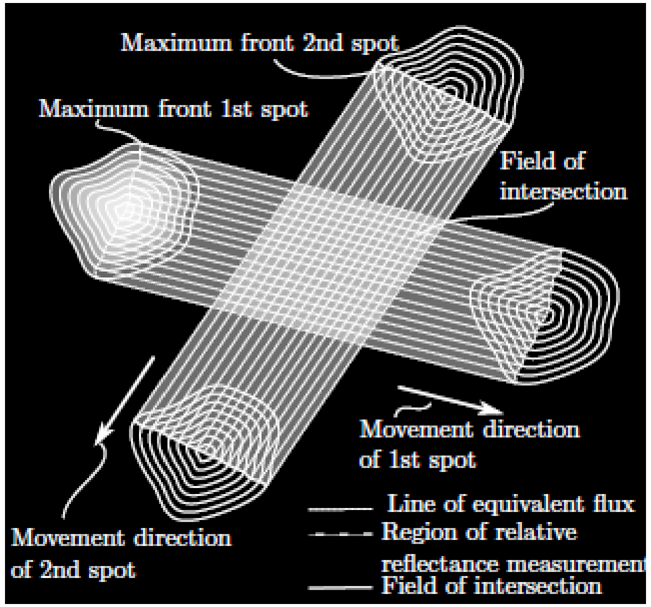
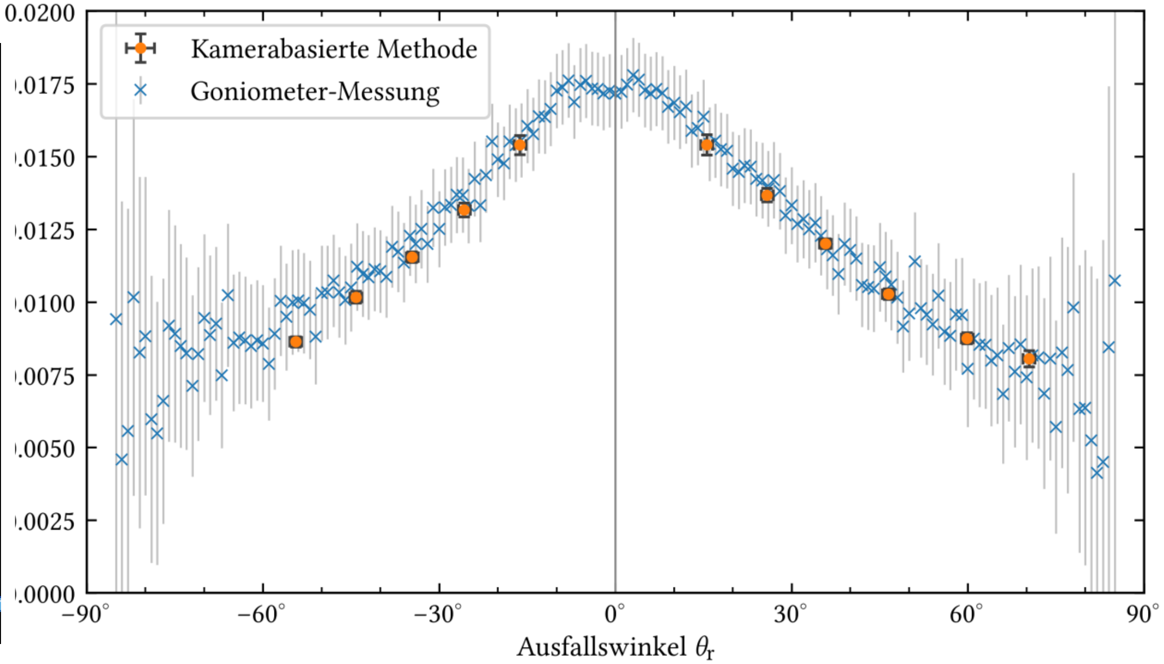
Instruments for field measurements

Remote Receiver Quality Assessment

Validated Far Field SVBRDF with uncalibrated lightsource



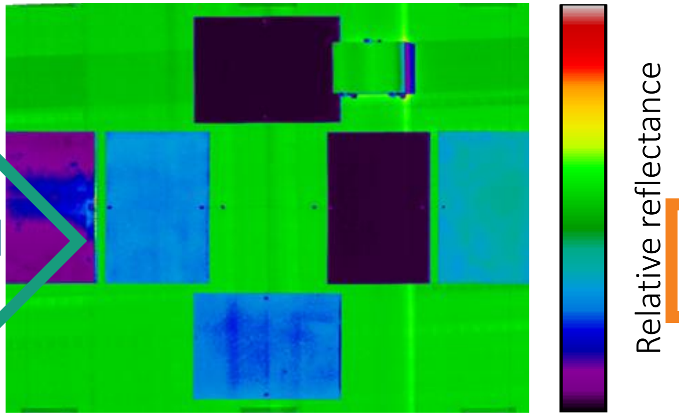


When is the best time to recoat? Was there a damaging event?

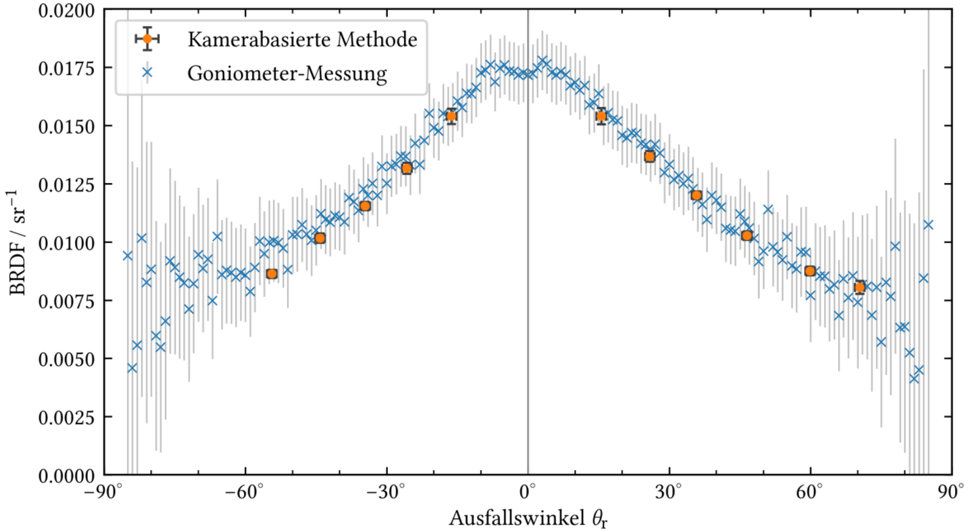
Remote SVBRDF Measurement

Validated Far Field SVBRDF with uncalibrated lightsource

Validated



To be applied



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Contact

Dr.-Ing. Gregor Bern
Head of Group Concentrating Systems and Technologies
Business Area Solar Thermal Power Plants and Industrial Processes
Tel. +49 458805906
gregor.bern@ise.fraunhofer.de

- Tracking Technologies
- Raytracing and Plant Modelling
- Concentrator and Collector Design
- Acceptance Testing and Optical Assessment

Fast and dense soiling assessment and shape assessment

3D scanning or terrestrial laser scanning (TLS)

Maitane Ferreres Eceiza: Later this afternoon

Coating Technology and Systems
Mirror and absorber coatings for CSP plants

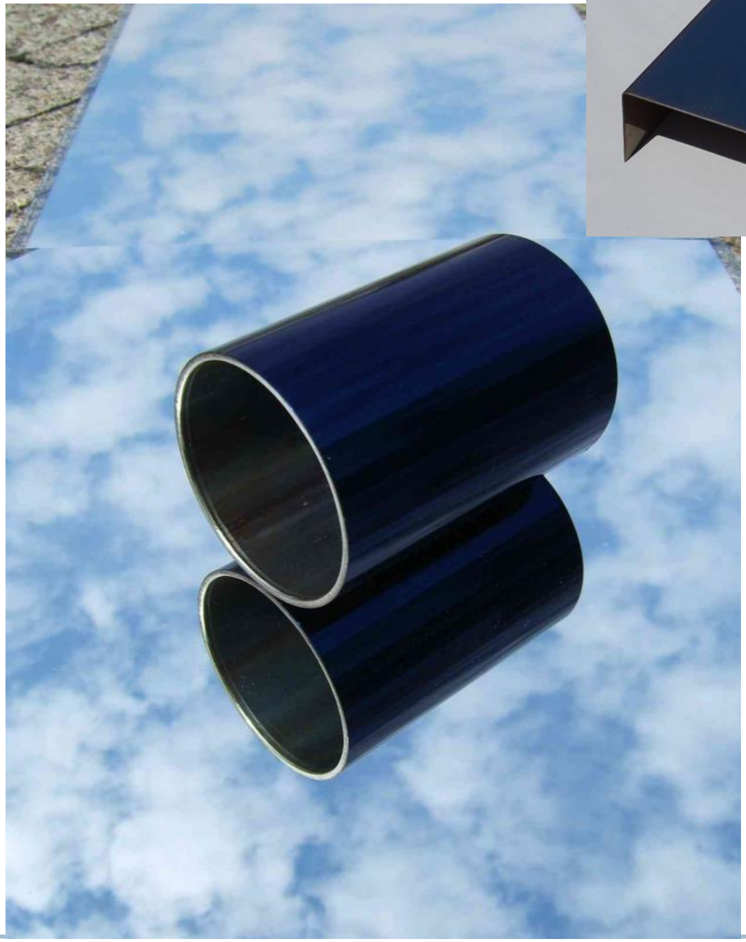
Functional Coatings for CSP plants

Our portfolio

Functional coatings based on PVD or CVD deposition

- High temperature stable absorber coatings for air or vacuum receivers
- High reflective mirror coatings for primary mirrors
- High reflective and high temperature stable mirror coatings for secondary mirrors

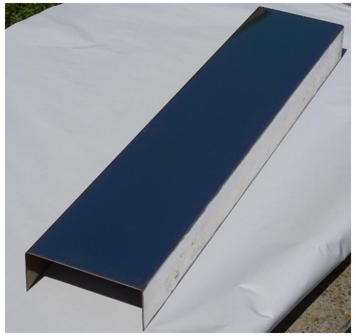
From lab-scale to production



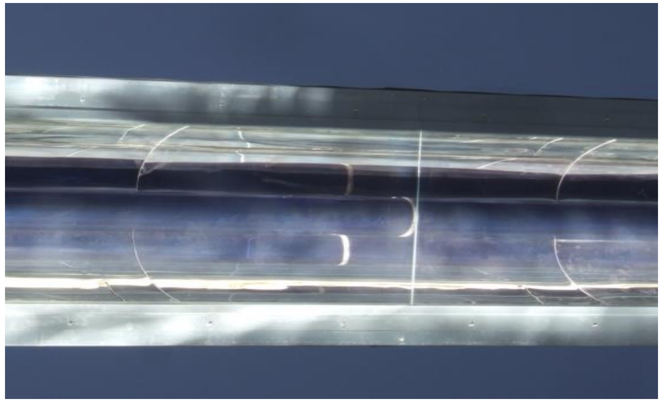
Functional Coatings for CSP plants

some reference developments

Functional coatings based on PVD or CVD deposition



- Absorber coating for vaccum receiver pipe developed for SCHOTT Solar
- High temperature stable secondary mirror and air-stable absorber developed and produced for demonstrator plant in Spain
- High reflective mirror coatings for primary mirrors
- High reflective and high temperature stable mirror coatings for secondary mirrors

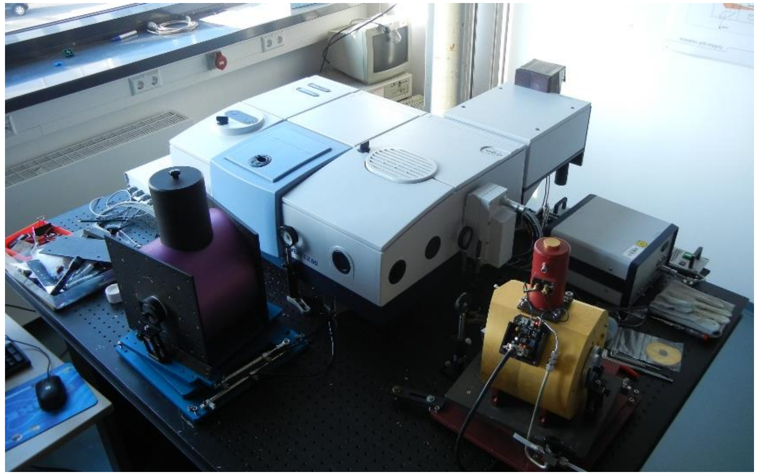


From lab-scale to production

Functional Coatings for CSP plants
Our portfolio

Available equimpment and services

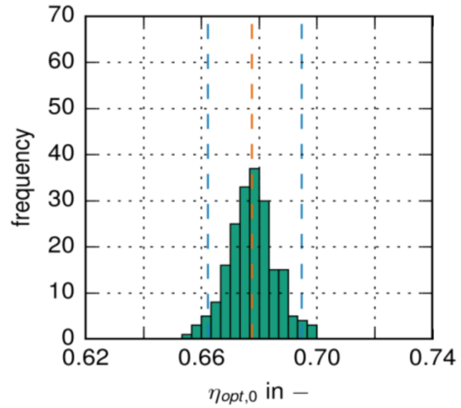
- Wide range of sputter deposition machines, up to the industrial prototype machine (substrate size 1.5x4 m^2, also for tubes and curved substrates)
- Heat treatment facilities (vacuum, air, gases)
- Accelerated aging testing
- Characterization tools (Fourier spectrometer, SEM, EDX, AFM)



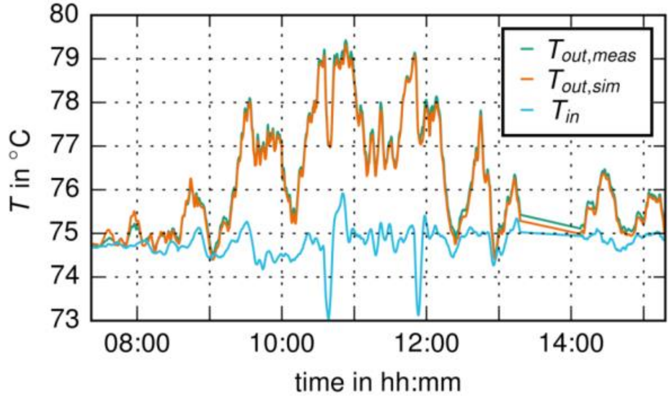
Wide range of depostion, test and characterisation equipment

Qualification and System Performance:

Parameter Identification



IN SITU



DYNAMIC

ENHANCED = information content & reliability of evaluation ↑ effort, time, costs ↓

Zirkel-Hofer et al., "Improved in situ performance testing of line-concentrating solar collectors. Comprehensive uncertainty analysis for the selection of measurement instrumentation," Applied Energy **184**, 298-312 (2016).
Zirkel-Hofer et al., "Confidence Interval Computation Method for Dynamic Performance Evaluations of Solar Thermal Collectors," Solar Energy (162), 58-596 (2018).

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Laser Scanning for Optical Assessment of Heliostat Fields

Maitane Ferreres Eceiza
SFERA-III Training for Industries: CST4SHIP
Freiburg, Nov 7, 2023
www.ise.fraunhofer.de

Content

Chapter 1

Introduction

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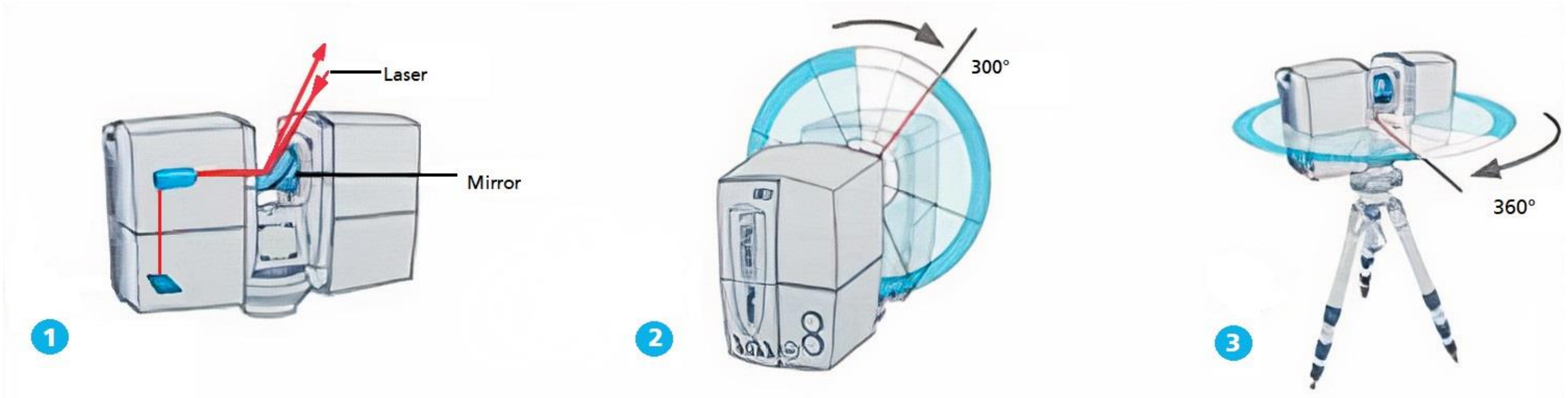
Introduction

Terrestrial laser scanning (TLS)

- Fast and non-contact measurement for acquiring 3D point clouds based on laser range determination
- Measuring method
  1. Distance: Laser beam time-of-flight and phase-shift
  2. Vertical angle: Mirror turning through 300° in vertical direction
  3. Horizontal angle: Scanner turns horizontally through 360°



- Integrated camera for RGB values (colorization of the point cloud)

Figure adapted from: Vahid, Salehi & Wang, Shirui. (2017). Using point cloud technology for process simulation in the context of digital factory based on a systems engineering integrated approach.

Introduction
Terrestrial laser scanning (TLS) for cleanliness assessment

- The product of TLS measurements is a **three-dimensional (XYZ) point cloud** acquired with high-density and high-accuracy
- TLS also receives the **backscatter power** of the laser beam from the observed object (TLS Intensity)

Chapter 2

Reflector cleanliness assessment

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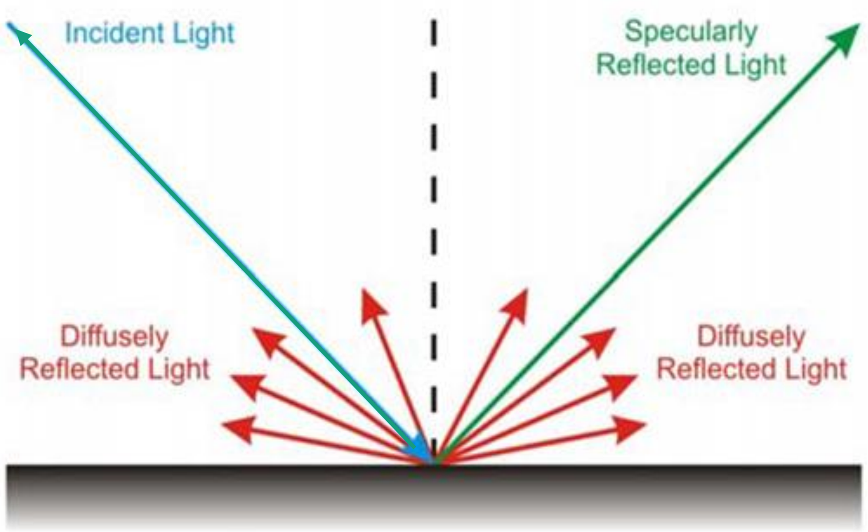
Correlation principle development

Cleanliness

Ratio of specular reflectance of a soiled mirror ($\rho_{\mathrm{soil,s}}$) and the specular reflectance of a clean reference mirror (ρ_{s}):



$$C_{\mathrm{s}} = \frac{\rho_{\mathrm{soil,s}}(\lambda, \varphi, \theta)}{\rho_{\mathrm{s}}(\lambda, \varphi, \theta)}$$

where λ is the wavelength of the light source, φ is the acceptance angle and θ is the incidence angle.

→ **Backscatter measurement ("TLS intensity") of the scanner must be related with the specular reflectance**

Figure: L. Basaca-Preciado, J. Rodríguez-Quiñonez, O. Sergiyenko, V. Tyrsa, W. Perdomo, J. Nieto, O. Starostenko, Oleg. "3D laser scanning vision system for autonomous robot navigation". Pp. 1773 - 1778. 2010.

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Correlation principle development

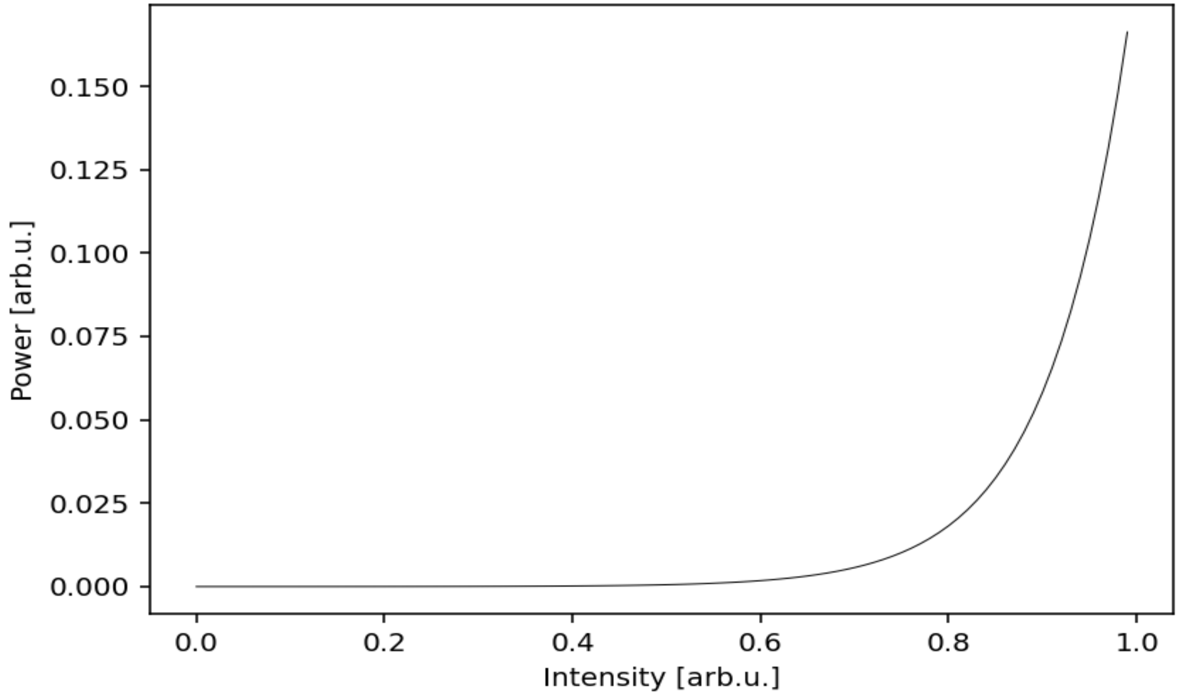
From “TLS intensity” to power

1. How is “TLS intensity” related with backscattered power (Φ_b)?

➢ **Modelling the avalanche photodiode and the logarithmic amplifier** with calibration data of 3 Lambertian samples.

$$\Phi_b = C\, 10^{\frac{(Intensity - a_1)}{a_0}}$$

a_0 and a_1 estimated from calibration measurements with 3 different reflectance Lambertian samples (ρ = 90%, 10%, 2%).



Correlation principle development

External influencing factors correction

1. How is “TLS intensity” related with backscattered power (Φ_b)?

- **Modelling the avalanche photodiode and the logarithmic amplifier** with calibration data of 3 Lambertian samples.

2. How can be correct the external influencing factors?

- Normalization of scans with fully characterized fixed **reference samples**

Sample coated with Pyromark 2500

Promat Duratec-1000 sample

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Correlation principle development

Influence of distance and incident angle

1. How is "TLS intensity" related with backscattered power (Φ_b)?

➢ **Modelling the avalanche photodiode and the logarithmic amplifier** with calibration data of 3 Lambertian samples.

2. How can be correct the external influencing factors?

➢ Normalization of scans with fully characterized fixed **reference samples**

3. Which influence have the **distance** and the **incident angle** in the measurements?

➢ **Calibration of distance and incident angle** influence on the backscattered power

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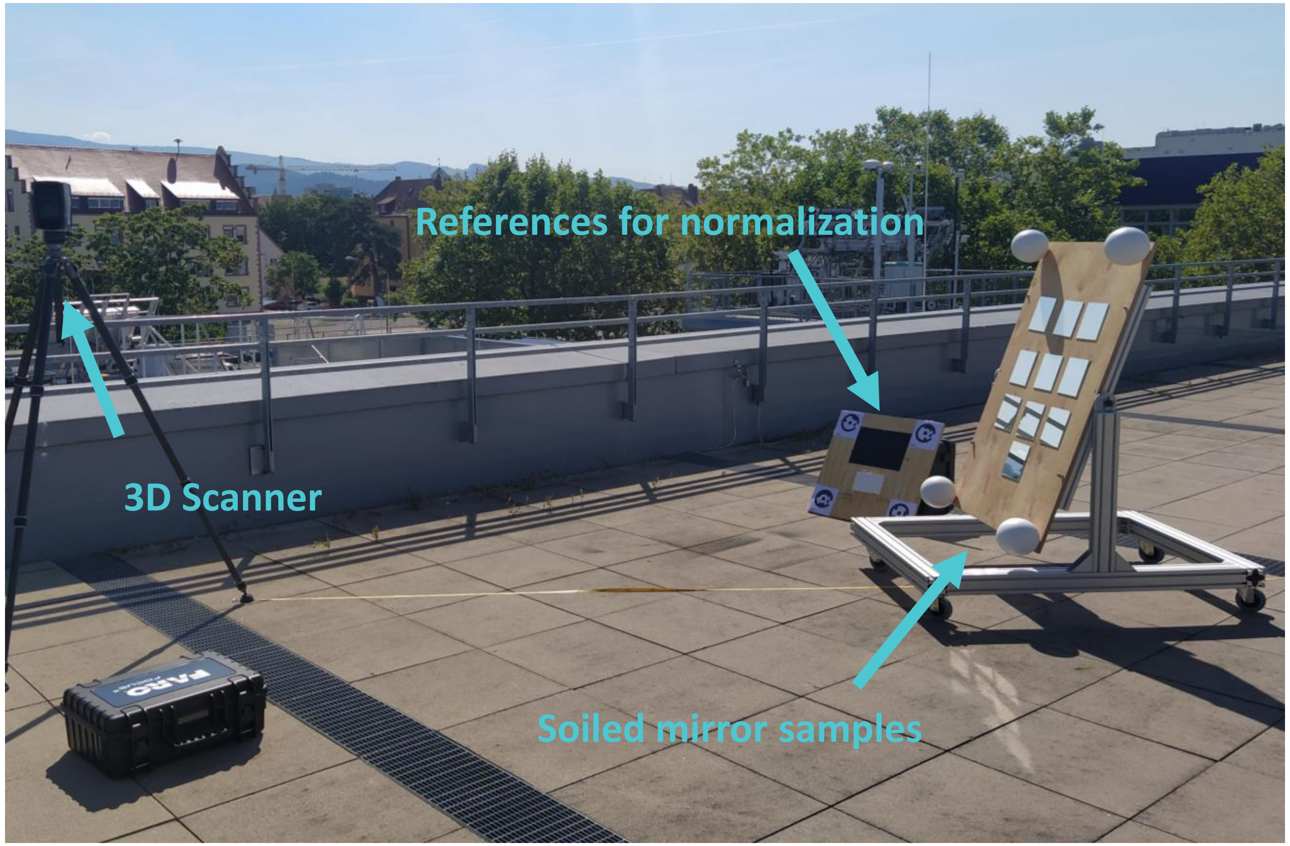
Correlation principle development

Measurement methodology for distance and incidence angle dependency

$$\Phi_{b,d_{\text{ref}},\theta_{\text{ref}}}(d,\theta) = \Phi_b \frac{f(d_{\text{ref}})g(\theta_{\text{ref}})}{f(d)g(\theta)} \eta_{\text{ext}}$$

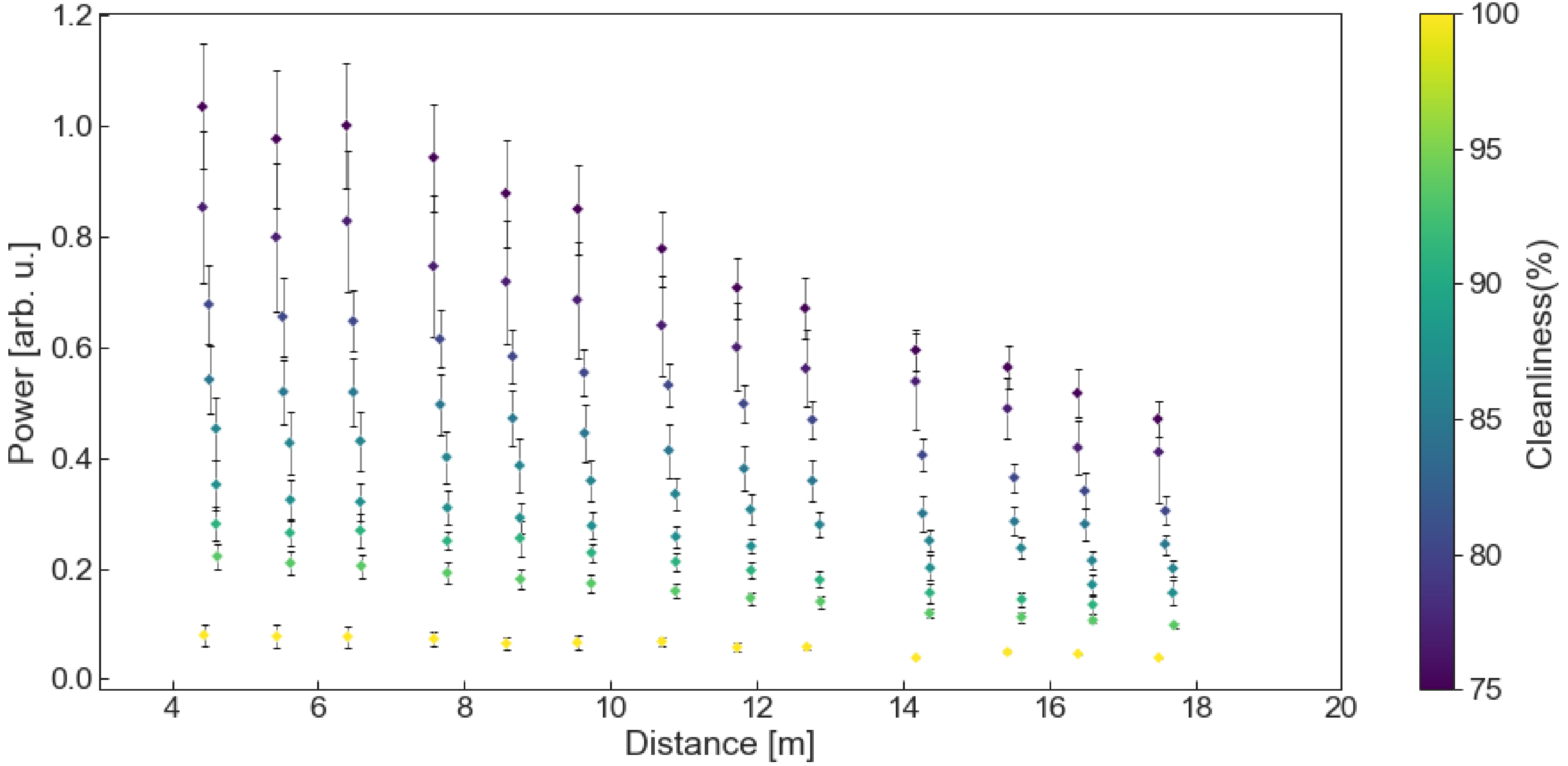
Measurement in artificially soiled mirrors for modelling backscatter behavior of:

- Incident angle with constant distance: $f(d)$
- Distance with constant incident angle: $g(\theta)$



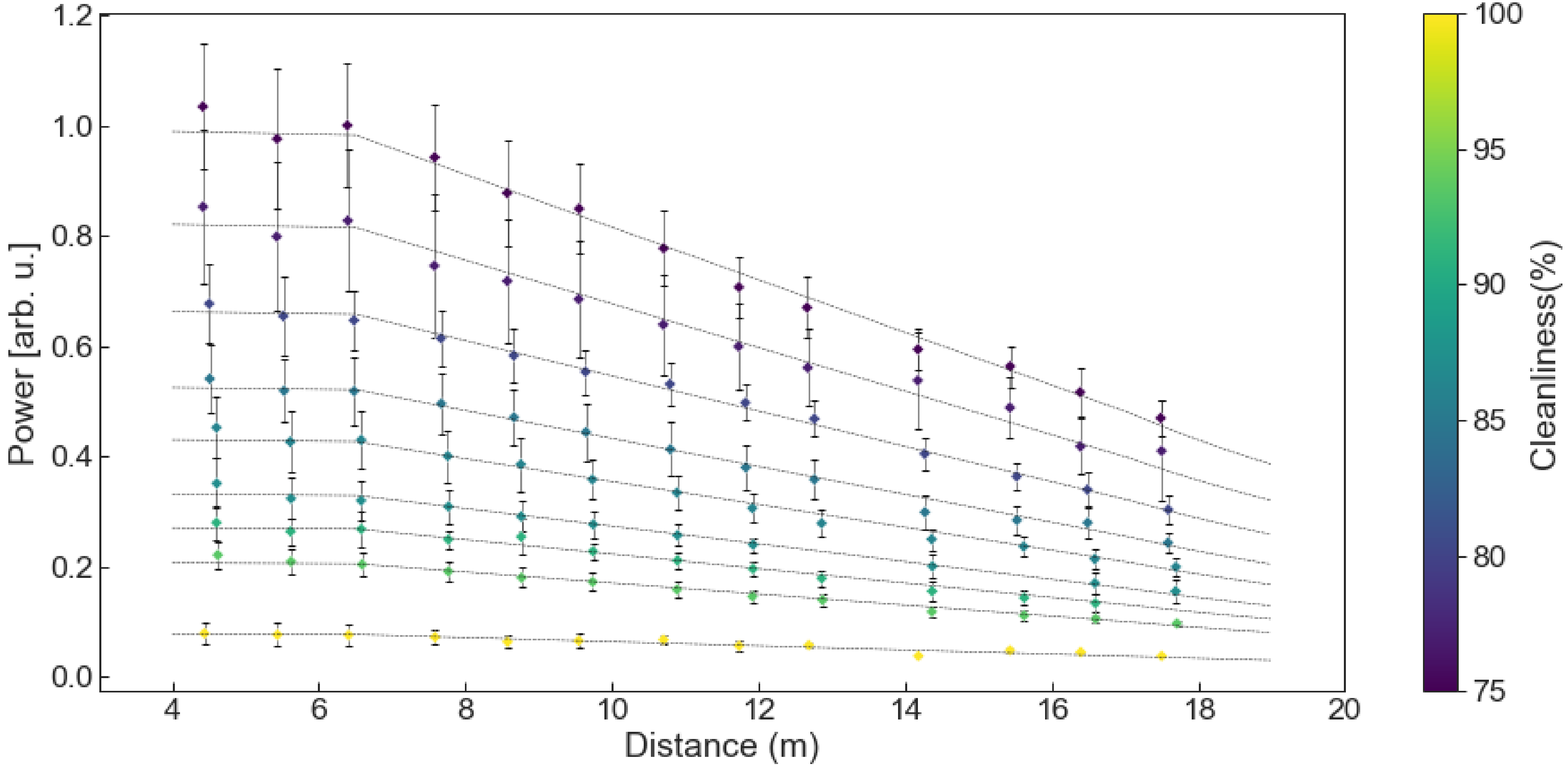
Correlation principle development

Results for backscatter power distance dependency



Correlation principle development

Results for backscatter power distance dependency



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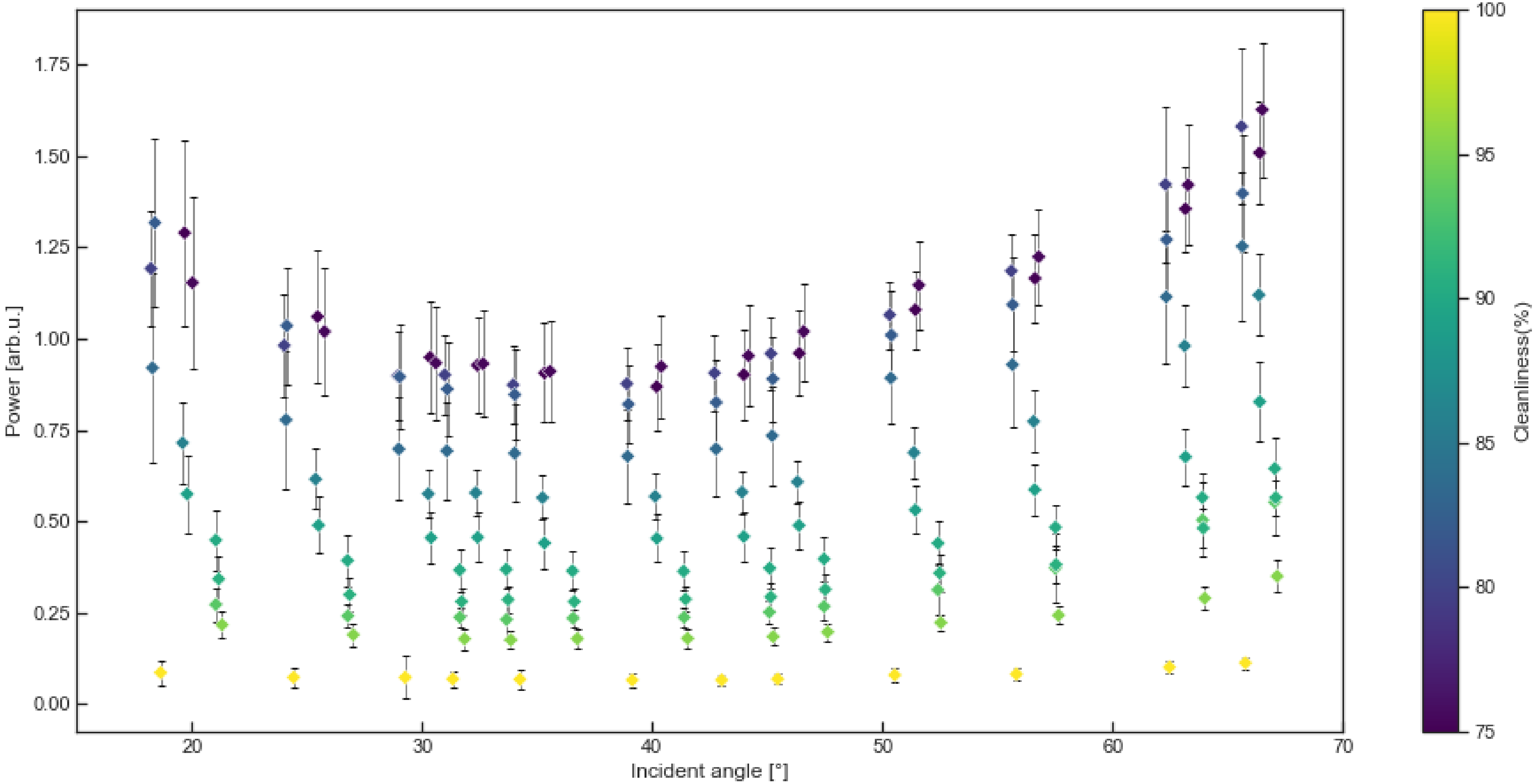
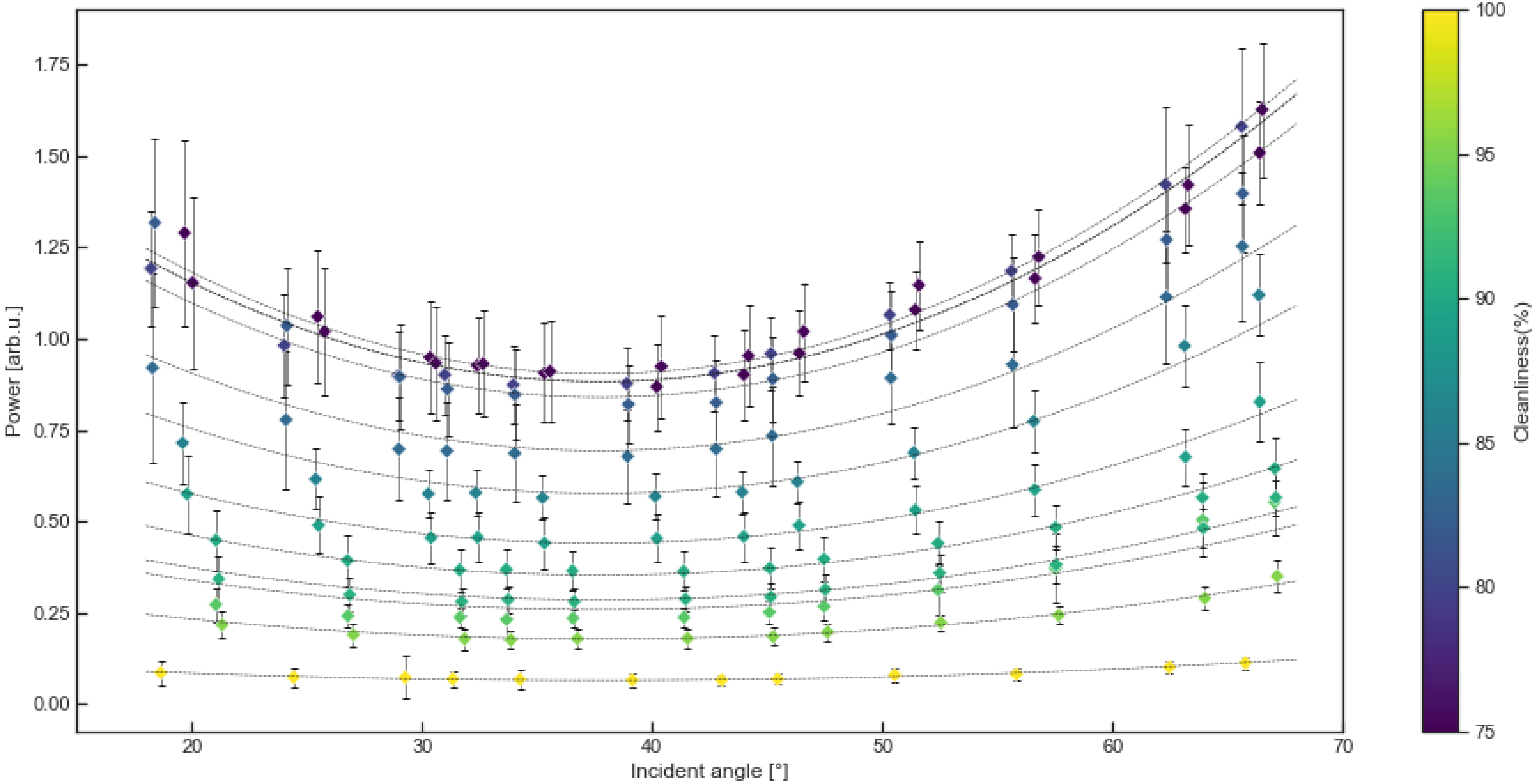
Correlation principle development

Results for backscatter power incidence angle dependency



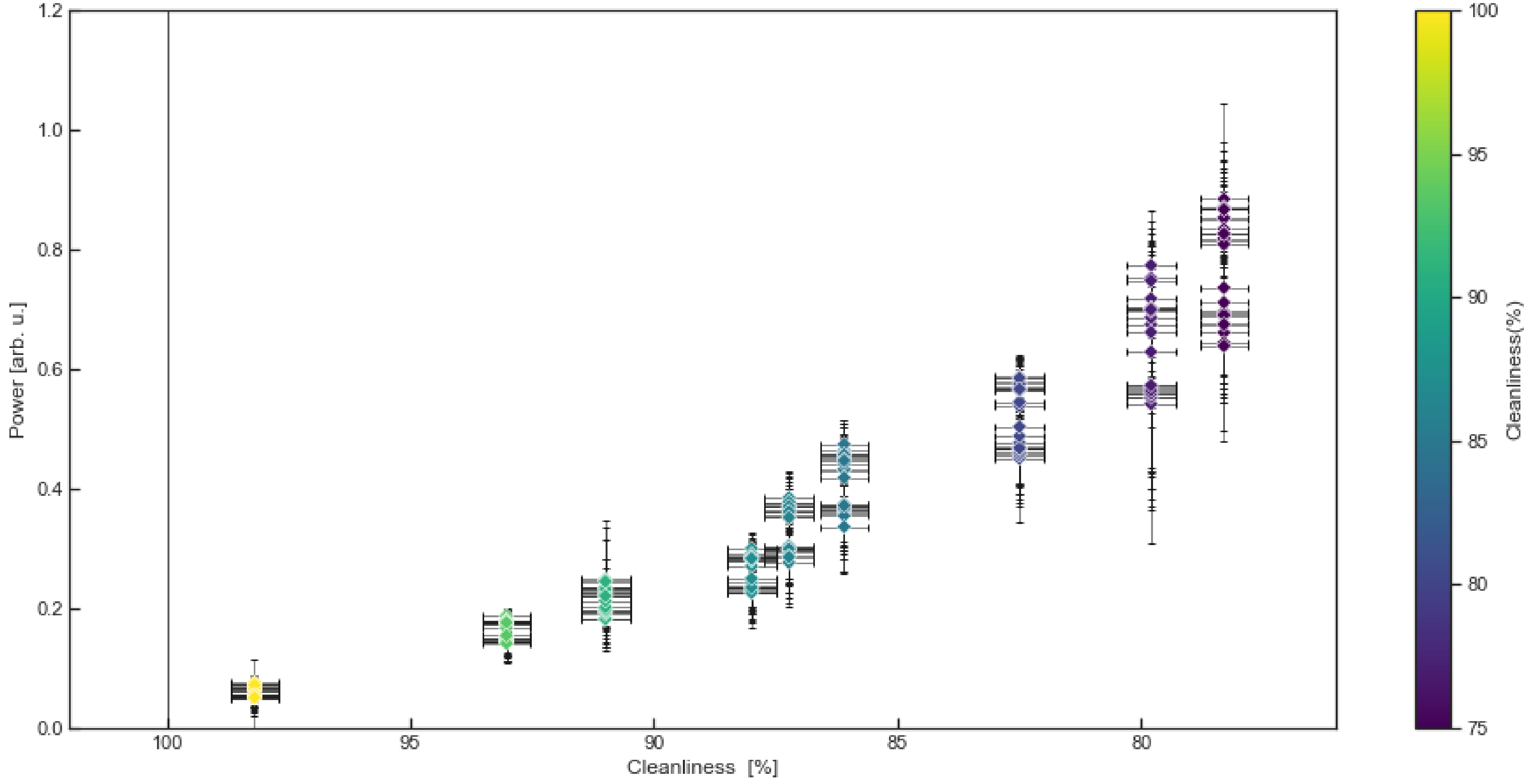
Correlation principle development

Results for backscatter power incidence angle dependency



Correlation principle development

Corrected backscatter power over cleanliness



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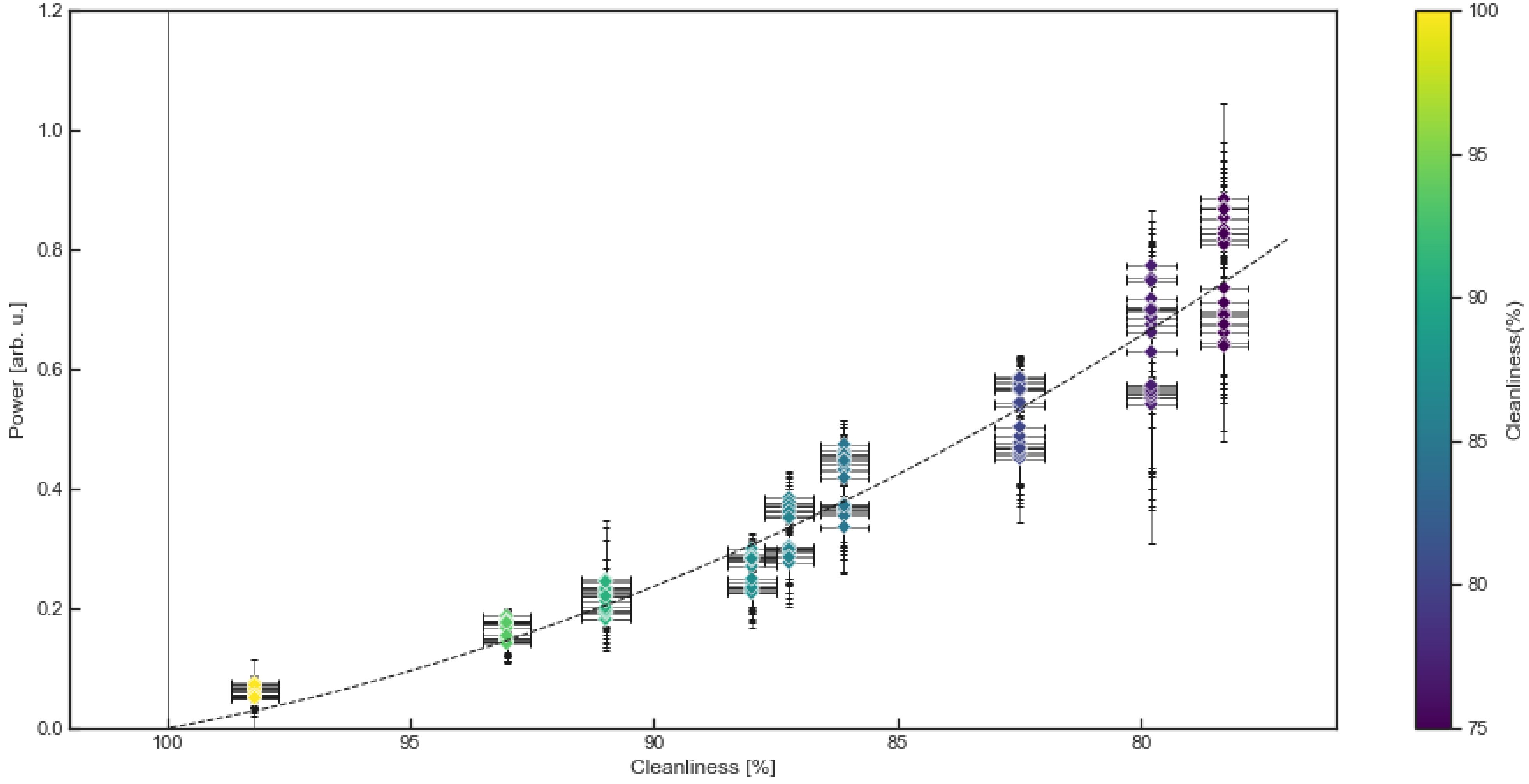
Correlation principle development

Corrected backscatter power over cleanliness



Validation of the measurement principle

IMDEA energy solar field

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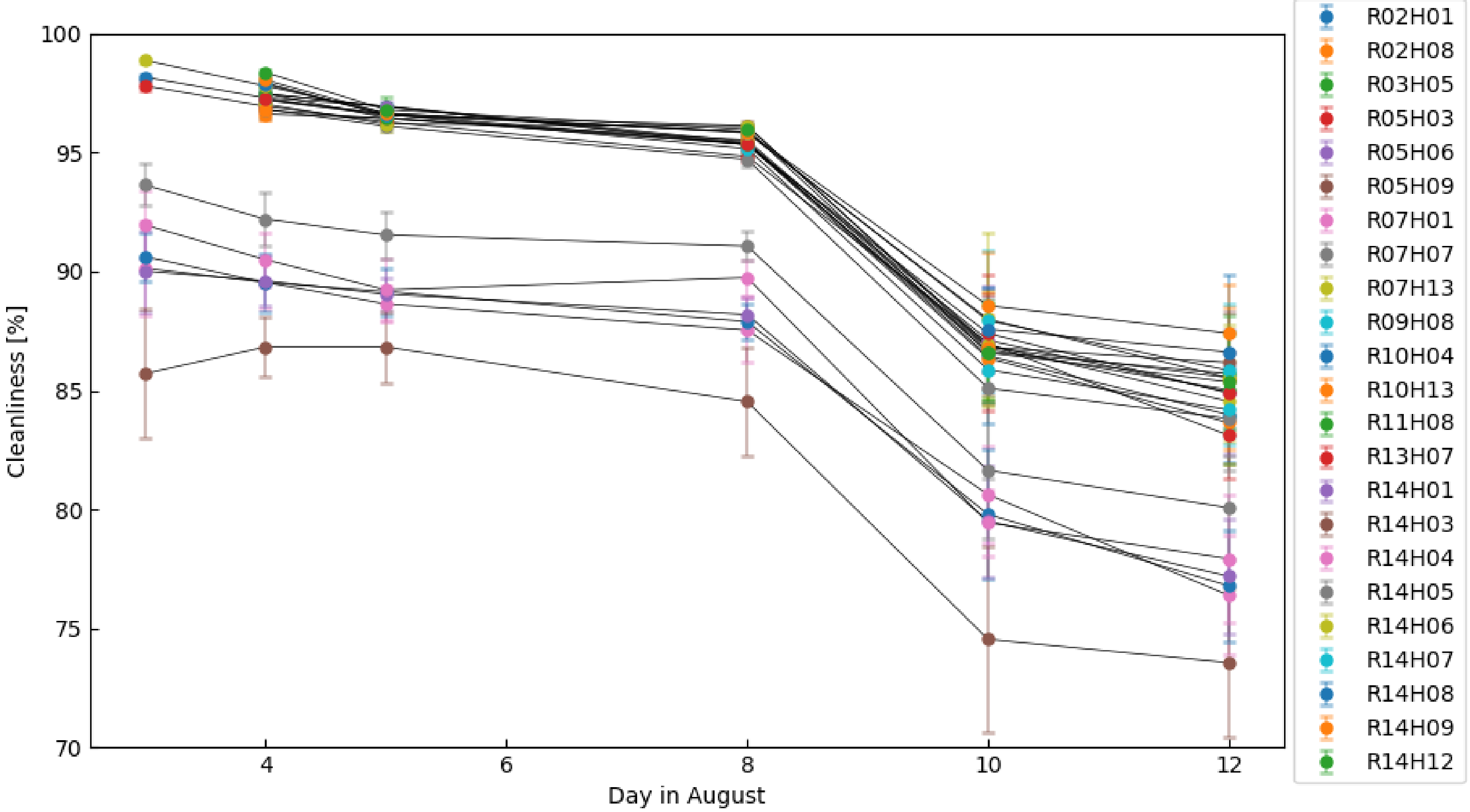
Validation of the measurement principle
pFlex reflectometer cleanliness measurements



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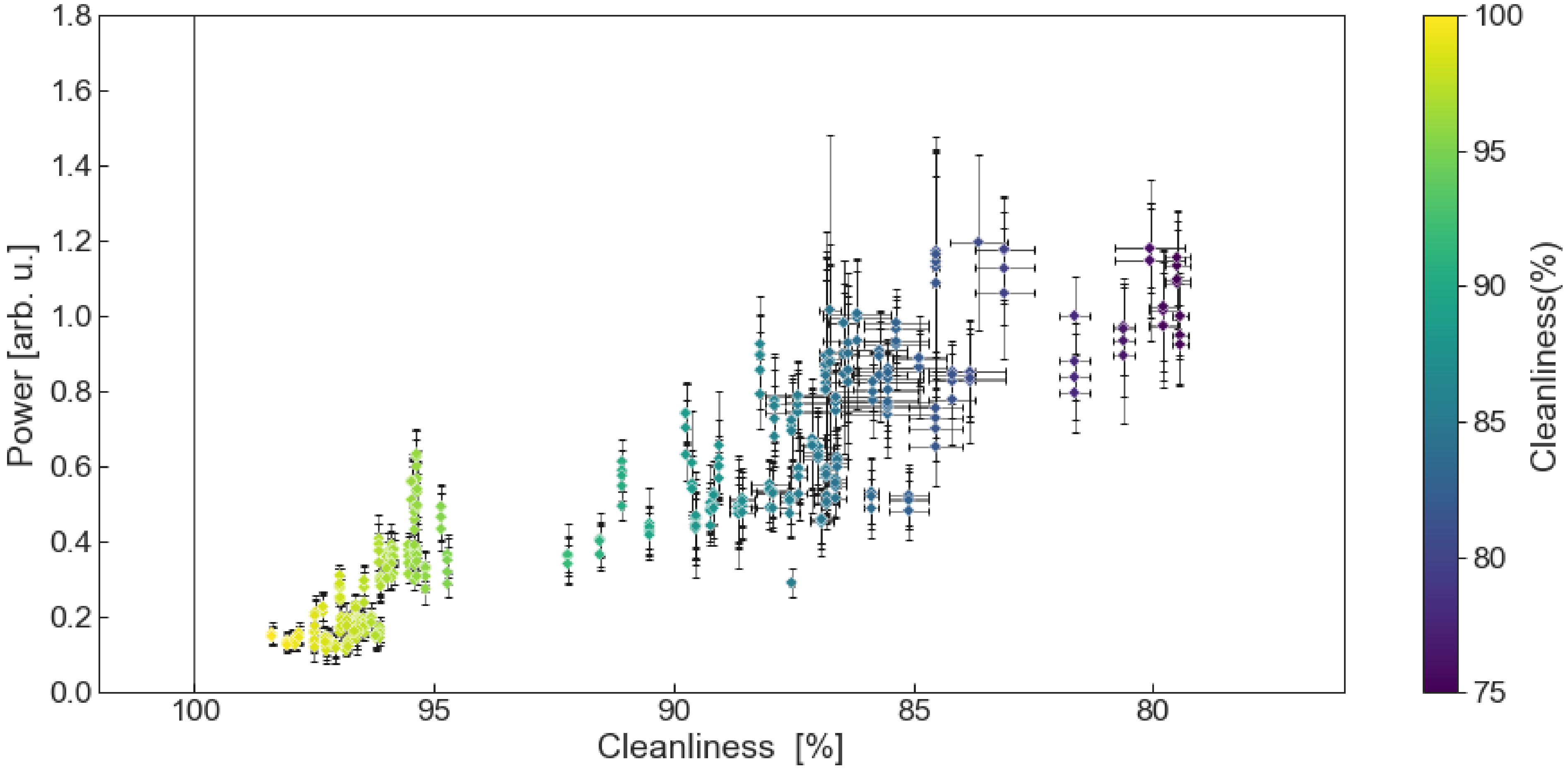
Validation of the measurement principle

IMDEA energy solar field scan

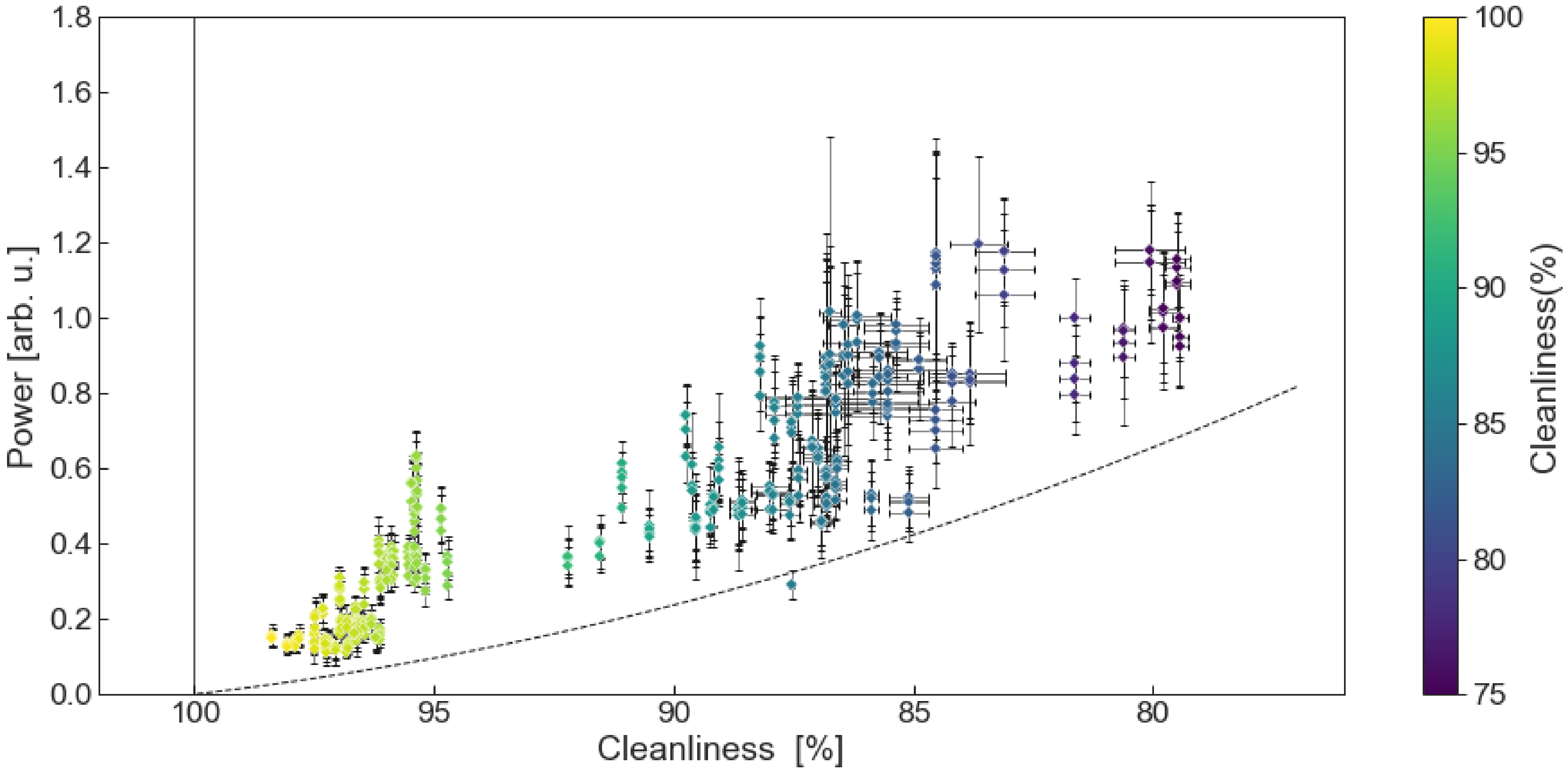
Validation of the measurement principle

Resulting corrected powers over cleanliness



Validation of the measurement principle

Resulting corrected powers over cleanliness



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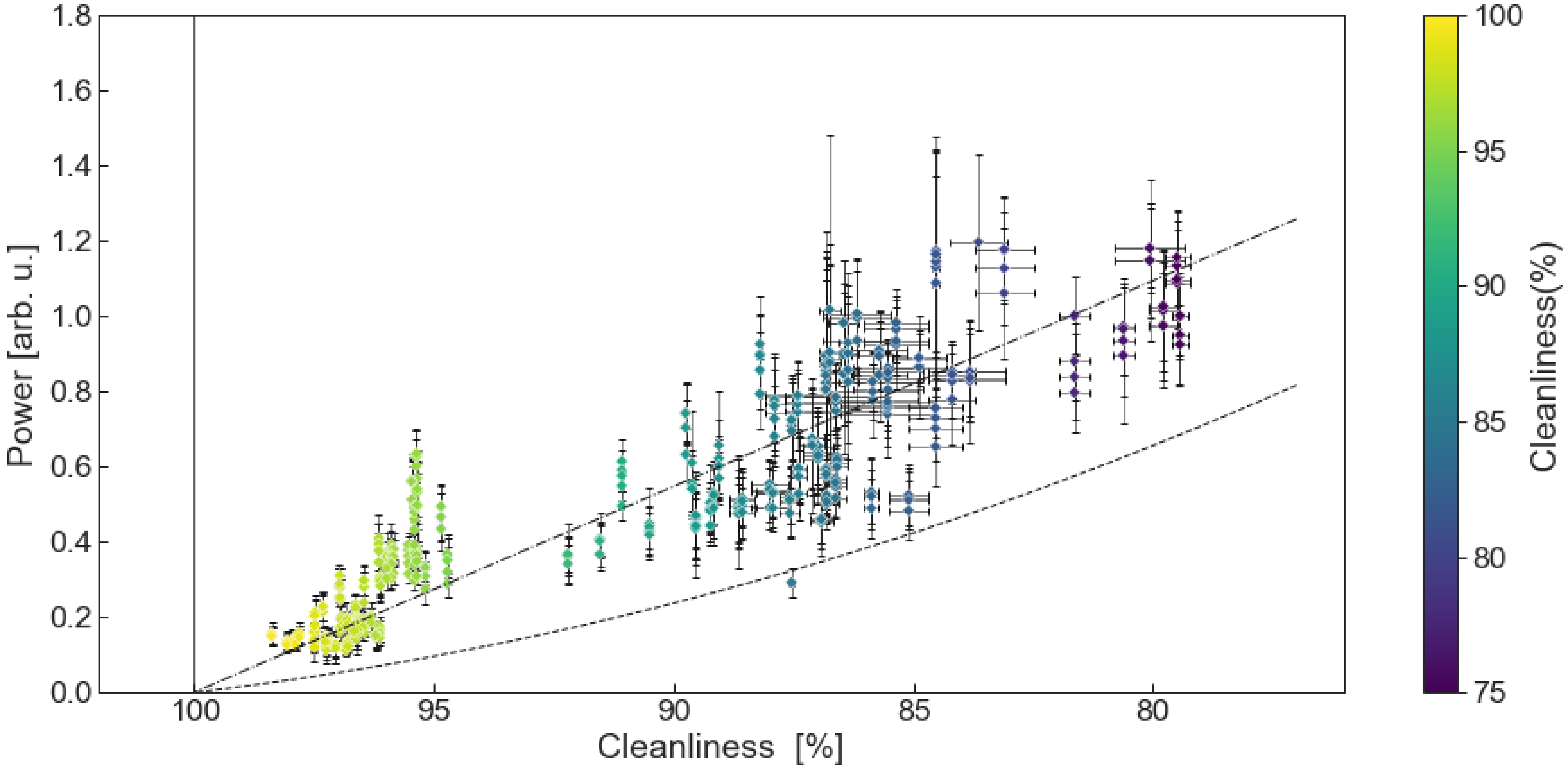
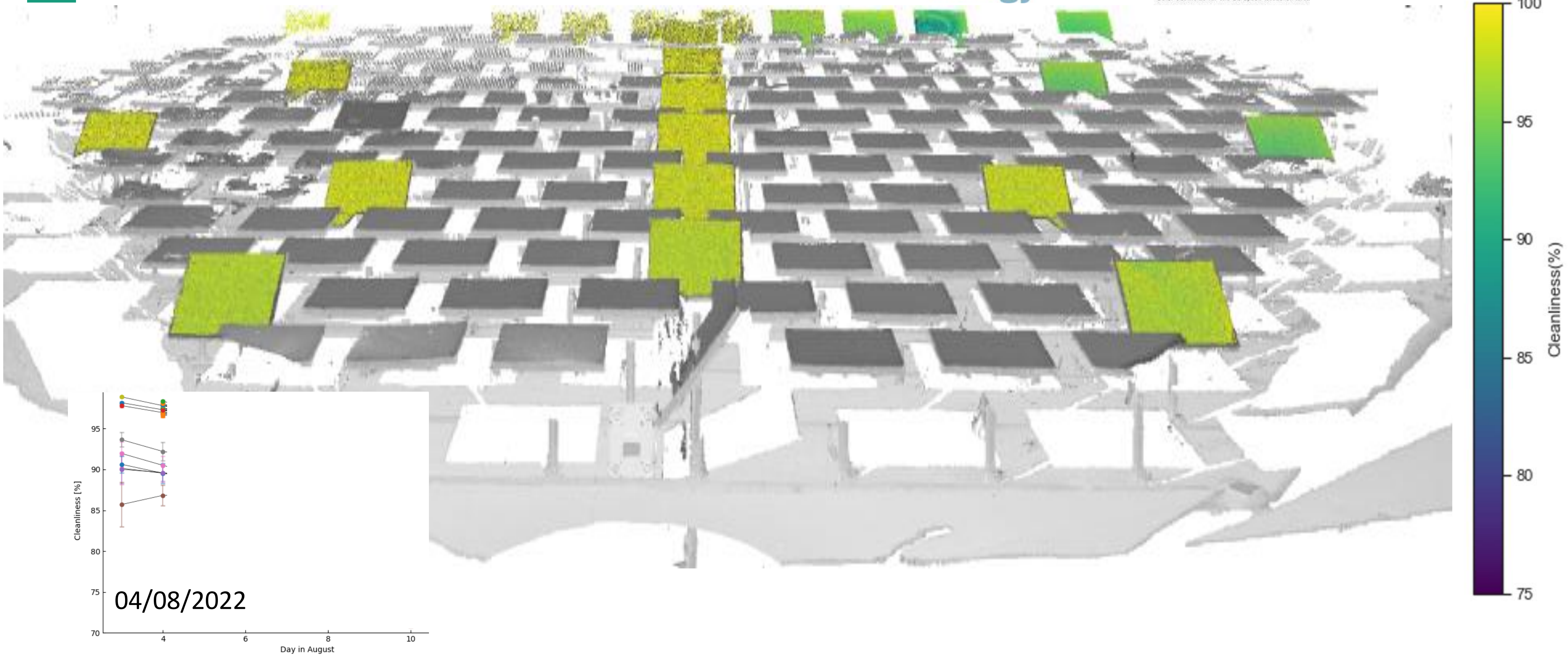
Validation of the measurement principle

Resulting corrected powers over cleanliness



Validation of the measurement principle

Spatially resolved cleanliness



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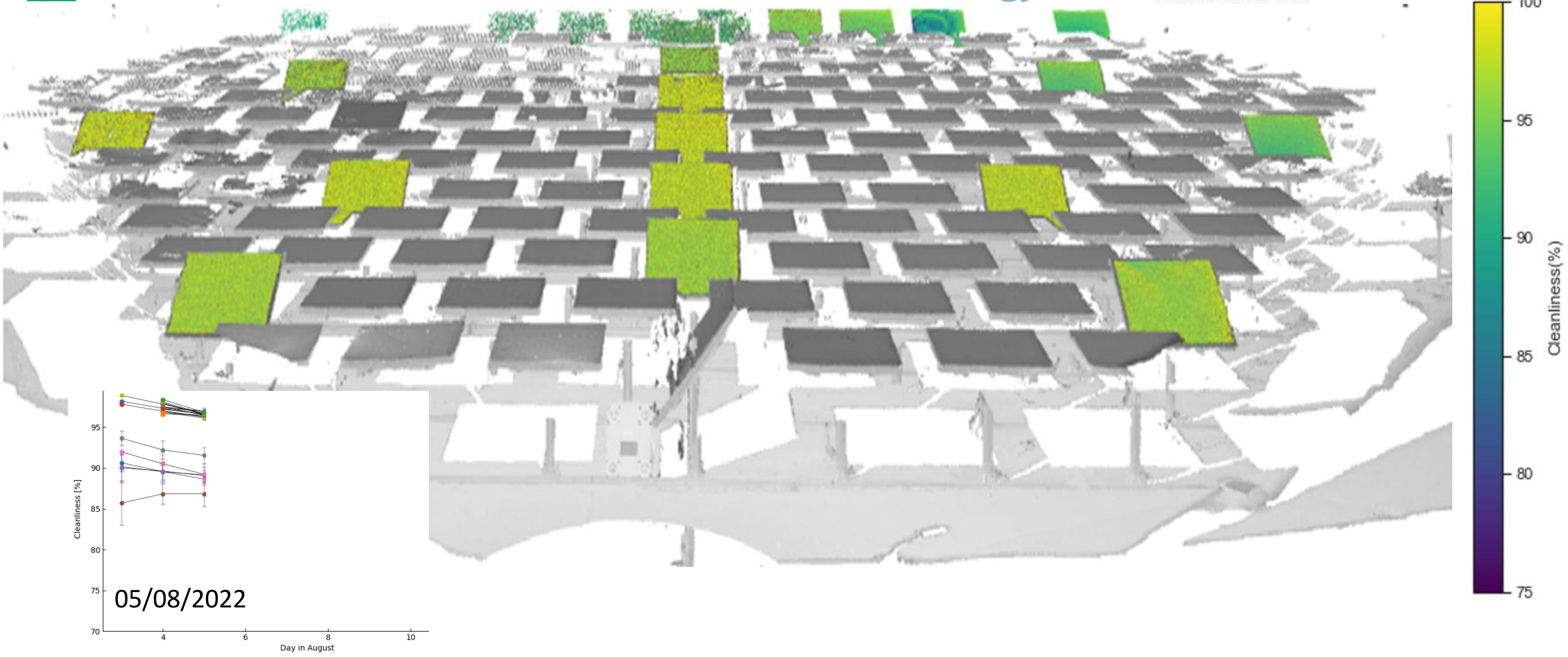
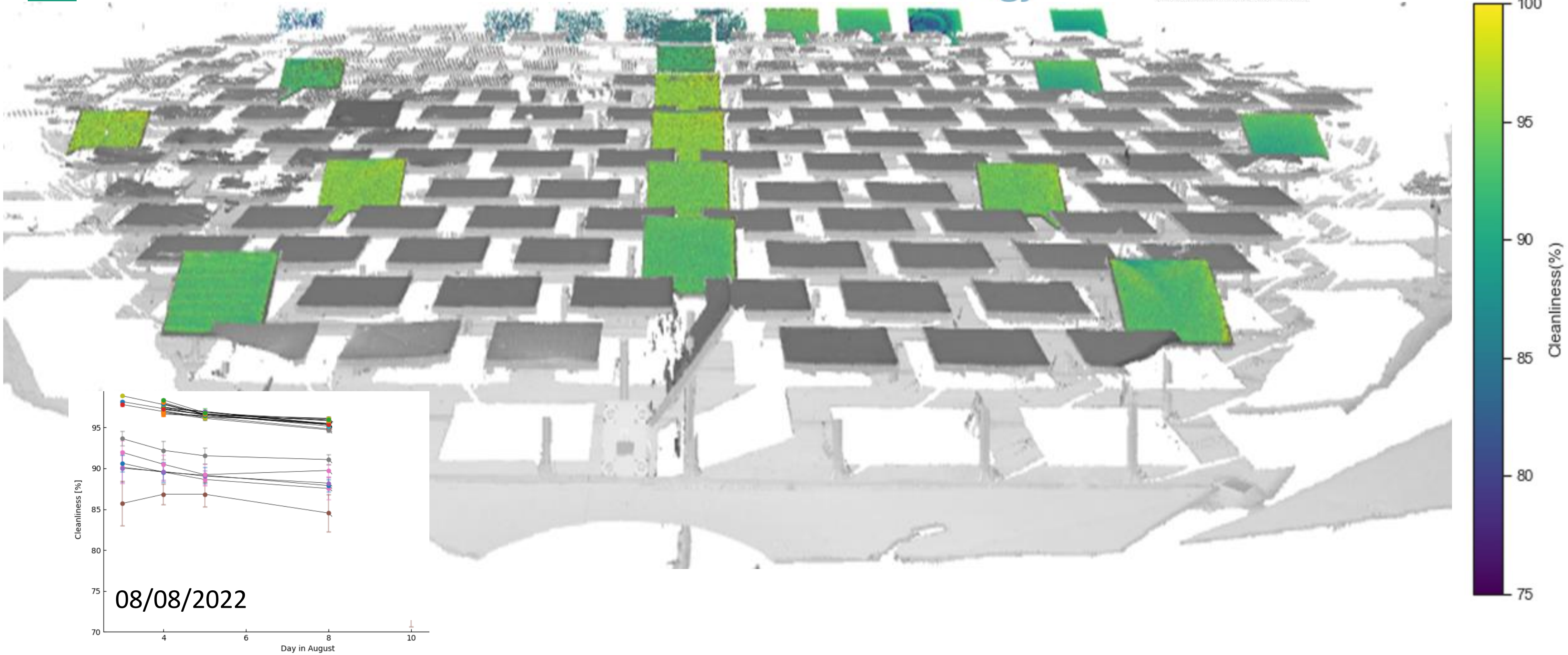
Validation of the measurement principle

Spatially resolved cleanliness



Validation of the measurement principle

Spatially resolved cleanliness



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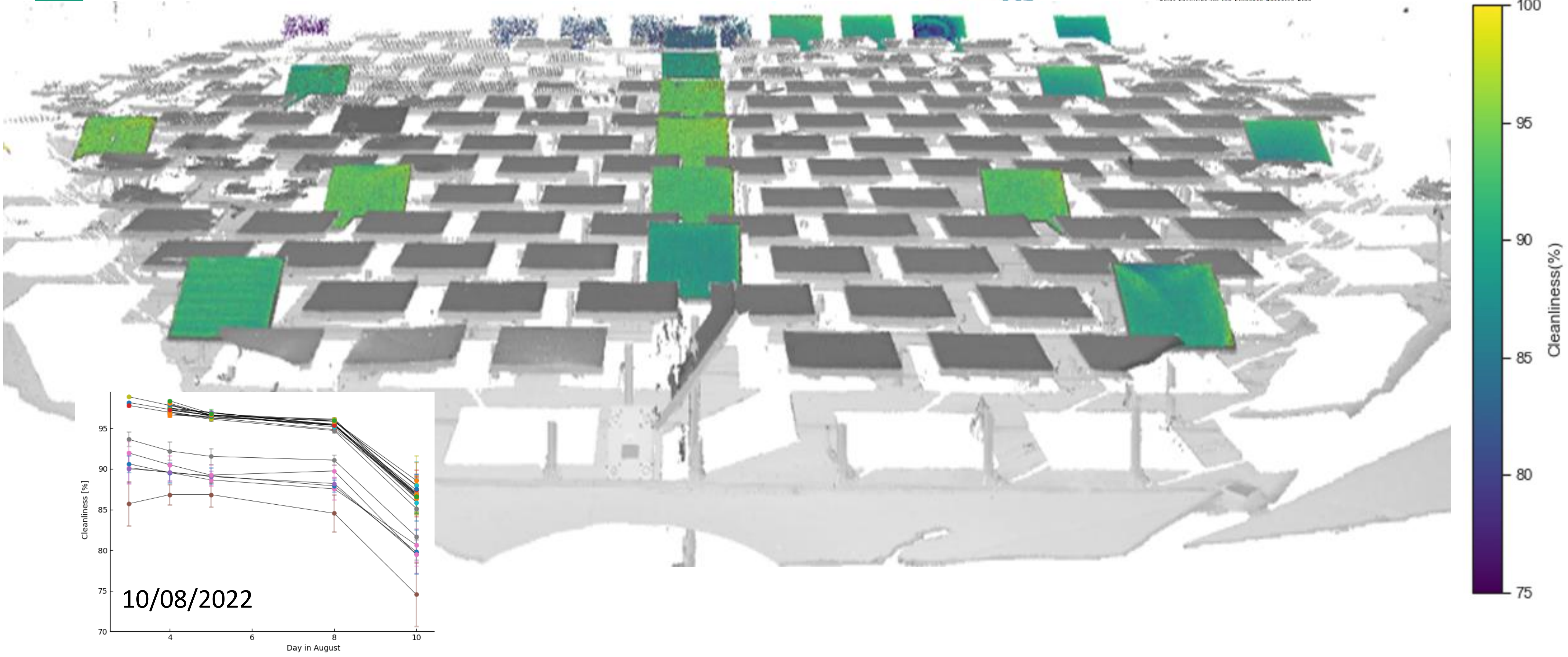
Validation of the measurement principle

Spatially resolved cleanliness



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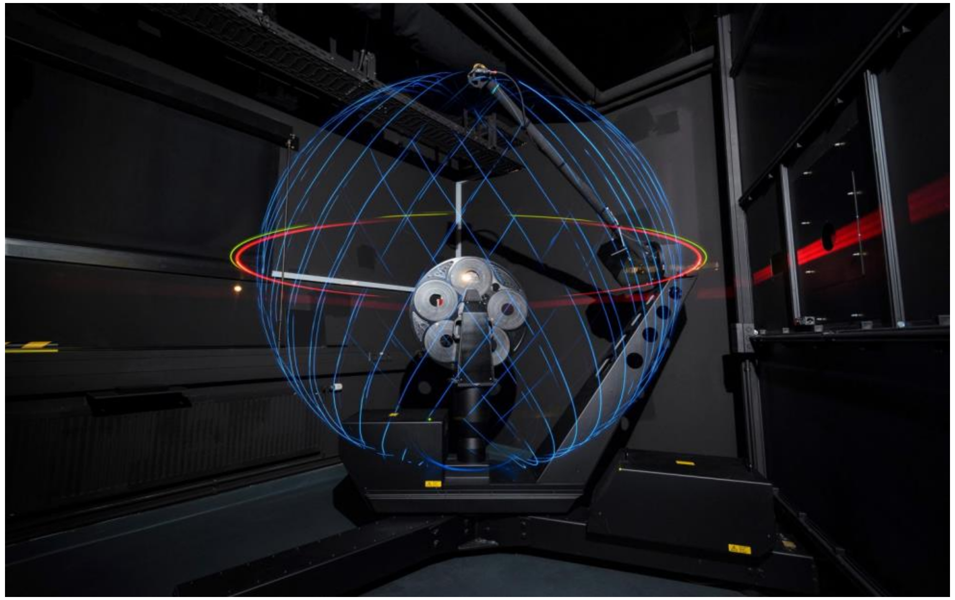
Conclusions

Main outcomes and next steps

- **Correlation** between backscattered power and mirror cleanliness **was found**, but different in lab and in the field (due to different sand type)

  - ➢ Development of an accurate model of the bidirectional reflectance distribution function (BRDF) of soiled mirrors with photogoniometer measurements

    - Better understanding of the incident angle influence in the backscatter
    - Analytical model of backscatter and specular reflectance



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Conclusions

Main outcomes and next steps

- **Correlation** between backscattered power and mirror cleanliness **was found**, but different in lab and in the field (due to different sand type)
  - ➢ Development of an accurate model of the bidirectional reflectance distribution function (BRDF) of soiled mirrors with photogoniometer measurements
- Validation showed **high uncertainty** of cleanliness
  - ➢ Assessment and reduction of the uncertainty of the measurement will be performed
- Terrestrial scanner offers **a very fast and spatially resolved solution** for cleanliness assessment
- Measurement principle has been **successfully validated** in the field

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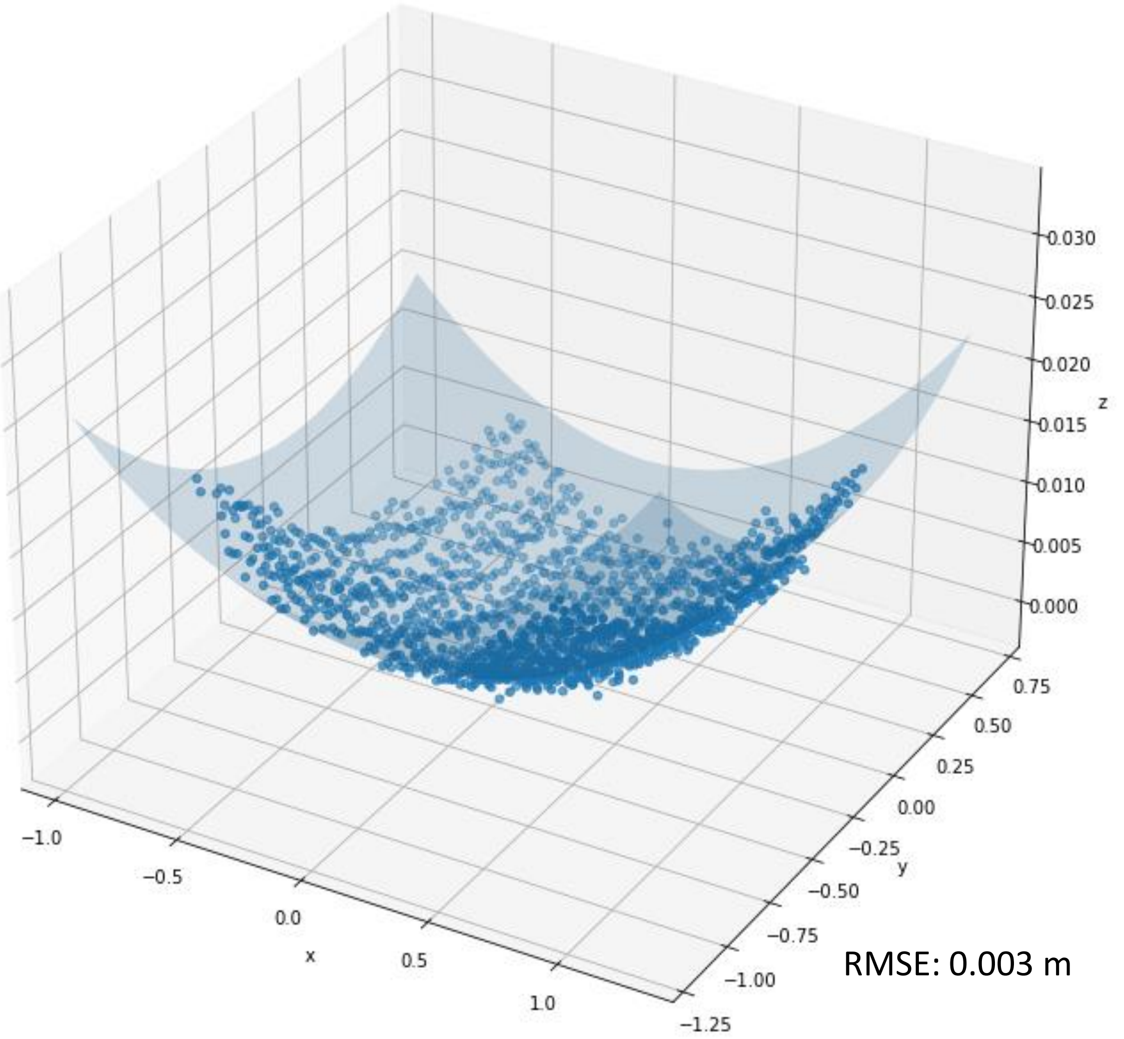
Outlook

Surface shape assessment fitting a **paraboloid or a sphere**



RMSE: 0.003 m

Chapter 3

Reflector surface shape determination

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Motivation

Laser scanning at the parabola of PROMES-CNRS?

- The challenge: Largest parabola in the world (40 m x 54 m) with a highly reflecting surface
- Original construction plans not available, exact condition after last mirror refurbishment is unknown
- Photogrammetry / Deflectometry for shape assessment is very time consuming
- → Laser scanning is a fast and simple method
- But: application of a diffuse coating to the front side is not feasible

Can we find a successful way to apply the 'naturally-soiled-mirror-scanning' method on this extreme case of a solar reflector for shape assessment?

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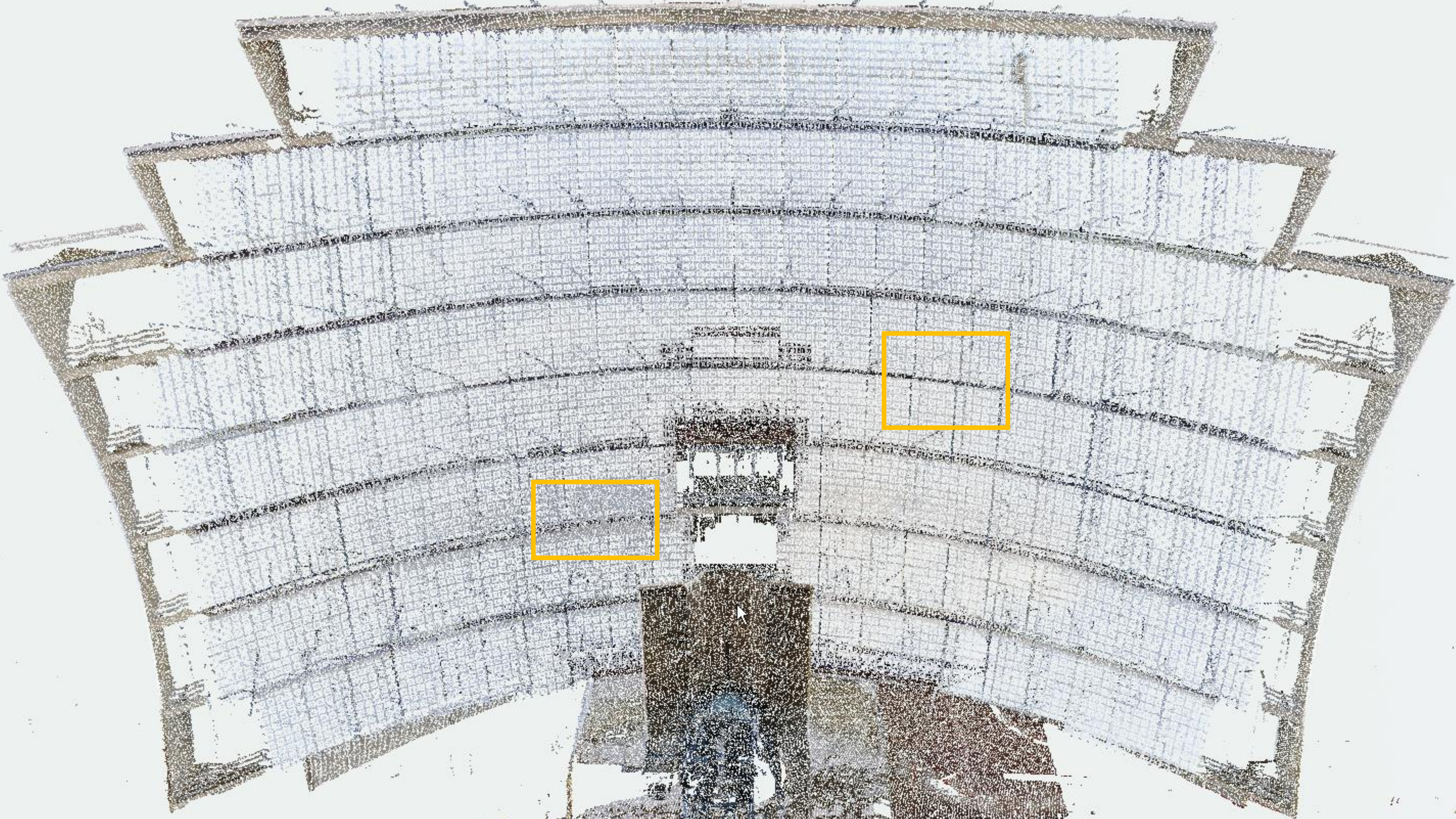
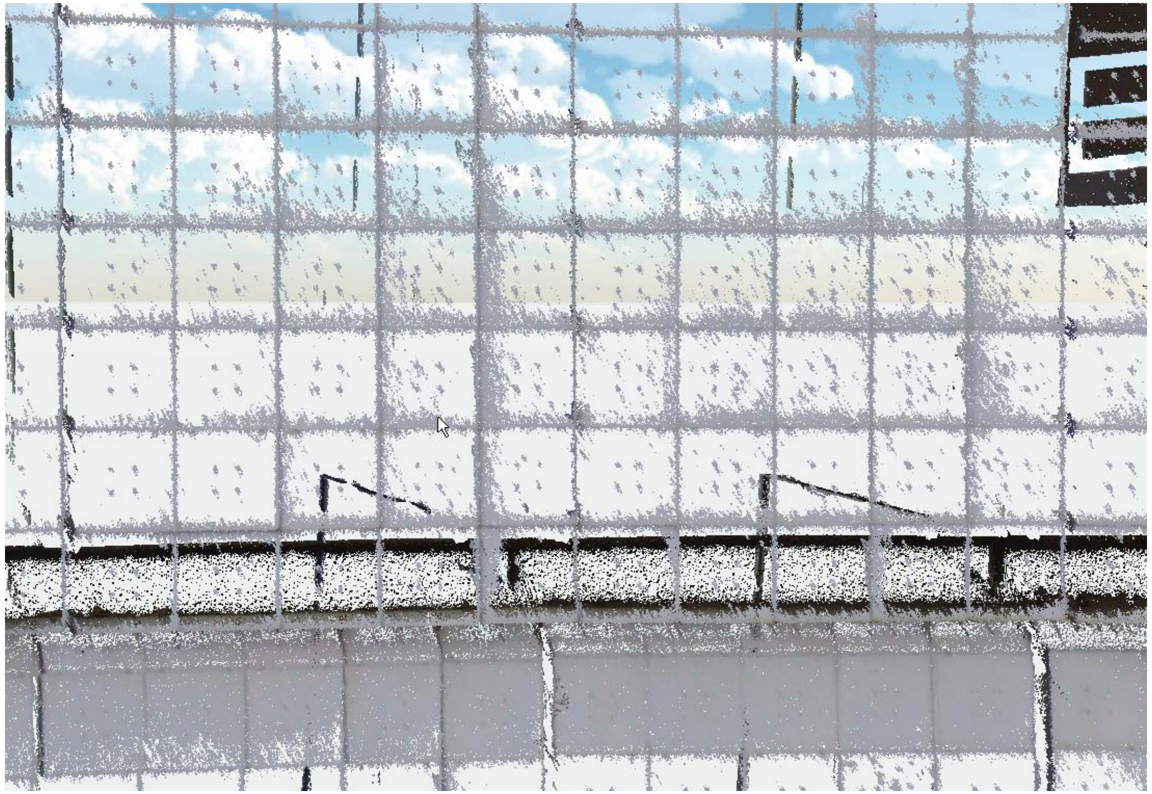
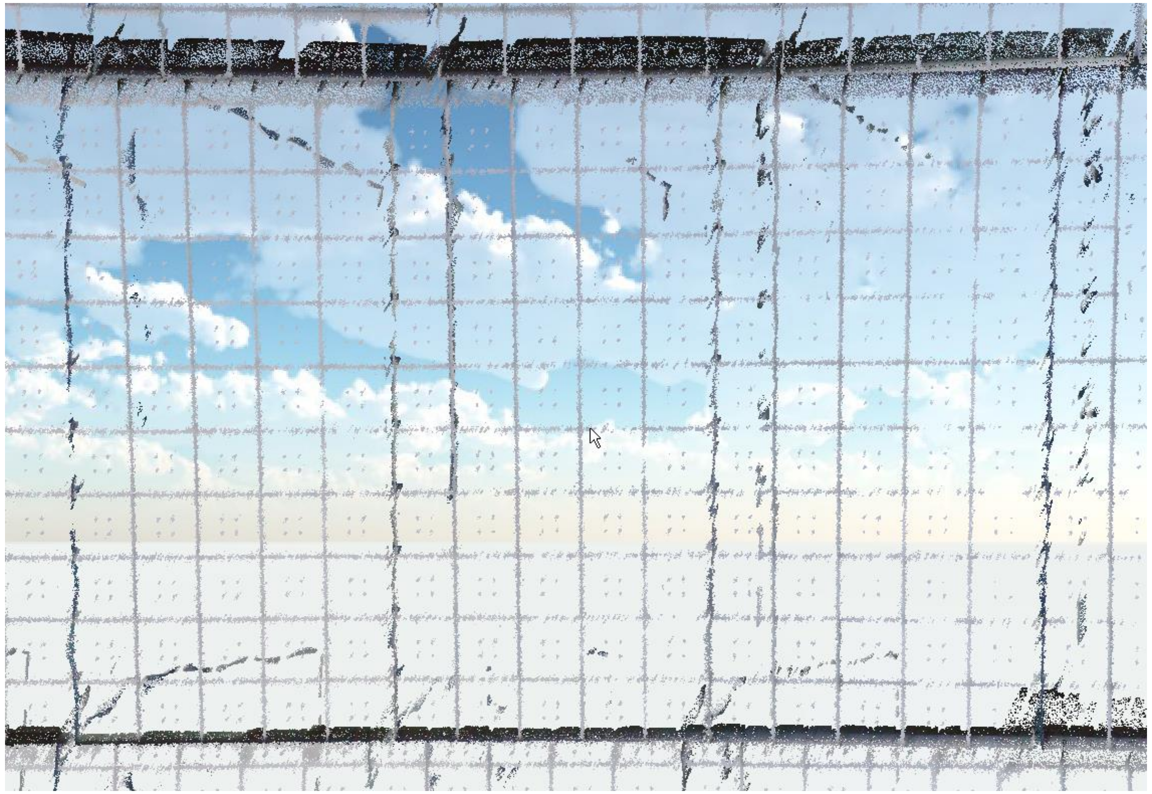


Setup / Measurements
Scanning from the ground – Details

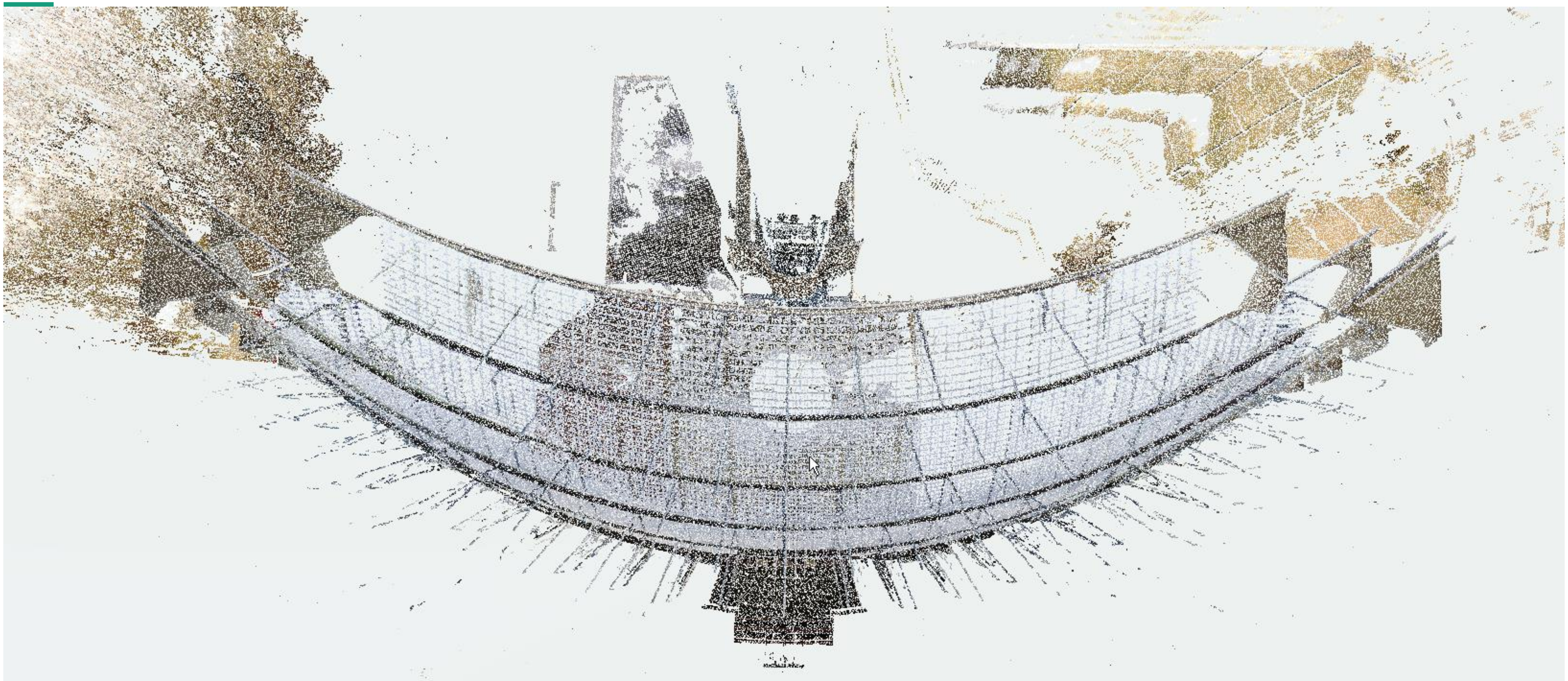


- Soiled mirrors: Signal from surface, edges and screws



- Clean mirrors: Signal mostly from edges and screws

Setup / Measurements
Scanning from the ground – Top view



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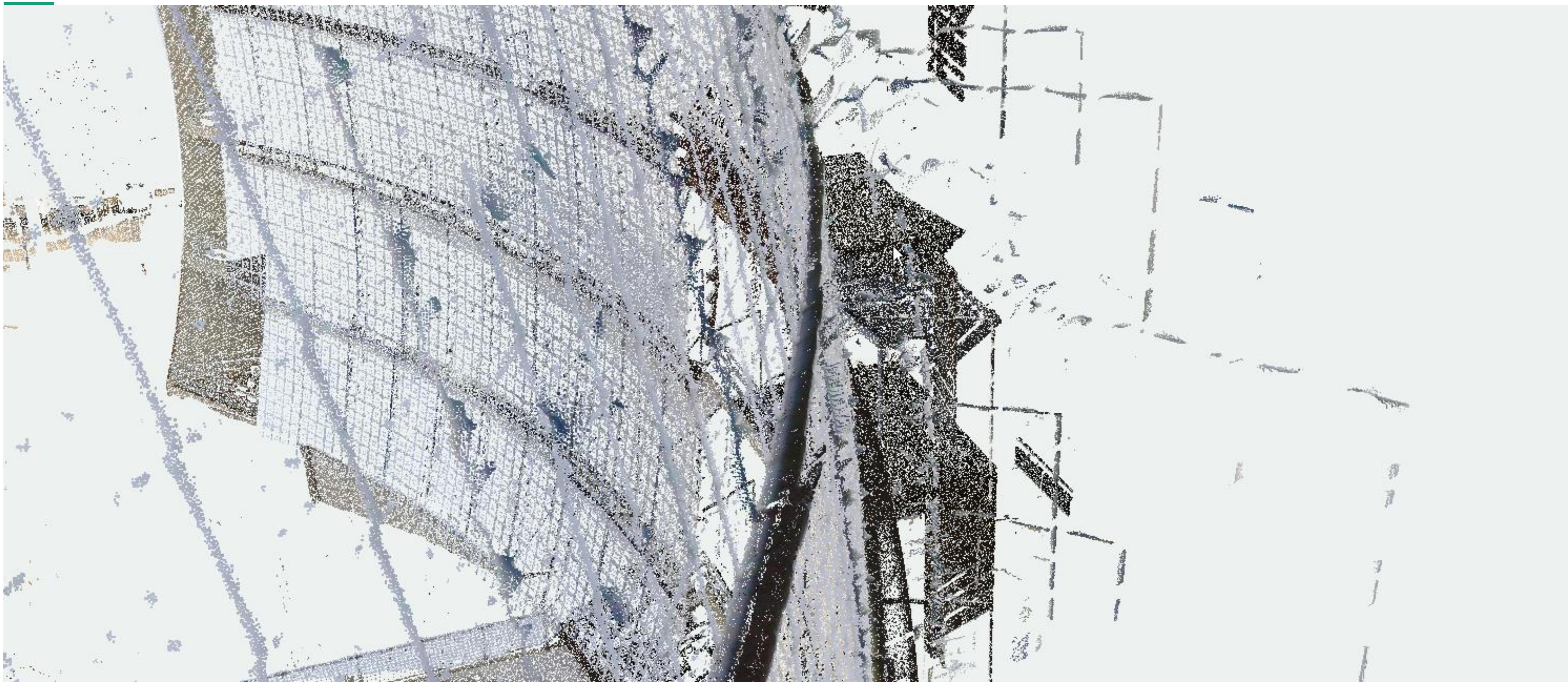
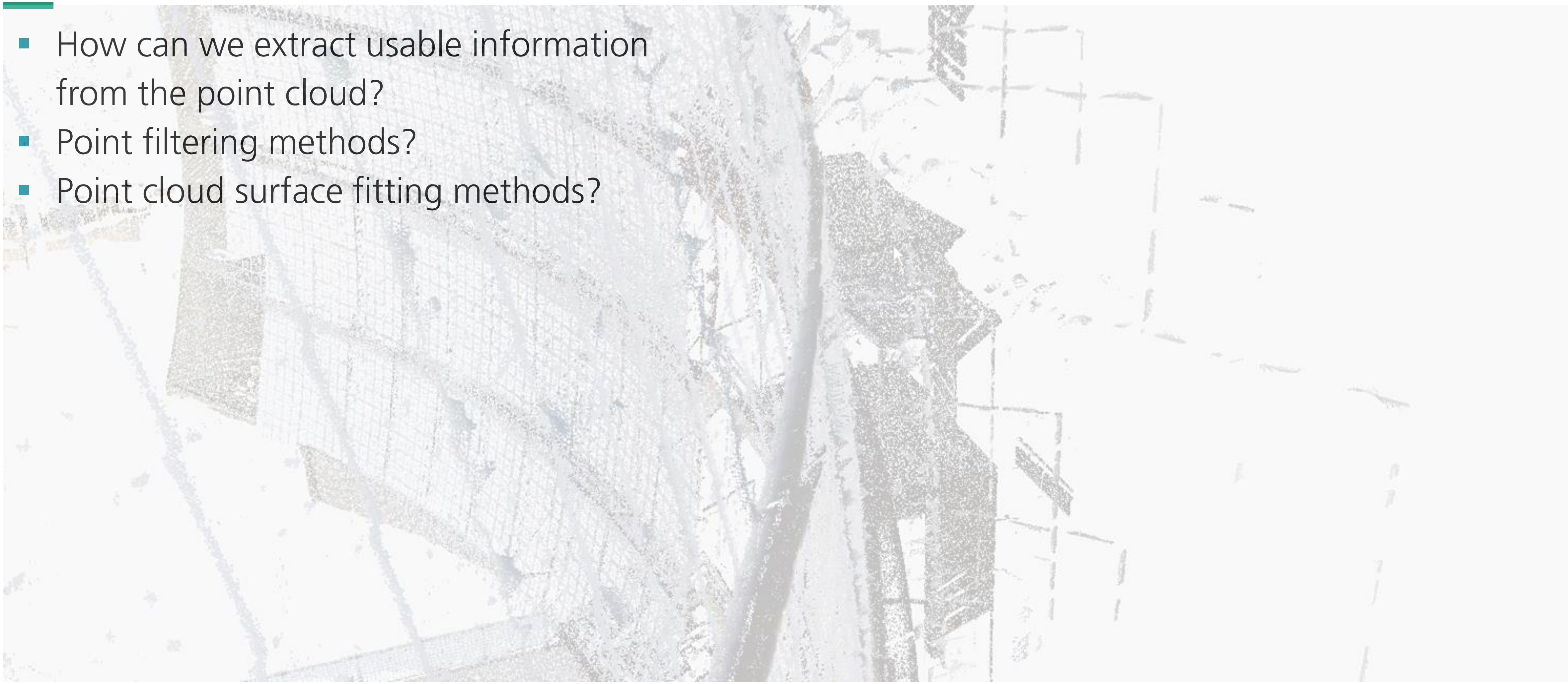
Setup / Measurements
Scanning from the ground – Side view



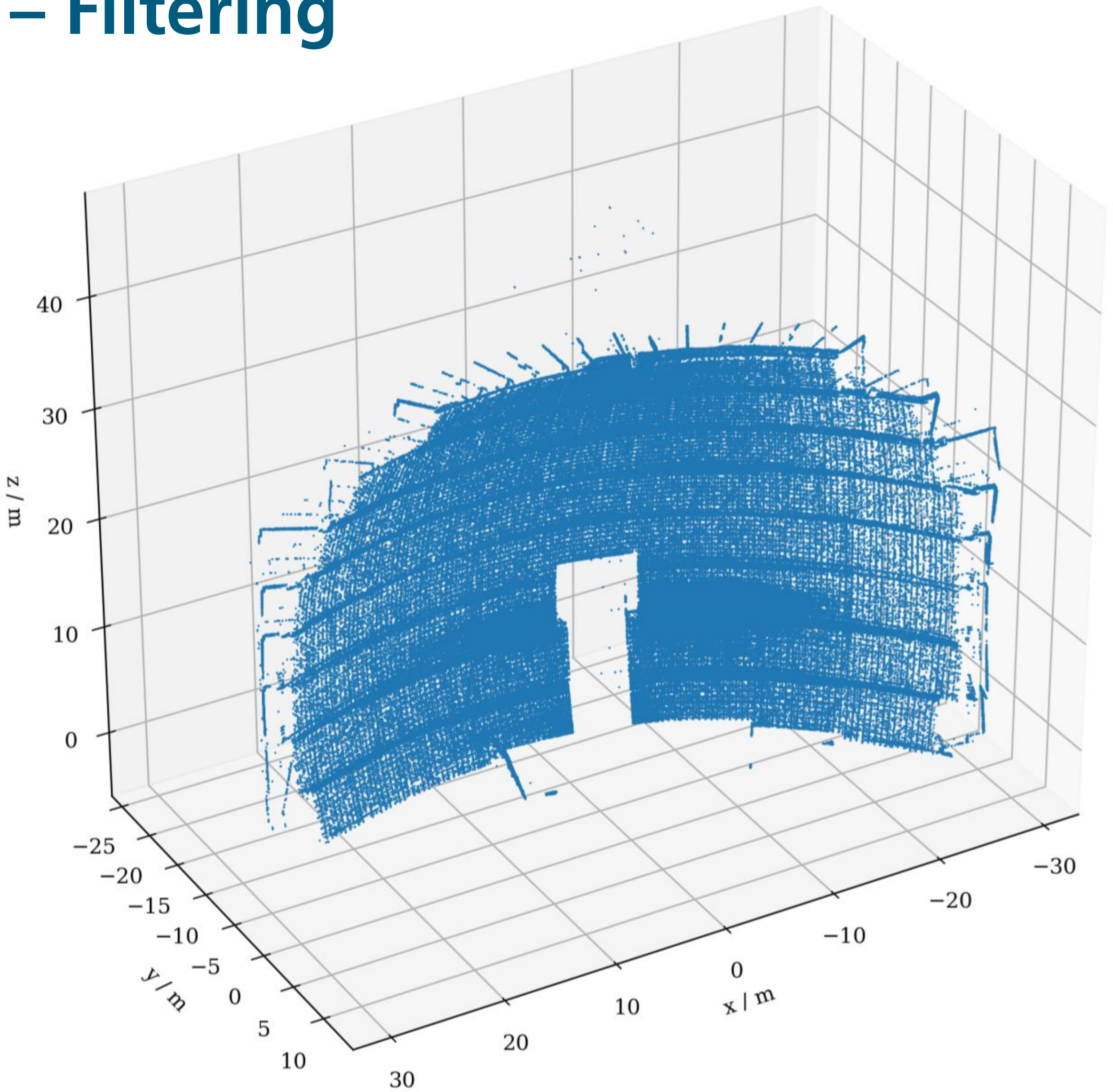
Data Processing



- How can we extract usable information from the point cloud?
- Point filtering methods?
- Point cloud surface fitting methods?

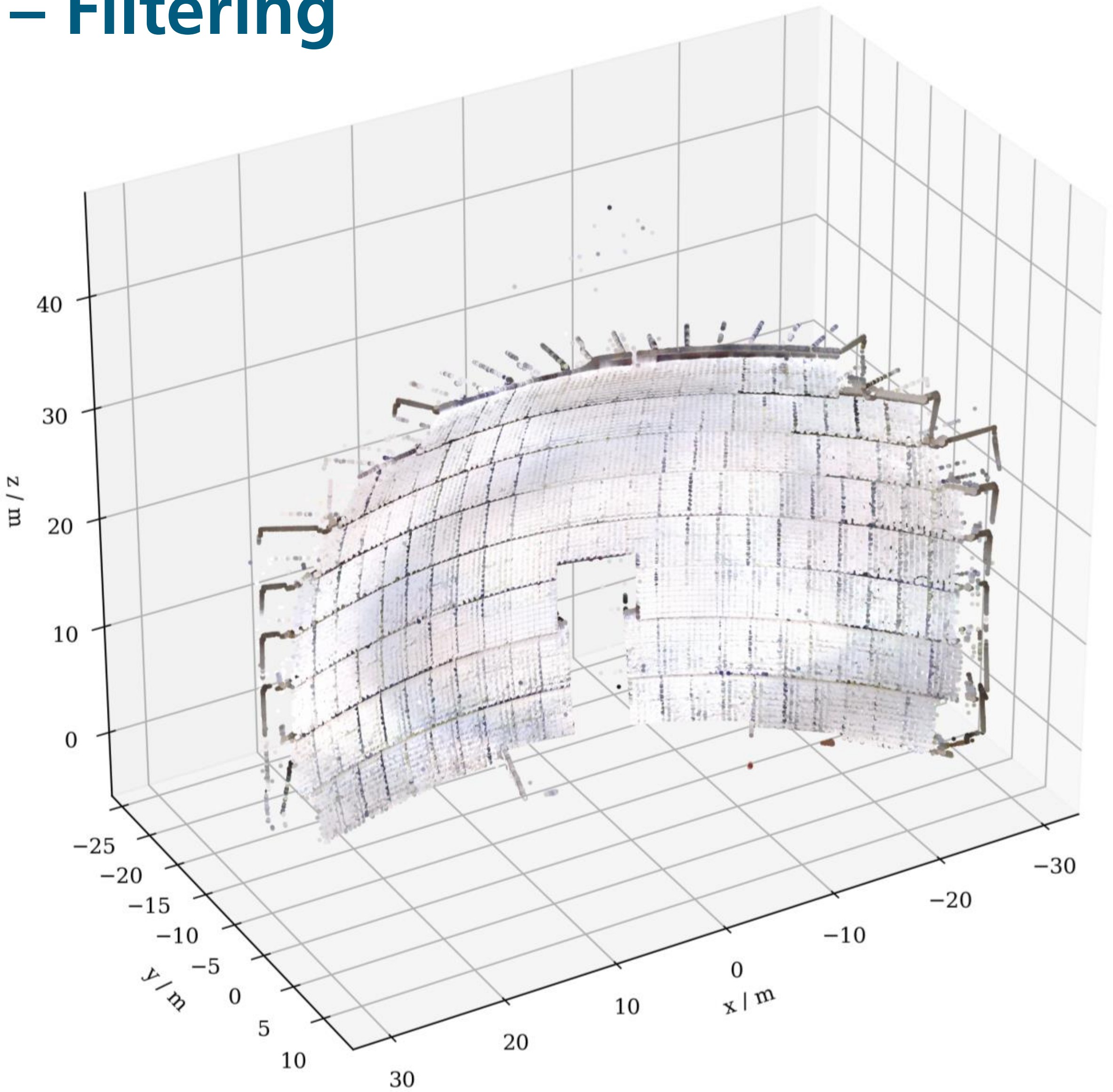
Data Processing – Filtering

- 3D Information (xyz)



Data Processing – Filtering

- 3D Information (xyz)
- VIS Information (RGB)



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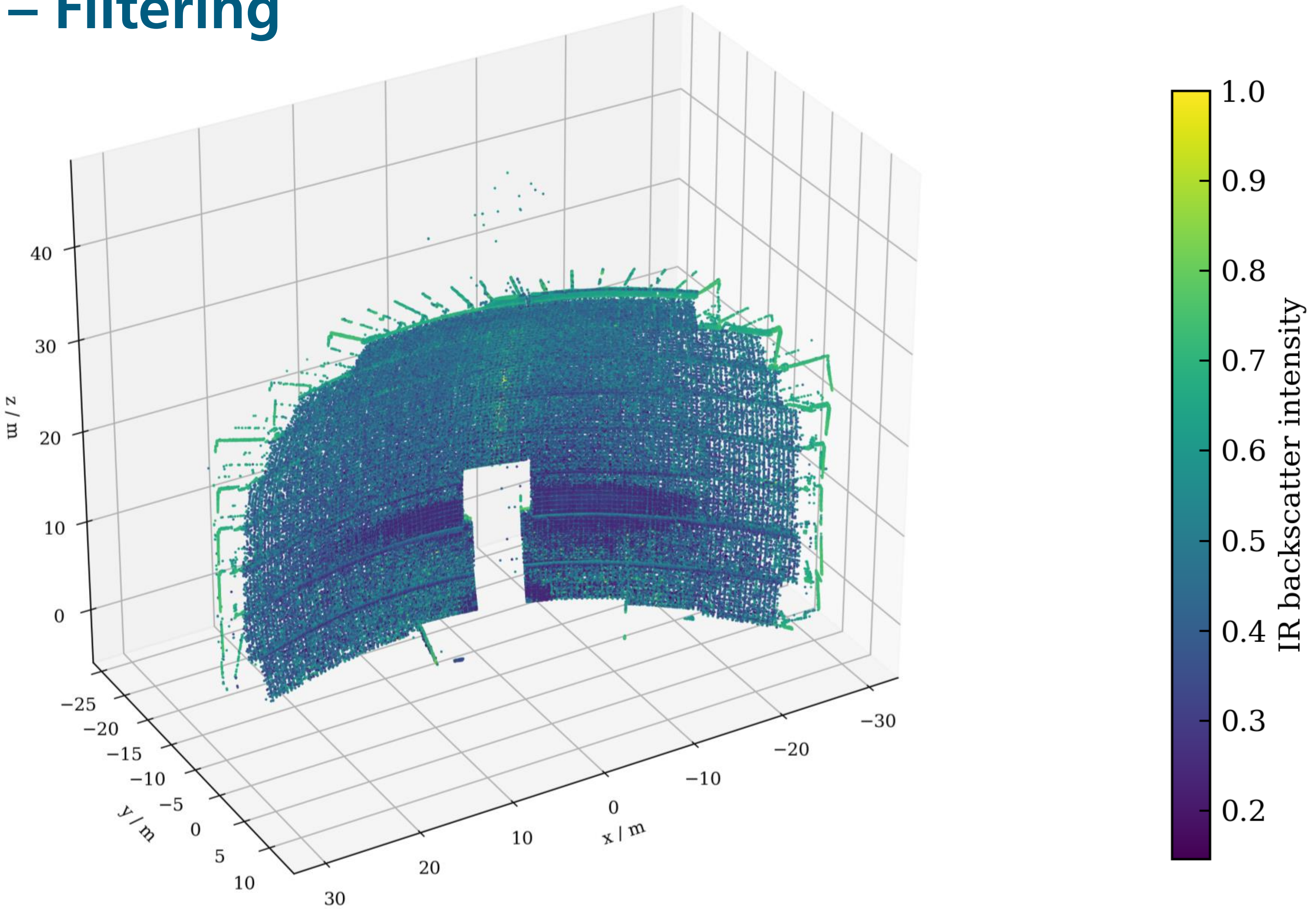
Data Processing – Filtering

- 3D Information (xyz)
- VIS Information (RGB)
- IR backscatter intensity



Terrestrial Laser Scanning for Fast Spatially Resolved Cleanliness Assessment of Heliostat Fields. M. Ferreres Eceiza, M. Bitterling, T. Schmidt, T. Boehret, D. Wohlfeld and G. Bern. SolarPACES Conference, September 27-30 2022, Albuquerque, NM

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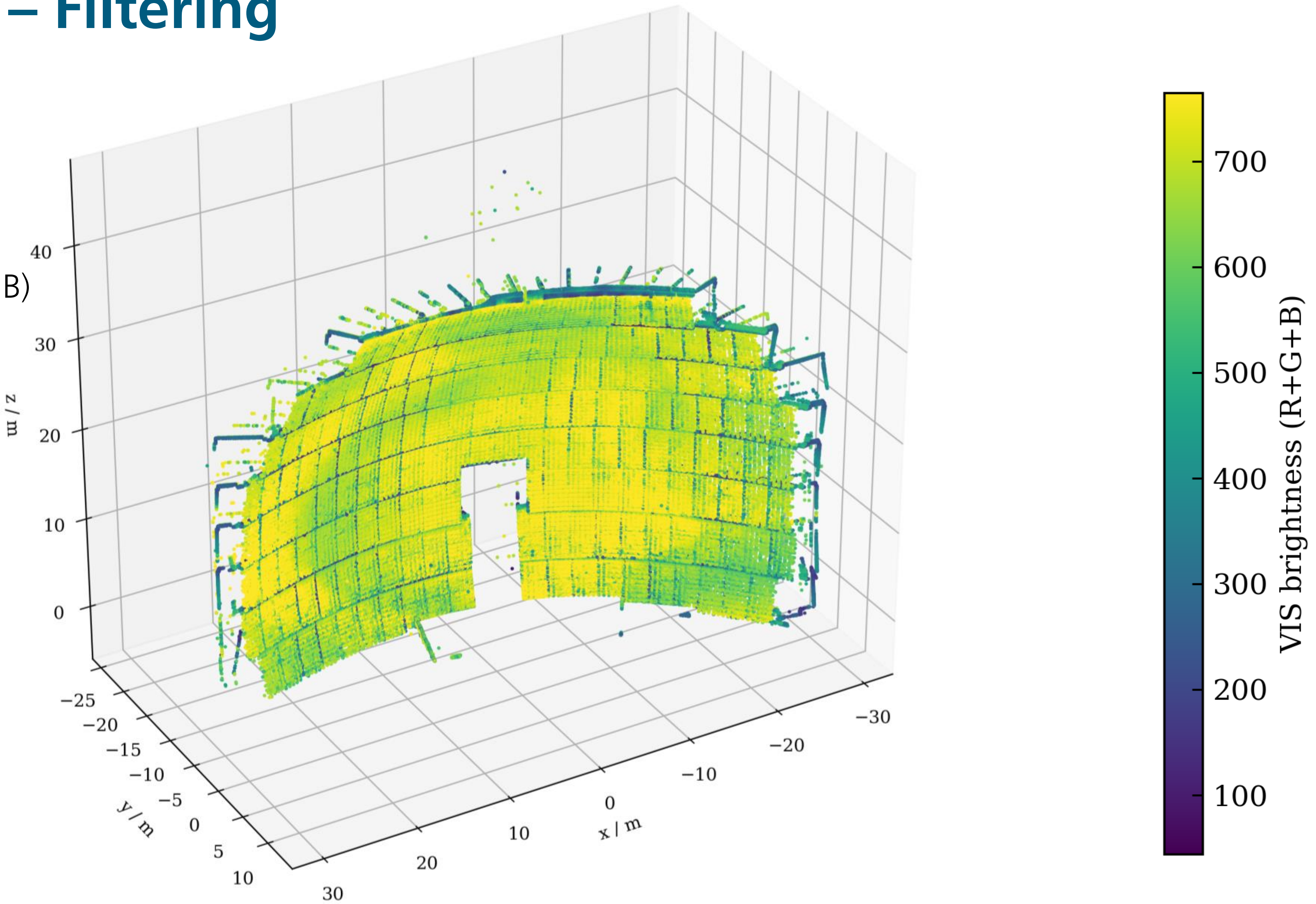
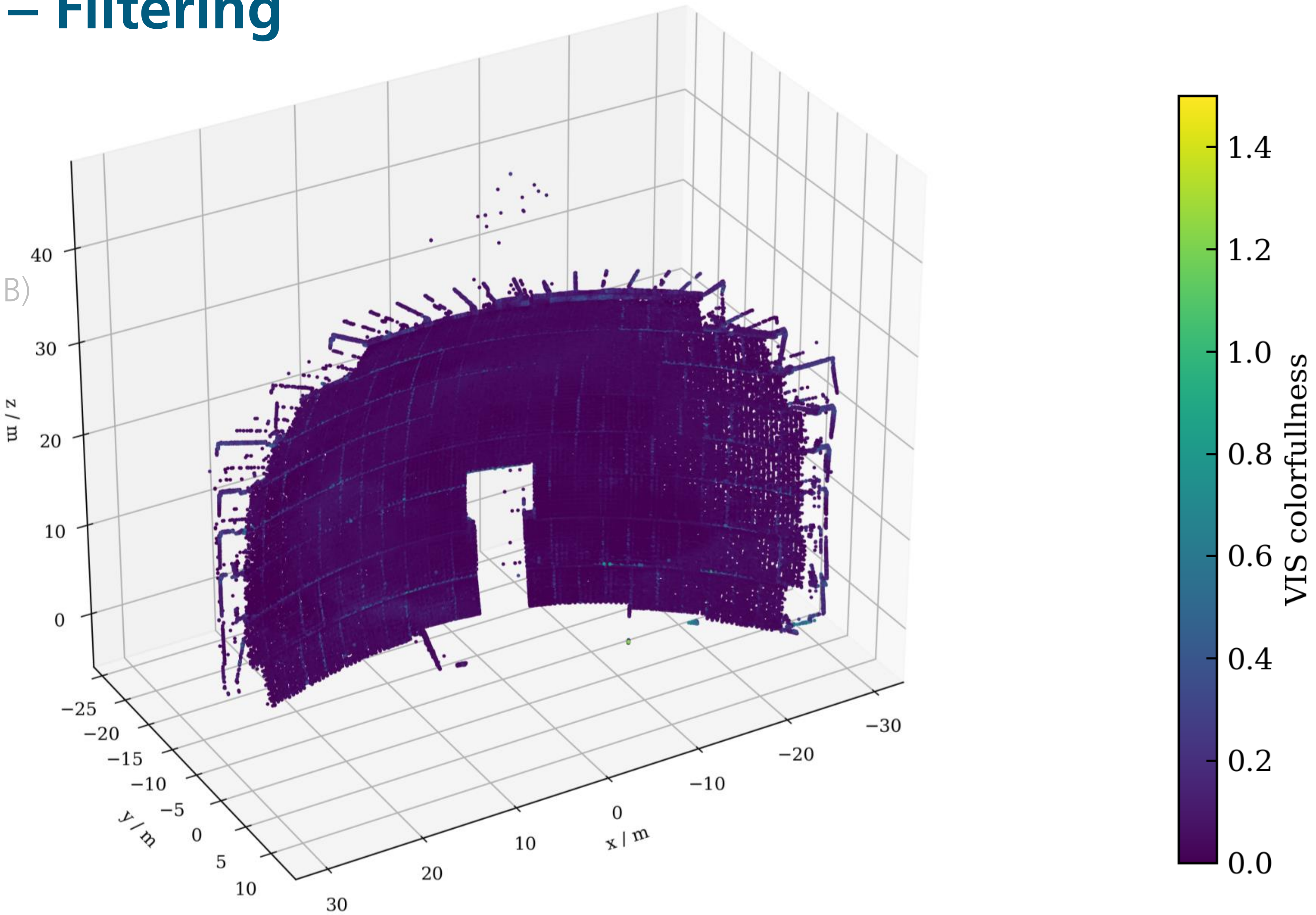
Data Processing – Filtering

- 3D Information (xyz)
- VIS Information (RGB)
- IR backscatter intensity
- → VIS brightness (from RGB)



Data Processing – Filtering

- 3D Information (xyz)
- VIS Information (RGB)
- IR backscatter intensity
- → VIS brightness (from RGB)
- → VIS ‘colorfulness’ (from RGB)



Data Processing – Filtering

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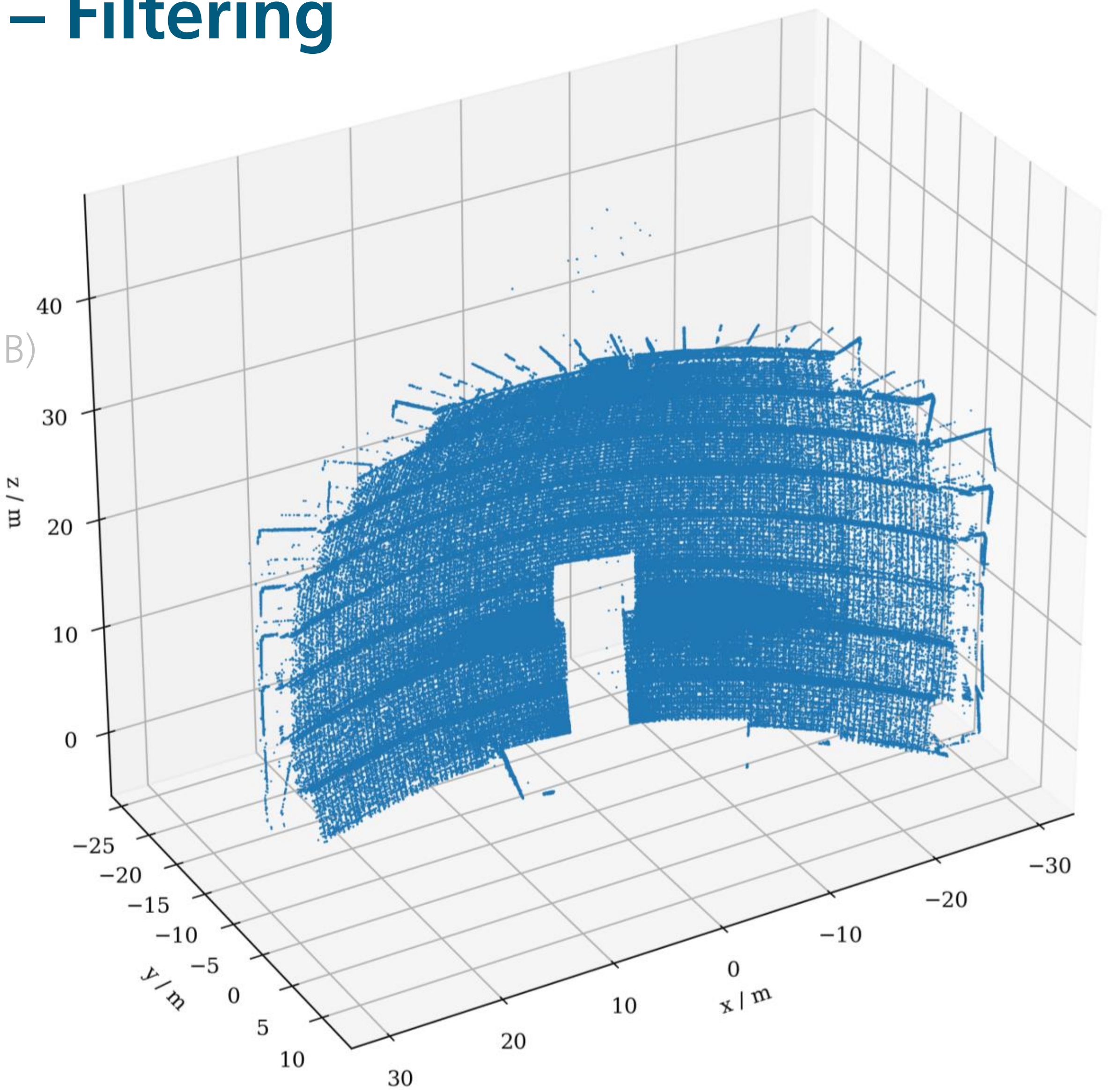

Data Processing – Filtering

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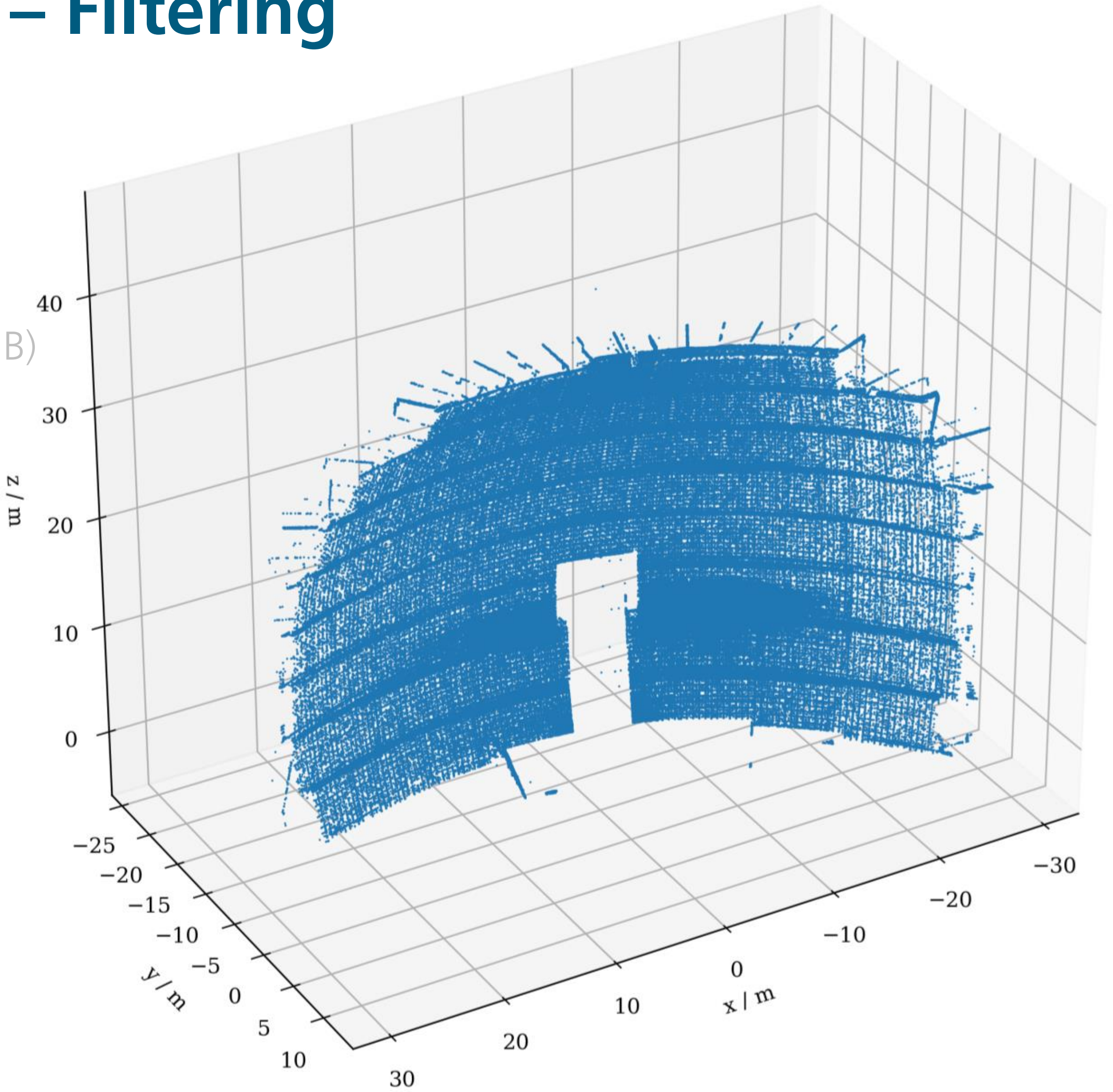

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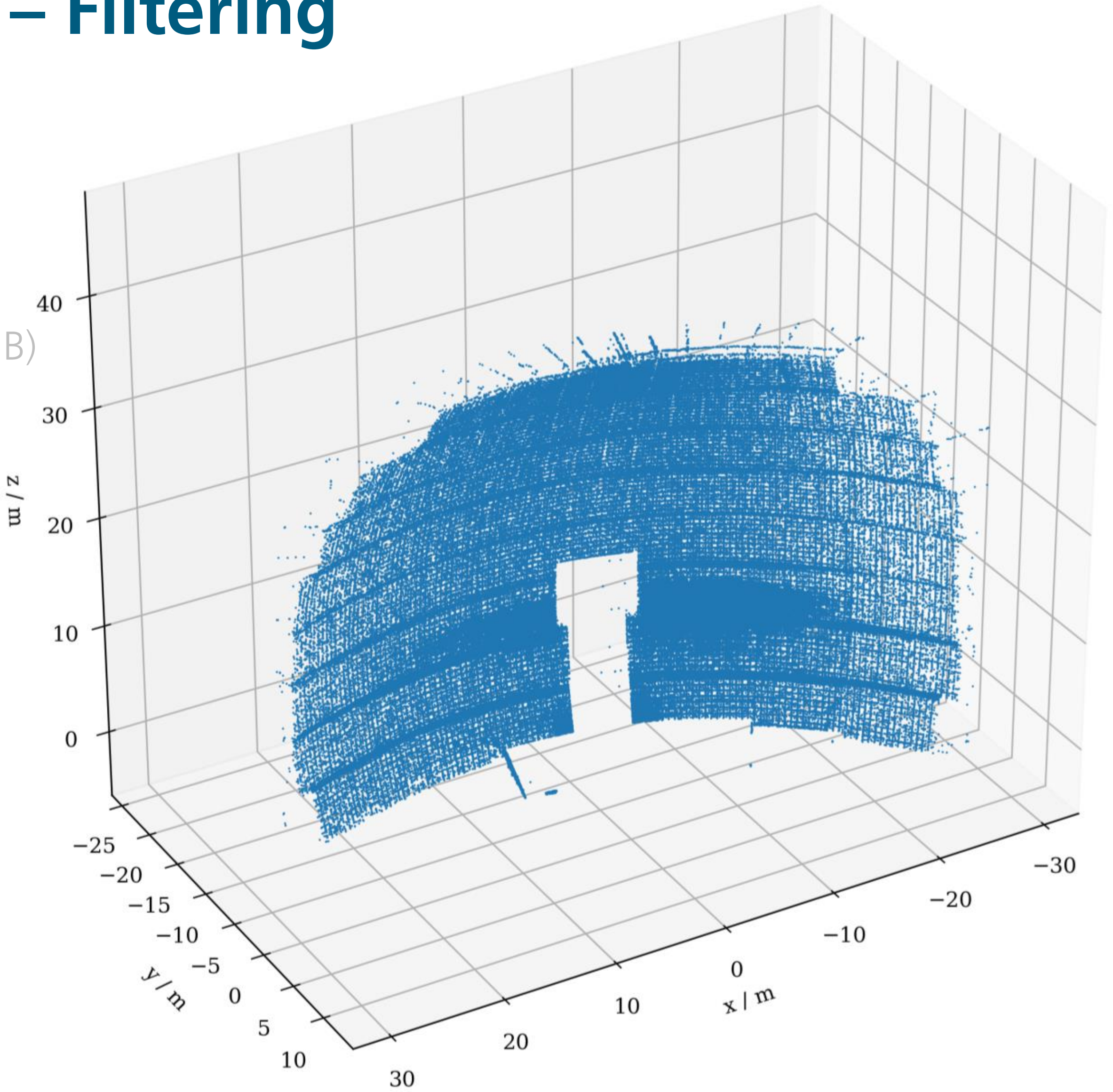

Data Processing – Filtering

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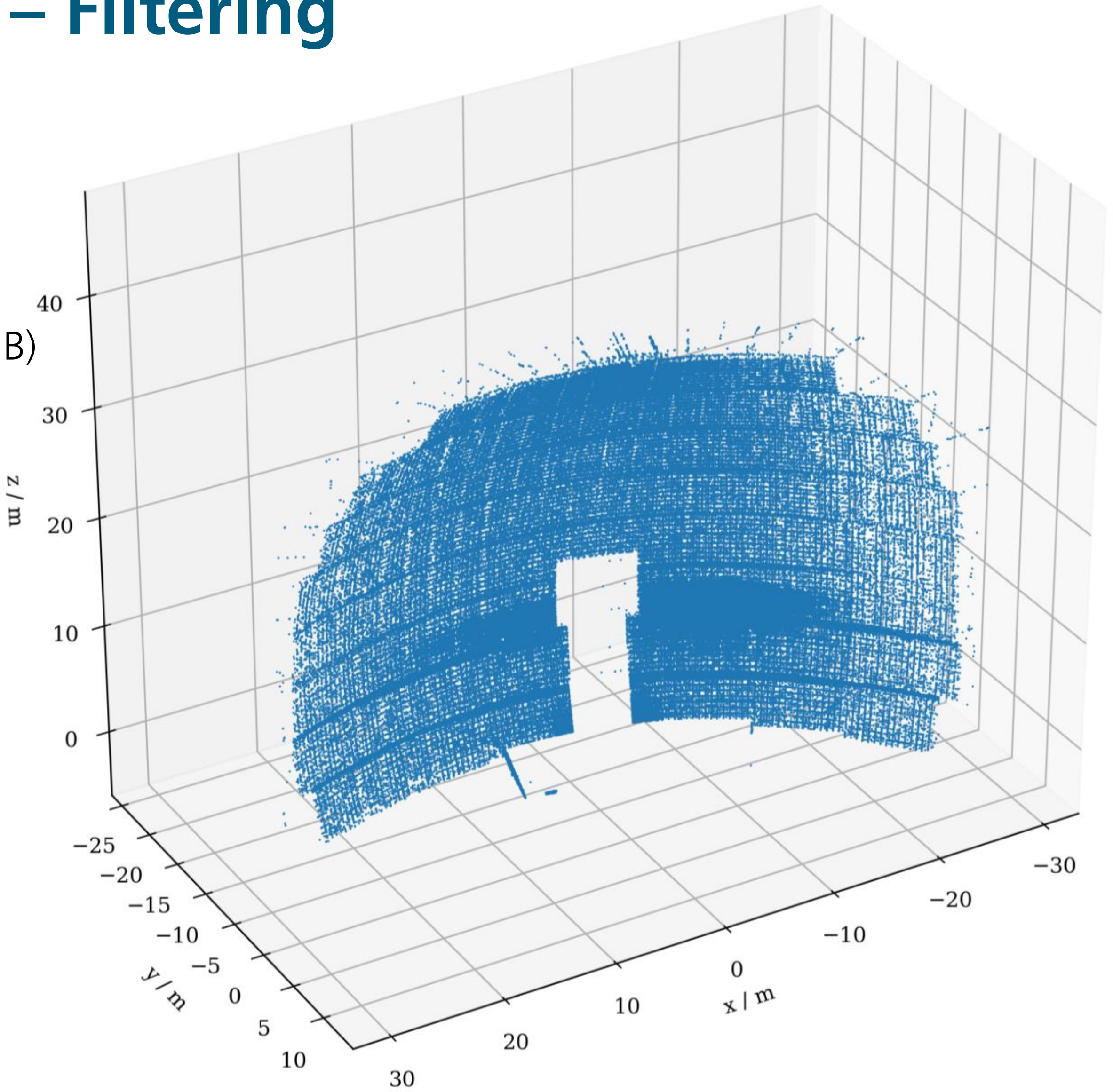
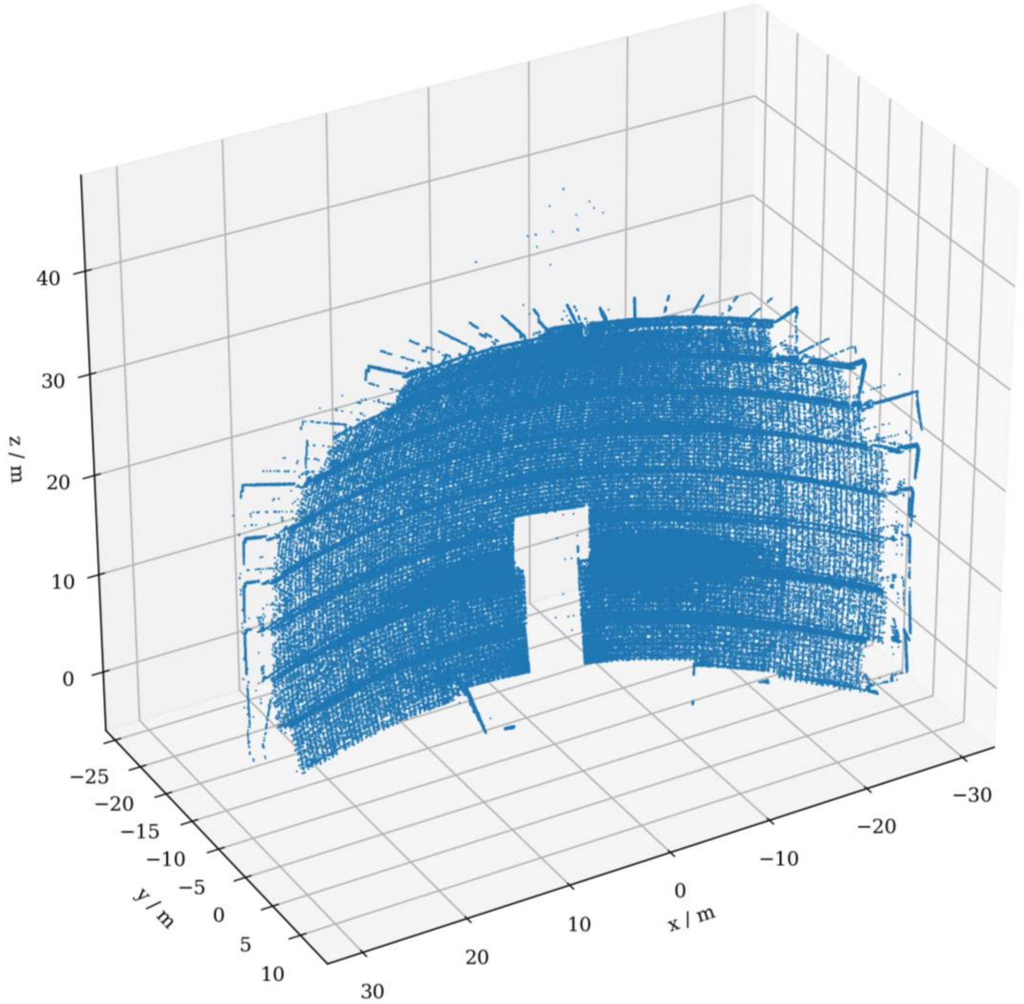
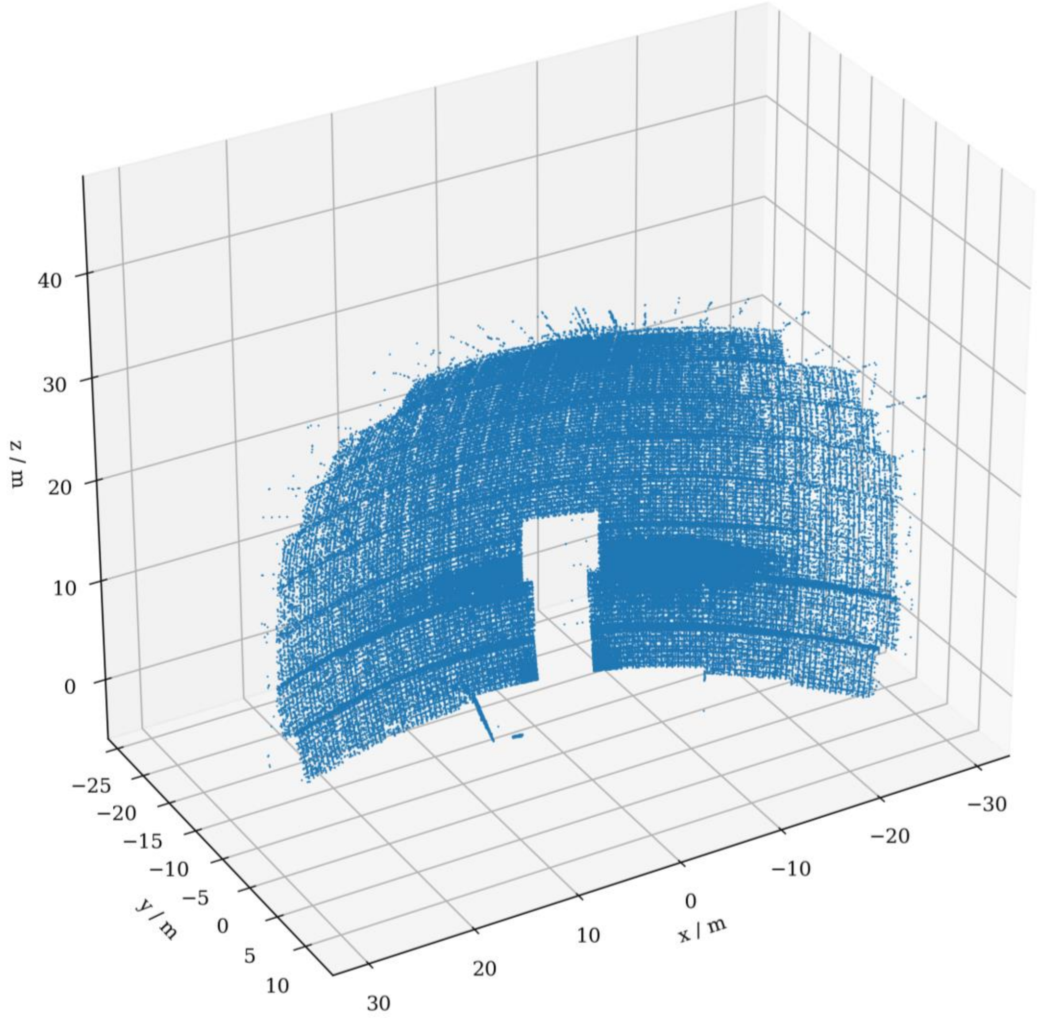


Data Processing – Filtering



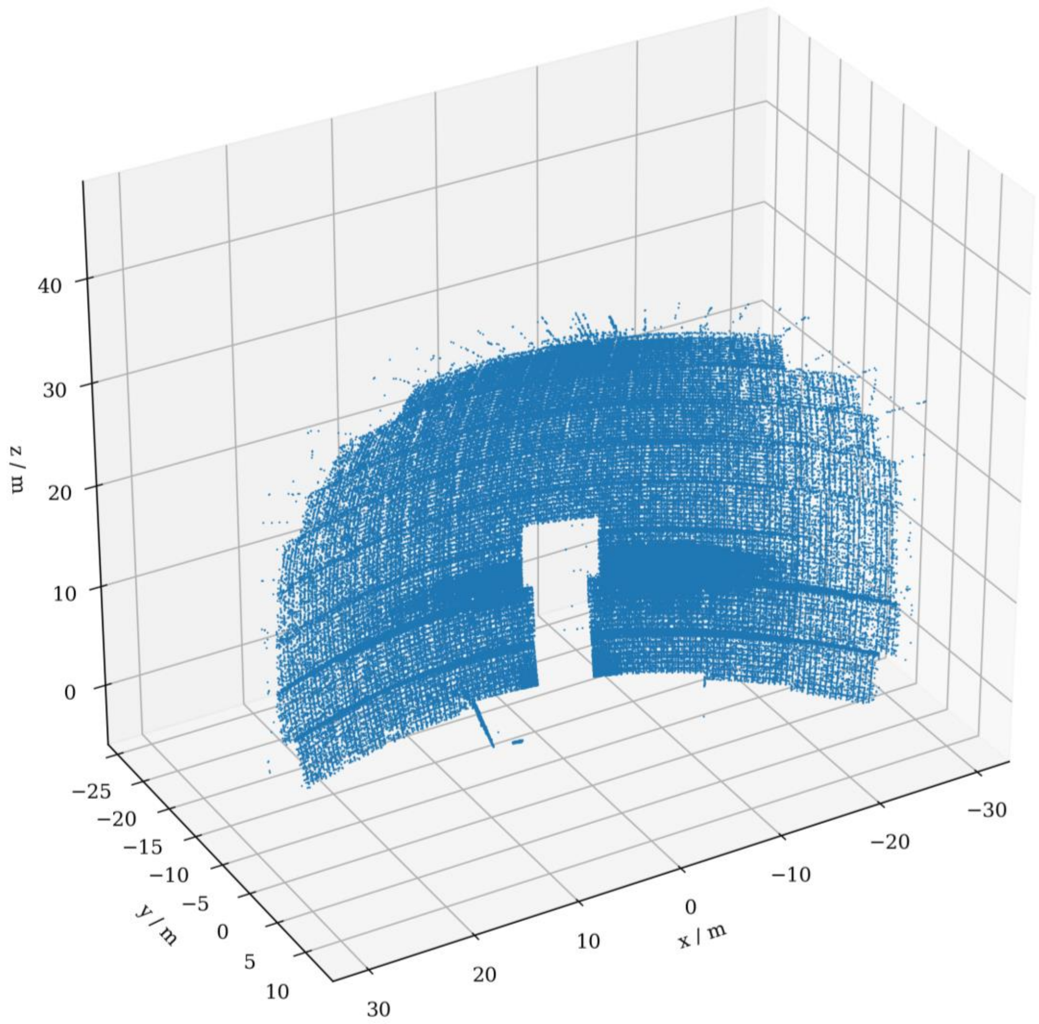
- No point cloud filtering: 55M points



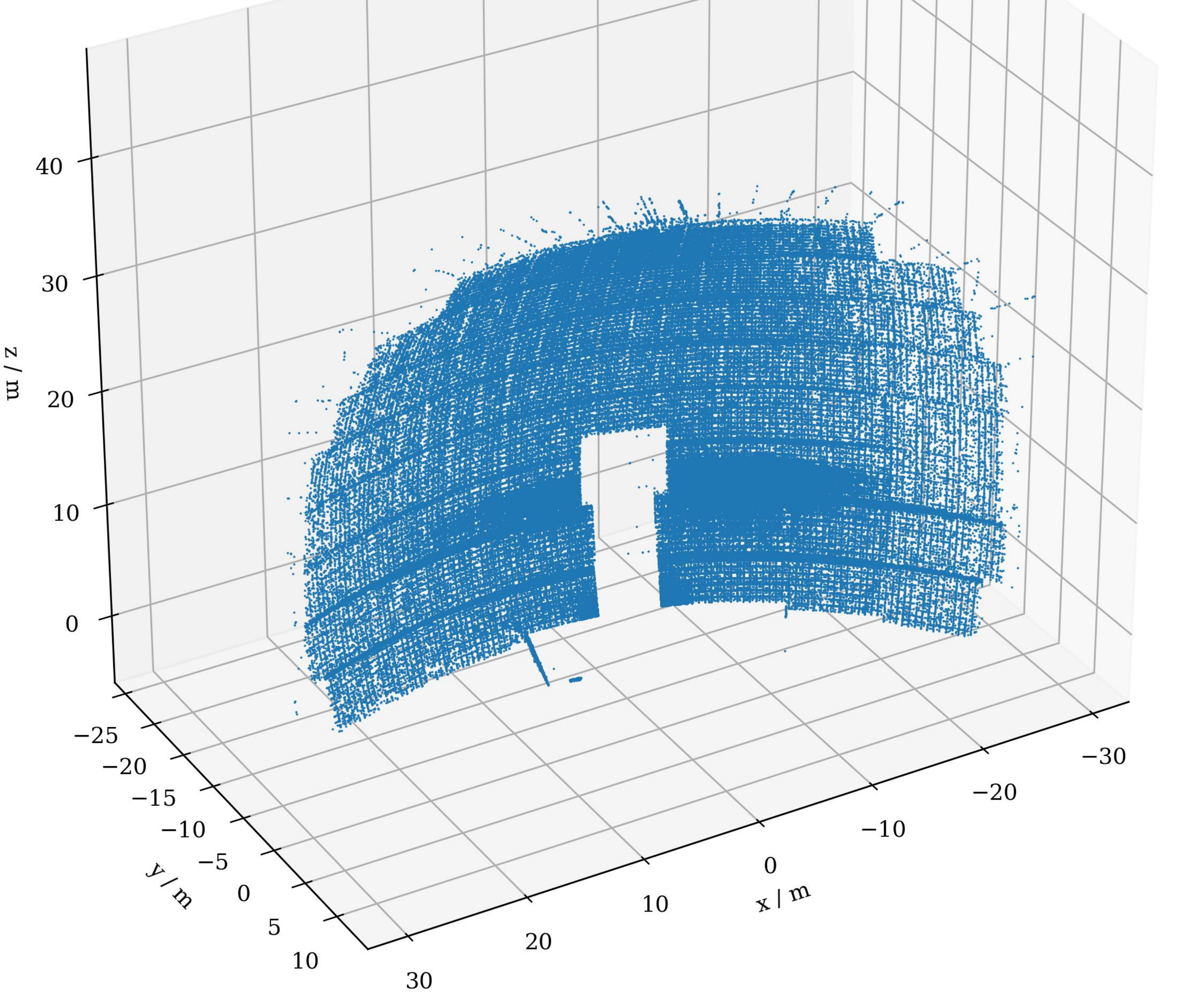
- After filtering: 35M points

Data Processing – Fitting Procedure

- Fit of the point cloud with ideal paraboloid
- Fit parameters:
  - 3 coordinates (translation scanner position – paraboloid vertex)
  - 2 angles (3rd rotation is undefined due to rotational symmetry)
  - Focal length of paraboloid
- Adaptive spatial filtering during fit to remove points far from the ideal surface



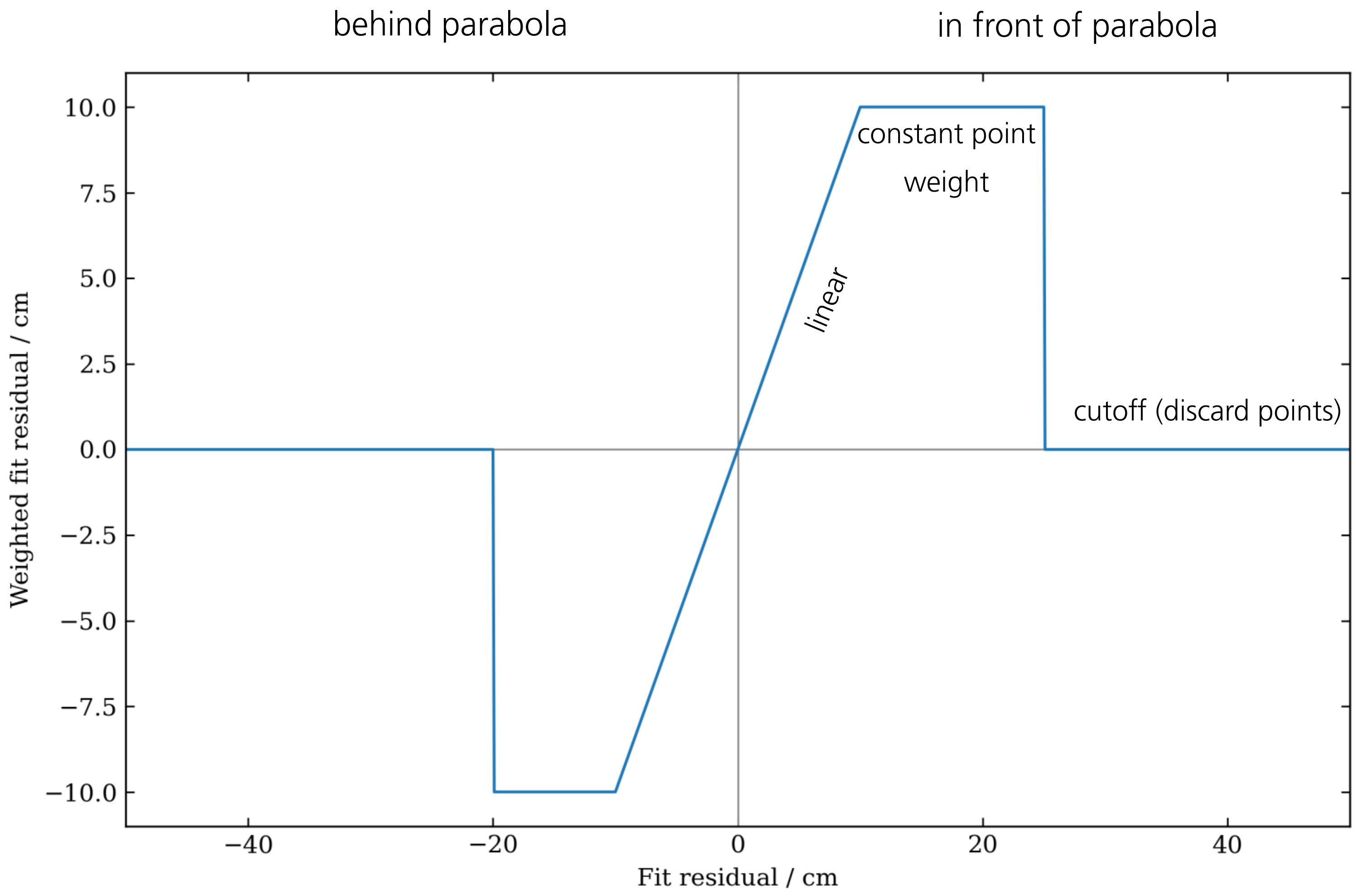
- After filtering: 35M points



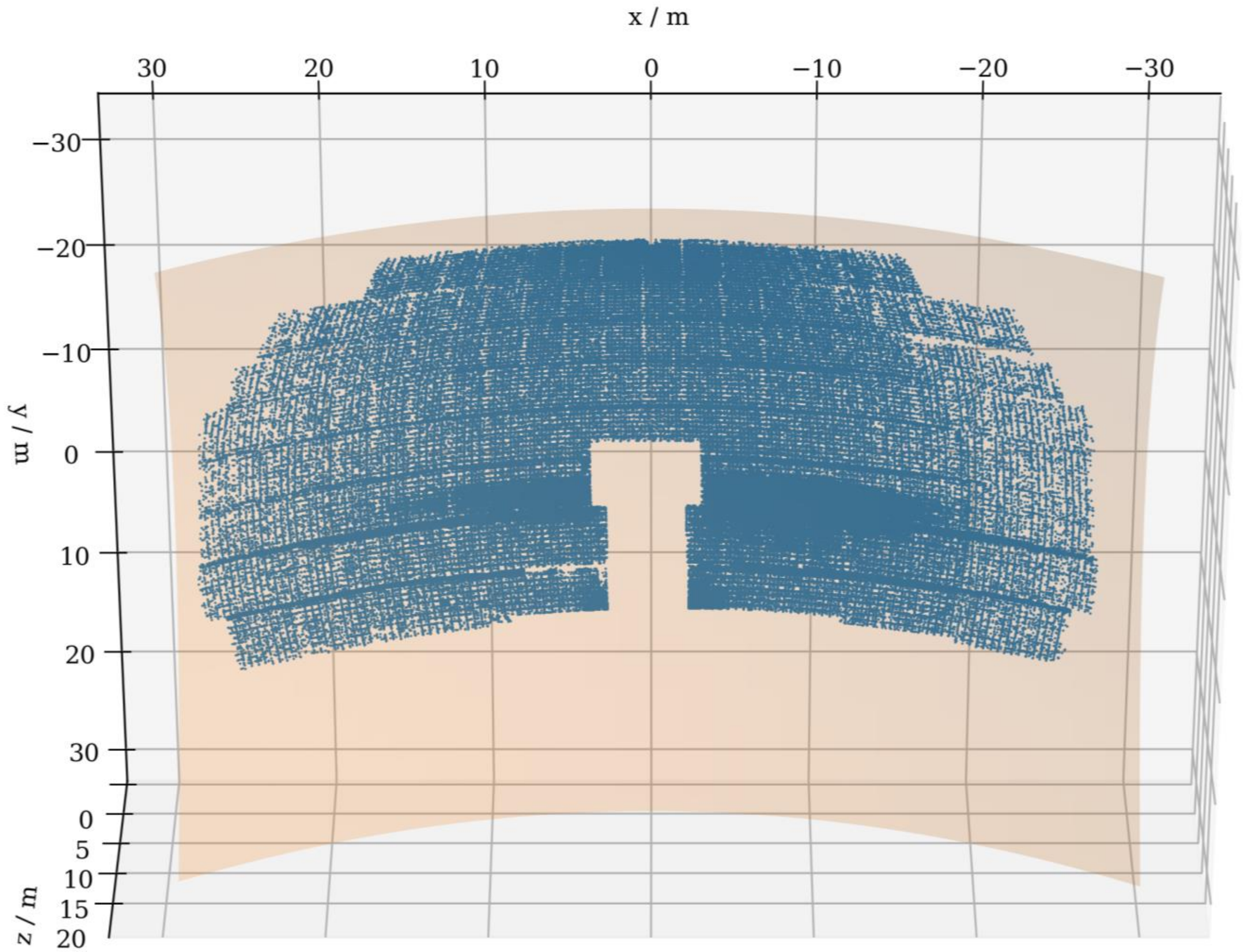
z / m
40
30
20
10
0
−25
−20
−15
−10
−5
0
5
10
y / m
30
20
10
0
−10
−20
−30
x / m

Data Processing – Fitting Procedure

Adaptive point filtering during fit: fit residual weighting



Data Processing – Fit Result



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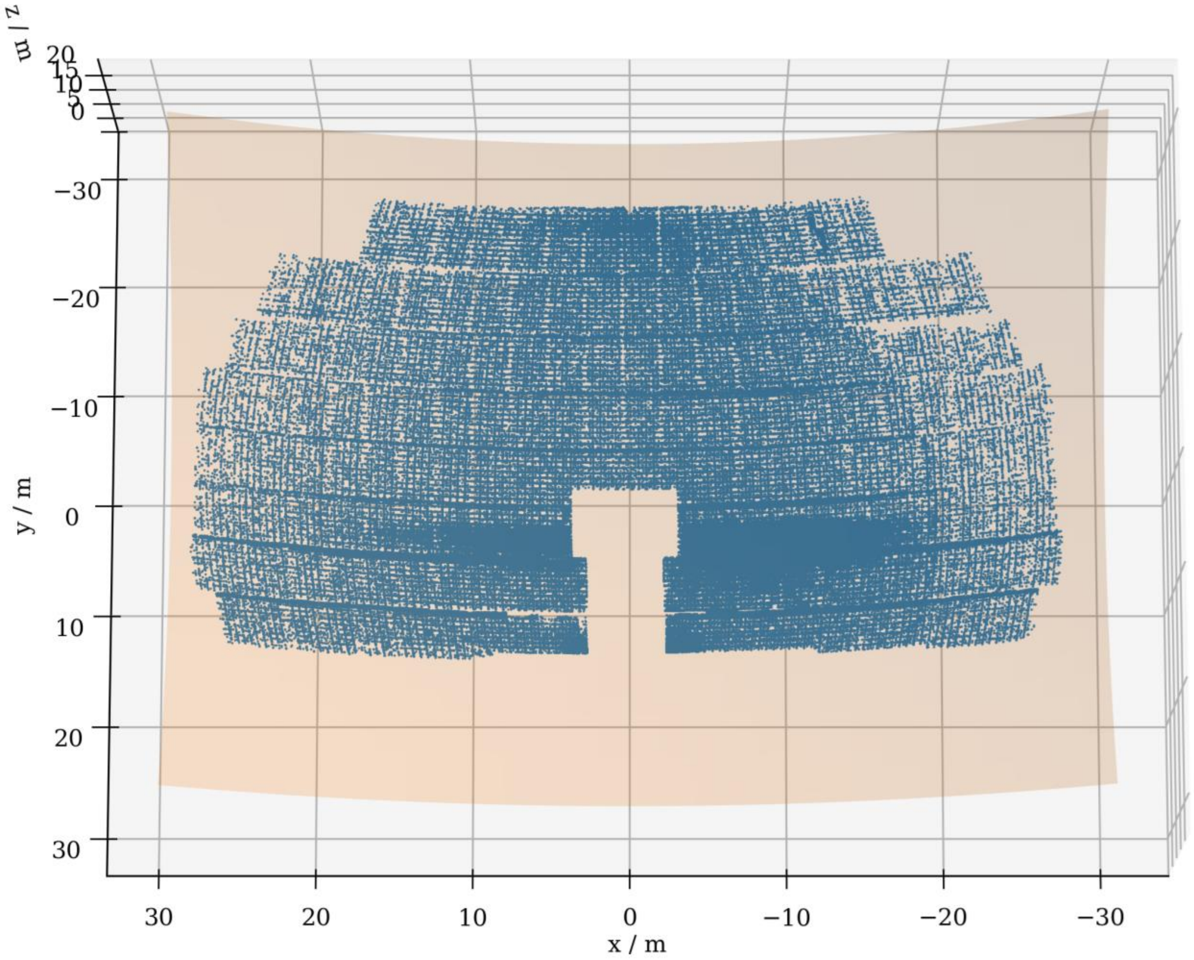
Data Processing – Fit Result



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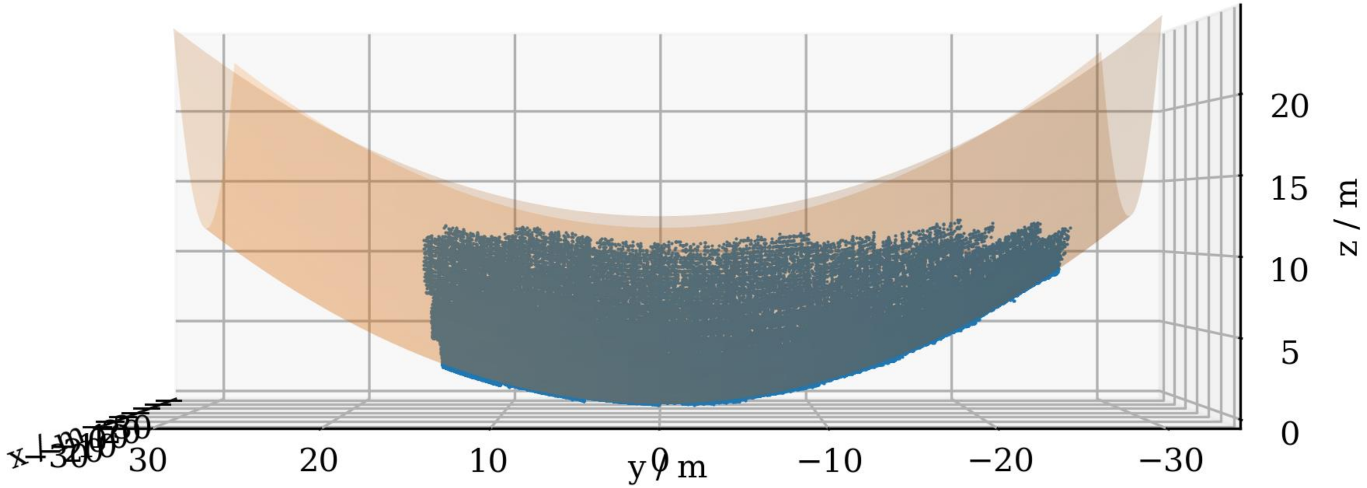
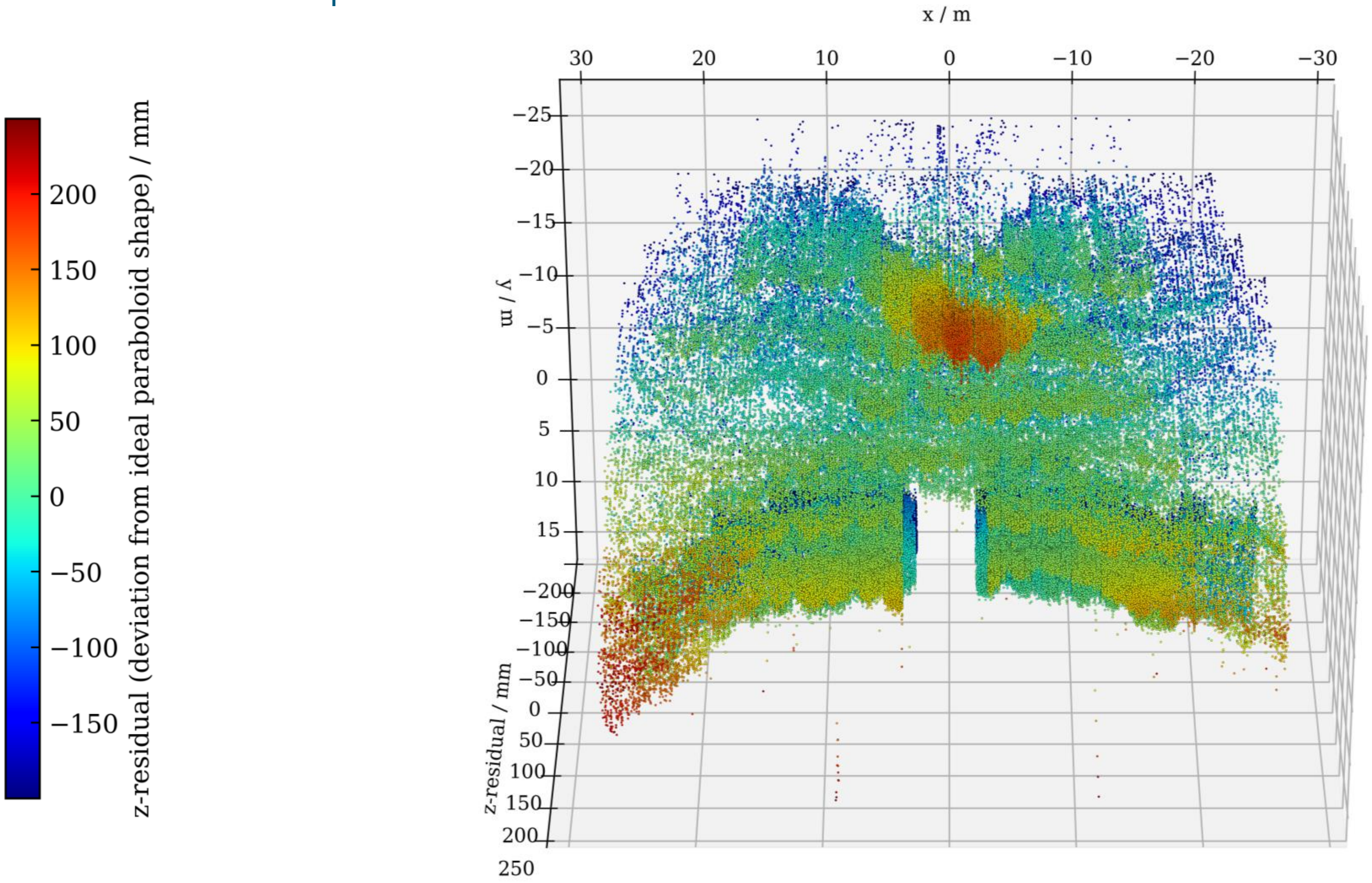
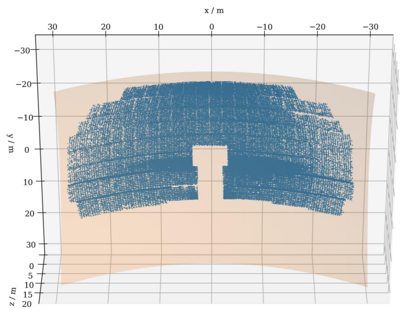
Data Processing – Fit Result



Data Processing – Fit Residuals

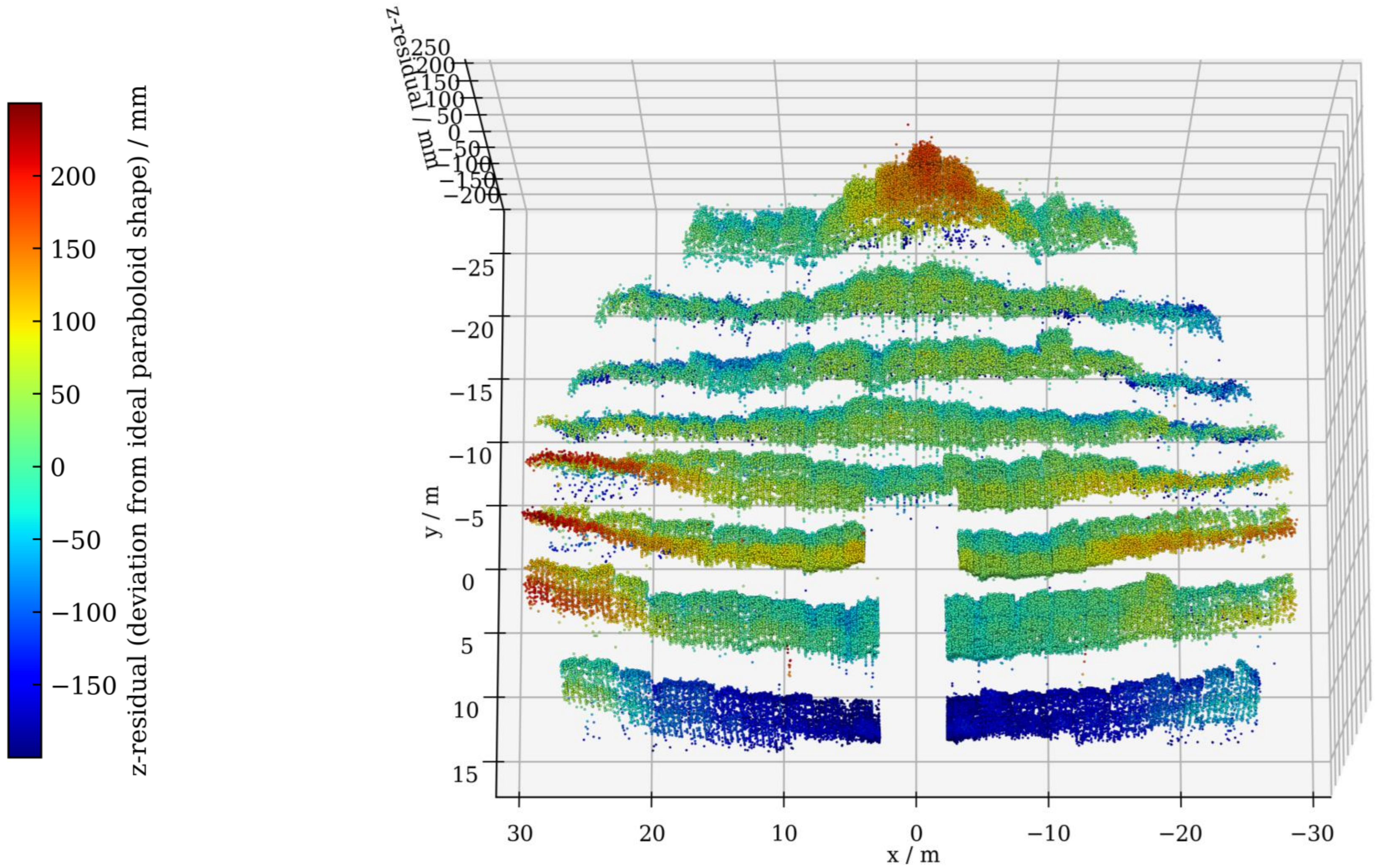
Deviations from ideal shape

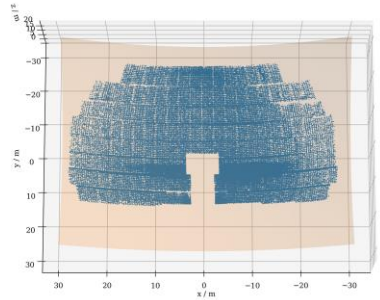




Data Processing – Fit Residuals

Deviations from ideal shape





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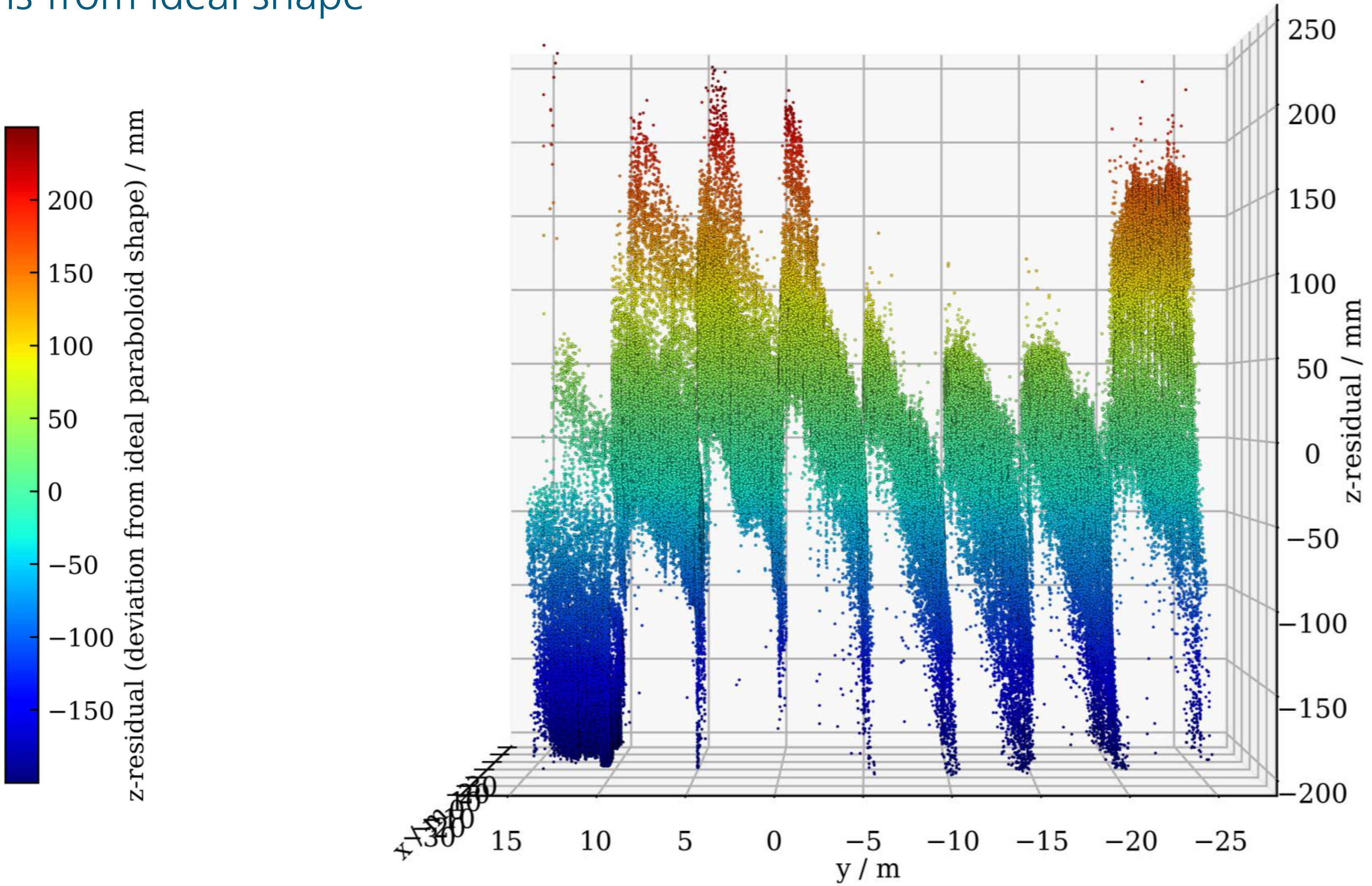
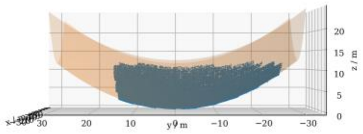
Data Processing – Fit Residuals

Deviations from ideal shape





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Fit Results

- Systematic deviation of the structure from ideal paraboloid shape
- Mean absolute error: 61 mm (median absolute error: 42 mm)
- Focal length of fitted paraboloid: **18.00095 ± 0.00010 m**
- Statistical uncertainty on scanner position in paraboloid coordinate system:

  less than 50 µm
- Statistical uncertainty on the focal direction of the Parabola:

  less than 2 µrad
- Slight canting bias of each gallery discovered, possibly to adjust focal point location

  → upshift of the focal point of around 25-35 cm compared to the ideal focal direction

→ Can we determine the direction of each facet?

Terrestrial Laser Scanning for Heliostat Surface Shape Determination and Canting Errors Correction. M. Ferreres Eceiza and M. Bitterling, T. Schmidt, W. Baltus, A. Perez, E. Guillot, G. Bern. 29th SolarPACES Conference in Sydney, Australia, October 10-13, 2023

Chapter 4

Heliostat canting error correction

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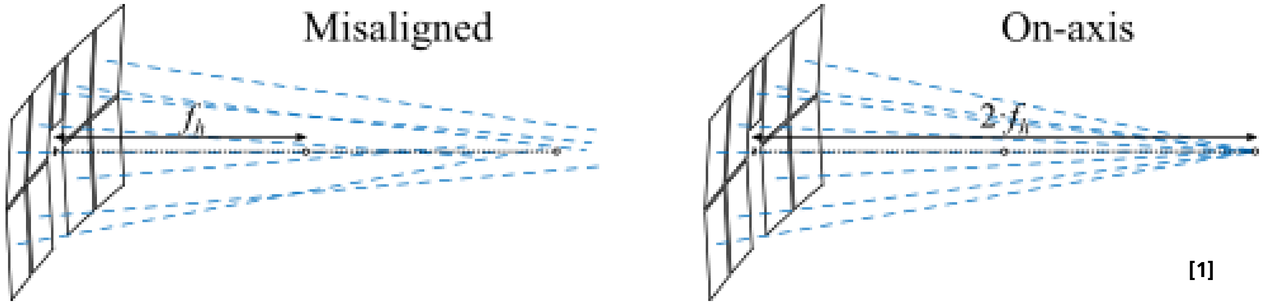
Introduction
Motivation – laser scanning in heliostat canting

- Canting errors: Heliostat facets are misaligned, resulting in their failure to accurately focus sunlight onto the same point.



[1]

[1] A. Sánchez-González, et al. "Determination of heliostat canting errors via deterministic optimization". Solar Energy 150 (2017) 136-146

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Introduction

Motivation – laser scanning in heliostat canting

- Canting errors: Heliostat facets are misaligned, resulting in their failure to accurately focus sunlight onto the same point.

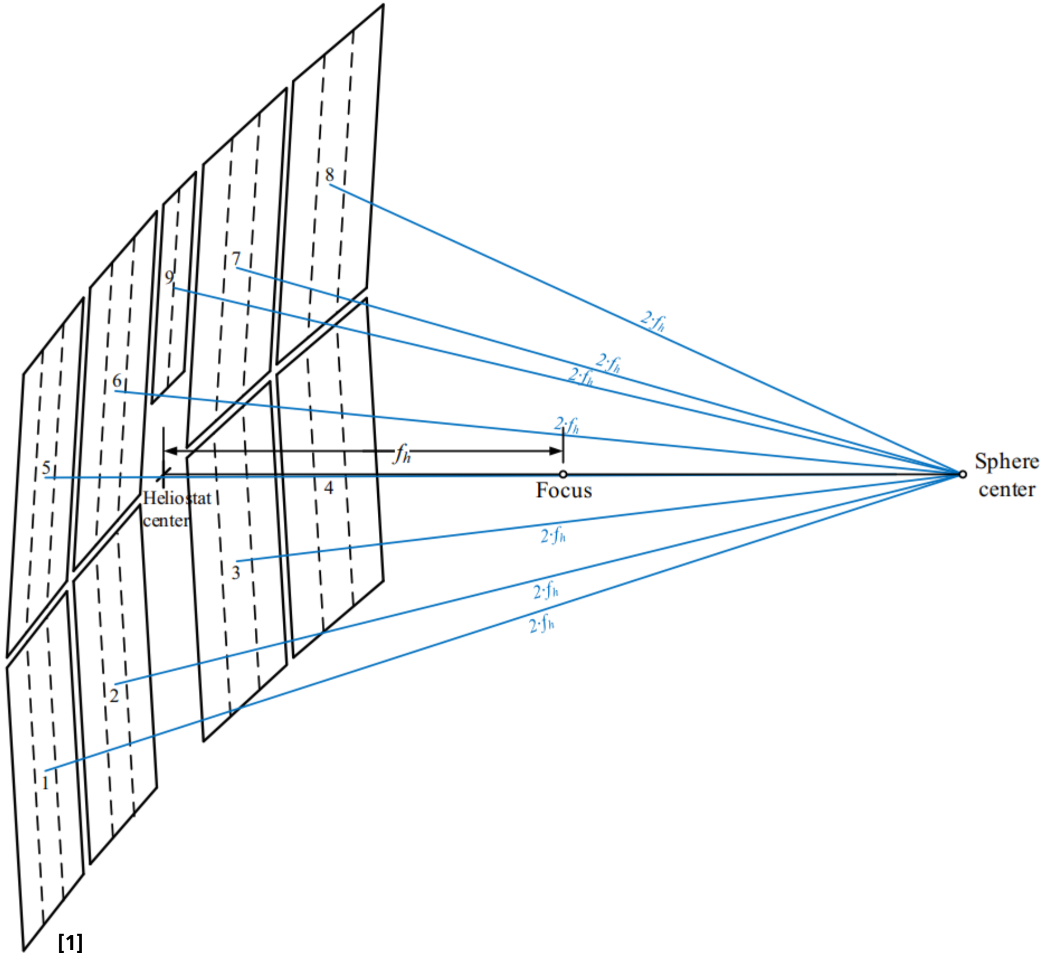
- Impact:
  - Identified as one of the key issues in central receiver power plants [2].
  - Current industry challenge: Lack of specialized field tools for precise and efficient measurement and correction of canting errors.

→ **Research gap**: Development of advanced tools capable of accurately and efficiently measuring heliostat canting

[1] A. Sánchez-González, et al. "Determination of heliostat canting errors via deterministic optimization". Solar Energy 150 (2017) 136-146

[2] M. Mehos M., et al., Concentrating Solar Power Best Practices Study: Tech. rep. National Renewable Energy Lab. (2020)

Introduction
THEMIS solar facility

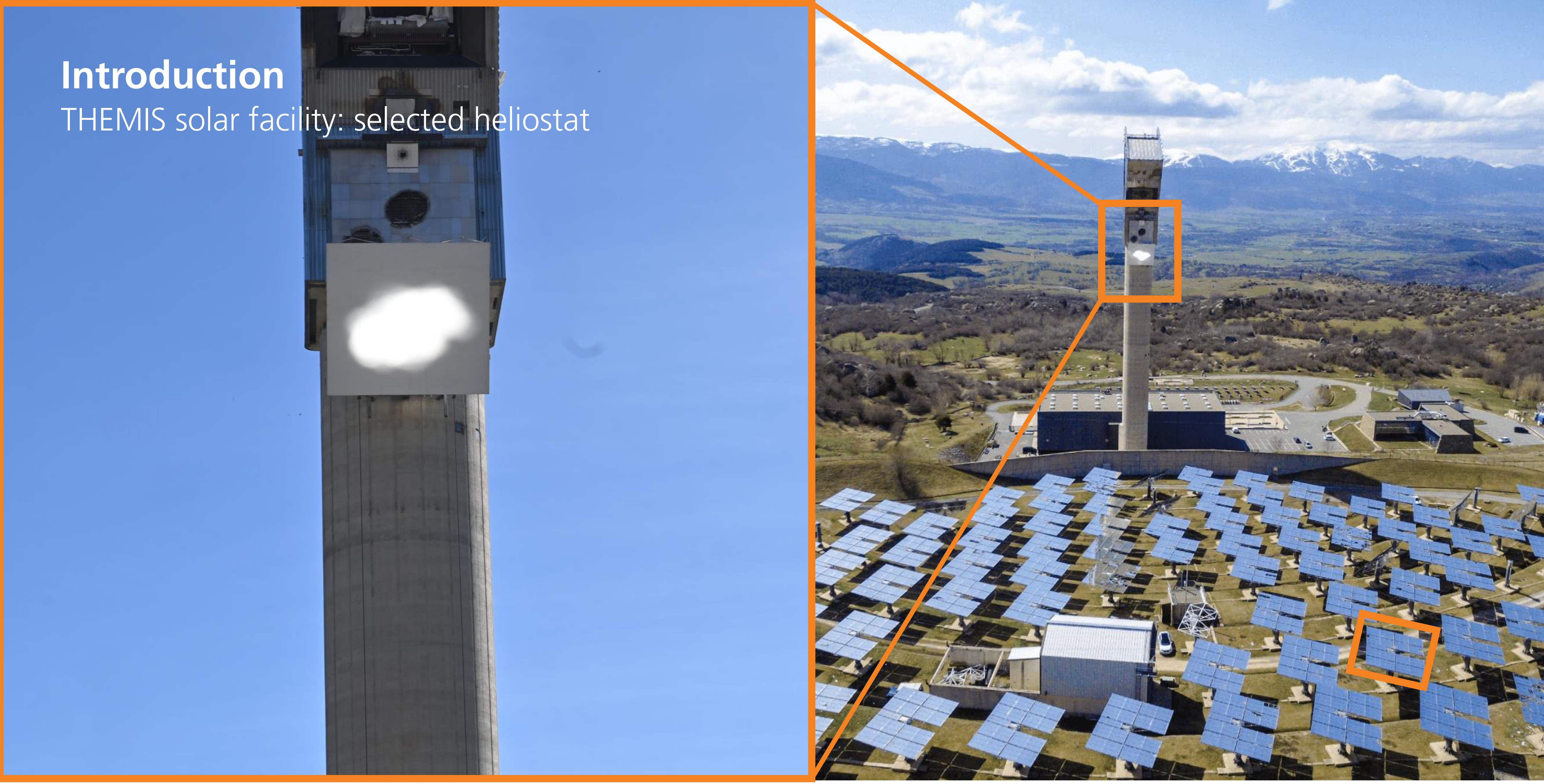


[1]

[1] A. Sánchez-González, et al. "Determination of heliostat canting errors via deterministic optimization". Solar Energy 150 (2017) 136-146

Introduction

THEMIS solar facility: selected heliostat



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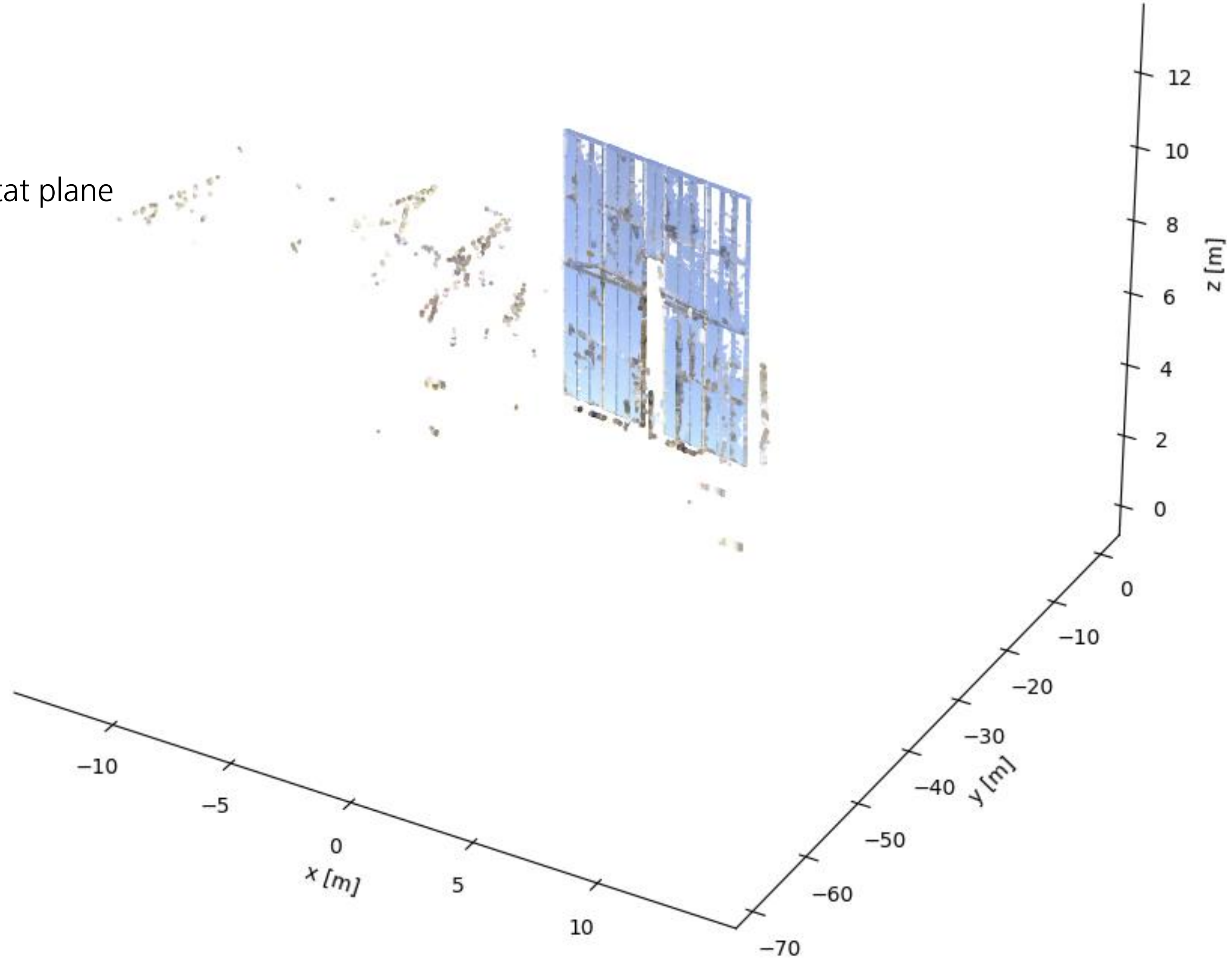
FARO
FOCUS

Method

Data proccessing and filtering

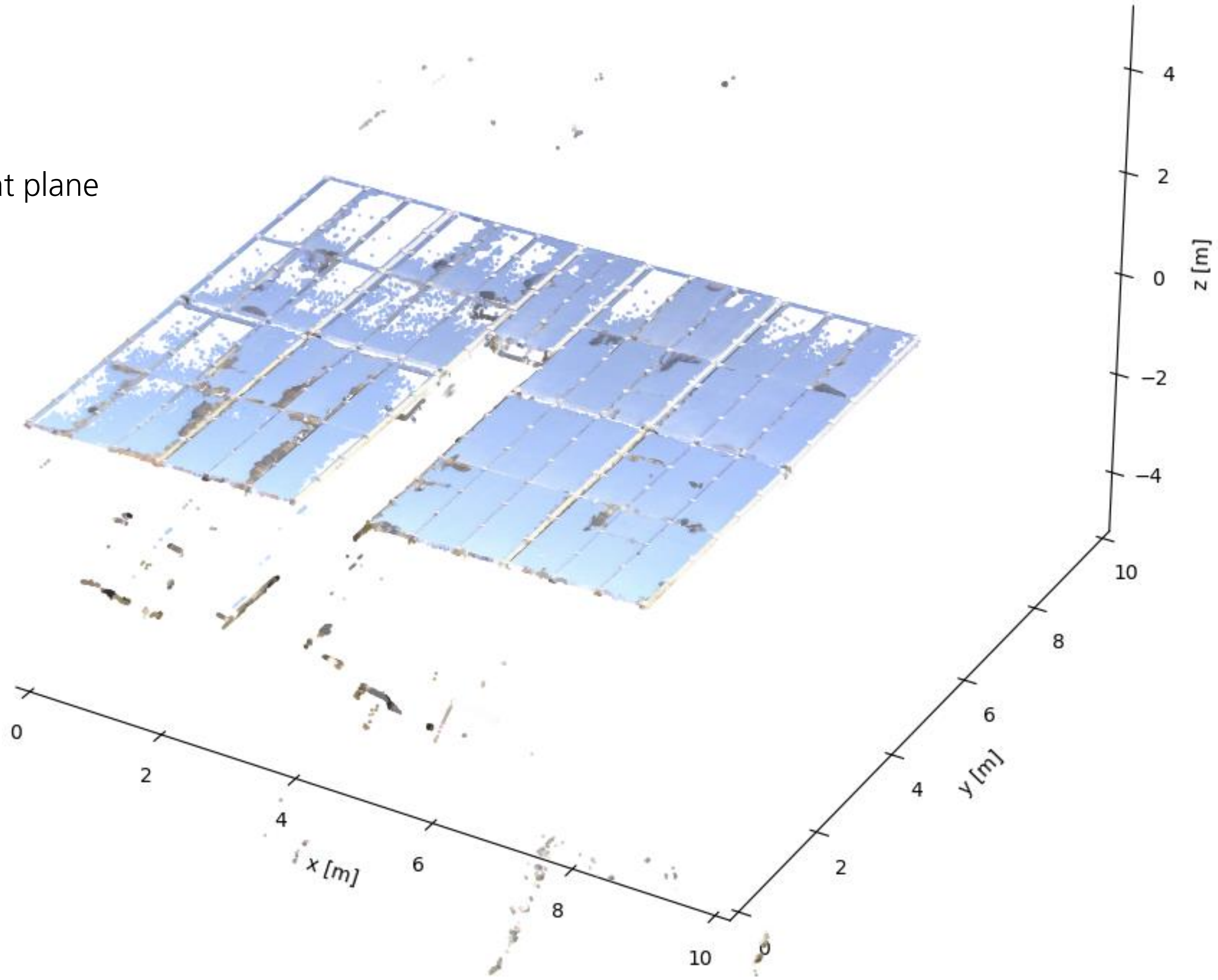
1. Approximate coordinate transformation to heliostat plane



Method

Data proccessing and filtering

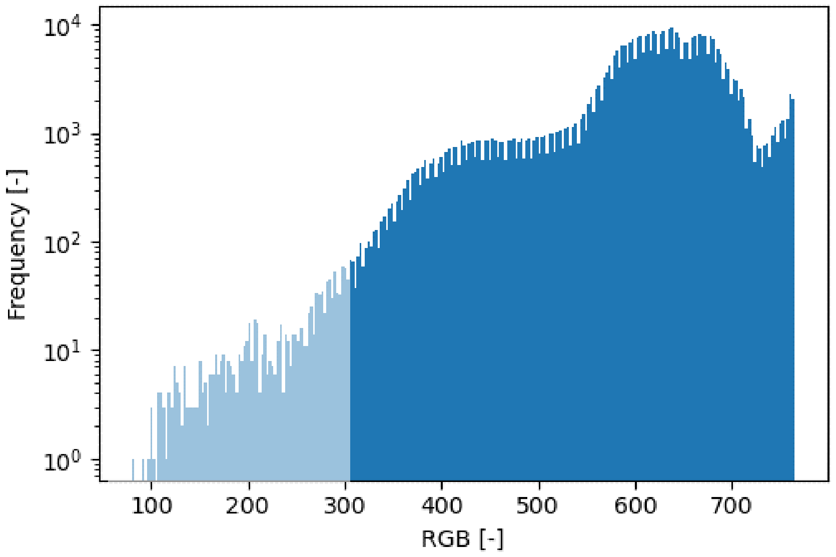
1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass

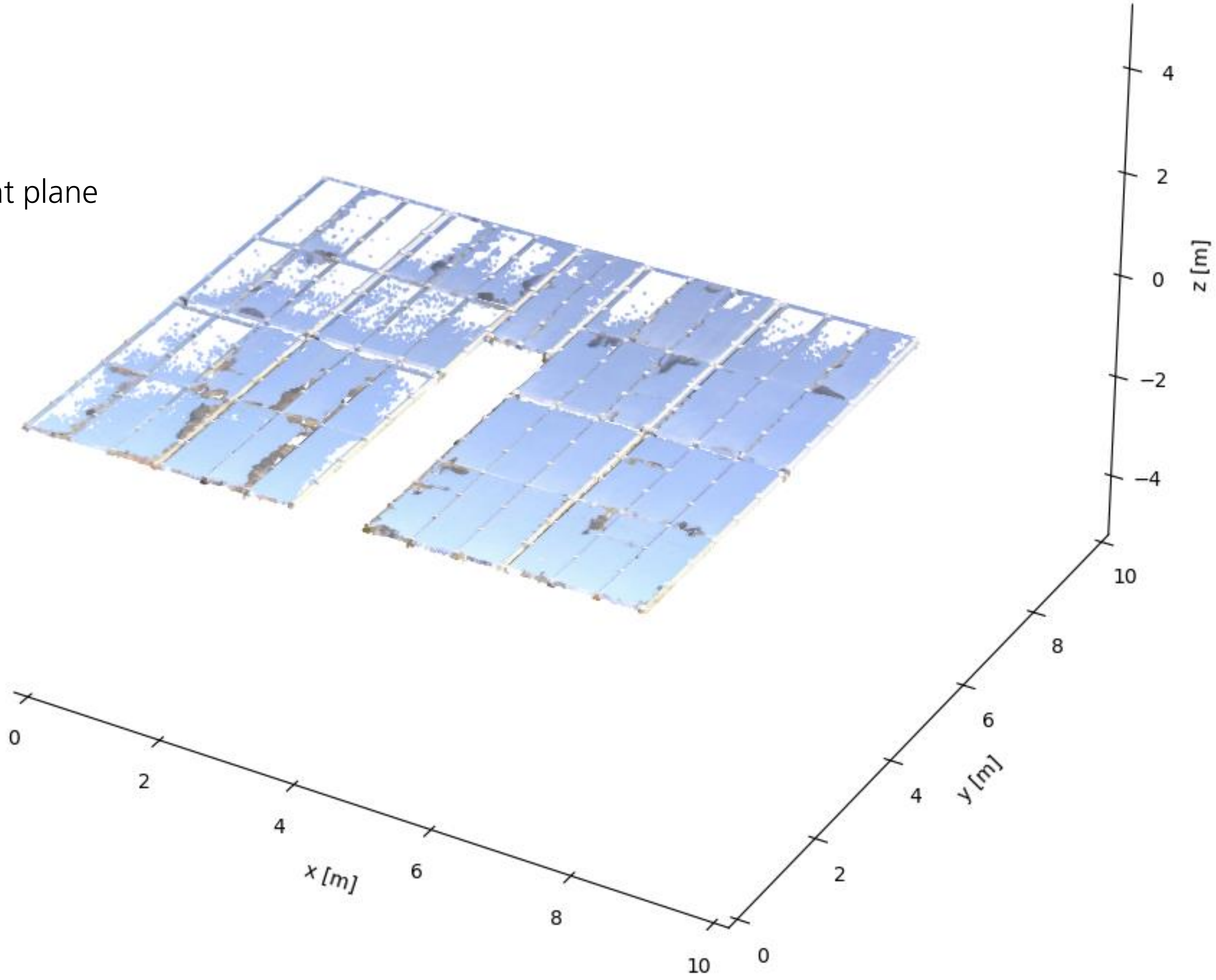


Method

Data proccessing and filtering

1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass
3. Remove points with low VIS brightness (from RGB)





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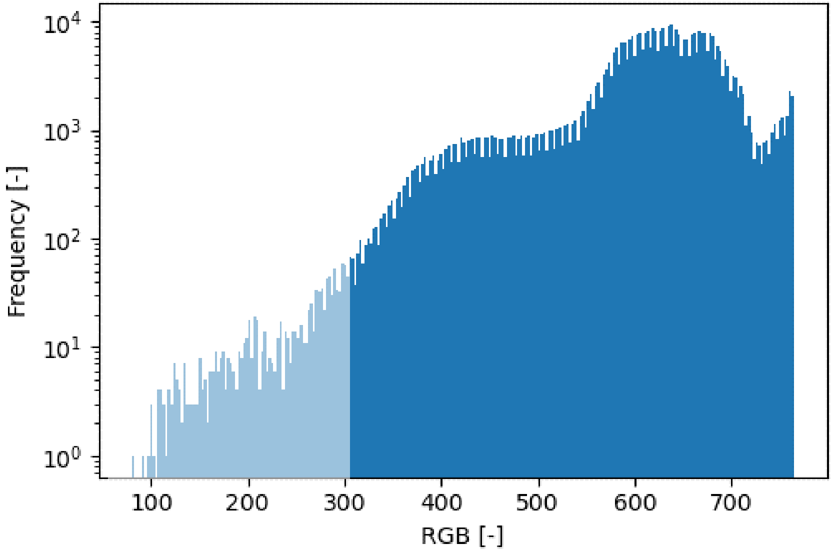
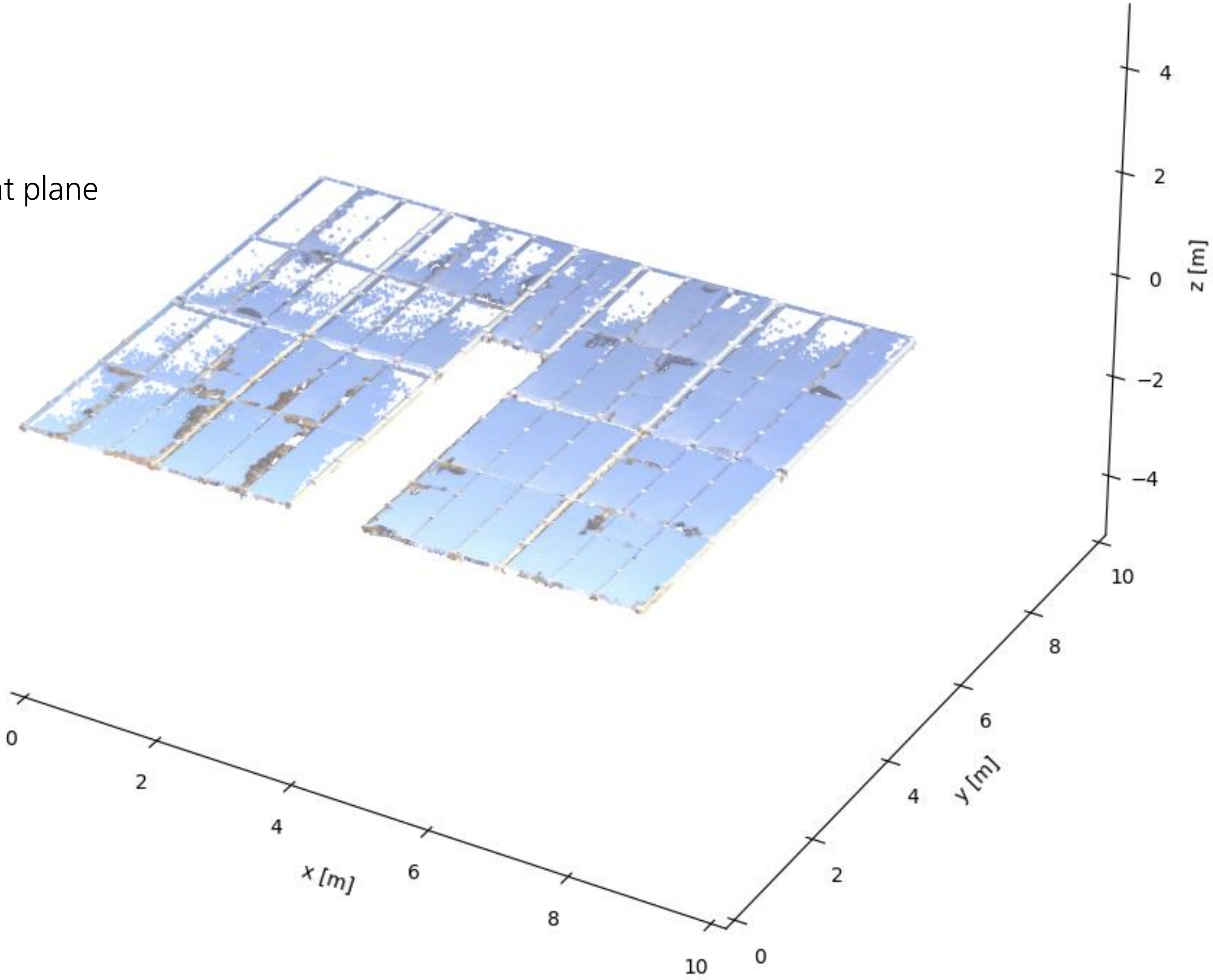
Method

Data proccessing and filtering

1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass
3. Remove points with low VIS brightness (from RGB)
4. Fit plane





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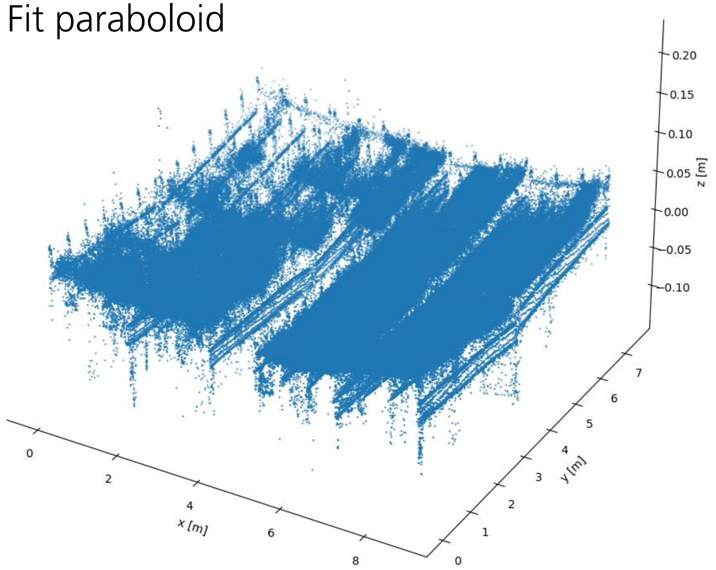
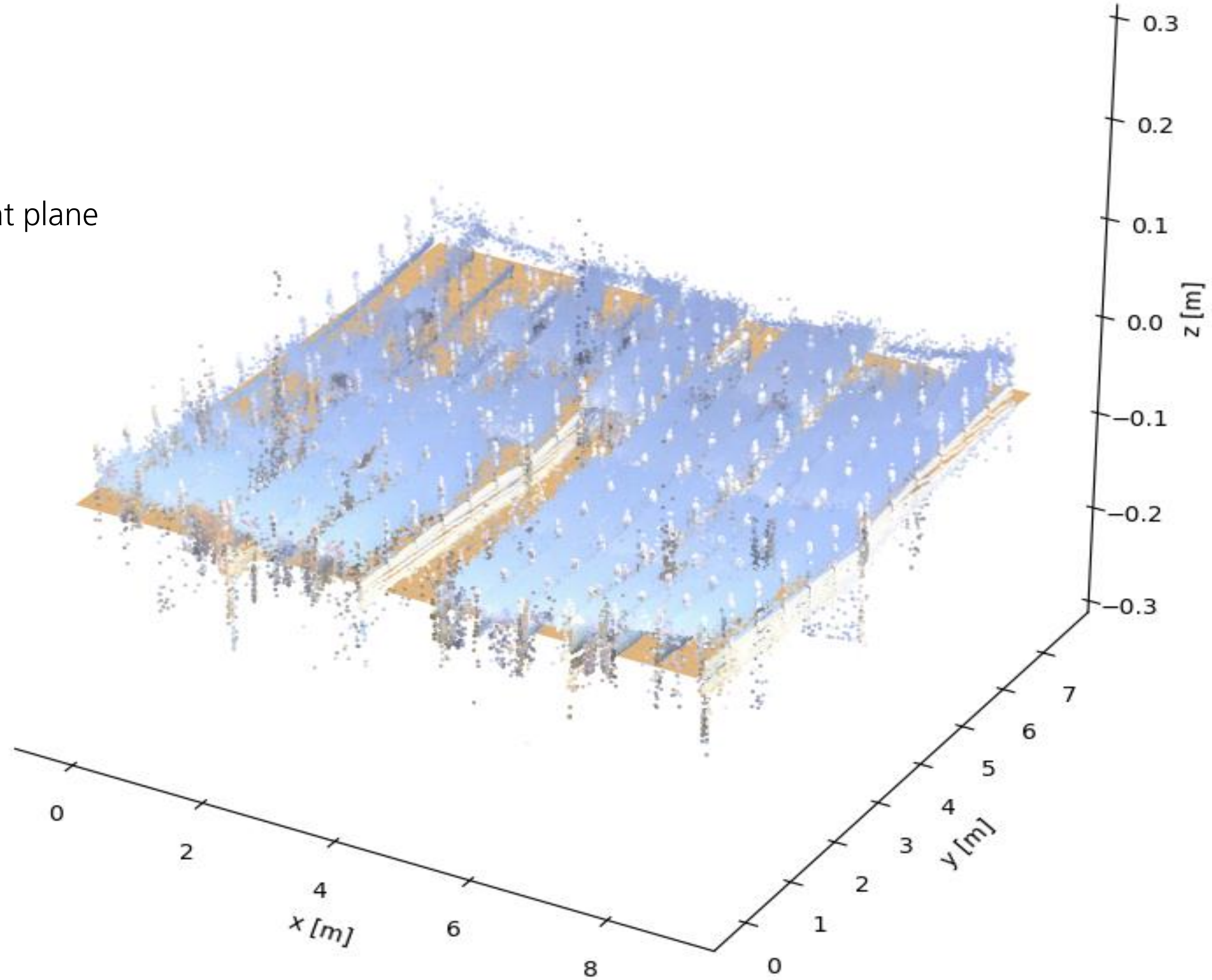
Method

Data proccessing and filtering

1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass
3. Remove points with low VIS brightness (from RGB)
4. Fit plane
5. Fit paraboloid

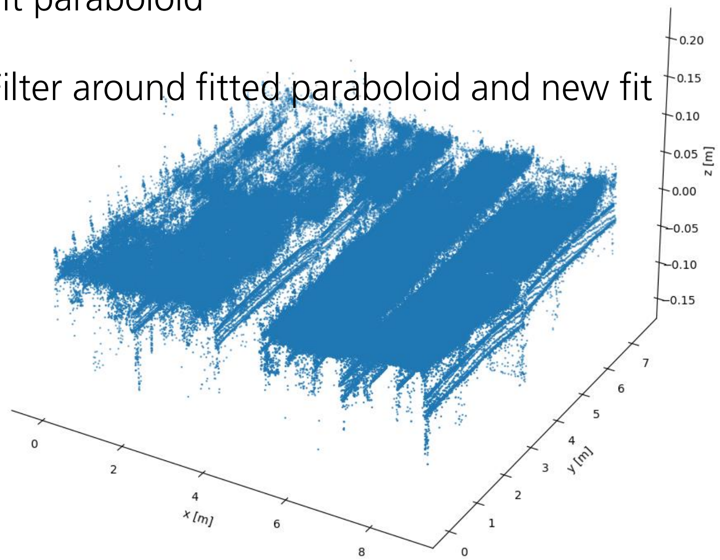


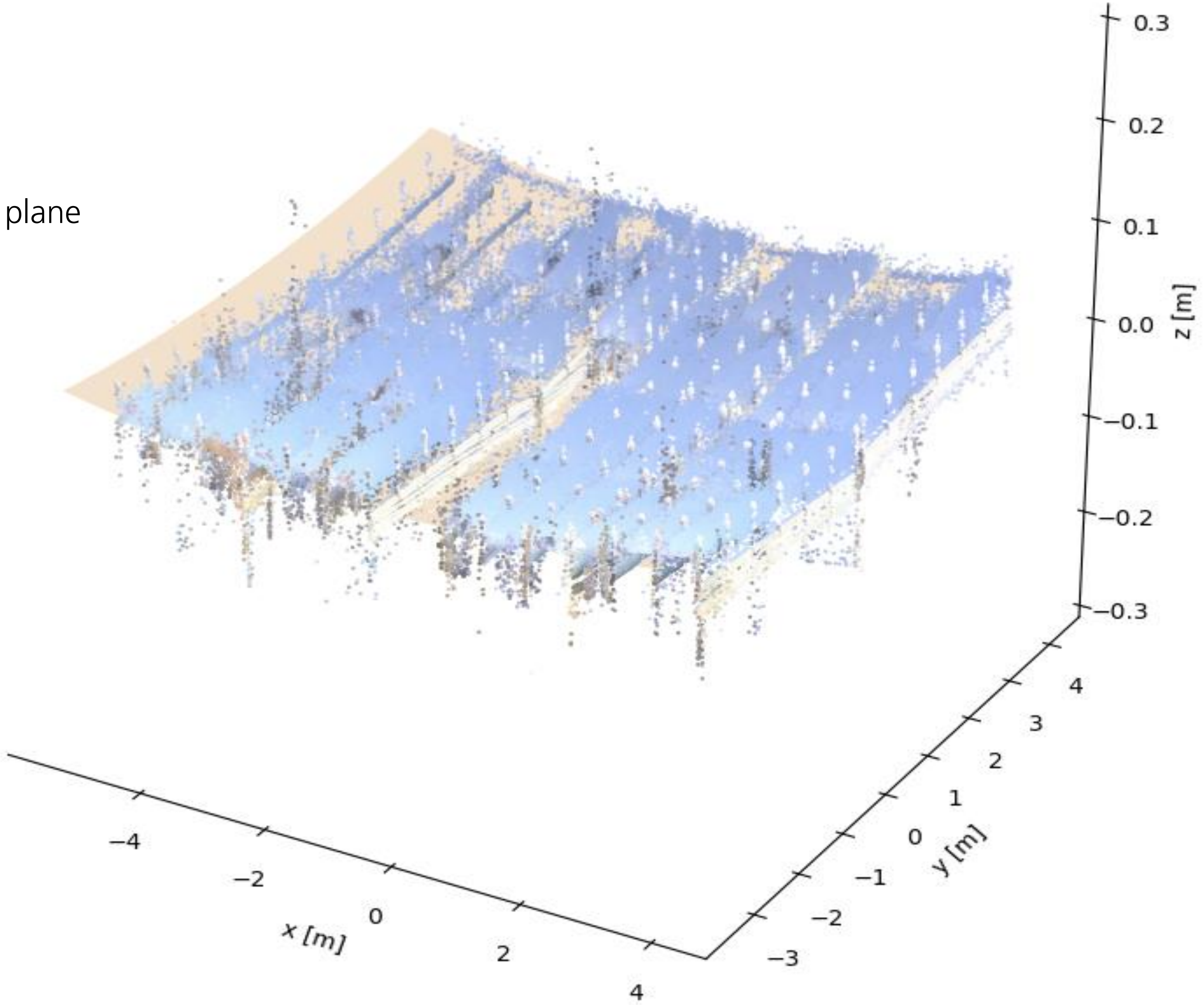


Method

Data proccessing and filtering

1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass
3. Remove points with low VIS brightness (from RGB)
4. Fit plane
5. Fit paraboloid
6. Filter around fitted paraboloid and new fit





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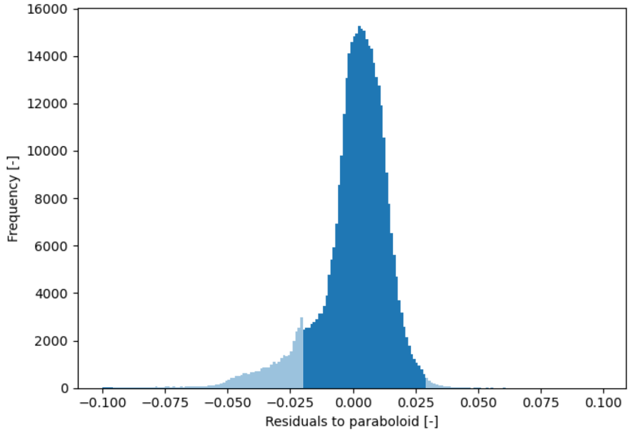

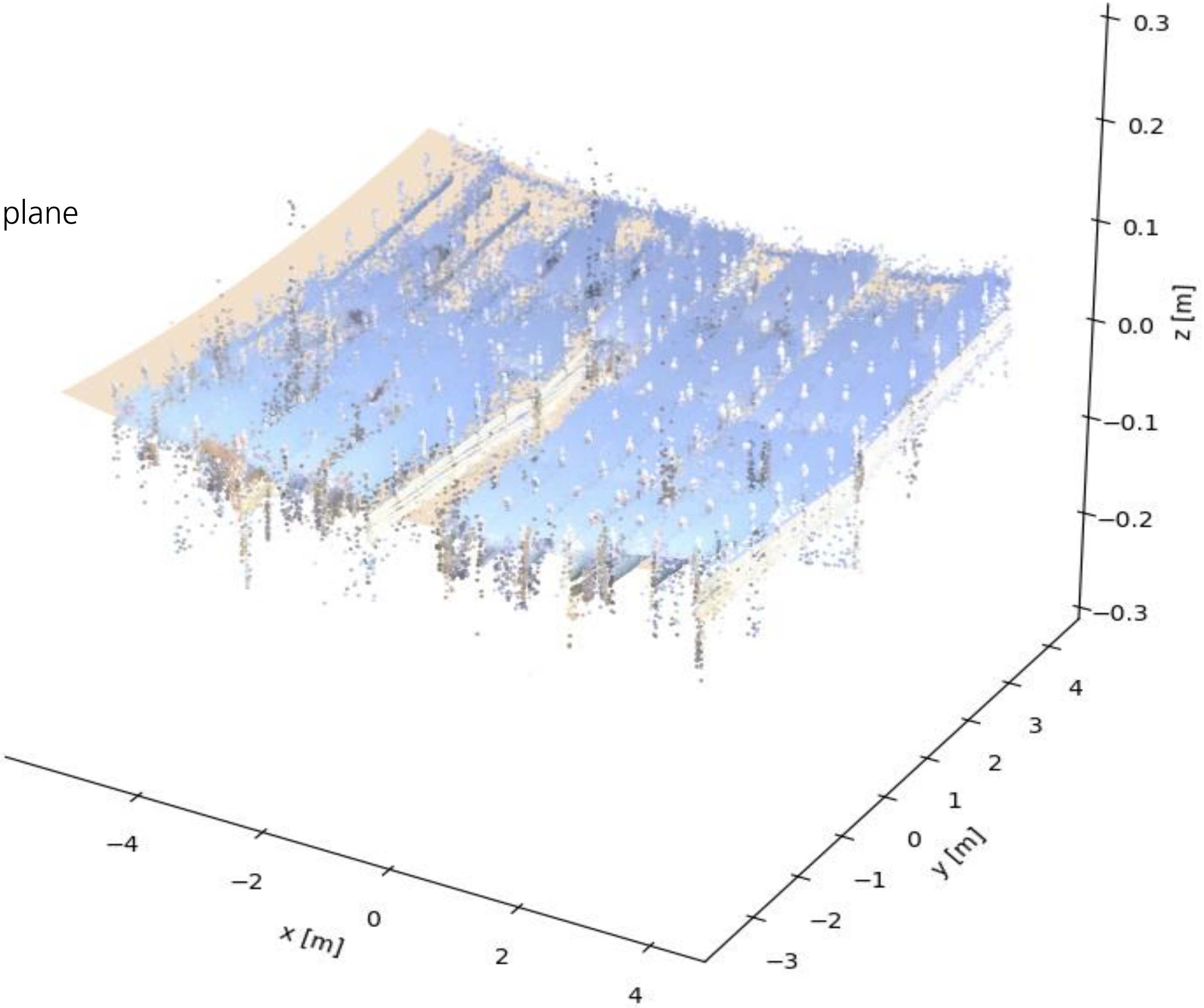

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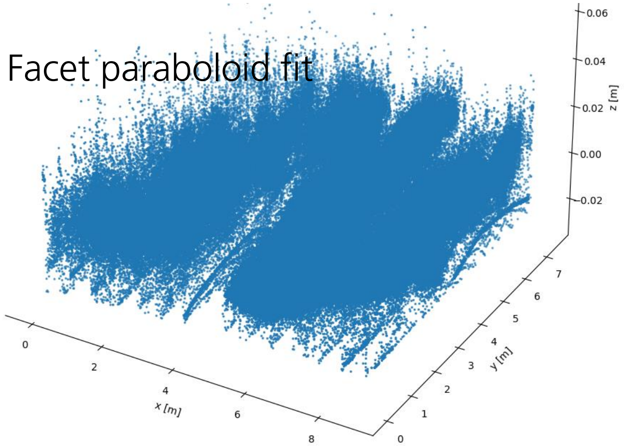
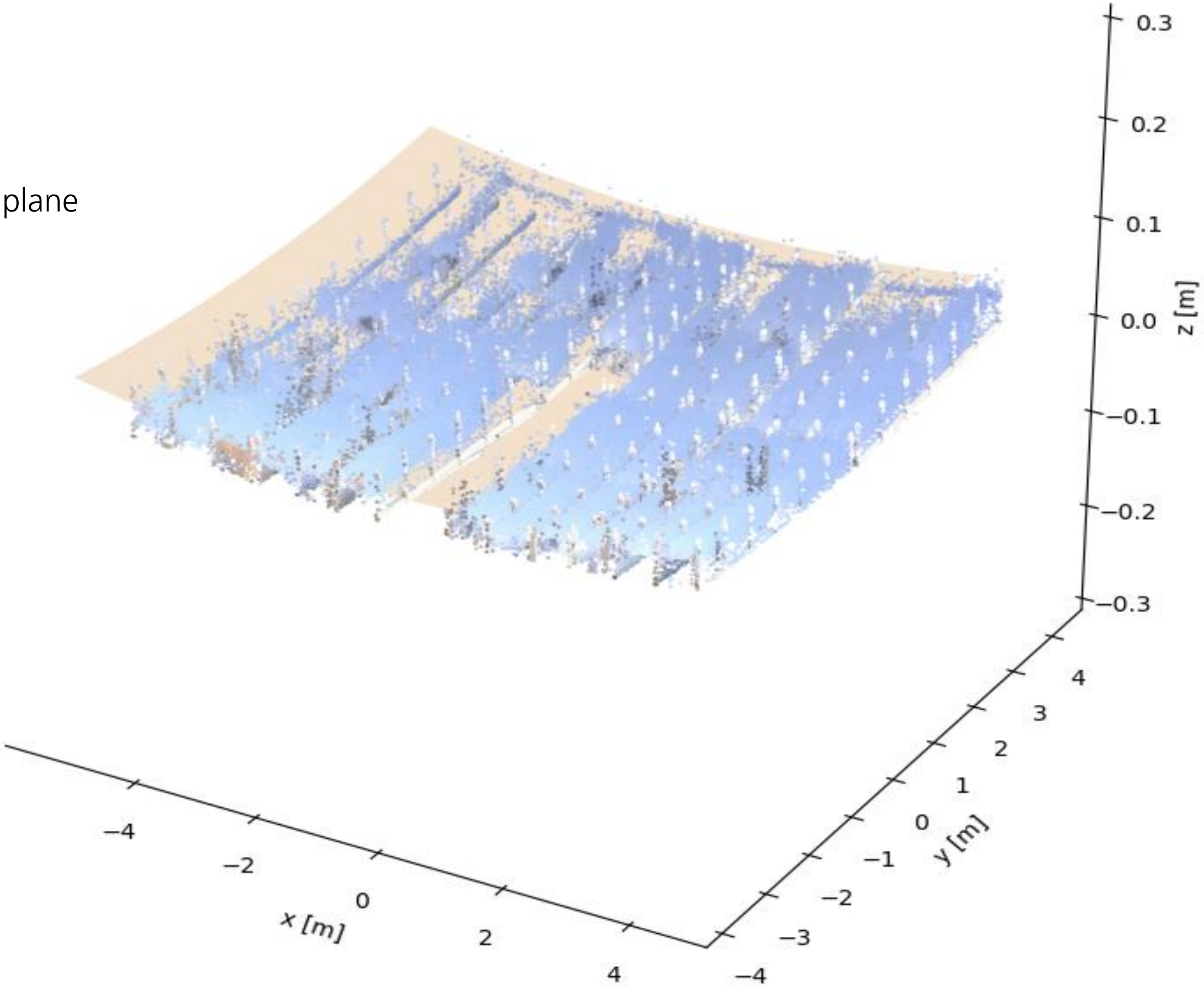
Method

Data proccessing and filtering

1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass
3. Remove points with low VIS brightness (from RGB)
4. Fit plane
5. Fit paraboloid
6. Filter around fitted paraboloid and new fit
7. Facet paraboloid fit





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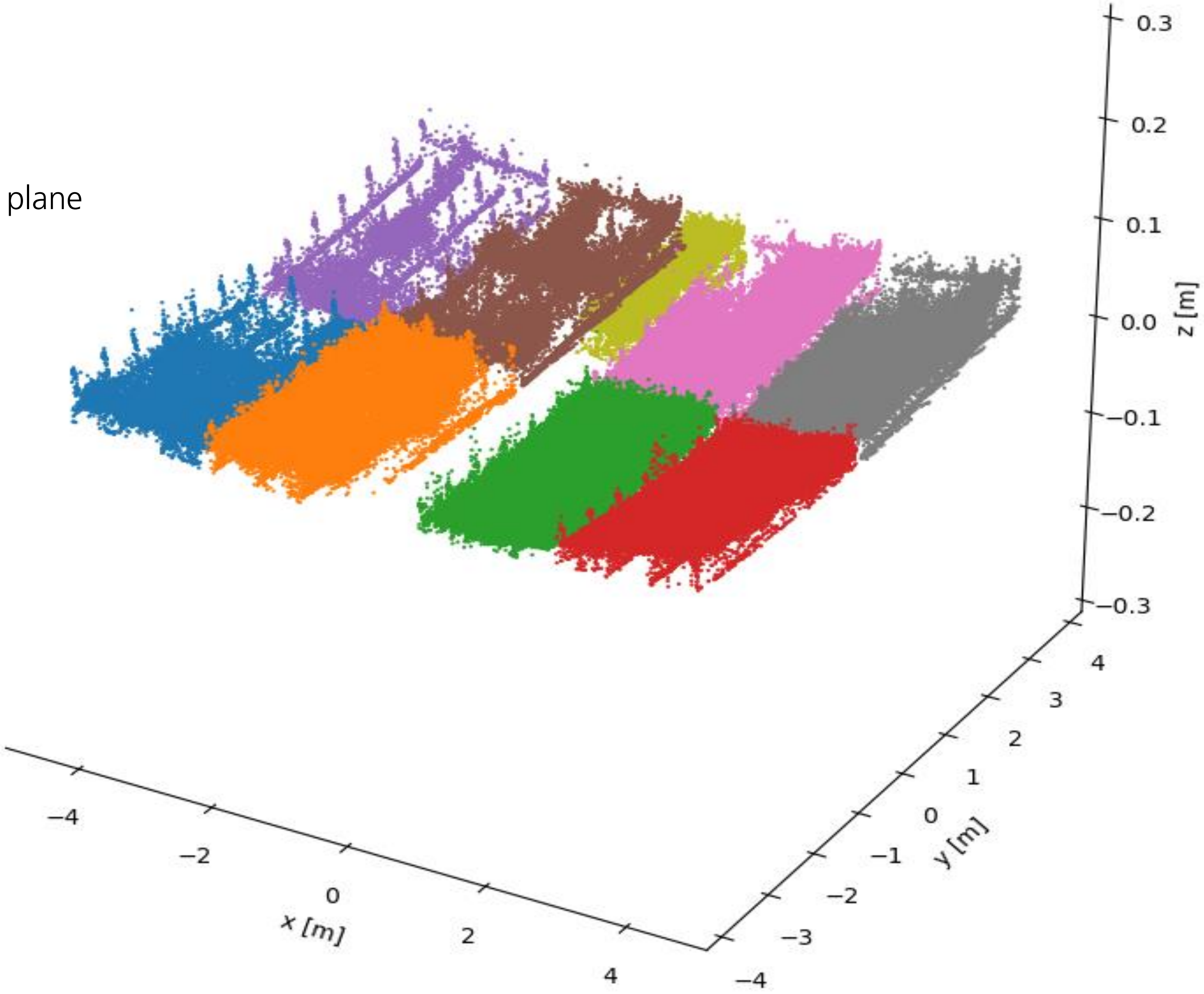
Method

Data proccessing and filtering

1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass
3. Remove points with low VIS brightness (from RGB)
4. Fit plane
5. Fit paraboloid
6. Filter around fitted paraboloid and new fit
7. Facet paraboloid fit



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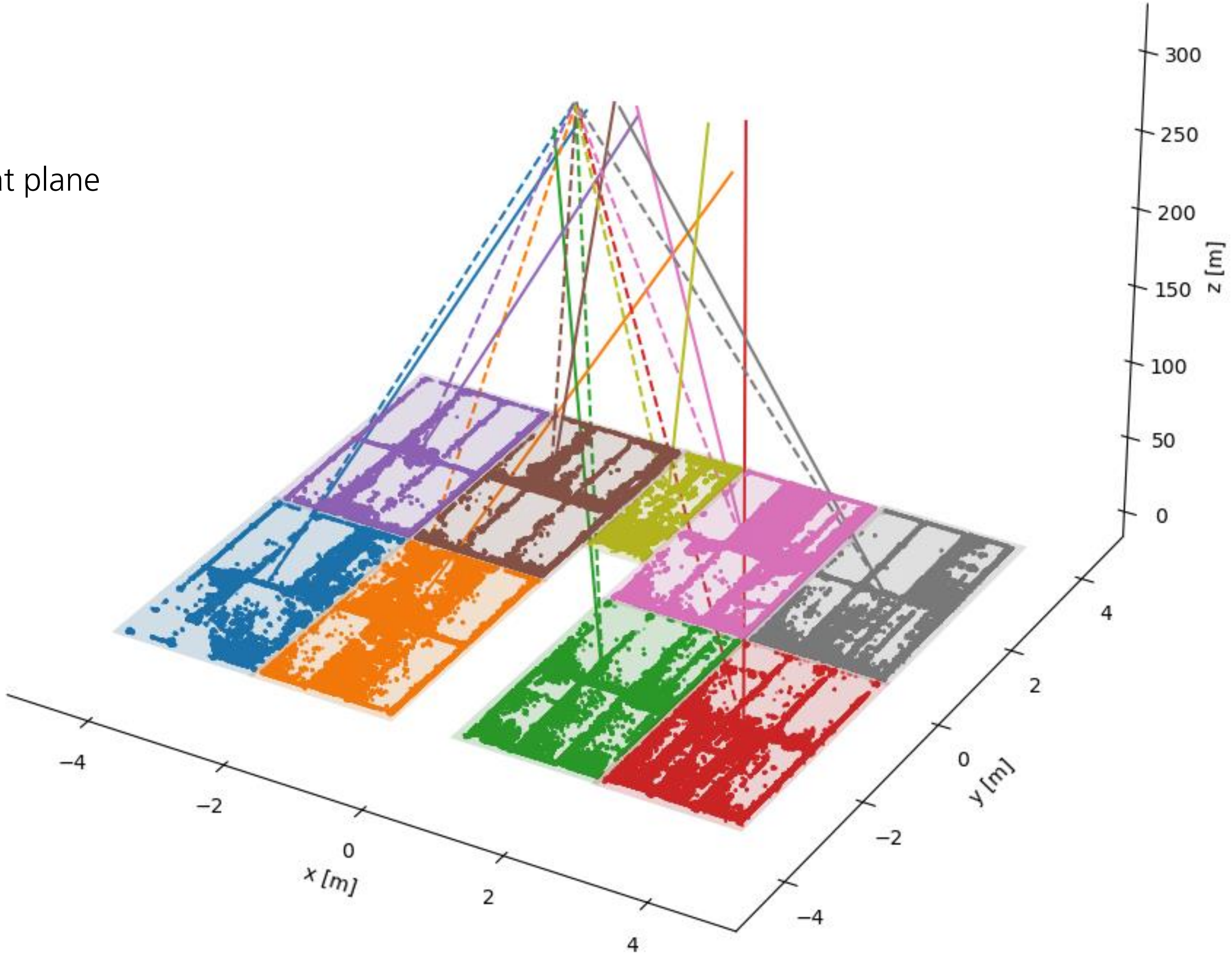
Method

Data proccessing and filtering

1. Approximate coordinate transformation to heliostat plane
2. Filter around center of mass
3. Remove points with low VIS brightness (from RGB)
4. Fit plane
5. Fit paraboloid
6. Filter around fitted paraboloid and new fit
7. Facet paraboloid fit
8. Facet normal vector comparison with theoretical



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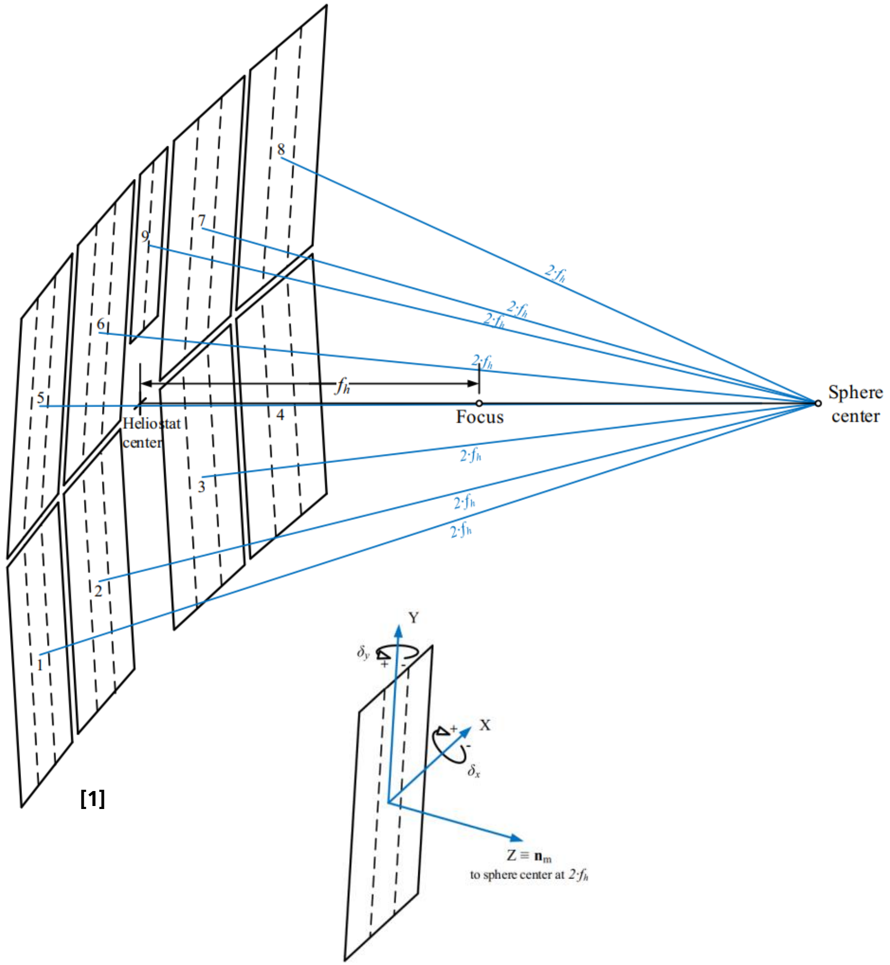
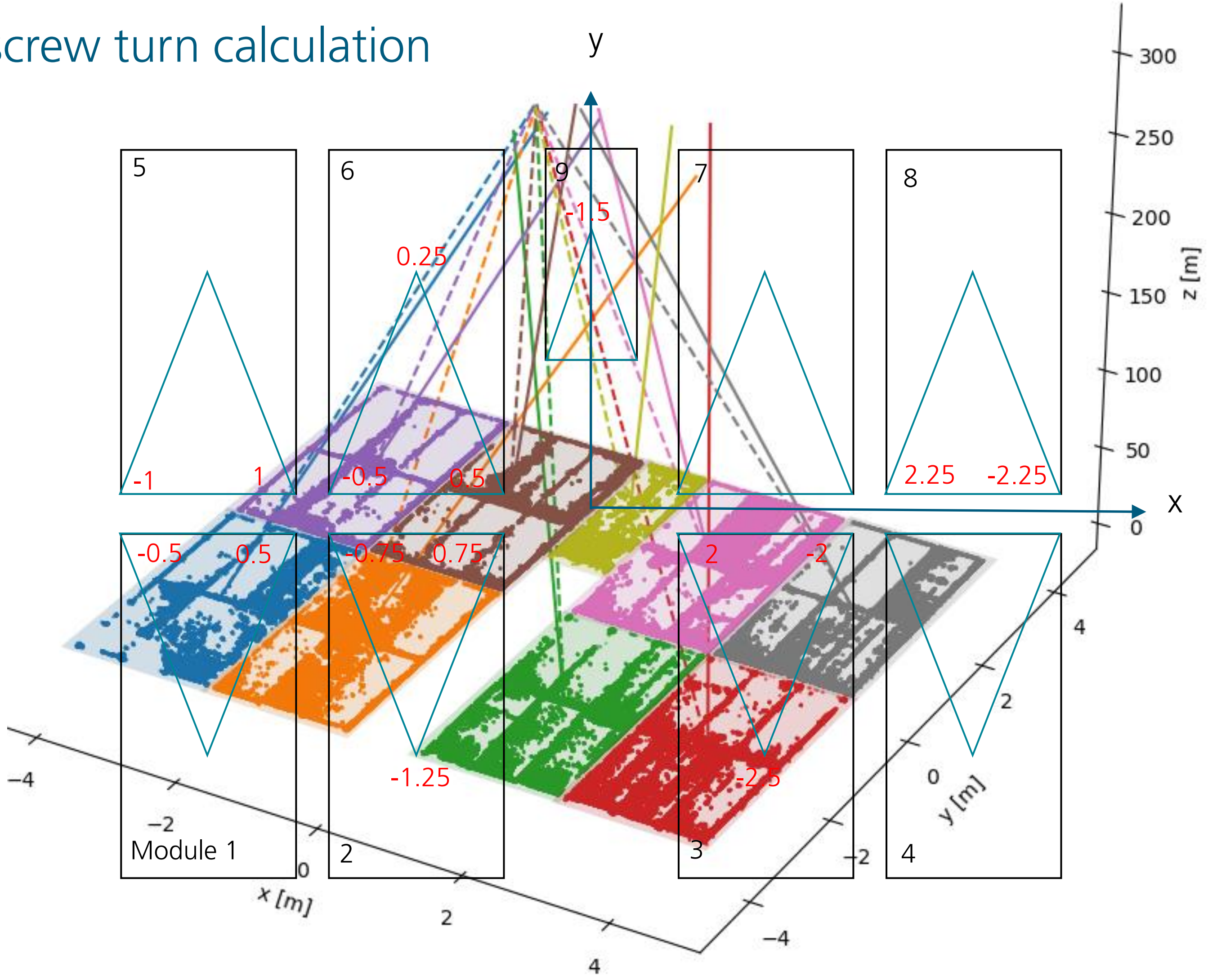
Results

Heliostat canting adjustment: automatic screw turn calculation





[1] A. Sánchez-González, et al. "Determination of heliostat canting errors via deterministic optimization". Solar Energy 150 (2017) 136-146

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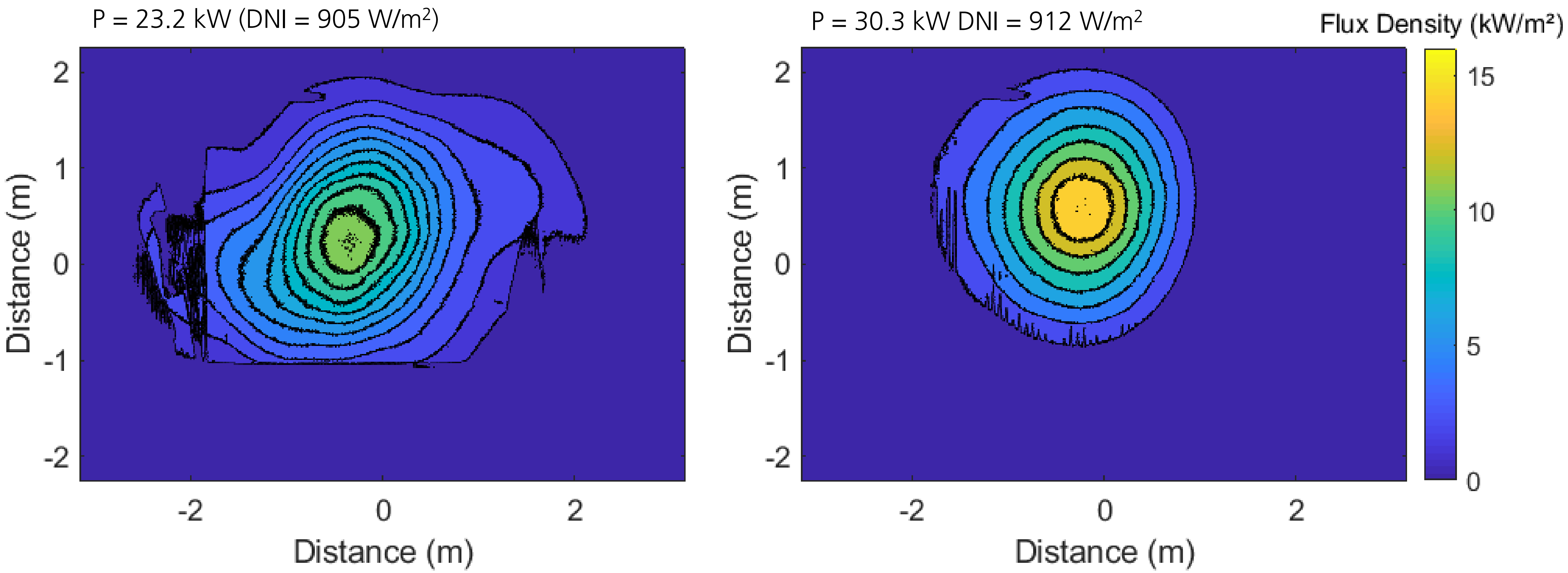
5
-1
1
6
0.25
-0.5
0.5
9
-1.5
8
2.25
-2.25
-0.5
0.5
Module 1
-0.75
0.75
-1.25
2
2
-2
-2.5
3

Results

Flux before vs. after canting error correction



Conclusion

Laser scanning for canting error correction

- Feasibility of laser scanning for fast off-target heliostat canting error correction was demonstrated.
- Accuracy of the method:
  - Mean absolute error of the fitting of facets below 8 mm
  - Uncertainty of canting angles (from fit): 0.03-0.1 mrad
- Heliostats facets with cleanliness lower than 97% could be measured.

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Chapter 5

Outlook

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Outlook

Laser scanning for canting, tracking and cleanliness

- Potential for a fast cleanliness, canting and tracking assessment in the heliostat field
- Room for improvement of accuracy and efficiency/time in further optimization and automatization

→ **Looking forward to discuss projects for such optimization with you**

Thanks for your attention!

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maitane.ferreres.eceiza@ise.fraunhofer.de

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Supported by:

Federal Ministry
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on the basis of a decision
by the German Bundestag

The work was supported by the German Federal Ministry for Economic Affairs and Climate Protection (BMWK) under contract 03EE5065A.

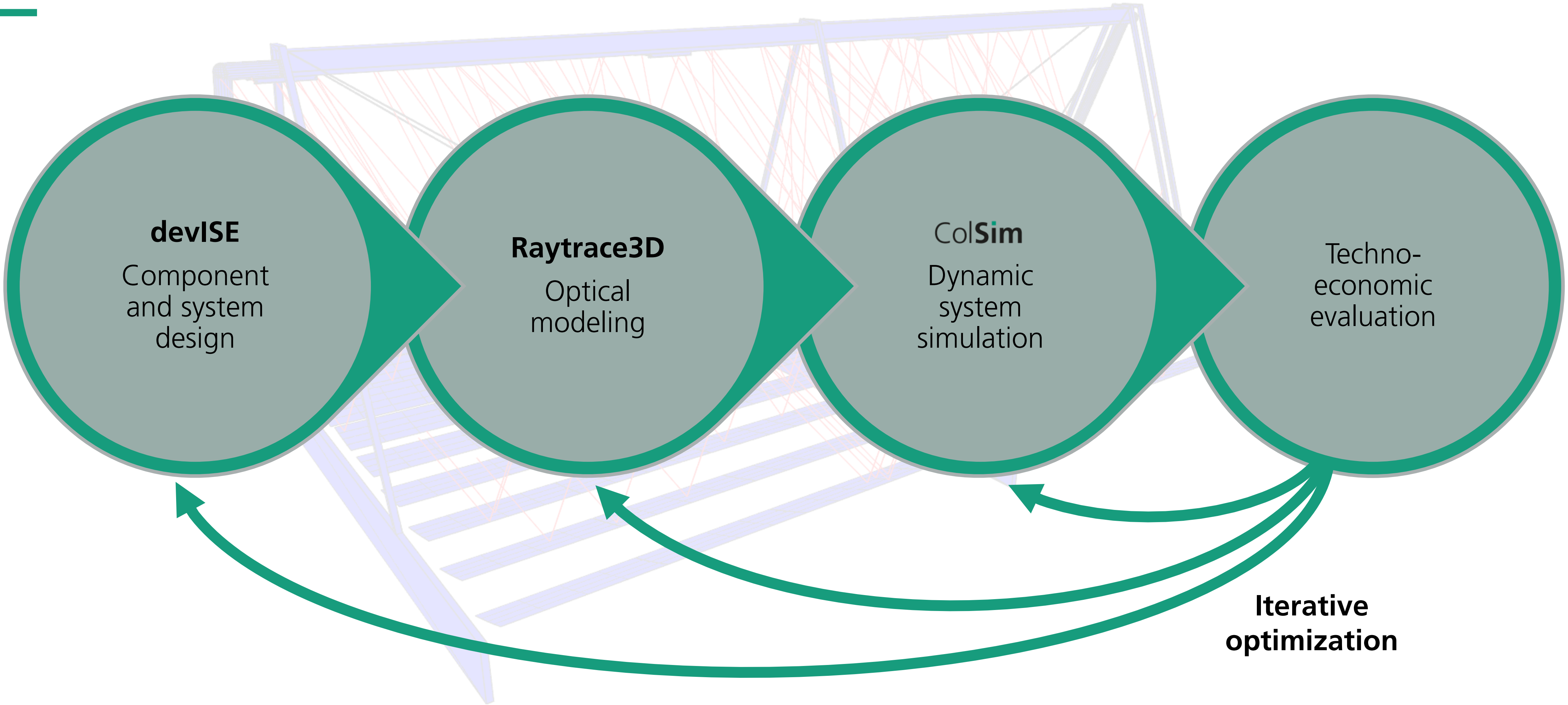
The support is gratefully acknowledged.

Optical Simulation of Concentrating Collectors

Peter Schöttl
SFERA-III Training for Industries: CST4SHIP
Freiburg, Nov 7, 2023
www.ise.fraunhofer.de

Digital CST toolchain

Design, simulation and optimization



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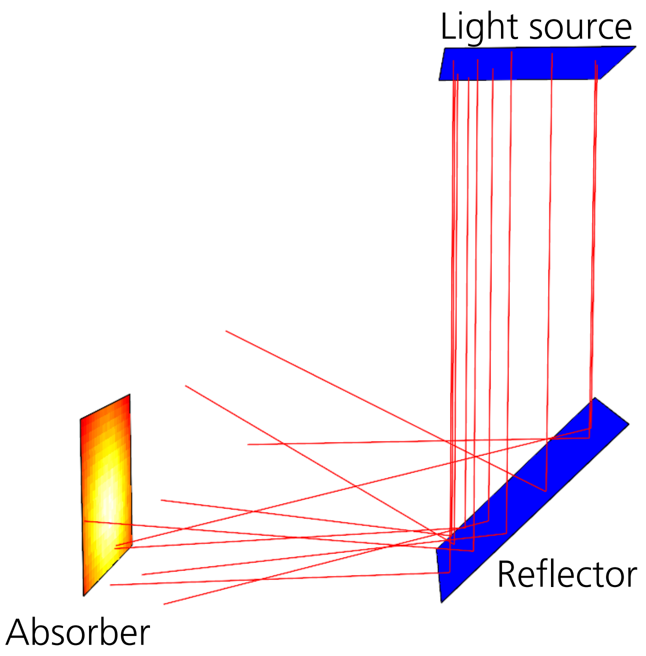
Optical Simulation of Concentrator Optics with Raytrace3D

Optical simulation of concentrator optics with Raytrace3D

Overview

Monte-Carlo forward ray tracing



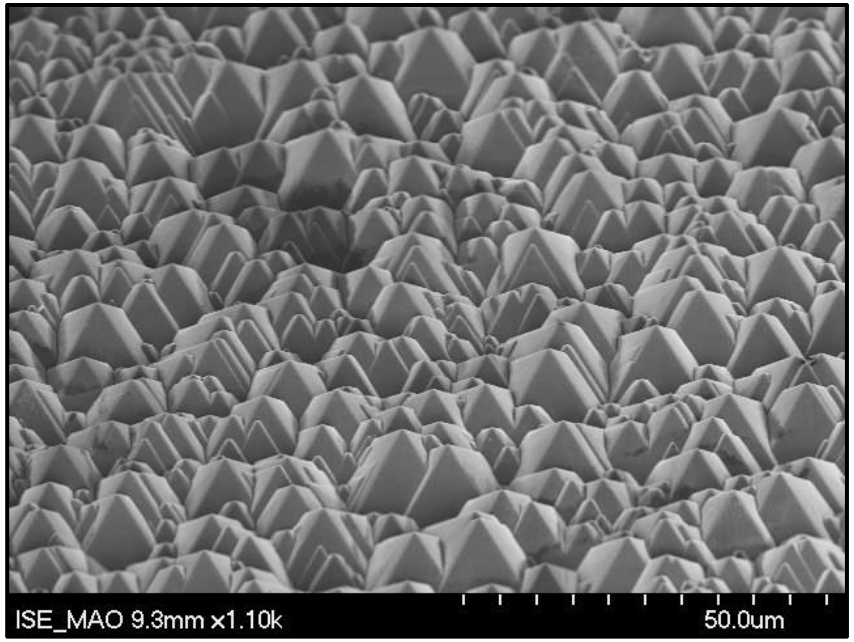
Features

- Comprehensive library of geometries/materials/light sources
  - detailed modeling of various solar applications
- Fully object-oriented
  - readily extensible
- Number crunching in C++ and pre/postprocessing in Python
  - Fast and versatile
- Parallelized
  - run on simulation servers

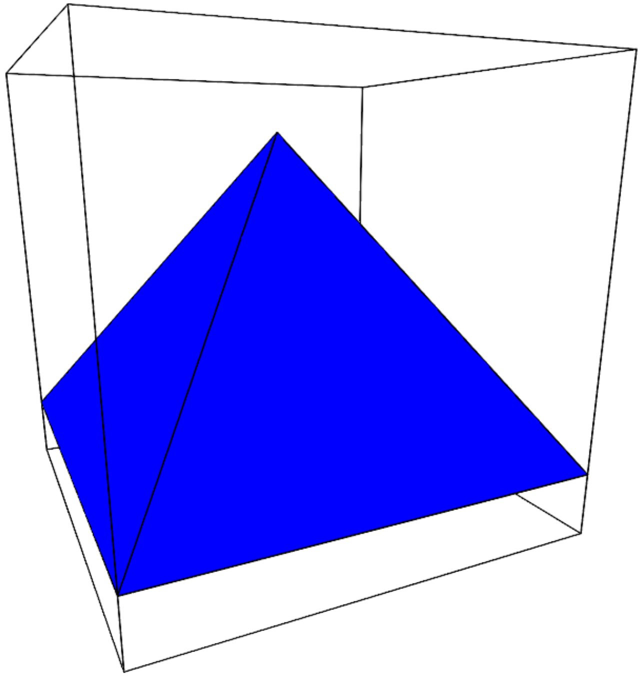
Schöttl et al., 2022, Raytrace3D by Fraunhofer ISE, https://www.ise.fraunhofer.de/content/dam/ise/de/downloads/pdf/raytrace3d.pdf

Optical simulation of concentrator optics with Raytrace3D

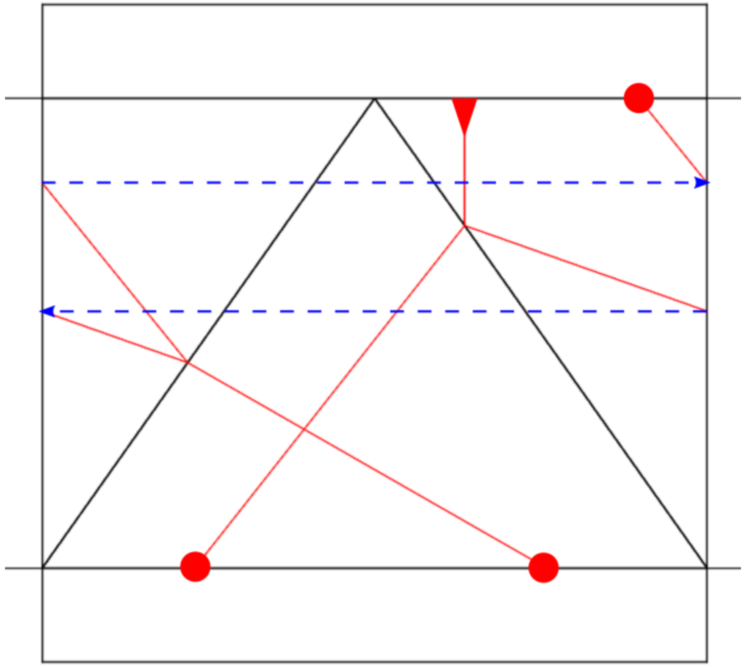
Applications: micro-textured surfaces



Micro-textured anti-reflective surface with randomly distributed pyramid structures



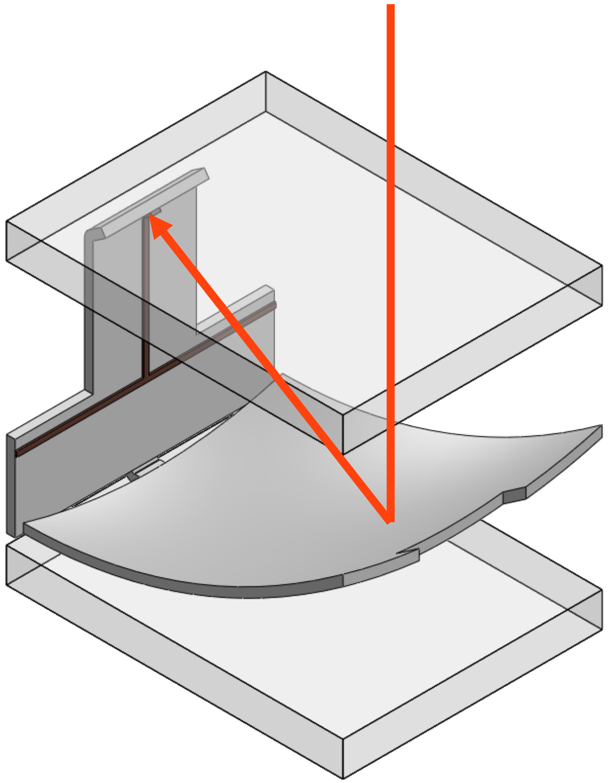
Ray tracing model with teleport walls



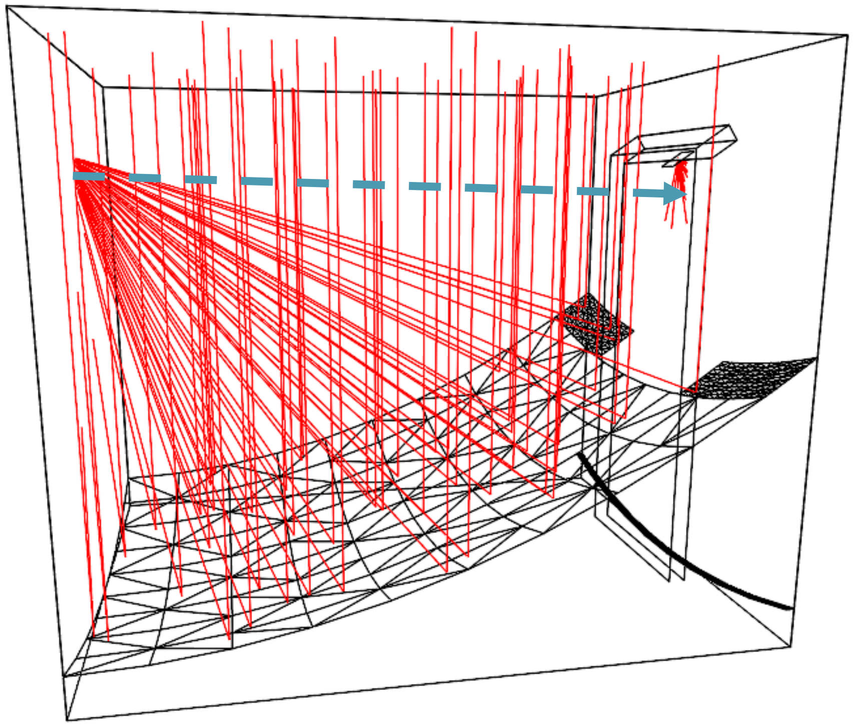
Single ray path

Optical simulation of concentrator optics with Raytrace3D

Applications: CPV concentrator



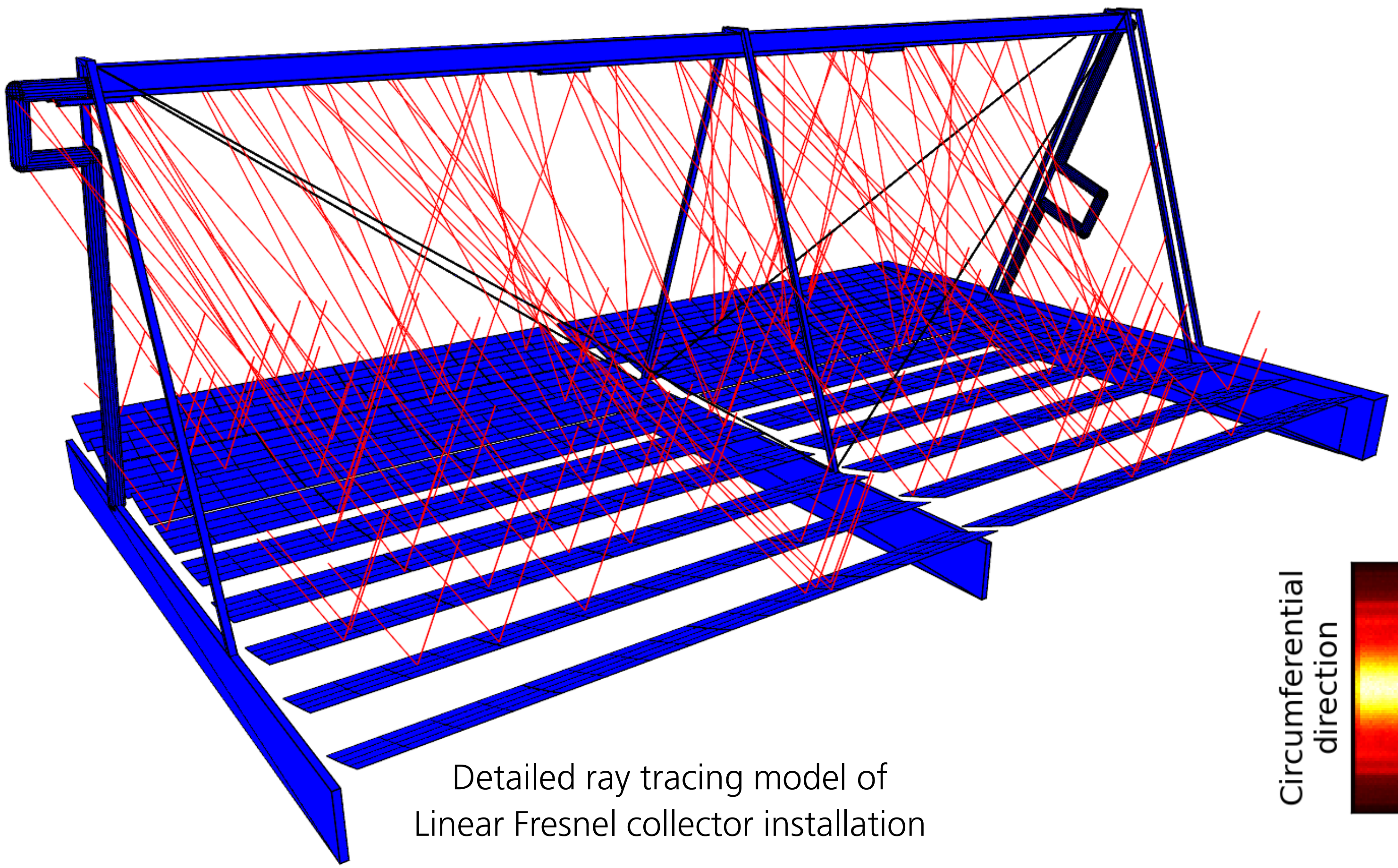
CPV collector based on parabolic mirror



Ray tracing model with teleport walls

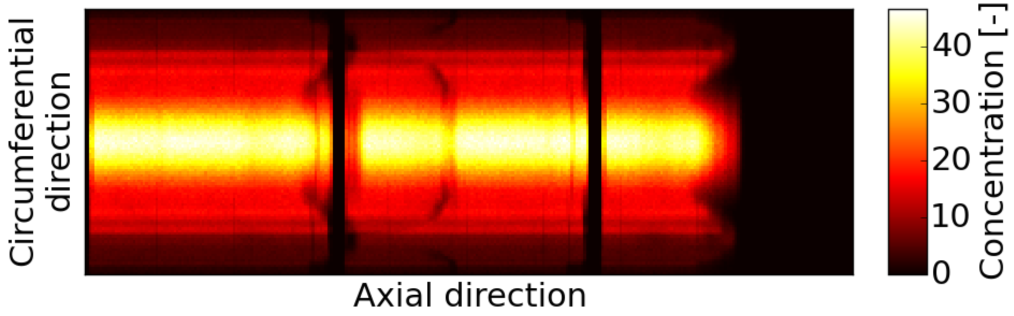
Optical simulation of concentrator optics with Raytrace3D

Applications: Linear Fresnel collector



Detailed ray tracing model of
Linear Fresnel collector installation

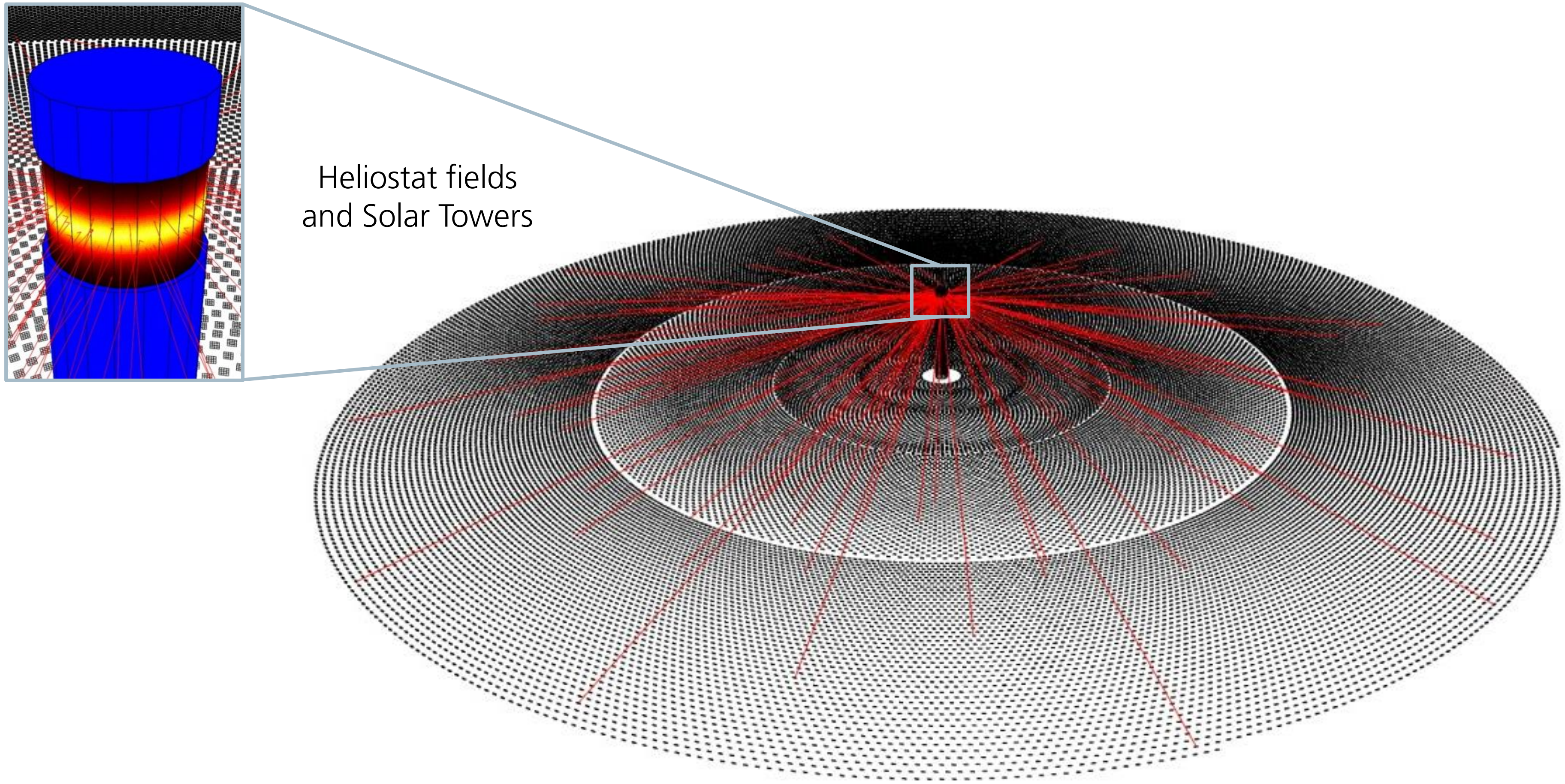
Concentration maps on absorber tube

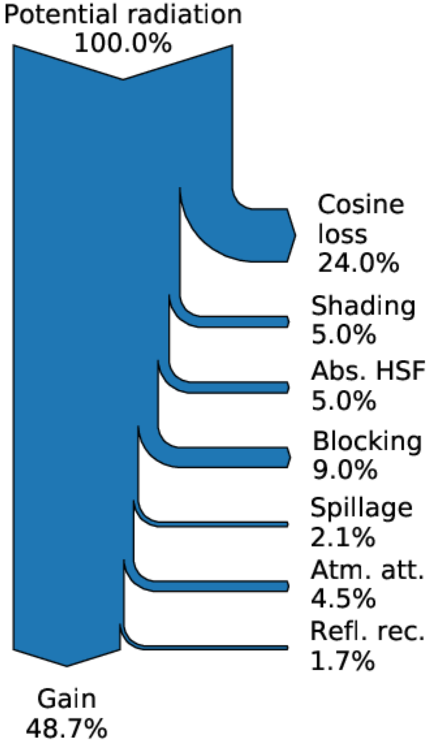


Optical simulation of concentrator optics with Raytrace3D

Applications: Solar Tower heliostat fields

Heliostat fields
and Solar Towers





Detailed loss analysis for a
large-scale heliostat field
based on annual simulation

Modeling of Reflectors/Mirrors

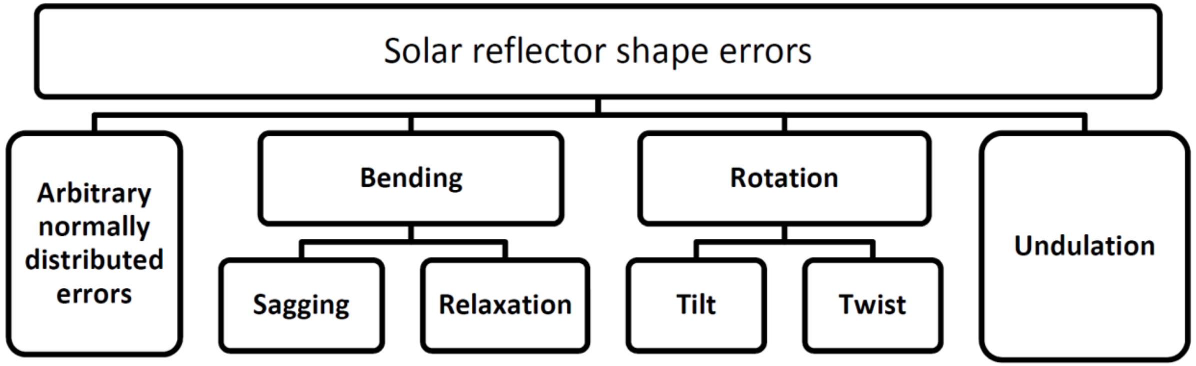
Reflectors/mirrors

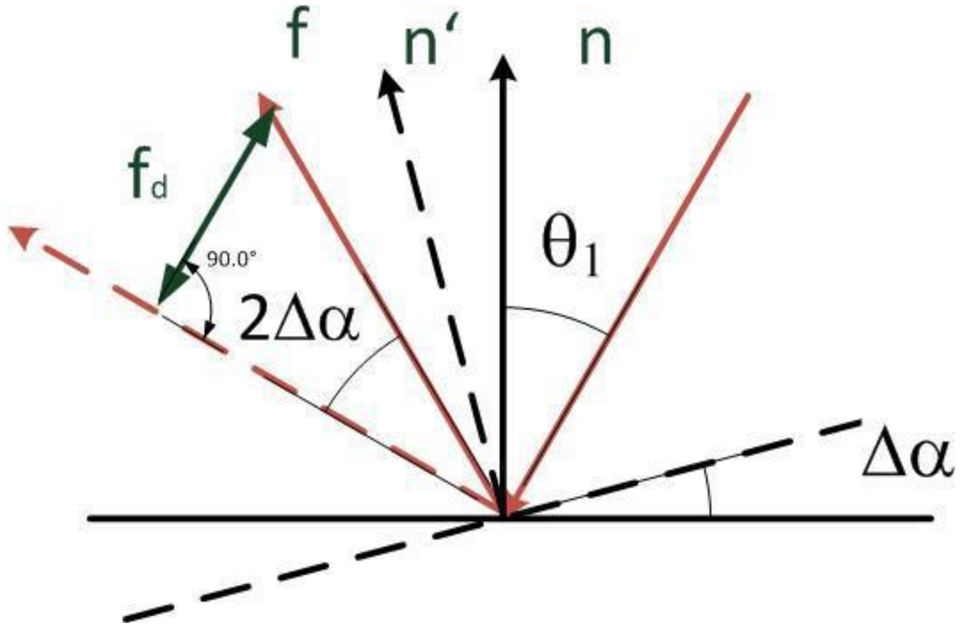
Scattering and slope deviations

- Different sources for shape errors
- Deviation of reflected ray is twice the slope deviation (2D)

- Important finding: angular deviations of the surface normal are much more relevant than positional deviations of the surface

- Models for surface slope deviations
  - Gaussian, radially symmetric distribution (*sigma* parameter)
  - User-defined, radially symmetric distribution (look-up table)
  - Local slope deviations mapped onto the ideal surface





Heimsath et al., Linear Fresnel collector mirrors - Measured systematic surface errors and their impact on the focal line, 2019, https://doi.org/10.1063/1.5117612.

Reflectors/mirrors

Scattering and slope deviations

Ray tracing with local slope deviations – effects on the focal line

- Measured slope deviations
- Slope deviations according to model function fitted to measurements

$$sd_{x,i} = \frac{\partial z_i}{\partial x_{\mathrm{mod},i}} - \frac{\partial z_i}{\partial x_{id,i}} \quad \text{with} \quad \frac{\partial z_i}{\partial x_{\mathrm{mod},i}} = a_0 + a_1 x_i + a_2 y_i + a_3 x_i^3$$

$$sd_{y,i} = \frac{\partial z_i}{\partial y_{\mathrm{mod},i}} - \frac{\partial z_i}{\partial y_{id,i}} \quad \text{with} \quad \frac{\partial z}{\partial y_{\mathrm{mod},i}} = a_4 + a_5 x_i + a_6 y_i + a_7 \sin(a_8 y_i)$$

- Mapping of local slope deviations has been validated by comparing with a triangulated mesh

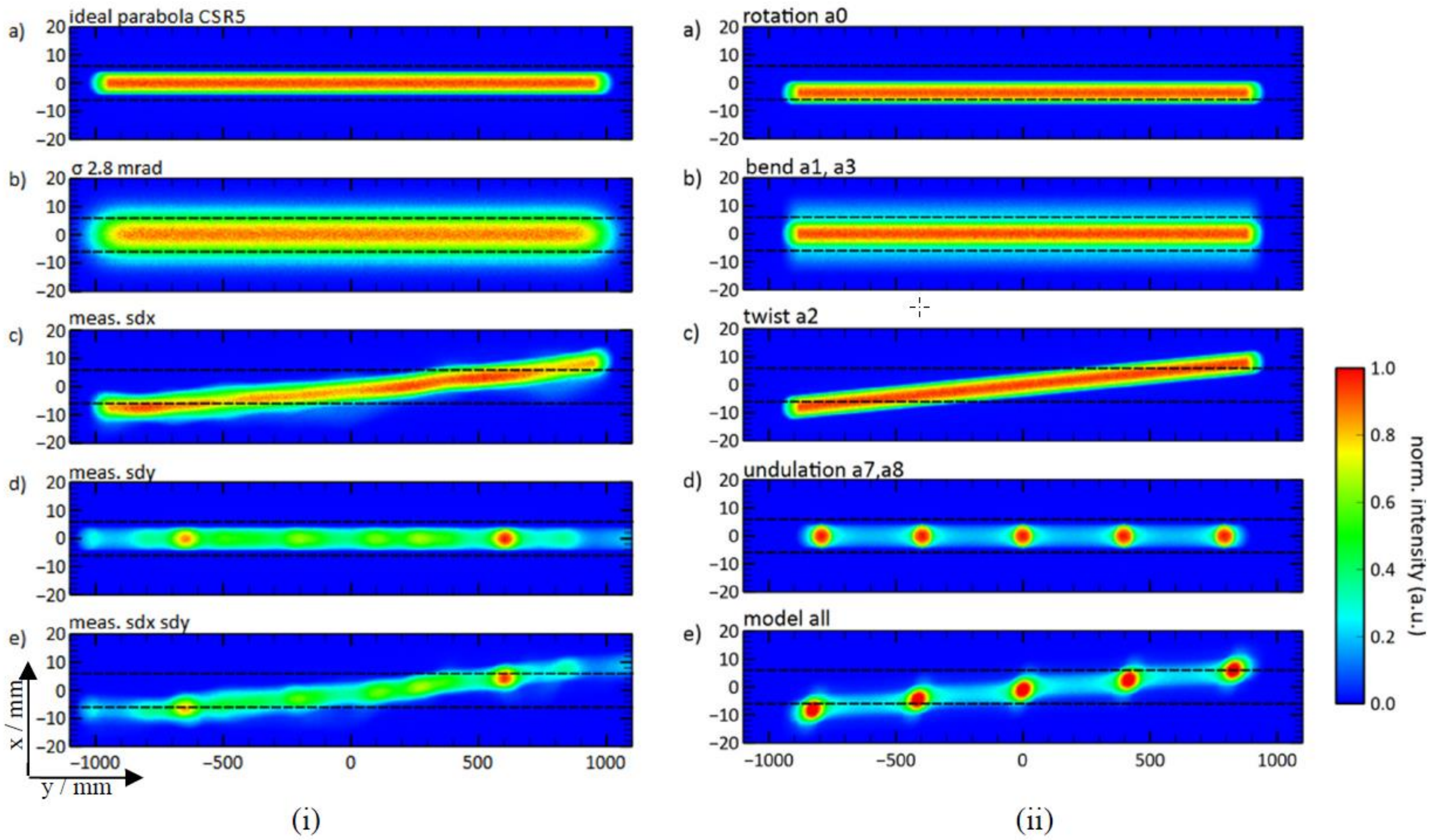


FIGURE 7. (i), Left column: a) Ideal focal line with CSR5. b) Focal line with slope error of σ=2.8 mrad. c) Focal line from measured slope deviations in curved direction, d) longitudinal direction e) full measured surface. (ii), Right column: Focal line of a surface according to the model function a) rotation (not by identified value, but by 2 mrad to clearly show the effect), b) bending c) torsion/twist. In longitudinal direction, the effect of undulation d) according to the sinusoidal model function is depicted. e) Modelled combination of all effects. Dotted black lines indicate the designated receiver aperture.

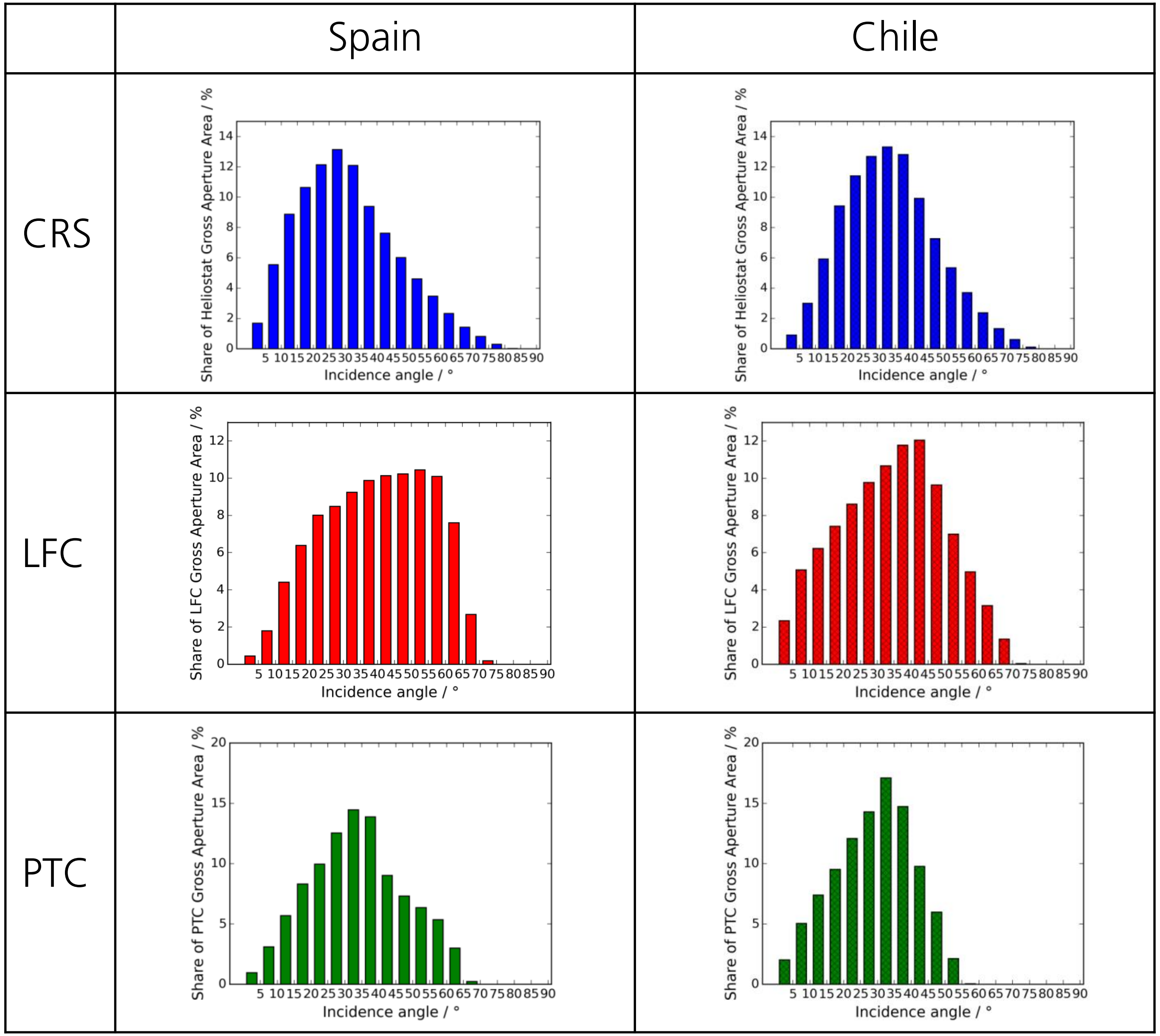
Heimsath et al., Linear Fresnel collector mirrors - Measured systematic surface errors and their impact on the focal line, 2019, https://doi.org/10.1063/1.5117612.

Reflectors/mirrors

Soiling and angle-dependent reflectance

- Annual distribution of incidence angles on gross aperture area
- Significant differences between technologies and sites

- Reflectance values for near-normal incidence might not be very representative



Heimsath, Optical Efficiency of Concentrating Solar thermal Collectors - Investigation of Optical Loss Mechanism of Solar Reflectors, Dissertation Universität Bremen, 2020.
Sutardhio, Claudia Gita (2016): Master thesis. Analysis of performance reduction due to soiling on concentrating solar power.

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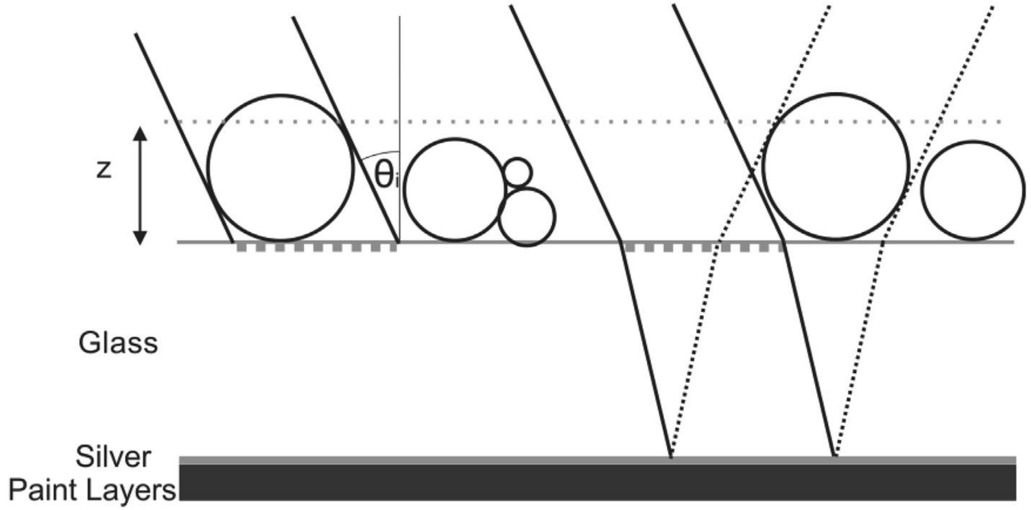
Reflectors/mirrors

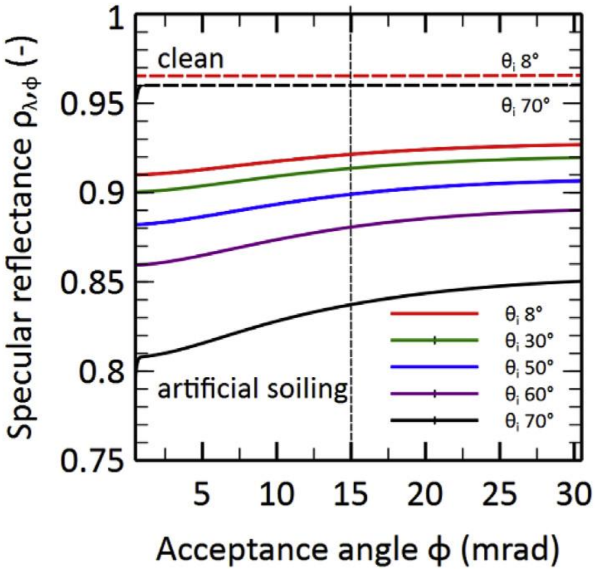
Soiling and angle-dependent reflectance

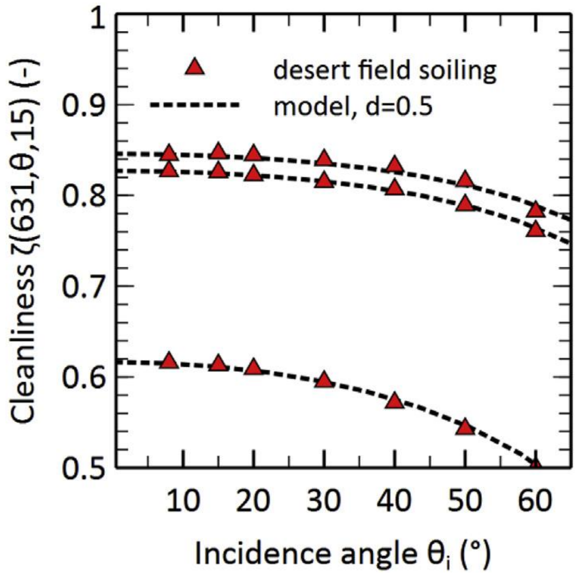


- Shading and blocking due to (spherical) dust particles
- Incidence angle dependency of reflectance
  - weak for clean mirrors
  - strong for soiled mirrors
- Geometric model with two degrees of freedom:
  - Soiling type parameter d
  - Soiling attenuation parameter μ

$$\zeta_{\lambda,\varphi}(\lambda, \theta_i, \varphi) = \frac{\rho_{\lambda,\varphi,soil}(\lambda, \theta_i, \varphi)}{\rho_{\lambda,\varphi}(\lambda, \theta_i, \varphi)} = \exp\left[-\left(\frac{2\mu}{\cos\theta_i}\right)^d\right]$$

- Good agreement with measurements of test dust and desert dust





Heimsath et al., 2019: The effect of soiling on the reflectance of solar reflector materials - Model for prediction of incidence angle dependent reflectance and attenuation due to dust deposition. Solar Energy Materials and Solar Cells.

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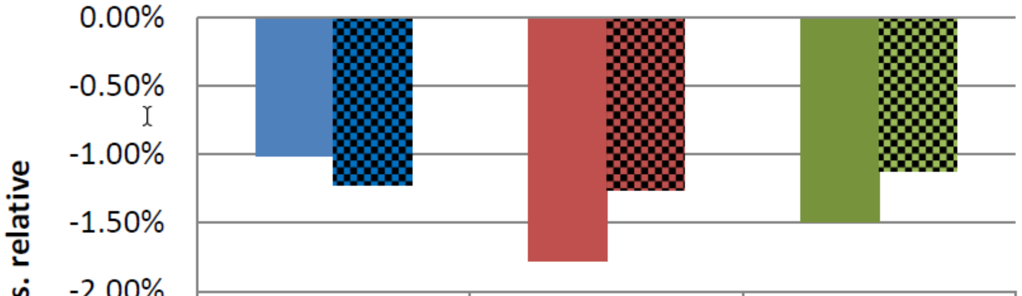
ISE

Reflectors/mirrors

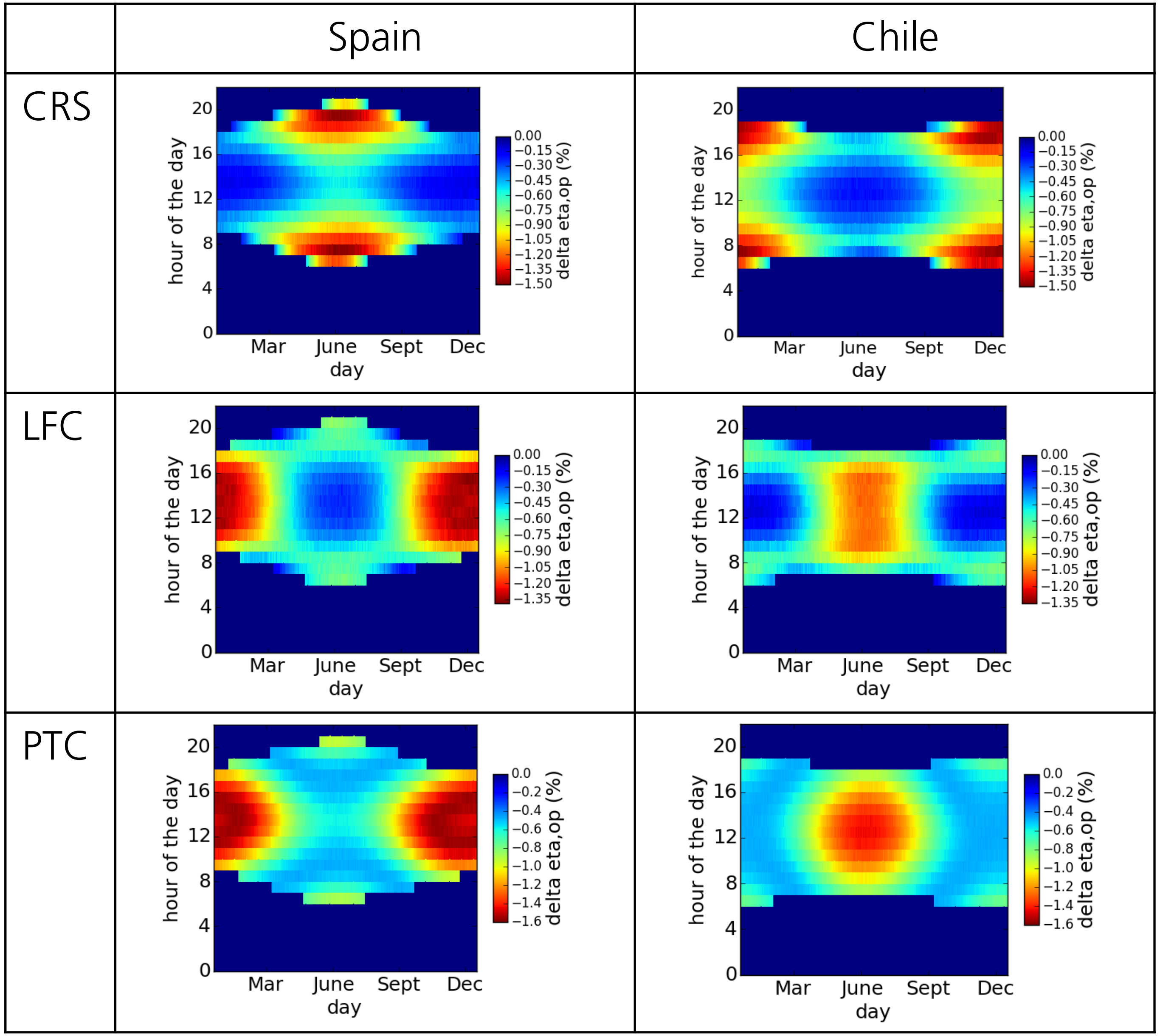
Soiling and angle-dependent reflectance

Impact of incidence angle dependent reflectance on optical efficiency, in comparison to a constant nominal reflectance

- Clean reflectance 95%
- Mean cleanliness of 93%



	Solar Tower	LFC	PTC
Spain	-1.01%	-1.78%	-1.49%
Chile	-1.22%	-1.26%	-1.12%



Sutardhio, Claudia Gita (2016): Master thesis. Analysis of performance reduction due to soiling on concentrating solar power.

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Conclusion

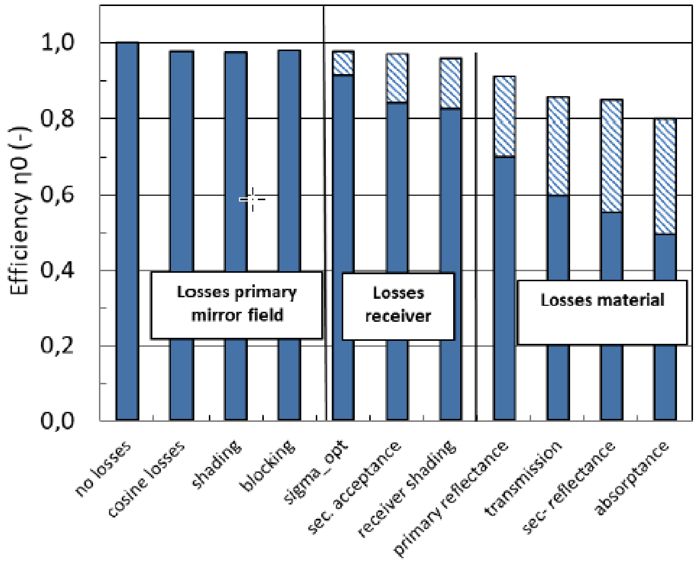

Figure 6.5: Optical loss effects – geometrical and material losses
The case study shows optical loss effects for normal incidence (θ_t=0; θ_i=0). The first part shows losses due to the primary mirror field geometry (cosine, shading, blocking), then the effecto of the total optical errors, acceptance of secondary geometry and receiver shading and losses due to material properties (reflection, transmission, absorption). The dark blue colums show the simulation results for a good geometrical configuration, but lower quality absorber and reflector properties. The light blue columns show the results for the same collector but with high quality components and low optical errors.(Adapted from Heimsath,2014[11]).

1 Need for detailed simulation models like ray tracing

2 Need for detailed material models

3 Angle-dependent material properties highly relevant for various applications

4 Choose model according to required level of detail

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What is SHIP? Technology and market overview

Author: Bärbel Epp, solrico
www.solrico.com; www.solar-payback.com
www.solarthermalworld.org

SFERA III Technical training
7 November 2023

Content

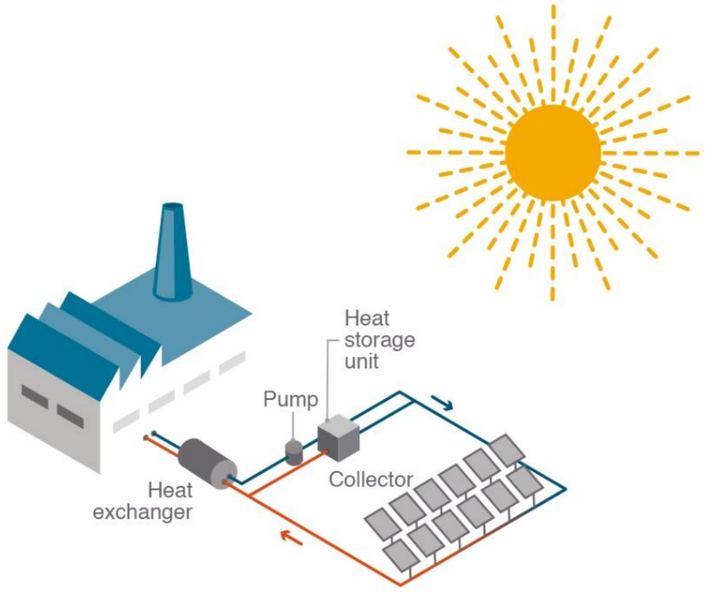
- Definition of SHIP
- Current flagship SHIP projects
- Global SHIP market development 2022 – supply side and demand side
- Costs and cost reduction potential
- Solar Industrial Heat Outlook 2023-2026

- Pdf will be provided to all participants!

What is SHIP = Solar Heat for Industrial Processes?

Definition of SHIP according to IEA Solar Heating and Cooling Programme:

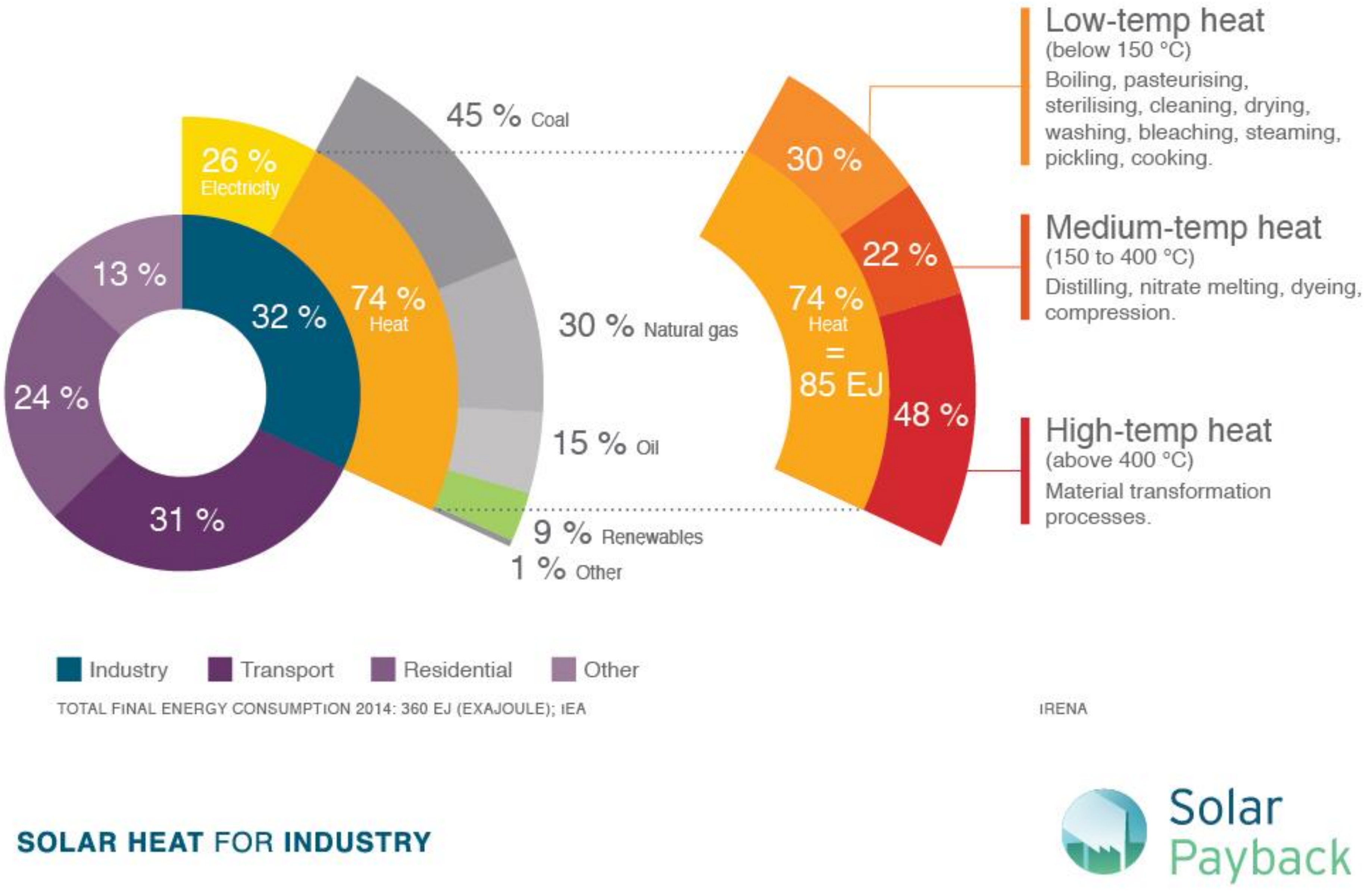
- ✓ Industrial applications such as cleaning, sterilisation, pasteurisation, pre-heating
- ✓ Agricultural applications like drying systems
- ✓ Heating of greenhouses and/or stables for food production, nurseries, animal sheds, vegetable farming
- ✓ Commercial laundries and car/truck washing



The following solar heat applications are not considered as SHIP:

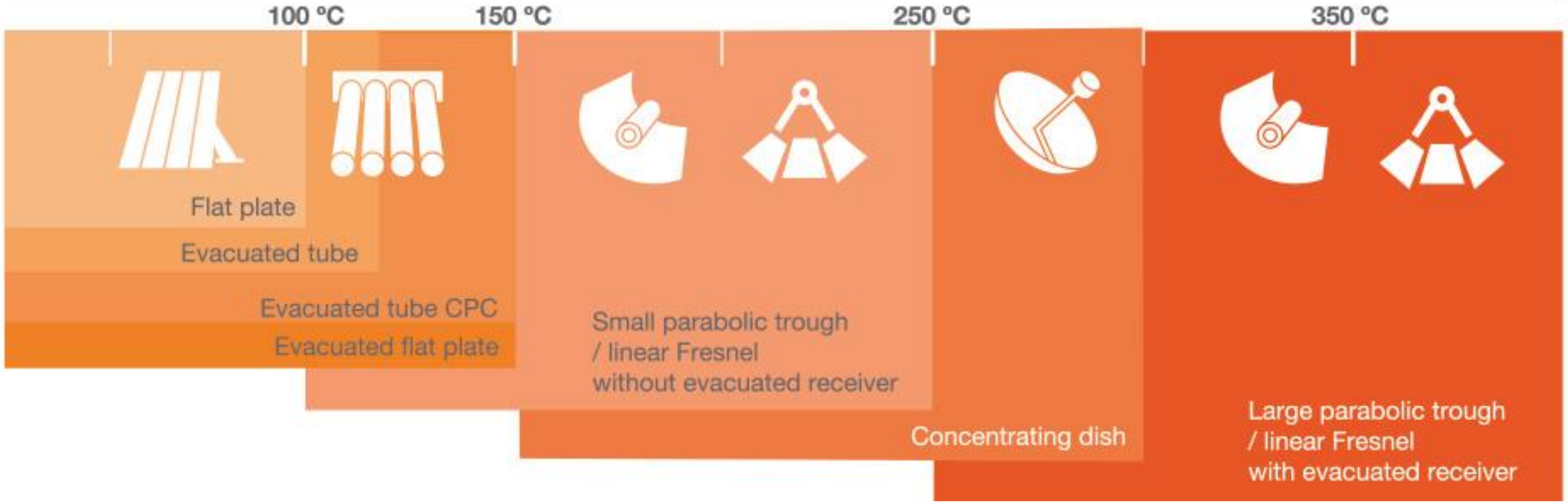
- Health sector (hospitals and clinics)
- Boarding schools and military barracks (Showers of Canteens for workers)
- Solar commercial cooking (India)
- CSP plants that aim at electricity production only

Enormous global heat demand in industry



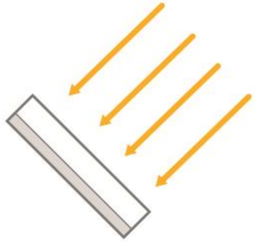
:om

INDUSTRY	LOW Below 150 °C	MEDIUM 150 to 400 °C	HIGH > 400 °C
Chemical	• Boiling	• Distilling	
Food and beverage	• Drying • Boiling • Pasteurising • Sterilising		
Machinery	• Cleaning • Drying		
Mining	• Copper electrolytic refining • Mineral drying processes	• Nitrate melting	
Textile	• Washing • Bleaching	• Dyeing	
Wood	• Steaming • Pickling • Cooking	• Compression • Drying	

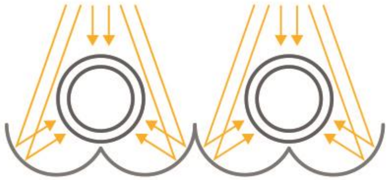


Solar Process Heat Technologies

STATIONARY COLLECTORS

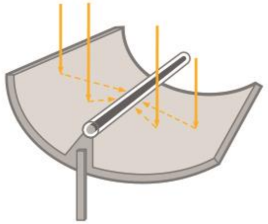


- Flat plate collector
- Evacuated flat plate collector
- Evacuated tube collector

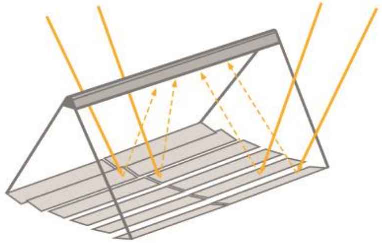


Evacuated tube collector with compound parabolic concentrator (CPC)

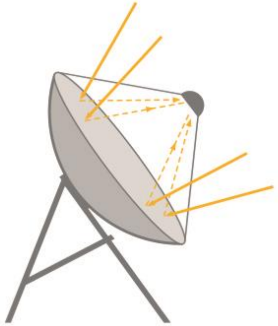
TRACKING COLLECTORS



Parabolic trough collector



Linear fresnel collector



Concentrating dish collector

Source: Solar Payback 2017

Turnhout, Belgium, 2.5 MW, chemical factory, parabolic trough collectors, inauguration 6th of September 2023, mineral oil, 20 % solar share

280 to 380 °C solar heat to the clients supply network

France, 10 MW, drying of malt in Boortmalt factory, 60 to 90 °C, since 2021 (10 %)

Agricultural sector in the Netherlands

190 m² flat plate collector field for a calf-breeding farm where the hot water is used to prepare food for the calves
Photos: G2 Energy

10.5 MW flat plate collector field (15,000 m²) since April 2020 in the Netherlands heat Freezia flower greenhouses at night (40 to 90 °C). The surplus energy in summer goes into an underground aquifer storage system with 160 m³.

SHIP plants for Heineken in Spain

30 MW parabolic trough collector field at Heineken Factor in Seville covering 50 % of the total heat demand of the factory Photo: IEA SHC Task 64

3.5 MW Linear Fresnel collector field for Heineken Factory in Quart de Publet, Valencia Photo: CSIN

SHIP plants for Heineken in Seville, Spain

Client	Beer brewer Heineken Spain
Aperture area of parabolic trough collector field	43,414 m^2
Thermal capacity of the parabolic trough collector field	30 MW
Solar share of the total heat demand of the factory	> 53 %
Type of collector	HYT6000/SL5770 (size of CSP collectors 12 m x 5.77 m)
Estimated solar yield	30,000 MWh/a
Specific estimated solar yield	691 kWh/m^2 aperture area
Type and size of heat storage	Eight pressurized steel tanks with a total capacity of 800 m^3 (68.8 MWh)
Heat transfer fluid in solar field	Pressurised water
Range of operation temperature of the solar field	Up to 210 °C
Range of operation temperature of the client's heat network	140 to 150 °C
Energy service company and owner of the SHIP plant	Engie España (Spain)
EPC for solar collector field	Azteq (Belgium) / Solarlite (Germany)
Duration of heat purchase agreement between Engie España and Heineken Spain	20 years
Period of construction of SHIP plant	June 2022 to June 2023
Total investment for SHIP plant including storage and installation	EUR 21 million
Specific investment costs	484 €/m^2 aperture area
Total amount of subsidy from the European Regional Development Fund	EUR 13.4 million

Miraah in Oman – largest SHIP plant worldwide (330 MW)

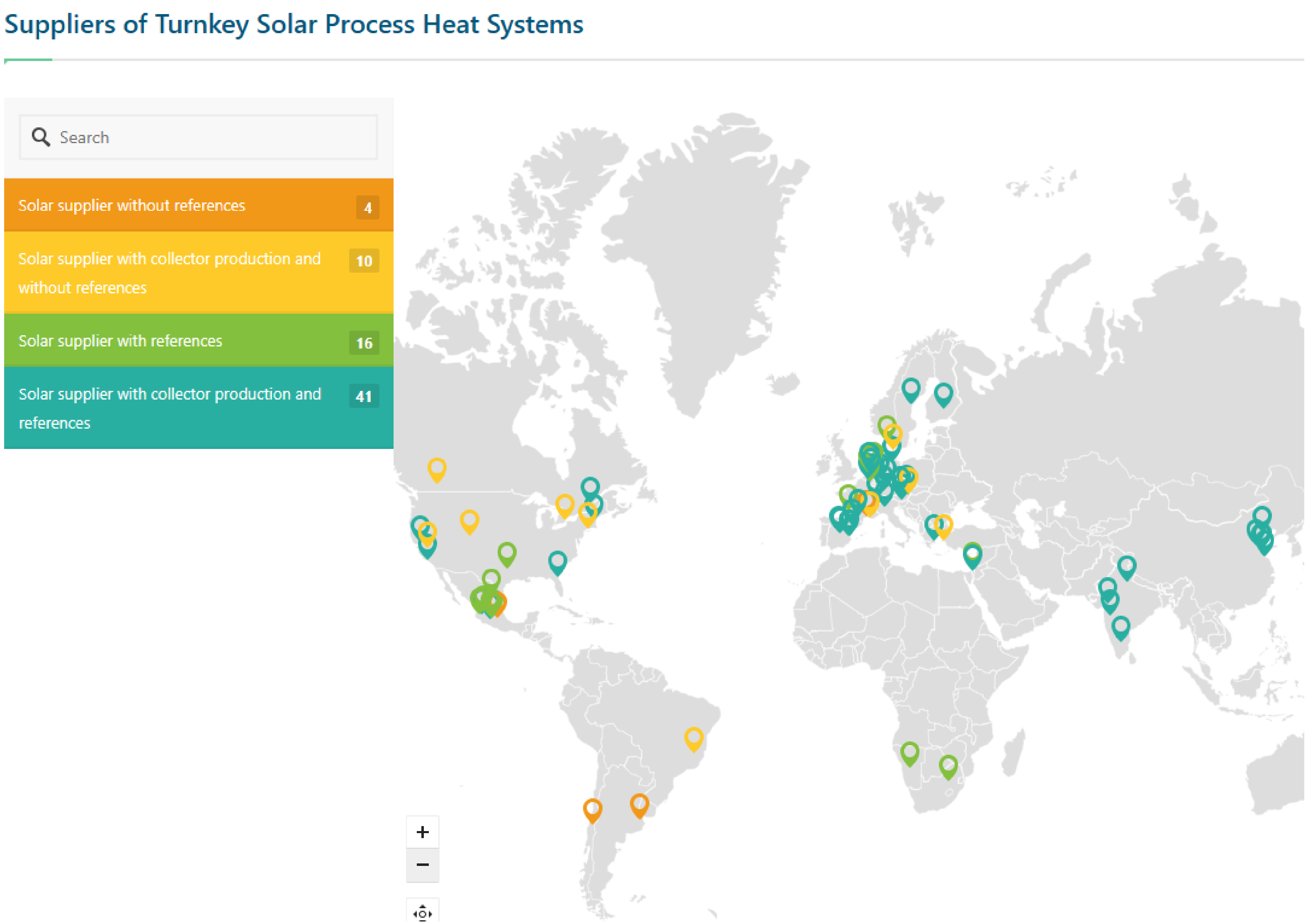
Owner and operator is Petroleum Development Oman, EPC was Glasspoint Solar, roof cleaning every night, light construction of the parabolic troughs, enhance oil recovery („Oil companies can spend as much as 60 % of their operation costs for fuel for EOR“)
Photos: Glasspoint

Summary of first part

- Enormous potential for SHIP because of huge demand of low and medium temperature industrial heat
- Different collector types according to temperature level of heat demand
- Commitment of multinational cooperations to reduce their carbon footprint of production (Heineken, Asahi, Carlsberg, Mayr-Melnhof Graphia, Pepsico, Boortmalt)
- Food and beverage, textile, chemical, automotive, mining and oil industry are the key sectors suitable for SHIP plants
- Good funding situation in some European markets (Austria, France, Netherlands, Germany, Spain) and United States – still an important decision driver

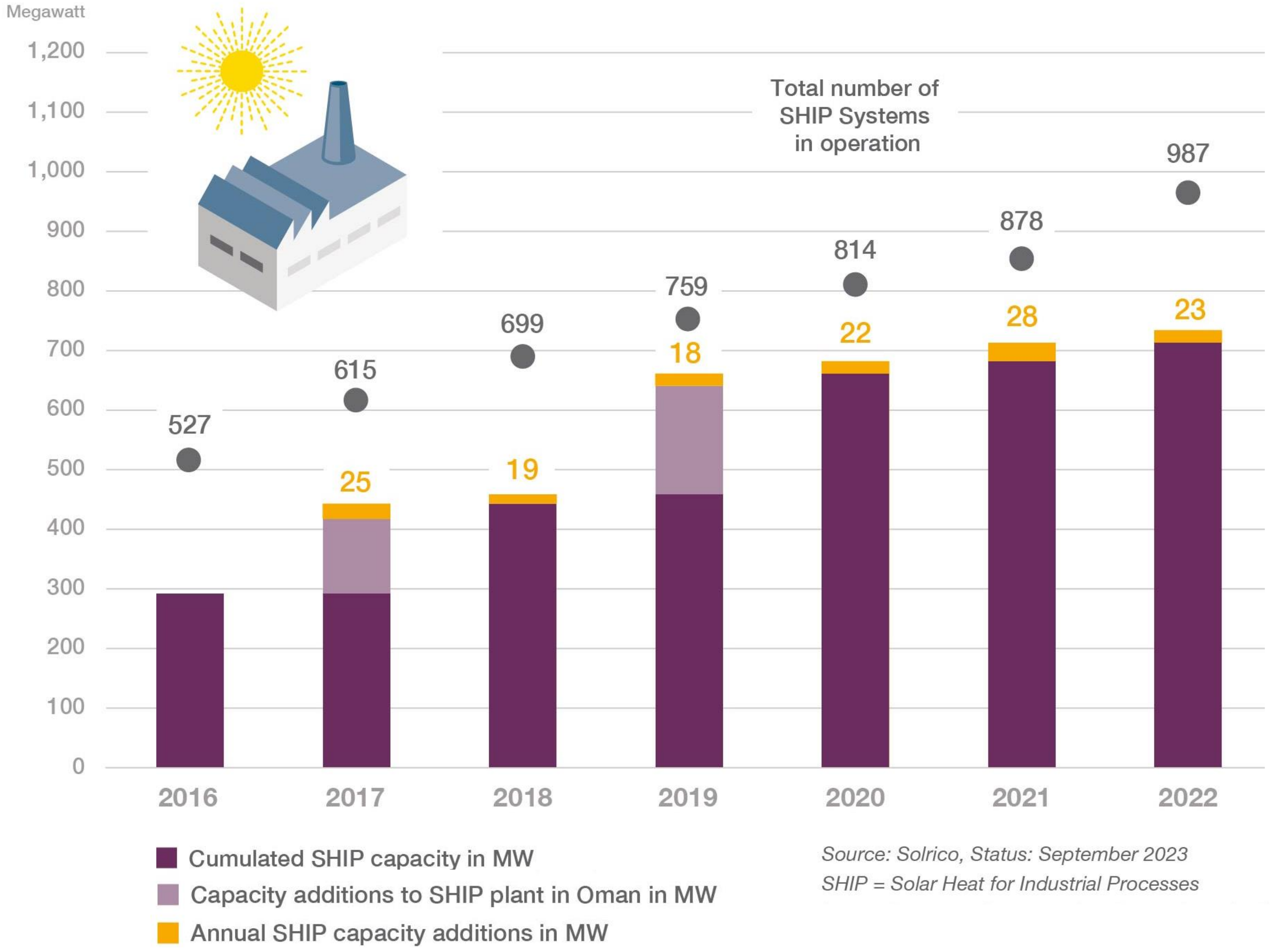
Global SHIP market development 2022: demand and supply side

Annual surveys since 2017



https://www.solar-payback.com/suppliers/

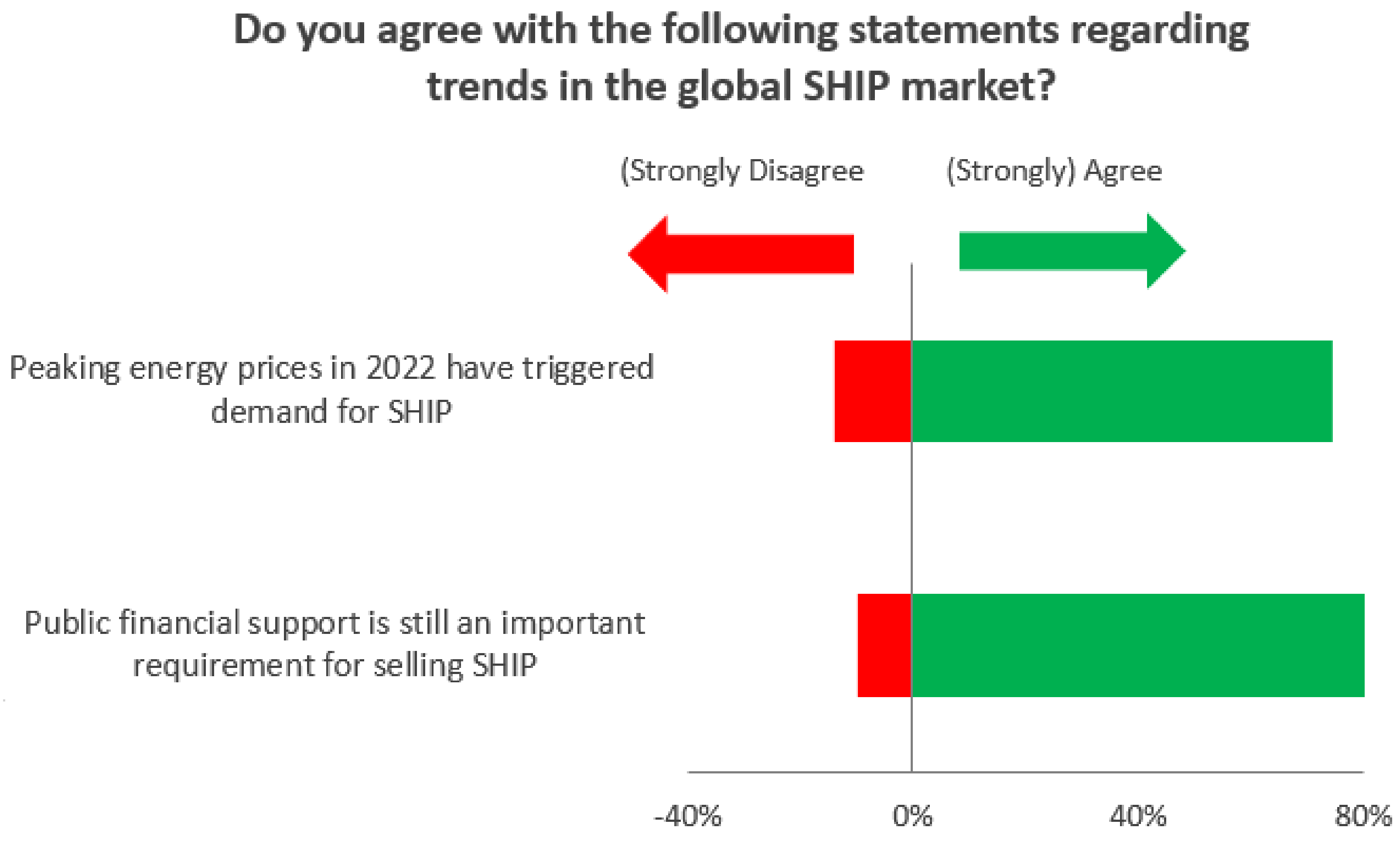
Cumulated SHIP capacity 2016 to 2022 outside China



Retarding factors:

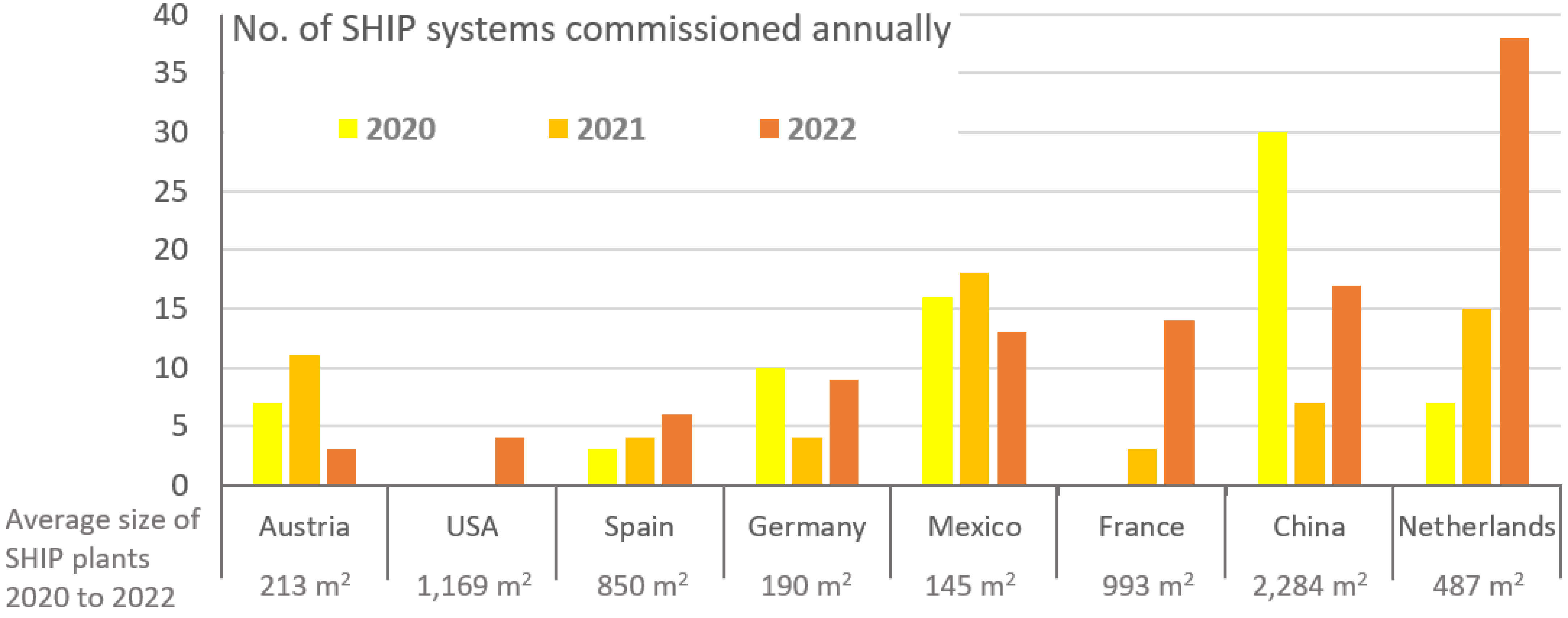
Slow decision making in management of industry companies and requirement for short payback periods

Mood on the SHIP market 2022

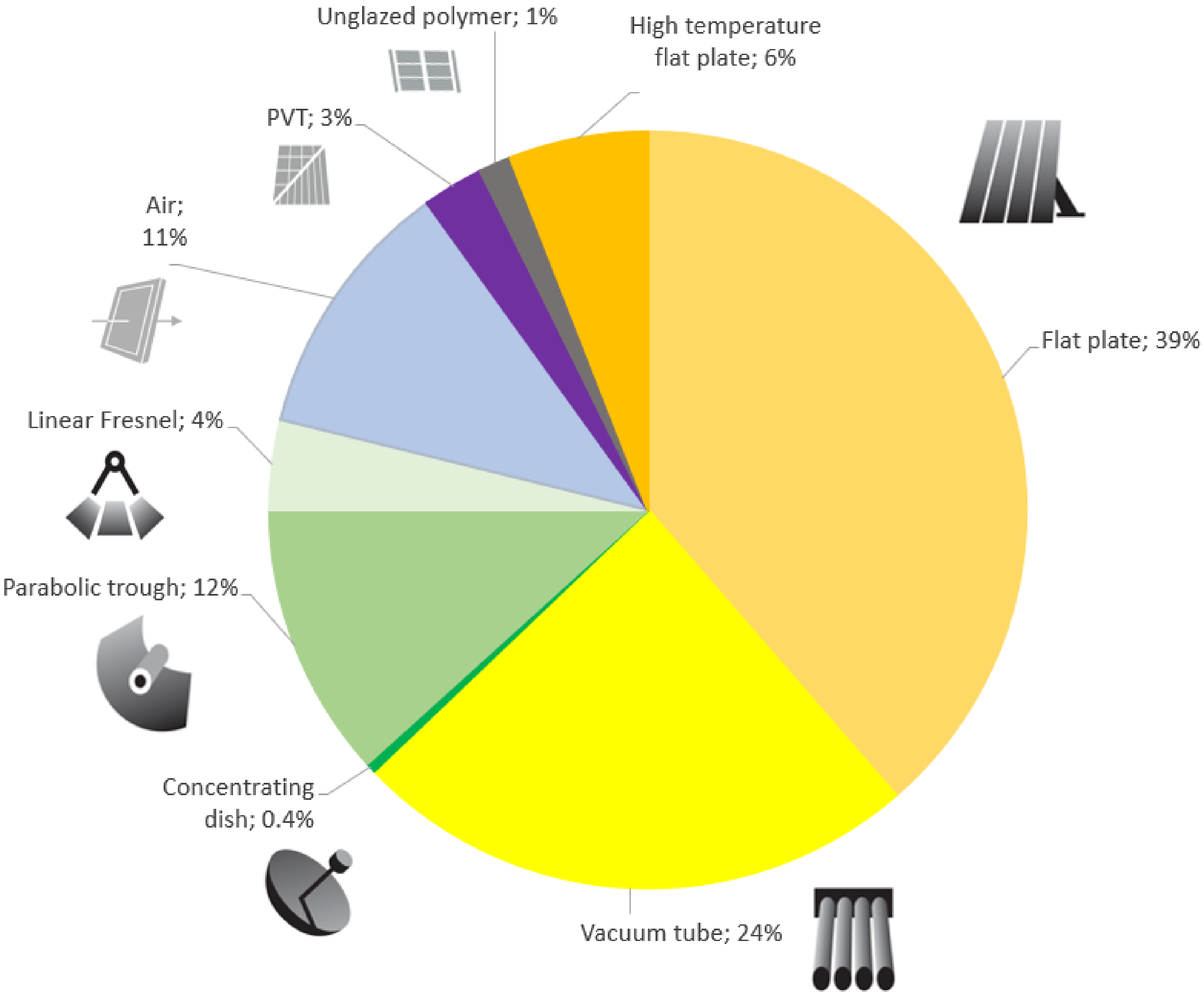


51 answers during survey in March 2023

SHIP world market 2020 to 2022



Growing diversity of SHIP system technologies



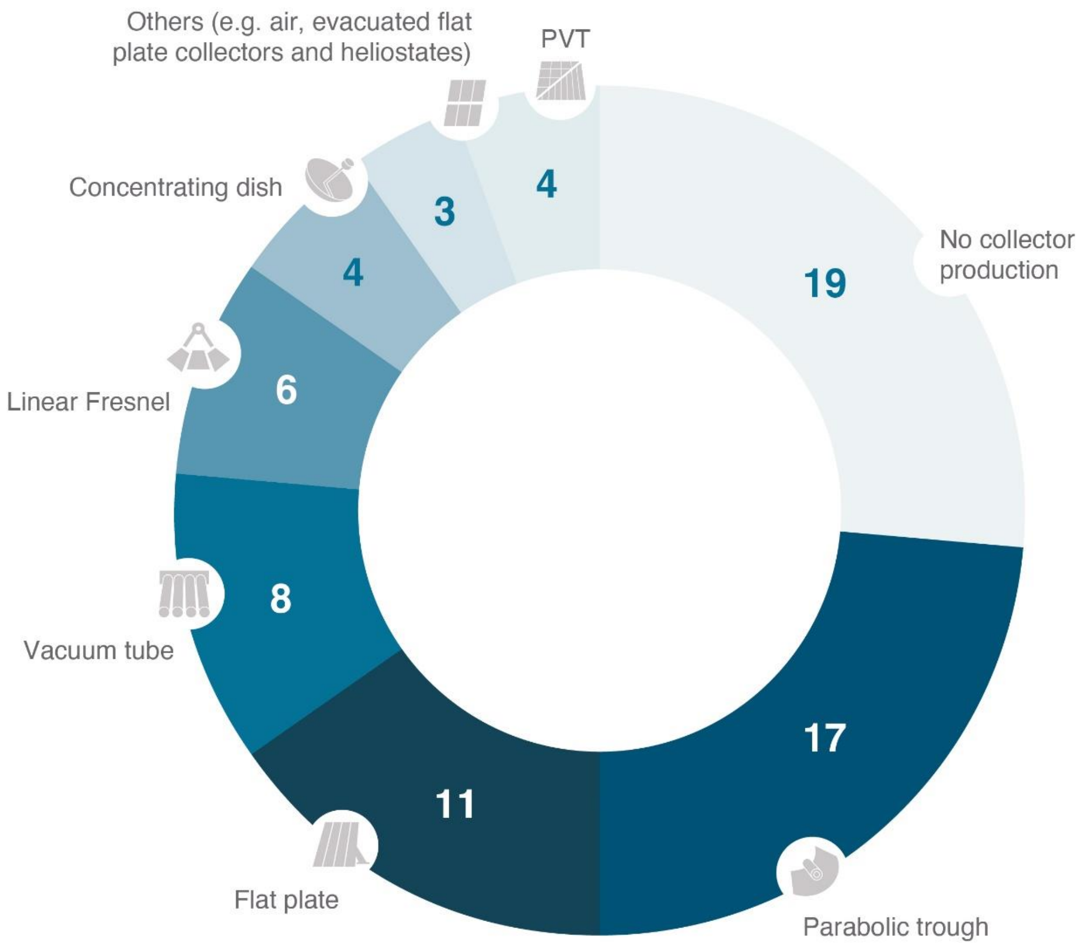
Distribution of collector type area in the SHIP world market 2022 [30 MW in total including China]

More concentrating than stationary collector manufacturers are listed on the updated SHIP Supplier World map

72 turnkey SHIP suppliers are currently depicted on the world map

74 % of the listed companies produce collectors in-house or on-site

Status: April 2023; Source: Modulus / solrico



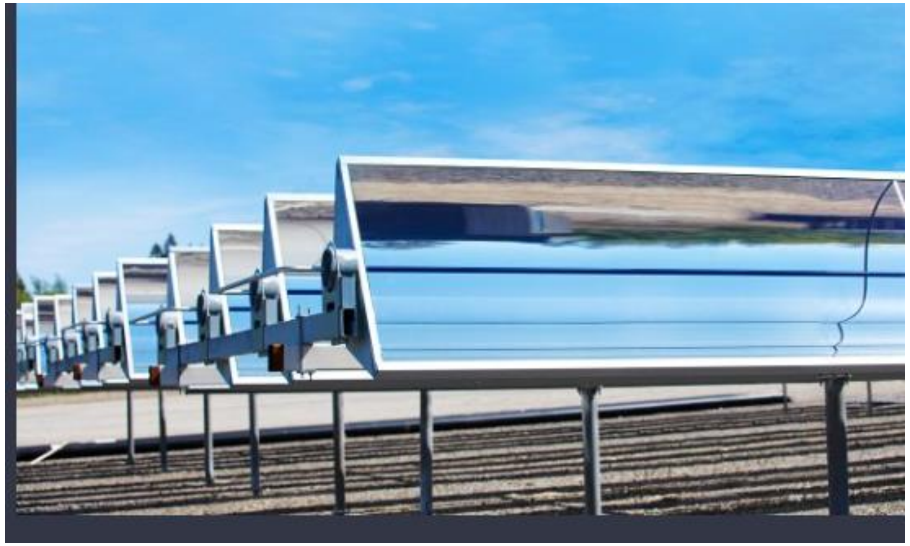
New providers of concentrating collector technologies

Solarsteam, Canada

Heliovis, Austria

Glasspoint USA

Idhelio, France



Phoenix Solar Thermal, Canada (production line from Absolicon, Sweden)

Turnkey suppliers with more than 10 reference projects at the end of 2022

Status: April 2023; Source: Modulus / solrico

Supplier	Country	Reference projects
Módulo Solar	Mexico	132
SolarEast Group	China	93
Linuo Paradigma	China	75
G2 Energy	Netherlands	74
Inventive Power	Mexico	72
Vicot Solar Technology	China	30
Ritter XL Solar	Germany	29
Millennium Energy Industries	Jordan	23
Soliterm	Germany	21
Sunoptimo	Belgium	20
Cona Solar	Austria	20
Solid Solar Energy Systems	Austria	17
Next Source	Netherlands	17
Sunda	China	16
Himin	China	15
Casolar	Mexico	14
Tigi	Israel	10
Sunnergy	Mexico	10

Industry hub in Mexico, China and Germany!

Costs and cost reduction potential (I added some slides on the methodology of the costs assessment with IRENA)

Cooperation

Unique database: cost-performance data sets for 942 solar heat projects with 879 MW commissioned between 2010 and 2020

Data providers: 32 technology suppliers and project developers and 3 funding agencies

Aknowledgements:
Austria:
Climate and Energy Funds,
GREENoneTECH,
SOLID Solar Energy Systems
Belgium:
Rioglass Solar
China:
Linuo Paradigma
Finland:
Savo-Solar
Germany:
Aschoff Solar,
Federal Office for Economic Affairs and Export Control, Industrial Solar, Solarlite CSP Technology, Viessmann

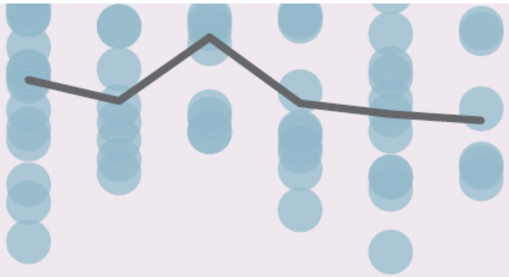
Greece:
Cosmosolar Solar Solutions
India:
Bipin Engineers, Emmvee Solar Systems, Intersolar, Nuetech Solar Systems, Quadsun, VSM Solar
Mexico:
Casolar, Citrus, Inventive Power, Módulo Solar
Spain:
Solatom CSP
Sweden:
Absolicon Solar Collector
Turkey:
Eraslan, Solimpeks Solar Energy Systems

Exceptional knowhow: Adapting the approved methodology of cost trend assessment of the annual *Renewable Power Generation Cost* report since 2010

Michael Taylor, Senior Analyst at IRENA

Methodology

Solar Payback | IRENA International Renewable Energy Agency | solrico



How to read this chart?

Each circle illustrates a solar heat project for which the following data is available in the IRENA database:

- Year and country of commissioning
- Collector type
- Application
- Size in kW / aperture area
- **Total costs in local currency including installation without VAT/subsidies**
- **Calculated/simulated solar heat yield in MWh/year**

The bold line represents the weighted-average installed costs in a year. The weighted-average is calculated as a sum of costs of all commissioned projects in this year times thermal capacity, divided by the sum of the thermal capacity.

How are LCOH calculated?

$$LCOH = \frac{I_0 + \sum_{t=1}^{n} \frac{M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Y_t}{(1+r)^t}}$$

LCOH = Levelised Cost of Heat and describes the heat costs averaged over the system lifetime of 25 years (n). **This methodology allows the comparison of costs in different countries and for different applications.**
As the equation uses a standardised **WACC** and lifetime for all projects, **LCOH** are different from solar heat prices that the individual plant owner reaches with its investment.

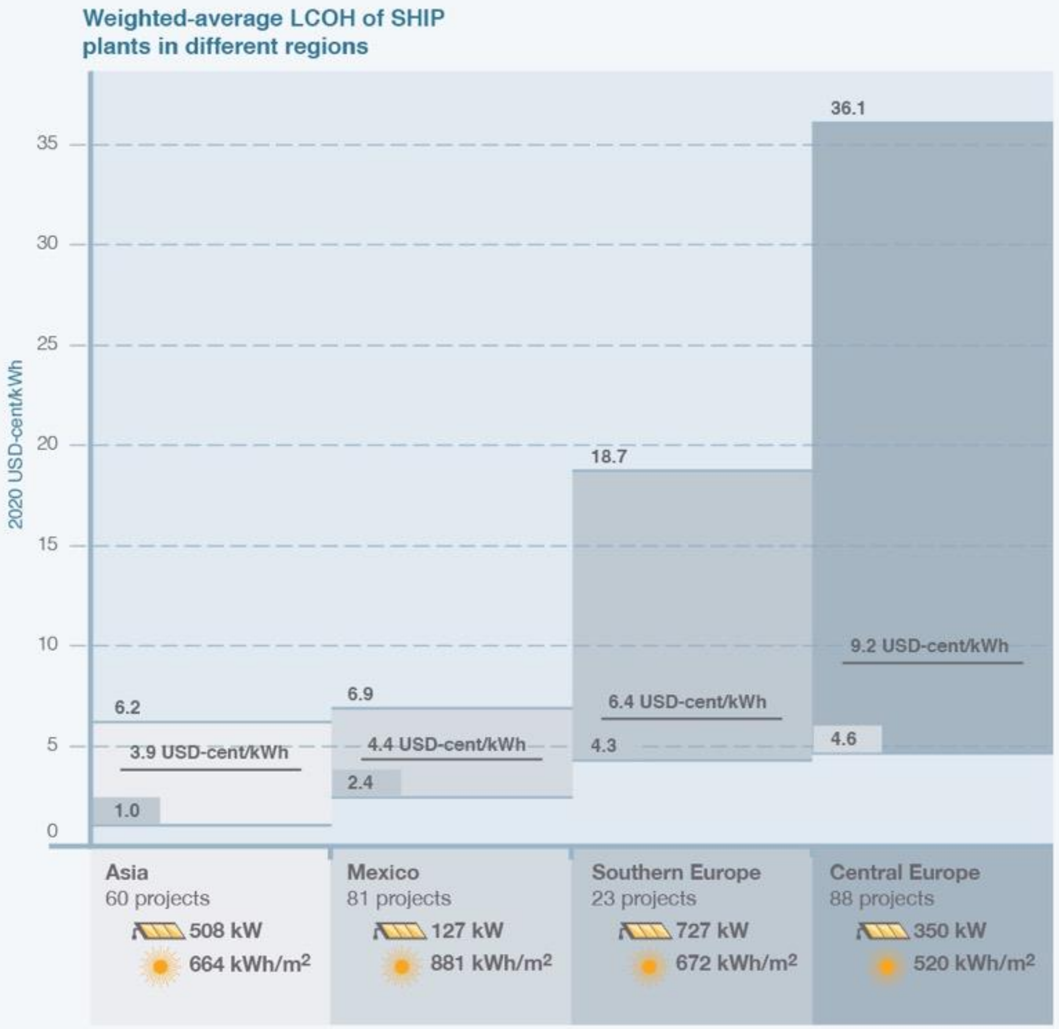
with

I_0 = investment expenditure in year zero
M_t = operation and maintenance expenditure estimated by IEA SHC Task 64 experts
- 1 % of total installed costs per year (≤ 1,000 m² aperture area of field)
- 0.5 % of total installed costs per year (>1,000 m² aperture area of field)

Y = project-specific annual heat generation [MWh/a]
r = discount rate (WACC) = 5 % (real)

The Mexican success story

Asia and Mexico are the markets with the lowest industrial solar heat costs



How to read this chart:

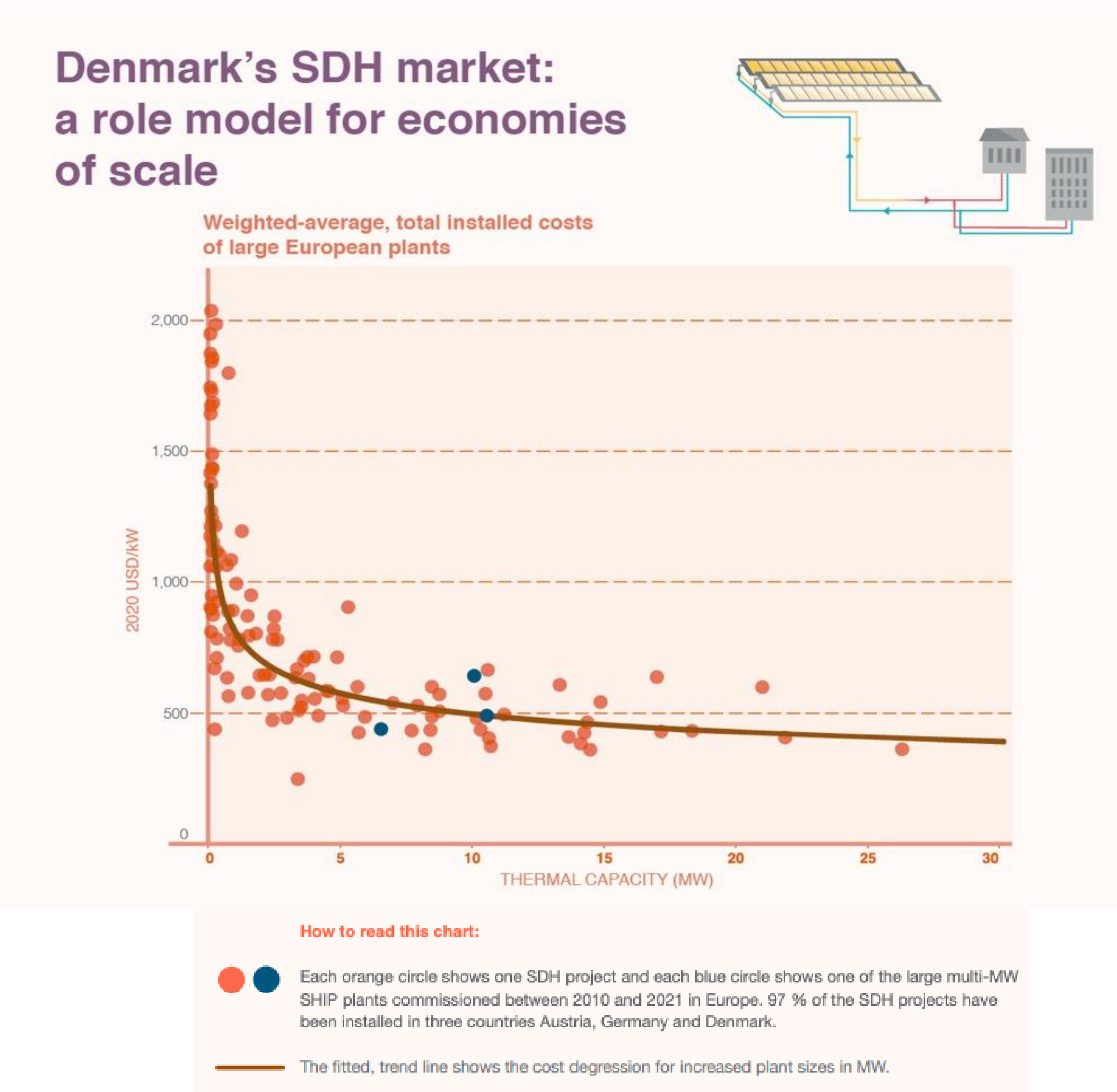
The grey bands show the 5th and 95th percentiles of LCOH by project for a region / country. Projects with various collector technologies are included all commissioned in the period 2010 to 2020. The LCOH is calculated with a standardised WACC of 5 % and 25 years lifetime.

The bold line represents the weighted-average installed costs for that country/region.

Average collector field size

Average annual solar yield

COST ANALYSIS: IRENA

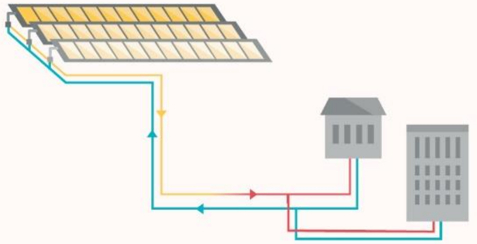


Economies of scale at the plant level:

The trend line suggests that for every doubling of the size of the plant, total installed costs will decline by **14 %**.

Extrapolating to a 110 MW plant implies costs of 296 USD/kW, somewhat lower than the data for Silkeborg.

Rapid scale up of SDH in Denmark reduced the costs



Total installed cost learning curve trends for solar district heating in Denmark

How to read this chart:

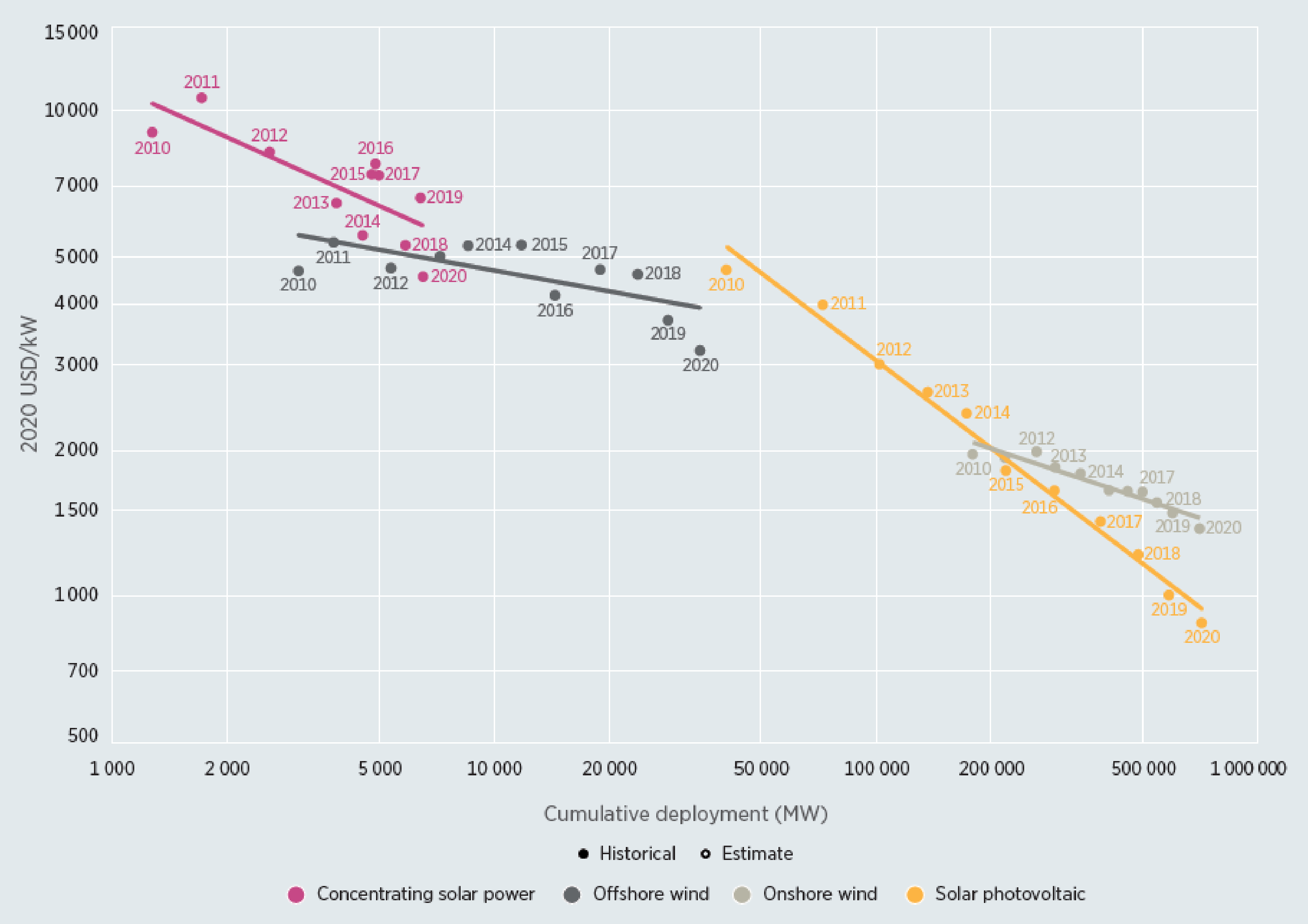
Simple average total cost values of Danish SDH plants per year and weighted-average total cost values per year are plotted over the national cumulative deployment rates in Denmark. Both trend lines are calculated including Denmark´s SDH plant with 110 MW in Silkeborg. The learning rate describes the percentage reduction of costs for every doubling of cumulative installed capacity and is graphed on a log-log scale to show as a straight line.

Solar Payback

COST ANALYSIS: IRENA

Learning curves for other renewable technologies

Figure 1.8 The global weighted-average total installed cost learning curve trends for solar PV, CSP, onshore and offshore wind, 2010-2020



Source: IRENA Renewable Cost Database

Learning rates for total installed costs of different renewable technologies in the ten years period 2010-2020 according to the IRENA-report "Renewable Power Generation Costs 2020":

Utility scale solar PV: 34 %
Concentrating Solar Power: 22 %
Offshore Wind: 9.4 %
Onshore Wind: 16.6 %

Source: Renewable Power Generation Costs in 2020 by IRENA

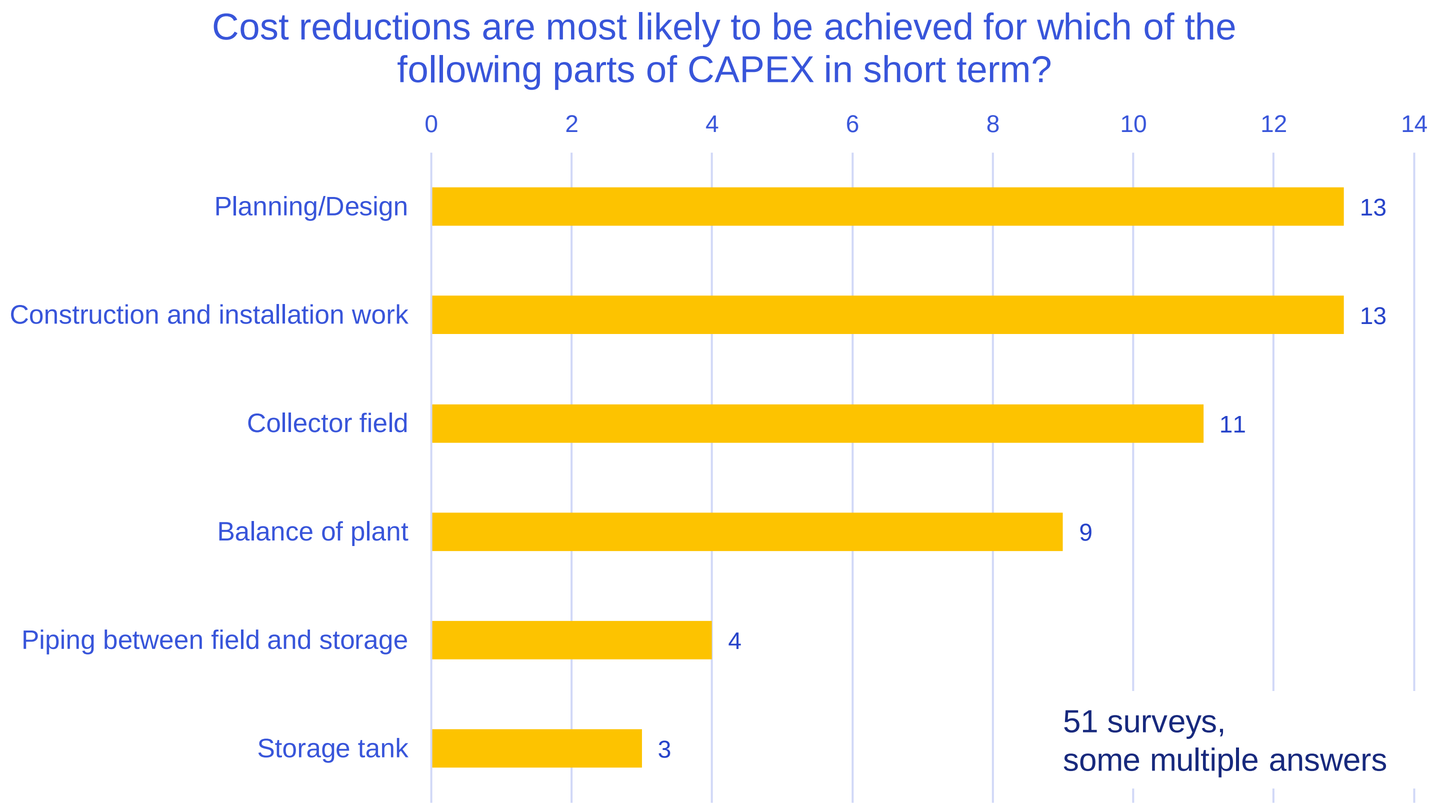
https://shorturl.at/iJO34

Analysis of the parts of CAPEX were cost reduction potential could be most easily achieved

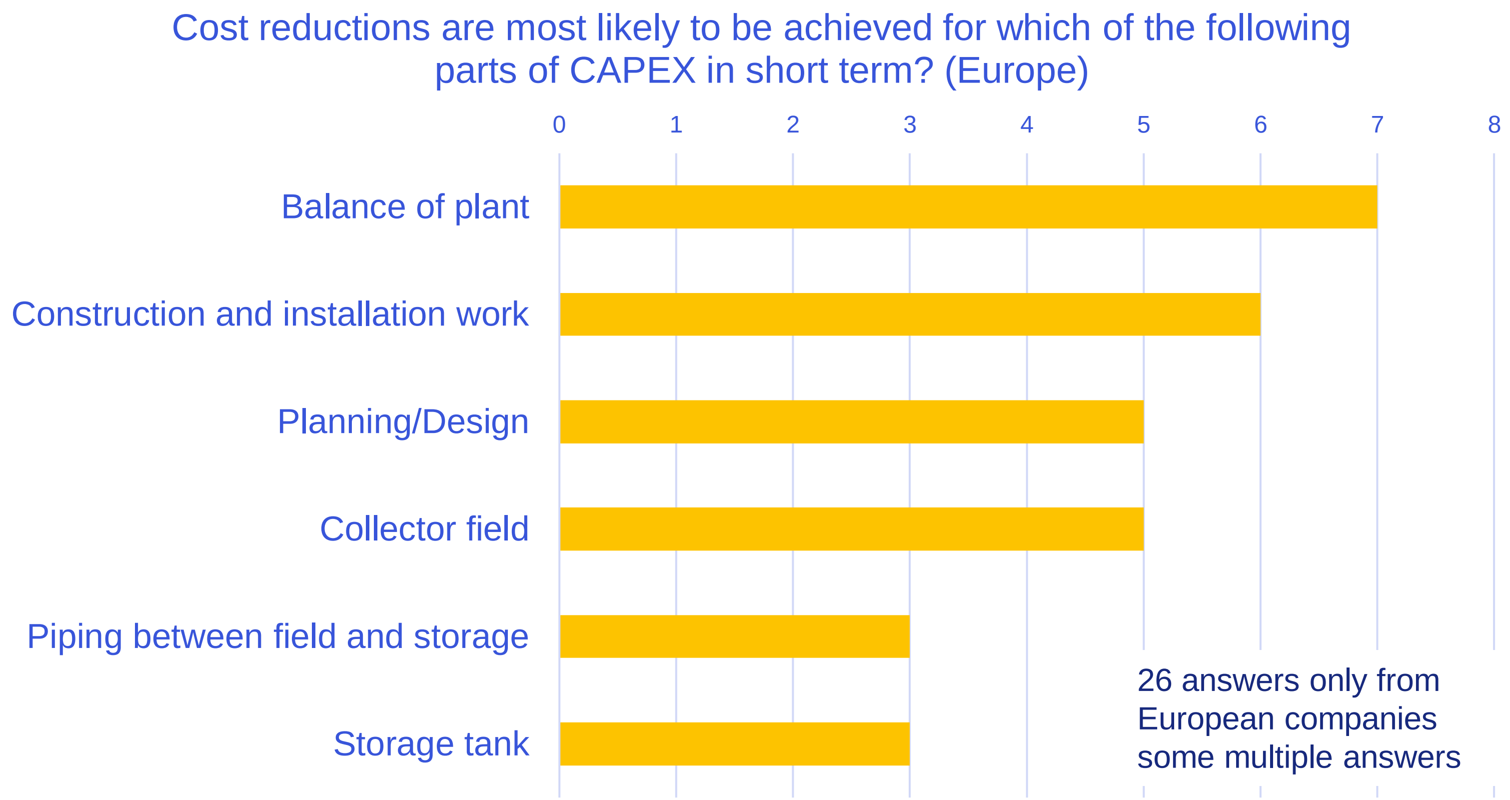
Cost reductions are most likely to be achieved for which of the following parts of CAPEX in short term?

Please select one option!

Planning/ Design	Collector field	Piping between field and storage	Balance of plant (integration of solar heat in client's network)	Construction and installation work	Storage tank
Please give reasons for your choice					



e) Analysis of the parts of CAPEX were cost reduction potential could be most easily achieved

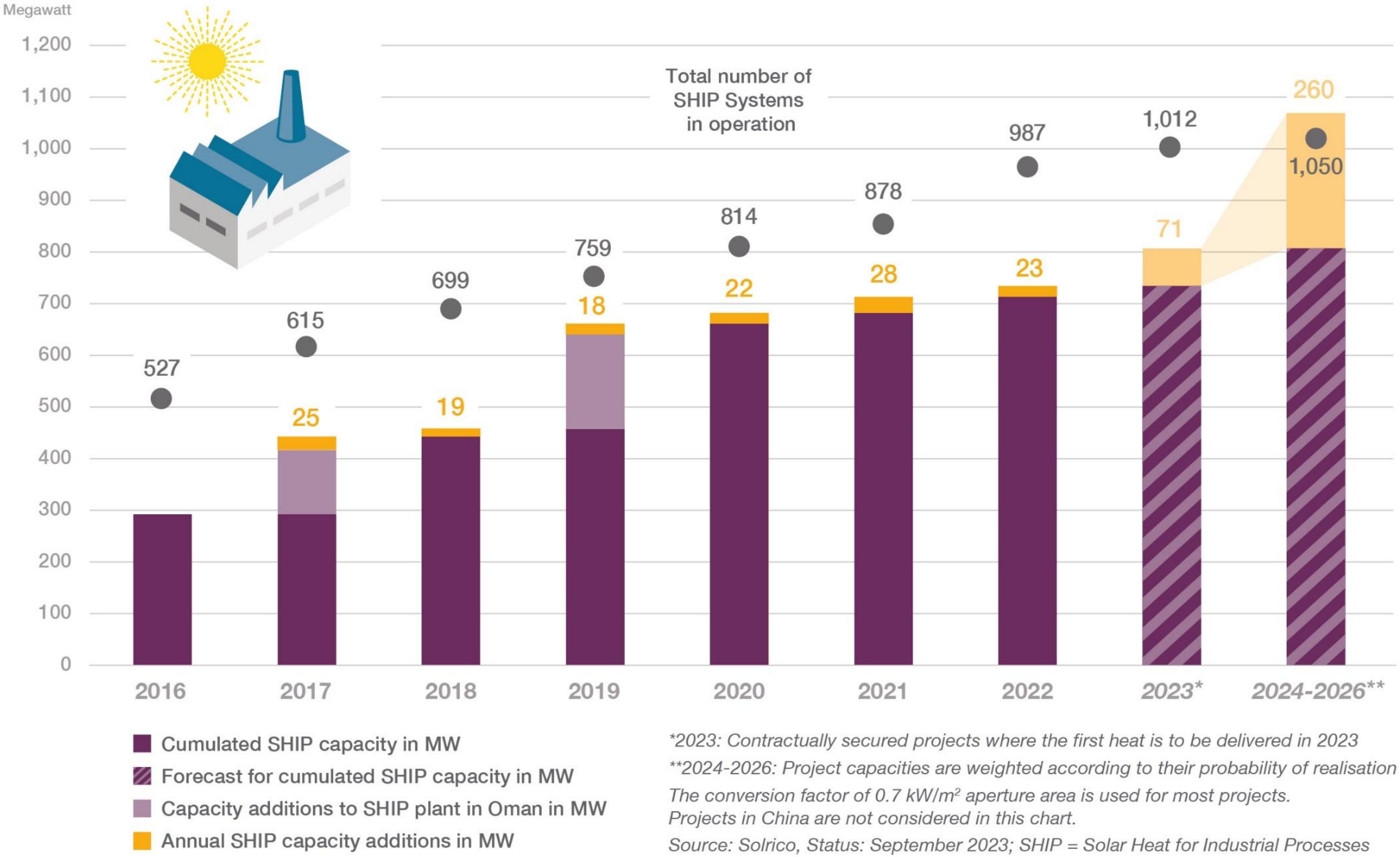


Summary of second part

- SHIP project development is still a tough business with long development times and demanding clients
- Gas price peaks in 2022 have increased demand
- Key ship markets in the last years were Netherlands, China, Mexico, France
- Wide range of LCOH for SHIP with Mexican/Chinese project developers reaching the most cost competitive heat prices (higher irradiation)
- Number of concentrating collector manufacturers offering EPC SHIP solutions is growing
- Economies of scale suggests great potential for cost savings
- Suppliers see cost reduction potential mainly in planning, construction and balance of plant.

Solar Industrial Heat Outlook 2023-2026

Solar Industrial Heat Outlook 2023-2026



*2023: Contractually secured projects where the first heat is to be delivered in 2023

**2024-2026: Project capacities are weighted according to their probability of realisation

The conversion factor of 0.7 kW/m² aperture area is used for most projects.
Projects in China are not considered in this chart.

Source: Solrico, Status: September 2023; SHIP = Solar Heat for Industrial Processes

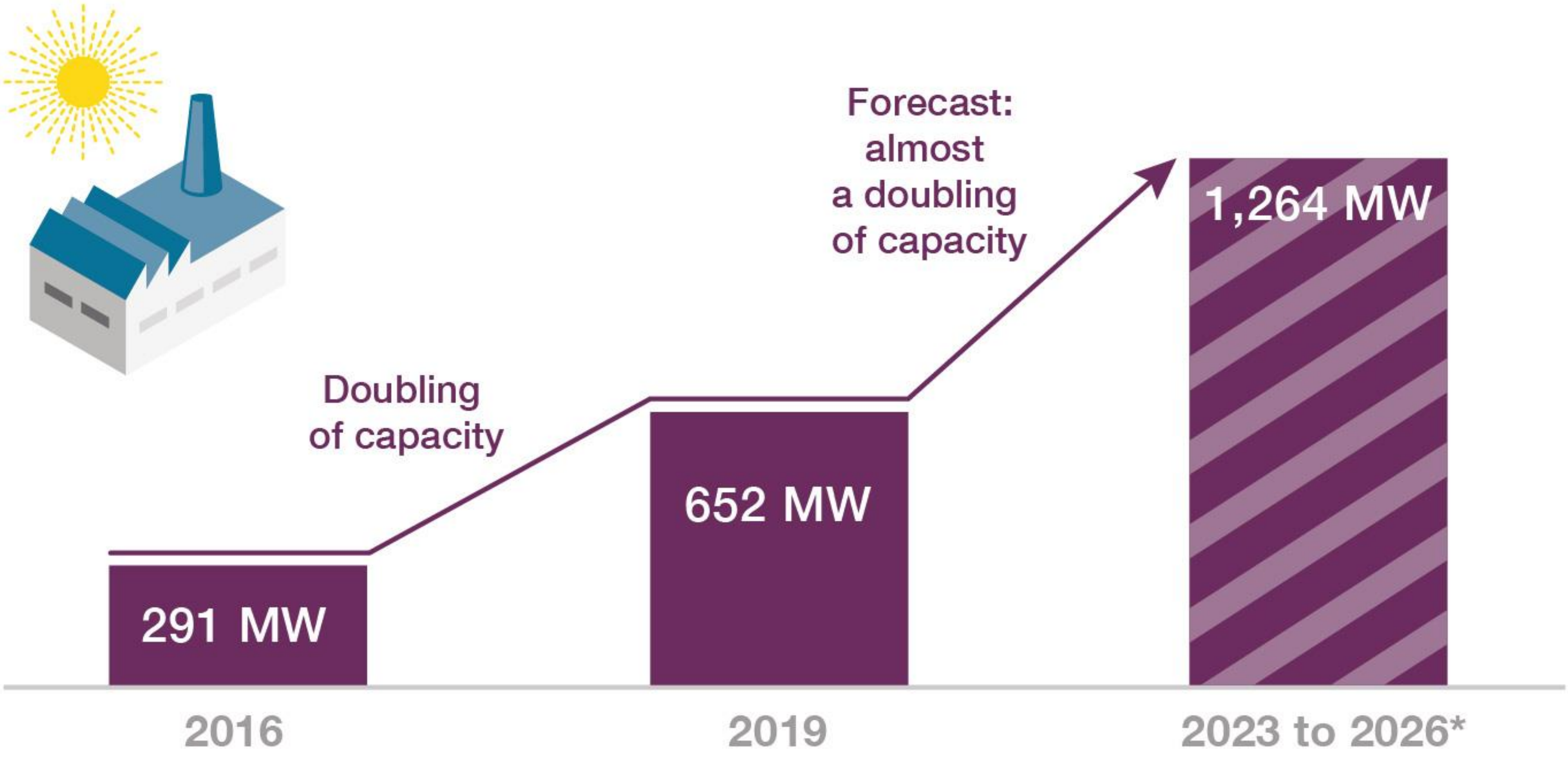
Solar Industrial Heat Outlook – participating companies

- 22 project developers contributed contracted projects and projects under planning:
  - Austria: Alexe Simona- greenXcloud, Heliovis, Solid Solar Energy Systems
  - Belgium: Azteq/Solarlite
  - Canada Rackam
  - France: New Heat
  - Germany: Industrial Solar, Protarget, Soliterm
  - India: Quadsun
  - Israel: Tigi
  - Mexico: Flemming Jørgensen, Inventive Power, Modulo Solar
  - Netherlands: G2Energy, Solho
  - Spain: Solatom, Tecnosol
  - Sweden: Absolicon
  - Switzerland: TVP Solar
  - USA: Glasspoint, Solar Dynamics

- 63 projects were reported with different status of planning

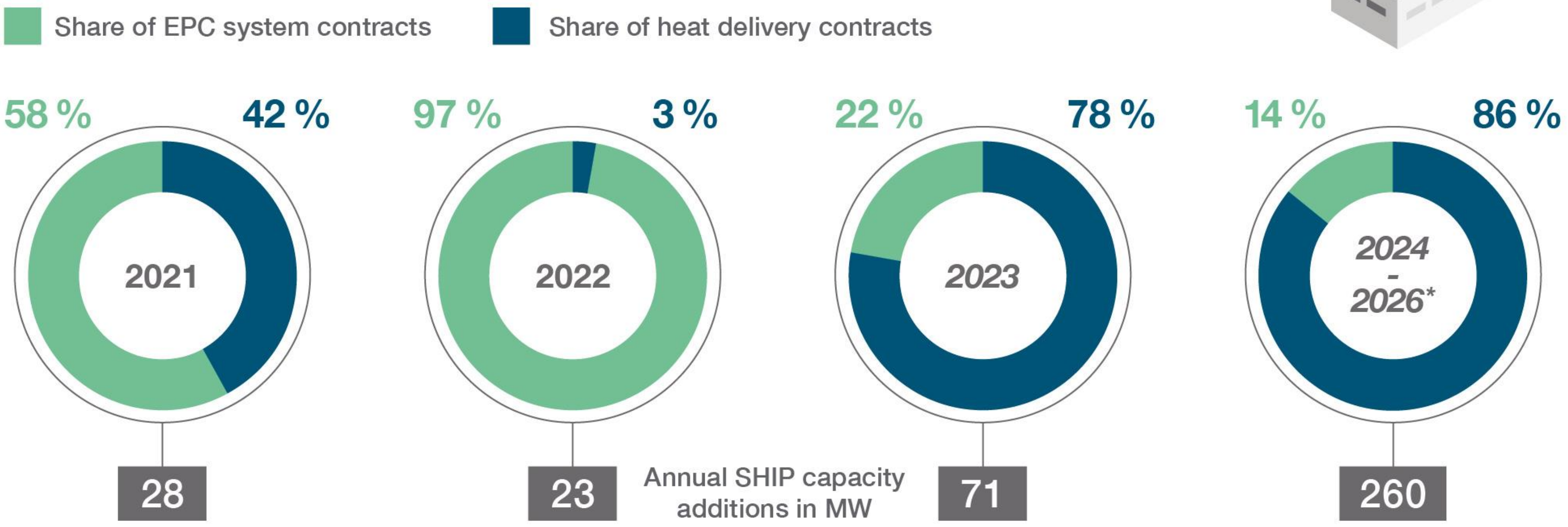
STATUS	Realisation potential
Signed LOI	30%
Signed MOU	30%
Ordered engineering study	60%
Submitted application for subsidies	60%
Approved subsidy / financing	60%
Signed EPC contract for collector field	100%
Signed heat delivery contract	100%
Construction started	100%
First heat to client delivered	100%

Solar Industrial Heat Outlook

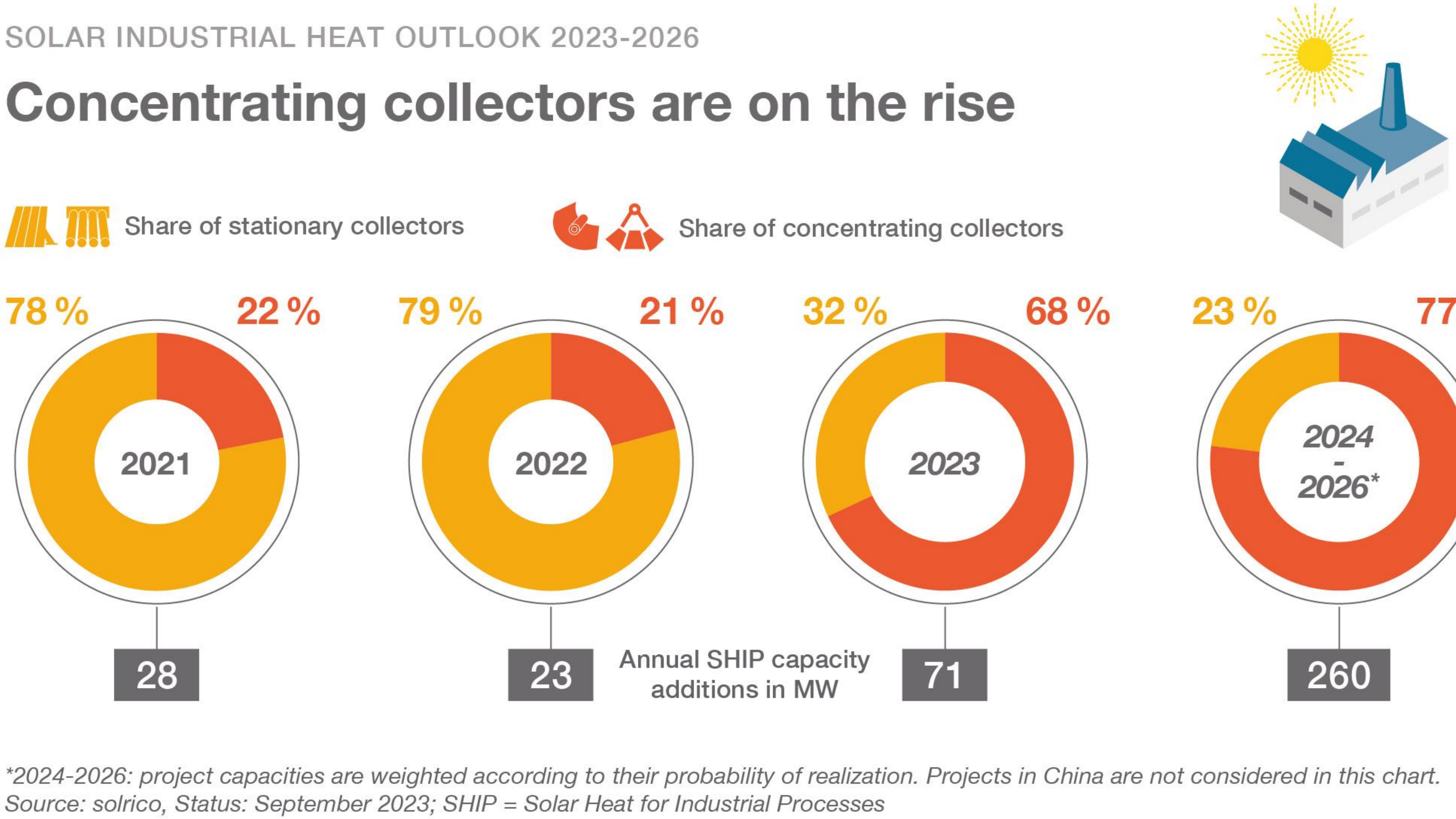


*2023 to 2026 includes all announced projects at full capacity.
Projects in China are not considered in this chart.
Source: Solrico, Status: September 2023; SHIP = Solar Heat for Industrial Processes

Heat delivery contracts dominate the future SHIP market



**2024-2026: project capacities are weighted according to their probability of realization. Projects in China are not considered in this chart.*
Source: solrico, Status: September 2023; SHIP = Solar Heat for Industrial Processes



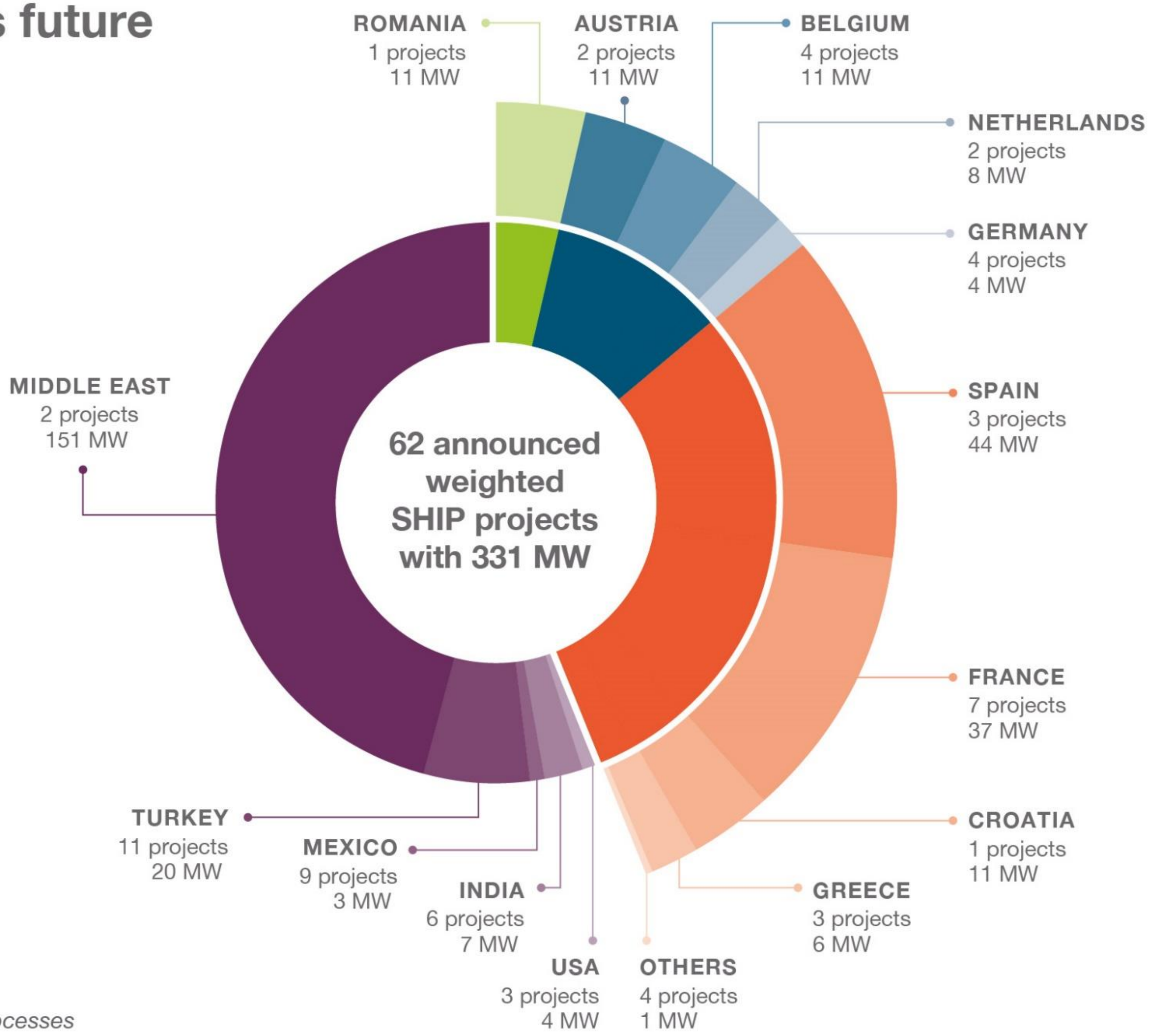
95 % of the announced concentrating capacity 2023-2026 is parabolic trough technology

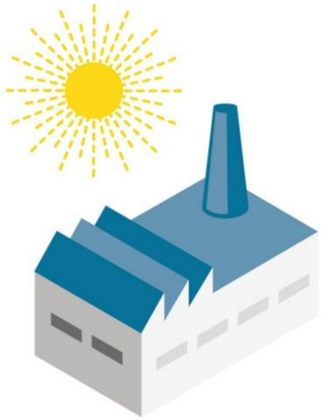
86 % of announced weighted stationary capacity 2023-2026 is flat plate collector technology

SOLAR INDUSTRIAL HEAT OUTLOOK 2023-2026

99 % of Europe's future SHIP capacity is developed by local companies

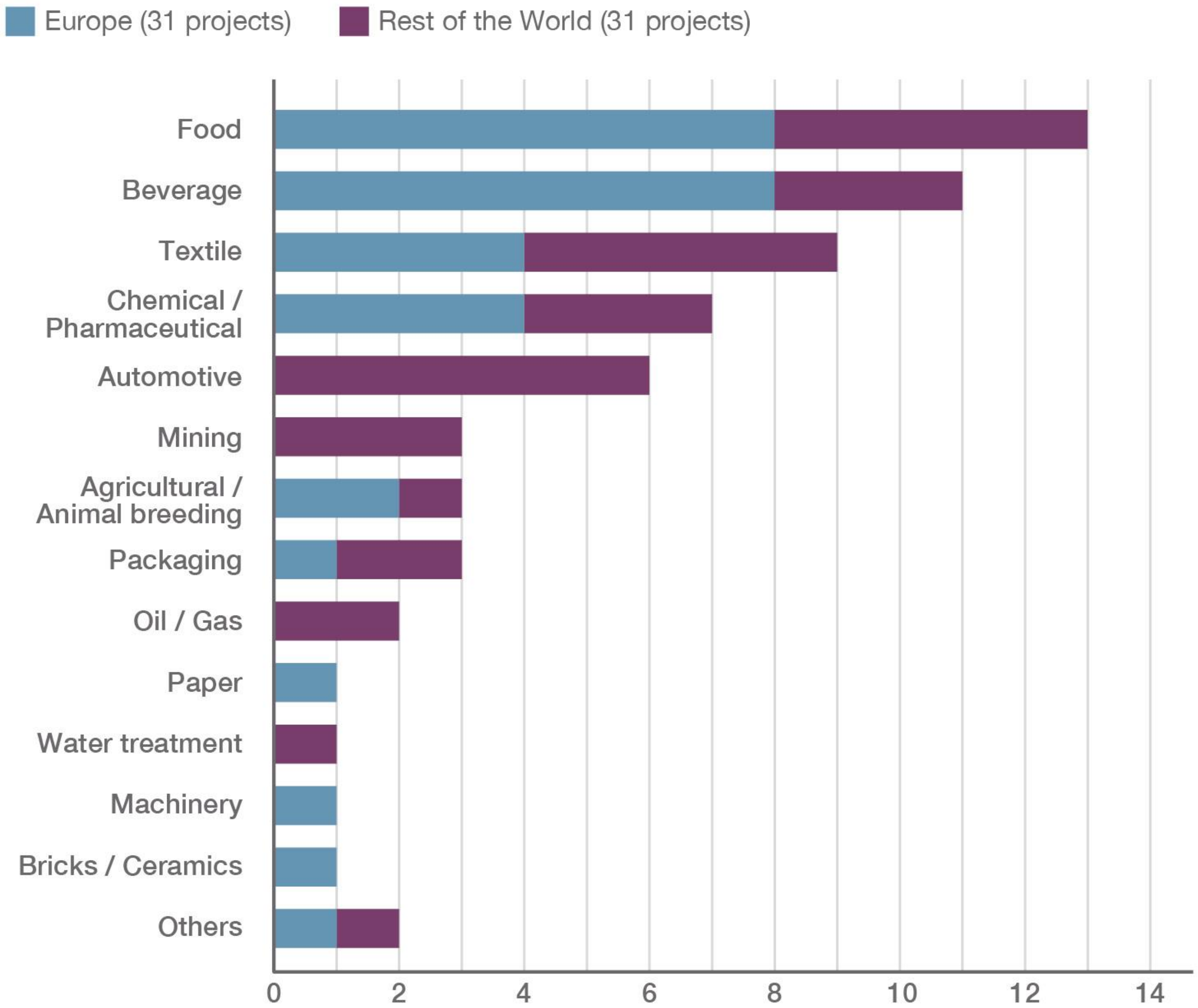
- Eastern Europe
- Central Europe
- Southern Europe





Source: solrico
Status: September 2023
SHIP = Solar Heat for Industrial Processes

A wide range of industrial clients trust solar industrial heat solutions worldwide



Industrial sectors of announced SHIP projects
Source: solrico, Status: September 2023

Read more….

- News articles about the most recent SHIP Supplier Surveys including : https://solarthermalworld.org/modulus/
- Check out the SHIP Supplier World map: http://www.solar-payback.com/suppliers/
- Download the infographics of the Solar Industrial Heat Outlook 2023-2026: https://solarthermalworld.org/news/promising-solar-industrial-heat-outlook-2023-2026/
- Use photos of SHIP plants for your presentations: https://www.solar-payback.com/gallery/gallone_en.php
- Keep updated on trends in the solar thermal industry by subscribing the monthly newsletter of solarthermalworld.org: https://solarthermalworld.org/newsletter/
- Follow us on twitter: https://twitter.com/solarthermal
- And further questions and comments to: Bärbel Epp: epp@solrico.com

Thanks for your attention!

Bärbel Epp, epp@solrico.com

www.solrico.com; www.solar-payback.com
www.solarthermalworld.org

Testing, Certification, Power and Energy yield Check Methods

Stefan Mehnert

SFERA-III Training for Industries: CST4SHIP

Freiburg, Nov 8, 2023

www.ise.fraunhofer.de

Agenda
Fraunhofer ISE

What can you expect here today?

- Certification of solar thermal collectors (09:15 – 09:45)
- Visit the outdoor testing facilities of the TestLab Solar Thermal Systems (09:45 – 10:15 + 15 Min coffee break)
- Performance Characterization and Function Testing of solar thermal collectors (10:30 – 11:15)
- Performance and Energy Yield Check Methods for large scale Systems (11:15 – 12:00)

What are your special interests regarding those topics?

- …

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Agenda
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Part 1
Certification of solar thermal collectors

Agenda
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- **Certification of solar thermal collectors (and Energy Labeling?)**
  - Why certification of solar thermal collectors?
  - Available certification marks
  - Comparison of certification marks
  - Solar Keymark Certification

Certification of solar thermal collectors

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Why certification of solar thermal collectors?

- To reduce trade barriers and promote the use of high quality solar thermal products
- Assuring end-consumers that the products are fully tested according to the relevant standards
- Allowing manufacturers to introduce new products into the market
- Demonstration of comparable results within publicly available data bases
- Governments recognize the certification as a useful for public support schemes.
- And others …

Certification of solar thermal collectors

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Available certification marks

Europe

- SKM - Solar Keymark Certification (https://solarkeymark.eu/)

USA

- SRCC – Solar Rating & Certification Corporation (ICC-SRCC™) (https://solar-rating.org/)

North America & Canada

- North America’s premier plumbing and mechanical product certification agency (https://www.iapmort.org/)

Autralia & New Zeeland

- StandardMark™ certification program (https://www.saiglobal.com)

Global

- GSCN – Global Solar Certification Network (www.gscn.solar)

(**The GSCN is not an original or primery certification mark.** It’s a global network of certification bodies, inspectors, test labs and solar thermal industr es committed to strengthening the solar thermal market.)

This Network works on the harmonization and the mutual recognition of regional certification schemes.

Certification of solar thermal collectors

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Comparison of certification marks

- All based on the same testing standard (ISO 9806:2017)
- SKM is related to EN12975:2022, since it is a European certification mark. But EN12975 is linked to ISO 9806
- SRCC and IAPMO are based on their own standards (OG-100 in case of SRCC), but those standards are also linked to ISO 9806
- GSCN provides no own certification scheme, just recognition/mutual agreements to existing once. Therefore, it provide guidance and suggestions for implementing certification schemes for solar thermal collectors in different countries and regions

IAPMO	SRCC	SKM	
			Scope
✓	✓	✓	SLHC (Solar Liquid Heating Collectors)
✓	✓	✓	SAHC (Solar Air Heating Collectors)
✓	✓	✓	WISC (Wind and Infrared Sensitive Collector)
✓	✓	✓	CSC (Concentrating Solar Collector)
✓	✓	✓	PVT (Photovoltaic Thermal Solar Collector)
			Thermal Performance
✓	✓	✓	SLHC performance measurement
✓	✓	✓	SAHC performance measurement
✓	✓	✓	Effective thermal capacity
×	×	×	Leakage rate
✓	✓	×	Time constant
			Durability, Reliability and Safety
✓	✓	✓	Internal Pressure Test
×	×	×	Rupture and Collapse Test
✓	✓	✓	Exposure Test
✓	✓	✓	External Thermal Shock Test
✓	✓	✓	Internal Thermal Shock Test
×	×	✓	Rain Penetration Test
×	×	✓	Mechanical Load Test
×	×	✓	Standard Stagnation Temperature
×	×	×	Maximum Start Temperature
✓	✓	✓	Pressure Drop
✓	✓	×	Impact Resistance
×	×	✓	Freeze Resistance
✓	✓	✓	Final Inspection
			Certification Requirements (surplus)
✓	✓	✓	Factory Inspection
✓	✓	✓	Remote Sampling

Source: Guide to ISO 9806:2017; https://www.iea-shc.org/Data/Sites/1/publications/Guide-to-Standard-ISO-9806-2017-2.0.pdf

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Certification of solar thermal collectors

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Solar Keymark Certification – Basics

SK is a product certification scheme according to EN ISO/IEC 17067:2013-12 and therefore the functional approach as described in ISO/IEC 17000:2004, Annex A. The functions are:

Functions	Responsible
▪ **selection**, which includes planning and preparation activities to collect or produce all the information and input needed for the subsequent determination function; ▪ **determination**, which includes conformity assessment activities such as testing, measuring, inspection to provide information regarding the product requirements as input to the review and attestation functions;	TestLab
▪ **review**, which means verification of the results of these activities, about fulfilment of specified requirements ▪ **decision** on certification; ▪ **attestation**, which means issue of a statement of conformity	CB
▪ **surveillance**, which means systematic iteration of conformity assessment activities as a basis for maintaining the validity of the statement of conformity	IB/CB

Certification of solar thermal collectors

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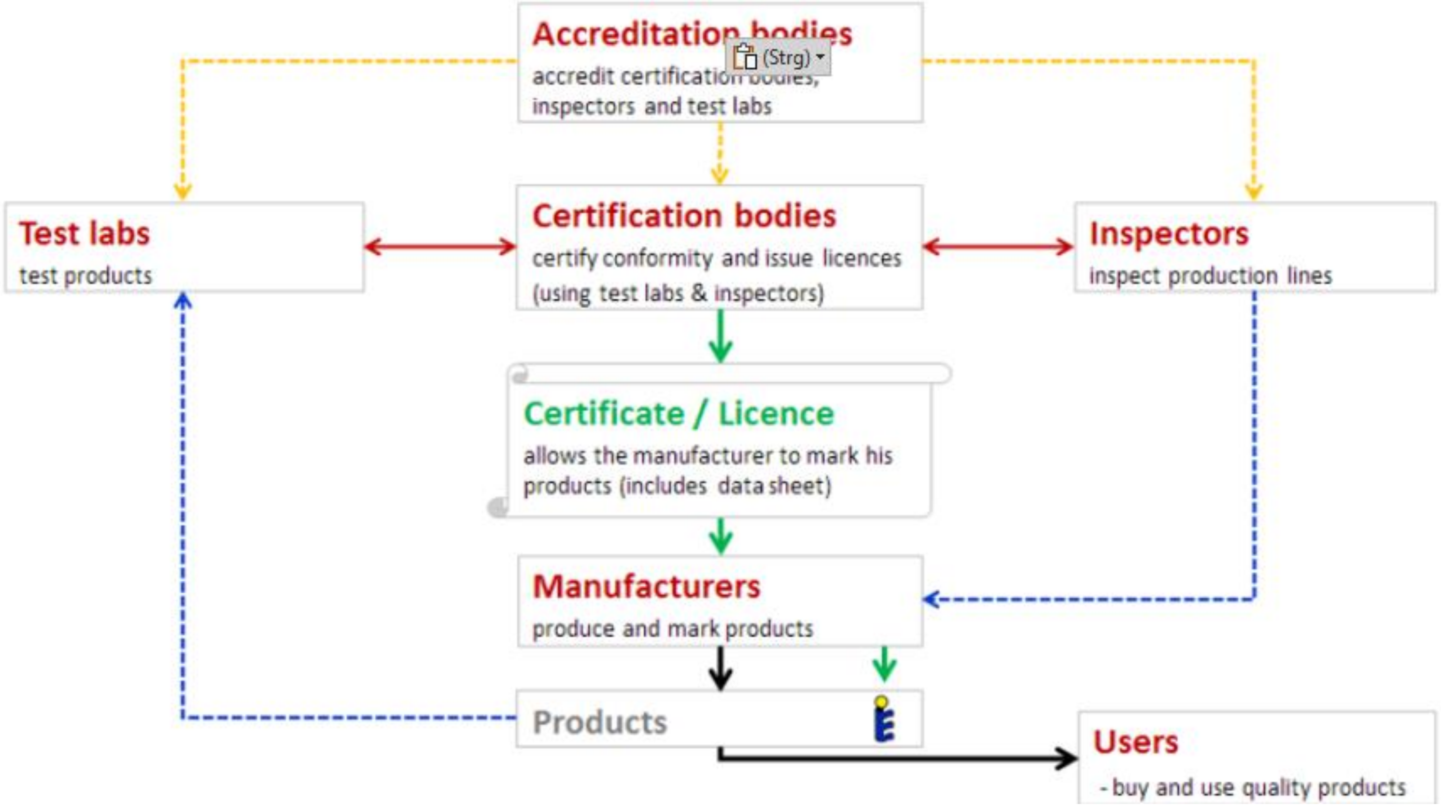
Solar Keymark Certification - Involved Parties and their Responsibility



Source: Guide to ISO 9806:2017; https://www.iea-shc.org/Data/Sites/1/publications/Guide-to-Standard-ISO-9806-2017-2.0.pdf

Certification of solar thermal collectors

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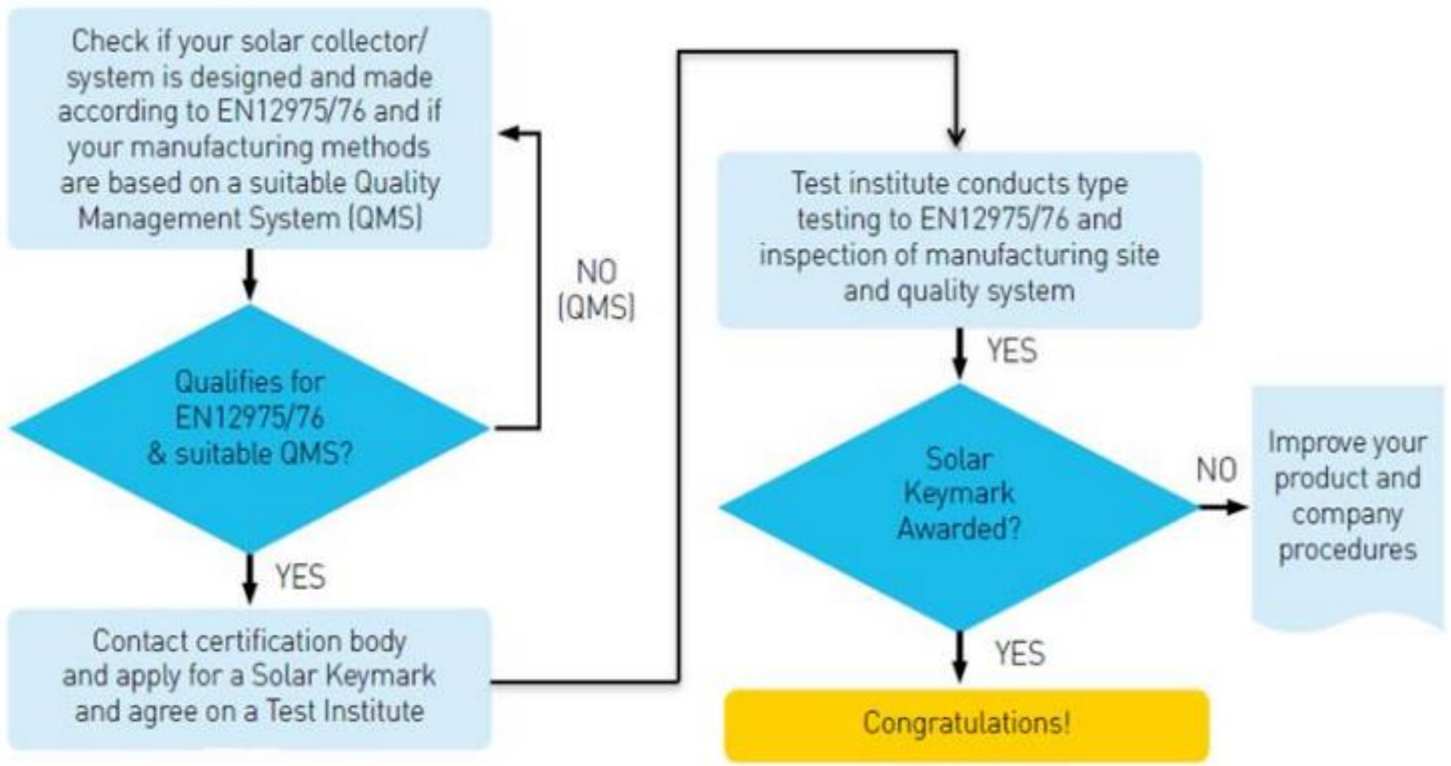
Solar Keymark Certification – Certification procedure



The flow chart shows the general certification process of Solar Keymark Certification. Due to legal requirements, a Solar Keymark Certificate can only be issued based on tests according to a European standard. For this reason, the European collector test standard EN 12975 is mentioned within this chart. Nevertheless, the tests and measurements must be performed according to ISO 9806, which defines the testing requirements and is the reference in EN 12975.

Source: Guide to ISO 9806:2017; https://www.iea-shc.org/Data/Sites/1/publications/Guide-to-Standard-ISO-9806-2017-2.0.pdf

Certification of solar thermal collectors

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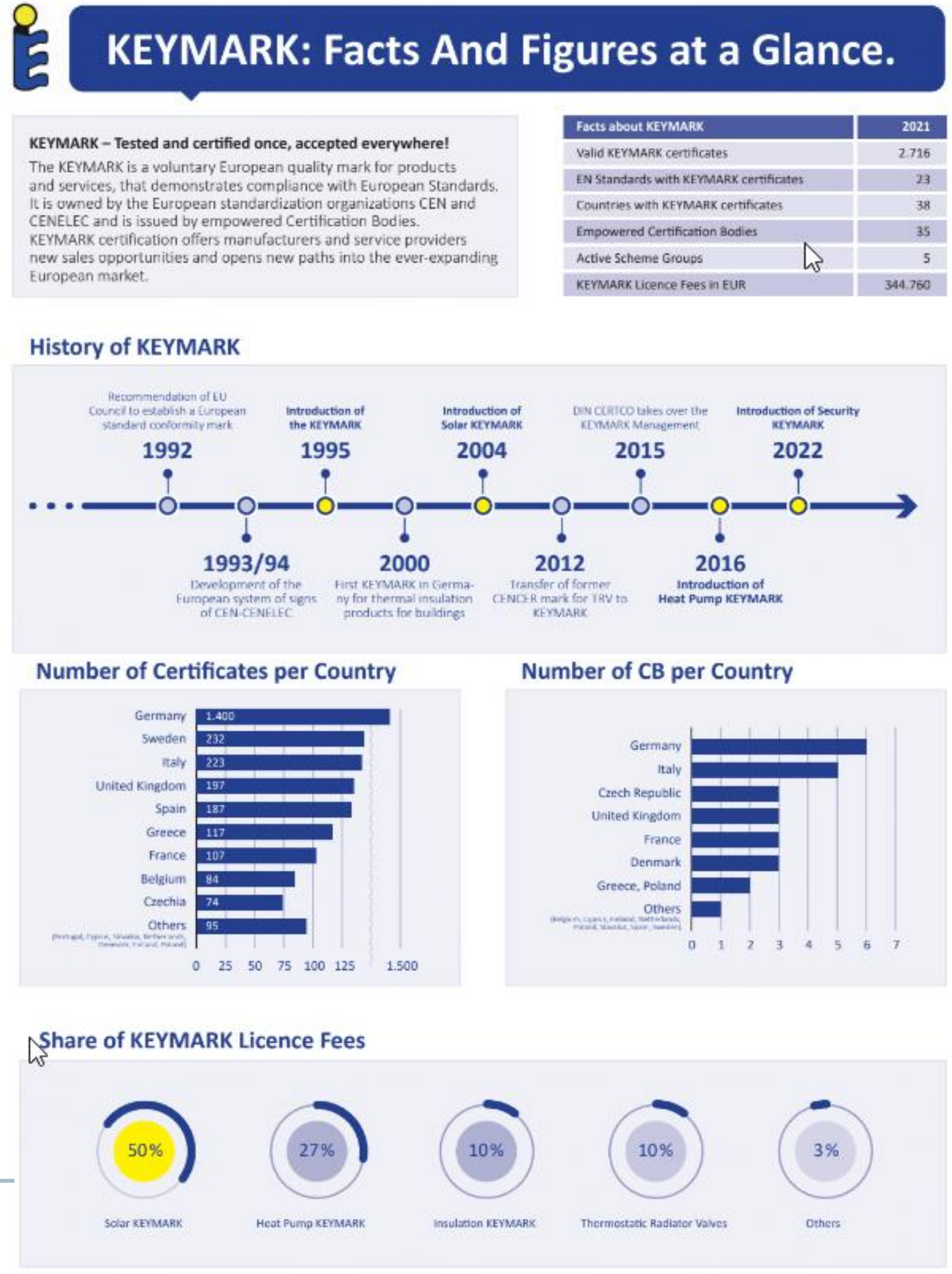
Solar Keymark Certification – Basics

- Developed by the Solar Heat Europe/ESTIF and CEN (European Committee for Standardization) in close co-operation with leading European TestLabs and with the support of the European Commission
- More than 35 Solar Keymark empowered certification bodies
- Around 25 Solar Keymark test labs
- 2100 different products/brands
- 740 Manufacturers/distributors from 36 different countries



>> More Information about "Solar Keymark across Europe" see: https://solarkeymark.eu/about-solar-keymark/solar-keymark-across-europe/

Certification of solar thermal collectors

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Solar Keymark Certification – Scheme Rules

The Solar Keymark Scheme Rules

The overall rules for the Solar Keymark certification scheme follow the general Keymark rules given in the CEN documents below.

CEN/CENELEC Internal Regulations: Part 4 Certification, July 2018 (PDF)

The specific Solar Keymark rules acts as a supplement to the general rules, giving the specific requirements related to the particular Keymark certification of solar thermal products.

SOLAR KEYMARK **SKN_N0444R6_SK_Scheme Rules** (PDF) / Edition 2022-06-02

SKN_N0484R9_History-and-List-of-changes-for-SRs-N0444

Source: https://solarkeymark.eu/the-network/certification-scheme-rules /

Certification of solar thermal collectors

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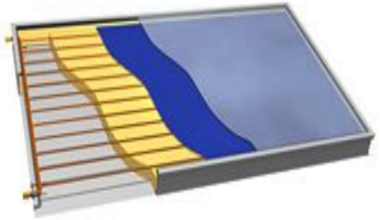
Solar Keymark Certification – Scheme Rules, Annexes

- Annex A - Inspection report templates
- Annex E - FPC
- Annex P - Product Specific Annex: Collectors EN 12975
- Annex Q - Product Specific Annex: Systems EN 12976
- Annex R - Product Specific Annex: Systems EN 12977
- Annex W - Weather Database

Source: https://solarkeymark.eu/the-network/certification-scheme-rules/



Certification of solar thermal collectors
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Solar Keymark Certification – Network

- to maintain and continuously improve the Solar Keymark scheme rules and procedures;
- harmonies practical procedures;
- exchange experience amongst operators;
- exchange information between industry and operators;
- arrange comparative testing "Round Robin" amongst test labs;
- inform about Solar Keymark;
- list certified products;
- list empowered and accredited operators

Become a member of the Solar Keymark Network, to represent your specific interests (https://solarkeymark.eu/stakeholders/manufacturers/)

Certification of solar thermal collectors
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Solar Keymark Certification – Transparency of decisions

Internal area on the homepage, providing

- all recent documents
- Internal regulations
- Publicly available decision list

Source: https://solarkeymark.eu/the-network/internal-documents/

Certification of solar thermal collectors

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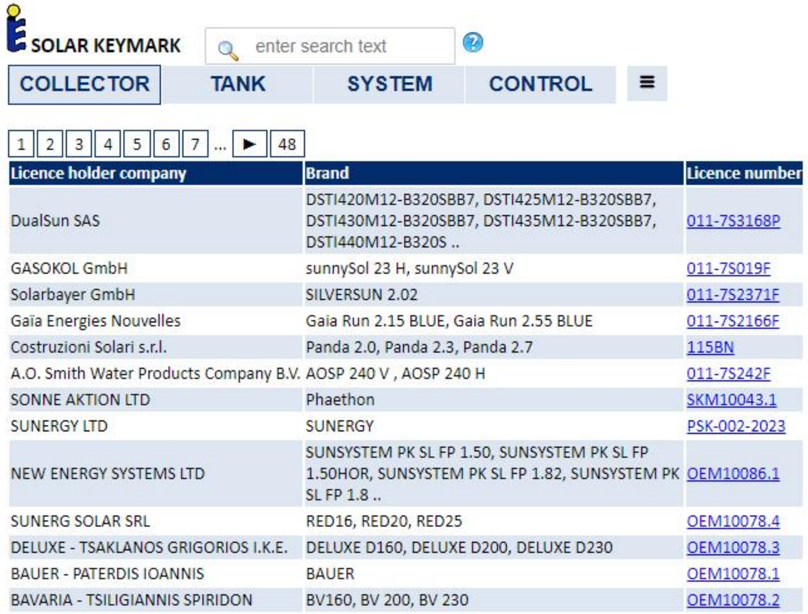
Solar Keymark Certification – The data base

- Lists all Solar Keymark certified collectors, tanks, systems and controllers in a standardized way
- Shows the conformity of the product with the related products standard (in case of collectors EN12975 and ISO 9806)
- Gives an overview about the test results in form of a standardized data sheet
- https://solarkeymark.eu/database/



Licence holder company	Brand	Licence number
DualSun SAS	DSTI420M12-B320SBB7, DSTI425M12-B320SBB7, DSTI430M12-B320SBB7, DSTI435M12-B320SBB7, DSTI440M12-B320S ..	011-7S3168P
GASOKOL GmbH	sunnySol 23 H, sunnySol 23 V	011-7S019F
Solarbayer GmbH	SILVERSUN 2.02	011-7S2371F
Gaïa Energies Nouvelles	Gaia Run 2.15 BLUE, Gaia Run 2.55 BLUE	011-7S2166F
Costruzioni Solari s.r.l.	Panda 2.0, Panda 2.3, Panda 2.7	115BN
A.O. Smith Water Products Company B.V.	AOSP 240 V , AOSP 240 H	011-7S242F
SONNE AKTION LTD	Phaethon	SKM10043.1
SUNERGY LTD	SUNERGY	PSK-002-2023
NEW ENERGY SYSTEMS LTD	SUNSYSTEM PK SL FP 1.50, SUNSYSTEM PK SL FP 1.50HOR, SUNSYSTEM PK SL FP 1.82, SUNSYSTEM PK SL FP 1.8 ..	OEM10086.1
SUNERG SOLAR SRL	RED16, RED20, RED25	OEM10078.4
DELUXE - TSAKLANOS GRIGORIOS I.K.E.	DELUXE D160, DELUXE D200, DELUXE D230	OEM10078.3
BAUER - PATERDIS IOANNIS	BAUER	OEM10078.1
BAVARIA - TSILIGIANNIS SPIRIDON	BV160, BV 200, BV 230	OEM10078.2

Source: https://solarkeymark.eu/database/

Certification of solar thermal collectors

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Solar Keymark Certification – The data sheet (Page 1)

- Shows the
  - standardizes power output per collector
  - The determined efficiency parameters
  - The determined IAM-Values
  - The boundary conditions for testing
  - The related test report
  - Some additional information (if required)

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Page 1/2

Annex to Solar Keymark Certificate - Summary of EN ISO 9806:2013 Test Results		Licence Number	011-7S140 F
		Date issued	2017-07-10
		Issued by	Din Certco
Licence holder	Sunex S.A.	Country	Poland
Brand (optional)		Web	www.sunex.pl
Street, Number	ul. Piaskowa 7	E-mail	info@sunex.pl
Postcode, City	47-400 Raciborz	Tel/Fax	+48324149214
Collector Type		Flat plate collector, glazed	

Collector name	Gross area (A_G)	Gross length	Gross width	Gross height	Power output per collector, Gb = 850 W/m²; Gd = 150 W/m², ϑm - ϑa: 0 K	10 K	30 K	50 K	70 K	75 K
	m²	mm	mm	mm	W	W	W	W	W	W
SX 2.0	2,01	1.900	1.060	100	1.429	1.358	1.207	1.044	870	825
SX 2.51	2,51	2.240	1.120	100	1.785	1.695	1.507	1.304	1.087	1.030
SX 2.85	2,85	2.240	1.270	100	2.026	1.925	1.711	1.480	1.234	1.170
Power output per m² gross area					711	675	600	519	433	411

Performance parameters test method	Steady state - outdoor		
Performance parameters (related to AG)	η0,hem	a1	a2
Units	-	W/(m²K)	W/(m²K²)
Test results	0,711	3,48	0,007

Incidence angle modifier test method		Steady state - outdoor								
Bi-directional incidence angle modifiers	No									
Incidence angle modifier	Angle	10°	20°	30°	40°	50°	60°	70°	80°	90°
Transversal	$K_{\theta T,coll}$	1,00	0,99	0,98	0,95	0,90	0,81	0,66	0,41	0,00
Longitudinal	$K_{\theta L,coll}$	1,00	0,99	0,98	0,95	0,90	0,81	0,66	0,41	0,00

Heat transfer medium for testing	Water		
Flow rate for testing (per gross area, A_G)	dm/dt	0,020	kg/(sm²)
Maximum temperature difference for thermal performance calculations	$(\vartheta_m - \vartheta_a)_{max}$	75	K
Standard stagnation temperature (G = 1000 W/m²; ϑ_a = 30 °C)	ϑ_{stg}	204	°C
Effective thermal capacity, incl. fluid (per gross area, A_G)	C/m²	4,9	kJ/(Km²)
Maximum operating temperature	$\vartheta_{max\ op}$	95	°C
Maximum operating pressure	$p_{max,op}$	600	kPa

Testing laboratory	TestLab Solar Thermal Systems, Fraunhofer ISE	http://www.collectortest.com	
Test report(s)	ktb-2017-02 ktb-2017-03	Dated	06.07.2017 06.07.2017

Comments of testing laboratory — Datasheet version: 5.01, 2016-03-01

According to Scenocalc v5.01 the power output per collector unit of a steady state performance test does not consider the fraction of the diffuse irradiance, but it is calculated based on η0,hem for a global hemispherical irradiance of 1000 W/m².

TestLab
Solar Thermal
Systems
Heidenhofstraße 2
D-79110 Freiburg
Tel: +49 (0)761 4588 5354

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Certification of solar thermal collectors

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Solar Keymark Certification – The data sheet (Page 1)

- Shows the:
  - Gross thermal yield per collector and m² at four different locations, Athens, Davos, Stockholm, Würzburg
  - Climate class which the collector has been tested for
  - Mechanical load boundaries
  - Data required for CDR (EU) No. 812/2013
- Gives additional information about:
  - Recommended heat transfer medium
  - Installation

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Page 2/2

Annex to Solar Keymark Certificate		Licence Number	011-7140 F
Supplementary Information		Issued	2017-07-10

Annual collector output in kWh/collector at mean fluid temperature ϑ_m, based on EN ISO 9806:2013 test results

Standard Locations		Athens			Davos			Stockholm			Würzburg		
Collector name	ϑ_m	25°C	50°C	75°C	25°C	50°C	75°C	25°C	50°C	75°C	25°C	50°C	75°C
SX 2.0		2.211	1.568	1.043	1.675	1.168	764	1.230	809	506	1.335	868	535
SX 2.51		2.762	1.957	1.302	2.092	1.459	954	1.536	1.010	632	1.667	1.085	669
SX 2.85		3.136	2.223	1.479	2.376	1.657	1.083	1.744	1.147	718	1.893	1.231	759
Annual output per m² gross area		1.100	780	519	834	581	380	612	402	252	664	432	266
Fixed or tracking collector		Fixed (slope = latitude - 15°; rounded to nearest 5°)											
Annual irradiation on collector plane		1765 kWh/m²			1714 kWh/m²			1166 kWh/m²			1244 kWh/m²		
Mean annual ambient air temperature		18,5°C			3,2°C			7,5°C			9,0°C		
Collector orientation or tracking mode		South, 25°			South, 30°			South, 45°			South, 35°		

The collector is operated at constant temperature ϑm (mean of in- and outlet temperatures). The calculation of the annual collector performance is performed with the official Solar Keymark spreadsheet tool Scenocalc Ver. 5.01 (March 2016). A detailed description of the calculations is available at www.solarkeymark.org/scenocalc

Additional Information

Collector heat transfer medium	Water-Glycole	
Hybrid Thermal and Photo Voltaic collector	No	
The collector is deemed to be suitable for roof integration	No	
The collector was tested successfully according to EN ISO 9806:2013 under the following conditions:		
Climate class (A, B or C)	B	--
Maximum tested positive load	2400	Pa
Maximum tested negative load	1200	Pa
Hail resistance using ice balls (diameter)	0	mm

Energy Labelling Information

	Reference Area, A_{sol} (m²)	Data required for CDR (EU) No 811/2013 - Reference Area A_{sol}		
SX 2.0	2,01	Collector efficiency (η_{col})	56	%
SX 2.51	2,51			
SX 2.85	2,85			

Remark: Collector efficiency (η_{col}) is defined in CDR (EU) No 811/2013 as collector efficiency of the solar collector at a temperature difference between the solar collector and the surrounding air of 40 K and a global solar irradiance of 1000 W/m², expressed in % and rounded to the nearest integer. Deviating from the regulation η_{col} is based on reference area (A_{sol}) which is aperture area for values according to EN 12975-2 or gross area for ISO 9806:2013.

Data required for CDR (EU) No 812/2013 - Reference Area A_{sol}		
Zero-loss efficiency (η_0)	0,711	--
First-order coefficient (a_1)	3,48	W/(m²K)
Second-order coefficient (a_2)	0,007	W/(m²K²)
Incidence angle modifier IAM (50°)	0,90	--

Remark: The data given in this section are related to collector reference area (A_{sol}) which is aperture area for values according to EN 12975-2 or gross area for ISO 9806. Consistent data sets for either aperture or gross area can be used in calculations like in the regulation 811 and 812 and simulation programs.

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Certification of solar thermal collectors

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Solar Keymark Certification – Summary

- Voluntary quality mark based on a third-party product certification scheme according to EN ISO/IEC 17067, System 5
- Industry driven (ESTIF)
- Implemented in codes, regulations, laws and subsidy instruments
- Based on EN Standards
- https://solarkeymark.eu/

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Thank you for your attention!

Comming next

Visit of our outdoor testing facilities (30 Min)

Short coffee break (until 10:30)

Performance Characterization and Function Testing solar thermal collectors

Performance Characterization and Function Testing solar thermal collectors

Agenda
Fraunhofer ISE

- **Performance Characterization and Function Testing solar thermal collectors**
- Most relevant standards – an overview
- Testing solar thermal collectors – Function Tests
- Testing solar thermal collectors – Performance Characterization
- Testing solar thermal collectors - Result Presentation + two exercises

Most relevant standards

Performance Characterization and Function Testing solar thermal collectors

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Most relevant standards – an overview

Reference	Tilte	Scope
EN ISO 9488:2022	Solar energy - Vocabulary	defines basic terms relating to solar energy
EN 12975:2022	Solar collectors - General requirements	secifies requirements … with respect to durability, reliability, safetyand thermal performance
ISO 22975-1:2016	Collector components and materials Part 1: Evacuated tubes	specifies definitions and test methods for materials, durability and performance <u>of all types of </u>evacuated tubes
ISO 22975-2:2016	Collector components and materials Part 2: Heat-pipes for solar thermal application	specifies definitions and test methods for durability and performance of heat-pipes for solar thermal application
ISO 22975-3:2014	Collector components and materials Part 3: Absorber surface durability	specifies a failure criterion of a solar absorber based on changes in optical performance of the absorber
ISO 22975-4:2023	Collector components and materials Part 4: Glazing material durability and performance	specifies definitions and test methods for glazing material durability and performance
ISO 9806:2017	Solar energy - Solar thermal collectors - Test methods	specifies test methods for assessing the durability, reliability, safety and thermal performance … . applicable for laboratory testing <u>and for in situ testing</u>.

Performance Characterization and Function Testing solar thermal collectors

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Most relevant standards – an overview

Reference	Tilte	Scope
EN ISO 9488:2022	Solar energy - Vocabulary	defines basic terms relating to solar energy
EN 12975:2022	Solar collectors - General requirements	secifies requirements … with respect to durability, reliability, safetyand thermal performance
ISO 22975-1:2016	Collector components and materials Part 1: Evacuated tubes	specifies definitions and test methods for materials, durability and performance of all types of evacuated tubes
ISO 22975-2:2016	Collector components and materials Part 2: Heat-pipes for solar thermal application	specifies definitions and test methods for durability and performance of heat-pipes for solar thermal application
ISO 22975-3:2014	Collector components and materials Part 3: Absorber surface durability	specifies a failure criterion of a solar absorber based on changes in optical performance of the absorber
ISO 22975-4:2023	Collector components and materials Part 4: Glazing material durability and performance	specifies definitions and test methods for glazing material durability and performance
ISO 9806:2017	Solar energy - Solar thermal collectors - Test methods	specifies test methods for assessing the durability, reliability, safety and thermal performance … . applicable for laboratory testing and for in situ testing.

Testing solar thermal collectors - Function Test

Performance Characterization and Function Testing solar thermal collectors

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Testing solar thermal collectors - Function checks

- Function test are intended to determine the ability of collectors to withstand normal operation conditions, like:
  - Pressures which might occur >> Internal pressure test
  - Operation and stagnation temperatures, humidity, rain, thermal cycling >> Exposure test, Stagnation test
  - Sudden cold rain on hot sunny days >> External thermal shock test
  - Sudden intake of cold heat transfer media >> Internal thermal shock test
  - Ingress of Water >> Rain penetration test
  - Freezing >> Freeze resistance test
  - Wind and snow loads >> Mechanical load test
  - Hail impacts >> Impact resistance test

(Annotation: List is incomplete, since tests for SAHC has not been considered)








Performance Characterization and Function Testing solar thermal collectors

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Testing solar thermal collectors - Function checks

- Results of Function Test are partly determined directly after testing (e.g., mechanical load) or even during the final inspection (e.g., rain penetration)
- Boundary conditions for Function Tests are only partly given by ISO 9806:2017
- Boundaries for the exposure class, permissible mechanical loads, internal pressure and hail resistance must be defined by the manufacturer and tested respectively
- Test boundaries can also result from previous tests (e.g., usage of determined Standard Stagnation Temperature for internal pressure test of polymeric absorbers)
- For detailed information about:
  - Test requirement and boundary conditions
  - How to conduct a certain test
  - Manufacturers information
  - Exemplary results

Please see: Guide to ISO 9806:2017

Let's have a short look together!

Performance Characterization and Function Testing solar thermal collectors

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Testing solar thermal collectors – Collectors with special attributes

- The ISO 9806:2017 covers the most current standard products. Some of those collectors has special attributes which must be considered in testing
- Special attributes are:
  - Collectors using external power sources for normal operation (e.g. SAHC, tracking and concentrating, …)
  - Collectors using active or passive measures for normal operation and self-protection (tracking and concentrating)
  - …
  - Further examples (e.g. Co-generating thermal and electrical power, Wind and/or infrared sensitive collectors (WISC), Façade collectors and others) see: Guide to ISO 9806:2017, Chapter 5.1

  - Let’s have a closer look on Collectors using external power sources and Tracking/Concentrating Collectors

Performance Characterization and Function Testing solar thermal collectors

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Testing solar thermal collectors - Testing solar thermal collectors with special attributes

- Collectors using external power sources and/or active or passive measures for normal operation and self protection:
  - If the collector which is using external power sources and/or active or passive for normal operation and self-protection is installed at the testing side of the testing laboratory, it is recommended that the manufacturer is present during the installation to avoid installation errors, errors in commissioning, and system settings;
  - External parts of collectors like cabinets, sensors, etc. shall be weatherproof. Components which are an integral part of the collector (e.g. actuators, motors, cabinets, etc.) for which water penetration can be expected shall be a part of the rain penetration test;
  - The function of a USP-System (undisturbed power supply) can easily be checked by interruption of main power supply.

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Testing solar thermal collectors - Testing solar thermal collectors with special attributes

- Tracking and concentrating collectors
  - To be tested using the supplier's tracking system;
  - Specific aspects related to durability testing, e.g., active protection;
  - The procedure for the determination of the incident angle modifier as given within ISO 9806:2017 might not be applicable in case of unsymmetrical collector constructions without further adaptions;
  - In-Situ testing might be necessary in case of large (tracking/concentrating) collectors;

Testing solar thermal collectors - Performance Characterization

Performance Characterization and Function Testing solar thermal collectors

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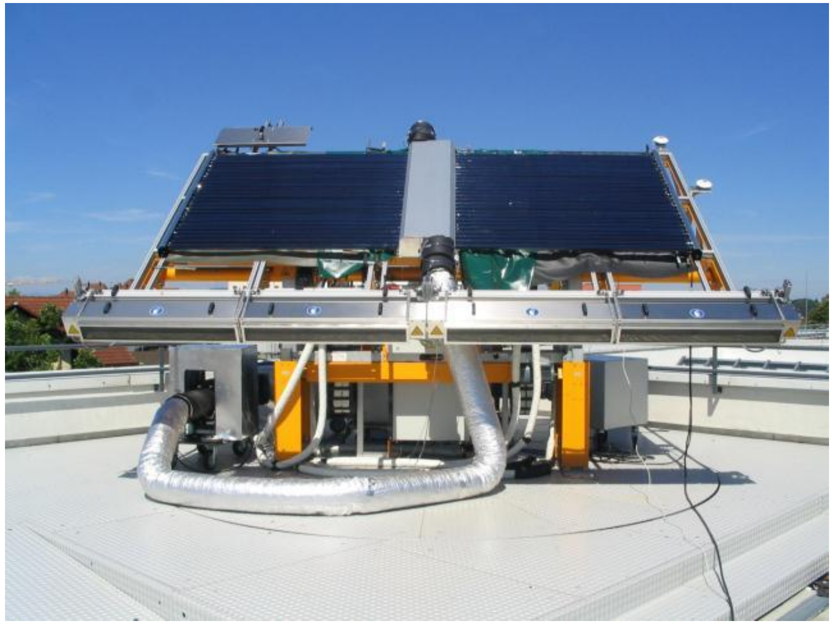
Performance characterization - Methods



- Typically, one of the two following measuring methods is used:
  - Steady-State Test >> see ISO 9806:2017, Chapter 23.6.1
  - Quasi-Dynamic Test >> see ISO 9806:2017, Chapter 23.6.2
  - In-Situ QDT >> see ISO 9806:2017, Chapte 23.6.1 and Annex P5.5 of the Solar Keymark Scheme Rules

Performance Characterization and Function Testing solar thermal collectors

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Performance characterization - Methods

- Steady State Testing (SST) and Quasi Dynamic Testing (QDT) exist as equivalent methods in the standard
- The methods have been compared in several round-robin tests and the overall uncertainty achieved was around ±2% (pp) for the $\eta_{0,hem}$ value
- Only the QDT model includes the differentiation of diffuse and direct radiation >> more applicable for collectors whose thermal performance is sensible to the diffuse fraction (e.g., concentrating collectors)
- QDT does not require a tracking facility >> might be an advantage
- SST, the boundary conditions have a direct influence on the collector parameters. Thus, the influence of single development steps (e.g., new absorber coating, etc.) can be easily observed

Collector type	SST	QDT
Concentrating Collector (SLHC)	-	✓
SLHC	✓	✓
SAHC	✓	-
OTA-SAHC	✓	-
WISC	✓	✓

SST	Steady State Testing
QDT	Quasi Dynamic Testing
SLHC	Solar Liquid Heating Collector
SAHC	Solar Air Heating Collector
OTA	Open To Ambient
WISC	Wind and Irradiance Sensitive Collector

Performance Characterization and Function Testing solar thermal collectors

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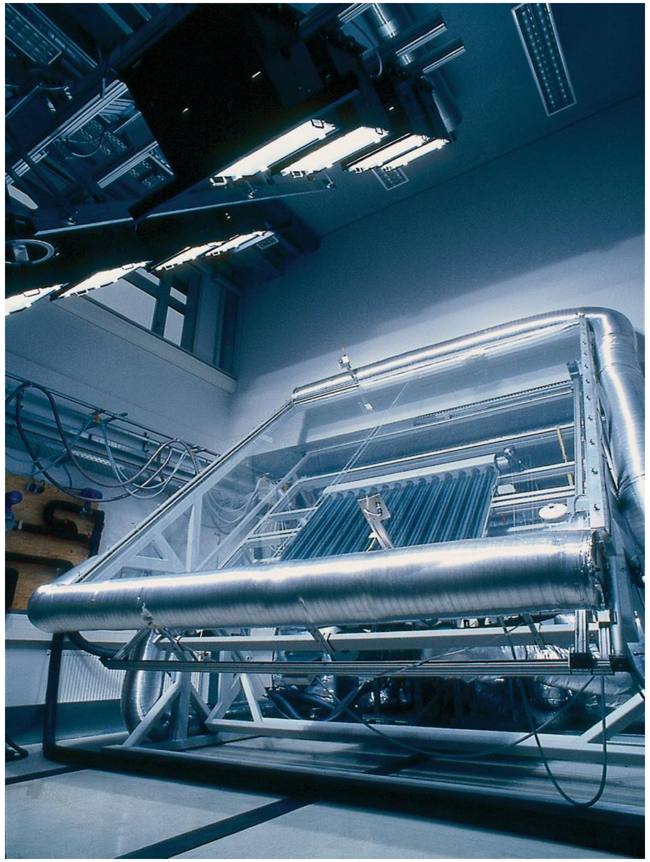
Performance characterization - Installation

- Installation requirements are defined by ISO 9806:2017, for:
  - Different collector technologies (e.g., flat plate, vacuum tube, WISC, tracking and concentrating, …), Indoor and outdoor performance characterization, SST and QDT performance characterization, Liquid heating and air heating collectors, Open to ambient and closed loop air heating collectors and others …
- The requirements covers:
  - Manufacturers specifications, surrounding conditions, air circulation, insulation conditions, …
- In case of In-Situ-Measurements additional parameters must be considered, like:
  - Usage of manufacturers tracking system, shadowing in case of fixed installations, and others …
- For more Information, please see Fact Sheet 22 of Guide to ISO 9806



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Performance Characterization and Function Testing solar thermal collectors

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Performance characterization - Instrumentation

- Instrumentation requirements are defined by ISO 9806:2017, for:
  - Solar radiation (Global, Diffuse and Direct Irradiance), Thermal radiation, Fluid temperature for liquid heating collectors and air heating collectors, Surrounding air temperature, Surrounding air speed, And others…
- The requirements covers:
  - Sensor specifications, permitted measurement uncertainties, sampling rates as well as installation location and instructions
- Fulfilling Instrumentation requirements is often one of the most challenging tasks in case of In-Situ-Measurements!!!

- For more details see Fact Sheet 21 of Guide to ISO 9806

Guide to the standard ISO 9806:2017

21 Instrumentation

Solar Radiation Measurement – General

Accurate irradiance measurements are quite difficult to perform but indispensable for accurate determination of collector efficiency. Care should be taken to avoid shading and reflected irradiance on collector and measuring equipment. Measurement equipment shall always be well aligned with the collector tilt and azimuth. If a Pyrheliometer is used, the tracking errors associated to the mounting on the tracker must not exceed ± 0.5°. All irradiance sensors must be Class I or better, as specified in ISO 9060.
A good maintenance of radiation instruments includes regular cleaning and checking of desiccant condition.

Global, Diffuse and Direct Irradiance

The power output of some collector designs such as ETCs, CPCs and any other concentrating type of collector will strongly depend on the distinction between beam and diffuse irradiance. Diffuse irradiance can be measured by a Pyranometer equipped with a shadow ring or tracking ball, direct irradiance by a tracked Pyrheliometer, global irradiance by a regular Pyranometer. Depending on the combination of instruments chosen, one of the quantities can be calculated from the formulas:

$$G_b = DNI \cos\theta$$
$$G_d = G_{hem} - G_b$$

Best results will be reached with a combination including a Pyrheliometer to measure the direct normal irradiance (DNI). For highly concentrating collectors (CR > 3) the usage of a Pyrheliometer is mandatory.

Thermal Radiation Measurement

The consideration of the long wave irradiance E_L is needed for the characterization of infrared sensitive collectors (e.g. collectors for swimming pool heating) and can be measured using a Pyrgeometer mounted in the plane of the collector. If long-wave irradiance is accounted for, it shall be determined to a standard uncertainty of 10 W/m².

Temperature Measurement - General

Mounting position, immersion depth and fluid flow characteristics are crucial for the quality of temperature measurements. The sensors shall not be more than 200mm from the collector inlet and outlet. The pipework should be carefully insulated, ideally including the sensor head itself.

Liquid Heating Collectors

The sensor probe shall always point upstream, and a bend in the pipe work, an orifice or a fluid-mixing device shall be placed upstream of the sensor to ensure turbulent flow at the position of temperature measurement. A large immersion depth up to 10 times the inner pipe diameter minimizes temperature losses to the outside. The difference between the collector outlet and inlet temperatures (ΔT) shall be determined to a standard uncertainty of < 0.05 K and to an accuracy of better than 1 %.

Air Heating Collectors

The flow distribution shall be homogenized constructively over the channel cross-section. The temperature measurement shall be designed in a way that temperature gradients are balanced over the channels cross-section. The temperature of the heat transfer fluid at the collector inlet shall be measured to a standard uncertainty of ± 0.2 K.

Supported by: The Solar Keymark CEN Keymark Scheme

Performance Characterization and Function Testing solar thermal collectors

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Performance Characterization - In-Situ testing (QDT)

- In-Situ Test procedures has been developed over a large range of different projects, and IEA SHC Tasks:
- Projekts:
  - Zekon In-Situ, Fraunhofer ISE:
    - Development of the ICC-Method for the in-situ performance characterization accord. ISO 9806
  - Project MeQuso, AEE-Intec:
    - Development of the D-Cat Method for quality assessment of large collector arrays under fully dynamic operating conditions
  - CollFieldEff, AEE-Intec:
    - Characterization of the thermal performance of collector arrays with covered flat-plate collectors in real system operation

Performance Characterization and Function Testing solar thermal collectors

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Performance Characterization - In-Situ testing (QDT)

- All three methods are generally based on ISO 9806. But there are differences in the parameters used within the methods. Also, there are differences within the interpretation and processing the ISO 9806.
- The different methods were developed for different application purposes
- They neither compete with nor contradict each other but may even complement each other.
- It is important for manufacturers, planners and operators of plants to first define the objectives of a measurement campaign, the expected information and accuracies as well as acceptable time and cost effort precisely before deciding on a procedure.
- A detailed comparison is given in IEA SHC Task 55- Integrating Large SHC-Systems into DHC-Networks >> Review of In Situ Test Methods for Solar Collectors and Solar Collector Arrays
- Further Information about In-Situ Testing is given within https://task45.iea-shc.org/, https://task49.iea-shc.org/ ; https://task55.iea-shc.org/ ; https://task57.iea-shc.org/ ; https://task64.iea-shc.org/ ; https://task68.iea-shc.org/ (ongoing);

Performance Characterization and Function Testing solar thermal collectors

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Performance Characterization - In-Situ testing (QDT)

- But, how are in-situ testing is implemented into standardisation and certification?
- **Standardization:**
  - Out of the projekt ZeKon In-Situ and IEA TASK 55 the scope of ISO 9806:2017 has been extended to in-situ measurements
  - QDT performance characterization is required
  - IAM deterimination must mostly be adopted to the certain situation. (e.g., ray-traycing simulations or adopted iterative prodedures, …)
- **Certification**
  - The SKM Scheme Rules has been extended by Annex P5.5 - In-Situ Collector Certification. This annex describes:
  - Slightly different boundary conditions regarding the stability of measurements like inlet/outlet temperature, mass flow rate, etc.
  - For more information please see: Annex P5.5 – In-Situ Certification

Testing solar thermal collectors - Parameter Identification

Performance Characterization and Function Testing solar thermal collectors

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Performance characterization - SST method

daten.dat - Editor

Datei Bearbeiten Format Ansicht Hilfe

```
#21.04 054950 20990  0:TrF6 1:rF6 2:T_mp 3:G 4:wind 5:Thimu 6:Thimo 7:Tamb 8:Tw
21.04 054950 20990  24.286 -99.990 28.386 442.933  0.082 18.266 21.540 22.545 2
21.04 055000 21000  24.314 21.587 28.373 453.740  0.082 18.285 21.542 22.576 22
21.04 055010 21010  24.431 21.356 28.334 459.263  0.082 18.296 21.544 22.600 22
21.04 055020 21020  24.287 21.590 28.328 462.388  0.082 18.305 21.540 22.611 22
21.04 055030 21030  24.382 21.590 28.278 464.517  0.082 18.309 21.542 22.648 22
21.04 055040 21040  24.388 21.589 28.265 465.851  0.082 18.316 21.536 22.681 22
21.04 055050 21050  24.340 21.542 28.182 466.690  0.082 18.314 21.540 22.714 22
21.04 055450 21290  24.839 20.979 27.616 466.825  0.082 18.264 21.458 23.293 24
21.04 055500 21300  24.815 20.980 27.582 466.818  0.082 18.260 21.458 23.317 24
21.04 055510 21310  24.816 20.980 27.564 466.683  0.082 18.260 21.451 23.339 24
```

Raw data

- Tin, Tout, Tamb, G, m, …
- Intervall 10 Sek or 30 Sek
- Const. Incident angle
- Mostly a tracking facility is used
- Clear sky conditions

Filter

Prozess

Permitted deviations during a measurement period

Parameter	Permitted deviation from the mean value	
	Liquid heating collector	Air heating collector
Hemispherical solar irradiance	±50 W/m²	
Thermal irradiance (WISC only)	±20 W/m²	
Ambient air temperature	±1,5 K	
Fluid mass flow rate	±1 %	±2 %
Fluid temperature at the collector inlet	±0,1 K	±1,5 K
Fluid temperature at the collector outlet	±0,4 K	±1,5 K
Surrounding air speed	±1,0 m/s deviation from set value	

#date	time	Tamb	wind	Twind	Gscan	m	Tin	Tout	Tout-Tin	Tmean	dT_G	eta
21.04	064330	27.60	0.09	29.01	991.6	142.12	25.80	32.89	7.0899	29.34	0.00033	0.5899
21.04	065330	27.53	0.08								0.00044	0.5936
21.04	073820	28.70	1.40								-0.00243	0.6010
21.04	074820	28.78	1.39								-0.00260	0.6020
21.04	075820	28.83	1.38								-0.00269	0.6036
21.04	082550	29.17	1.36								-0.00302	0.6070
21.04	083550	29.31	1.36								-0.00312	0.6083
21.04	084550	29.24	1.36								-0.00318	0.6071

Filtered mean data

- 10 Min mean values, fulfilling the stability criteria
- At least 4 different temperature levels
- At least 4 valid data points per temperture level

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Performance Characterization and Function Testing solar thermal collectors

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Performance characterization - SST method

#date	time	Tamb	wind	Twind	Gscan	m	Tin	Tout	Tout-Tin	Tmean	dT_G	eta
21.04	064330	27.60	0.09	29.01	991.6	142.12	25.80	32.89	7.0899	29.34	0.00033	0.5899
21.04	065330	2							349	29.34	0.00044	0.5936
21.04	073820	2							015	29.38	-0.00243	0.6010
21.04	074820	2							394	29.40	-0.00260	0.6020
21.04	075820	2							953	29.43	-0.00269	0.6036
21.04	082550	2							737	29.36	-0.00302	0.6070
21.04	083550	2							190	29.39	-0.00312	0.6083
21.04	084550	2							284	29.39	-0.00318	0.6071

Filtered mean data

- 10 Min mean values, fulfilling the stability criteria
- At least 4 different temperature levels
- At least 4 valid data points per temperture level

- statistical least square curve fitting
- T ratio (parameter value/standard deviation of parameter value) < 3],this parameter shall be set to 0
- u' = u -3 m/s

$$\dot{Q} = A_G \left[\begin{array}{l} \eta_{0,\mathrm{hem}} G_{\mathrm{hem}} - a_1 (\vartheta_m - \vartheta_a) - a_2 (\vartheta_m - \vartheta_a)^2 - a_3 u' (\vartheta_m - \vartheta_a) + \\ a_4 \left(E_L - \sigma T_a^4\right) - a_6 u' G_{\mathrm{hem}} - a_7 u' \left(E_L - \sigma T_a^4\right) - a_8 (\vartheta_m - \vartheta_a)^4 \end{array} \right]$$

only Ghem is considered >> eta0,b and Kd must be calculated based on seperated IAM-Measurement

		Standard deviation	Unit	Decimal places
$\eta_{0,\mathrm{hem}}$			—	3
$\eta_{0,\mathrm{b}}$			—	3
K_{d}			—	2
a_1			W/m²K	2
a_2			W/m²K²	3
a_3			Ws/(m³·K)	3
a_4			—	2
a_5			Ws/(m²·K)	0
a_6			s/m	3
a_7			s/m	2
a_8			W/m²K⁴	3
C/A			Ws/(m²·K)	0

Nominal flowrate during the measurement $\dot{m}$ = _____ kg/h

$\eta_{0,\mathrm{hem}}$ is calculated using $\eta_{0,\mathrm{hem}} = \eta_{0,\mathrm{beam}}\,(0{,}85 + 0{,}15\,K_{\mathrm{d}})$

Performance Characterization and Function Testing solar thermal collectors

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Performance characterization - QDT method

daten.dat - Editor

Datei Bearbeiten Format Ansicht Hilfe

```
#21.04 054950 20990  0:TrF6 1:rF6 2:T_mp 3:G 4:wind 5:Thimu 6:Thimo 7:Tamb 8:Tw
21.04 054950 20990  24.286 -99.990 28.386 442.933  0.082 18.266 21.540 22.545 2
21.04 055000 21000  24.314 21.587 28.373 453.740  0.082 18.285 21.542 22.576 22
21.04 055010 21010  24.431 21.356 28.334 459.263  0.082 18.296 21.544 22.600 22
21.04 055020 21020  24.287 21.590 28.328 462.388  0.082 18.305 21.540 22.611 22
21.04 055030 21030  24.382 21.590 28.278 464.517  0.082 18.309 21.542 22.648 22
21.04 055040 21040  24.388 21.589 28.265 465.851  0.082 18.316 21.536 22.681 22
21.04 055050 21050  24.340 21.542 28.182 466.690  0.082 18.314 21.540 22.714 22
21.04 055100 21                                                          740 22
21.04 055110 21                                                          778 22
21.04 055120 21                                                          819 23
21.04 055130 21                                                          850 23
21.04 055140 21                                                          874 23
21.04 055150 21                                                          898 23
21.04 055200 21                                                          922 23
21.04 055210 21                                                          938 23
21.04 055220 21                                                          979 23
21.04 055230 21                                                          017 23
21.04 055240 21                                                          027 23
21.04 055250 21                                                          045 23
21.04 055300 21                                                          067 23
21.04 055310 21                                                          093 23
21.04 055320 21                                                          126 23
21.04 055330 21                                                          139 23
21.04 055340 21                                                          157 23
21.04 055350 21                                                          172 23
21.04 055400 21                                                          209 23
21.04 055410 21                                                          214 23
21.04 055420 21                                                          220 23
21.04 055430 21                                                          260 23
21.04 055440 21                                                          271 23
21.04 055450 21                                                          293 24
21.04 055500 21                                                          317 24
21.04 055510 21                                                          339 24
```

Raw data
- Tin, Tout, Tamb, G, m, …
- Intervall 30 Sek
- Fixed installation to south
- Different incident angles, Tamb, G over the day
- Different surrounding conditions required, clear sky and (partly) cloudy sky

Filter
Prozess

Required measurement periods and stability criteria:
- Four Temperature levels equally distributed over the operating range
- Tin shall be held stable within +- 1K
- Mass flow rate shall be held stable within +- 5%

```
#date   time      Tamb    wind    Twind    Gscan    m        Tin     Tout    Tout-Tin  Tmean   dT_G      eta
 21.04 064330     27.60   0.09    29.01    991.6    142.12   25.80   32.89   7.0899    29.34   0.00033   0.5899
 21.04 065330     27.53   0.08                                                                 0.00044   0.5936
 21.04 073820     28.70   1.40                                                                -0.00243   0.6010
 21.04 074820     28.78   1.39                                                                -0.00260   0.6020
 21.04 075820     28.83   1.38                                                                -0.00269   0.6036
 21.04 082550     29.17   1.36                                                                -0.00302   0.6070
 21.04 083550     29.31   1.36                                                                -0.00312   0.6083
 21.04 084550     29.24   1.36                                                                -0.00318   0.6071
```

Filtered mean data
- 15 Min mean values, fulfilling the stability criteria
- At least 4 different temperature levels
- still contains all possible operating states

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Performance Characterization and Function Testing solar thermal collectors

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Performance characterization - QDT method

#date	time	Tamb	wind	Twind	Gscan	m	Tin	Tout	Tout-Tin	Tmean	dT_G	eta
21.04	064330	27.60	0.09	29.01	991.6	142.12	25.80	32.89	7.0899	29.34	0.00033	0.5899
21.04	065330	27.53	0.08	28.91	991.6	142.11	25.77	32.91	7.1349	29.34	0.00044	0.5936
21.04	073820	28.70	1.40	31.79	991.6	142.55	25.78	32.98	7.2015	29.38	-0.00243	0.6010
21.04	074820								7.2394	29.40	-0.00260	0.6020
21.04	075820								7.2953	29.43	-0.00269	0.6036
21.04	082550								7.1737	29.36	-0.00302	0.6070
21.04	083550								7.2190	29.39	-0.00312	0.6083
21.04	084550								7.2284	29.39	-0.00318	0.6071

Filtered mean data
- 15 Min mean values, fulfilling the stability criteria
- At least 4 different temperature levels
- still contains all possible operating states

- statistical least square curve fitting
- T ratio (parameter value/standard deviation of parameter value) < 3],this parameter shall be set to 0
- u' = u -3 m/s

$$\dot{Q} = A_G \left[\eta_{0,b} K_b(\theta_L, \theta_T) G_b + \eta_{0,b} K_d G_d - a_1(\vartheta_m - \vartheta_a) - a_2(\vartheta_m - \vartheta_a)^2 - a_3 u'(\vartheta_m - \vartheta_a) + a_4(E_L - \sigma T_a^4) - a_5(d\vartheta_m/dt) - a_6 u' G - a_7 u'(E_L - \sigma T_a^4) - a_8(\vartheta_m - \vartheta_a)^4 \right]$$

		Standard deviation	Unit	Decimal places
$\eta_{0,hem}$			—	3
$\eta_{0,b}$			—	3
K_d			—	2
a_1			W/m²K	2
a_2			W/m²K²	3
a_3			Ws/(m³·K)	3
a_4			—	2
a_5			Ws/(m²·K)	0
a_6			s/m	3
a_7			s/m	2
a_8			W/m²K⁴	3
C/A			Ws/(m²·K)	0

Nominal flowrate during the measurement $\dot{m}$ = _____ kg/h

$\eta_{0,hem}$ is calculated using $\eta_{0,hem} = \eta_{0,beam}\,(0{,}85 + 0{,}15\,K_d)$

Gb and Gd are considered >> eta0,b; Kd and IAM are direct results of the last sqare fit

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Performance Characterization and Function Testing solar thermal collectors

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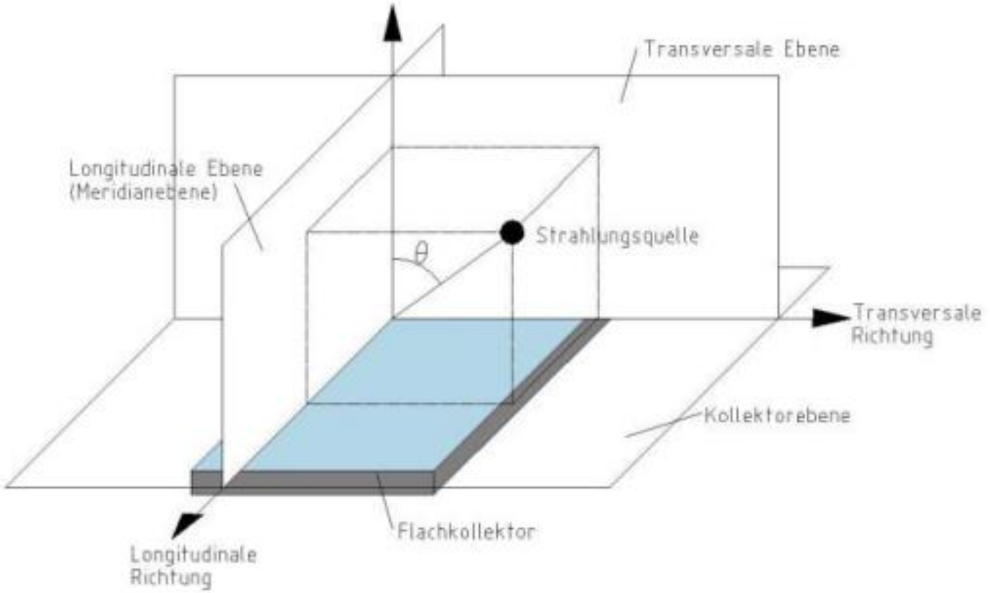
Performance characterization - Incident Angle Modifier (IAM)

- SST efficiency parameters are determined at normal incidence
- Separate measurement at one certain incident angle to determine the IAM and therefore to calculate the performance of the collector under any incidence angle is required
- The IAM is defined by:

$$K_{\mathrm{b}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})=\frac{\eta_{0,\mathrm{b}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})}{\eta_{0,\mathrm{b}}}$$

$$K_{\mathrm{hem}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})=\frac{\eta_{0,\mathrm{hem}}(\theta_{\mathrm{L}},\theta_{\mathrm{T}})}{\eta_{0,\mathrm{hem}}}$$



Performance Characterization and Function Testing solar thermal collectors

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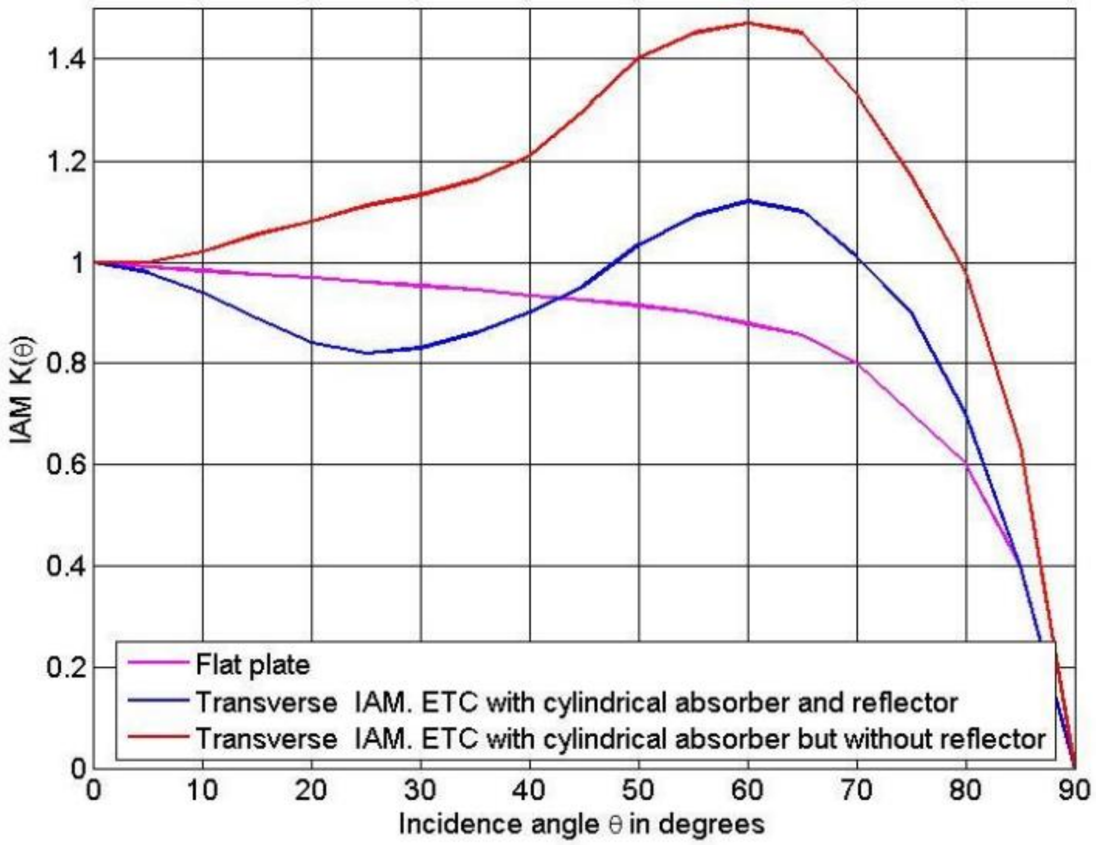
Performance characterization - Incident Angle Modifier (IAM)

- For conventional flat plate collectors, the IAM can be given as a constant value for e.g., 50°. The IAM It can also be given as constant values at 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, and 80° without distinguishing between longitudinal and transversal.
- For collectors with non-symmetric optical characteristics and therefor bi-axial IAM behavior, it is necessary to distinguish between the longitudinal and transversal IAM
- For collectors with a multi-axial IAM (e.g., LFC), the of the IAM for each of the four quarter spheres could be required
- The IAM is presented over an angular range from 0° to 90°
- Calculation based eigther on „Ambrosetti" or b0-apprach
- Both calculation methods show the same results



Testing solar thermal collectors - Result Presentation

Performance Characterization and Function Testing solar thermal collectors

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Result presentation - Standard Reporting Conditions (SRC)

- Standard Reporting conditions are implemented to:
  - Determine and represent comparable results for all kind of collector technologies
  - The collector output (table and graphical presentation) shall be reported in a comparable form, independent of the test method and for the same climatic standard reporting conditions
  - For all calculations, the model used for the analysis of the measurements shall be used (SST or QDT)
  - But how does this work in detail?

Climatic conditions	Blue sky	Hazy sky	Grey sky
G_b	850 W/m²	440 W/m²	0 W/m²
G_d	150 W/m²	260 W/m²	400 W/m²
ϑ_a	20°C	20°C	20°C
$E_L\text{-}\sigma\cdot\vartheta_a^4$ [a]	−100 W/m²	−50 W/m²	0 W/m²
u [a]	1,3 m/s	1,3 m/s	1,3 m/s
$d\vartheta_m/dt$ [b]	0 K/s	0 K/s	0 K/s

[a] For WISC collectors only.

[b] For quasi dynamic tested collectors only.

Performance Characterization and Function Testing solar thermal collectors

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Result presentation - Power curve/Power output per collector unit under Standard Reporting Conditions (SRC)

Climatic conditions	Blue sky	Hazy sky	Grey sky
G_b	850 W/m²	440 W/m²	0 W/m²
G_d	150 W/m²	260 W/m²	400 W/m²
ϑ_a	20°C	20°C	20°C
$E_L-\sigma\cdot\vartheta_a^4$ [a]	−100 W/m²	−50 W/m²	0 W/m²
u [a]	1,3 m/s	1,3 m/s	1,3 m/s
$d\vartheta_m/dt$ [b]	0 K/s	0 K/s	0 K/s

[a] For WISC collectors only.

[b] For quasi dynamic tested collectors only.

Input

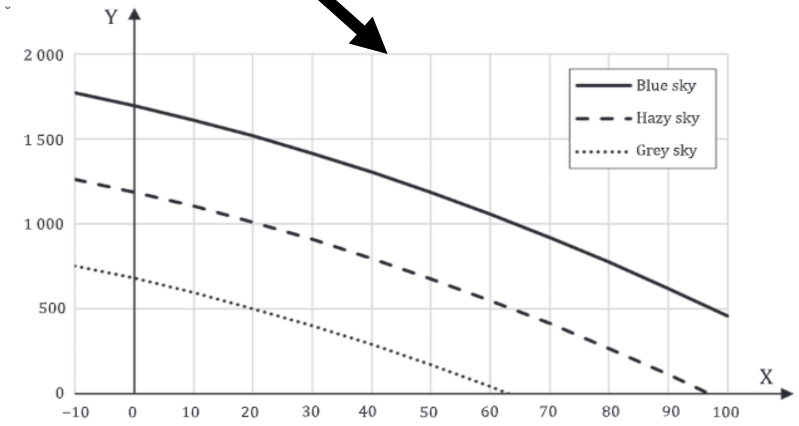
$$\dot{Q} = A_G \left[\eta_{0,hem} G_{hem} - a_1(\vartheta_m-\vartheta_a) - a_2(\vartheta_m-\vartheta_a)^2 - a_3 u'(\vartheta_m-\vartheta_a) + a_4\left(E_L-\sigma T_a^4\right) - a_6 u' G_{hem} - a_7 u'\left(E_L-\sigma T_a^4\right) - a_8(\vartheta_m-\vartheta_a)^4 \right]$$

The model used for the analysis of the measurements shall be used!

		Standard deviation	Unit
$\eta_{0,hem}$			—
$\eta_{0,b}$			—
K_d			—
a_1			W/m²K
a_2			W/m²K²
a_3			Ws/(m³·K)
a_4			—
a_5			Ws/(m²·K)
a_6			s/m
a_7			s/m
a_8			W/m²K⁴
C/A			Ws/(m²·K)

Output

	Standard reporting conditions		
$\vartheta_m - \vartheta_a$	Blue sky	Hazy sky	Grey sky
−10			
0			
10			
...			
Max. tested temperature difference + 30 K			
Nominal flowrate during the measurement $\dot{m}$ = ____kg/h			



Key

X $(\vartheta_m - \vartheta_a)$ (K)

Y power output per collector unit (W)

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Performance Characterization and Function Testing solar thermal collectors

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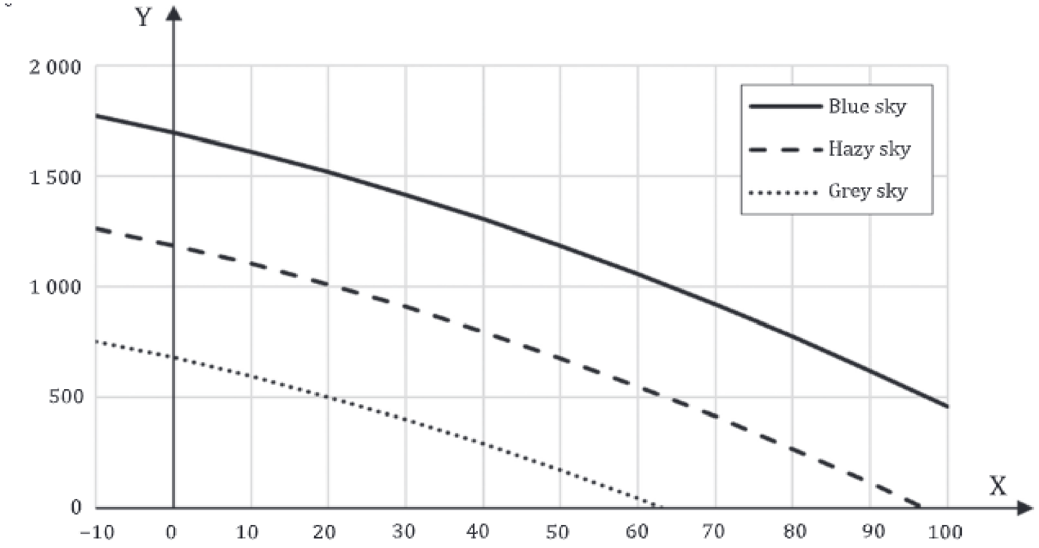
Result presentation – ScenoCalc >> Exercise 1

- Three sets of typical parameters (hand out)
- Calculate the power output at SRC
- Show results in a table and graphically

- Good luck -

	Standard reporting conditions		
$\vartheta_m - \vartheta_a$	Blue sky	Hazy sky	Grey sky
-10			
0			
10			
...			
Max. tested temperature difference + 30 K			
Nominal flowrate during the measurement $\dot{m}$ = ____kg/h			



Key

X $(\vartheta_m - \vartheta_a)$ (K)

Y power output per collector unit (W)

Performance Characterization and Function Testing solar thermal collectors

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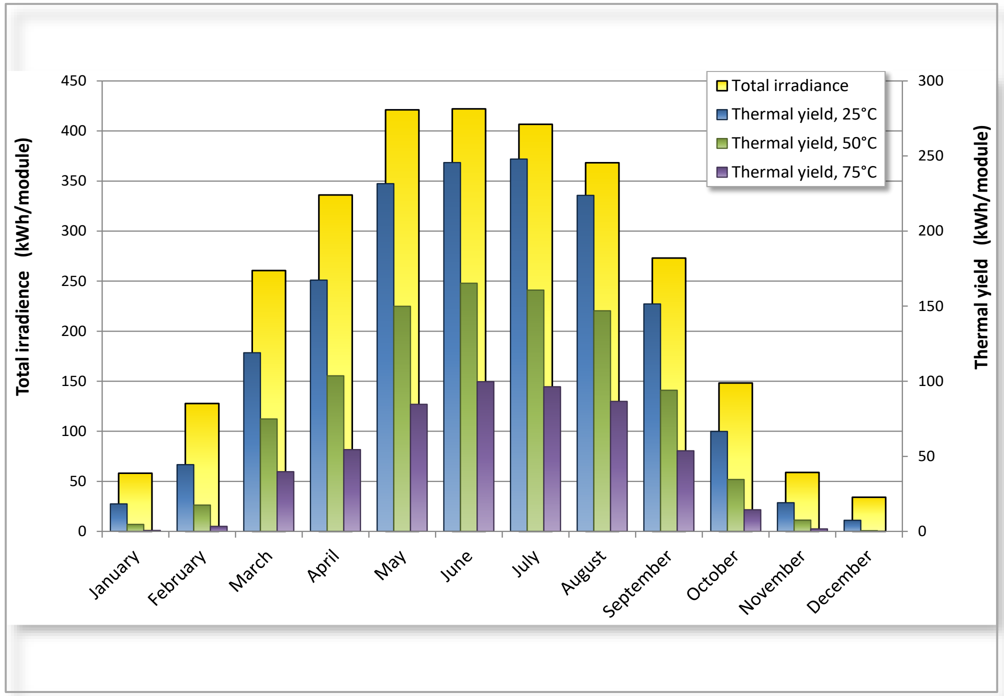
Result presentation – ScenoCalc >> Calculation GTY

- Developed in the framework of the project QAIST – Quality Assurance In Solar Thermal
- Open source (xlsx) calculator to provide the annual gross thermal yield of a collector
- Aiming on comparability regarding the energy output of different collectors, to avoid comparison of single KPI's like eta_0 without considering e.g., IAM-Values, Kd, and others, what can be misleading
- It's not a system simulation, since all energy produced by the collector is summed up within the result. There is no load profile behind
- Capacitive effects of the collector are not considered
- Is implemented into the Solar Keymark Scheme and therefore harmonize such an approach for Europe
- Provide information to subsidy schemes



Performance Characterization and Function Testing solar thermal collectors

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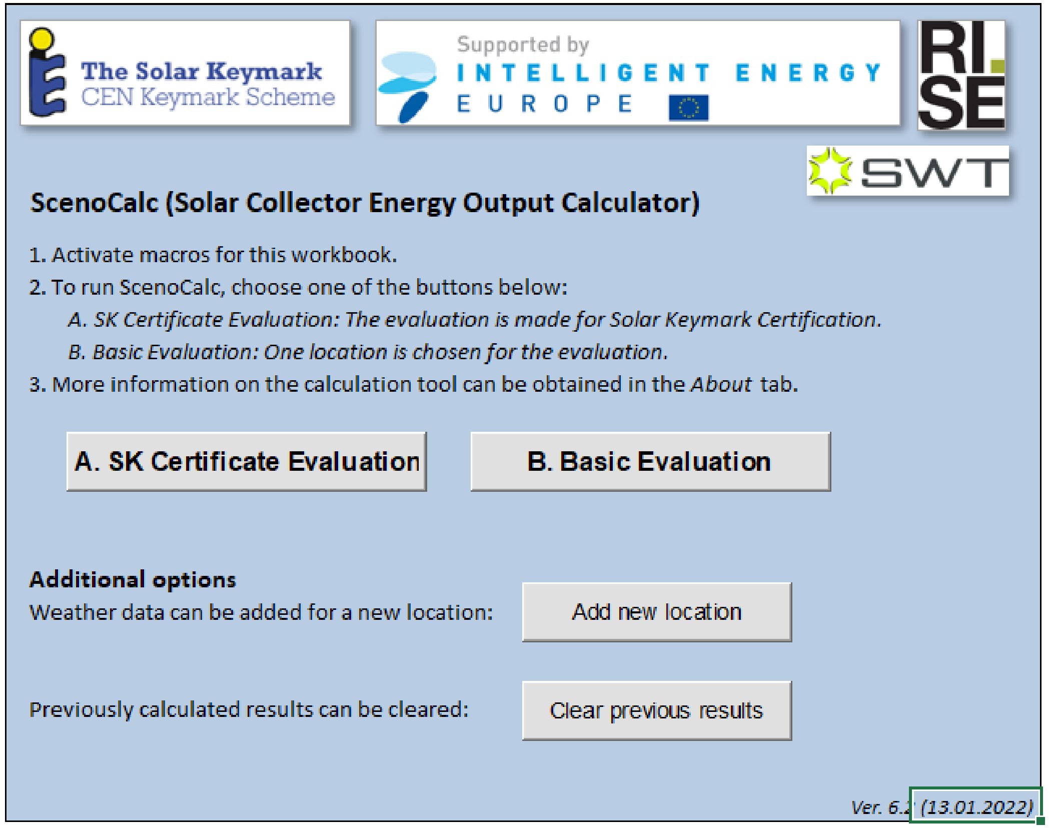
Result presentation – ScenoCalc >> Calculation GTY

- SK Certificate Evaluation
  - Calculates the Power Output per collector according SRC
  - Calculates the GTY at three constant fluid mean temperatures
  - Shows results for four different locations (Athens, Davos, Würzburg, Stockholm). Respective weather data is implemented
  - Used for certification reasons
- Basic Evaluation
  - Allows to adjust temperature levels, locations, orientation of the collector and tracking modes
  - Considers tracking mechanisms and non-symmetrical IAM-behaviour
- Link >> Complete description of ScenoCalc and it's calculation methods

-> let's have a closer look on it together



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Performance Characterization and Function Testing solar thermal collectors

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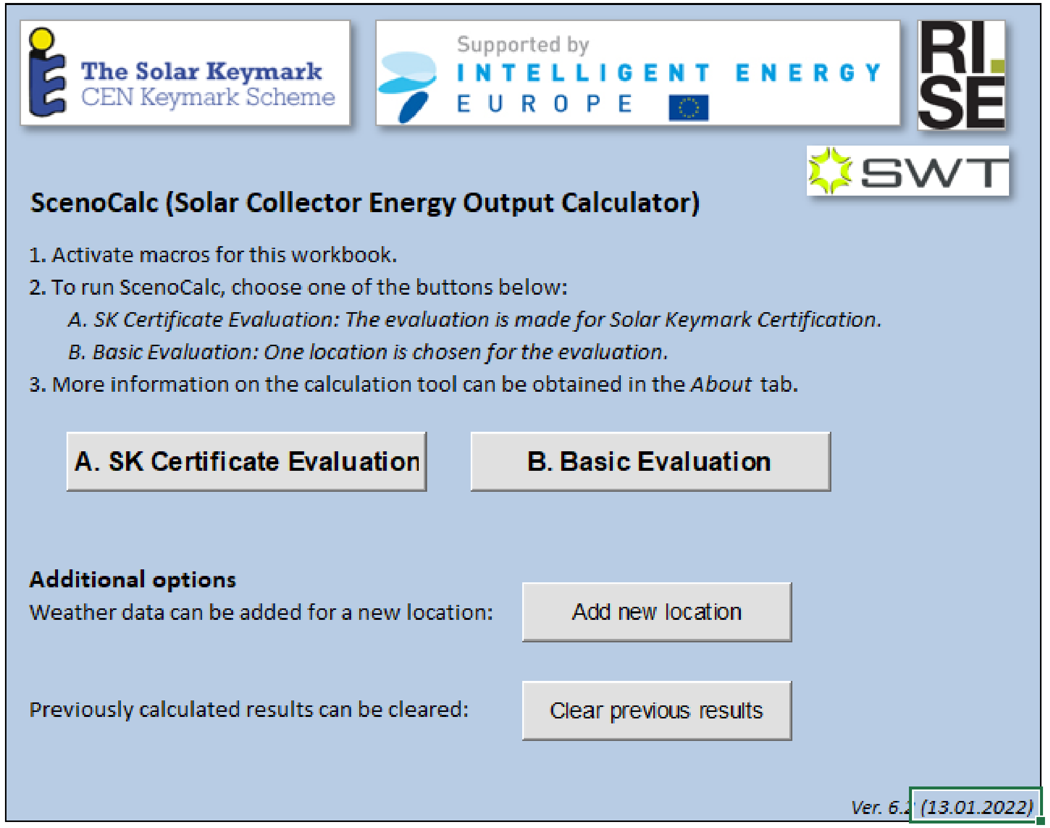
Result presentation – ScenoCalc >> Exercise 2

- Three sets of typical parameters (hand out)
- Please download ScenoCalc >> https://solarkeymark.eu/calculation-tools/ (see bottom, left on the side)
- Calculate the power output at SRC (check your results from exercise 1)
- Calculate the Gross Thermal Yield
- Let us compare and discuss the results



- Good luck -

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Performance and Energy Yield Check Methods for large scale Systems

ISO 24194:2022

Performance Characterization and Function Testing solar thermal collectors

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Introduction

- Large solar thermal plants are identified as a key technology to provide renewable heat in residential, commercial, industrial (SHIP), and district heating applications, with substantial growth worldwide in recent years
- Heat production costs are stable and competitive (30-60 €/MWh), but only if optimal quality plant operation ensures high energy yields over the lifespan
- Two ISO standards provide a framework for quality control of solar thermal installations:
  - ISO 9806 [2] addresses the performance of single new collectors under lab conditions, generating product data sheets for plant design or simulations.
  - ISO 24194 (“Solar energy, Collector fields, Check of performance”) introduces two methods for collector arrays

Performance Characterization and Function Testing solar thermal collectors

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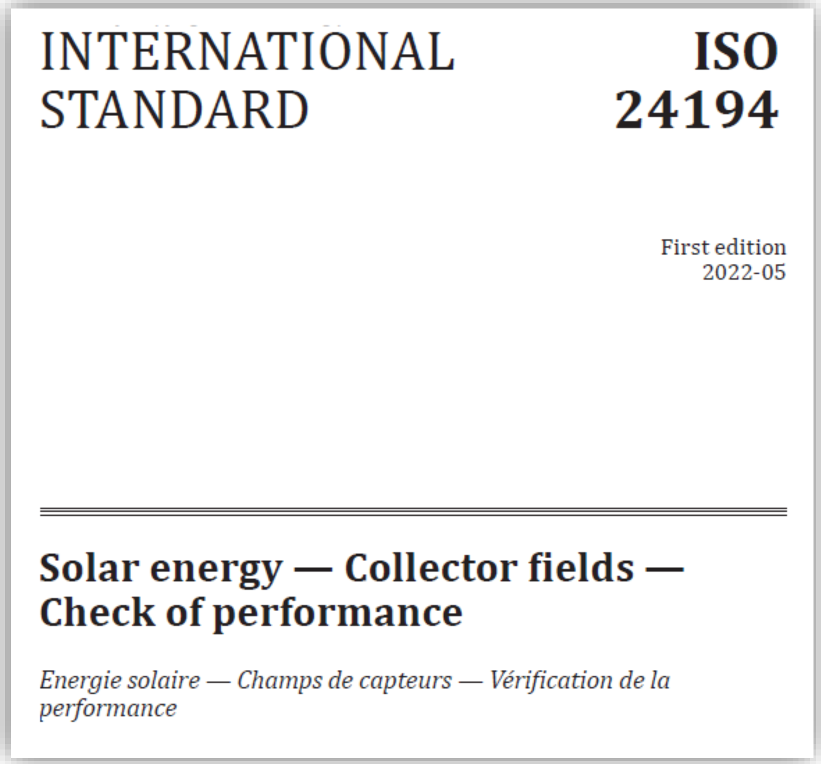
ISO 24194:2022

- New standard for **performance check** and **daily yield check** of **solar thermal collector fields**, first edition in 2022-05
- Previous versions of the method were developed in Denmark and used **for guarantee-procedures for SDH plants**
- Further development within IEA SHC Task 45 and IEA SHC Task 55 (Fact sheets: 45.A.3.1 ; 45.A.3.1 ; B-D2; B-D1.1)
- DRAFT ISO/DIS 24194 Solar energy Collector fields — Check of performance (2020 / 2021)
- Currents status: DIN EN ISO 24194/A1 Collector fields –Check of performance – Amendment 1 (ISO 24194:2022/DAM 1:2023)
- ISO 24194 is the **first standard** of its kind by targeting energy efficiency of **solar thermal collector fields**


INTERNATIONAL STANDARD

ISO 24194

First edition
2022-05

Solar energy — Collector fields — Check of performance

Energie solaire — Champs de capteurs — Vérification de la performance

Performance Characterization and Function Testing solar thermal collectors

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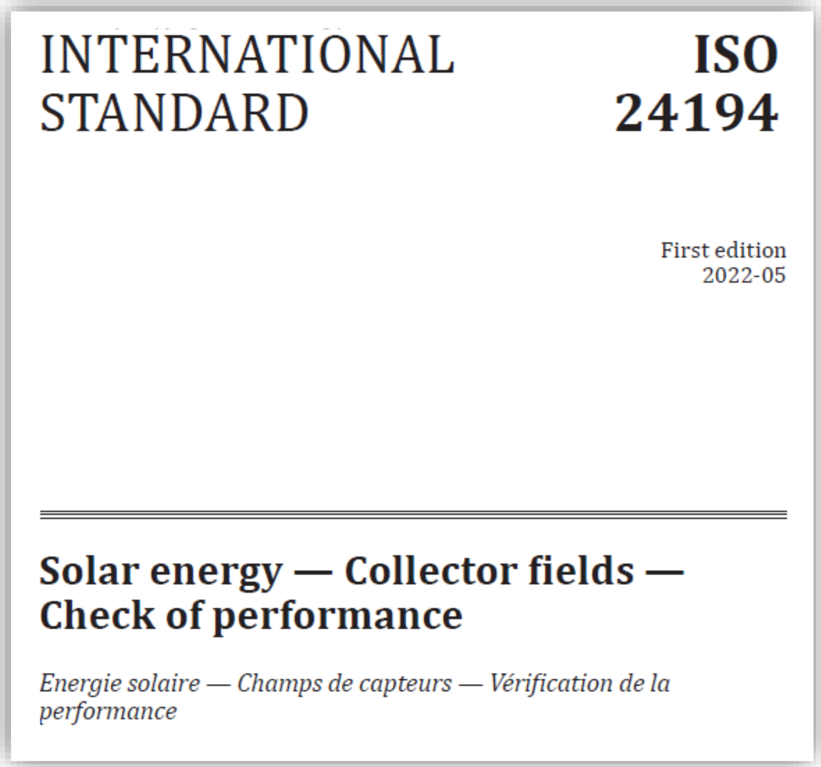
ISO 24194:2022 - Scope

- Two procedures to check the peak performance/daily yield of solar thermal collector fields
- Applicable to glazed flat plate collectors, evacuated tube collectors and/or tracking/concentrating collectors used as collectors in fields.
- Check can be done on the peak thermal power output of the collector field or on the daily yield of the collector field.
- The document specifies for the two procedures how to compare a measured output with a calculate
- The document applies for all sizes of collector fields


INTERNATIONAL STANDARD

ISO 24194

First edition
2022-05

Solar energy — Collector fields — Check of performance

Energie solaire — Champs de capteurs — Vérification de la performance

Performance Characterization and Function Testing solar thermal collectors

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ISO 24194:2022 – Main methods

Procedure for checking the **power performance** of solar thermal collector fields (Power Check Method)

Procedure for checking the **daily yield** of solar thermal collector fields (Daily Yield Method)

Measurements needed

Contents

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Performance Characterization and Function Testing solar thermal collectors

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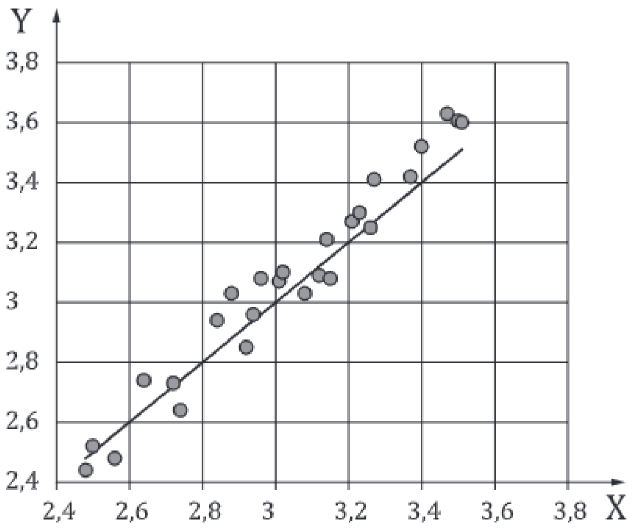
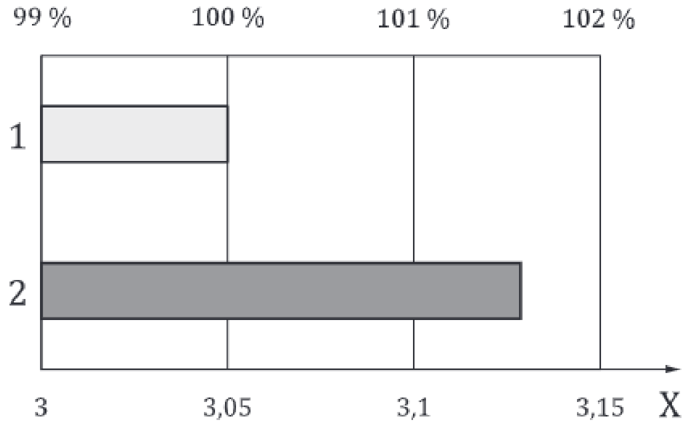
ISO 24194:2022 – Performance Check Method

- The method features a performance number KPI, defined as the ratio of measured vs. expected plant output, corrected for boundary conditions like weather, temperature levels, heat demand, or system control.
- This KPI allows for comprehensive plant operation monitoring
- The performance check is fulfilled as far as Q_meas >= Q_estimate
- The daily yield check is fulfilled a far as Q_heat meter,d ≥ Qestimate-sys,d
- The collector field is considered, not the individual collector
- Measurements of inlet and outlet field temperature are carried out on the primary side at the heat exchange point
- Required measured parameters are Ghem, Gb, Gd, wind, mass flow rate
- Q_meas is thereby derived from real measurement data at nearly peak power conditions to Q_meas = m*cp*dT
- But how to calculate Q_estimate and Qestimate-sys,d?





X average power for valid points MW

1 average power (Est.)

2 average power (Meas.)

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ISO 24194:2022 – Performance Check Method – Calculate Q_estimate

- Q_estimate is calculated based on ISO 9806 parameters, combined with real measurement data (G, Tamb, Tin, Tout, …) according to one of the following equations:
- For non-concentrating collectors:

$$\dot{Q}_{\text{estimate}} = A_{\text{GF}} \cdot \left[\eta_{0,\text{hem}} K_{\text{hem}} (\theta_{\text{L}}, \theta_{\text{T}}) G_{\text{hem}} - a_{1,\Delta Q} (\vartheta_{\text{m}} - \vartheta_{\text{a}}) - T_{\Delta Q} (\vartheta_{\text{m}} - \vartheta_{\text{a}})^2 - a_5 (\text{d}\vartheta_{\text{m}} / \text{d}t) \right] \cdot f_{\text{safe}}$$

- Non- or low-focussing collectors (CR < 20)

$$\dot{Q}_{\text{estimate}} = A_{\text{GF}} \cdot \left[\eta_{0,\text{b}} K_{\text{b}} (\theta_{\text{L}}, \theta_{\text{T}}) G_{\text{b}} + \eta_{0,\text{b}} K_{\text{d}} G_{\text{d}} - a_{1,\Delta Q} (\vartheta_{\text{m}} - \vartheta_{\text{a}}) - T_{\Delta Q} (\vartheta_{\text{m}} - \vartheta_{\text{a}})^2 - a_5 (\text{d}\vartheta_{\text{m}} / \text{d}t) \right] \cdot f_{\text{safe}}$$

- Focusing collectors with high concentration ratio (CR ≥ 20)

$$\dot{Q}_{\text{estimate}} = A_{\text{GF}} \cdot \left[\eta_{0,\text{b}} K_{\text{b}} (\theta_{\text{L}}, \theta_{\text{T}}) G_{\text{b}} - a_{1,\Delta Q} (\vartheta_{\text{m}} - \vartheta_{\text{a}}) - a_5 (\text{d}\vartheta_{\text{m}} / \text{d}t) - a_8 (\vartheta_{\text{m}} - \vartheta_{\text{a}})^4 \right] \cdot f_{\text{safe}}$$

- Whereby f_safe = Safety factor to consider pipe losses measurement uncertainties, model uncertainties etc. >> as more specific those parameters are known as smaller the uncertainty of this procedure
- The standard defines three uncertainty levels depending on used sensors, uncertainty calculation, etc.
- The calculation of Qestimate-sys,d follows the same logic. For more information, please refer to the standard.

Performance Characterization and Function Testing solar thermal collectors

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ISO 24194:2022 – Performance Check Method – boundary conditions

- No shadows on the collector field
- To limit uncertainties, it is important to give restrictions on the operation conditions for which the estimate is valid.
- Only measurement points are considered when the collector field is close to stable full power operation

Operation condition	Limits			Comments
	Formula (1)	Formula (2)	Formula (3)	
Shadows	No shadows			See 5.5
Change in collector mean temperature	≤5 K			To avoid big change in collector temperature during one hour
Ambient temperature	≥5 °C			To avoid snow, ice, condensation on solar radiation sensors
Wind velocity	≤10 m/s			To be measured so it is representative for the wind velocity 1 m to 3 m above highest point of collectors
G_{hem}	≥800 W/m^2	-	-	
G_b	-	≥600 W/m^2	≥600 W/m^2	

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ISO 24194:2022 – Daily Yield Check Method– boundary conditions

- Shadows partly allowed, but must taken into consideration
- To limit uncertainties, it is important to give restrictions on the operation conditions for which the estimate is valid
- Only days in the summer half-year between 21.03. and 21.09. in the northern hemisphere and between 21.09. and 21.03. in the southern hemisphere at latitudes ≥ 25° shall be used.

Operation condition	Limits	Comments
Shadows	Only shading losses of the collector rows taken into account are permitted	Shadows of collector rows are normal and are considered in the calculation (see. Formula (21))
Daily Irradiation H_{hem}	≥5,5 kWh/m²	This restriction prevents invalid points
Total irradiance G_{hem}	≥100 W/m²	Lower radiation not relevant

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Performance Characterization and Function Testing solar thermal collectors

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ISO 24194:2022 – Performance Check Method – summery

- Simple procedure to check the power performance against an estimated power performance based on ISO 9806 parameters
- shows in a simple way whether field performance matches the expected performance
- the significance is unfortunately limited to peak power conditions
- Due to the selected boundary conditions, the field performance is only a good indicator of the field yield to a verry limited extent.
- The field behavior/energy output under different conditions is still unknown
- The required high irradiation (Ghem > $800 W/m^2$) severely restricts the applicability, e.g. this limit can hardly be achieved in façade applications
- The method has been implemented into the open-source software SunPeek (http://demo.sunpeek.org), developed by AEE-Intec, Austria
- Within Task 68 – Efficient Solar District Heating – a Guide to ISO 24194 is currently under construction
- The mentioned restrictions has been recognized, and it is planed to open ISO 24194 for their next revision in 2024.

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The Solar Thermal Energy Plant of the Staatsbrauerei Rothaus AG

Rothaus

Fraunhofer ISE

Workshop am 8.11.2023

Content

- **Introduction Badische Staatsbrauerei Rothaus AG**
- **Sustainability in Rothaus**
- **Solar thermal energy plant**

Introduction

- founded in 1791 by a prince-abbot from St. Blasien Abbey
- a stock company since 1922
  (with Baden-Württemberg as the only shareholder)
- 220 employees
- 65 mil. € annual revenue

- Annual energy consumption:
  - 6,800 MWh green electricity
  - 13,700 MWh thermal energy, of which
    9,500 MWh from renewable energy sources

2016 - 2020

Introduction

Introduction

„As a manufacturer of pure natural products, we are greatly interested in preservation of our environment and sustainable development.“

Content

- Introduction Badische Staatsbrauerei Rothaus AG
- Sustainability in Rothaus
- Solar thermal energy plant

Sustainability in Rothaus

- Since 1996 Quality DIN EN ISO 9001
- Since 2002 Environment DIN EN ISO 14001
- Since 2015 Energy DIN EN ISO 50001
- Since 2018 WIN!Charta
- Since 2020 Klimabündnis Land BW
- Since 2030 Rothaus „climate positive“

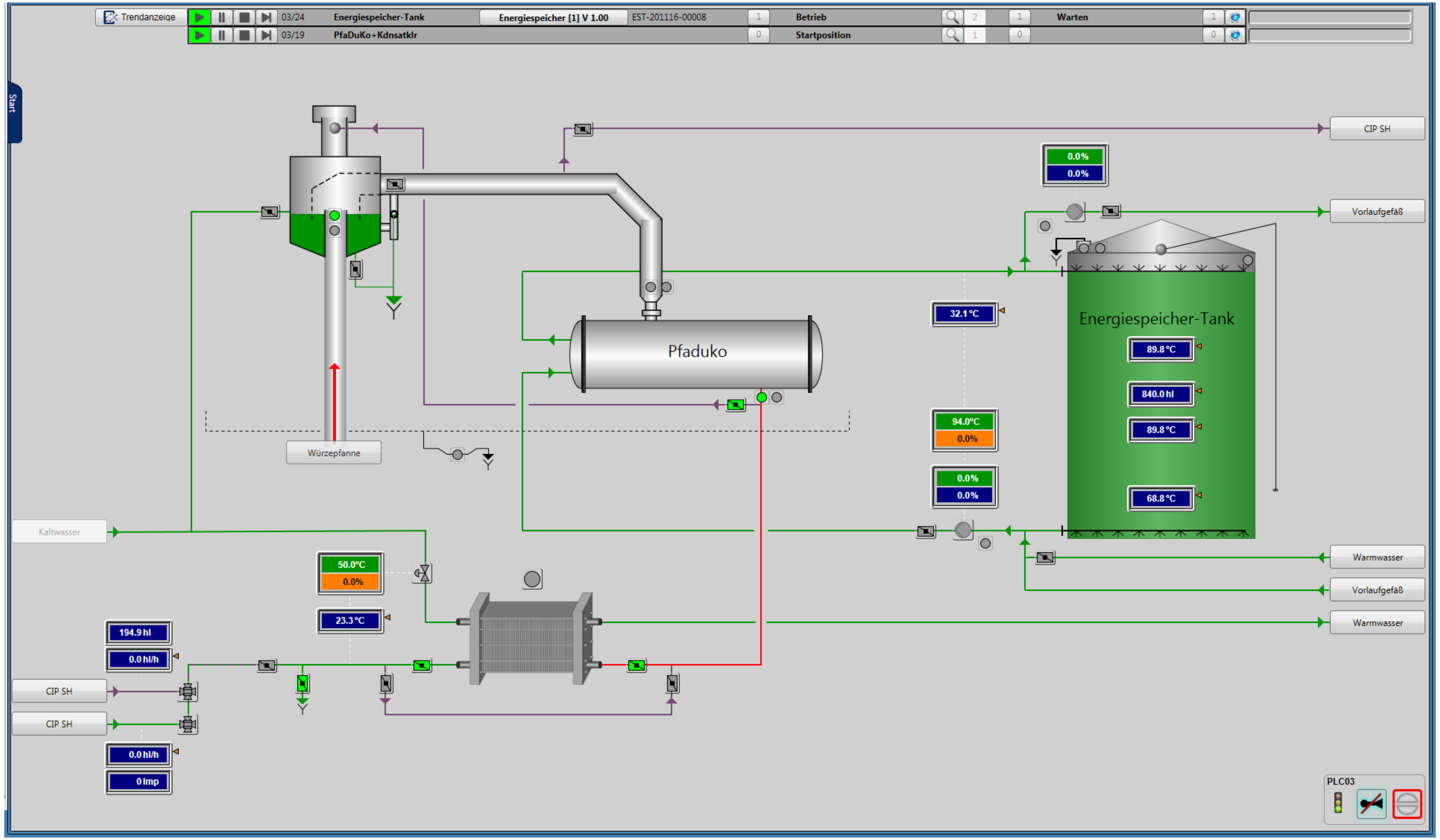
Sustainability in Rothaus

Sustainability in Rothaus

Waste heat utilisation of the compressed air and refrigeration compressors for heating the warehouses and loading halls

Sustainability in Rothaus

Vent condenser and energy storage to heat up the wort in brewhouse

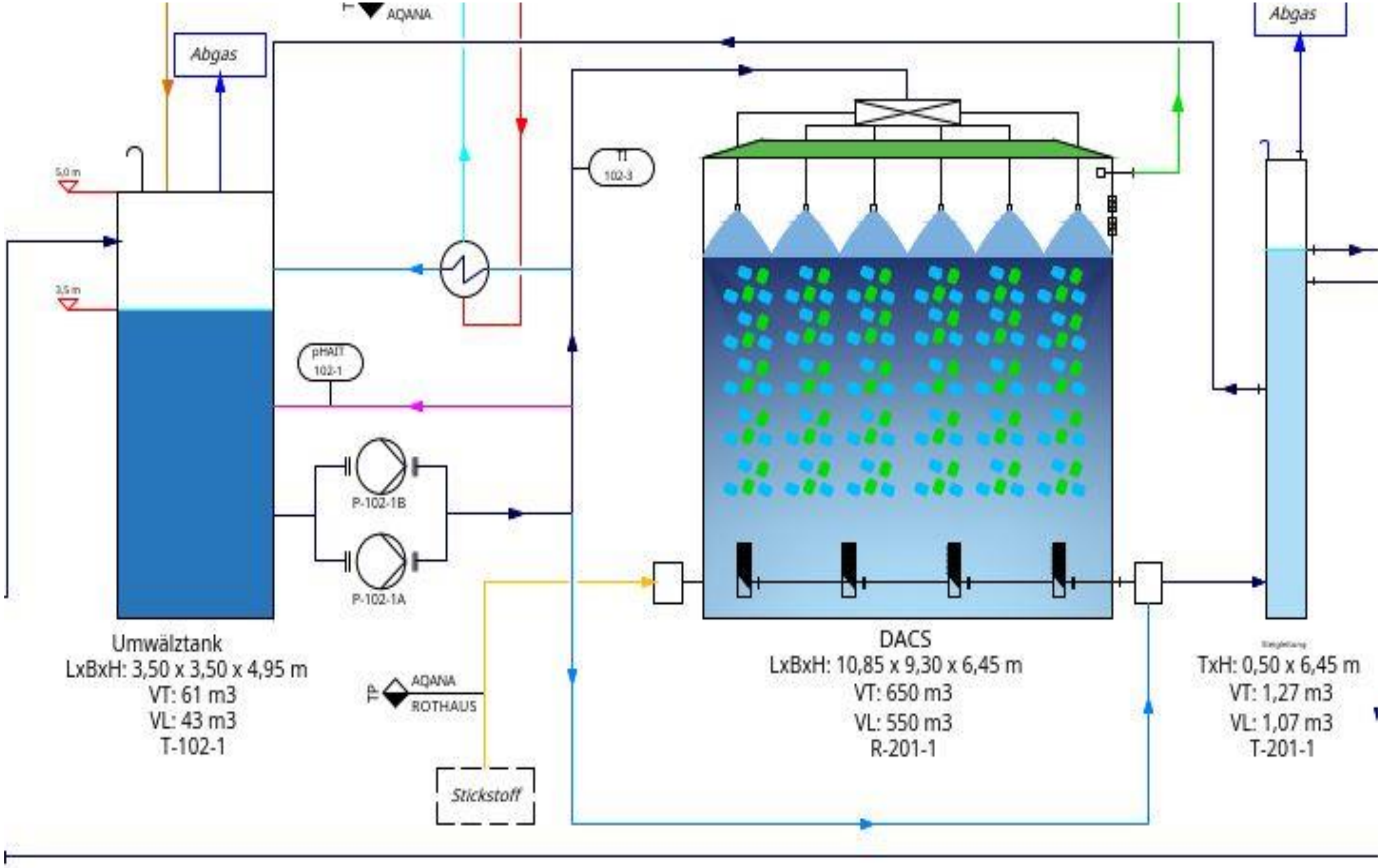


Sustainability in Rothaus

PV modules
with 1550 kW
peak since
March 2023

Sustainability in Rothaus

Rebuild of the wastewater treatment plant with an anaerobic decomposition stage (under construction)



Inhalt des Vortrags

- Introduction Badische Staatsbrauerei Rothaus AG
- Sustainability in Rothaus
- Solar thermal energy plant

Solar thermal energy plant - Funding

- 45% of the calculated total costs of 1,070,000 € were approved by BAFA[1] as subsidy (482,000 €)
- Solar heat generation/production costs **without** subsidy are € 130/MWh for a 20-year term, **with** subsidy € 70/MWh

[1] The Federal Office for Economic Affairs and Export Control (BAFA)

Solar thermal energy plant – key data

- Gross collector area 998 m²

  206 vacuum tube collectors with 30 heat pipe tubes each
- Peak power ca. 400 kW
- Annual useful solar heat yield ca. 300 MWh
- Operating temp. energy storage 70-95 degrees Celsius

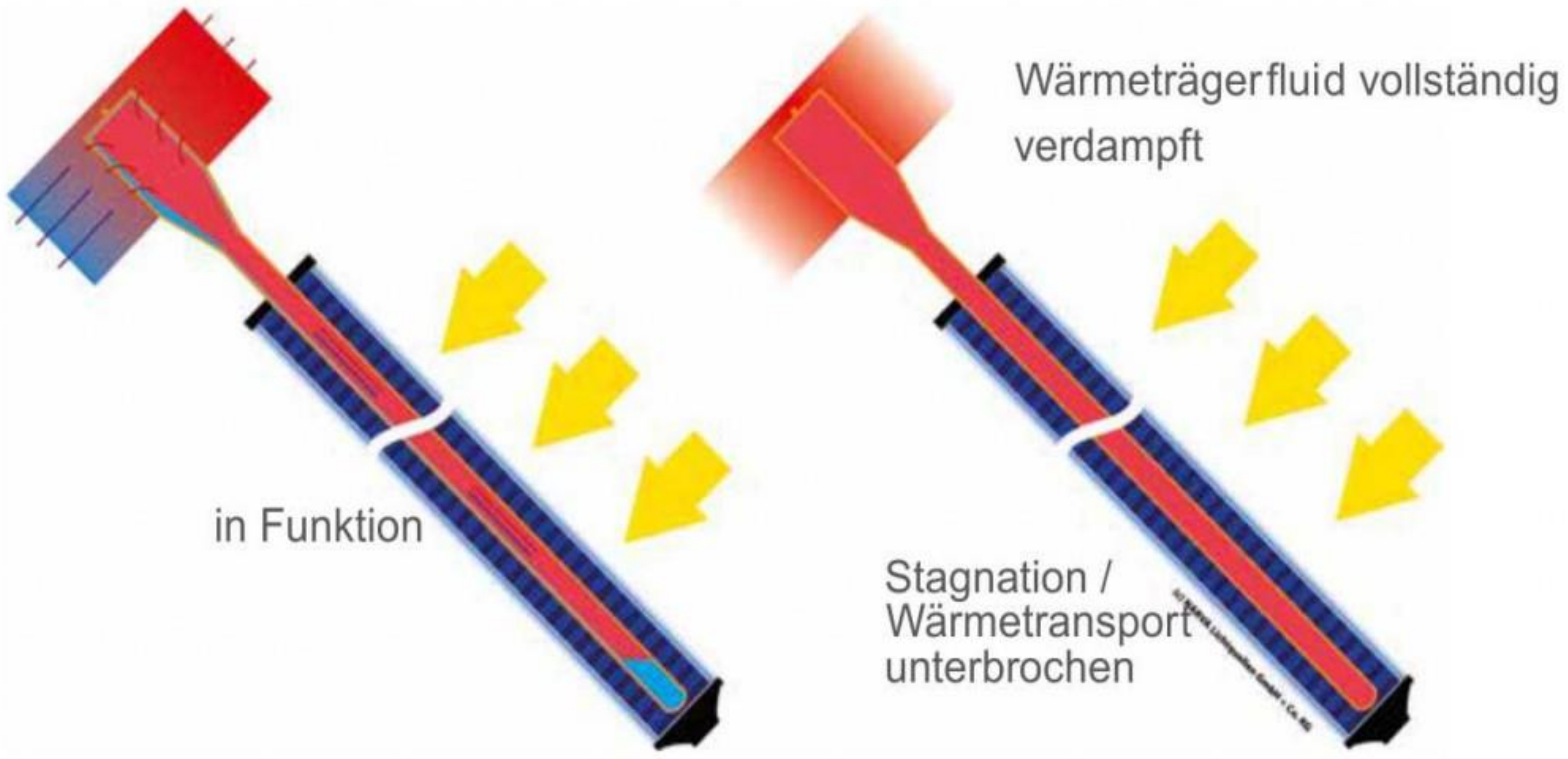
- Construction period April to October 2018

Solar thermal energy plant – key data

Amounts of heat generated and consumed			
	heat generation	heat consumption	Reduction of CO_2
	MWh	MWh	t
Jan	2	1	0
Feb	10	8	3
Mar	31	29	9
Apr	32	29	9
May	40	38	12
Jun	47	45	14
Jul	50	47	15
Aug	51	44	14
Sept	24	21	7
Oct	17	15	5
Nov	3	2	1
Dec	3	1	0
total			
	310	280	89

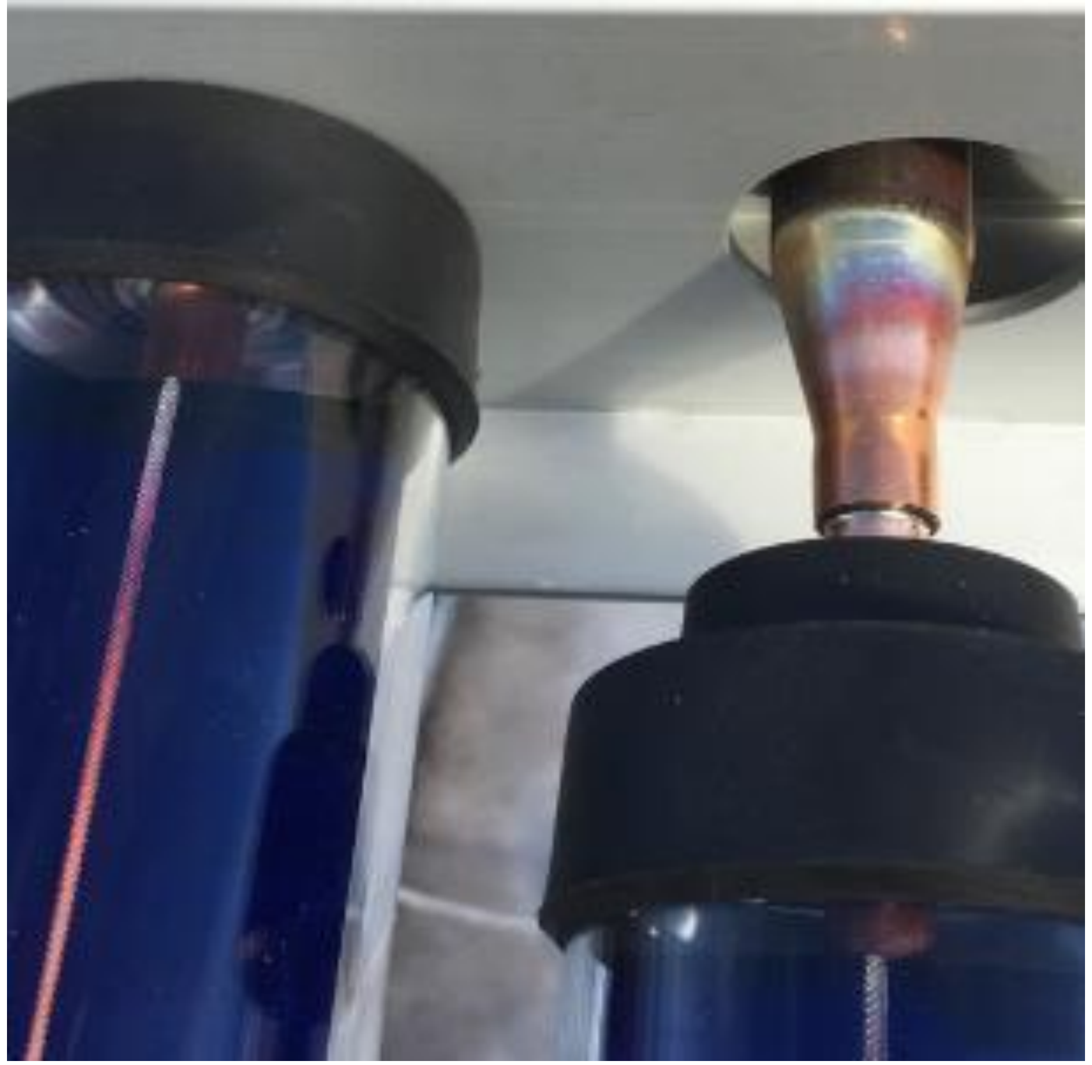
Solar thermal energy – Heat Pipes

Structure of an evacuated tube collector



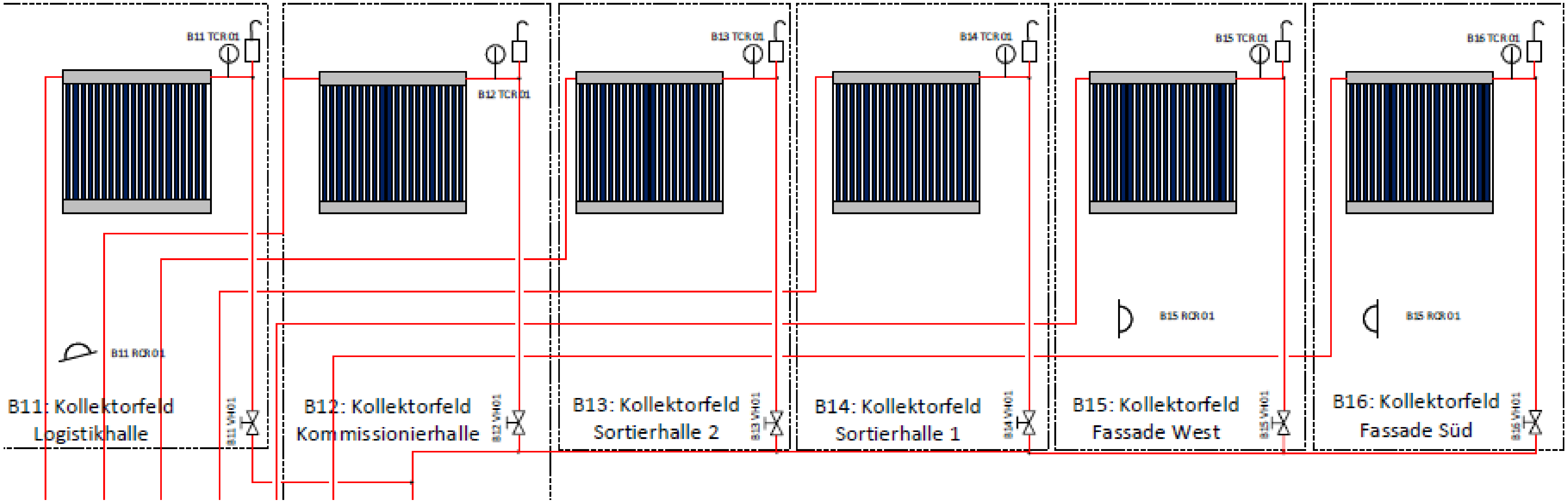
Solar thermal energy – Heat Pipes

Structure of an evacuated tube collector



Solar thermal energy - Collectors

- 6 collector fields, 4 on the roof, 2 on the facade
- Total area 998 square meters



Solar thermal energy - Collectors

Solar thermal energy - Collectors

South-east side:

30° inclination

Solar thermal energy - Collectors

South-east side:

30° inclination

Solar thermal energy - Collectors

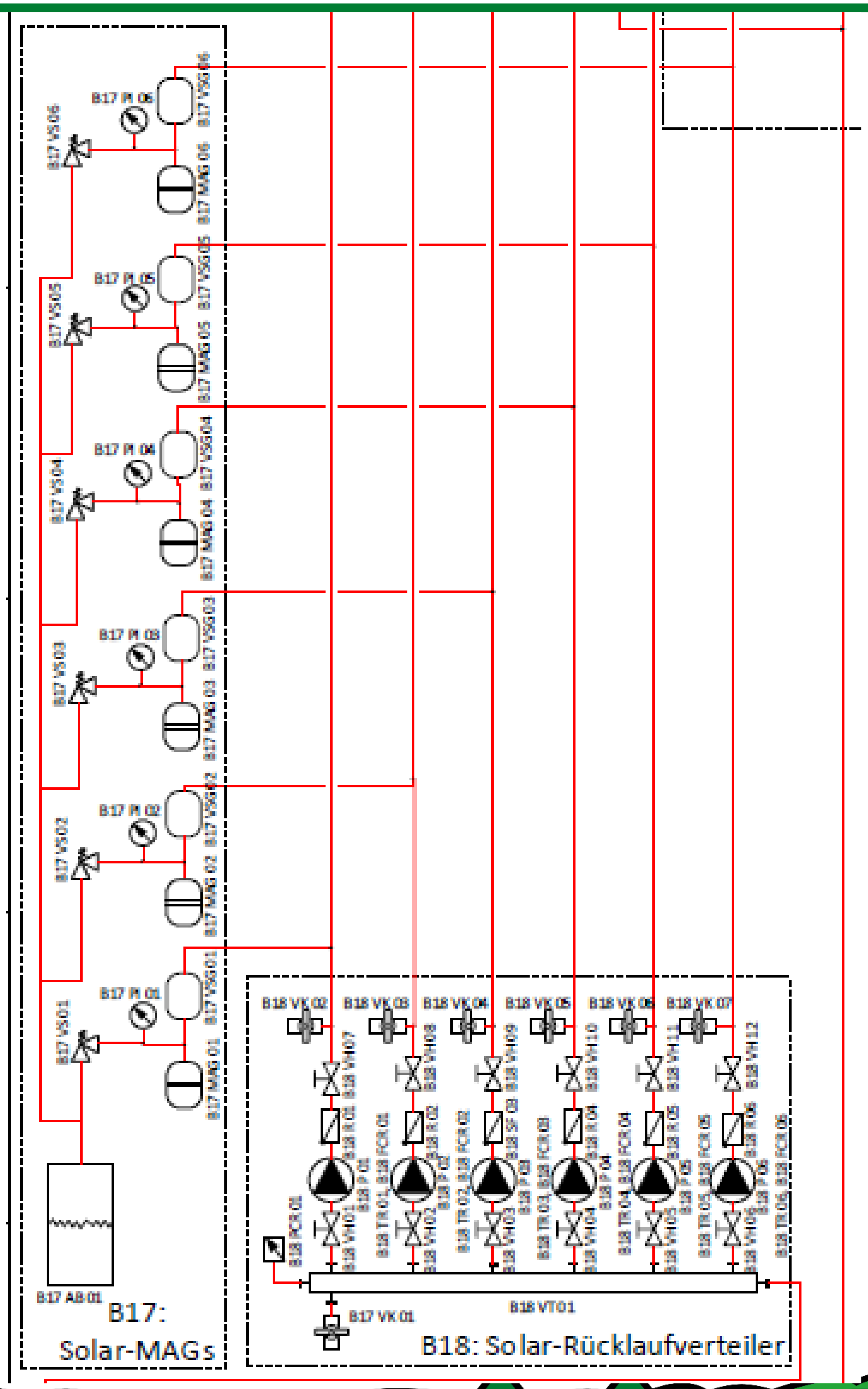
West-side:
10° inclination and
25° rotation of the
tubes

Solar thermal energy - Collectors

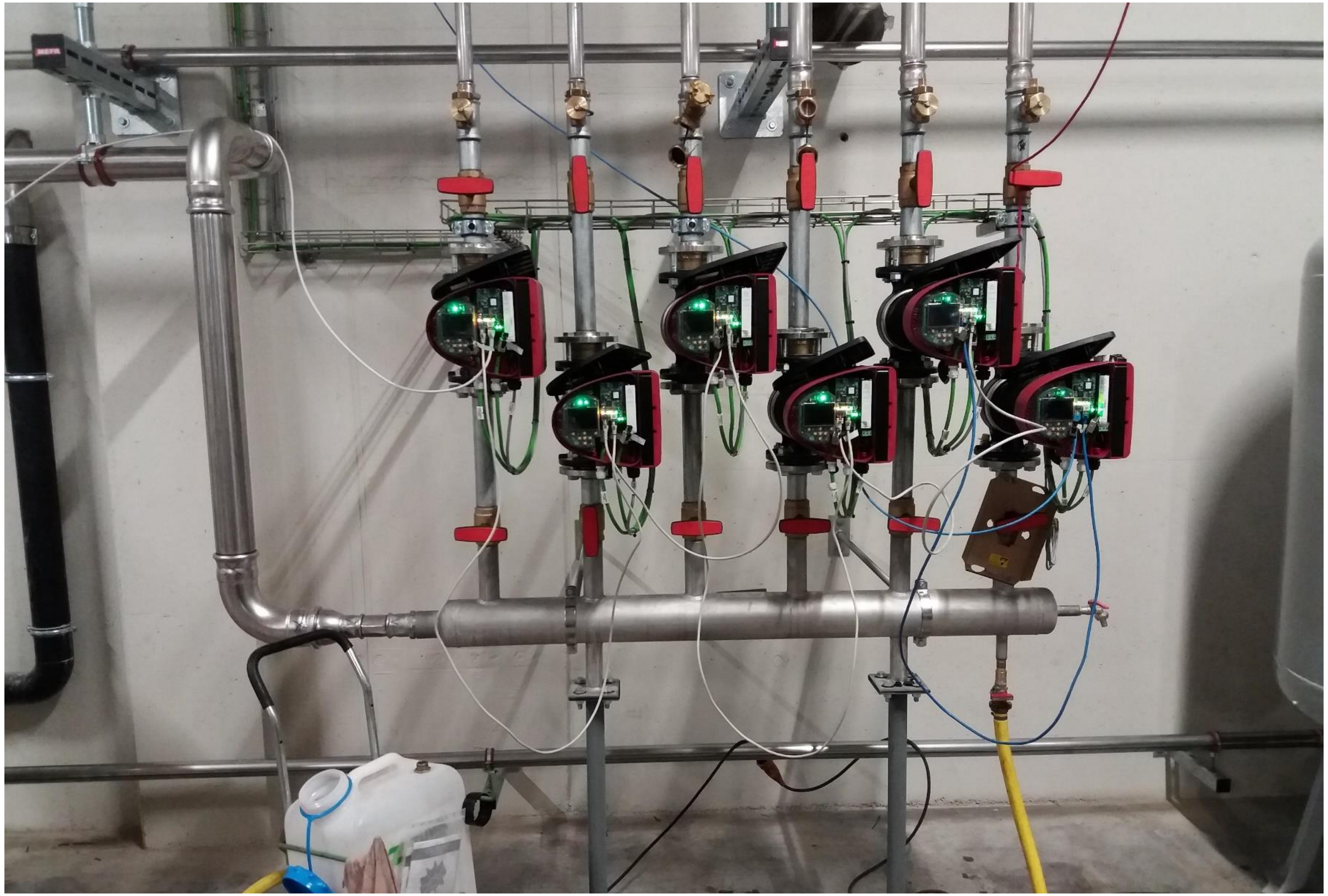
South-east facade

Solar thermal energy - Technology

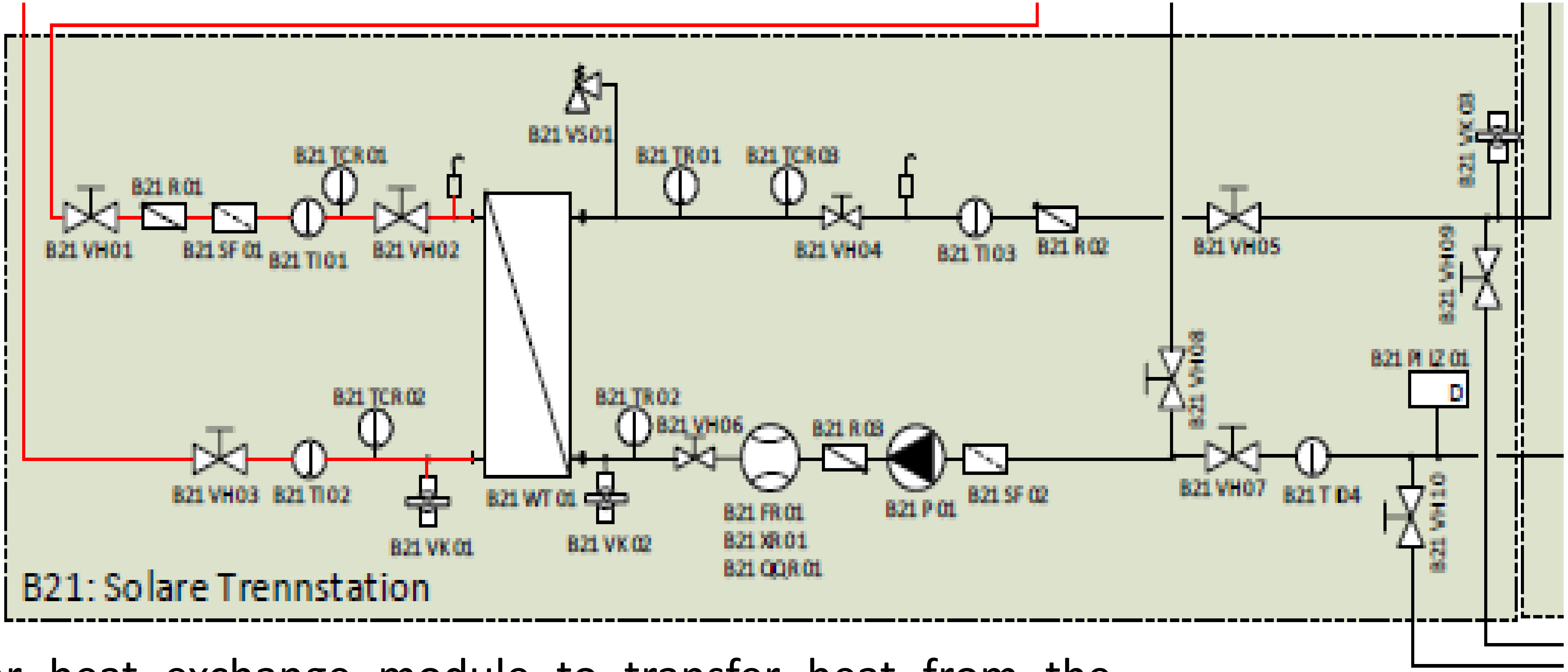
- Each collector field with controlled circulation pump, buffer tank and safety valve



Solar thermal energy - Technology

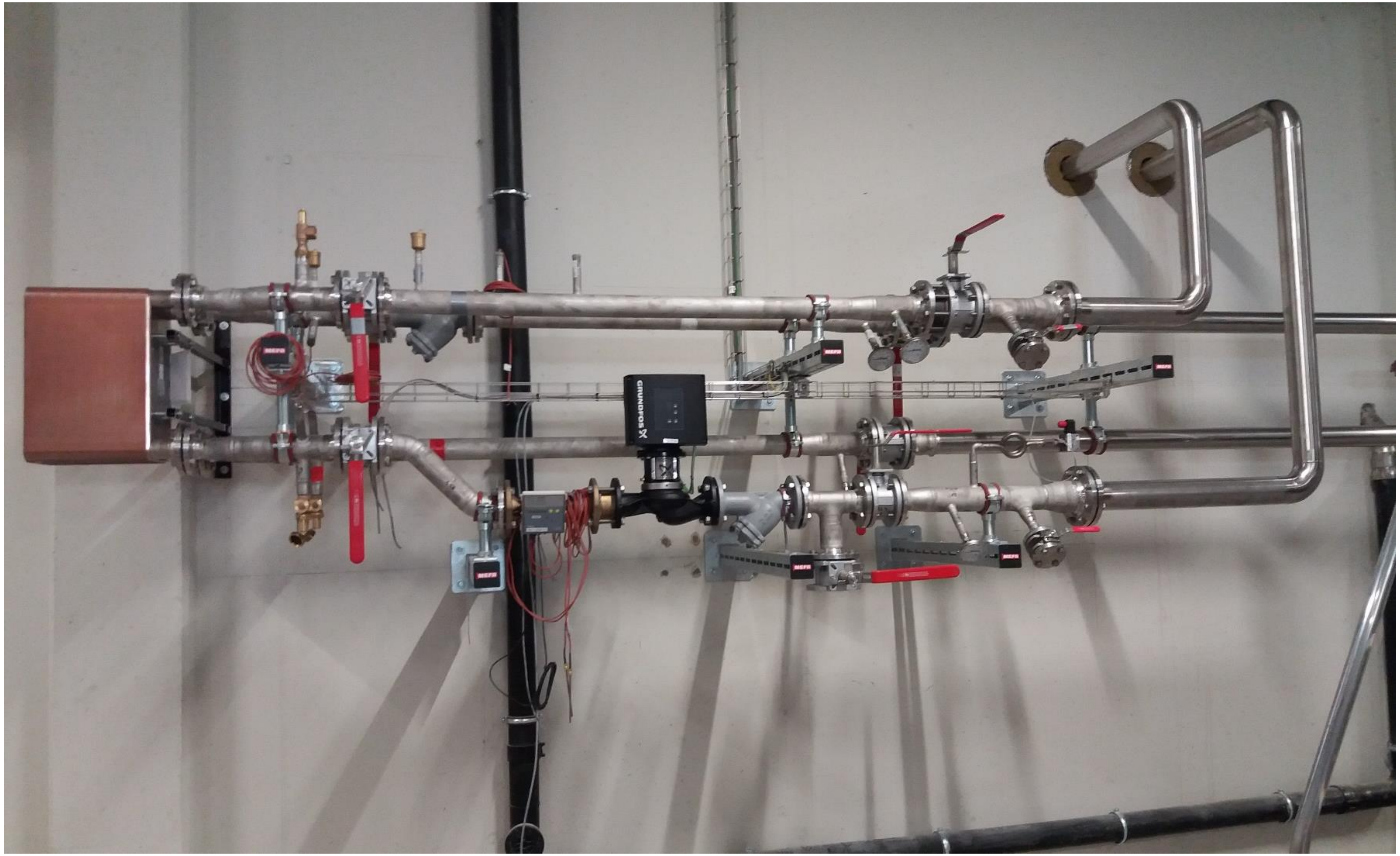


Solar thermal energy - Technology



- Solar heat exchange module to transfer heat from the glycol side (solar collectors) to the water side (energy storage and consumption)
- Measurement of the solar heat generated

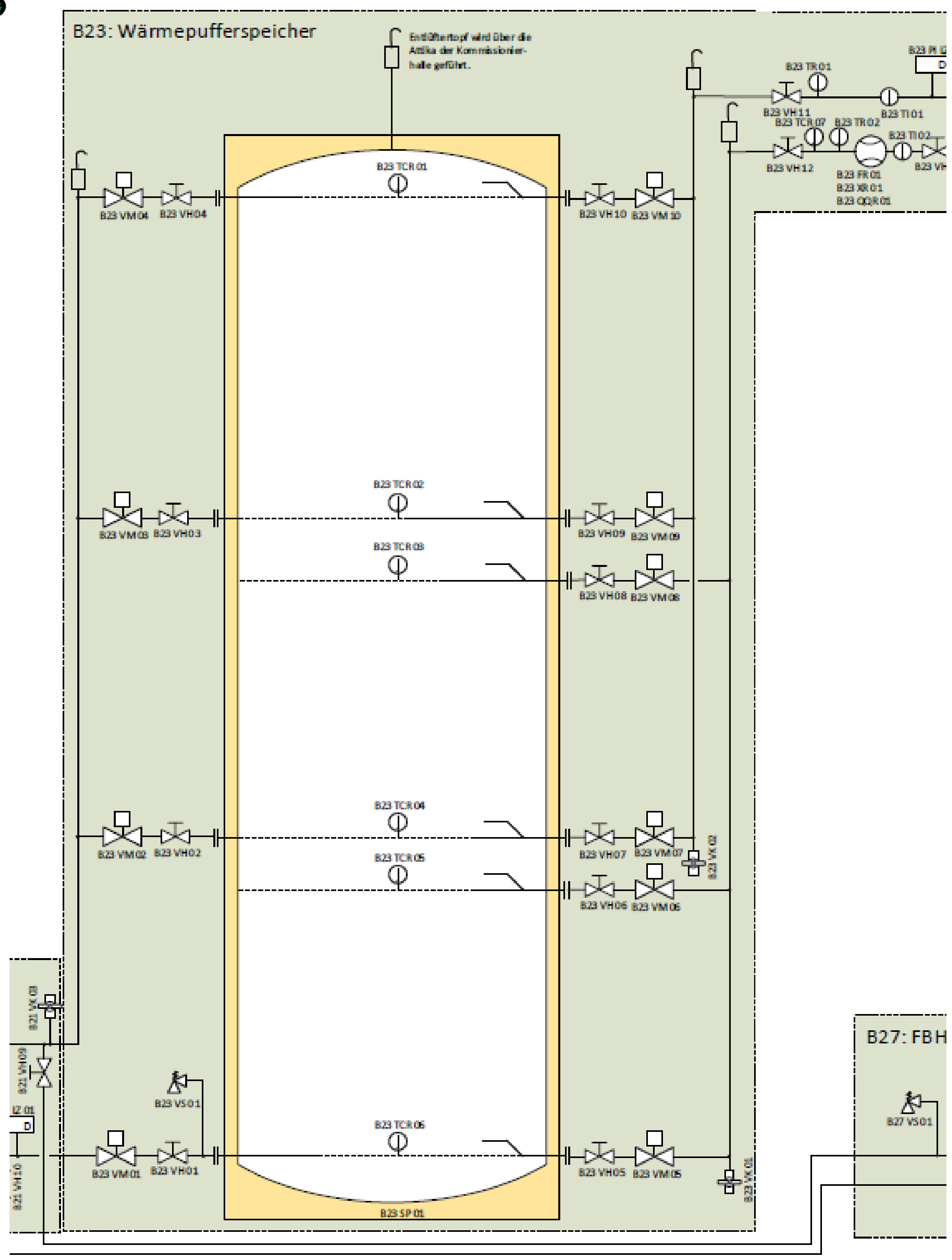
Solar thermal energy plant - Storage



Solar thermal energy plant - Storage

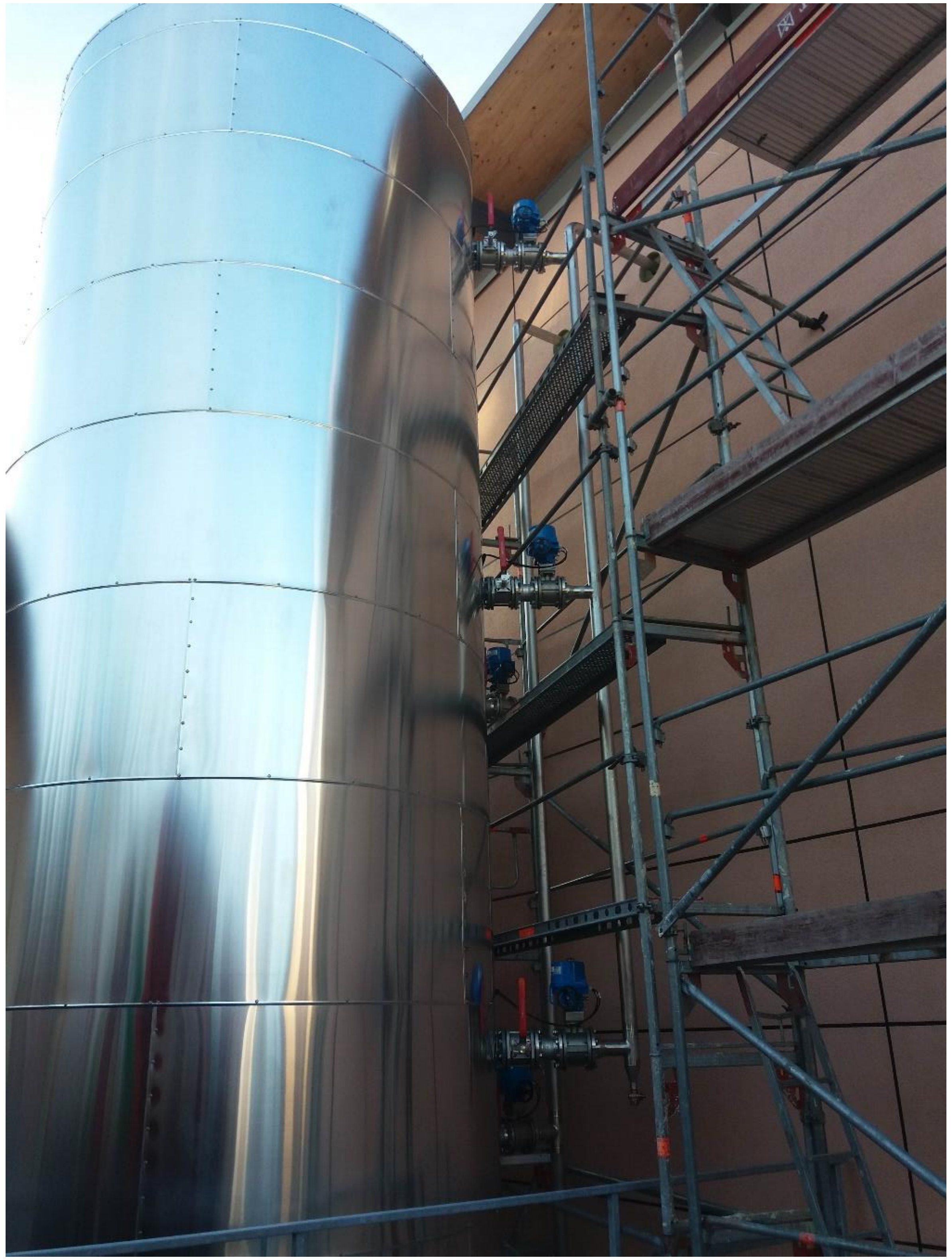
Energy storage:

- volume 55 m^3
- storage capacity 2.3 MWh



Solar thermal energy plant - Storage

Solar thermal energy plant - Storage



Solar thermal energy – Heat utilisation

- Bottle washing machines of bottling plants 3 and 4 for cleaning of reusable bottles
- Bottling in 3-shift operation
- Ca. 50000 bottles per hour are cleaned here at temperatures of approx. 80°C with a 2% lye (alkaline solution)
- The alkaline solution is heated in a separate heat exchanger using solar thermal energy; if there is insufficient heat energy, the solution is additionally heated in the exchanger with steam

Solar thermal energy – Heat utilisation

Solar thermal energy – Heat utilisation

Solar thermal energy – Heat utilisation

Solar thermal energy – Heat utilisation

- Heating of brewing water from the brewery's own sources for use in the brewhouse from 10°C to 70°C
- Existing hot water storage tanks enable the utilisation of the heat that is generated when bottling stands still, especially at weekends

Solar thermal energy – Heat utilisation

Solar thermal energy plant – Partners

enersolve
storage technology

Rothaus

SOLAR.
UNI-KASSEL.DE

Gatti
SANTÄR & HEIZUNG GmbH

KRAMER
DÄMMTECHNIK

RULAND

Thank you for your attention!

About us

Inventive Power

Breaking new ground in Energy

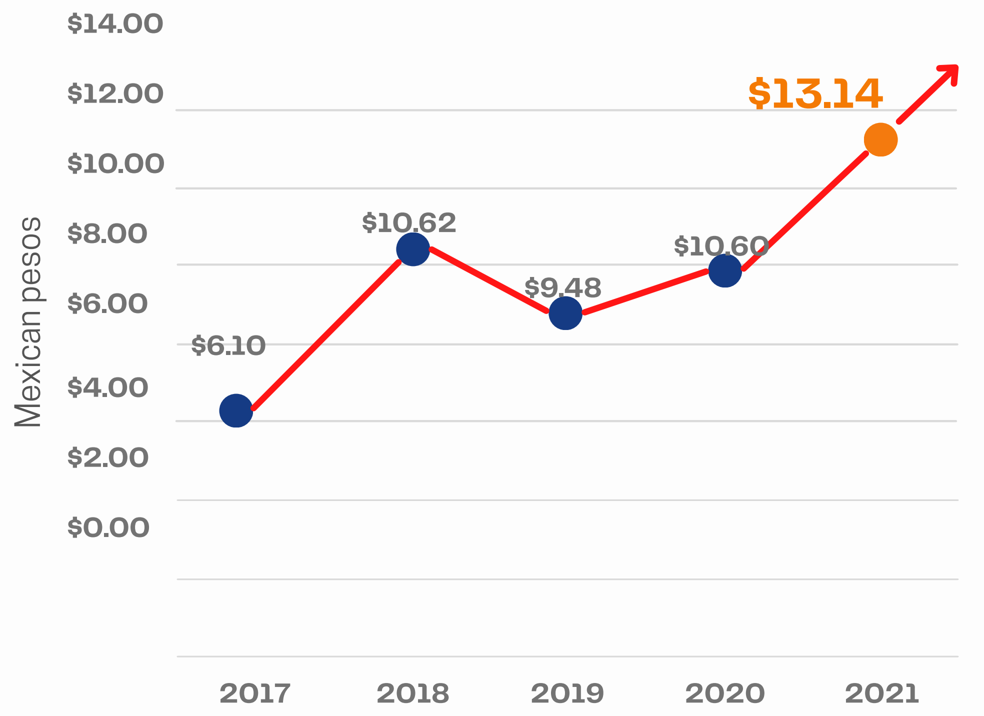
Confidence, Savings and
Returns

Inventive Power is born from the need to produce thermal energy in the industrial sector in México and the rest of the world, without polluting at a much lower cost.

In Mexico are more than 12,000 boilers and water heaters installed. The majority use fossil fuels, which makes their operating costs unstable and more expensive.

During 2021 in Mexico, we suffered a considerable increase on the cost of fuel and electricity. **Do you remember the cost of your bill in 2017?** Surely today that bill has increase considerably.

In just one year, LP Gas had an increase of more than:

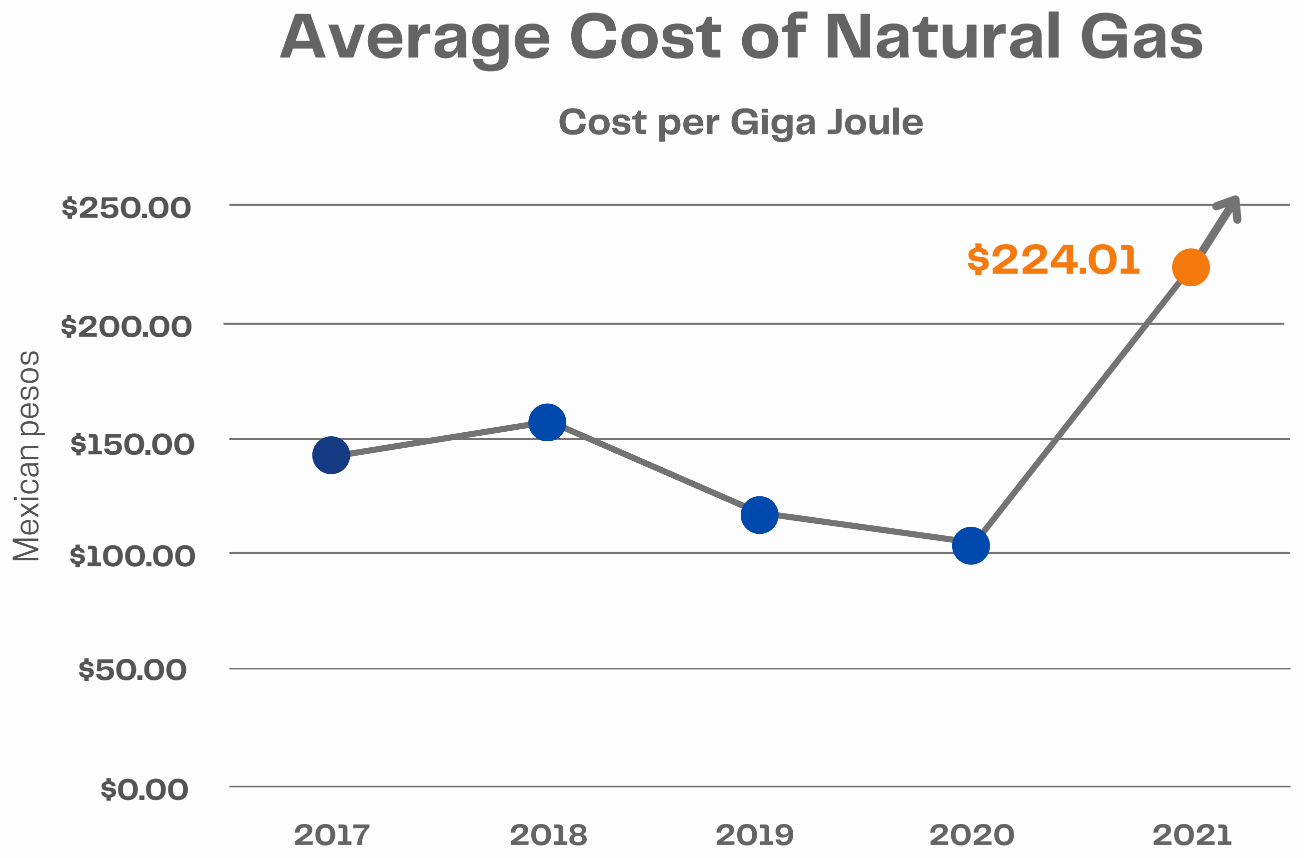


+20%

Compared to the previous year and a

53%

Compared to 2017.



Remember the freezing of wells in Texas?

+122%

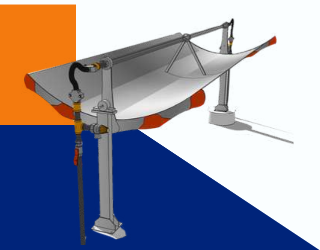
In 2021 we experienced an unprecedented increase in the average cost of natural gas.

FUEL OIL THE MOST POLLUTING AND INEFFICIENT FUEL IN THE WORLD

History IP

2010

Inventive Power is established as a Legal Company.



2010 - 2012

Technological development of the Power Trough 110. Begins to commercialize products and sells first 4 projects for 2.3 M mexican pesos.

2013

It was awarded by the Inter-American Development Bank as the best green business in Latin America and the Caribbean.

2014

Angel and Aldo were named entrepreneurs of the year by CNN Expansion magazine.

2014...

IP is consolidated as the best company that supplies solar thermal energy for the industrial and commercial sector

2017

The patent technology is obtained in Mexico and USA

2018 - 2020

ISO9001:2015 certification and recertification

2021

First Mexican and Latin American company to sign solar steam sale agreement (PPA)

More than 12 years of experience...

Leaders in the energy sector

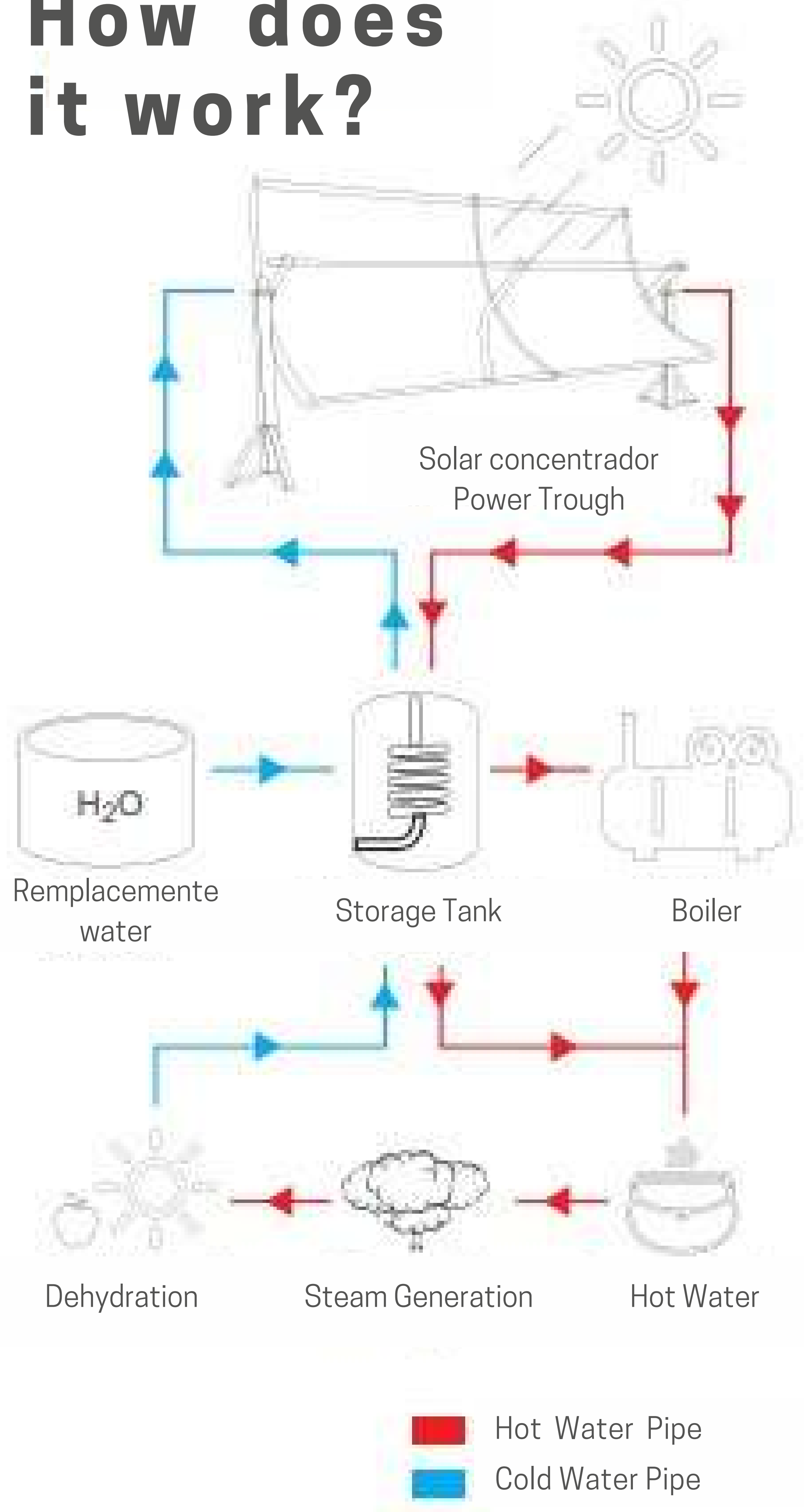
+150
Projects installed

+140 MDP
Savings generated

+28,000 m2
Solar collection area

+12,000 TON
Annual CO2 reduction

How does it work?

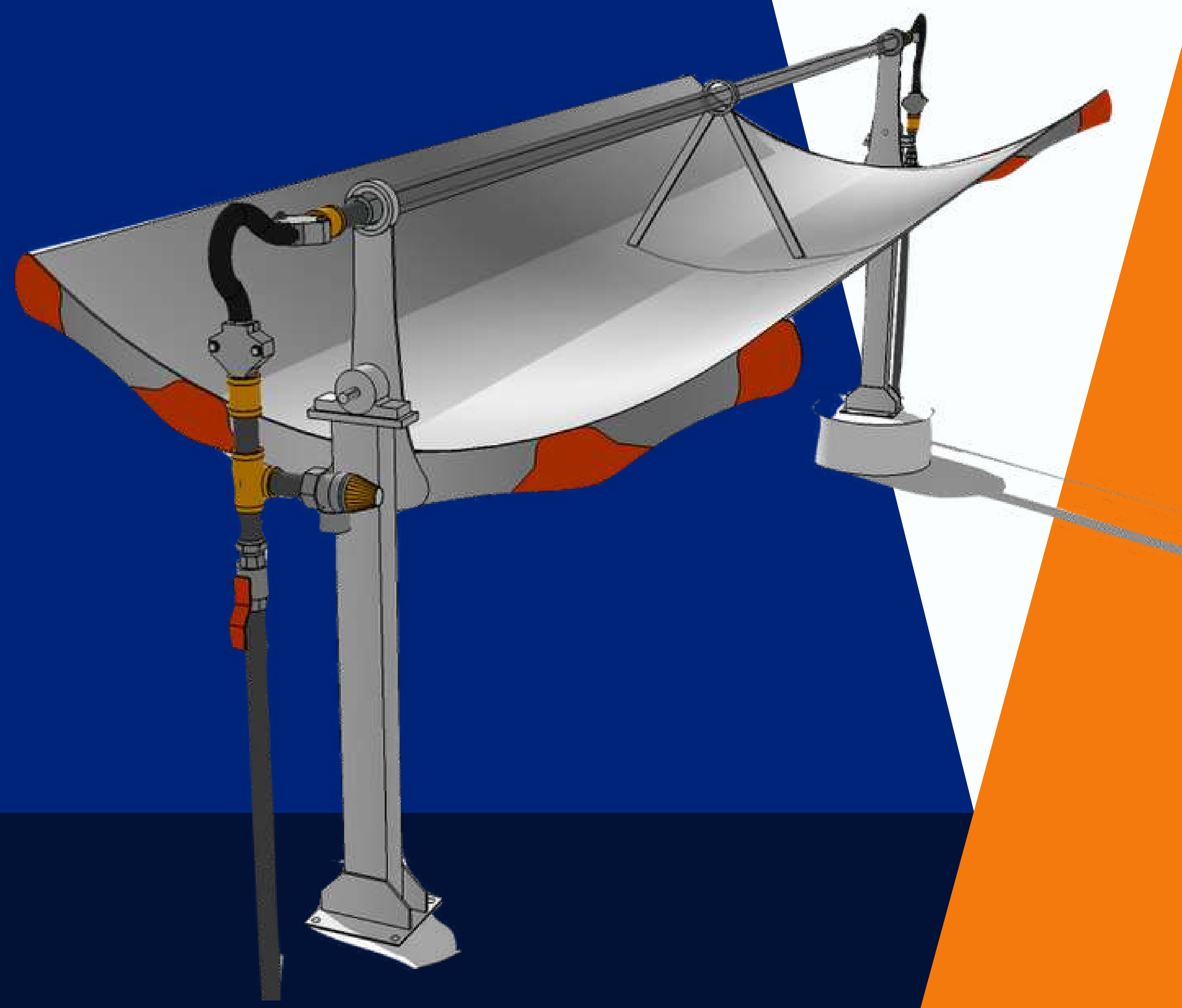


Our Solar Tecnology

IT IS SUPERIOR

to the available in the market

We generate hot water and steam from 50°C to 250°C



PATENTS:

Mexico: MX/A/2012/003407 – PCT/MX2013/000022

United States: US 2015/0122309 A1

74
#of solar concentrators

80°C
Temperature Delivered

m² 814
Solar Collection area

Textile Company leader in research, manufacture and development of textiles, protection in different sectors such as, industrial, ballistic, and marine.

Annual fuel displacement
2,100,000
m3 / Natural Gas

Annual Savings
+13.6 MDP
Mexican Pesos

Hot Water for Process

CAROLINA PERFORMANCE®

Salvatierra, Guanajuato

99 #of solar concentrators Delivered

120°C Temperature

m^2 320 Solar Collection area

Mexican Leader mezcal producer, in both in domestic market and Duty-Free Mexico. With presence growing in the United States and Europe.

Annual fuel displacement 53,079 liters fuel

Annual Savings +662,965 Mexican Pesos

Hot water for Process

Tlacolula de Matamoros, Oaxaca.

CASA ARMANDO GUILLERMO PRIETO

69
# of solar concentrator

120°C
Deliveren Temperature

759 m²
Solar collection area

Leading global company of electronic engineering components, network solutions, marine telecommunication systems and consumer goods in more than 150 countries.

Annual fuel displacement
187,709
liters / fuel

Annual Savings
+1.9 MDP
Mexican Pesos

Hot water for process

TE connectivity

Hermosillo, Sonora.

72350 kg/h

Delivering solar steam daily

#of solar concentrators

792

Solar collection area

Company from Guanajuato, Mexico. Which produces dairy products, ferments, and derivatives.

Heat Purchase Agreement

Annual fuel displacement

181,364.73

liters /LP Gas

10% LESS

of LP Gas liter cost

Solar Steam Sale Agreement

Solar Production 100% Sustainable

San José de Iturbide, Guanajuato

1379
# of solar panels

500 kW
Power delivered

8140 m²
Solar collection area

Company that specializes on the production of specific food for cattle, horses, pigs, sheep, and poultry.

140
#of solar concentrators

Annual fuel displacement
142,364
liters fuel

Annual Savings
+3.2 MDP
Mexican Pesos

Hybrid Project

Extension of Photovoltaic system

Lagos de Moreno, Jalisco.

Comfosa
ALIMENTOS BALANCEADOS DESDE 1962

130
# of solar concentrator

5.2 Ton
Delivered Steam per day

1300
Solar collection area

Leader company in the manufacturing, comercialization, and technical services regarding explosives solutions for the mining industry.

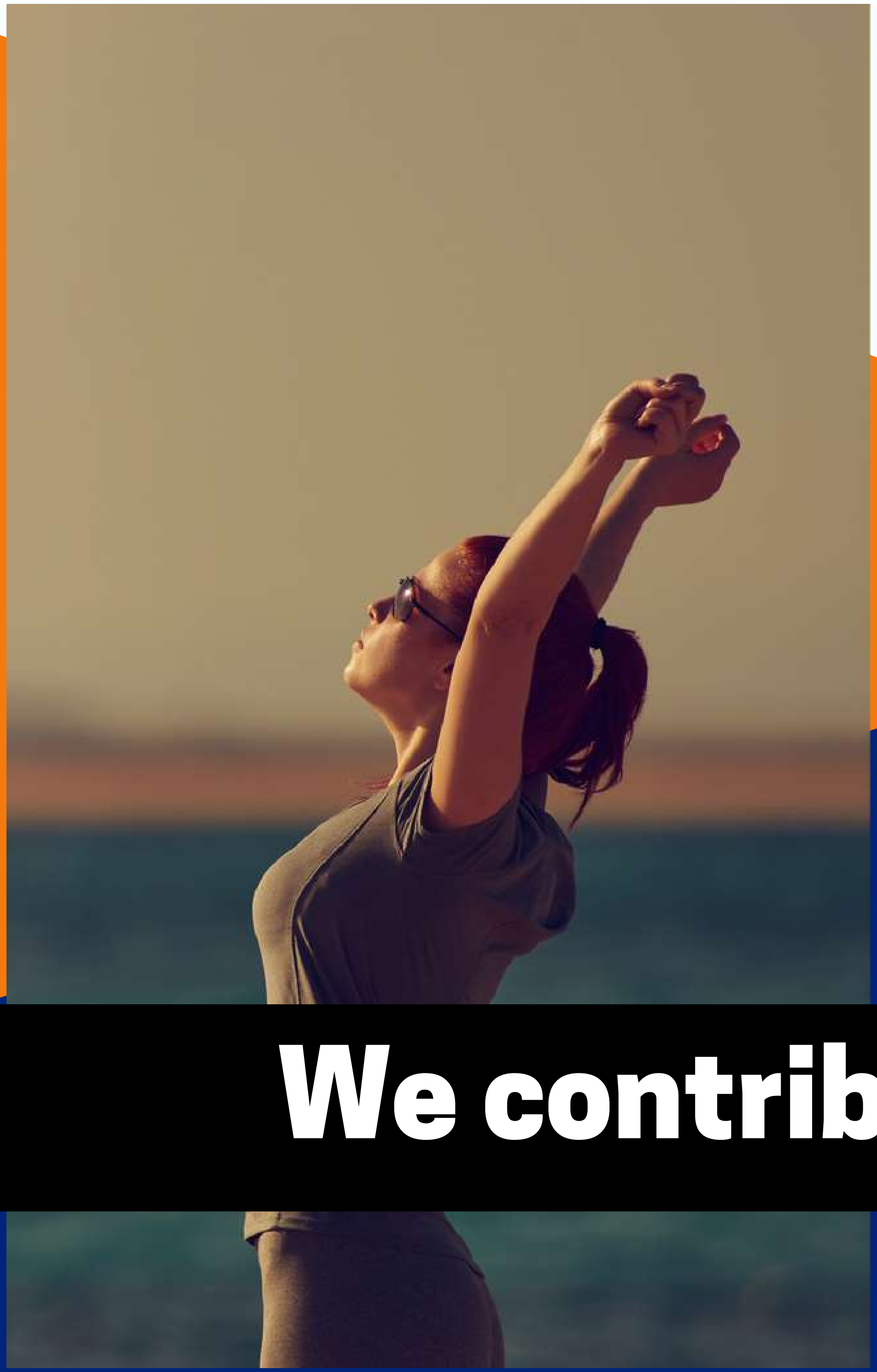
Annual fuel displacement
210,294.33
liters of Diesel per year

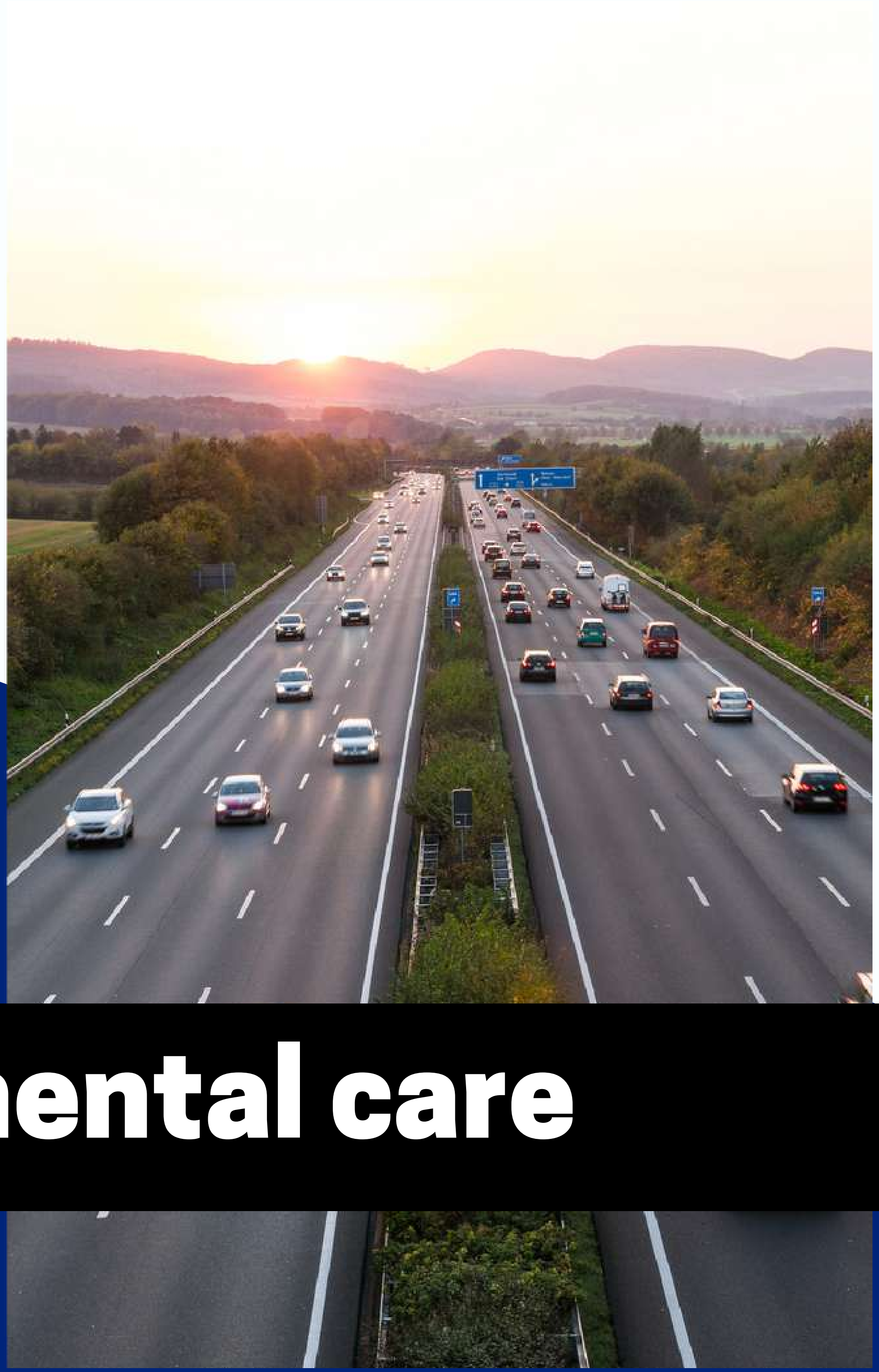
Annual Savings
+199,779.61 USD
per year

Solar Steam Generation

HANKA

Hermosillo, Sonora.





We contribute to environmental care

+12,000

Ton of CO2 emissions

122,400

Planted Trees

4,223

Removing Cars from the streets

Projects in Execution

Inventive Power

Breaking new ground in Energy

50
# of solar concentrator

80°C
Deliveren Temperature

m² 165
Solar collection area

Swiss multinational manufacturer of aroma, fragrances, and active cosmetics ingredients. Since 2008, it's the world's largest company in aroma and fragrance industries.

Annual fuel displacement
910.46
GJ / Natural Gas

Annual Savings
+200,238
Mexican Pesos

Hot water for process

Givaudan

Cuernavaca, Morelos.

70
# of solar concentrator

95°C
Deliveren Temperature

m^2 231
Solar collection area

Transnational company, leading manufacturer of infantile formula with their star products Enfamil and Choco milk.

Annual fuel displacement
34,914.59
M3 / año, de Gas Natural

Annual Savings
+225,892.58
Mexican Pesos

Boiler Pre- Heating

Mead Johnson™ Nutrition

Inventive Power

Breaking new ground in Energy

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enviarme un WhatsApp

Thermal Energy Storage and Solar Thermal Process Heat Integration

Tom Fluri
SFERA-III Training for Industries: CST4SHIP
Freiburg, Nov 8, 2023
www.ise.fraunhofer.de

Agenda

1. **Thermal Energy Storage – Technology Overview**
2. **Pre-Feasibility and Feasibility assessment**
3. **Solar Thermal Process Heat Integration**
4. **Contribution from Participants**
    1. **Swissfurnace,** Cem Vardar
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    4. **Solatom**, Miguel Frasquet

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Thermal storage - Motivation and benefits

Offering the de-coupling of heat supply and heat demand

Thermal Storage …

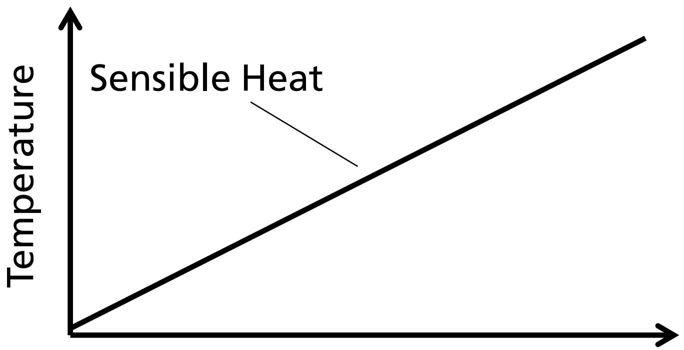
- … is the cheapest energy storage technology
- … makes use of abundant materials
- … has a low carbon footprint

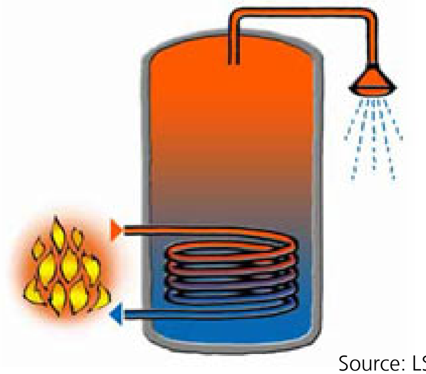
The de-coupling of heat supply and heat demand is …

- … enabling an increased share of fluctuating renewable heat sources, e.g. solar thermal
- … facilitating the use of surplus heat recovery for re-use on demand
- … offering to store cheap off-peak electricity as thermal energy via power-to-heat directly to (high temperature) heat storage
- … using flexible cost of energy supply, e.g. variable electricity tariffs
- … providing peak-shaving of electrical and thermal loads
- … contributing to grid stability and reducing grid congestion
- … offering additional backup heat supply to support robust operation
- …

Thermal Energy Storage Concepts

Sensible Heat Storage

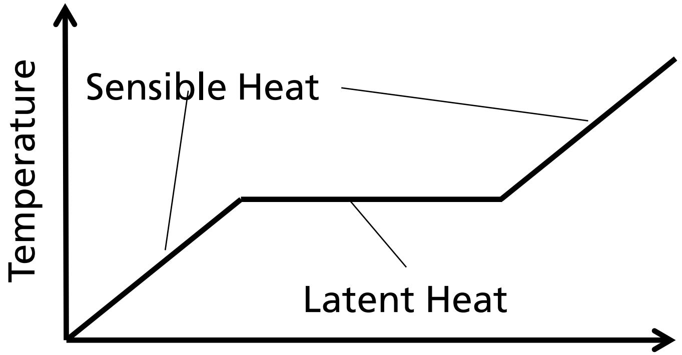


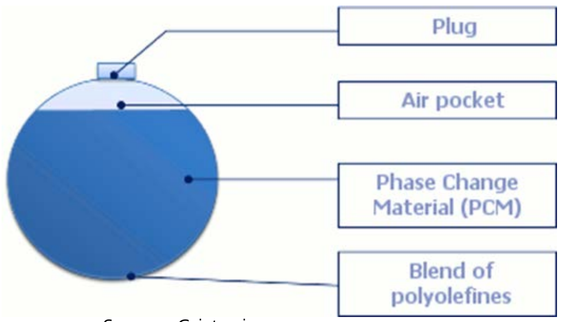


Source: LSI

Latent Heat Storage

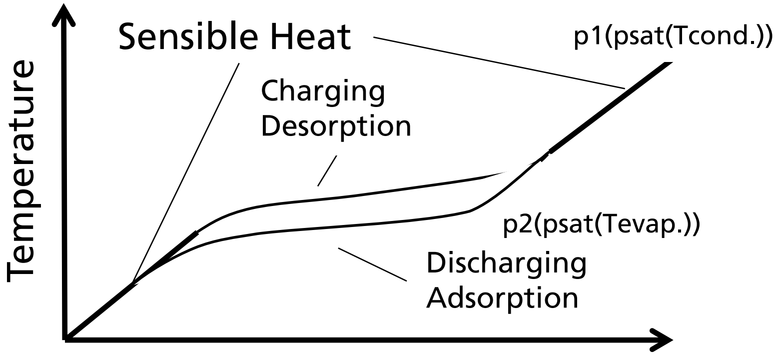
(Phase Change Material, PCM)

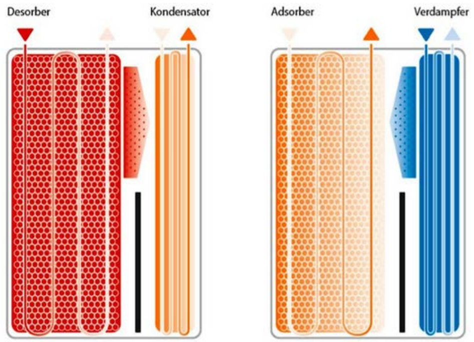




Source: Cristopia

Thermo-Chemical Heat Storage & Sorption Storages





Source: Sortech

Investigated Concepts at Fraunhofer ISE

Thermal storage

- Sensible
  - Thermal oil (up to 300 °C)
  - Molten salt (up to 700 °C)
  - Packed-bed (up to 1400 °C)
  - Solid bodies (up to 1400 °C)
- Latent / PCM (-30 °C – 1400 °C)
  - Slurry
  - Micro encapsulation
  - Macro encapsulation
  - Embedded heat exchanger

Technology Overview

Thermal storage

	Regenerator	Regenerator	Molten Salt	Ruths	Phase Change Material	Liquid Metal	Hot Water
Storage Material	Ceramics	Natural Rock	Nitrate Salt (molten)	Pressurized Water	Nitrate Salts, Aluminium,…	ZrSiO4,…	Water
Energy density *in kWh/m³*	75 - 200	75 - 200	75 - 200	up to 100	50 - 200	75 - 200	60-80
Max. Capacity	1000 MWh	23 MWh	4500 MWh	30 MWh	500 MWh	100 kWh	scalable
Typ. Temperatures	400-1600 °C	200-800 °C	170-560 °C	150-230 °C	130-330 °C	100-700 °C	< 280°C
Typ. Heat Transfer Fluids	Gases	Gases	Salt	Water/Steam	Steam	Lead/Bismuth	Water
Investment cost TES *in €/kWh*	15 – 40	-	15 – 70	70 – 300	40 – 80	Not known	25-30
Maturity (TRL)	6 – 9	4 – 5	4 – 9	8 – 9	4 – 5	3 – 4	9

Main Components of a SHIP system

Thermal Energy Storage (TES)

- Heat storage is required for mismatch between thermal energy supply and energy demand
- Commonly used TES are based on water:
  - Relatively inexpensive
- Different types of TES are available:
  - Pressurized or non pressurized (atmospheric)
  - With internal or external heat exchanger

Thermal Energy Storage for SHIP

Water Storage

Unpressurized Tmax < 90°C

Pressurized Tmax > 90°C

Steel vessels with insulation

The standard solution for solar process heat systems is water storage

Other fluids are thermal oil and molten salt for higher temperatures

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Thermal Energy Storage for SHIP

Water Storage

Example: Copper mine “Gabriela Mistral”, Chile, non-pressurized water storage

Storage volume: 4300 m^3

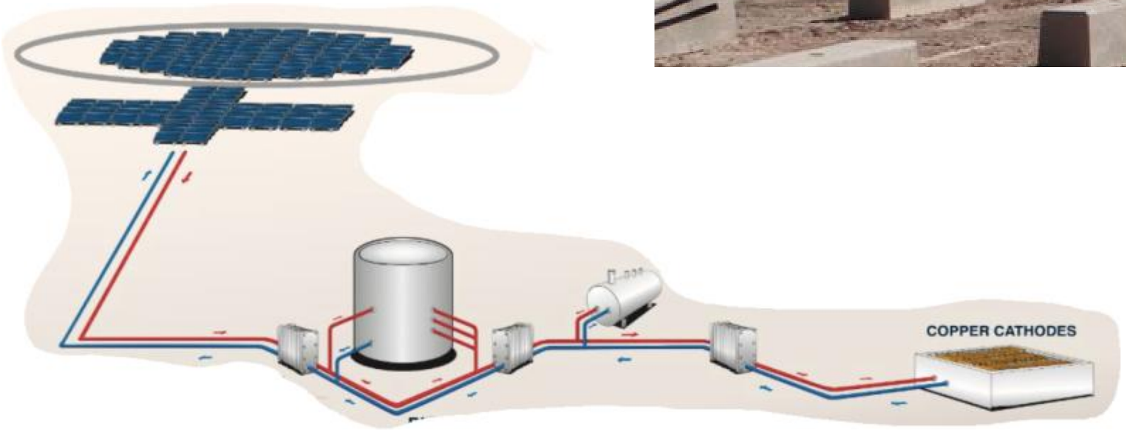
Collector field area: 39,300 m^2 FPC

Solar fraction: 85-100%

electro winning of copper

electrolyte kept at 50°C

cleaning processes



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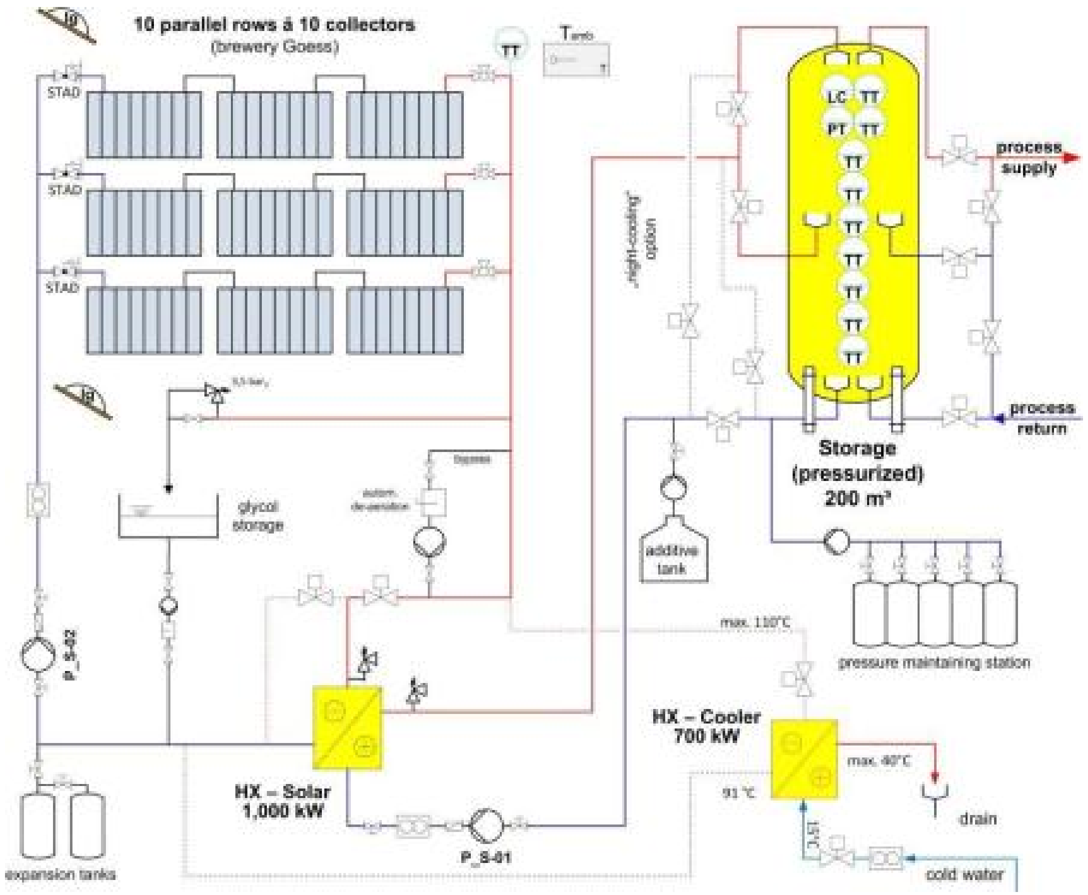
Thermal Energy Storage for SHIP

Water Storage

Example: Brewery Göss, Austria, large pressurized water storage (200 m³)



Thermal Energy Storage for SHIP

Steam Storage

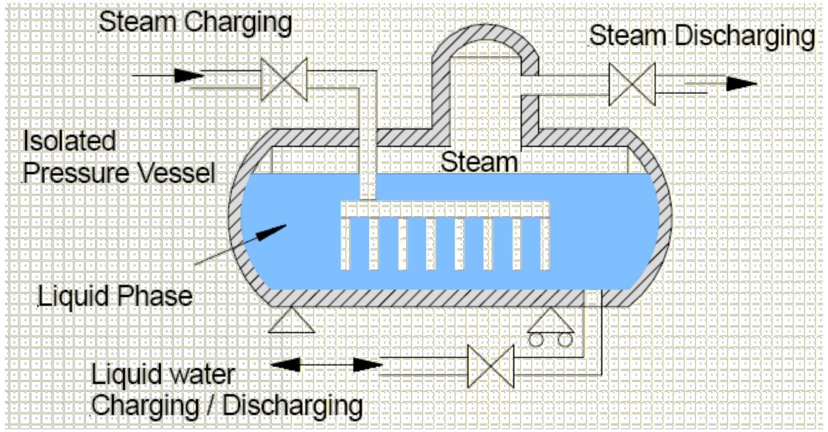
Ruths Storage

Steam charging and steam discharging

Pressurized water/steam in the tank

High investment cost due to expensive pressure vessel

Very expensive option for large-scale / high-pressure applications

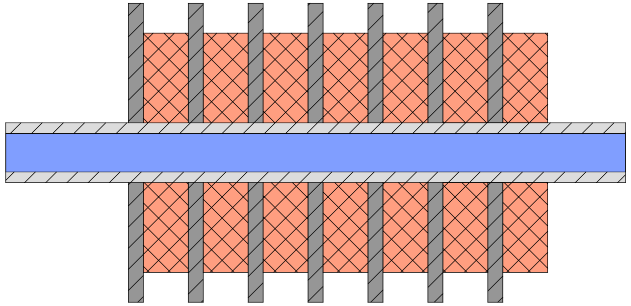


Ruths storage (©DLR)

Thermal Energy Storage for SHIP

Steam Storage

- Latent heat storage with Phase Change Material PCM
- Traditional approach: Finned tube configuration
- Heat transport from HTF into PCM with low conductivity (λ=0,5 W/mK)
  →Large heat exchanger area required
- Fins from graphite / aluminium
- high costs, further R&D necessary



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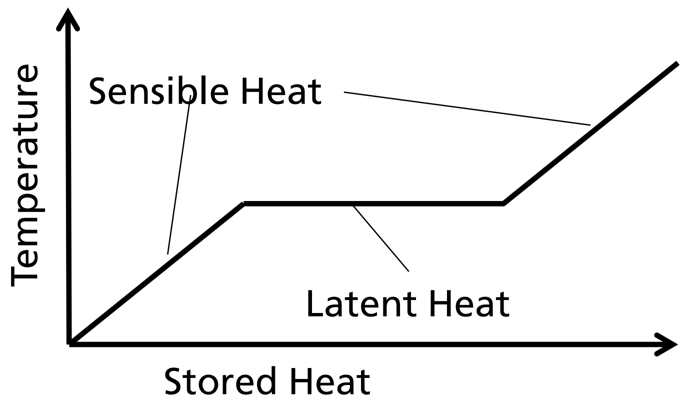
Challenges and Oportunities for Latent Heat Storage

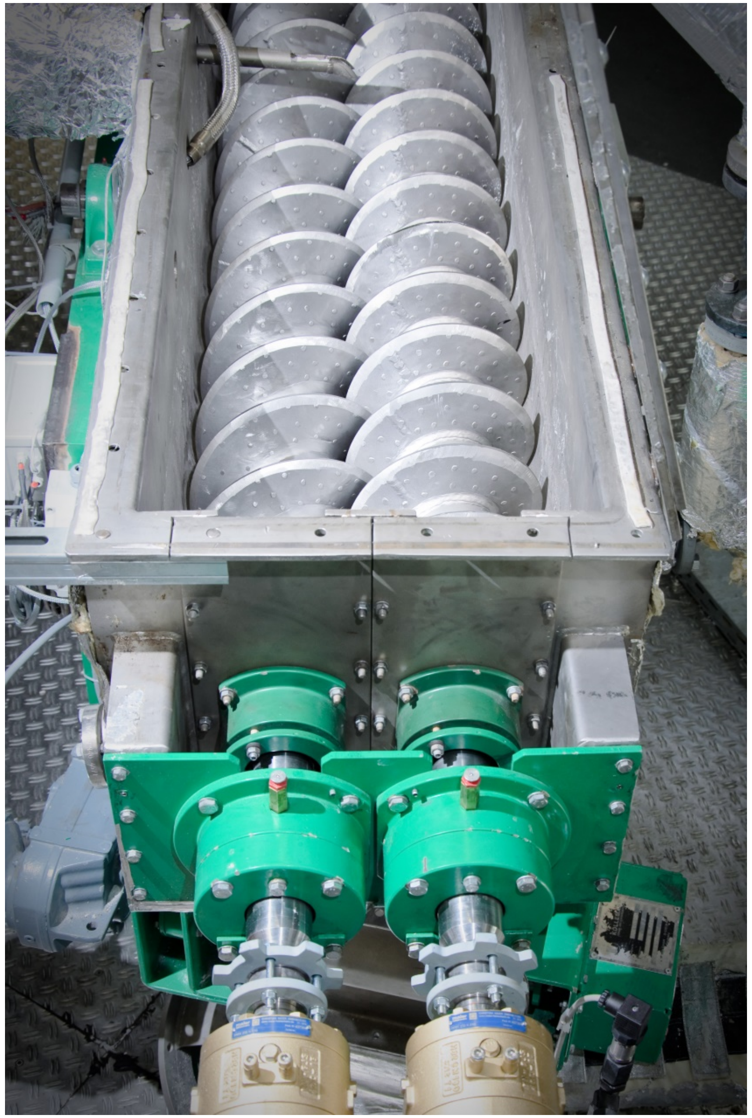
Challenges:
- Not matching well with heat transfer fluids without phase change
- Low heat conductivity in solid state → large heat exchanger surface area required
- Identification of phase change materials with good long term stability
- Lack of suppliers with commercial solutions
- Cost of materials

Opportunities:
- Potential of compact solution

Latent Heat Storage
(Phase Change Material, PCM)



Screw heat exchanger (SHX) module



Screw heat exchanger (SHX) with direct steam input / output through central heilces

Novel concept for **de-coupling of storage capacity and thermal power** was proven in lab-scale

Charging procedure: Steam passes through center of helices, melting up eutectic salt mixture

Discharging procedure: Liquid salt „poured“ over the helices produces steam from pressurized water passing through the center of the helices

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High Temperature Thermal Energy Storage

Established technology – Molten Salt Storage for Concentrating Solar Power Plants

Globally installed capacity: > 21 GWh [1]

Salt mixture: 60% $NaNO_3$, 40% KNO_3

Temperature range: 290°C - 565°C

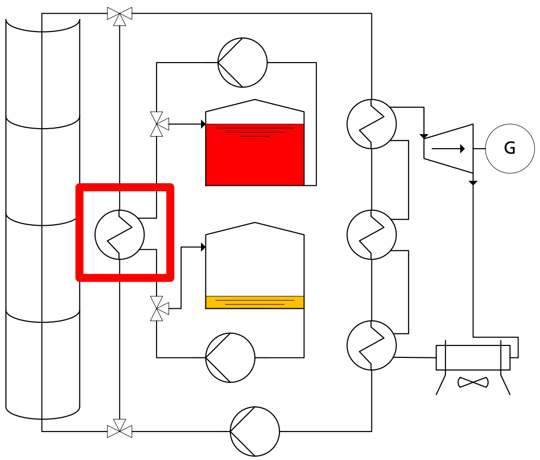
[1] IRENA (2020), Innovation Outlook: Thermal Energy Storage, International Renewable Energy Agency, Abu Dhabi.

Evolution of molten salt storages

The path to lower cost?

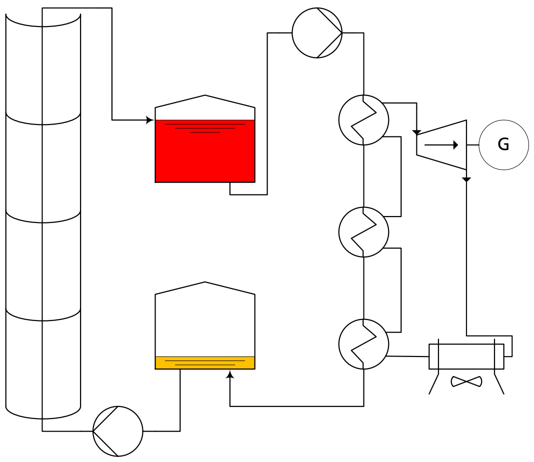
Two-tank indirect

- Temperature loss due two double HX
- Temp. limited by oil
- One tank always empty



Two-tank **direct**

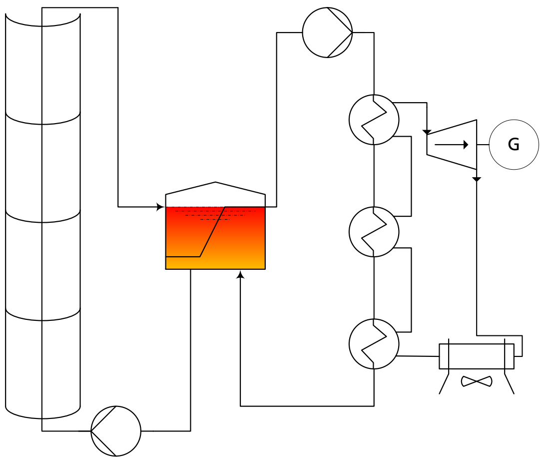
- Molten salt also in collector
- Higher temp. possible
- Less T loss & equipment



- State of the art in solar towers

Single thermocline tank

- One tank less
- Possible integration of HX
- Additional use of filler material reduces amount of salt



- Testing / Pilots

Thermal Energy Storage

Potential Roles in Industrial Applications

- Storage of heat from solar thermal collectors
- Storage of waste heat for use at a later time or at a different location
- Storage of heat in a Power-to-Heat (P2H) application
- Storage of heat in a Power-to-Heat-to-Power (P2H2P) application (Carnot Battery)
- …

High Temperature Thermal Energy Storage

Solid State Storage – The Choice of many Solution Providers

Advantages:

- Low cost of materials
- Easy handling of materials (non-toxic, non-flammable)
- Robustness
- High temperatures >700 °C are achievable
- No risk of freezing
- Storage shell not pressurized

Disadvantages /Challenges:

- Low energy density of heat transfer fluid potentially leading to high parasitic losses and large equipment
- Additional heat exchange from heat transfer fluid to storage medium

High Temperature Thermal Energy Storage

Example for a Waste Heat to Power Application

Site: Bayreuth, Germany

Waste Heat Storage and Supply to ORC-Cycle

Capacity: 1.5 MWh

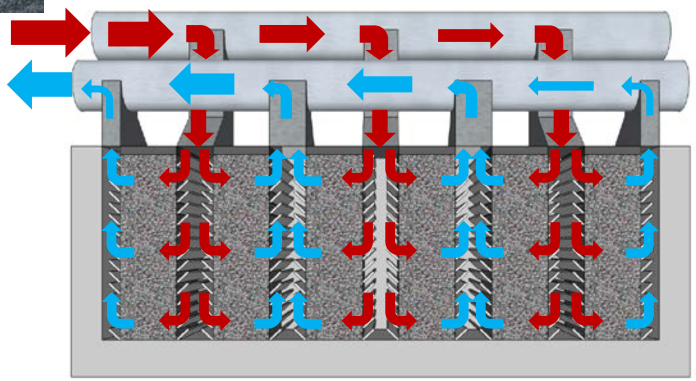
Storage material: Silica Sand

Max allowable operation temperature: 600 °C

Commissioning: 2015

Aim: Technology demonstration

Source: enolcon



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High Temperature Thermal Energy Storage

Example for Direct Steam Generation from Storage

Site: Porsgrunn, Norway

Integration in steam supply of fertilizer factory

Capacity: 4 MWh

Storage material: Concrete

Max allowable operation temp. / pressure: 420 °C / 100+ bar

Min operation pressure: 1 bar / 100 °C

Planned commissioning: Q2/2022

Aims:

- Prevention of excess steam dumping
- Reducing need for hot standby boilers
- Flexible and instant steam provision

Source: EnergyNest

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Project example: Thermal energy storage integration

Heat recovery in ceramics industry

Aim:
Development and optimization of cost-effective storage material and demonstration in industrial application

Scope:
- Development and optimization of filler materials
- Combination with various heat transfer fluids (oil, molten salt, air)
- Compatibility testing
- Technology selection
- Storage integration

Partners:
- Kraftblock GmbH
- Comet Schleifscheiben GmbH
- Fraunhofer ISE


30 kWh lab prototype with molten salt


Installation of additional sensors on site


0.9MWh demonstrator using air (© KraftBlock)


Crucibles and samples for compatibility testing

Agenda

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   3. **Naked Energy**, Axel Mellor
   4. **Solatom**, Miguel Frasquet

Prefeasibility and Feasibility Procedures

General procedure

Definition of solar process heat potential

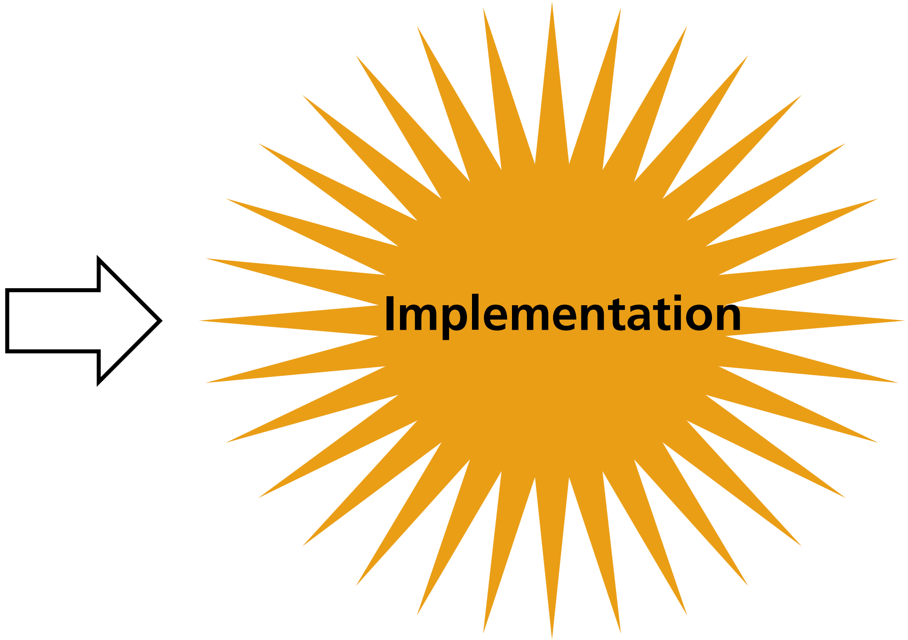
Pre-evaluation

Identification of possible integration points

Technical analysis

Economic analysis

Recommendation for solar integration



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Typical Approach

Pre-Feasibility
- Boundary conditions
- Remote data acquisiton
- Processing of first information
- Preliminary assessment

Detailed analysis of Status Quo
- Site visit
- Additional sensors & measurement campaign
- Energetic optimization (Pinch analysis)

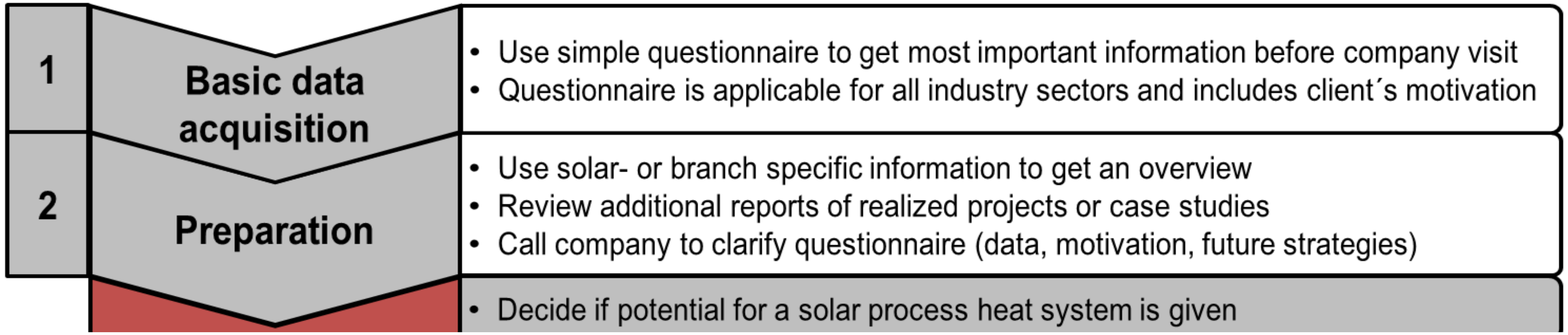
Definition of technology options & optimal transition paths
- Optimization based on simulation
- Concept development

Investment and cost analysis

Prefeasibility and Feasibility Procedures

Pre-Assessment

Aim: Evaluation of potential for solar process heat



[1]

[1] www.solar-process-heat.eu/checklist

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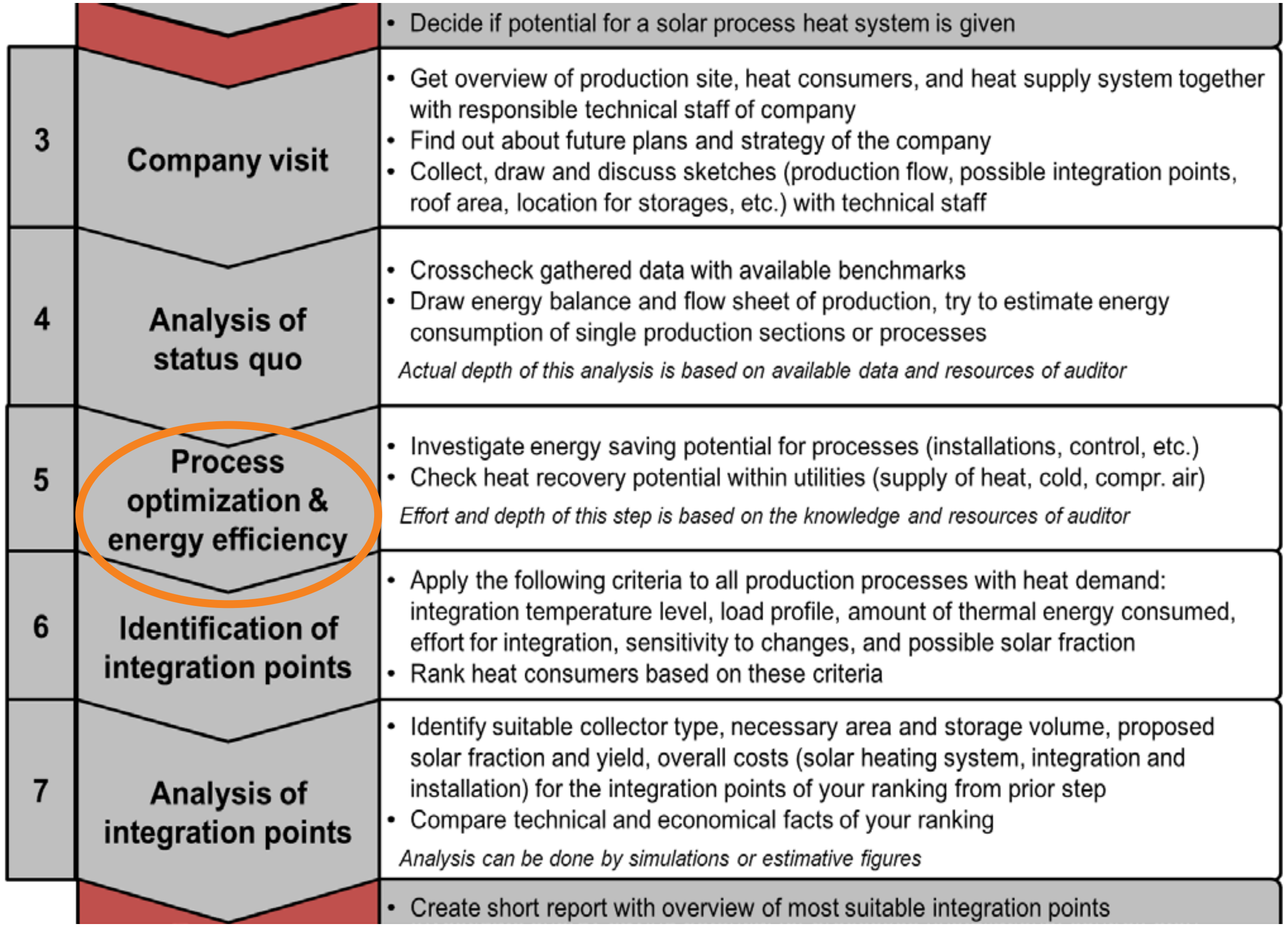
Prefeasibility and Feasibility Procedures

Feasibility Study

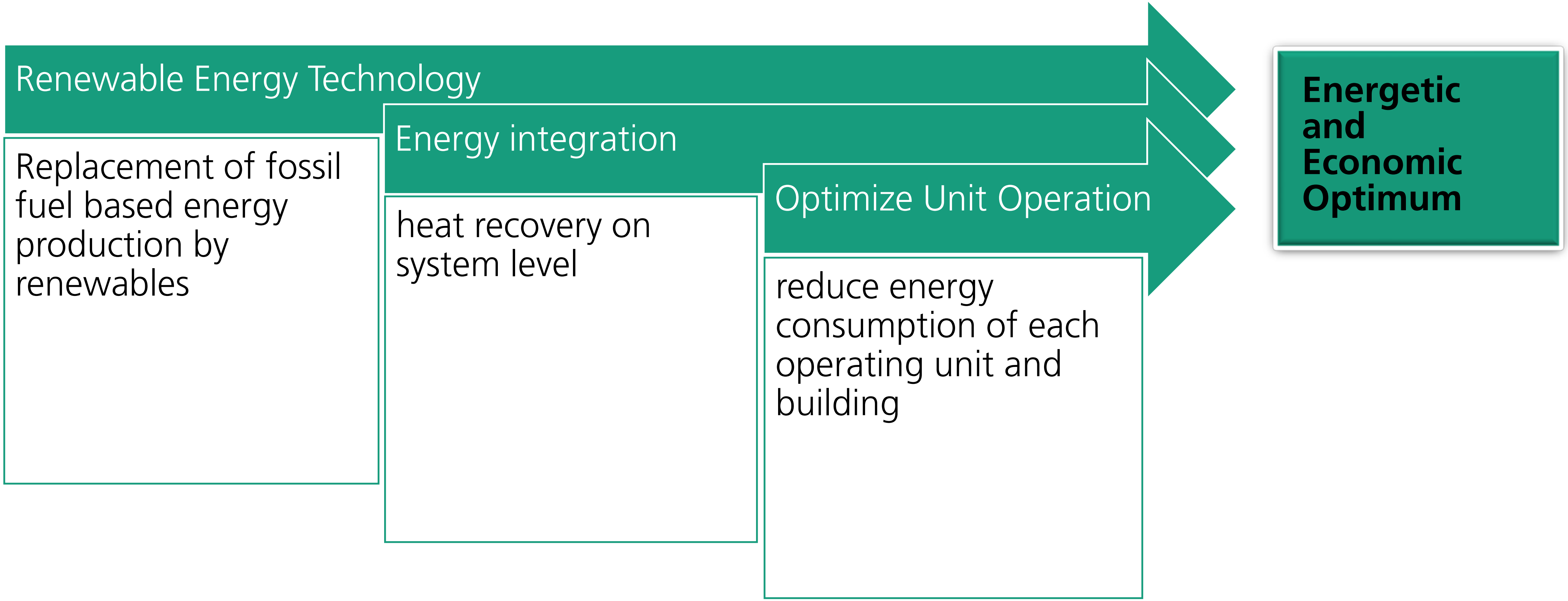
Aim: Recommendation for decision making



[1]

[1] www.solar-process-heat.eu/checklist

Decarbonization of Industrial Processes – Three Levels



Prefeasibility and Feasibility Procedures

Efficiency First!

Typical measures:

- Thermal insulation of components
- Reduction of temperatures/pressures
- Replace steam networks with hot water networks
- Process integration (internal use of waste heat) → ideally derived from pinch analysis
- Waste heat utilization (e.g. from compressors)

Non-heat related:

- Efficient lighting (LED)
- Variable speed drives for fans, pumps

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Prefeasibility and Feasibility Procedures

Conclusion

Steps 8-9

Decision and detailed planning

		• Create short report with overview of most suitable integration points
8	Decision	• Discuss possibilities for solar process heat system with company • Based on the results of the prior step, the company should be able to decide if a solar heating system is desired and which concept shall be realized
9	Detailed planning	• Start detailed planning based on the company's decision • Repeat some of the prior steps again if necessary (e.g. to measure specific energy flows that are important to verify status quo)

[1]

[1] www.solar-process-heat.eu/checklist

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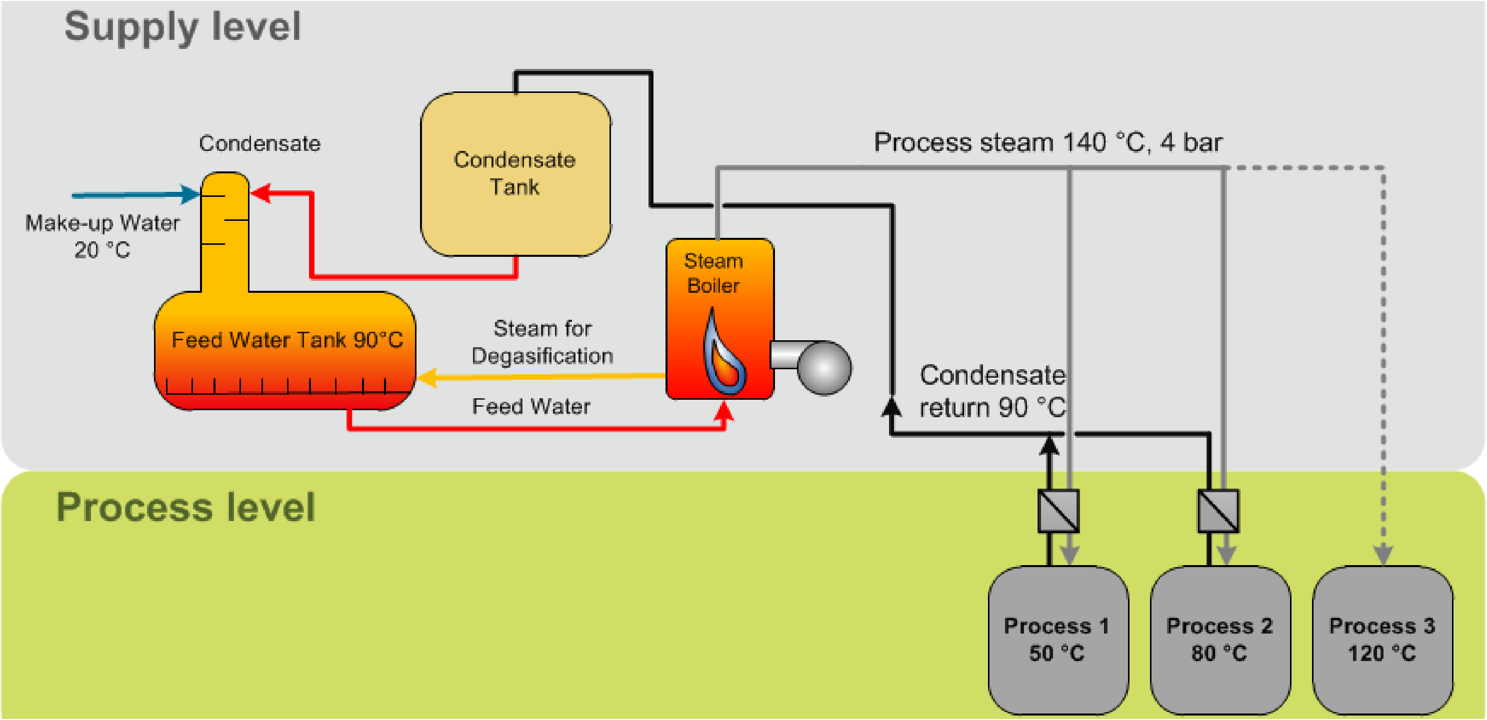
Integration Concepts
Classification

Solar heat (steam or hot water) can be integrated into

- heat distribution network
- different processes



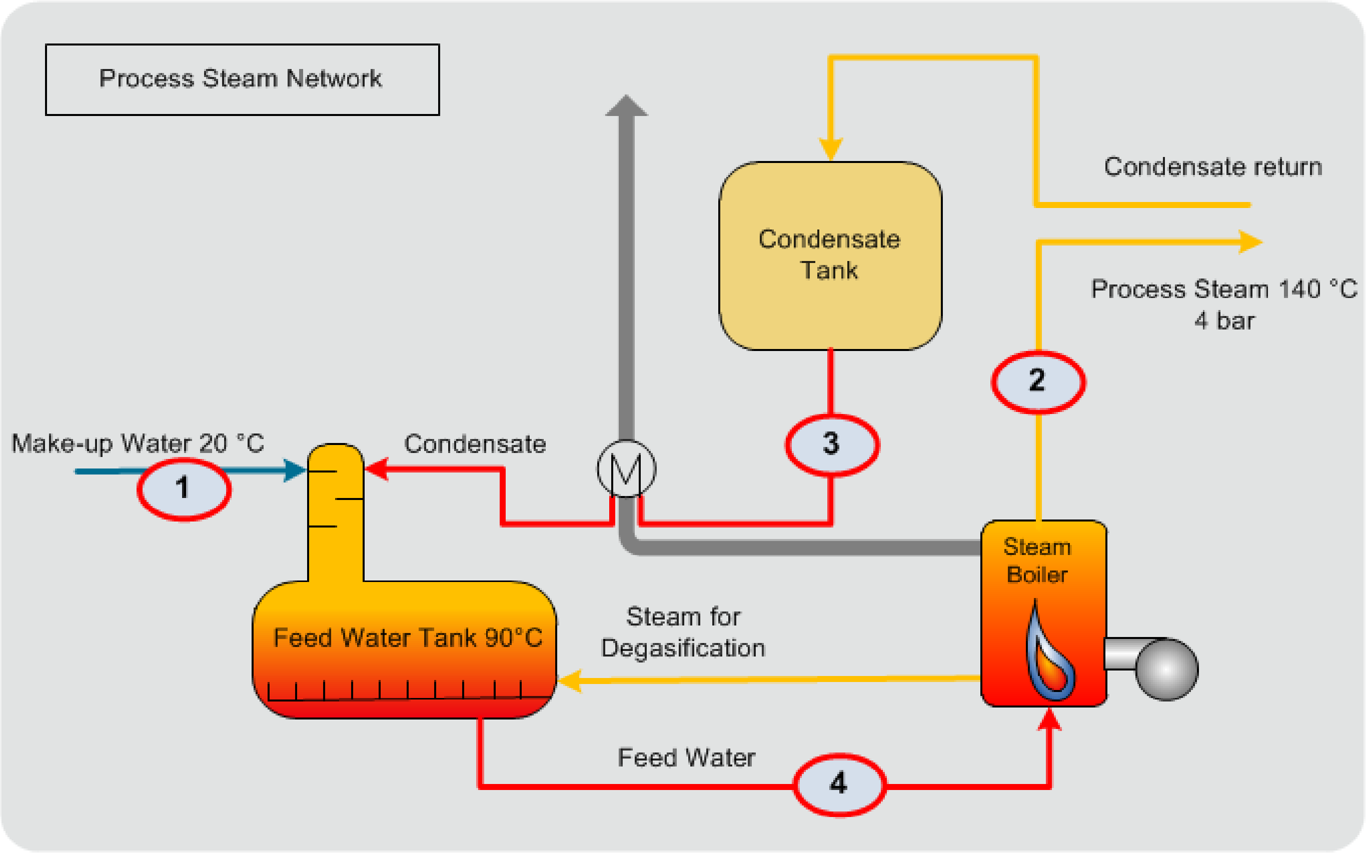
Integration Concepts

Supply Level Integration

Solar heat supply to all processes through heat distribution network (mostly steam networks and hot water networks)

Options:

- Make-up water pre-heating and/or condensate pre-heating(1/3)
- Steam generation to directly feed steam network (2)
- Pre-heating of boiler feed water (4)



Integration Concepts

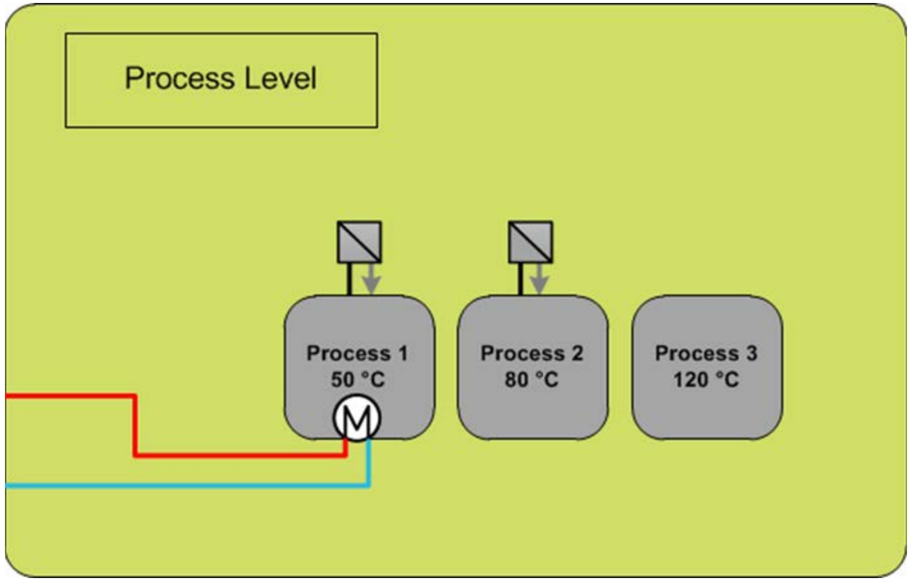
Process Level Integration

Solar heat directly supplied to process

- Particularly interesting for processes that require low temperature heat (until 100 °C)
- Typically, lower temperatures than supply level
  →Lower thermal losses lead to higher solar gains per square meter

Drawback:

- High dependency on changes in the process
- Potentially high fluctuation in demand

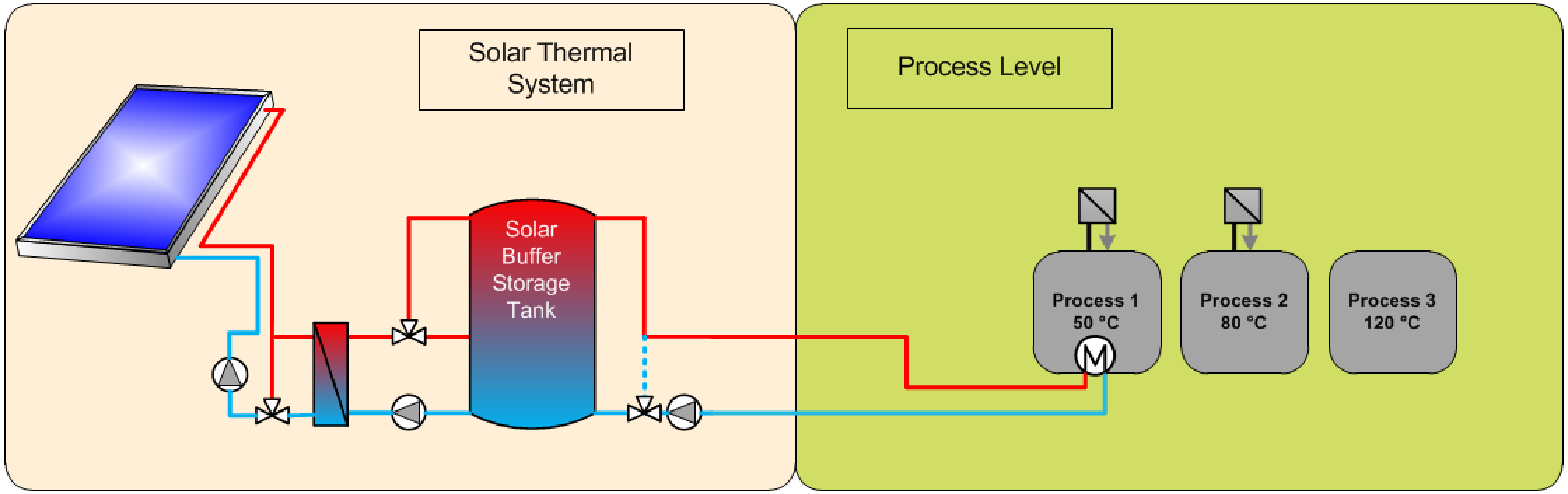


Integration Concepts

Process Level - Example

Possible applications:

- Heating of cleaning or process water
- Heating of galvanic baths
- Heating of drying air



Integration Concepts

Criteria for Process or Supply Level Integration

Criteria	Process level	Supply level
Detailed process data	Required	Not needed
Preliminary process integration analysis	Essential	Generally recommended
Flexibility to adapt to later changes in processes	Low	High
Collector efficiency	Potentially higher	Usually lower
Solar heat contribution potential	Restricted	Usually higher
Heat storage necessity	Depends on the profile of the selected process stream(s)	Not necessary if not exceeding the base load of the utility

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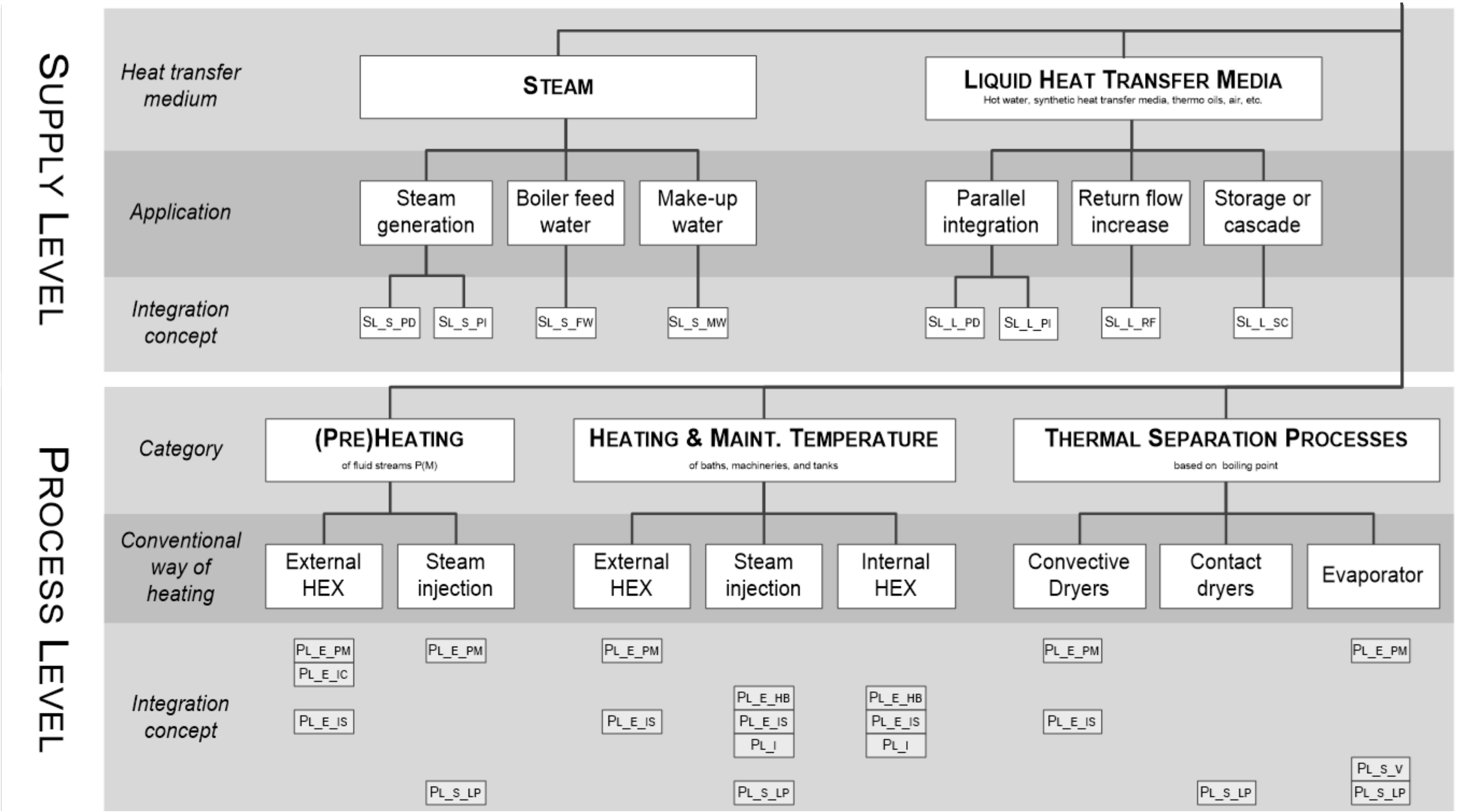
Integration Concepts

Integration of Solar Heat in Industrial Applications



[1]

[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

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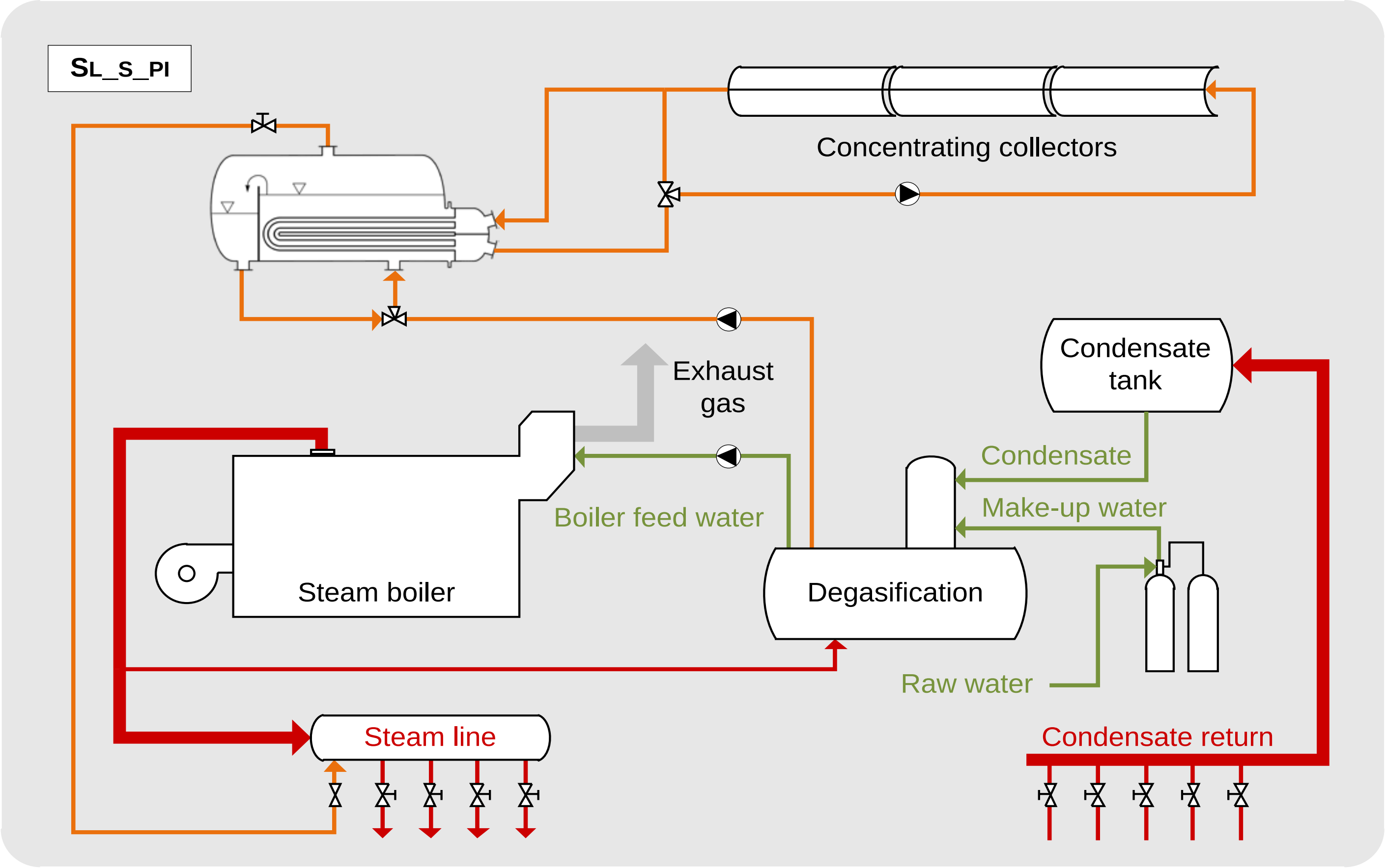
Integration Concepts

Examples

SL_S_PI

Indirect solar steam generation



[1]

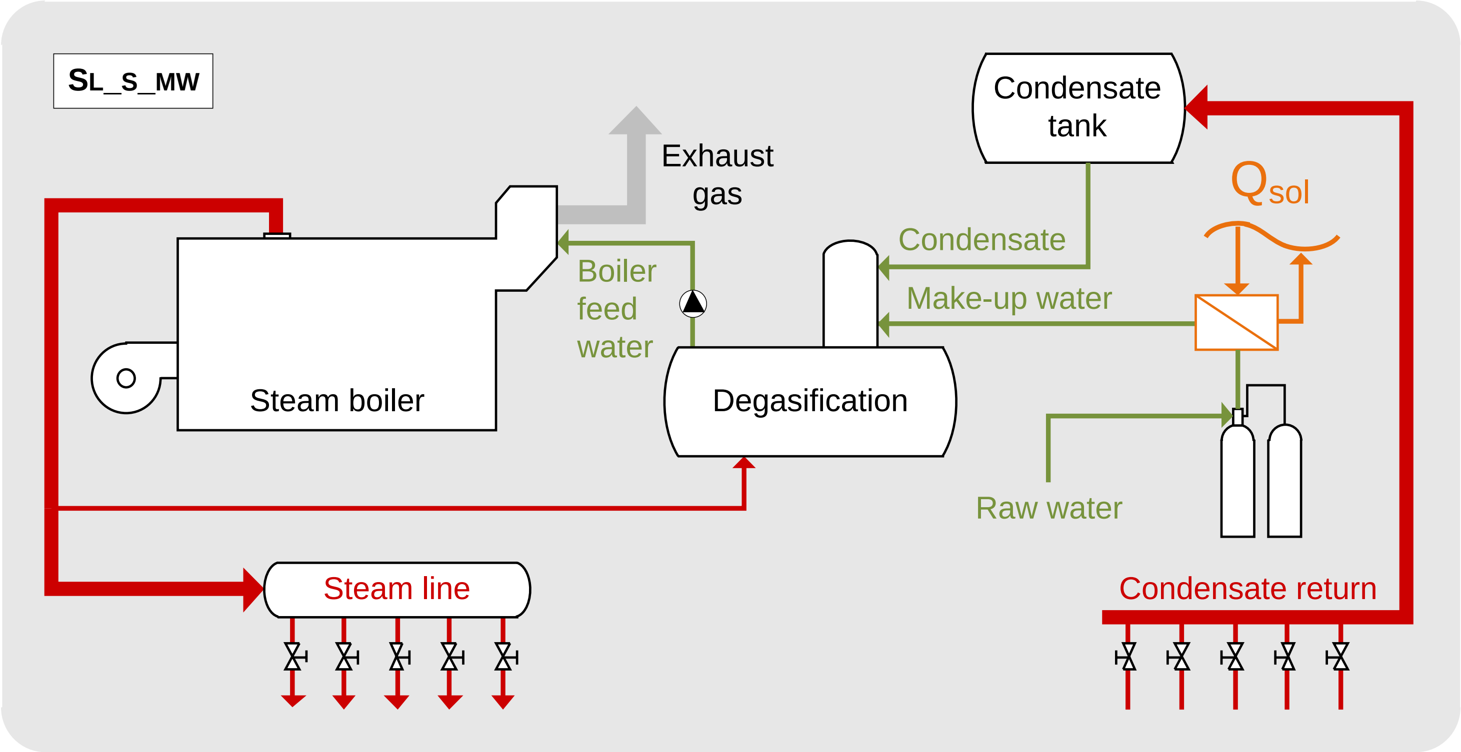
[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

Integration Concepts

Examples

SL_S_MW

Solar heating of make-up water



[1]

[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

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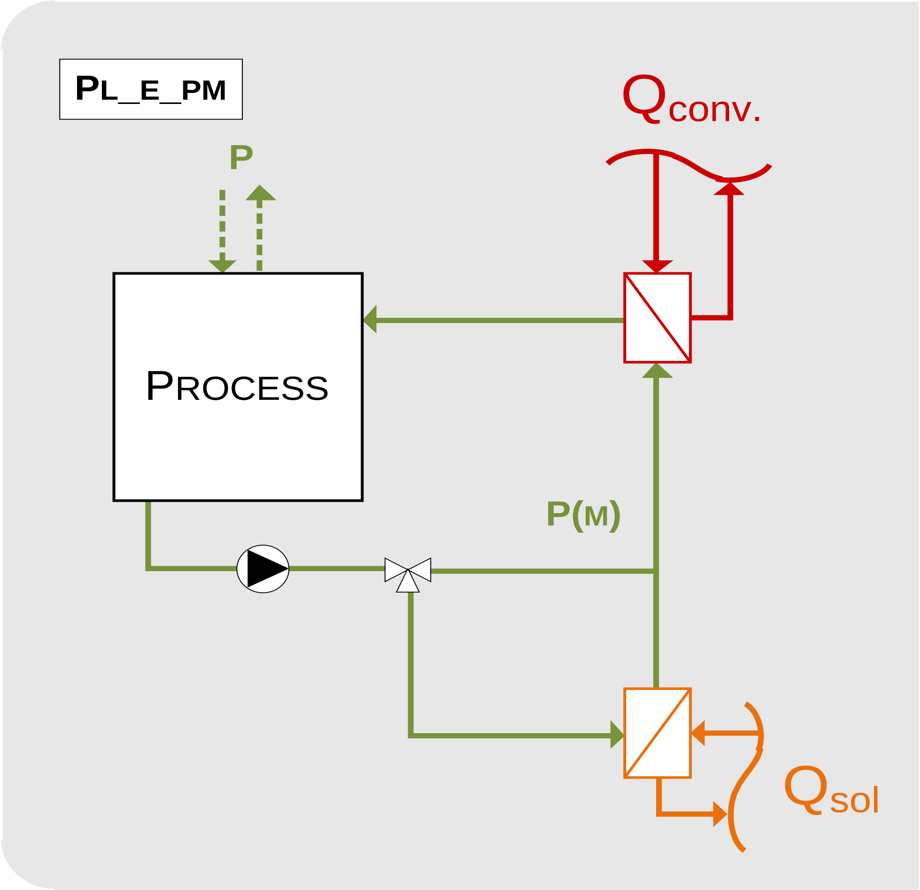
Integration Concepts

Examples

PL_E_PM

External HEX for heating of product or process medium



[1]

[1] Muster B. et al.: Integration Guideline, IEA TASK 49, Technical Report B2, 2015

Integration Concepts

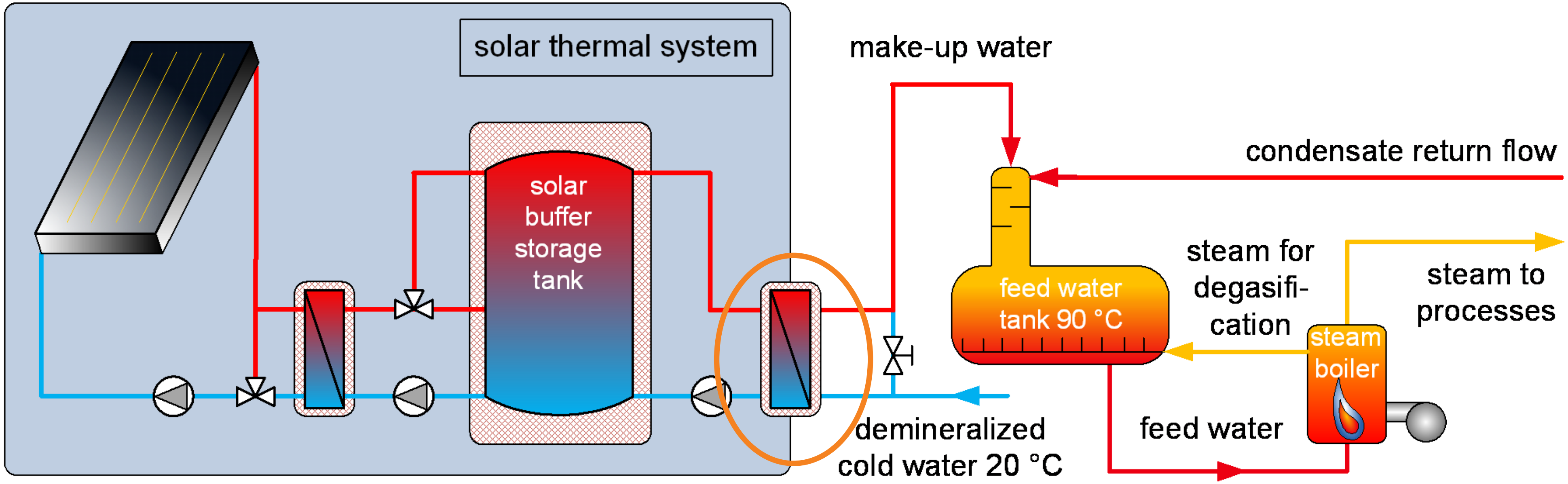
Most favorable integration points

Selection of integration point

- Low temperature level -> higher efficiency
- High temperature difference (feed & return) -> better storage utilization & efficiency
- Continuous load profile (preferably 7 days a week, limited fluctuations) -> higher efficiency
- Easy connection to existing system -> lower cost
- Existing storage can be used -> lower cost

Integration Concepts

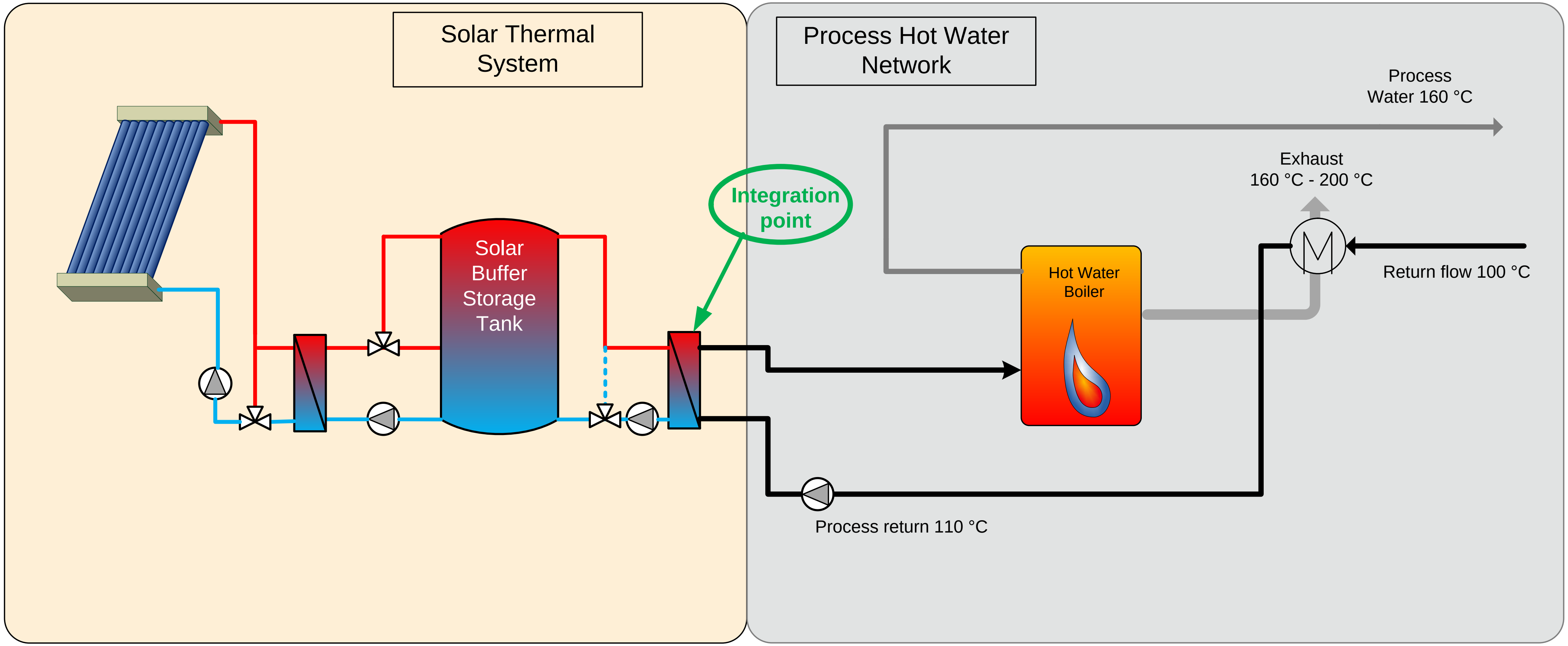
Layout - Pre-heating of make-up water



- Example: Small laundry
- High solar gains because of low temperature level

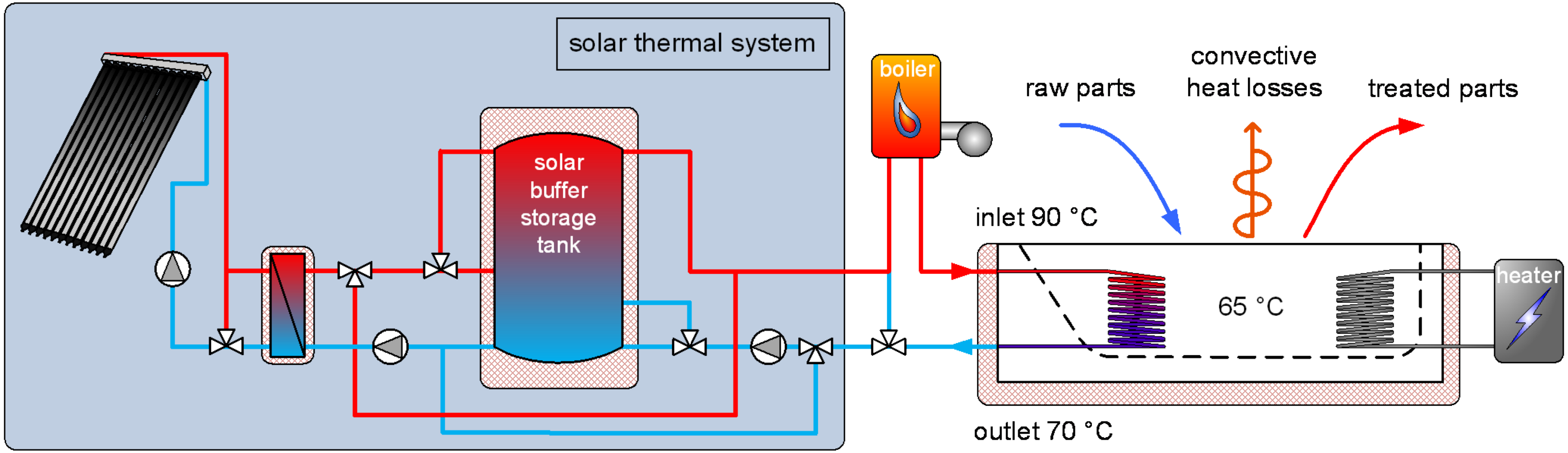
Integration Concepts

Return flow temperature lift



Integration Concepts

Layout - Solar Heating of Industrial Bath



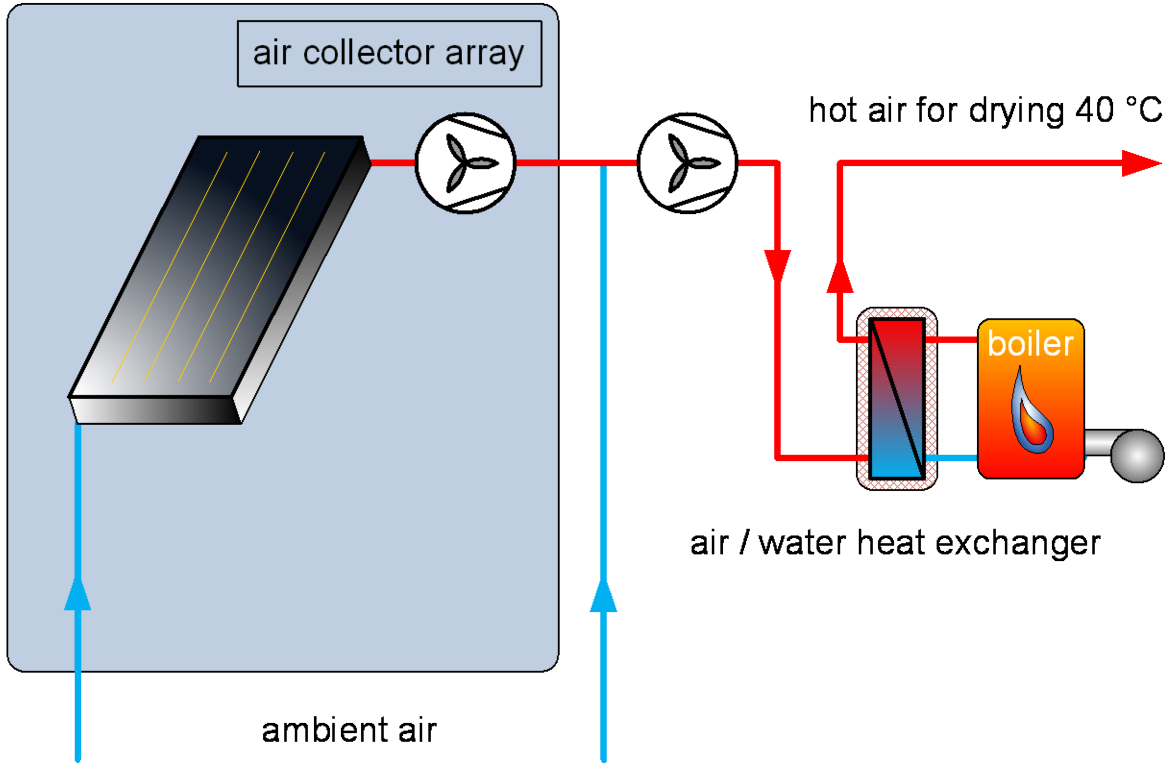
Closed process: Economics highly depend on the bath temperature

The electrical heater is used for temperature control

Integration Concepts

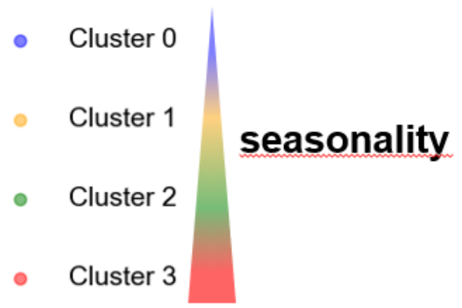
Layout - Convective drying with hot air

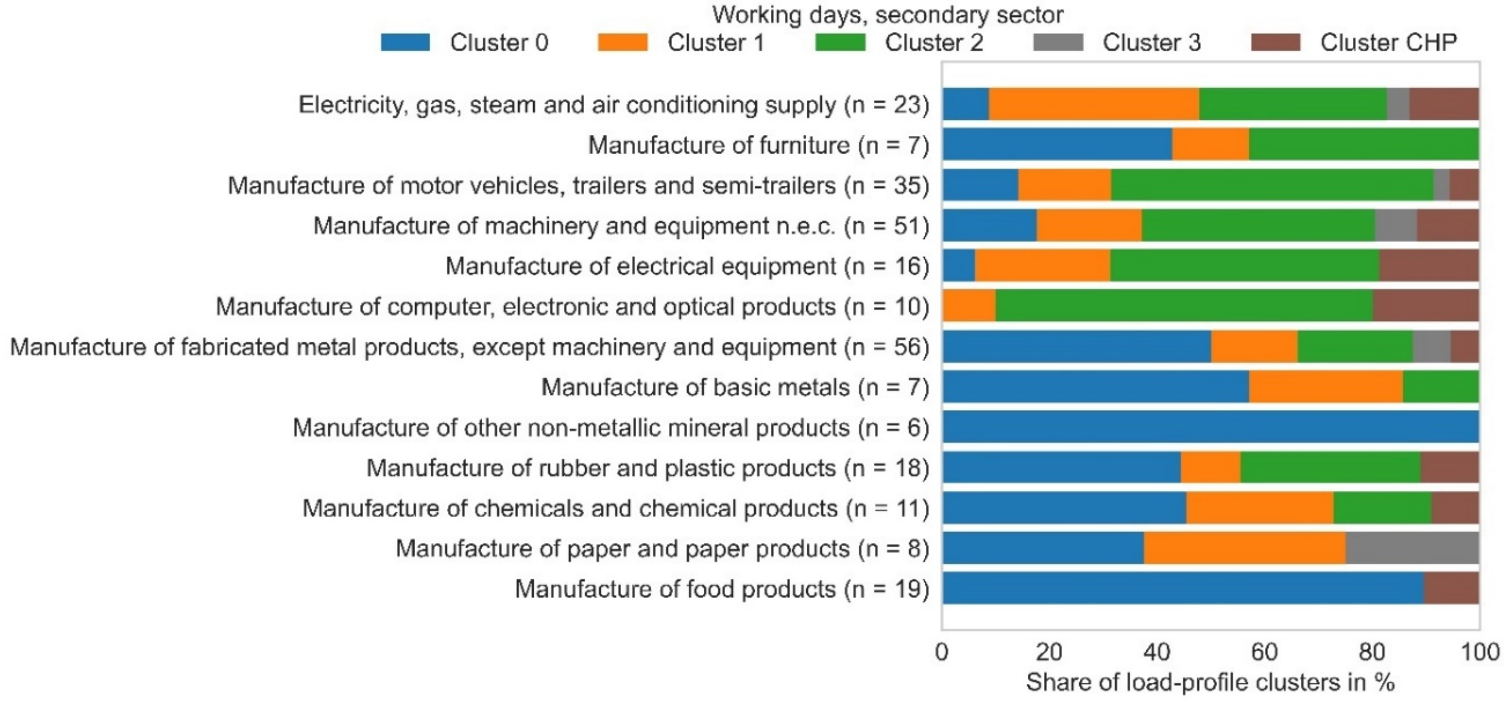
Exemplary system concept of an open drying process. The open air collector system is serially supported by a boiler (solar blower left, conventional blower right)



Integration aspects: Load profiles

- Load profile for heat supply will influence design and integration
- Dependency of industrial load profiles on ambient temperatures has a significant impact → clustering w.r.t. seasonality
- Different industrial sectors have different "typical" load profiles / clusters



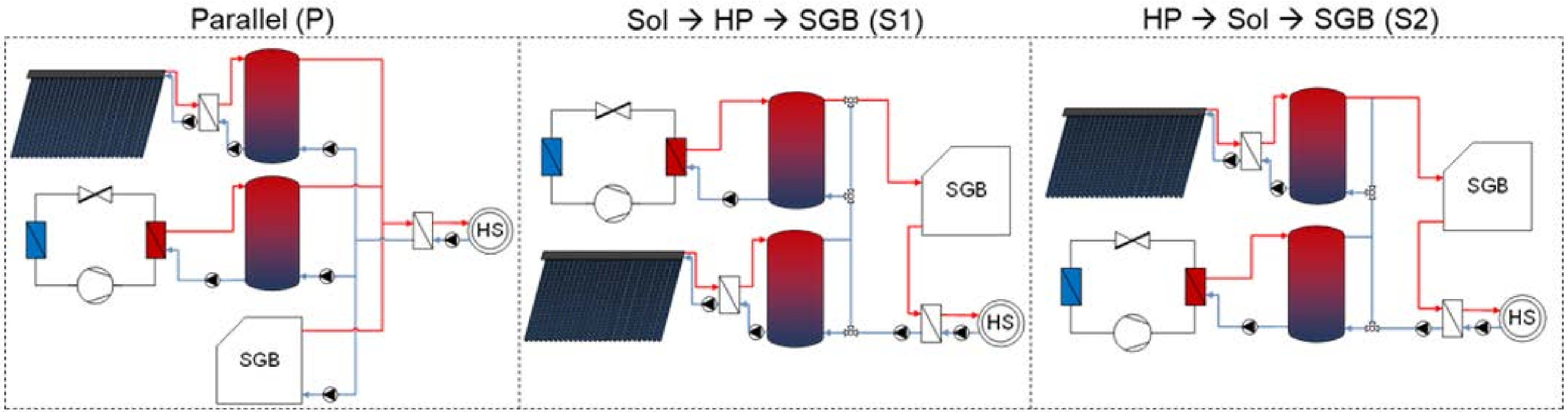


source: Univ. Kassel / based on German load profiles / IEA SHC Task 64 Subtask A

Integration aspects: Hybridisation with Heat Pumps

Integration concepts of ST+HP systems (low temperature)

- Hydraulics based on work of EnPro Project (AEE-INTEC, AT) - in parallel / in series
- Performance similar for all integration concepts → case by case assessment recommended
- Not considered: solar collectors as direct source for HP

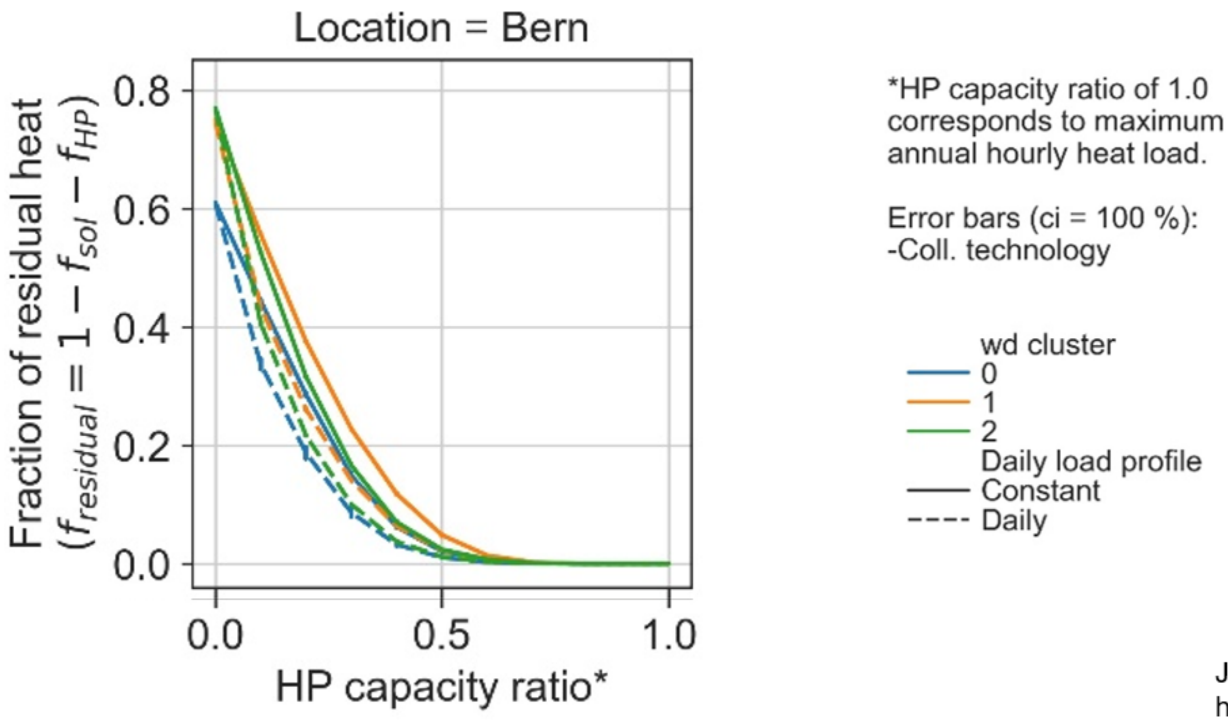


source: Univ. Kassel / temperature levels 80/60°C / IEA SHC Task 64 Subtask A

Integration aspects: Hybridisation ST with Heat Pumps

Sizing of Heat Pump System

- $\dot{Q}_{HP} > 0.4..0.5\ \dot{Q}_{demand,p}$: >90 % of heat demand covered



*HP capacity ratio of 1.0 corresponds to maximum annual hourly heat load.

Error bars (ci = 100 %):
-Coll. technology

source: Univ. Kassel / temperature levels 80/60°C / IEA SHC Task 64 Subtask A

Jesper et al. 2022, https://doi.org/10.1016/j.seja.2023.100034

Agenda

1. Thermal Energy Storage – Technology Overview

2. Pre-Feasibility and Feasibility assessment

3. Solar Thermal Process Heat Integration

4. Contribution from Participants

    1. **Swissfurnace,** Cem Vardar
    2. **Ecotherm**, Antoni Castells
    3. **Naked Energy**, Axel Mellor
    4. **Solatom**, Miguel Frasquet

Fraunhofer ISE

Contact

Dr. Tom Fluri
Climate Neutral Industrial Processes and High Temperature Storage
Tel. +49 761 4588 5994
tom.fluri@ise.fraunhofer.de

GIVAUDAN IBÉRICA, S.A.

CHEMICAL FACTORY

Location: Sant Celoni (BARCELONA)

Size: 800m^2

Commissioning: 2023

Status: Operational & Testing

HTF: Steam at 20 barg

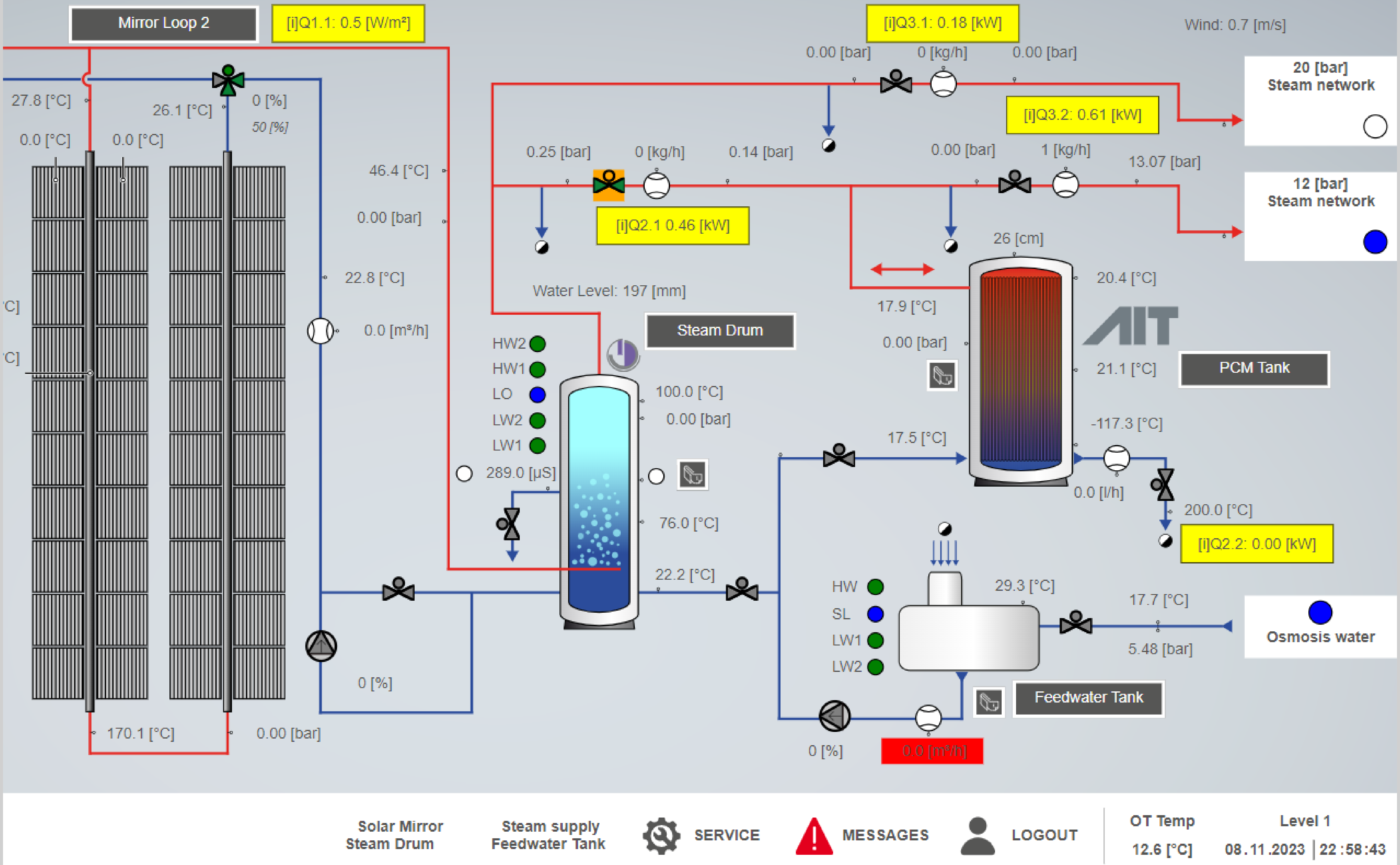
Steam at 12 barg

ECOTHERM SOLAR – REFERENCES

GIVAUDAN IBÉRICA, S.A.

ECOTHERM HEAT TRANSFER SOLUTIONS

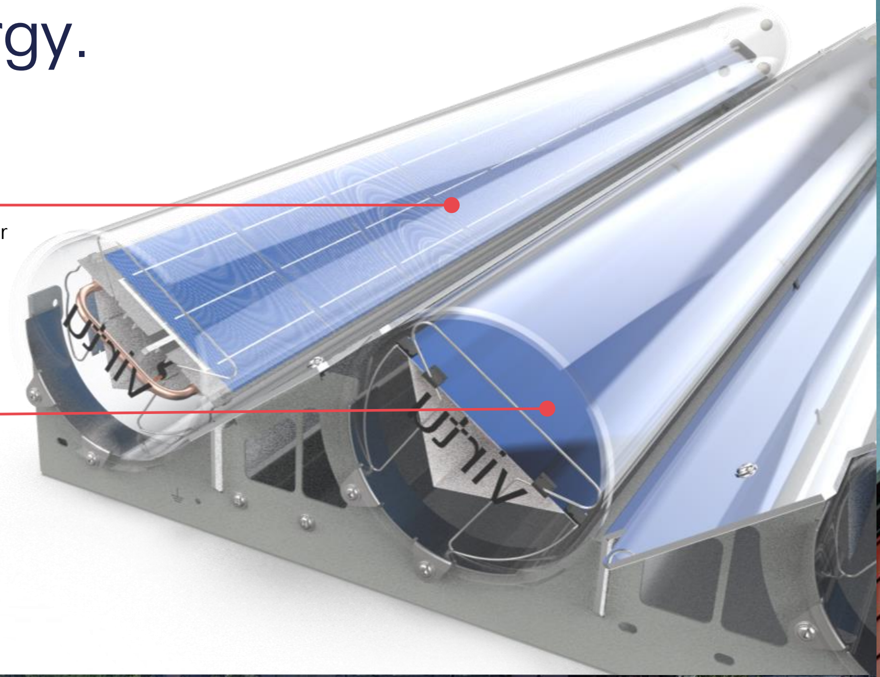
INTEGRATION FOR STEAM GENERATION


Mirror Loop 2
[i]Q1.1: 0.5 [W/m²]
[i]Q3.1: 0.18 [kW]
Wind: 0.7 [m/s]
0.00 [bar]
0 [kg/h]
0.00 [bar]
20 [bar]
Steam network
27.8 [°C]
26.1 [°C]
0 [%]
50 [%]
[i]Q3.2: 0.61 [kW]
0.0 [°C]
0.0 [°C]
0.25 [bar]
0 [kg/h]
0.14 [bar]
0.00 [bar]
1 [kg/h]
13.07 [bar]
12 [bar]
Steam network
46.4 [°C]
0.00 [bar]
[i]Q2.1 0.46 [kW]
26 [cm]
22.8 [°C]
Water Level: 197 [mm]
20.4 [°C]
17.9 [°C]
0.0 [m³/h]
Steam Drum
0.00 [bar]
HW2
HW1
LO
LW2
LW1
21.1 [°C]
PCM Tank
100.0 [°C]
0.00 [bar]
-117.3 [°C]
17.5 [°C]
289.0 [µS]
0.0 [l/h]
76.0 [°C]
200.0 [°C]
[i]Q2.2: 0.00 [kW]
22.2 [°C]
HW
29.3 [°C]
17.7 [°C]
SL
LW1
LW2
5.48 [bar]
Osmosis water
0 [%]
Feedwater Tank
170.1 [°C]
0.00 [bar]
0 [%]
0.0 [m³/h]
Solar Mirror
Steam Drum
Steam supply
Feedwater Tank
SERVICE
MESSAGES
LOGOUT
OT Temp
12.6 [°C]
Level 1
08.11.2023
22:58:43

Naked Energy.

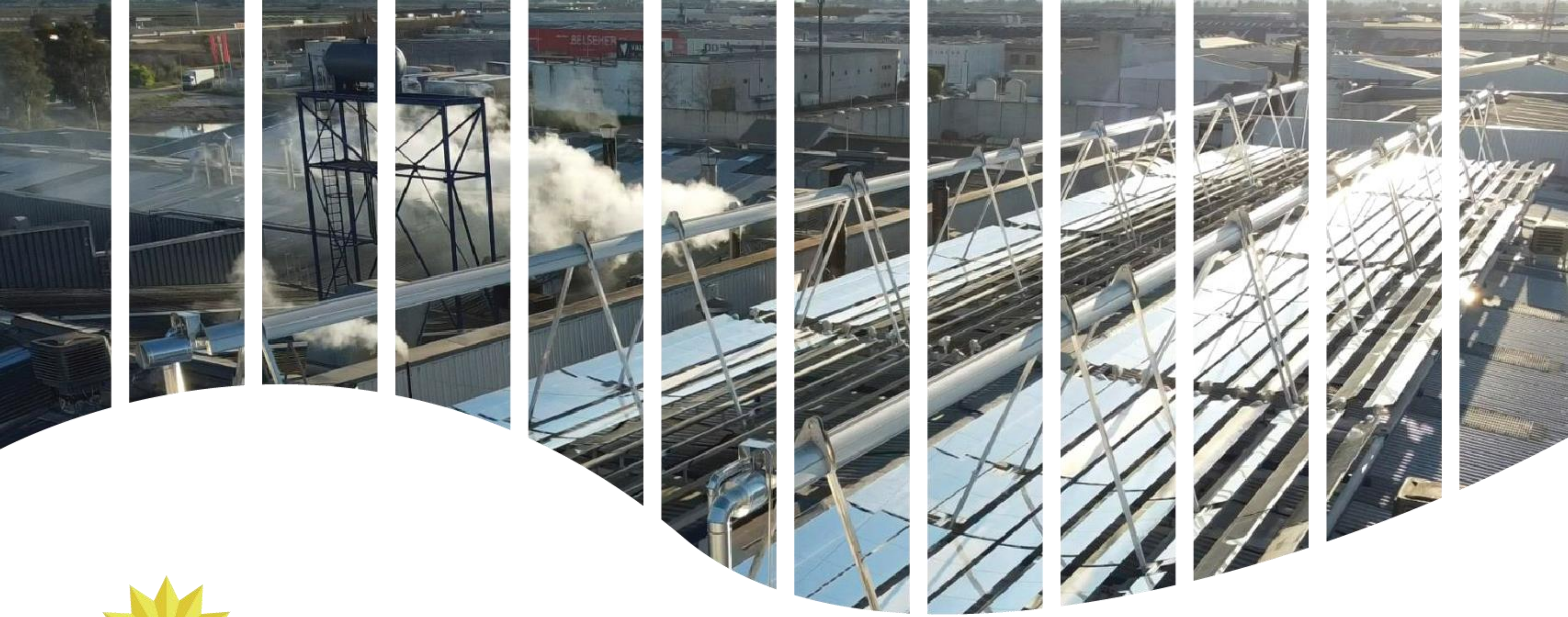
virtu PVT

Hybrid solar collector producing power
and heat up to 75℃ / 167°F



virtu HOT

Solar collector producing
heat up to 120℃ / 248°F



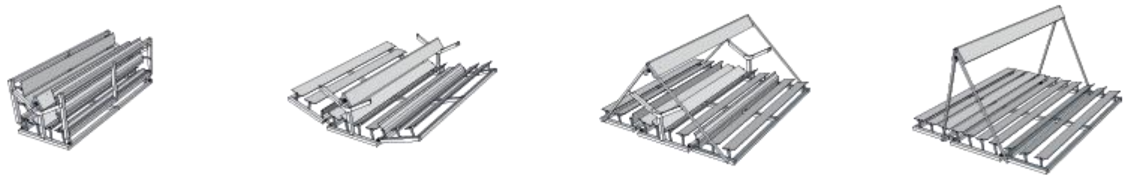
SOLATOM

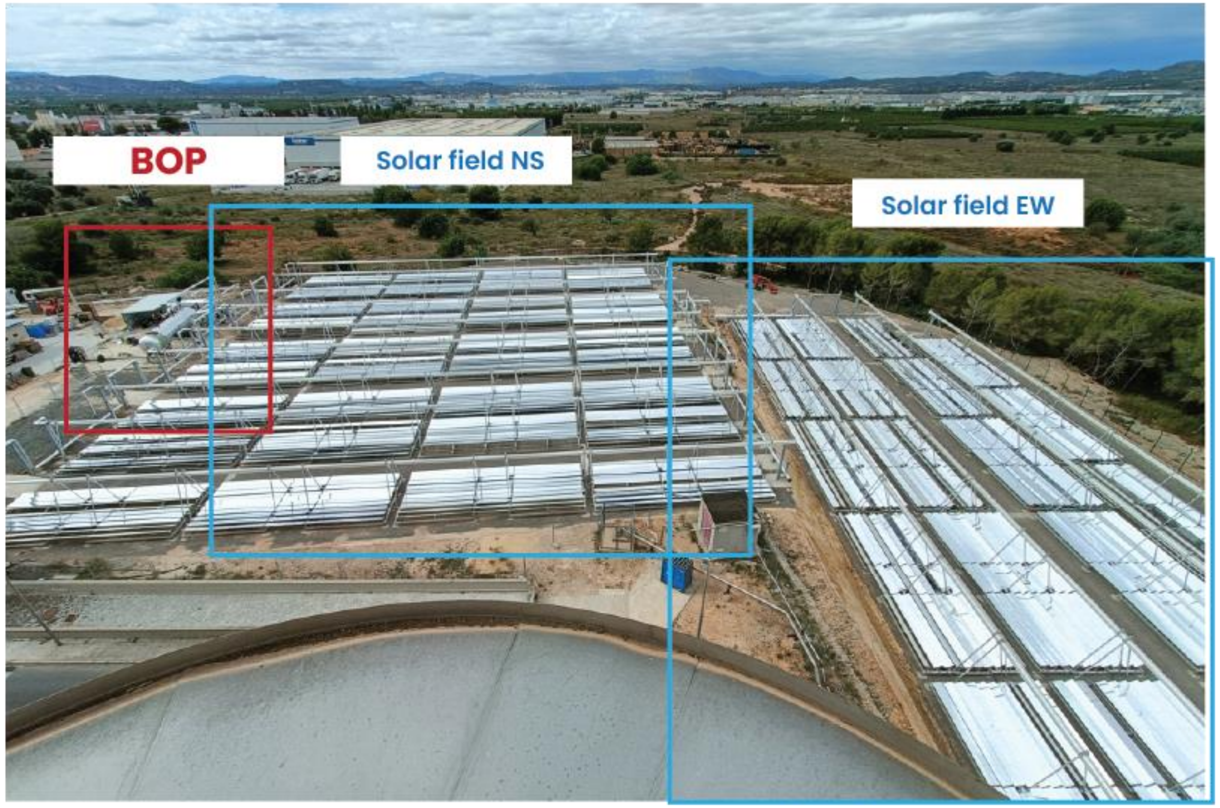
Solar steam for industries

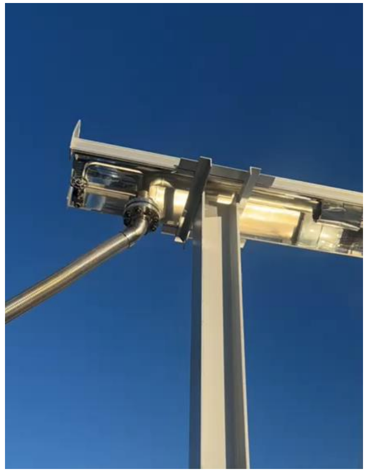
SFERA

Process Heat Application for CST Technologies
System Integration, Design, Performance Assessment

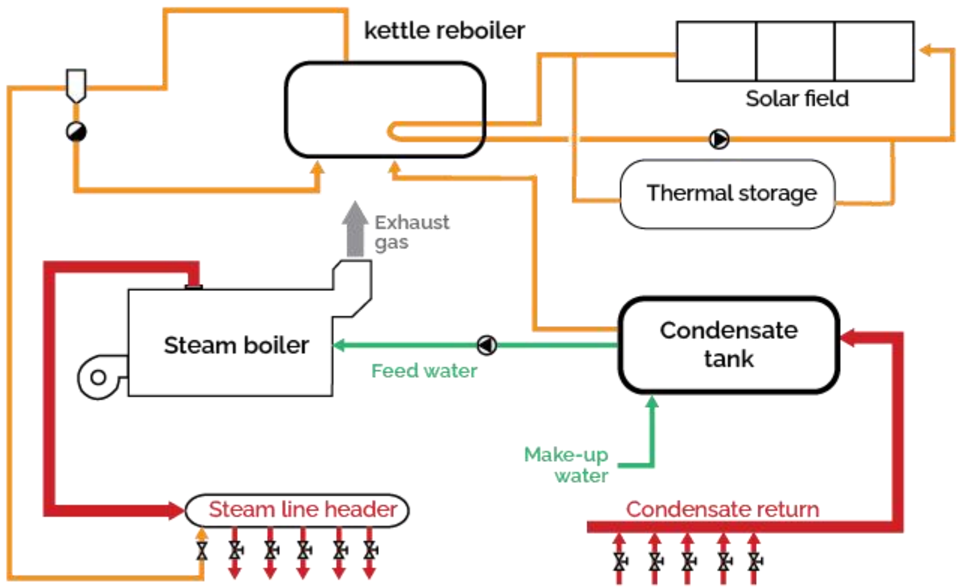
LINEAR FRESNEL PROJECT
Indirect steam generation

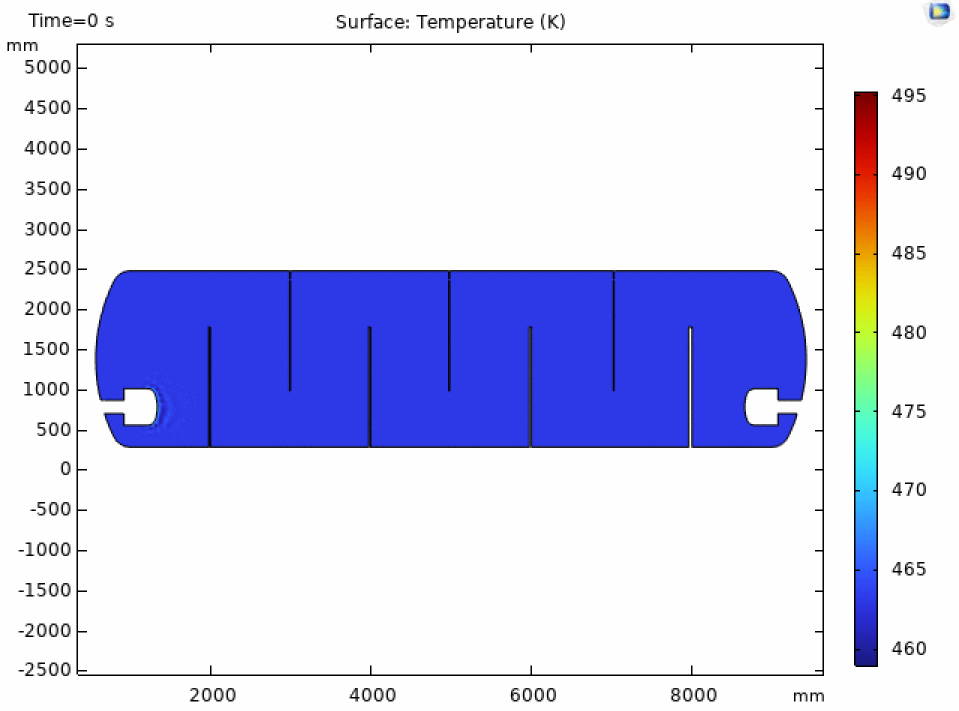




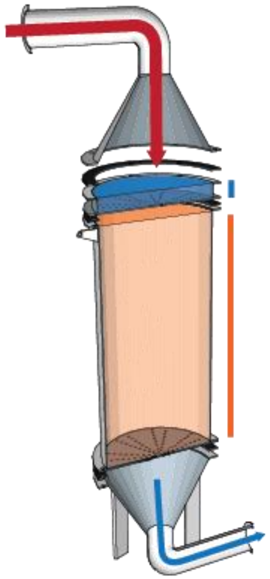


LINEAR FRESNEL PROJECT
Indirect steam generation





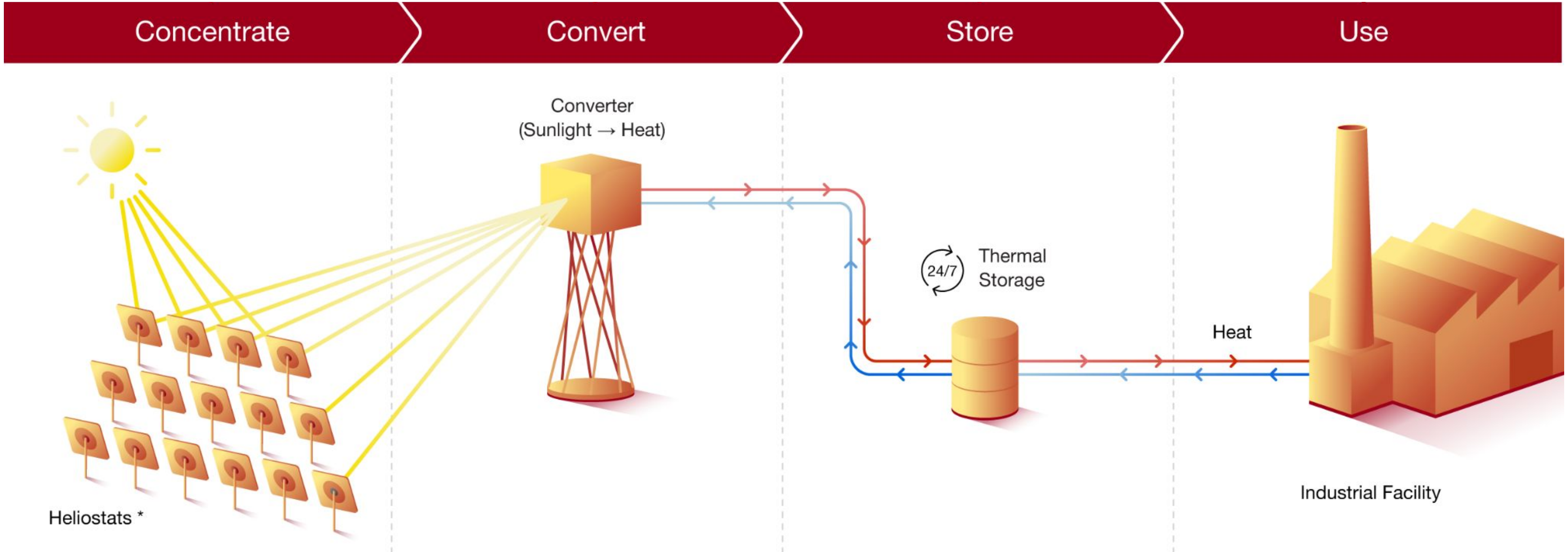
REPSOL



Steam for an Industrial Plant

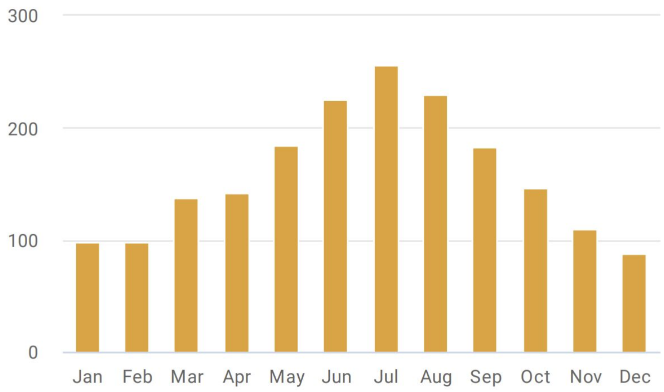
Application study

System Overview



THE SWISS FURNACE

Site Information



Monthly direct normal irradiation averages (kWh/m2)

THE SWISS FURNACE

Calculated Solar Generated Steam Output
at 18 Bar 209.8°C (kg per hour)

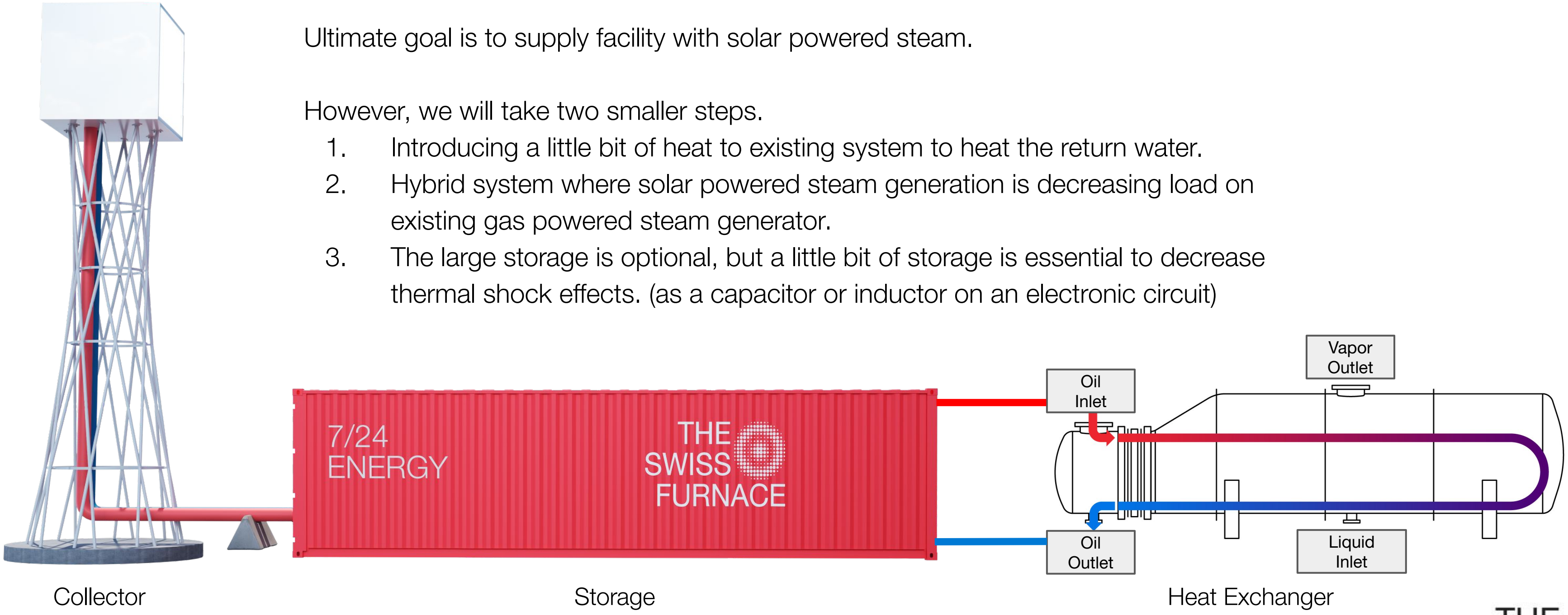
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	0	0	0	0	0	0	0	0	0	0	0	0
1 - 2	0	0	0	0	0	0	0	0	0	0	0	0
2 - 3	0	0	0	0	0	0	0	0	0	0	0	0
3 - 4	0	0	0	0	0	0	0	0	0	0	0	0
4 - 5	0	0	0	0	0	0	0	0	0	0	0	0
5 - 6	0	0	0	17	253	666	374	50	0	0	0	0
6 - 7	0	0	127	693	1480	2008	2030	1381	737	176	0	0
7 - 8	132	385	1282	1650	2200	2805	2910	2607	2261	1551	693	138
8 - 9	1271	1573	2068	2217	2767	3389	3554	3334	2987	2426	1898	1249
9 - 10	1986	2112	2563	2607	3163	3768	4016	3823	3488	2915	2426	1892
10 - 11	2310	2426	2789	2816	3372	3977	4307	4137	3735	3218	2723	2167
11 - 12	2420	2519	2882	2893	3378	3999	4390	4230	3785	3268	2750	2266
12 - 13	2398	2486	2822	2827	3251	3873	4373	4170	3686	3218	2695	2272
13 - 14	2316	2343	2739	2723	3119	3702	4252	4043	3510	3042	2530	2123
14 - 15	2134	2178	2569	2536	2893	3493	4038	3807	3234	2789	2255	1909
15 - 16	1782	1887	2255	2222	2580	3240	3719	3455	2882	2277	1755	1414
16 - 17	622	1287	1826	1810	2189	2871	3284	2965	2332	1205	369	242
17 - 18	0	121	688	1161	1678	2360	2662	2096	880	39	0	0
18 - 19	0	0	0	105	413	1249	1392	336	0	0	0	0
19 - 20	0	0	0	0	0	11	11	0	0	0	0	0
20 - 21	0	0	0	0	0	0	0	0	0	0	0	0
21 - 22	0	0	0	0	0	0	0	0	0	0	0	0
22 - 23	0	0	0	0	0	0	0	0	0	0	0	0
23 - 24	0	0	0	0	0	0	0	0	0	0	0	0
Sum (steam kg/day)	17372	19319	24611	26278	32736	41410	45310	40431	33517	26124	20095	15672
Sum (steam kg/month)	538,522	545,761	762,935	788,327	1,014,802	1,242,312	1,404,625	1,253,368	1,005,500	809,829	602,838	485,829
Sum (steam kg/year)	10,454,649											

Application

Ultimate goal is to supply facility with solar powered steam.

However, we will take two smaller steps.

1. Introducing a little bit of heat to existing system to heat the return water.
2. Hybrid system where solar powered steam generation is decreasing load on existing gas powered steam generator.
3. The large storage is optional, but a little bit of storage is essential to decrease thermal shock effects. (as a capacitor or inductor on an electronic circuit)

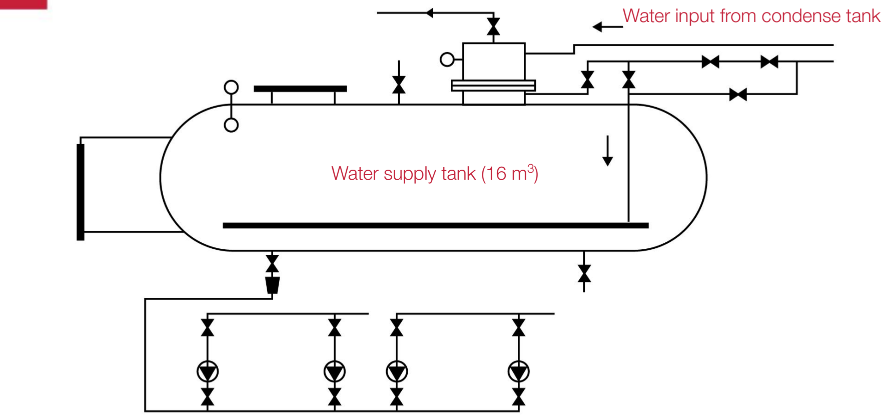


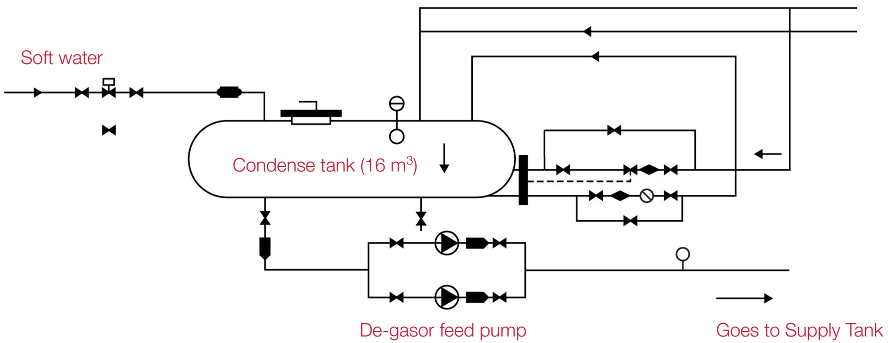
THE
SWISS
FURNACE

Facility picture

THE SWISS FURNACE

Real Life System Photos





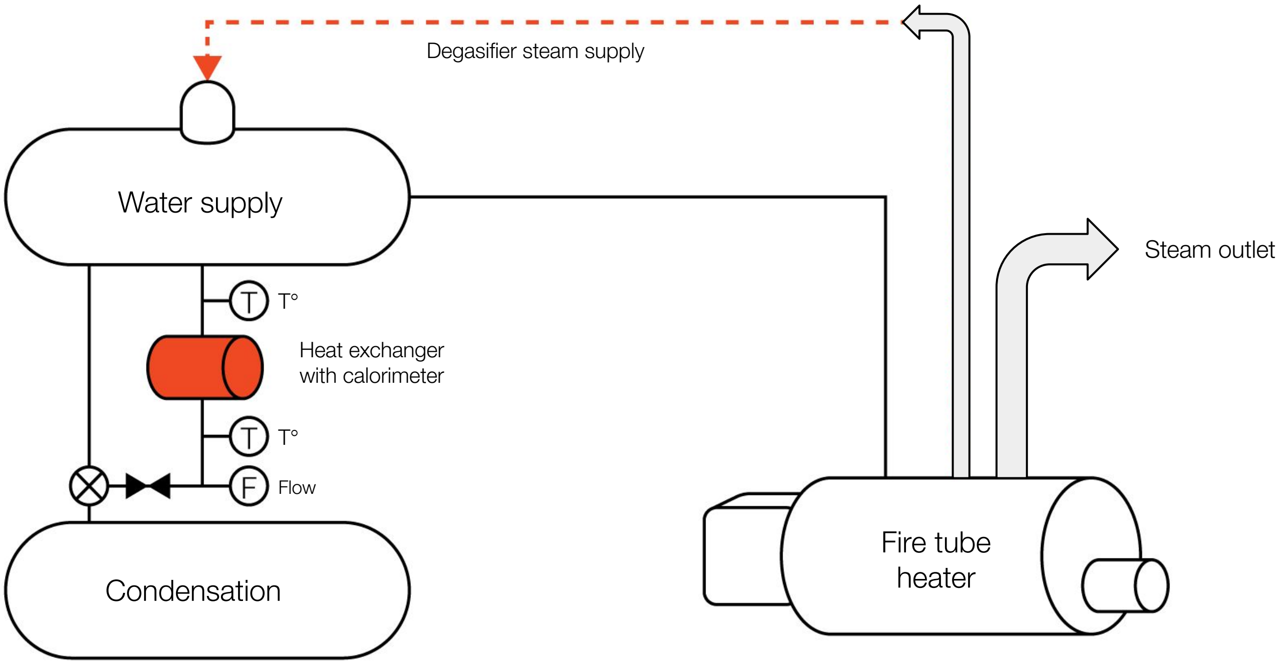
THE SWISS FURNACE

Real Life System Photos - Gas Burner

THE SWISS FURNACE

Application Step 1

Elevating water temperature using a small heat exchanger to eliminate/decrease degasifier steam supply

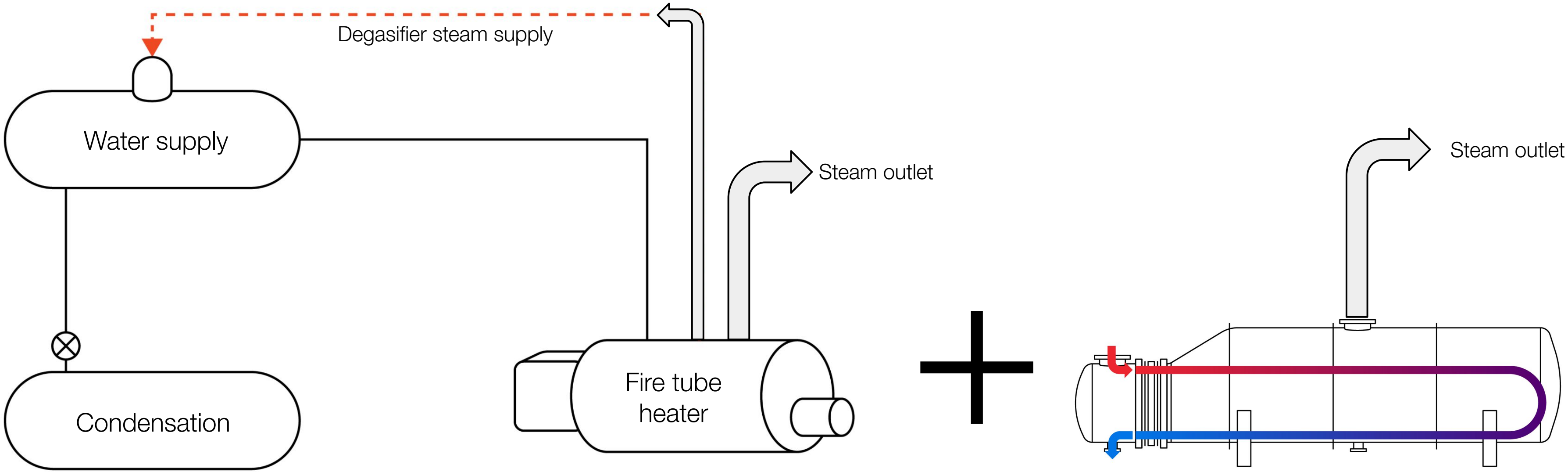


Case to study: Increase water temperature at condensation tank outlet

THE SWISS FURNACE

Application Step 2

Hybrid steam generation



Case to study: Combining gas burning boiler and kettle type reboiler

Economic Assessment

Fanny Hübner
SFERA-III Training for Industries: CST4SHIP
Freiburg, Nov 9, 2023
www.ise.fraunhofer.de

See also Solar Payback Guideline:
https://www.solar-payback.com/download/ship-guidelines-for-feasibility-performance-optimisation-and-design/

Cash Flow Model for SHIP

Cash Flow Model

Inflows / Outflows

Regular approach for long-lasting, high productive real assets

Revenues:
Saved energy cost
Subsidies

Inflows

Outflows

Expenses:
Capital Expenses (CAPEX)
Operational Expenses (OPEX)
Financial Costs

Cash Flow Model for SHIP

Inflow

Annual energy yield

- Forecast derived from simulations

*

Conventional energy cost

- Vary widely (type of fuel, between industries, regional, high temporal voltility)
- Affected by energy price inflation

=

Revenue from saved energy = Inflow

Solar Payback
Fraunhofer ISE

Cash Flow Model for SHIP

Outflow - Investment Costs

planning, material, components, installation

Broad variation

- Heat Transfer Medium — Air < Water < Steam < Thermal oil
- Process temperature — \$ Up to 40°C < more than 120° \$
- Collector technology — \$ Stationary < tracking \$
- System‘s complexity
- Effort of connection & integration
- Demand profile
- System‘s size — \$ Up to 50 m² > 50-100 m² > 100-500 m² > 500-1000 m² \$

Solar Payback

Fraunhofer ISE

Cash Flow Model for SHIP

Outflow - Operating Costs

Comperatively low

- Auxiliary for pumps & control is minimal
- Technical & commercial management is not required
- Regular maintanance & monitoring! -> 0.5 to 1% of the investment costs per year

Cash Flow Model for SHIP

Outflow - Capital Costs

- interest rates payable to (debt) lenders
- required equity returns expected by (equity) investors

→Country specific risk

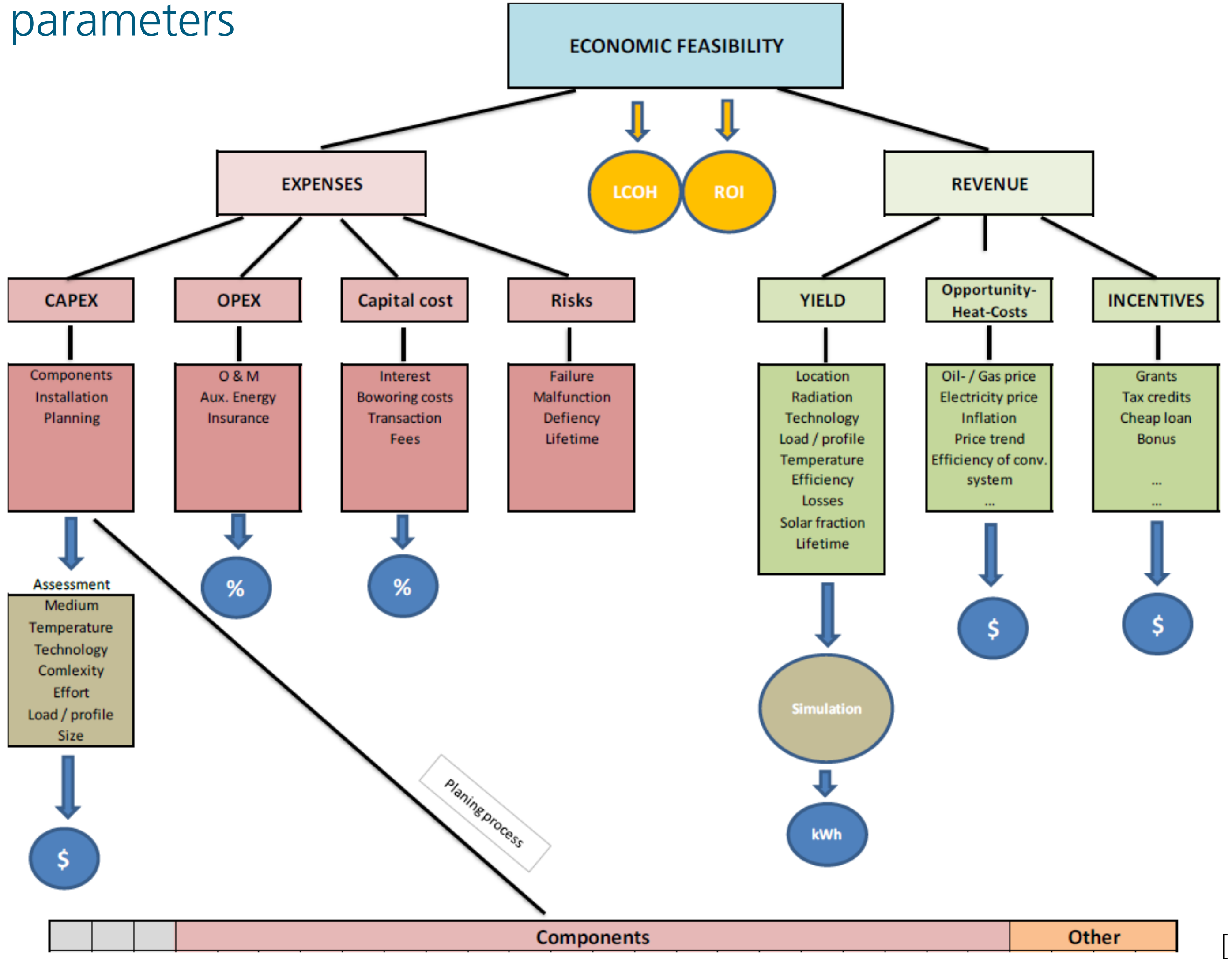
- Political stability
- Protection of investor’s property
- Public debt rate
- Credit rating

Solar Payback

Fraunhofer ISE

Cash Flow Model for SHIP

Input and Output parameters



[1]

[1] RENAC, 2017. Solar Payback: Interim Report: A financial business model for industrial solar thermal energy supplementation

Economic Assessment Parameters - KPIs

Assessment parameters - KPIs

- Payback time (static, dynamic)
- Internal rate of return (IRR)
- Net present value (NPV)
- Levelized cost of heat (LCoH)

SHIP characteristic:

fundamentally different temporal cost distribution compared to conventional heat generation technologies:

- High costs at beginning
- Low operational costs

→ Risk assessment has high impact on investment decision

Driving forces

The implementation of a SHIP system usually is driven by the following:

- Reducing carbon emissions
- Replace uncertain future conventional operational heat costs by well-known initial investment costs
- Reduction of risks associated with increasingly volatile and rising fuel prices

→ **Long-term cost stabilization**

Assessment parameters - KPIs

Payback time

- Time required to recover the cost of investment
- The lower the payback time the better
- Relates investment cost to annual cash flows

→ Easy to understand

→ Risk evaluation Indicator <u>not</u> Profit Indicator!

Simple Payback vs. Discounted Payback

Assessment parameters - KPIs

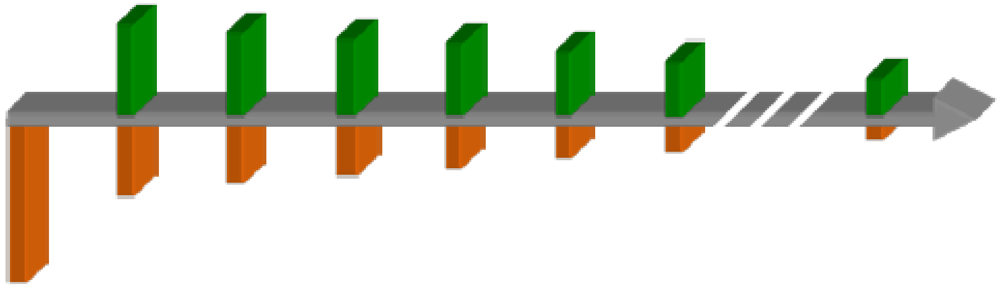
Net present value (NPV)

Future capital flows will be discounted to the year of investment:

$$NPV = I_0 + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t}$$

where:

I_0 = the initial capital investment in Period t=0 (<0)
C_t = net cash flow in each subsequent period
i = discount rate
n = number of analysis periods

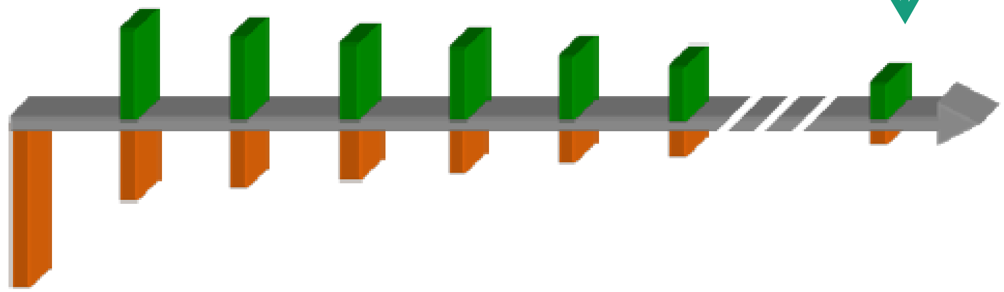


Assessment parameters - KPIs

Net present value (NPV)

Inflows and Outflows will be discounted to the year of investment

$$NPV = (ci_0 - co_0) + \frac{(ci_1 - co_1)}{(1+i)} + \frac{(ci_2 - co_2)}{(1+i)^2} + \ldots + \frac{(ci_t - co_t)}{(1+i)^t} = (ci_0 - co_0) + \sum_{t=1}^{n} \frac{(ci_t - co_t)}{(1+i)^t}$$



where:

ci_t = cash inflows in period t
co_t = cash outflows in period t
i = discount rate
n = number of analysis periods

→ Indicator for total benefit during life time of the investment!

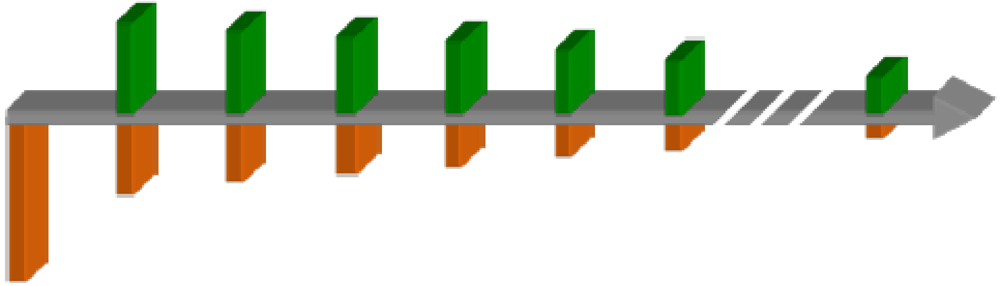
Assessment parameters - KPIs

Internal Rate of Return (IRR)

IRR is interest rate for which NPV equals zero!

$$NPV = I_0 + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t} = \mathbf{0}$$

$$i \rightarrow IRR$$



Solar Payback

Fraunhofer ISE

Assessment parameters - KPIs

Internal Rate of Return (IRR)

Project IRR

Inflow:
- full amounts of money needed in project

Outflow:
- cash generated by project

Assumption:
- No debt was used for the project

Equity IRR

Inflow:
- = required cash flows – debt

Outflow:
- Cash flows from project – interest & debt repayment

“leveraged” version of IRR

Assessment parameters - KPIs

Levelized Cost of Heat (LCoH)

Investment of technology

Annual operation costs

- Fuel costs
- CO2 price
- Fixed and var costs

$$LCOH = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

Annual energy output

- Location
- System
- Degradation

Discount rate (WACC)

- Technology risk
- Investor expectation
- Region specific risk

→ Good for comparison of different energy sources

Assessment parameters - KPIs

Levelized Cost of Heat (LCoH) - Reference

For comparison, the levelised (discounted) cost of the conventional system for the same amount of heat has to be considered.

$$LCOH_{sol} = \frac{I_0 + \sum_{t=1}^{T} \frac{OM + Taxpay}{(1+i)^t}}{\sum_{t=1}^{T} \frac{M_{t,th}}{(1+i)^t}} \quad [1]$$

vs.

$$LCOH_{ref} = \frac{\sum_{t=1}^{T} \frac{M_{t,th} \cdot Cost_{fuel,t}}{(1+i)^t}}{\sum_{t=1}^{T} \frac{M_{t,th}}{(1+i)^t}} \quad [1]$$

→ If incentives are included is a matter of investment assessment perspective

[1] Solar Payback Online Calculator

Assessment parameters - KPIs
Summary

Several KPI exist for economic evaluation

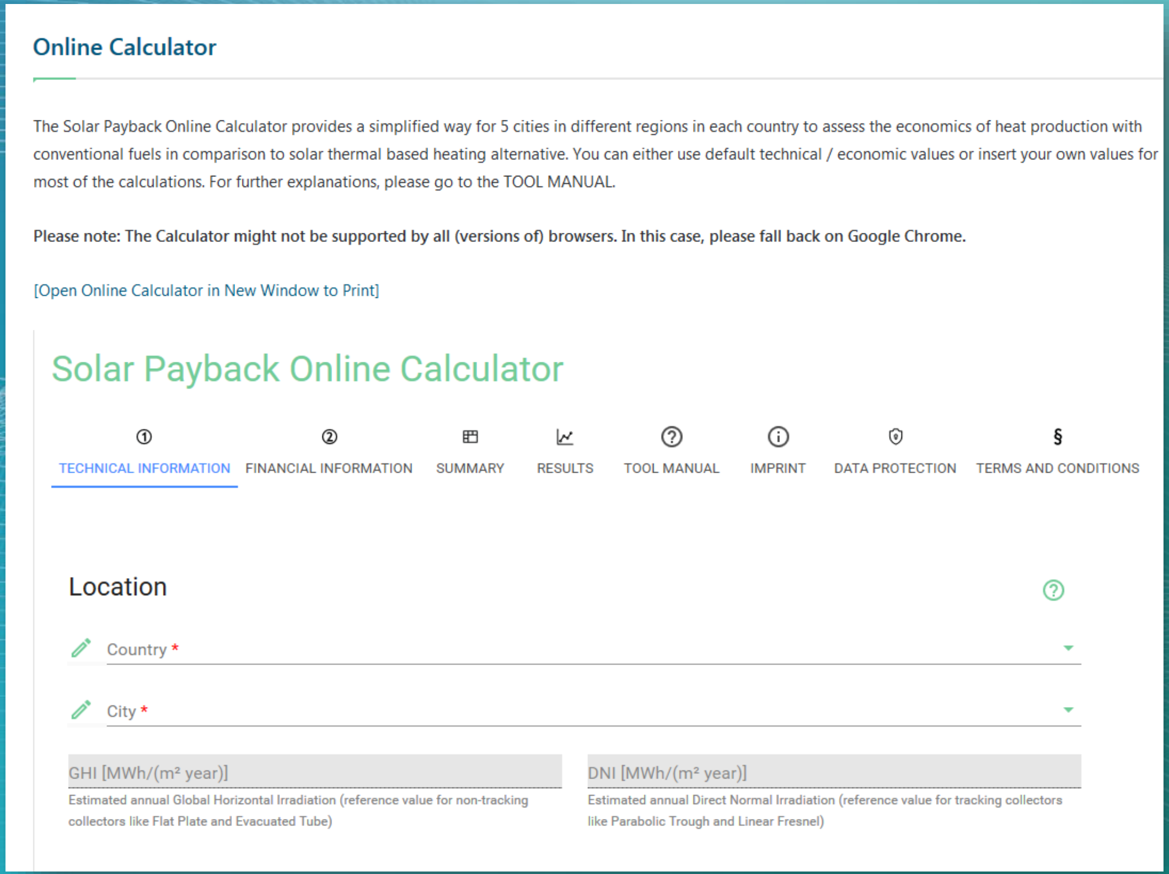
- Risk → Paybacktime
- Rate of return → IRR
- Total return of investment → Net present value
- Cost of Heat → LCOH

All of them are important to get a complete picture of the economic feasibility

[1] Solar Payback Online Calculator

https://www.solar-payback.com/calculator

Solar Payback Online Calculator



Exercise

Task 1a - Daytime

Exercise:

https://oc.ise.fraunhofer.de/index.php/s/EjD67TAYg3vc7wf?path=%2FOnline%20Calculator%20Exercise#pdfviewer

Excel File to insert results:

https://docs.google.com/spreadsheets/d/1z8cWD4cwhz-2r0y8Exl4FAWuwFIbpBzQu07QYTfGMhM/edit?usp=sharing

Results

Task 1a - Daytime

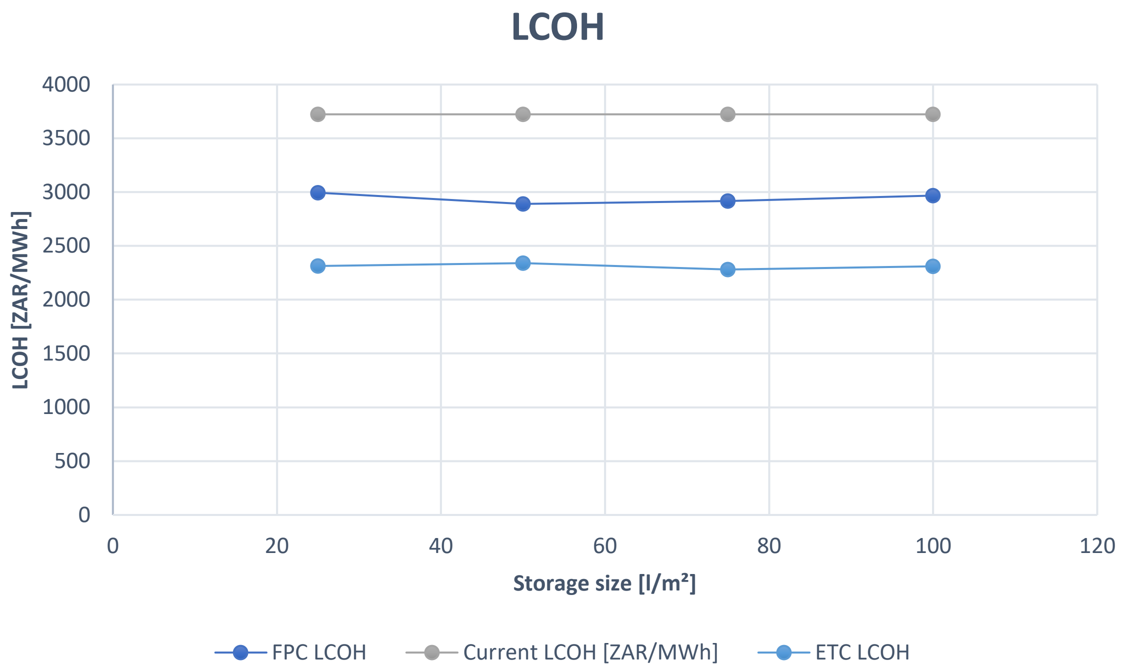
FPC	Spec. storage size [l/m²]	Spec Solar yield [MWh/(m²year)]	Collector aperture area [m²]	Storage size [m³]	Invest cost [ZAR]	NPV project margin [ZAR]	Project IRR [%]	Simple Payback [years]	Discounted Payback [years]	Solar LCOH [ZAR/MWh]	Current LCOH [ZAR/MWh]	CoC [%]
	25	0.535	299.1	7.5	2357682	776315	19.1	5.1	11	2994	3721	14.8
	50	0.589	271.6	13.6	2250798	881261	19.9	4.9	10.2	2889	3721	14.8
	75	0.624	256.4	19.2	2279263	853313	19.7	4.9	10.4	2917	3721	14.8
	100	0.652	245.4	24.5	2329448	804037	19.3	5	10.7	2966	3721	14.8

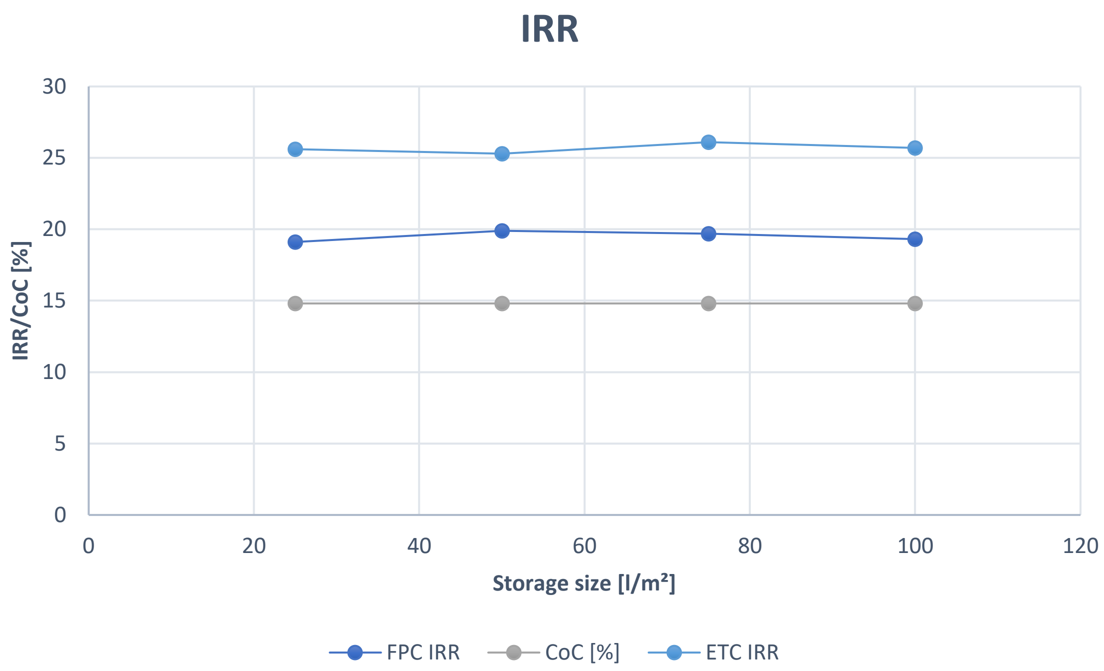
[1]

ETC	Spec. storage size [l/m²]	Spec Solar yield [MWh/(m²year)]	Collector aperture area [m²]	Storage size [m³]	Invest cost [ZAR]	NPV project margin [ZAR]	Project IRR [%]	Simple Payback [years]	Discounted Payback [years]	Solar LCOH [ZAR/MWh]	Current LCOH [ZAR/MWh]	CoC [%]
	25	0.761	210.2	5.3	1657503	1458728	25.6	3.5	6	2314	3721	14.8
	50	0.825	193.9	9.7	1684945	1432134	25.3	3.6	6.2	2340	3721	14.8
	75	0.876	182.6	13.7	1623584	1491600	26.1	3.4	5.8	2281	3721	14.8
	100	0.918	174.3	17.4	1654467	1461670	25.7	3.5	5.9	2311	3721	14.8

Results

Task 1a - Daytime





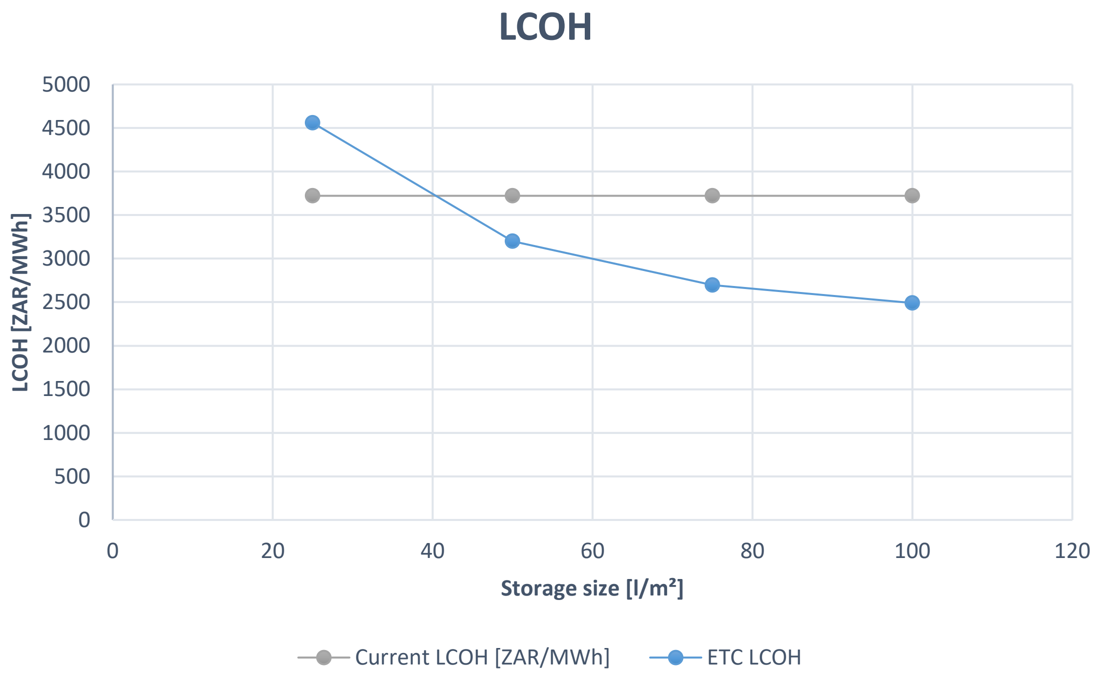
Results

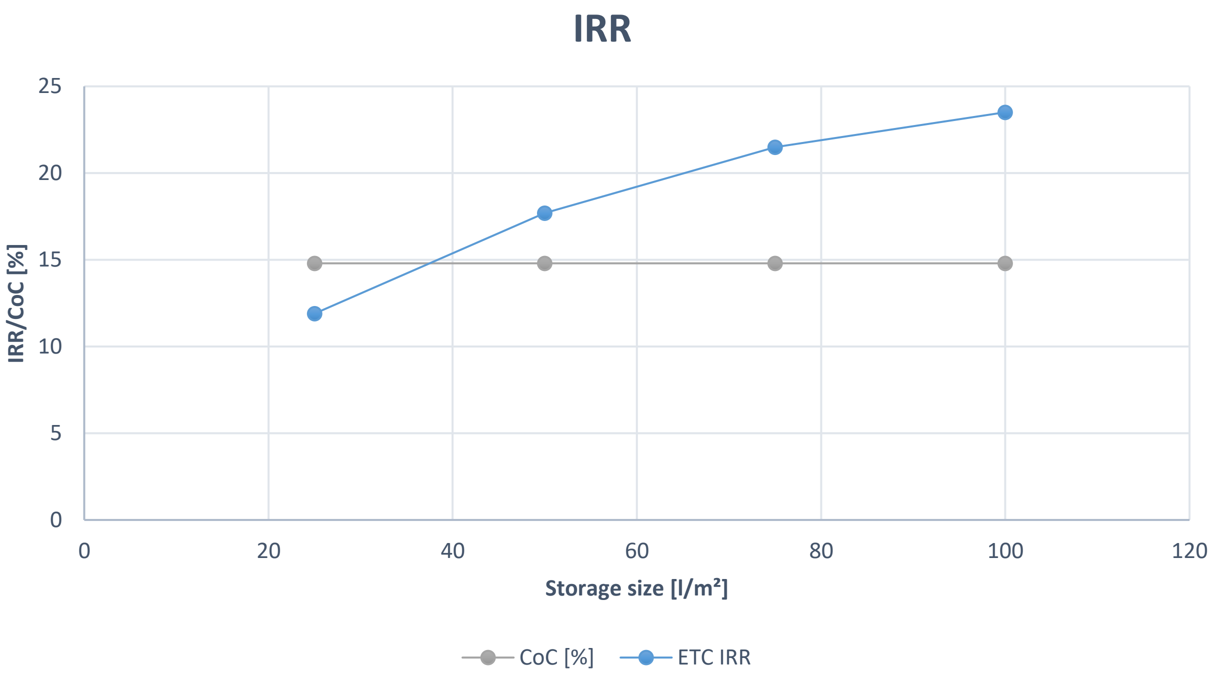
Task 1a - Daytime

ETC	Spec. storage size [l/m²]	Spec Solar yield [MWh/(m²year)]	Collector aperture area [m²]	Storage size [m³]	Invest cost [ZAR]	NPV project margin [ZAR]	Project IRR [%]	Simple Payback [years]	Discounted Payback [years]	Solar LCOH [ZAR/MWh]	Current LCOH [ZAR/MWh]	CoC [%]
	25	0.284	563.4	14.085	3929282	-804785	11.9	8	19	4558	3721	14.8
	50	0.516	310.1	15.505	2569225	568607	17.7	5.5	12.8	3201	3721	14.8
	75	0.693	230.9	17.3175	2052323	1076099	21.5	4.4	8.6	2695	3721	14.8
	100	0.826	193.7	19.37	1838741	1283086	23.5	3.9	7.1	2489	3721	14.8

Results

Task 1b - Nighttime





Results

Task 2a – Supply Level

PTC	Spec. storage size [l/m²]	Spec Solar yield [MWh/(m²year)]	Collector aperture area [m²]	Storage size [m³]	Invest cost [ZAR]	NPV project margin [ZAR]	Project IRR [%]	Simple Payback [years]	Discounted Payback [years]	Solar LCOH [ZAR/MWh]	Current LCOH [ZAR/MWh]	CoC [%]
	25	0.802	498.8	12.5	5361534	2463802	20.7	4.6	9.3	2786	3721	14.8
	50	0.861	464.6	23.2	5274448	2549310	21	4.5	9	2752	3721	14.8
	75	0.906	441.5	33.1	5278863	2544975	21	4.5	9	2753	3721	14.8
	100	0.944	423.7	42.4	5322033	2502587	20.8	4.6	9.2	2770	3721	14.8

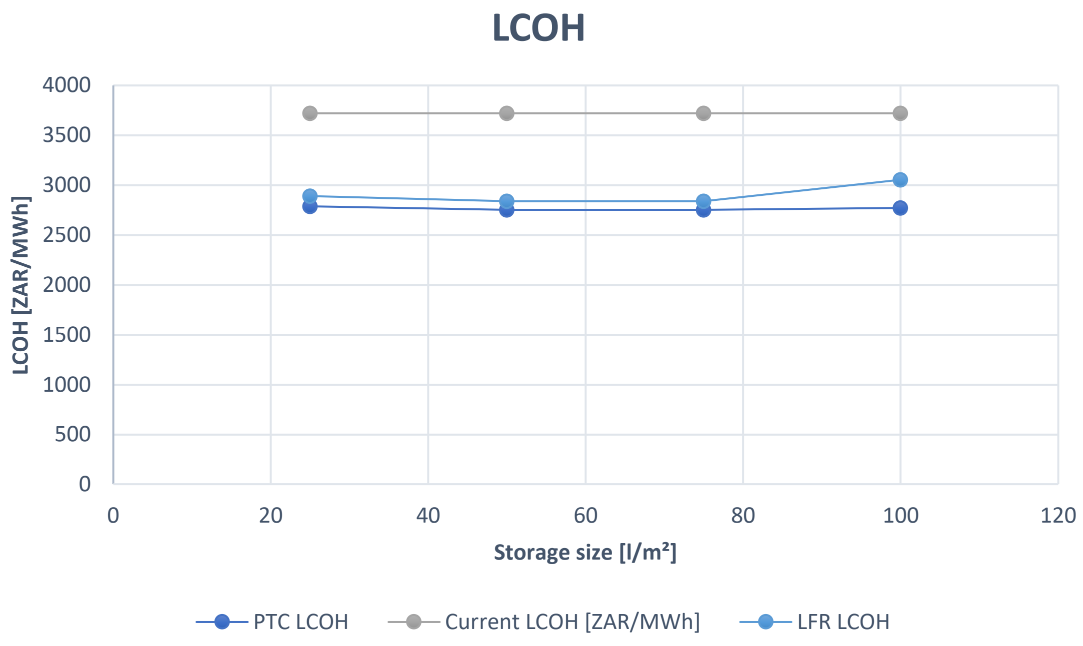
LFR	Spec. storage size [l/m²]	Spec Solar yield [MWh/(m²year)]	Collector aperture area [m²]	Storage size [m³]	Invest cost [ZAR]	NPV project margin [ZAR]	Project IRR [%]	Simple Payback [years]	Discounted Payback [years]	Solar LCOH [ZAR/MWh]	Current LCOH [ZAR/MWh]	CoC [%]
	25	0.692	578	14.5	5627298	2202856	19.9	4.9	10.2	2890	3721	14.8
	50	0.752	531.9	26.6	5499255	2328578	20.3	4.7	9.7	2840	3721	14.8
	75	0.797	501.9	37.6	5491581	2336113	20.3	4.7	9.7	2837	3721	14.8
	100	0.831	481.3	48.1	6045728	1792012	18.7	5.2	11.5	3053	3721	14.8

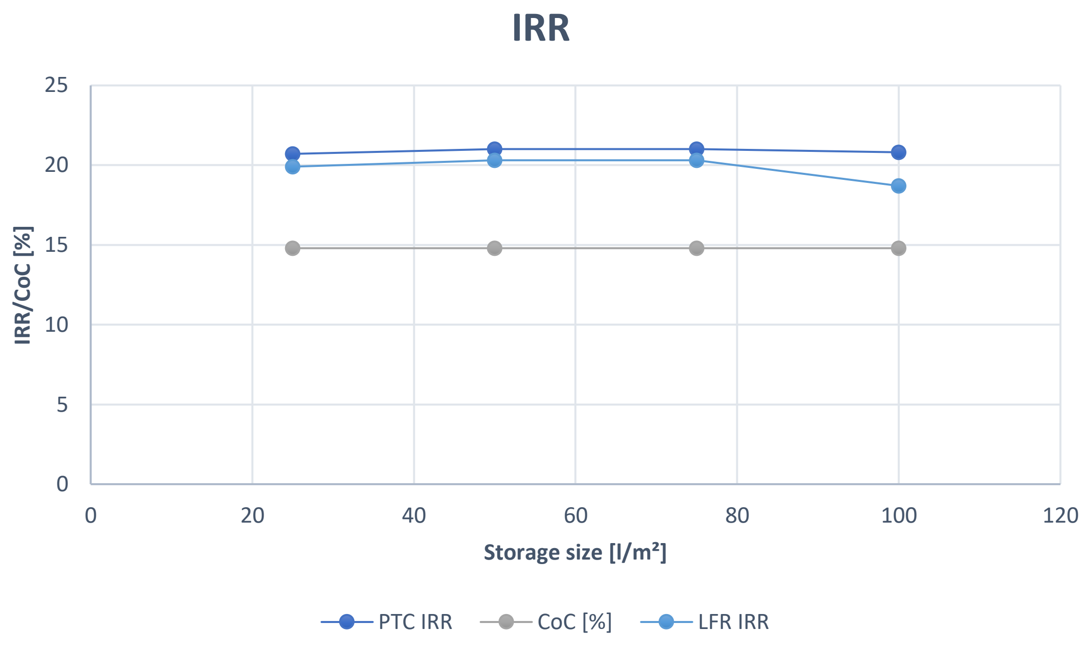
Solar Payback

Fraunhofer ISE

Results

Task 2a – Supply Level





Results

Task 2b – Critical CO2 tax

With 120 ZAR/$t_{CO2,eq}$

- IRR: 13.7%
- NPV project margin : -400875 ZAR

With 700 ZAR/$t_{CO2,eq}$

- IRR: 14.8%
- NPV project margin: 13449 ZAR

Results

Task 2c – Critical interest rate

With 11.97%

- CoC: 14.8%
- IRR: 13.7%
- NPV project margin : -400875 ZAR

With 8.5%

- CoC: 13.6%
- IRR: 13.7%
- NPV project margin: 40024 ZAR

Results

Update 2023

06. Nov. 2023:

- Diesel Price: 26.28 ZAR/l (https://de.globalpetrolprices.com/South-Africa/diesel_prices/)
- CO2 tax: 144 ZAR/l

→Solar LCOH 3342 : 6773 ZAR/MWh Current LCOH → 1:2 !
→IRR: 34.3%
→Discounted Payback: 3,6 years

Contact

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High Temperature Solar Thermal and Industrial Processes
Tel. +49 761 4588 5732
Fanny.huebner@ise.fraunhofer.de

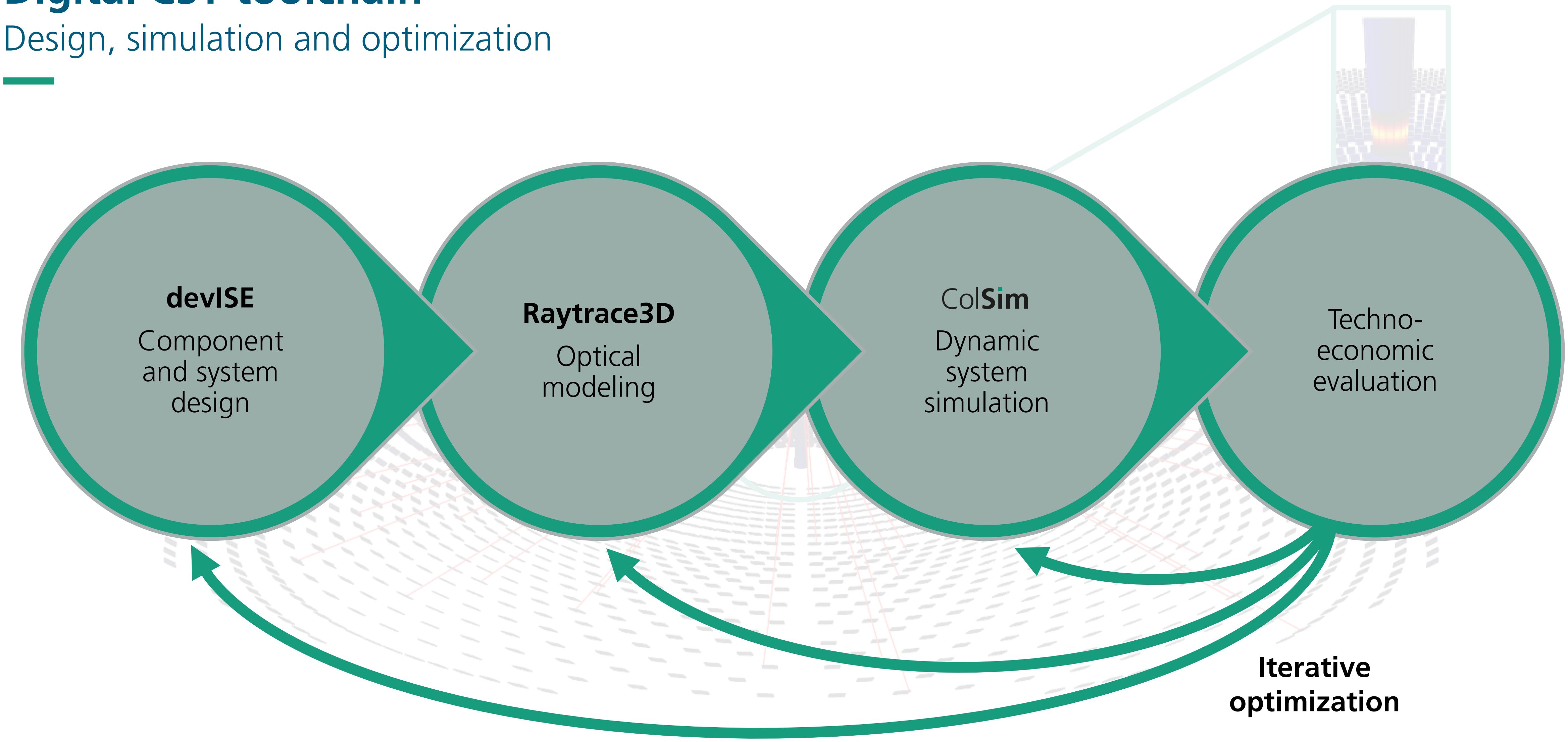
Techno-Economic Optimization

Peter Schöttl, Shahab Rohani
SFERA-III Training for Industries: CST4SHIP
Freiburg, Nov 9, 2023
www.ise.fraunhofer.de

See also Solar Payback Guideline:
https://www.solar-payback.com/download/ship-guidelines-for-feasibility-performance-optimisation-and-design/

Digital CST toolchain

Design, simulation and optimization



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System simulation with ColSimCSP

System simulation

Software complexity

Best suitable for solar system design

Energy flow model

Dynamic system simulation

CFD (Computational Fluid Dynamics)

LOW Complexity/Computational Cost HIGH

Excel

EES Engineering Equation Solver

TRNSYS18

T*SOL

ColSim

POLYSUN

ANSYS

STAR-CCM+

OpenFOAM

Fraunhofer ISE

ColSim

Dynamic system simulation

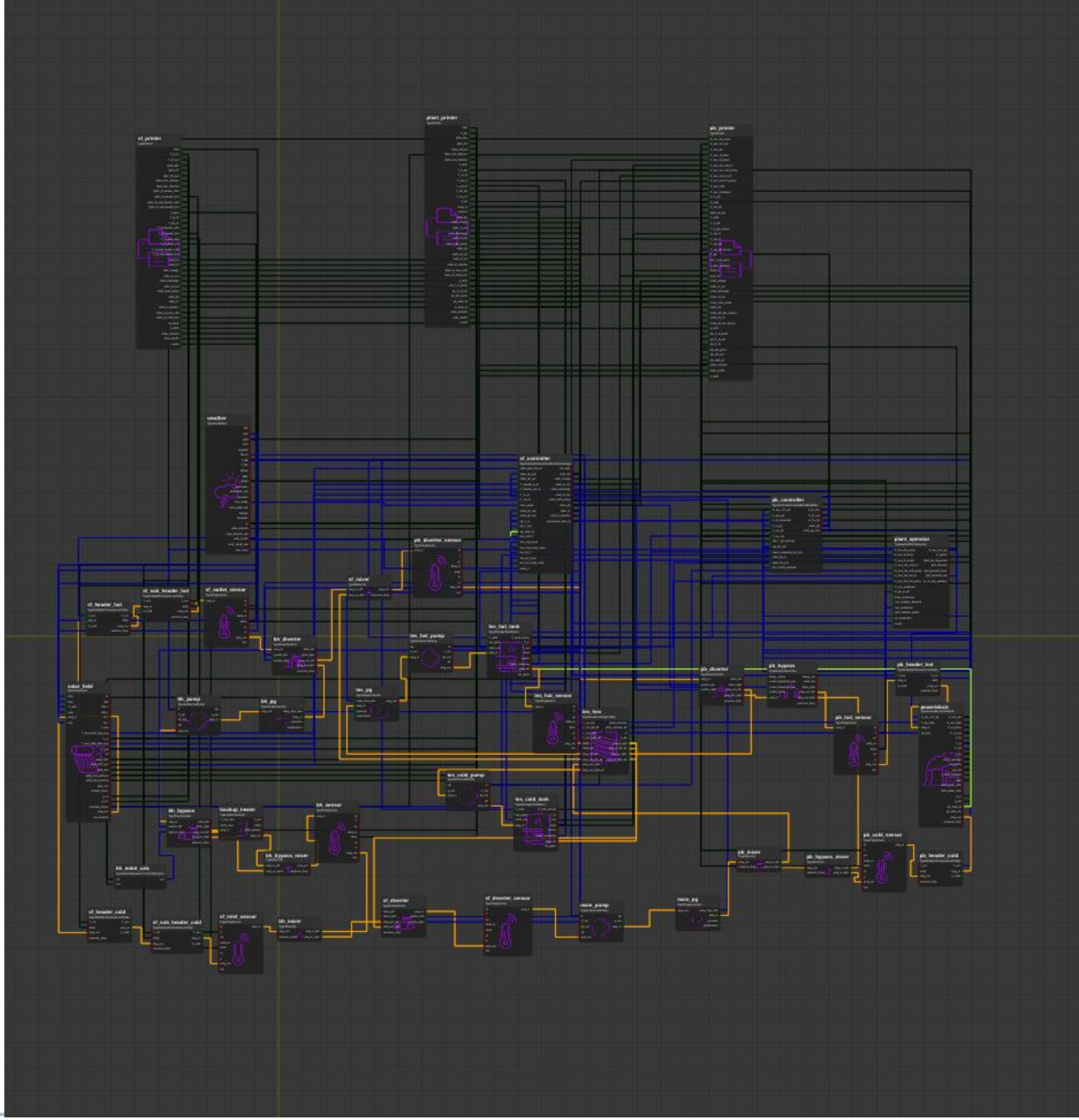
Modeling

- Thermo-hydraulic plug-flow model
- Transient simulation with thermal inertia
- Comprehensive component library
- Easily extensible
- Complex plant layouts
- Drag&Drop GUI

Performance

- Numbers crunching in C++
- Low simulation time, small simulation time steps
- Parallelization for parameter studies
- Annual simulations for thousands of cases

Variable level of detail

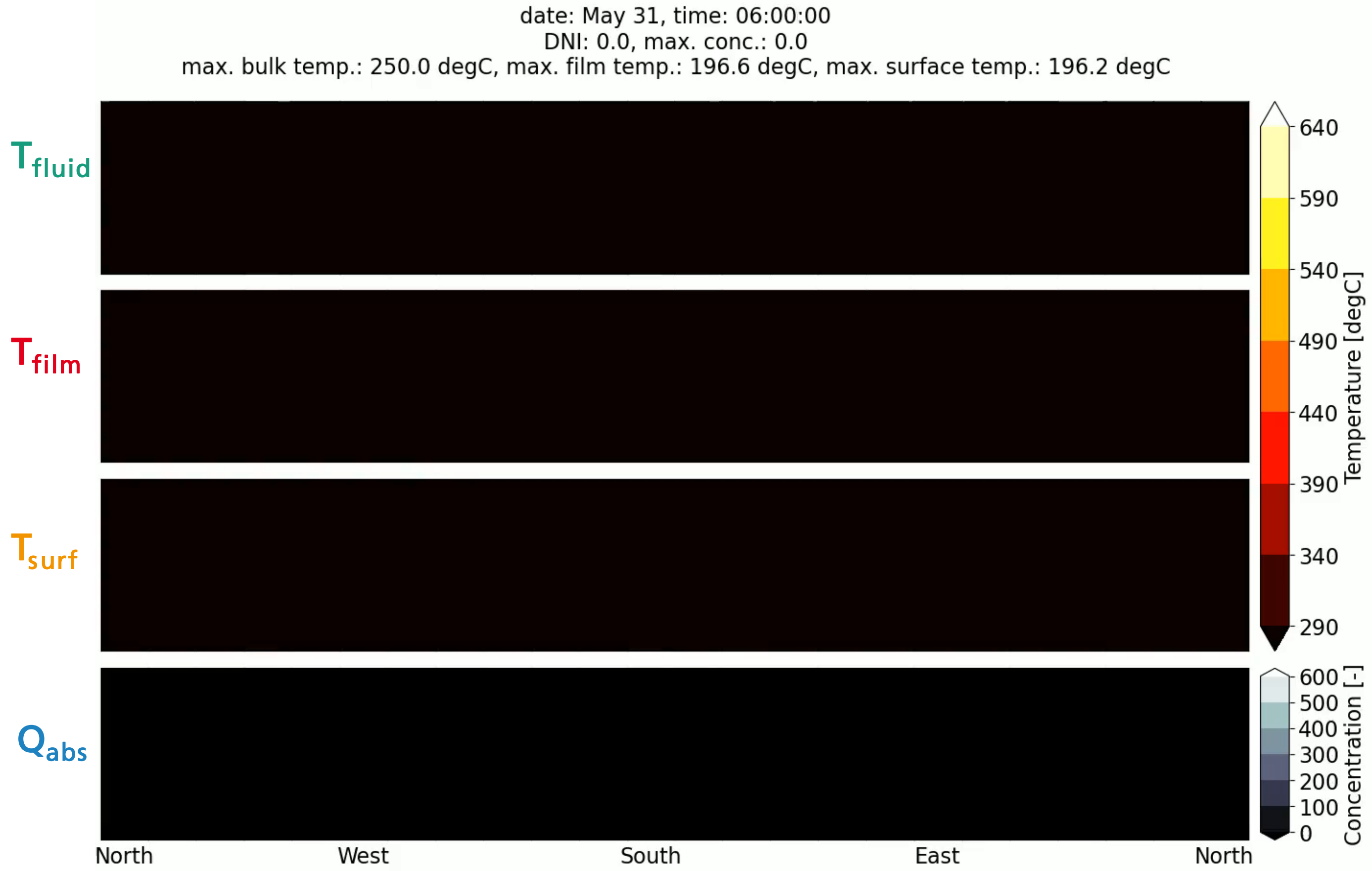


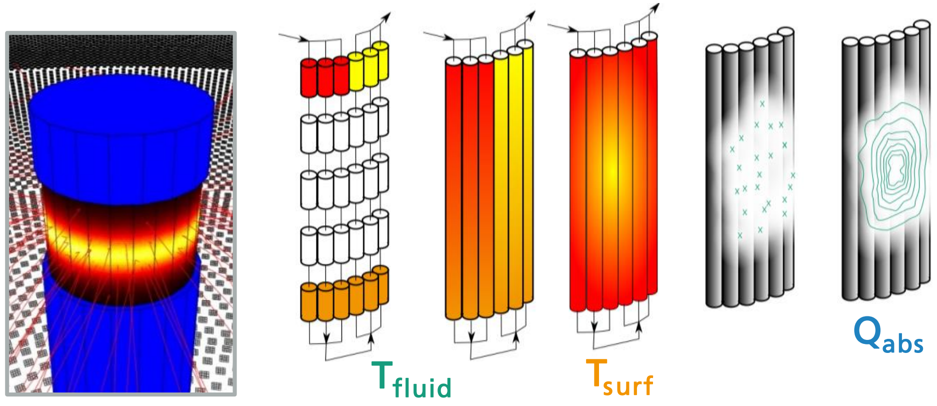
Screenshot of ColSim GUI

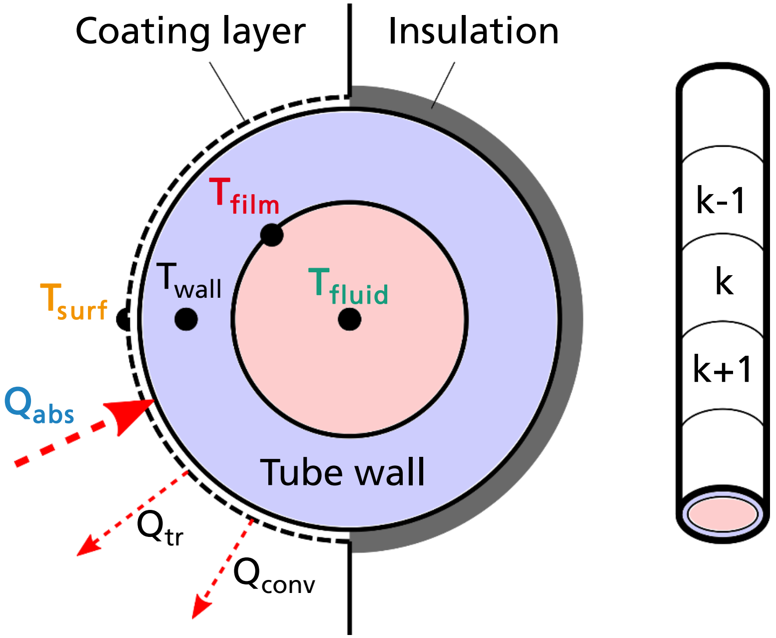
Fraunhofer ISE

ColSim

Solar Tower modeling





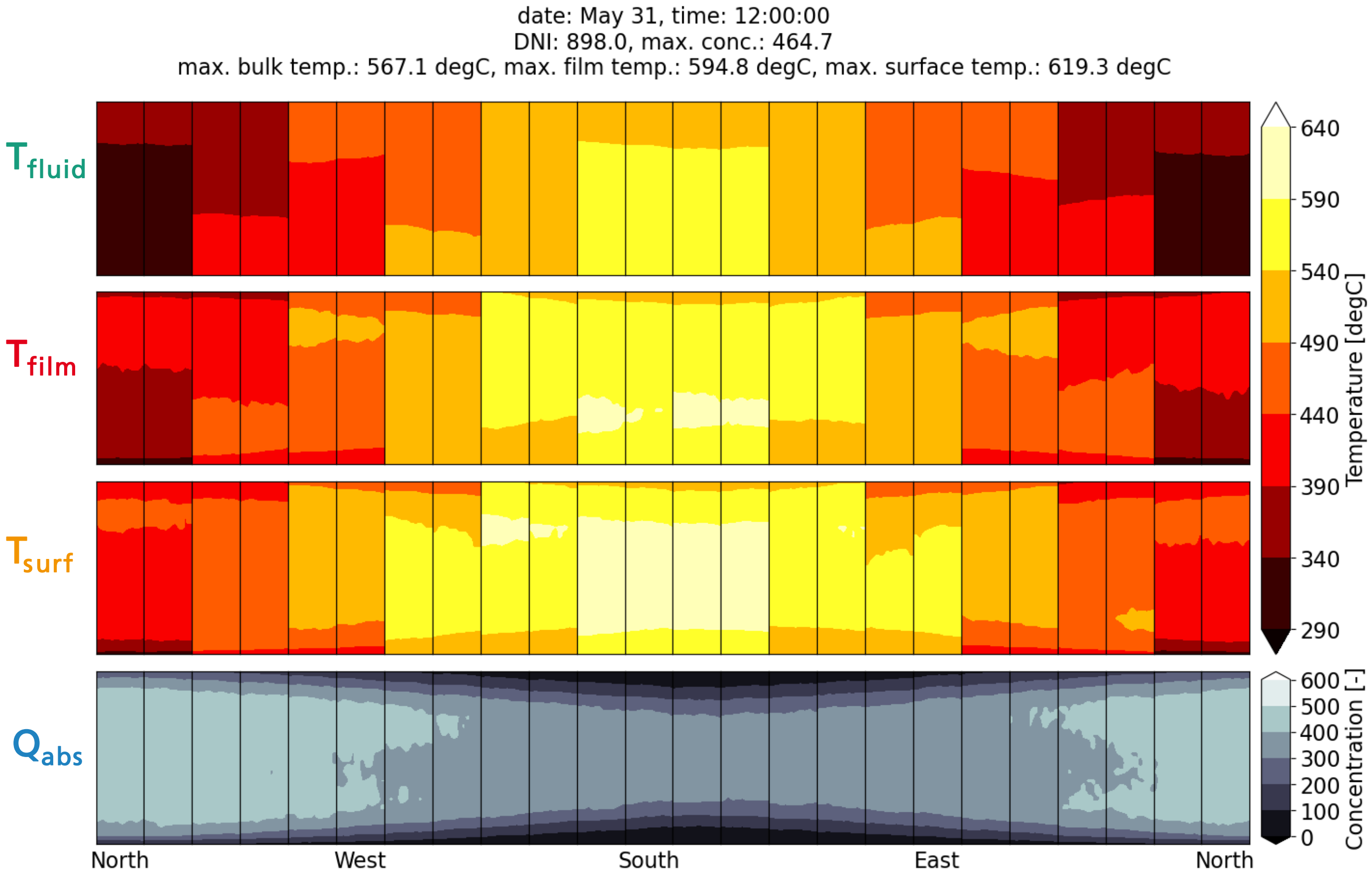


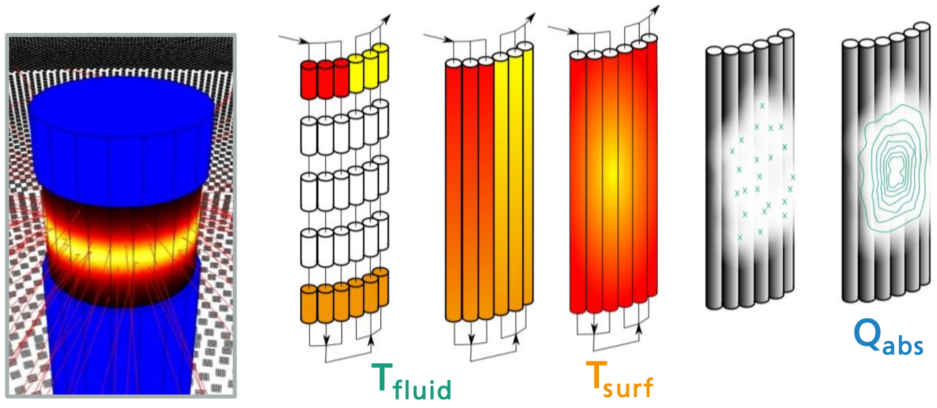
Transient operation of external receiver with aiming and defocusing strategies

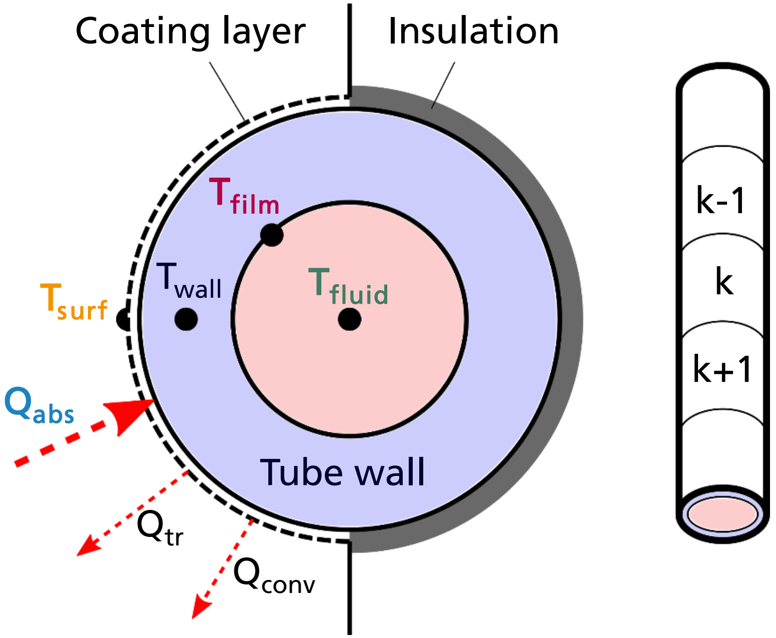
System similar to Noor-3, Ouarzazate, 70'000 heliostats, 600 MW_{th} receiver

ColSim

Solar Tower modeling





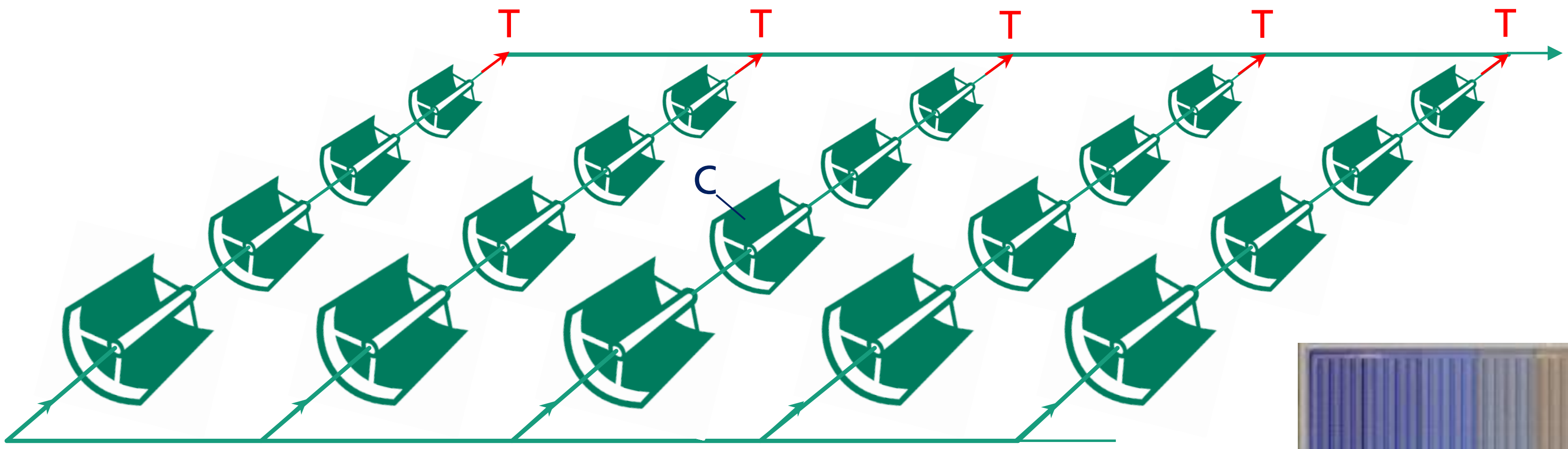


Transient operation of external receiver with aiming and defocusing strategies

System similar to Noor-3, Ouarzazate, 70‘000 heliostats, 600 MW_{th} receiver

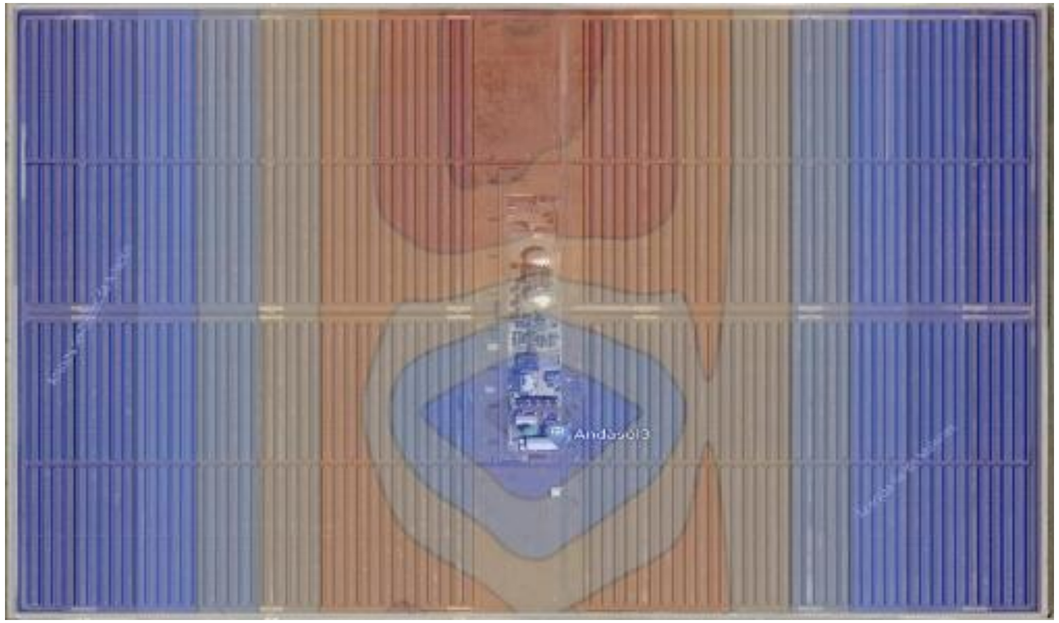
Fraunhofer ISE

ColSim
Solar field modeling



Modeling of individual Collector Modules and Loops in large-scale Parabolic Trough solar fields

Local DNI and soiling maps based on measurements



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Simulation Model:
CST Integration for Solar Process Heat

Base scenario

Rules of thumb: solar field size

Base parameters/assumptions:

- Site: Seville
- $DNI_{ann} = 2348\, kWh/(m^2 a)$
- Annual average collector efficiency $\eta_{ann} = 45\%$
- Nominal heat demand $\dot{Q}_{dem,nom} = 30\, MW$
- Demand profile: flat
- Annual heat demand $Q_{dem,ann} = P_{nom} \cdot 8760 = 262.8\, GWh$
- Target solar fraction $F_{sol} = \frac{Q_{sol}}{Q_{dem,ann}} = 40\%$
- Collector type: Eurotrough, $A_{ap,coll} = 817.36 m^2$

Calculation of solar field aperture area:

- Solar field aperture area

$$A_{ap,SF} = \frac{Q_{dem,ann} \cdot F_{sol}}{DNI_{ann} \cdot \eta_{ann}} = 99500\, m^2$$

Assuming 10 collectors per loop:

- Number of loops $n_{loops} = \frac{A_{ap,SF}}{A_{ap,coll} \cdot 10} \approx 12$

Note: solar field aperture area << solar field space requirements!

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Base scenario

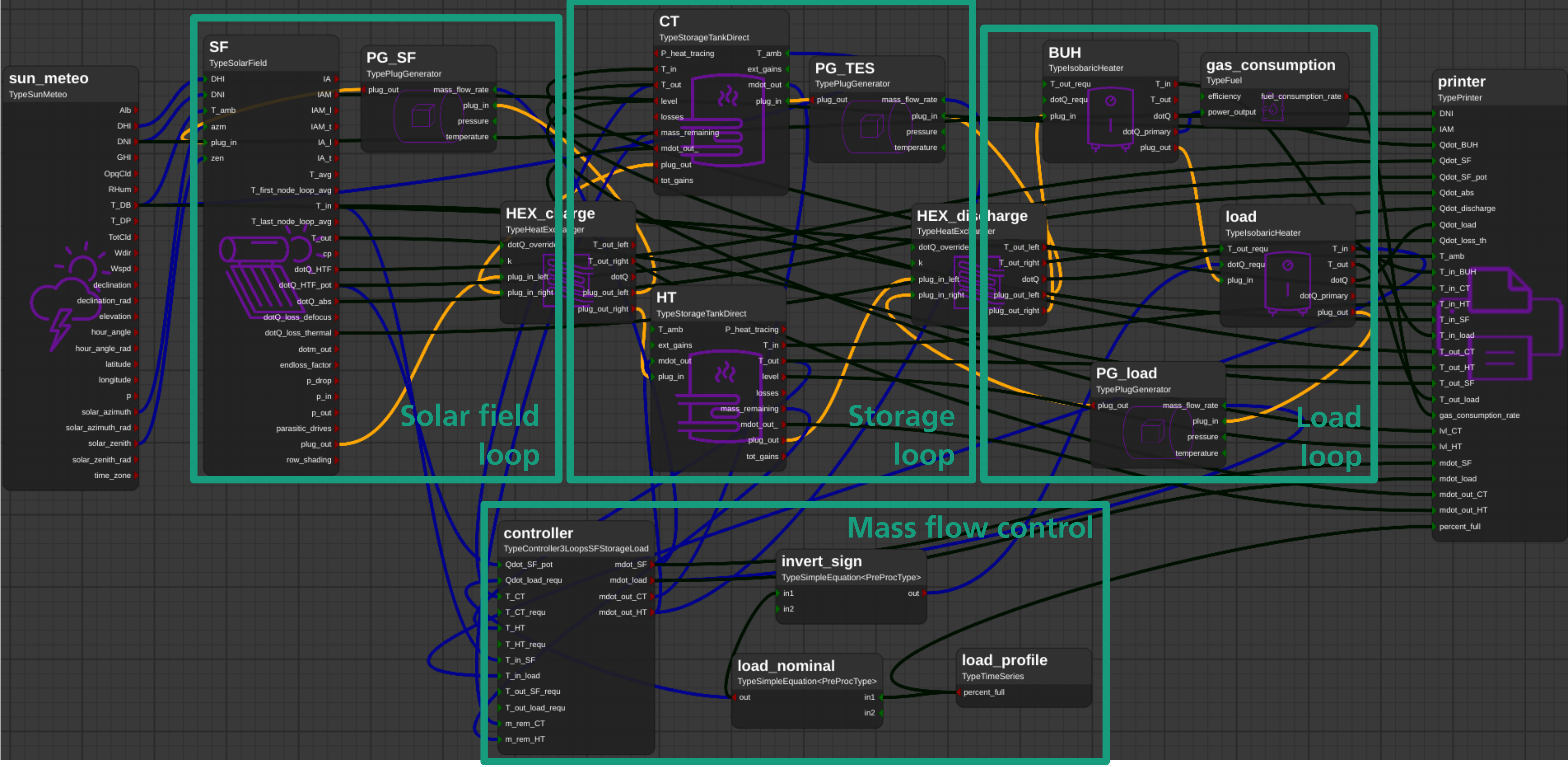
Rules of thumb: storage size

Base parameters/assumptions:

- Two-tank storage
- Target storage duration: $t_{storage} = 16h$
- Storage medium properties:
  - Specific enthalpies h_{hot}, h_{cold}
  - Density ρ

Calculation of storage size

- Tank energy: $Q_{tank} = P_{nom} \cdot F_{sol} \cdot t_{storage} = 192\ MWh$
- Tank volume: $V_{tank} = \frac{m_{fluid}}{\rho_{fluid}} = \frac{Q_{tank}}{\rho_{fluid} \cdot (h_{hot} - h_{cold})} = 3875\ m^3$



sun_meteo
TypeSunMeteo
Alb
DHI
DNI
GHI
OpqCld
RHum
T_DB
T_DP
TotCld
Wdir
Wspd
declination
declination_rad
elevation
hour_angle
hour_angle_rad
latitude
longitude
p
solar_azimuth
solar_azimuth_rad
solar_zenith
solar_zenith_rad
time_zone
SF
TypeSolarField
DHI
DNI
T_amb
azm
plug_in
zen
IA
IAM
IAM_l
IAM_t
IA_l
IA_t
T_avg
T_first_node_loop_avg
T_in
T_last_node_loop_avg
T_out
cp
dotQ_HTF
dotQ_HTF_pot
dotQ_abs
dotQ_loss_defocus
dotQ_loss_thermal
dotm_out
endloss_factor
p_drop
p_in
p_out
parasitic_drives
plug_out
row_shading
PG_SF
TypePlugGenerator
plug_out
mass_flow_rate
plug_in
pressure
temperature
Solar field
loop
CT
TypeStorageTankDirect
P_heat_tracing
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T_out
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losses
mass_remaining
mdot_out
plug_out
tot_gains
T_amb
ext_gains
mdot_out
plug_in
PG_TES
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mass_flow_rate
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temperature
HEX_charge
dotQ_override
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T_out_right
dotQ
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HT
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T_out_right
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plug_out_right
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BUH
TypeIsobaricHeater
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T_in
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power_output
fuel_consumption_rate
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loop
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TypePrinter
DNI
IAM
Qdot_BUH
Qdot_SF
Qdot_SF_pot
Qdot_abs
Qdot_discharge
Qdot_load
Qdot_loss_th
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T_in_BUH
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gas_consumption_rate
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lvl_HT
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mdot_out_HT
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Mass flow control
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out
in1
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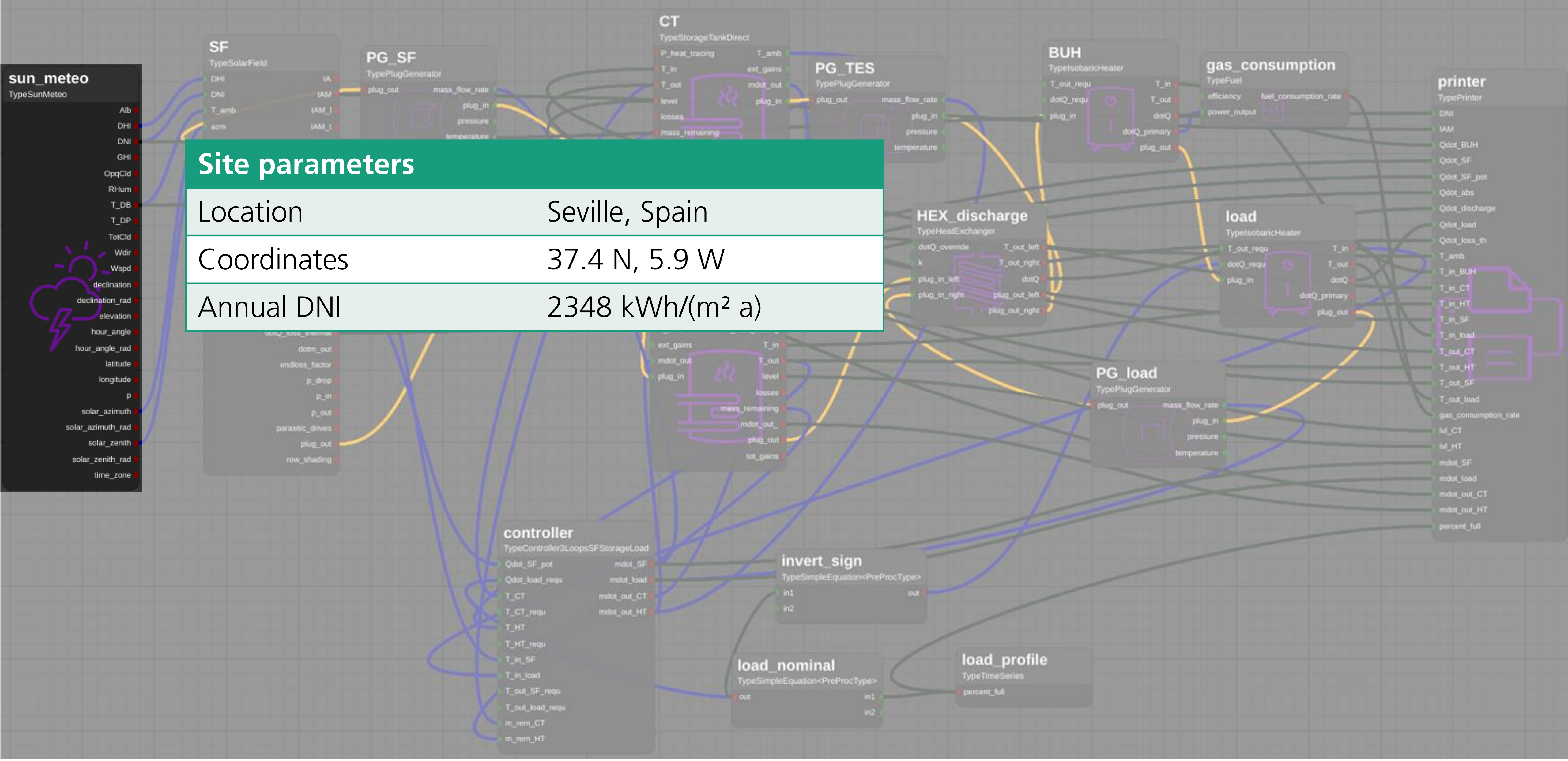
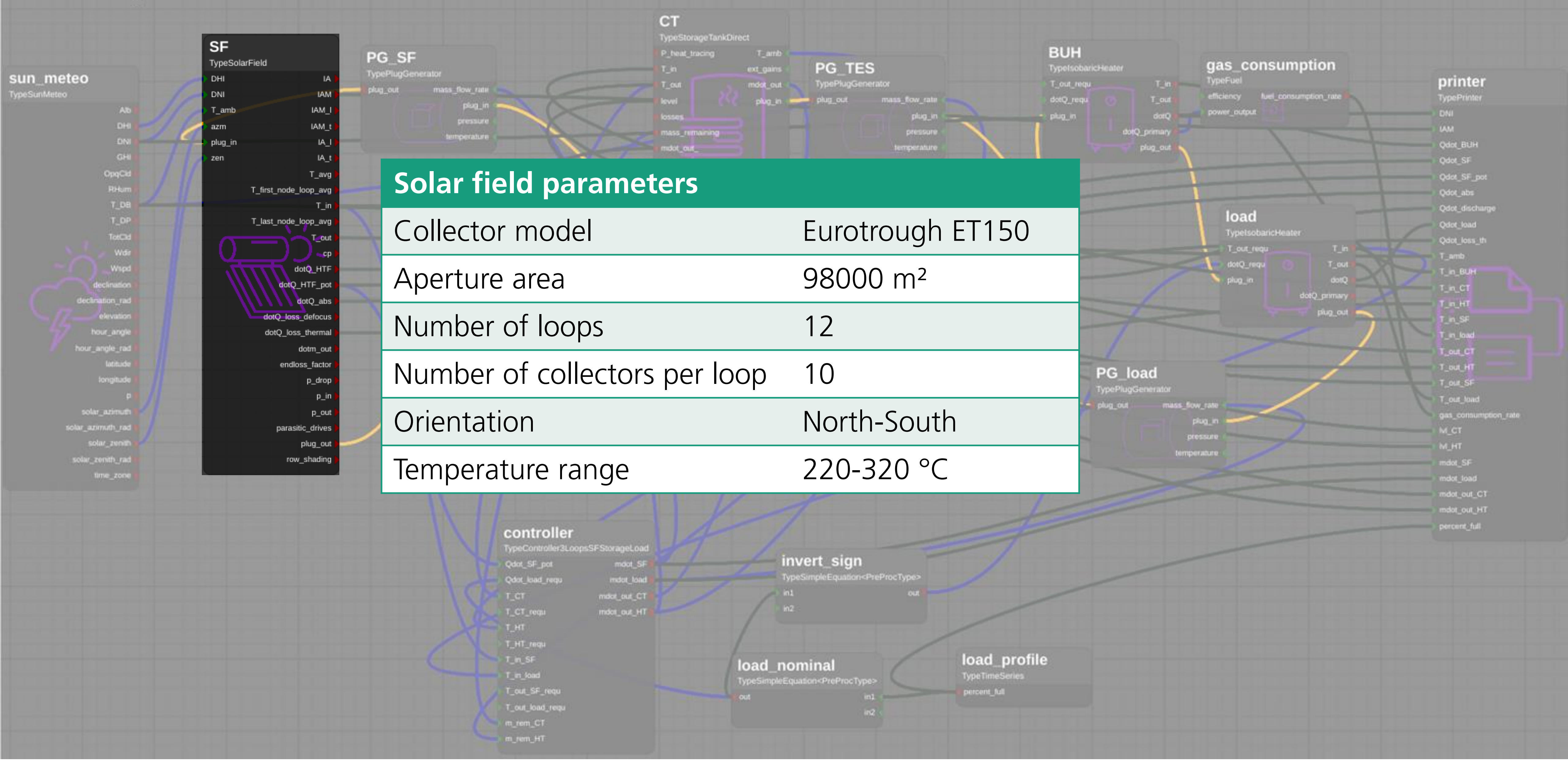
percent_full

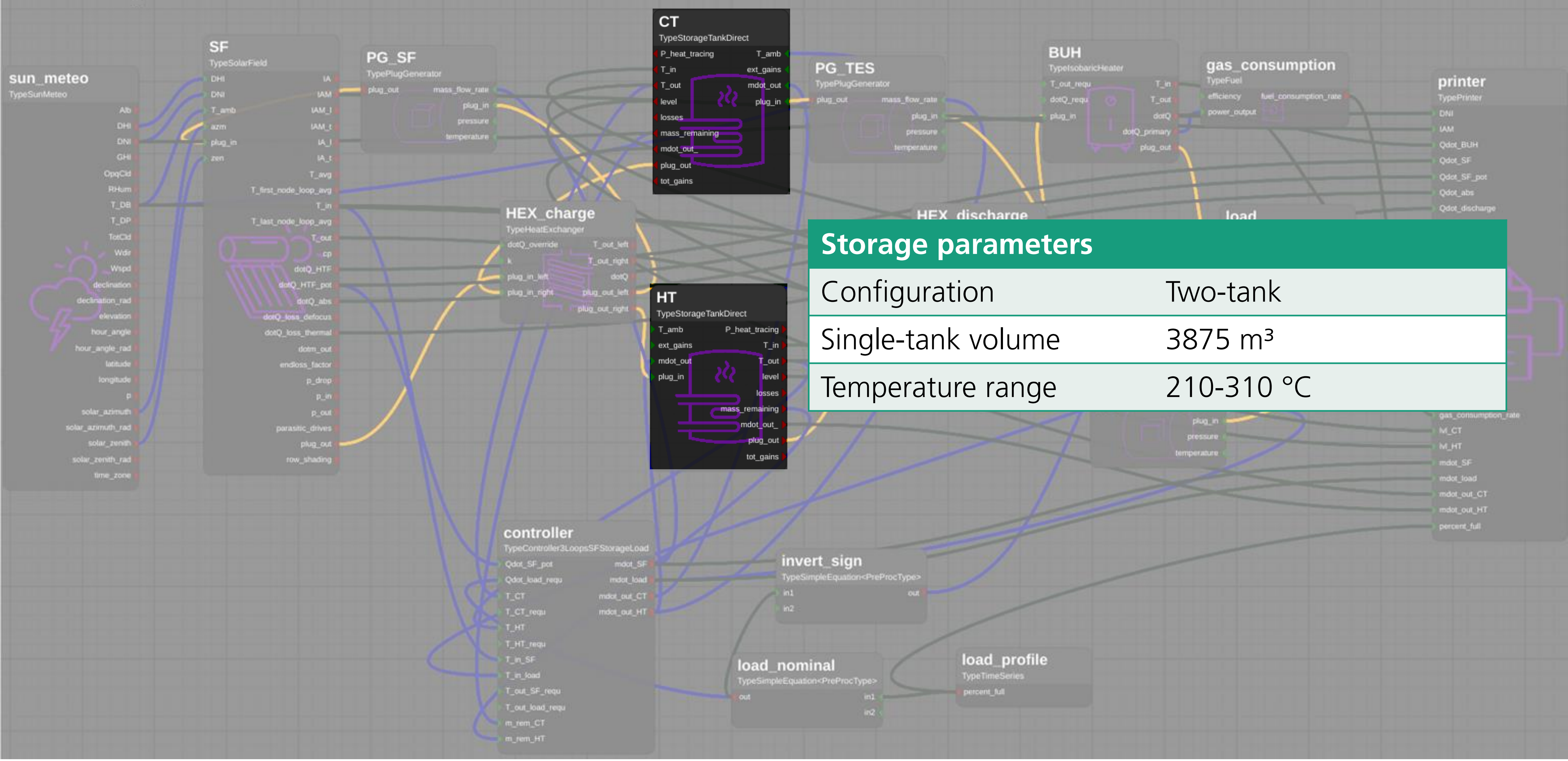


Site parameters

Site parameters	
Location	Seville, Spain
Coordinates	37.4 N, 5.9 W
Annual DNI	2348 kWh/(m² a)

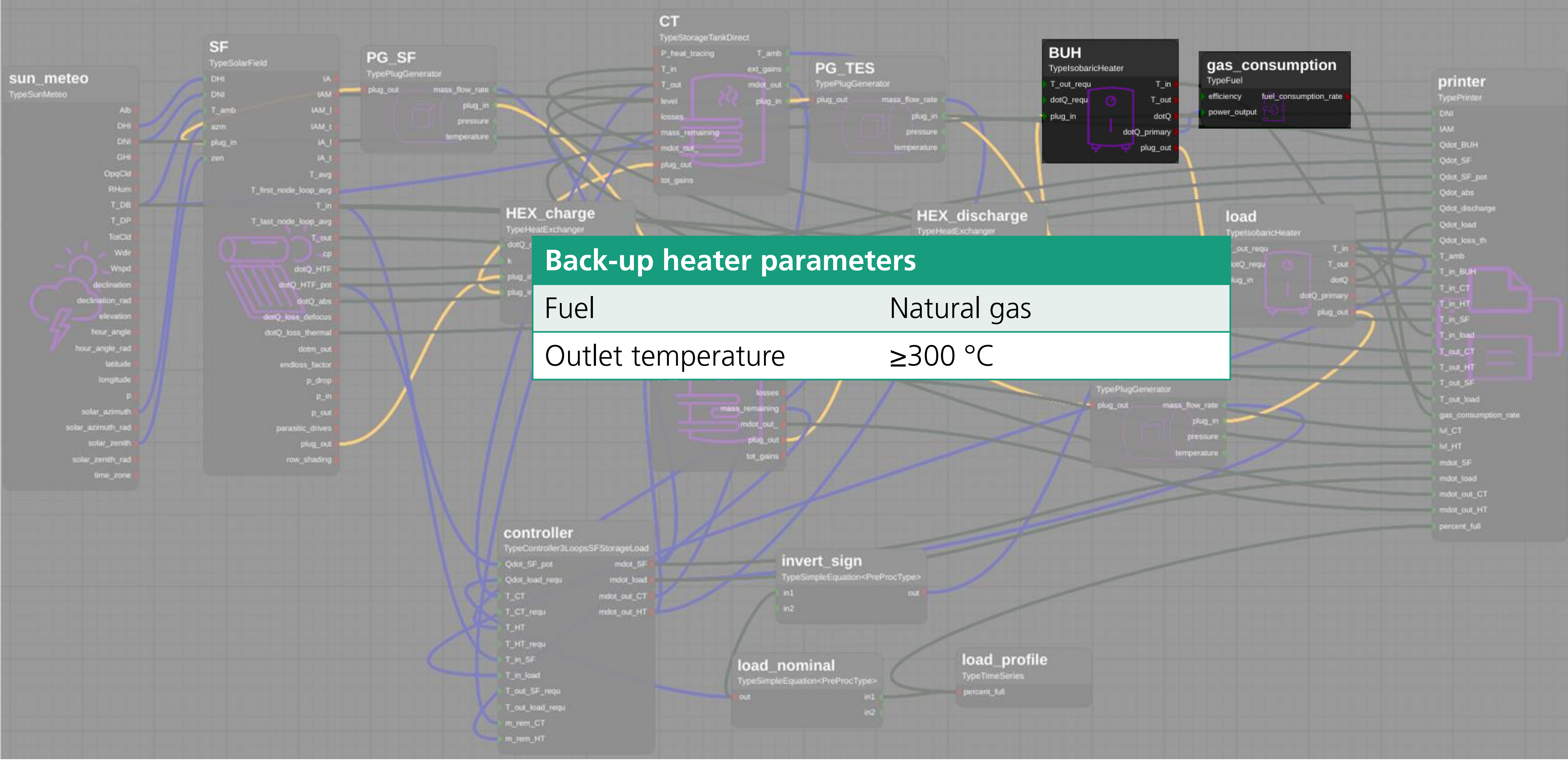


Solar field parameters	
Collector model	Eurotrough ET150
Aperture area	98000 m²
Number of loops	12
Number of collectors per loop	10
Orientation	North-South
Temperature range	220-320 °C



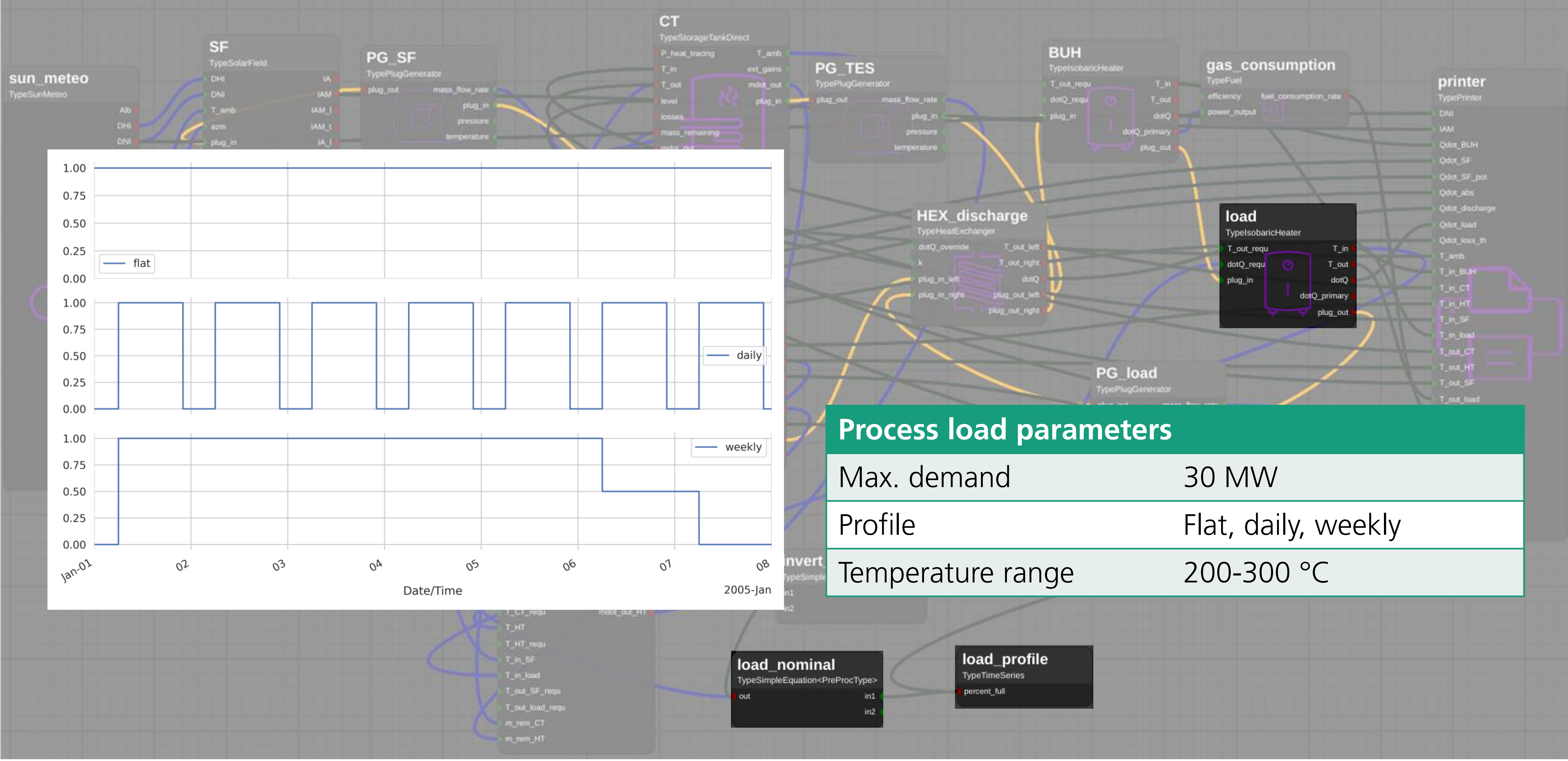
Storage parameters

Configuration	Two-tank
Single-tank volume	3875 m³
Temperature range	210-310 °C



Back-up heater parameters

Fuel	Natural gas
Outlet temperature	≥300 °C

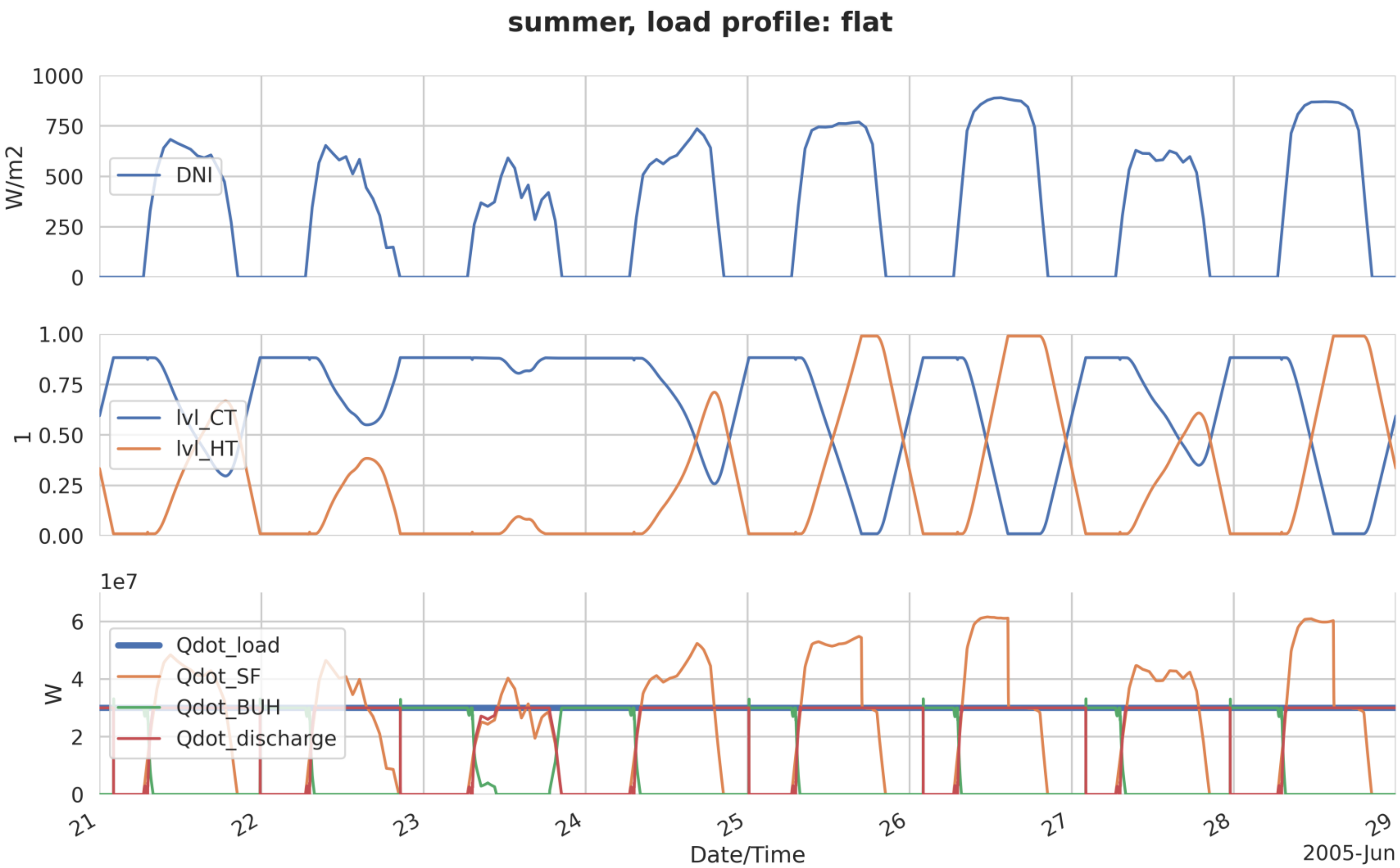


Process load parameters	
Max. demand	30 MW
Profile	Flat, daily, weekly
Temperature range	200-300 °C

Base Scenario: Summer/Winter Comparison and Annual Assessment

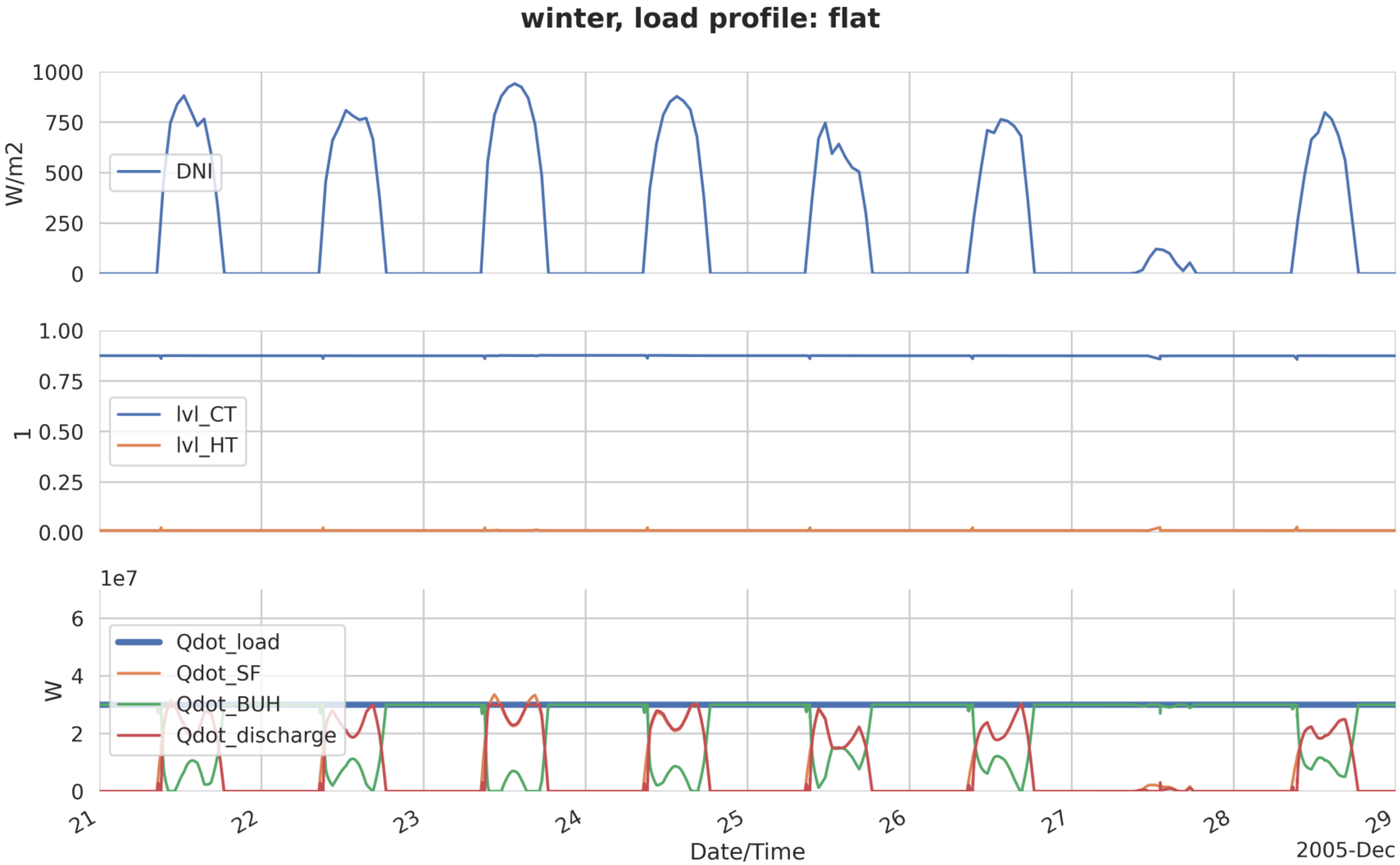
Summer/winter comparison

Summer, load profile: flat



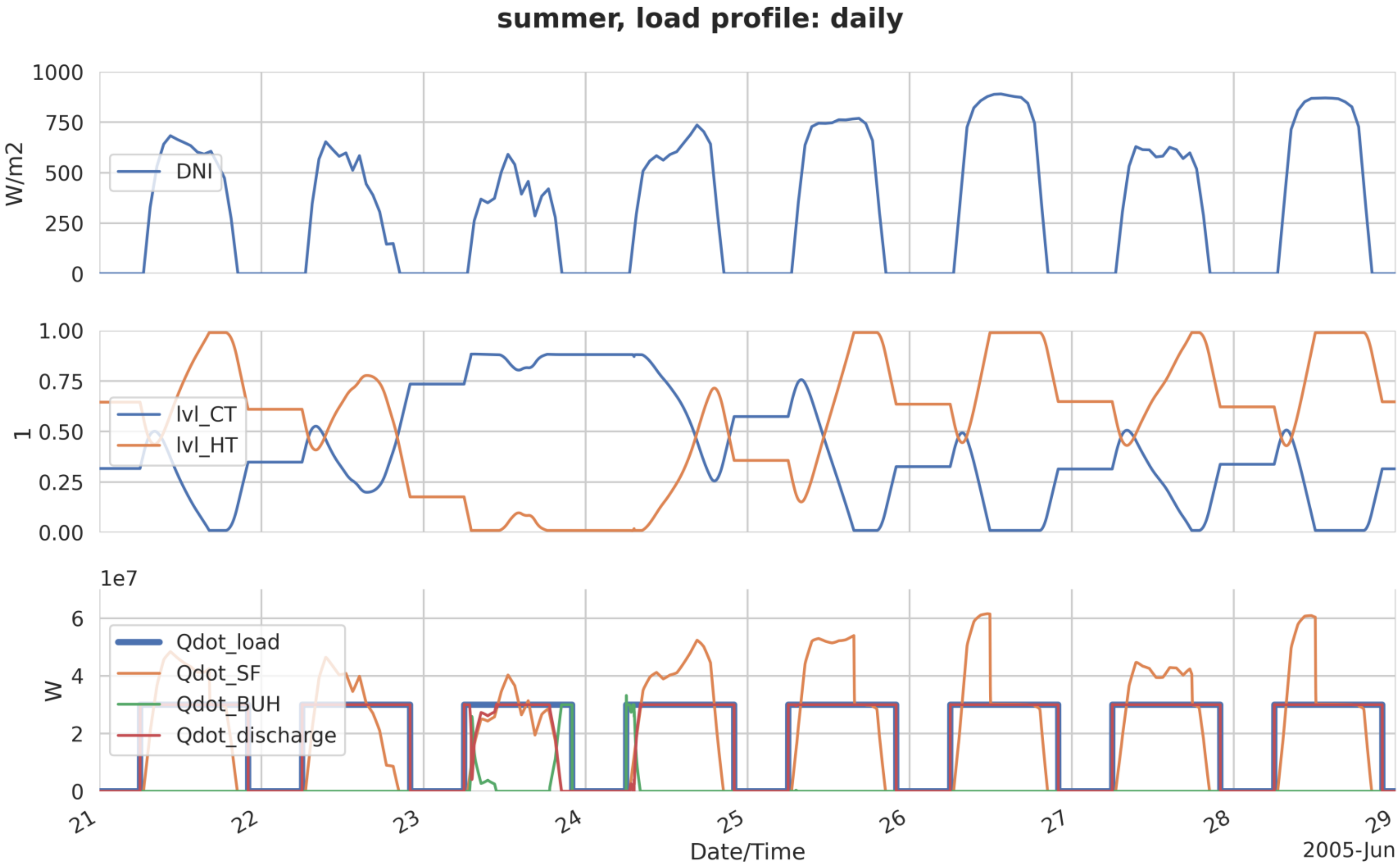
Summer/winter comparison

Winter, load profile: flat



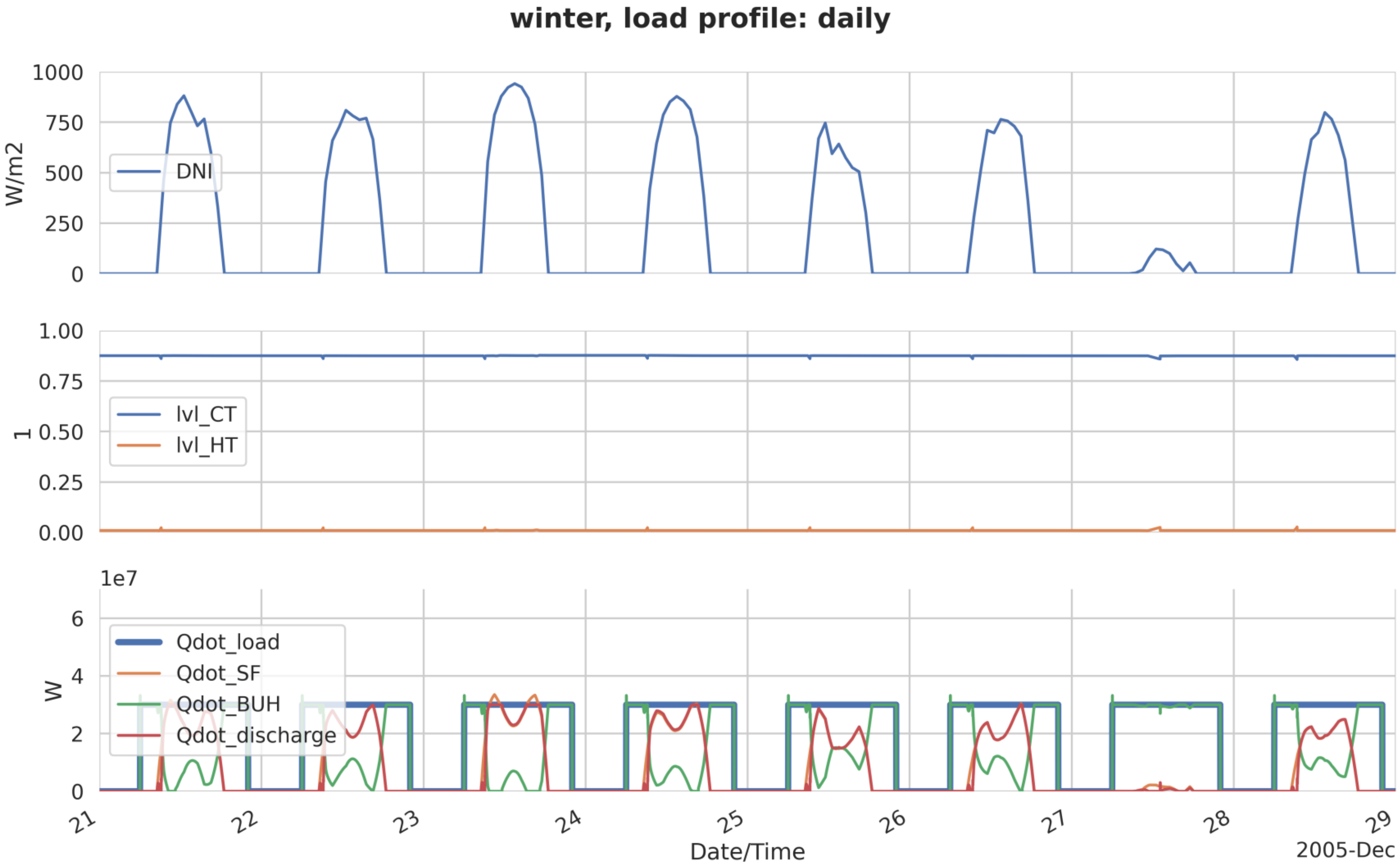
Summer/winter comparison

Summer, load profile: daily



Summer/winter comparison

Winter, load profile: daily



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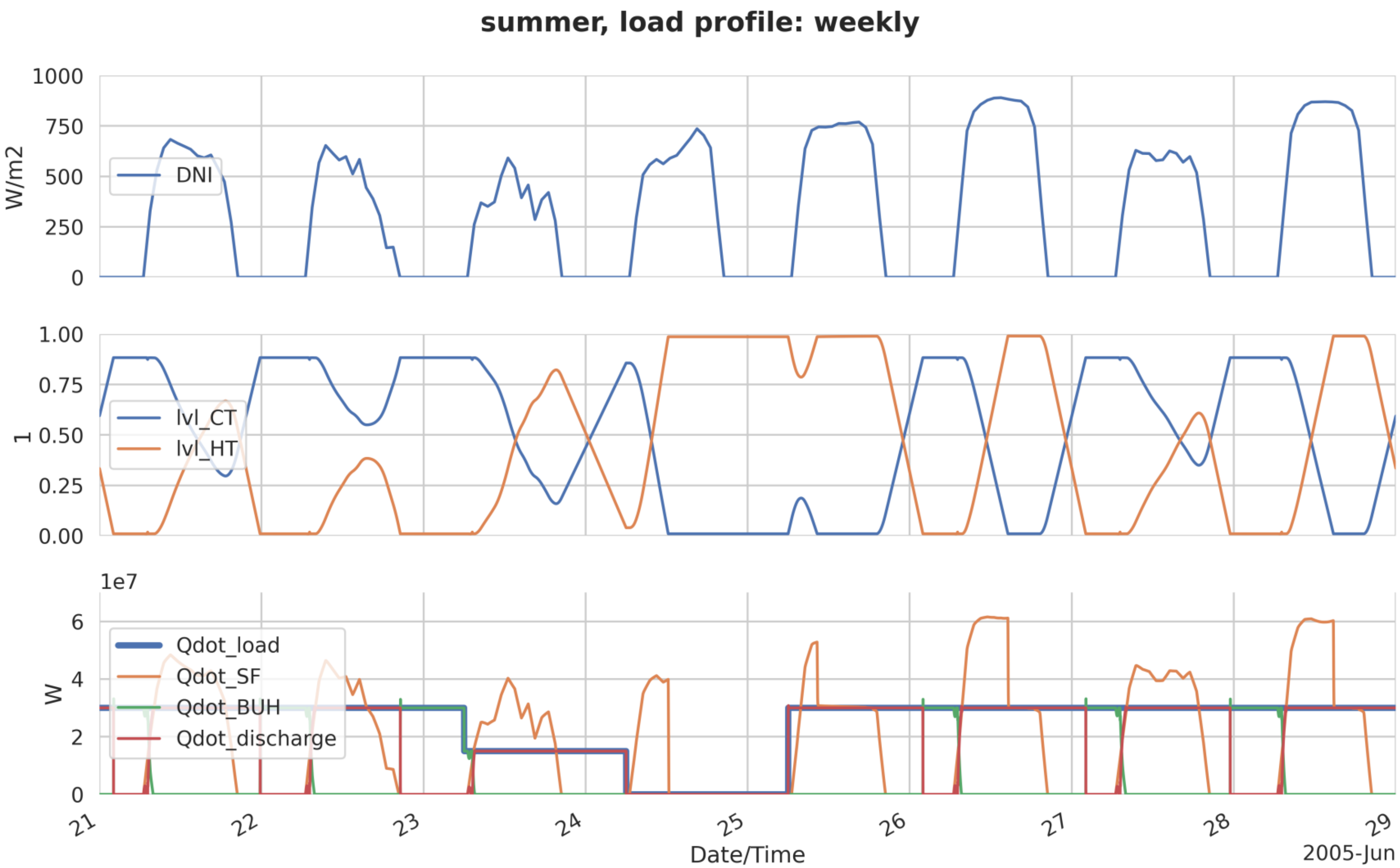
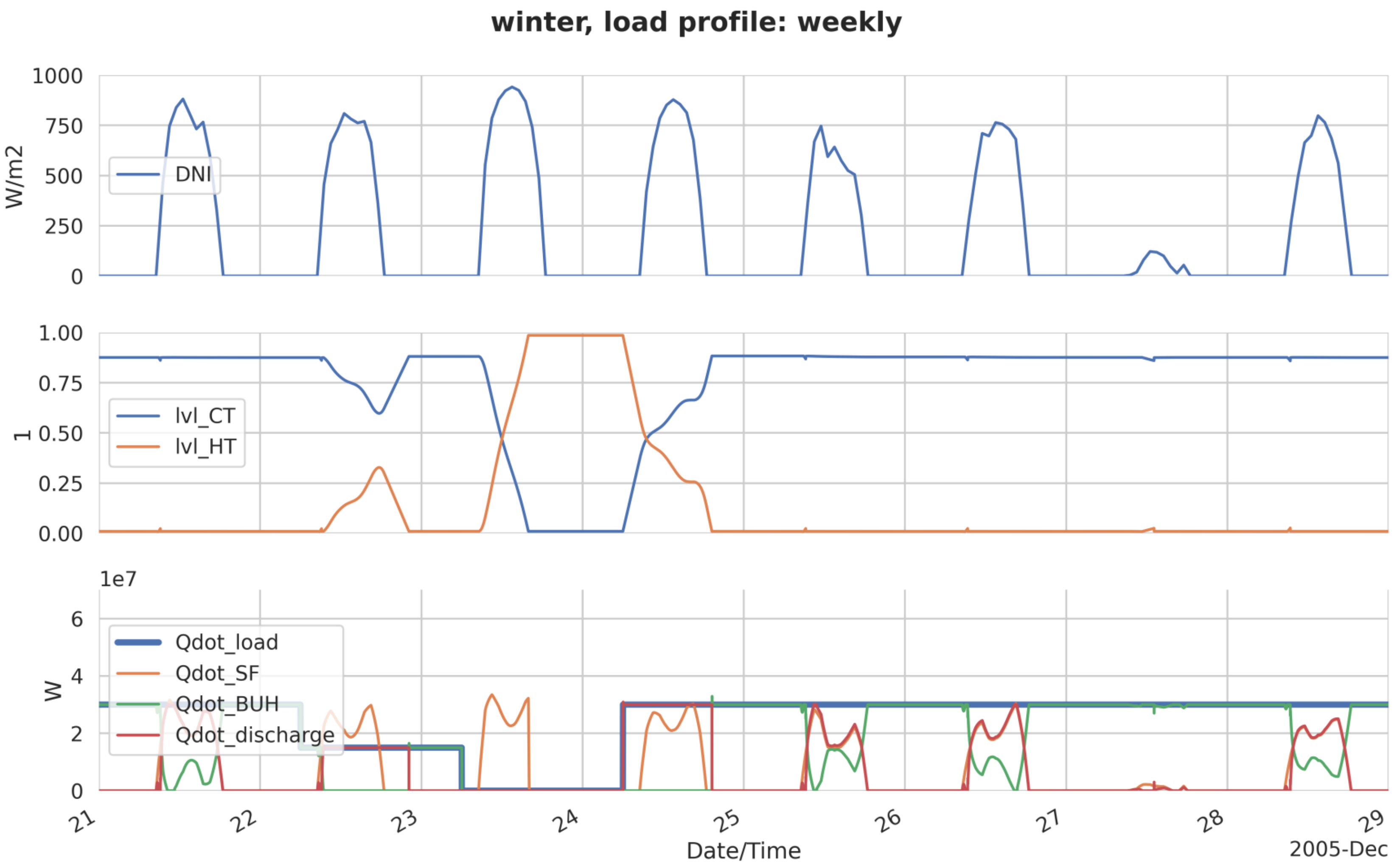
Summer/winter comparison

Summer, load profile: weekly



Summer/winter comparison

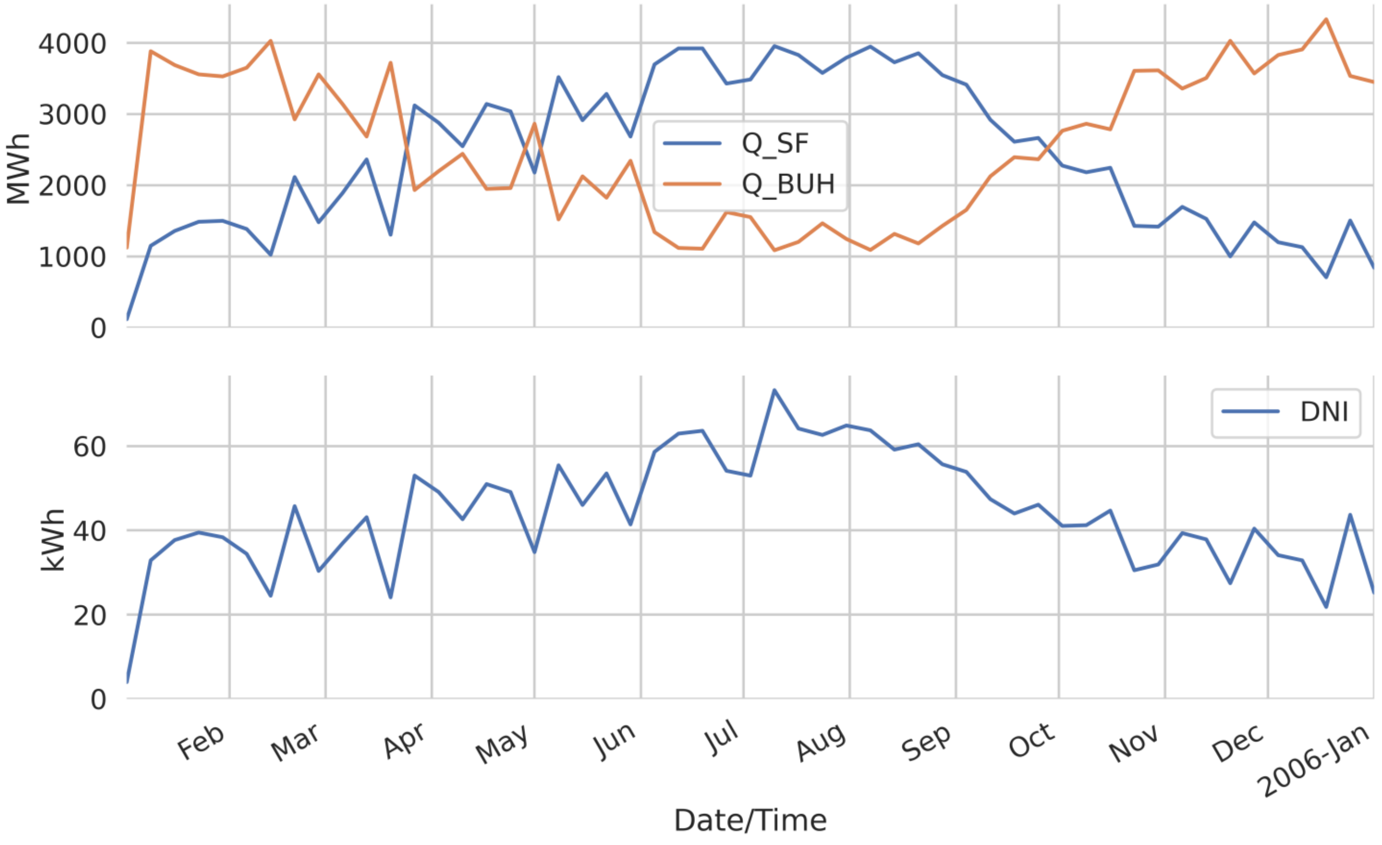
Winter, load profile: weekly



Annual assessment

Nominal design, flat load profile

- Weekly integrals
  - Solar field yield Q_{SF}
  - Back-up heater yield Q_{BUH}
  - Direct normal irradiation DNI
- Solar fraction: 48.6%
- Solar field yield roughly correlates with DNI
- Summer-winter difference more pronounced for solar field yield



Techno-Economic Optimization Study: Solar Field and Storage Size

Dimensioning of components

Solar field size

SMALL — **Solar field size** — **LARGE**

- Low demand
- Small storage (no/low shift of solar gain to nighttime)
- High solar irradiation
- Low temperature level

➔ Lower thermal losses & higher efficiency

- High demand
- Large storage (shift of solar gain to nighttime)
- Low solar irradiation
- High temperature level

➔ Higher thermal losses & lower efficiency

Dimensioning of components

Storage size

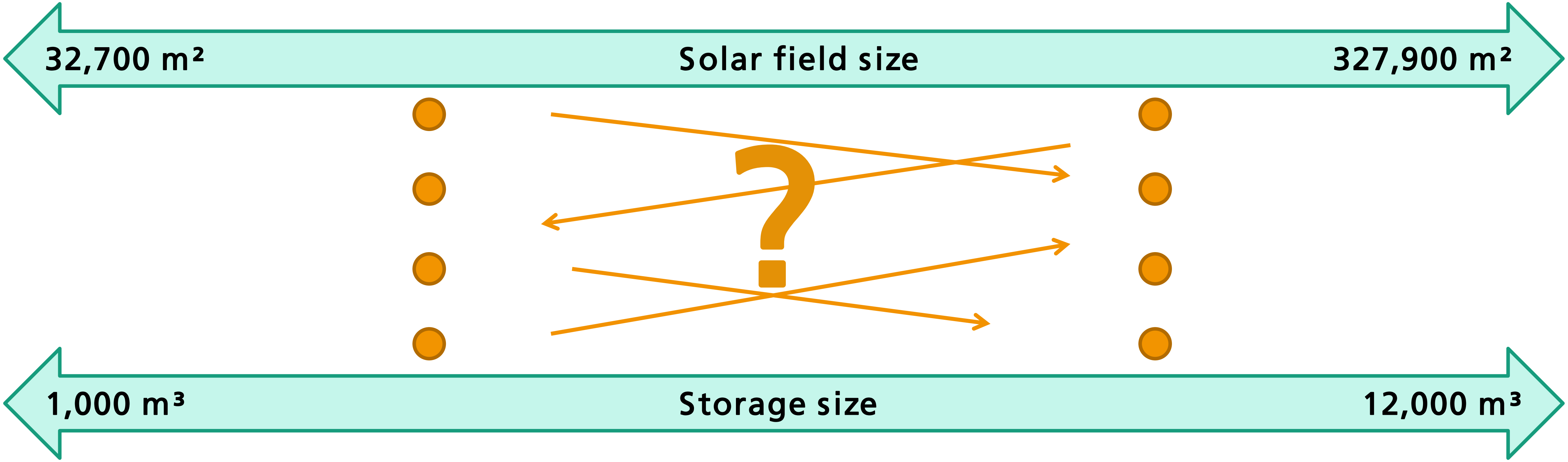
SMALL — Storage size — LARGE

- High temperature difference
  ➔ High storage capacity per volume
- Demand occurs during daytime
- Demand curve is stable

- Low temperature difference
  → Low storage capacity per volume
- Demand occurs during nighttime
- Demand curve is fluctuating

Dimensioning of components

Optimization problem



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Excursus: CSP/Solar Tower

Solar/Optical/Thermal Multiple

Solar Multiple

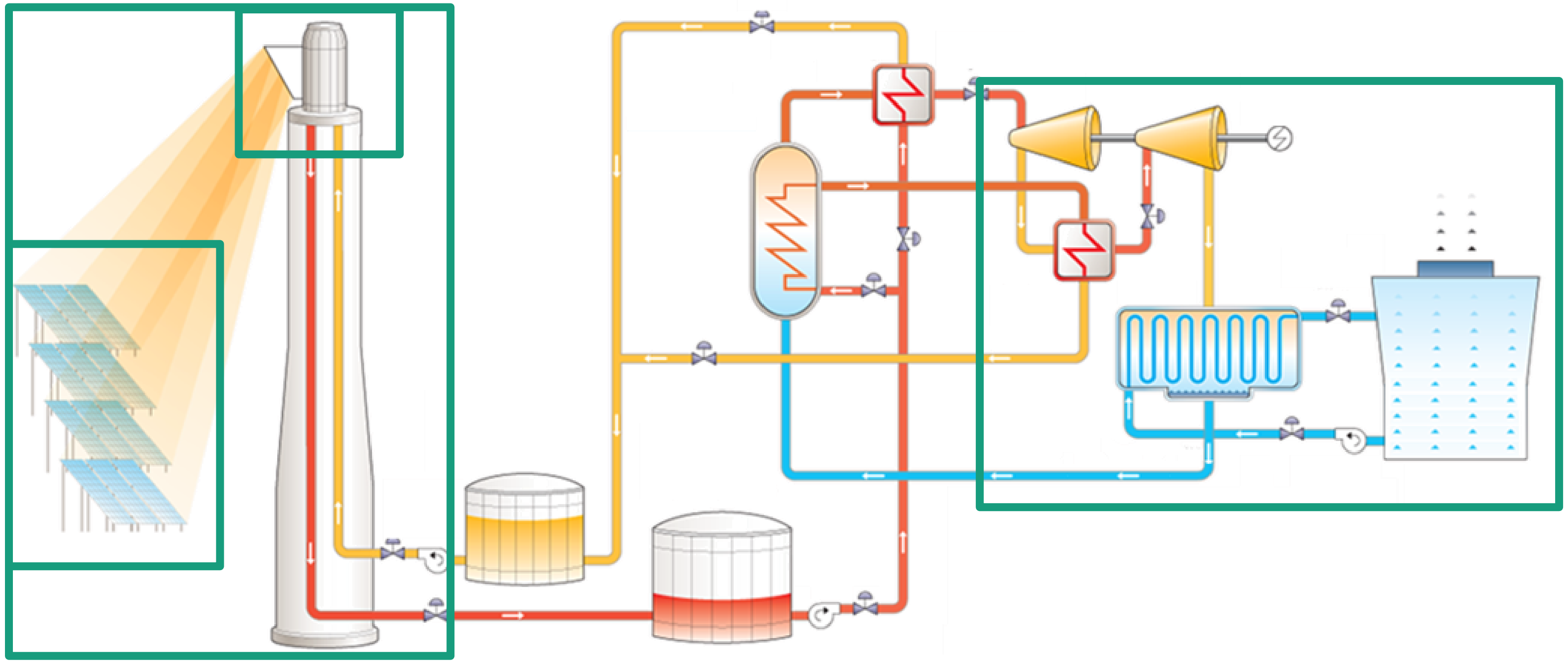
$$SM = \left.\frac{\dot{Q}_{SF}}{\dot{Q}_{load}}\right|_{\substack{design\\point}}$$
$$= OM \cdot TM$$

Optical Multiple

$$OM = \left.\frac{\dot{Q}_{HSF}}{\dot{Q}_{rec}}\right|_{\substack{design\\point}}$$

Thermal Multiple

$$TM = \left.\frac{\dot{Q}_{rec}}{\dot{Q}_{load}}\right|_{\substack{design\\point}}$$



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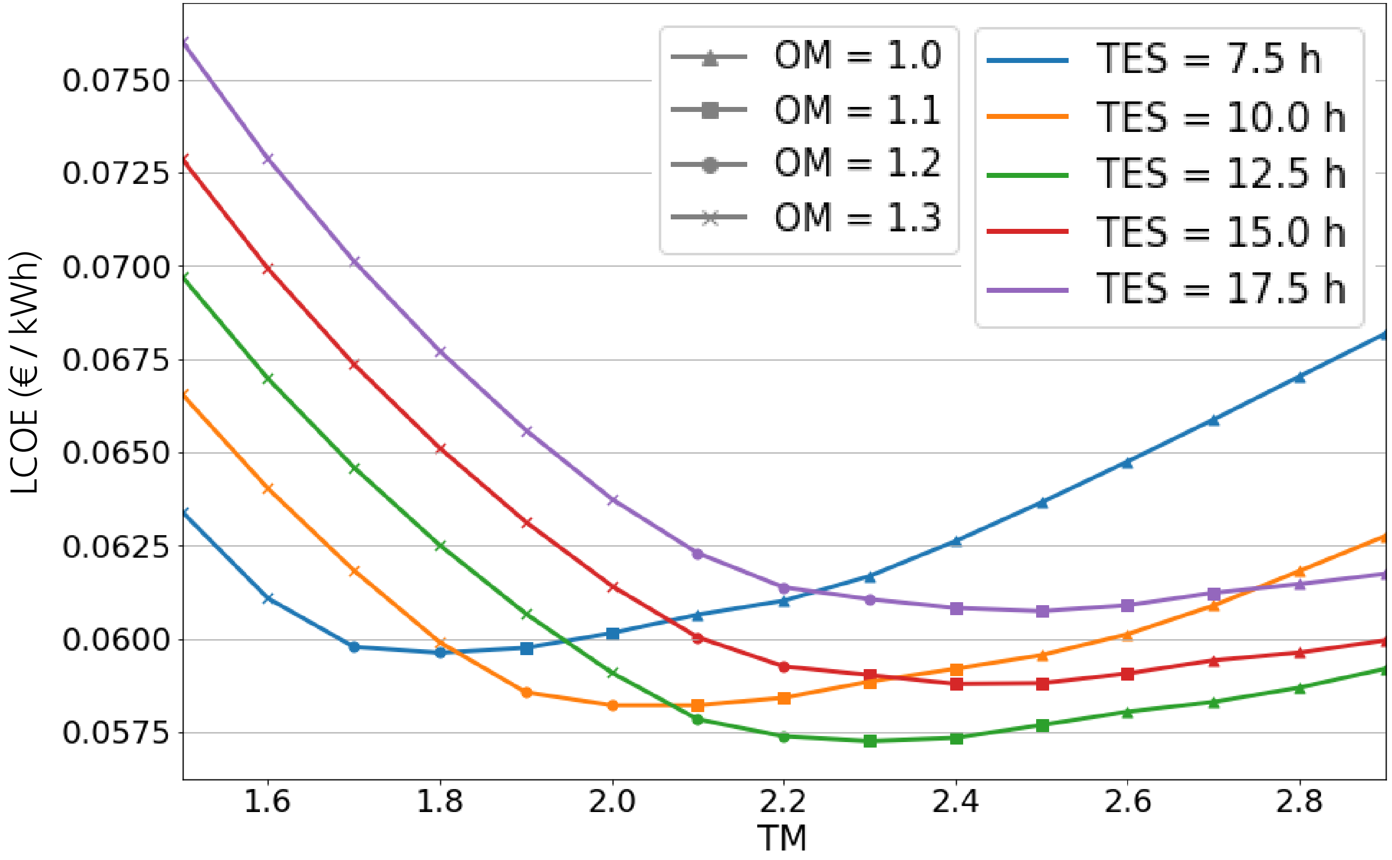
Excursus: CSP/Solar Tower

Solar/Optical/Thermal Multiple



Minimizing LCOE by identifying optimal storage capacity, Optical Multiple (OM) and Thermal Multiple (TM) for a Solar Tower plant in Chile

Contact

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High Temperature Solar Thermal and Industrial Processes
Tel. +49 761 4588 5732
peter.schoettl@ise.fraunhofer.de

Financing and using incentives/funding programmes for SHIP

Some aspects / inputs from the IEA SHC/SolarPACES Task 64/IV

- **Subtask E "Guideline to Market"** - non-technical barriers / issues
  Co-lead Subtask E by Peter Nitz, Fraunhofer ISE

- **Funding programmes and incentives**

- **Financing - Re-cap of online Workshop Oct 5, 2023**

- **Outlook: Report on SHIP Value proposition, Cost, Business models, Financing (in preparation in Task 64/IV, Subtask E)**

source: Peter Nitz / Fraunhofer ISE, Wolfgang Gruber-Glatzl, Jürgen Fluch / AEE-INTEC
IEA SHC Task 64 Subtask E "Guideline to Market", https://task64.iea-shc.org/

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Funding / incentives programmes for SHIP

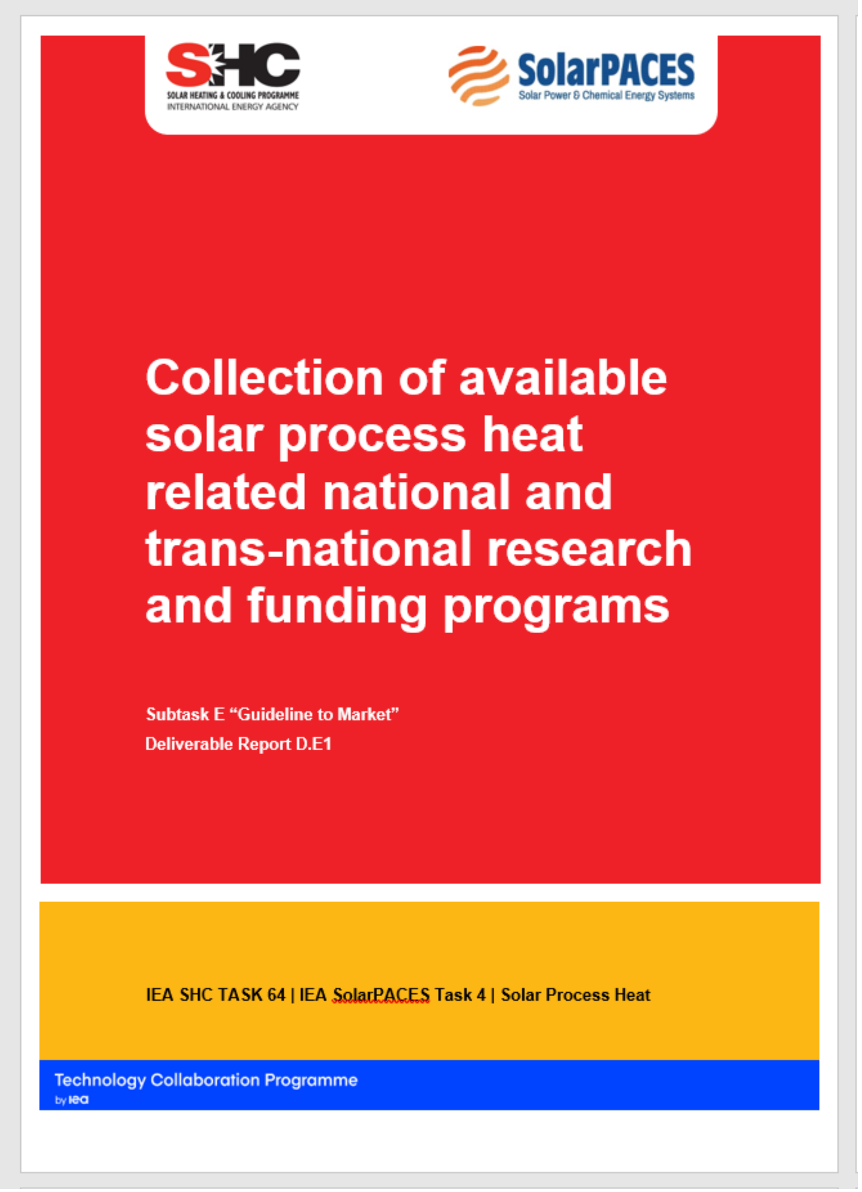
Some aspects / inputs from the IEA SHC/SolarPACES Task 64/IV

- Deliverable report D.E1, April 2021
- Available at https://task64.iea-shc.org/

- Recommendation of Task Expert Group:

- Strong favour to implement incentives
- Strong preference for CAPEX funding programmes as compared to other funding mechanisms

- **Quick feedback from the participants group: Do you agree to the recommendations? ➔ yes ☺**



source: Peter Nitz / Fraunhofer ISE, Wolfgang Gruber-Glatzl, Jürgen Fluch / AEE-INTEC
IEA SHC Task 64 Subtask E "Guideline to Market", https://task64.iea-shc.org/

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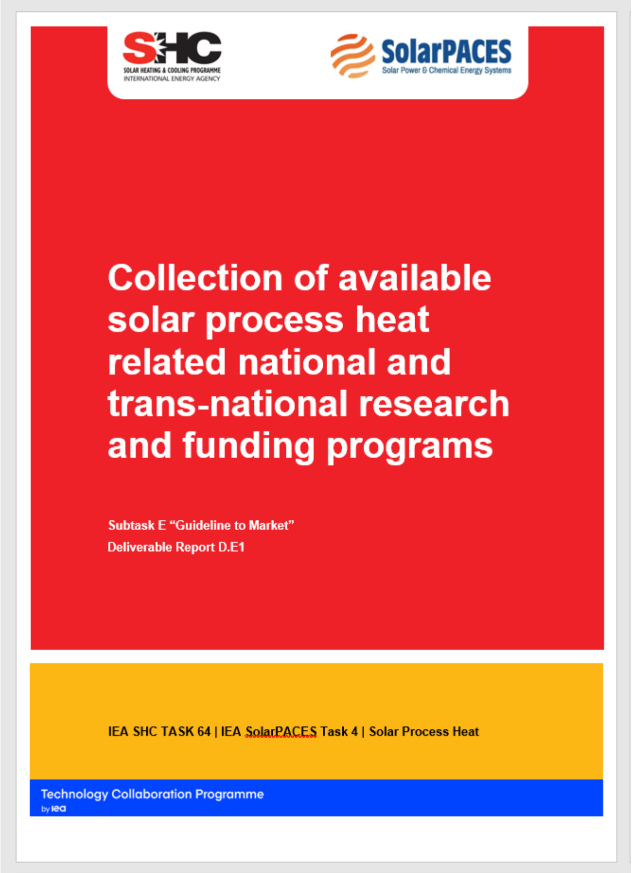
Update on Activities E1/E3 - Deliverable DE.1 „Collection of available solar process heat related national and trans-national research and funding programs”

- Survey concluded - (only) 18 responses from 32 countries approached
- DE.1 Final version, **April 2021, published on Task Website**


Collection of available solar process heat related national and trans-national research and funding programs

Subtask E “Guideline to Market”
Deliverable Report D.E1

IEA SHC TASK 64 | IEA SolarPACES Task 4 | Solar Process Heat

Technology Collaboration Programme

Contents

Addressing the financing sector – Webinar Oct 5, 2023 “Financing Solutions for SHIP projects”

110°	Meriaura Energy Oy
Aalborg CSP A/S	MG Sustainable Engineering
Absolicon AB	Moss Infrastructure
ABSOLICON SOLAR COLLECTOR AB	NACEN Enegy Consulting
Adani Group	Neofaktur eG
ADM WILD Europe Gmbh & Co. KG	Phoenix Solar Thermal
AEE INTEC	Promigas
Aigner Energie Contracting GmbH	Protarget AG
ASIA ENERGY ADVANCED SDN BHD	realitylab gmbh
casolar	REENAG Holding GmbH
CDER	Research Student
CITRUS	Sandvik Mining and Construction Gmbh
Climate Plus Sdn Bhd	sbp sonne gmbh
Climeworks	Solar Heat Europe/ESTIF
DCSP	Solar-Institut Jülich
Elevator Ventures	Solas Capital
ergSol, Inc.	SOLATOM CSP SL
FH JOANNEUM	Solho
Fichtner GmbH	Solitermgroup GmbH
Flemming Jorgensen SA de CV	solrico
Fraunhofer ISE	SONATRACH
GASOKOL GmbH	Styrcon GmbH
GIZ - Hydrogen Diplomacy Office Riyadh	Sunrise CSP India Pvt Ltd
GREENoneTEC Solarindustrie	Tigi Ltd.
GRUPO NOVEM	Uni Kassel
Igsr	Universidad de Cuenca
ILF	Universidad Politécnica de Madrid
JLL	WACKER Chemie AG
Lallemand GmbH	WCO

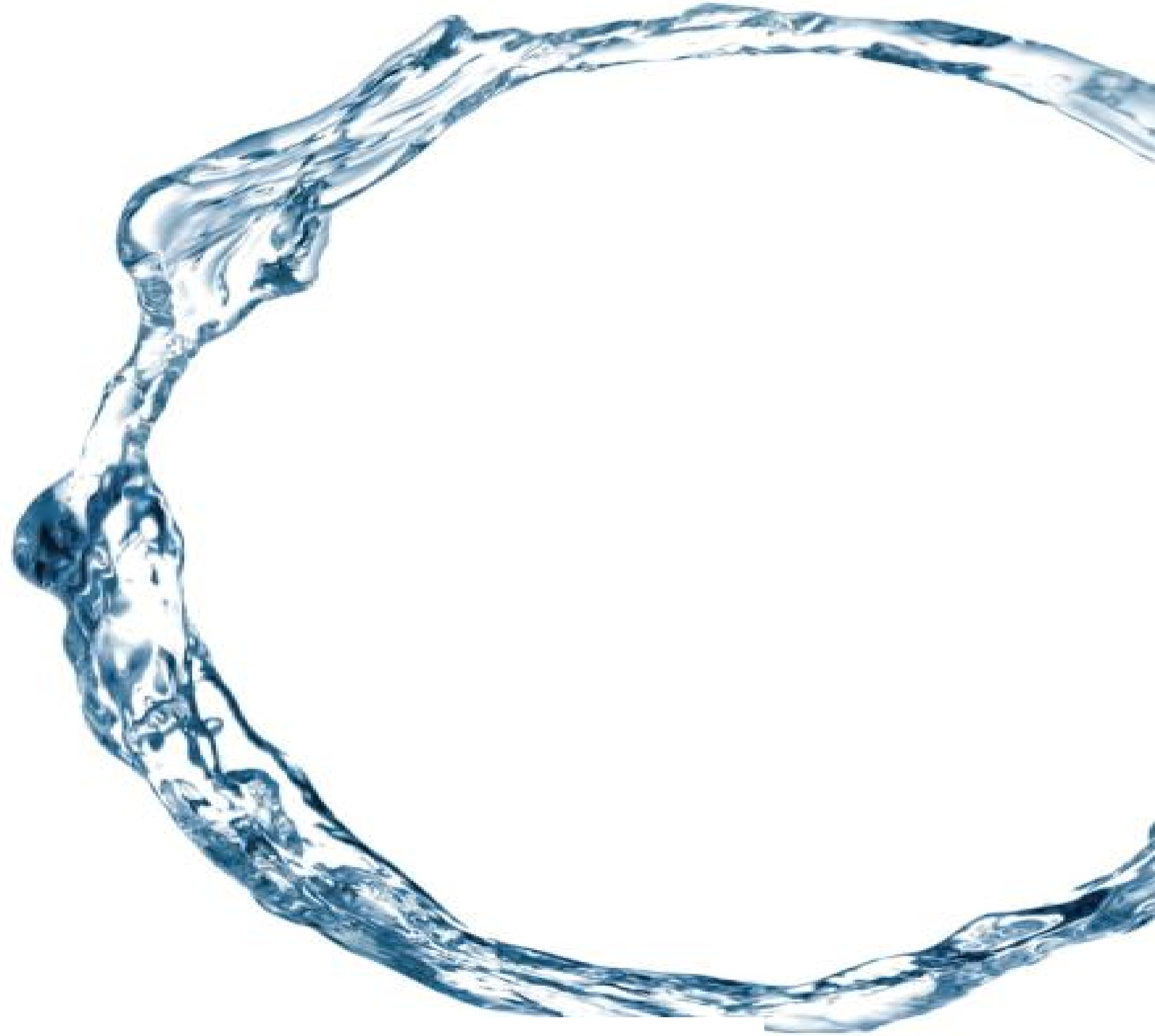
- Adressed mainly to the financial sector
- Invitation distributed through
  - Task Experts,
  - Industry Associations,
  - personal contacts to the financial sector
- Organised via Platforms of AEE INTEC
  - Presentations: https://www.aee-intec.at/webinar-financing-solutions-for-solar-heat-in-industrial-processes-ship-projects-downloads-339
  - Recordings: https://youtu.be/aFI3AOdKX98?si=mPBh-CAahi3ozumd
- 63 registrations / 32 participants / 79 watched recordings on YouTube

Agenda - Financing Solutions for Solar Heat in Industrial Processes (SHIP) Projects

- Welcome, Introduction and Moderation
  Peter Nitz, Fraunhofer ISE, Germany, www.ise.fraunhofer.de
- ***SHIP - technologies and best practice examples***
  Christoph Brunner, CEO of AEE INTEC – Research Institution on Sustainable Technologies, Austria, www.aee-intec.at
- ***Financing models for SHIP projects***
  Winfried Braumann, Founder and CEO of REENAG – Project development and financing of renewable energy and energy efficiency, Austria, www.reenag.com
- ***Experiences on financing small-scale decarbonisation projects on cash-flow basis***
  Slawomir Huss, Partner of Solas Capital – Investment in energy efficiency & self-consumption PV, Switzerland, www.solas.capital
- ***Q&A and open discussion***

Download Presentations
https://www.aee-intec.at/webinar-financing-solutions-for-solar-heat-in-industrial-processes-ship-projects-downloads-339

Webinar - Financing Solutions for Solar Heat in Industrial Processes (SHIP) Projects IEA Task 64



reenag

Eine Investmentholding für Erneuerbare Energie

Financing models for SHIP projects – summary

Winfried Braumann

Financing by asset owners

- Investments in production facilities including process heat supply have traditionally been carried out and financed by **production companies themselves**
- Financing **requires equity** by asset owner and debt financing (investment loans) from banks. **Leasing financing is also possible**.
  All proven investment financing instruments are available for companies' own investments in renewable energy.
- Sellers can facilitate financing by offering **trade credit** (e.g. export credit)

Financing by third parties

- For large projects, a **separate project company** can be founded, which realizes the project with equity and project loans.
- For smaller projects the instrument of **forfaiting** (long-term sale of receivables) can be used to refinance the debt capital it has raised.
- Also a **joint venture** of companies (e.g. within the framework of an energy community) can take on the role of third-party investor.

Financing small-scale decarbonisation projects on cash flow basis – Solas Sustainable Energy Fund (SSEF)

Tailormade SSEF financing offering
Through sale of receivables structures no direct contractual relationship between end customer and SSEF required. **ESCO is the only face to the customer which fosters sales**.
Facility based financing offering. Pre-approval of end customers based on credit scoring of external credit data providers such as Bisnode/Dun & Bradstreet or Bureau van Dijk, which ESCO has access to. In consequence **bankability of end customers is checked in the beginning of the sales process.**
Based on pre-agreed terms SSEF offers **financing within the EU**.
SSEF financing structures are **flexible and built around the ESCO`s needs**. Depending on the specific contractual profile, asset collateral is not a pre-condition.
SSEF offers financing tenors **matching the lifetime** - up to 10 years financing tenor incl. SMEs and for selected projects, e.g. PV or public projects 15+ years.

Slawomir Huss – Solas Capital
www.solas.capital

Financing solutions for SHIP projects – Webinar Oct 5, 2023

Financial sector

SHIP Community

What do you (financial sector) need from the SHIP community?

transparency
structured projects
Turnkey solutions
uniformity
projects
performance guarantee

What do you (the SHIP community) need from the financial sector?

business cases
scale solutions
Streamlined procedures
trust in technology
financing options

Outlook: Task 64/IV Subtask E Deliverable Report D.E2/E3 on SHIP Value proposition, Cost, Business models, Financing

- In preparation,
- Due end of 2023

- To be published on Task Website
  https://task64.iea-shc.org/

  ~ Jan/Feb 2024

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY | SolarPACES Solar Power & Chemical Energy Systems

E2 Update on technology costs, statistics and cost reduction trends, including suitable energy cost evolution perspectives and promoting the use of LCOH as benchmark for the comparison of innovative heating/cooling production /

E3 New trends on financing schemes and business models to SHIP and collection of available SHIP financing possibilities

Subtask E "Guideline to Market"

Deliverable Reports D.E2 and D.E3

IEA SHC TASK 64 | IEA SolarPACES Task IV | Solar Process Heat

Technology Collaboration Programme by iea

SHC SOLAR HEATING & COOLING PROGRAMME INTERNATIONAL ENERGY AGENCY | SolarPACES Solar Power & Chemical Energy Systems

Update on technology costs, statistics and cost reduction trends, including suitable energy cost evolution perspectives and promoting the use of LCOH as benchmark for the comparison of innovative heating/cooling production systems /

New trends on financing schemes and business models to SHIP and collection of available SHIP financing possibilities

This is a report from SHC Task 64 / SolarPACES Task IV: Solar Process Heat and work performed in Subtask E: Guideline to Market

Author/s: Wolfgang Gruber-Glatzl, Peter Nitz
Date December xx, 2023
Report number: Task 64/IV, Deliverable Reports D.E2 and D.E3

The contents of this report do not necessarily reflect the viewpoints or policies of the International Energy Agency (IEA) or its member countries, the IEA Solar Heating and Cooling Technology Collaboration Programme (SHC TCP) members or the participating researchers.

Technology Collaboration Programme by iea

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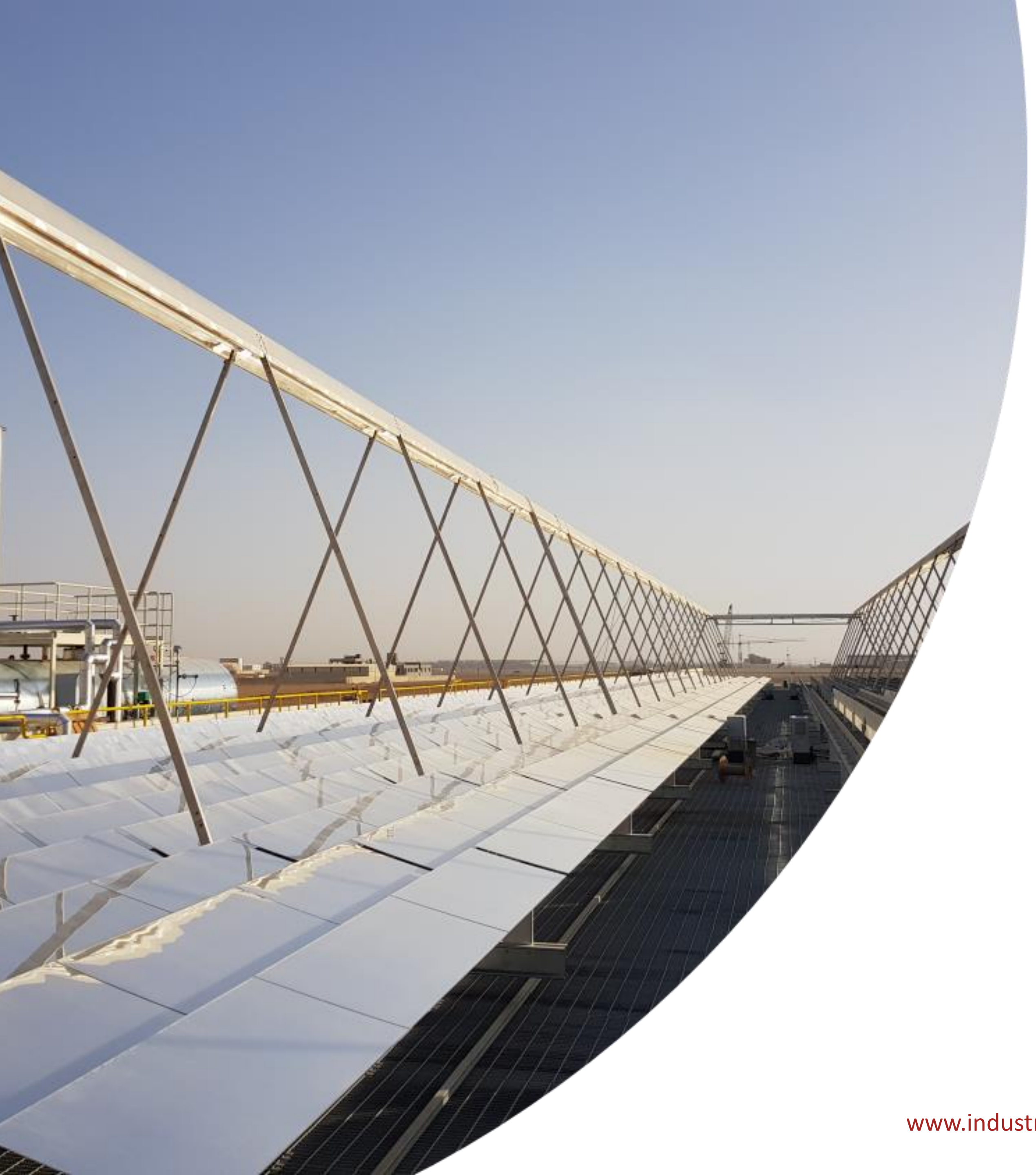


INDUSTRIAL SOLAR
renewables onsite

SHIP

Business Models & Financing Schemes

Irapua Ribeiro

Industrial Solar GmbH

10th November 2023

Agenda

- Introduction
- Business Models
- Funding Programmes & Incentives
- Final Remarks

Introduction

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 792276.
Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

SHIP Market Prospects

Summary

Several successful stories of implemented projects around the world

Diverse funds resources available for SHIP projects

Decreasing SHIP costs throughout time

High fossil fuels prices & climate commitments boost solar thermal market

Possible alternative for several segments of the industrial sector

Trending technologies for the last 15 years

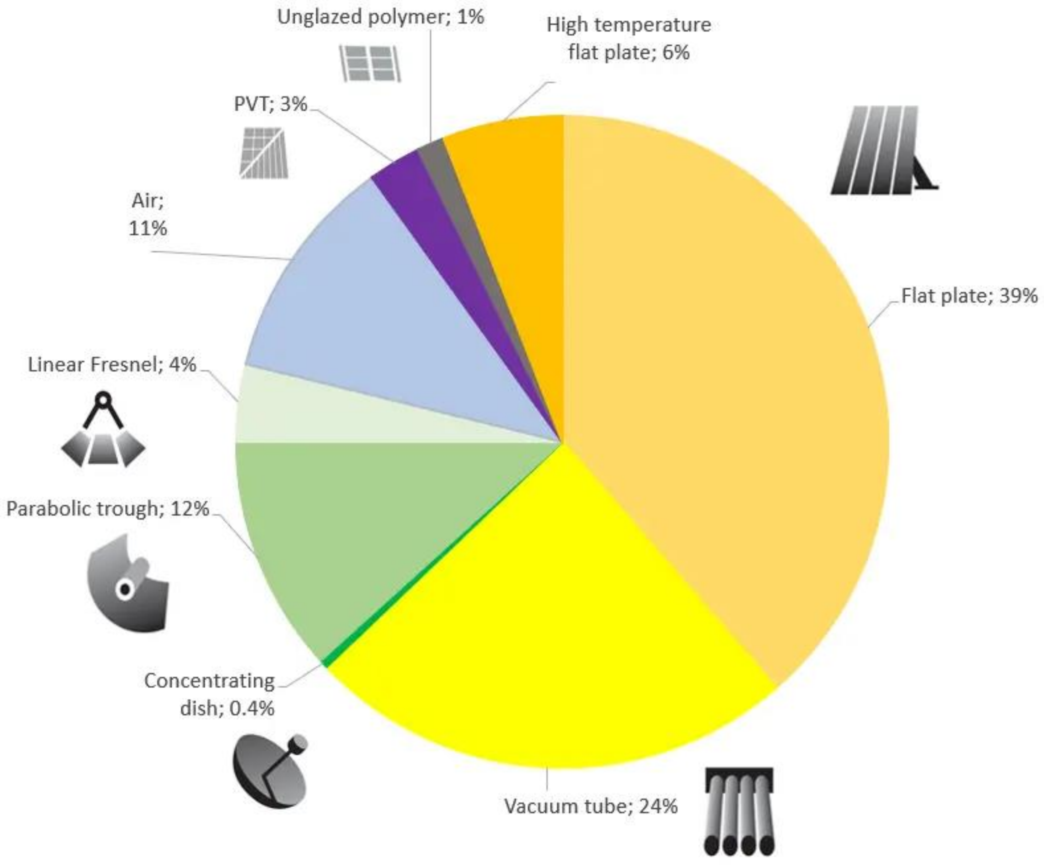
SHIP Market Prospects

A dynamic market

High level of dynamism on the SHIP world market in 2022

	2017	2018	2019	2020	2021	2022	Total until 2022
No. of SHIP systems	107	99	86	85	71	114	at least 1,089

Source: SolarThermalWorld



Stats of 2022 by technology type

SHIP Project Value Chain

Stakeholders

Industrial Companies

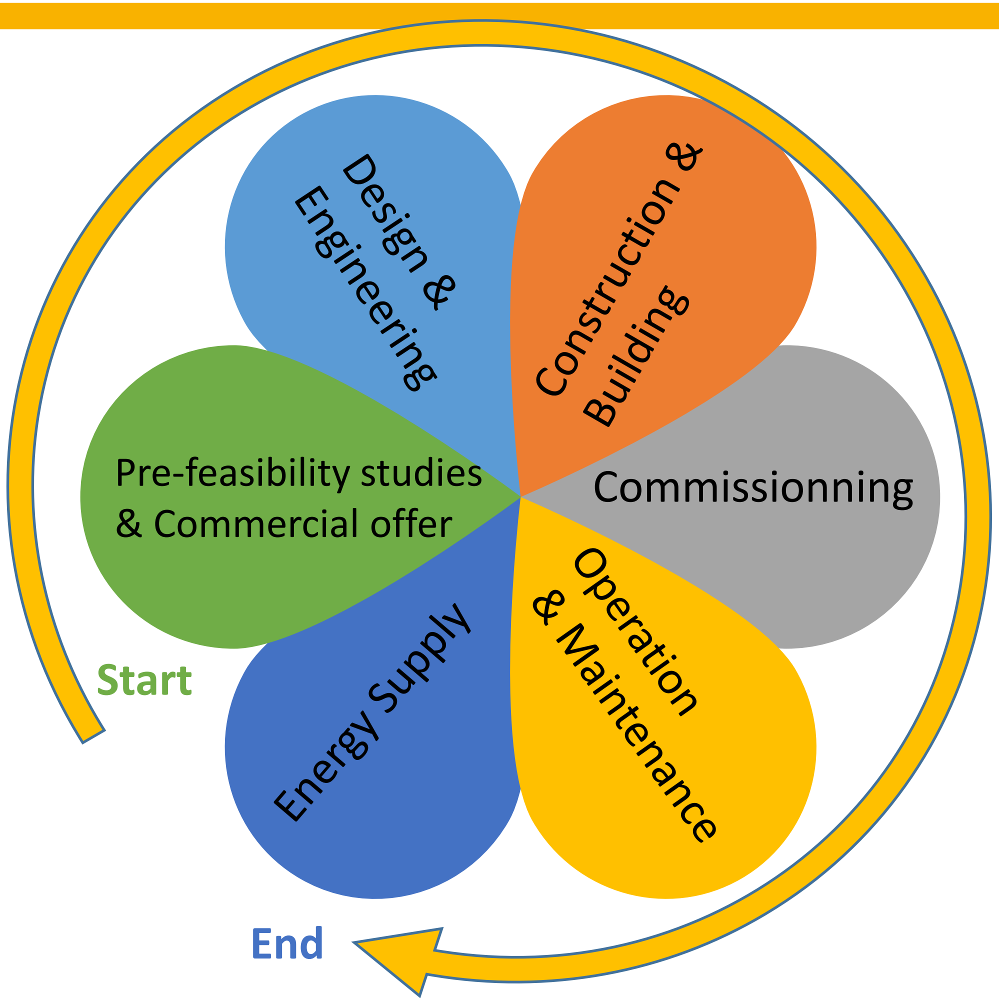
Industrial companies whose heat demand fits the range of application of solar thermal (i.e. the agro-food industry). They are the potential clients in the value-chain

Energy/Heat Suppliers

Companies that are supplying heat to their customers. They can also assume the role of facility operator

Government, Policy Makers, European organizations and national institutions

Policy makers in charge of changing regulation related to renewable heat sources. They shape the environment within the different players evolved. They provide guidance for the development of less traditional systems



Energy Consulting Companies

Companies that help their customers make informed choices about their energy consumption/provisions. They can also assist them in the building phase

Solar Thermal Equipment Manufacturers or suppliers

Companies that manufacture the different types of solar thermal equipment

Third party investors

investment companies that specialises in the third-party financing of renewable heat production projects and energy efficiency projects.

EPC Contractors and O&M

Third party in charge to physically build the installation once materials and detailed design are provided. This role could be assumed by the equipments manufacturers or supplier

Solar Heat for Industrial Process towards Food and Agro Industries commitment in Renewables

SHIP Project Launch

Sales engagement process flow

Phase 0

"Discovery Estimate"

- Quick assessment of the solar heat potential
- FREE

Phase 1

"Feasibility Study"

- Site-unseen engineering study
- FREE or on a fee basis (depending on the case)

Phase 2

"Engineering Study"

- Full-spec engineering study + bill of components
- On a fee basis

Phase 3

Turnkey Contract/ Heat Purchase Agreement

- Signed contract / agreement

Business Models

SHIP2FAIR Business Model

Business Model Options

Build & Handover Model

- The industrial customer invests & operates the solar thermal system
- Optional operation & maintenance contract

Build & Operate Model

- SHIP project developer pays the investment cost, owns & operates the solar thermal system
- The industrial partner buys solar heat

Hybrid Model

- Like the Build & Operate model with one difference:
- After 10 or 15 years of operation the ownership of the solar thermal system is transferred to the industrial customer

SHIP2FAIR

SHIP2FAIR Business Model

Business Model – Build & Handover

Industrial Customer willingness to decarbonize using solar thermal to cover its heat demand

Industrial Customer pays for the installation, investment and risks are allocated on the Industrial Customer

Potential incentives or subsidies from local authorities or EU institutions

Contract between both parties

Development of the project with the turnkey supplier & SHIP developer handling the different stages

SELL

BUY

Handover of the facility to the Industrial Customer (owner)

SELL

BUY

Industrial Customer uses the SHIP plant to supply its heat demand, and operates and maintain the plant

Solar Thermal turnkey supplier & SHIP projects developer

Energy Consulting Companies
Solar Thermal Equipment Manufacturers, etc.

Solar Heat for Industrial Process towards Food and Agro Industries commitment in Renewables

SHIP2FAIR Business Model

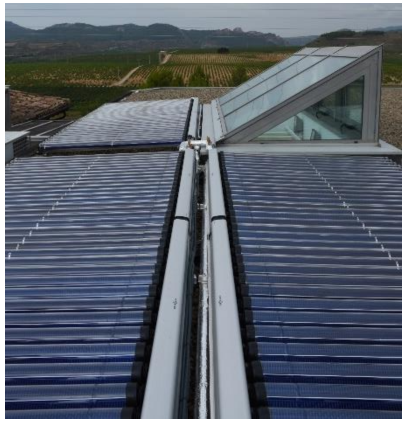
Build & Handover: SHIP2FAIR Demo-sites

Business model:

- Build
- Demonstrate (fine-tune)
- Transfer the ownership (*not applied in RODA case)
- O&M support agreement

BODEGAS RODA RIOJA ALTA

RODA, La Rioja, ES



M&R, Turin, IT

Jean Larnaudie, Castelnaudary, FR

Solar Heat for Industrial Process towards Food and Agro Industries commitment in Renewables

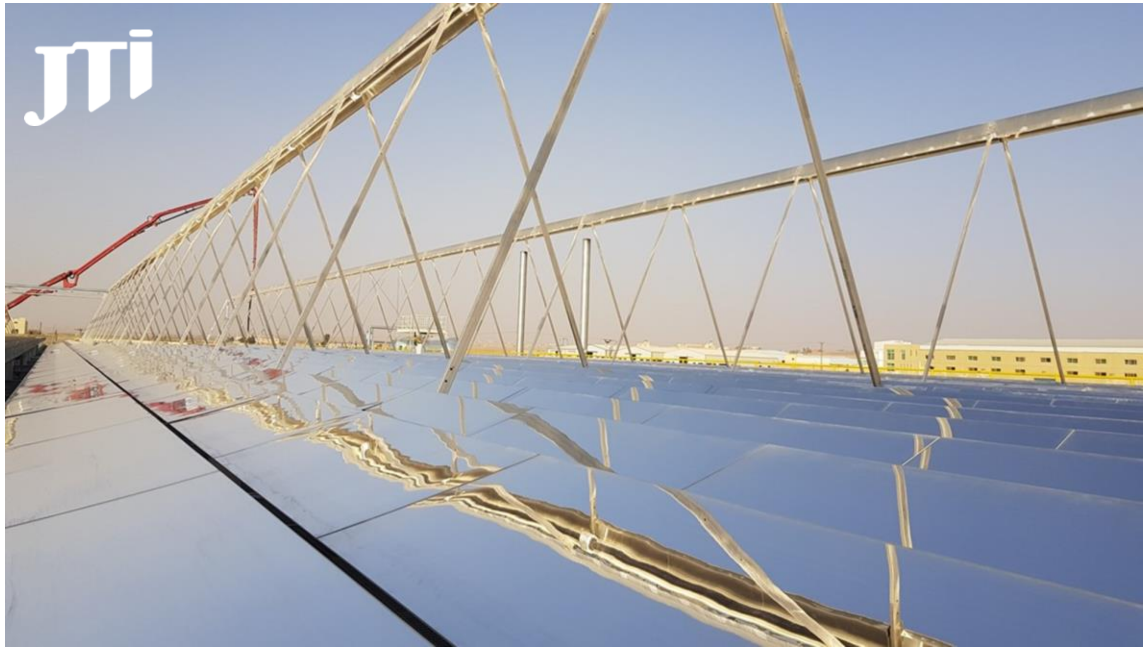
SHIP2FAIR Business Model

Build & Handover: other examples

Business model:

- Build
- Transfer of ownership
- O&M support agreement in place since 2017

JTI Jordan, Amman



SHIP2FAIR Business Model

Business Model – Build & Operate

Solar Thermal turnkey supplier & SHIP projects developer

Agreement between both parties

ESCO sells projects to use solar thermal to cover the Industrial Customer´s heat demand

Agreement between both parties

Industrial Customer willingness to decarbonize using solar thermal to cover its heat demand

Technical inputs regarding the process constraints

Project development by ESCO and its subcontractors

ESCO pays for the installation investment and risks are allocated on the ESCO

ESCO owns the plant, operates and maintains it

Industrial Customer using solar heat energy from the facility for its processes

ESCO sells the heat to the Industrial Customer to recover from expenses

Also known as: HPA - Heat Purchase Agreements

SHIP2FAIR Business Model

Build & Operate: Example of Solar District Heating

Dorkwerd project, Groningen, NL

Project developer:	Novar (Solarfields), NL
Connected consumers:	10’000 citizens
Annual solar share:	25% of heating needs
Solar field:	Tech provider: TVP Solar Capacity: 37MW Heat delivery: 25GWh/y Size: 48’000 m2

Business model

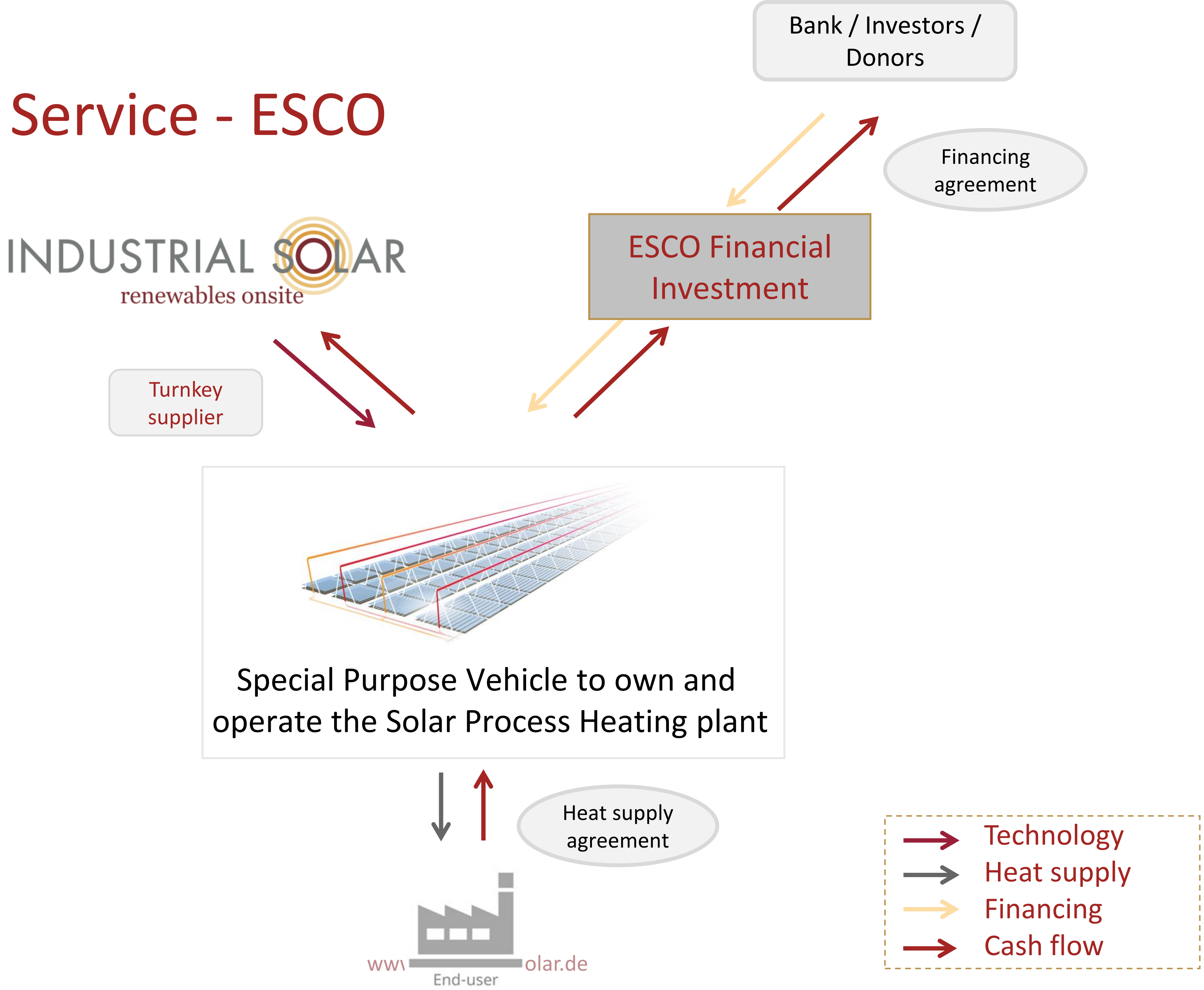
A Special Purpose Vehicle (SPV) was founded by the:

- ⇨ Project developer (Novar)
- ⇨ Investor (K3)
- ⇨ Technology provider (TVP Solar)

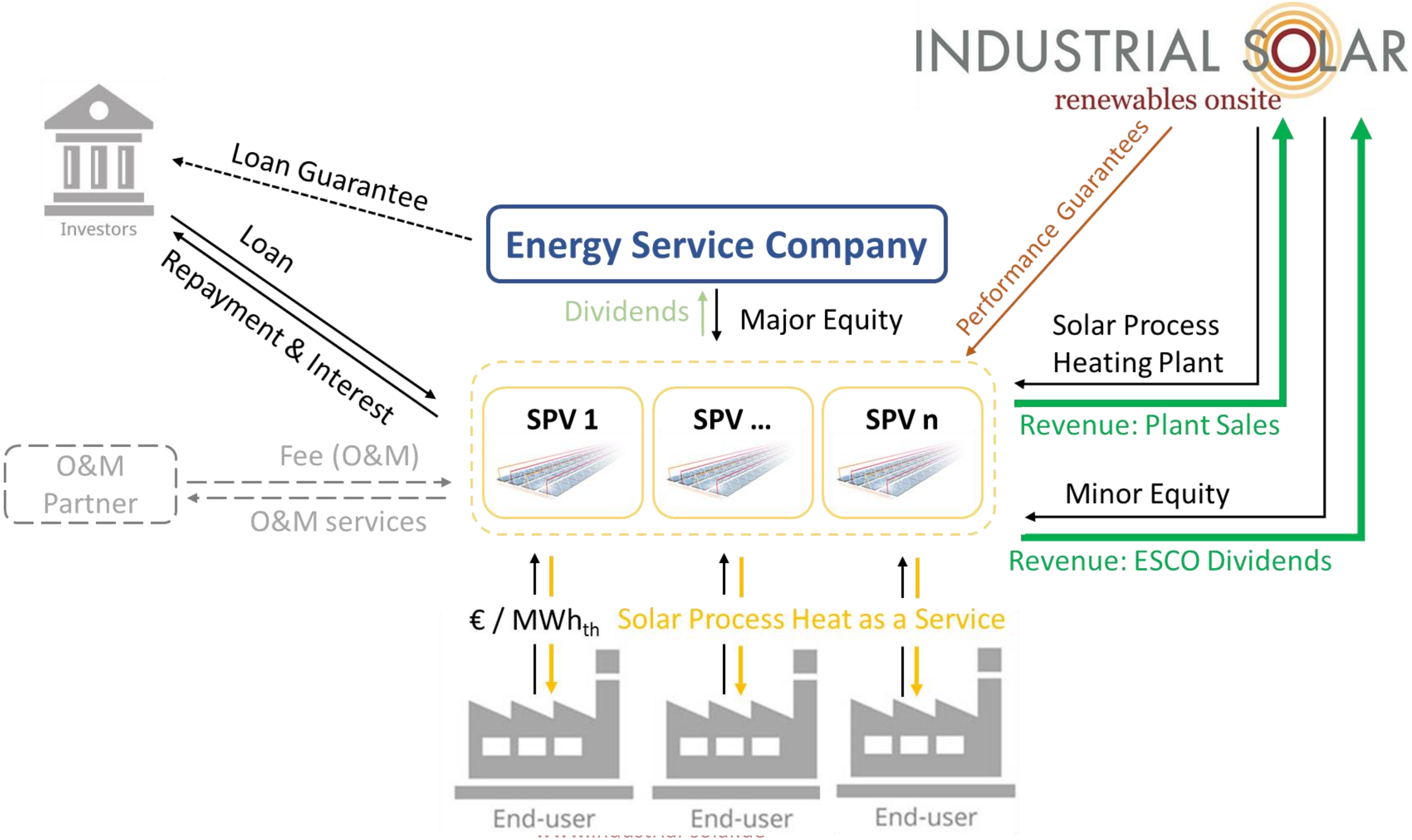
The SPV owns & operates the SDH system

A 30-year Heat Purchase Agreement (HPA) has been signed with local DHN operator (utility Warmtestad)

Energy as a Service - ESCO

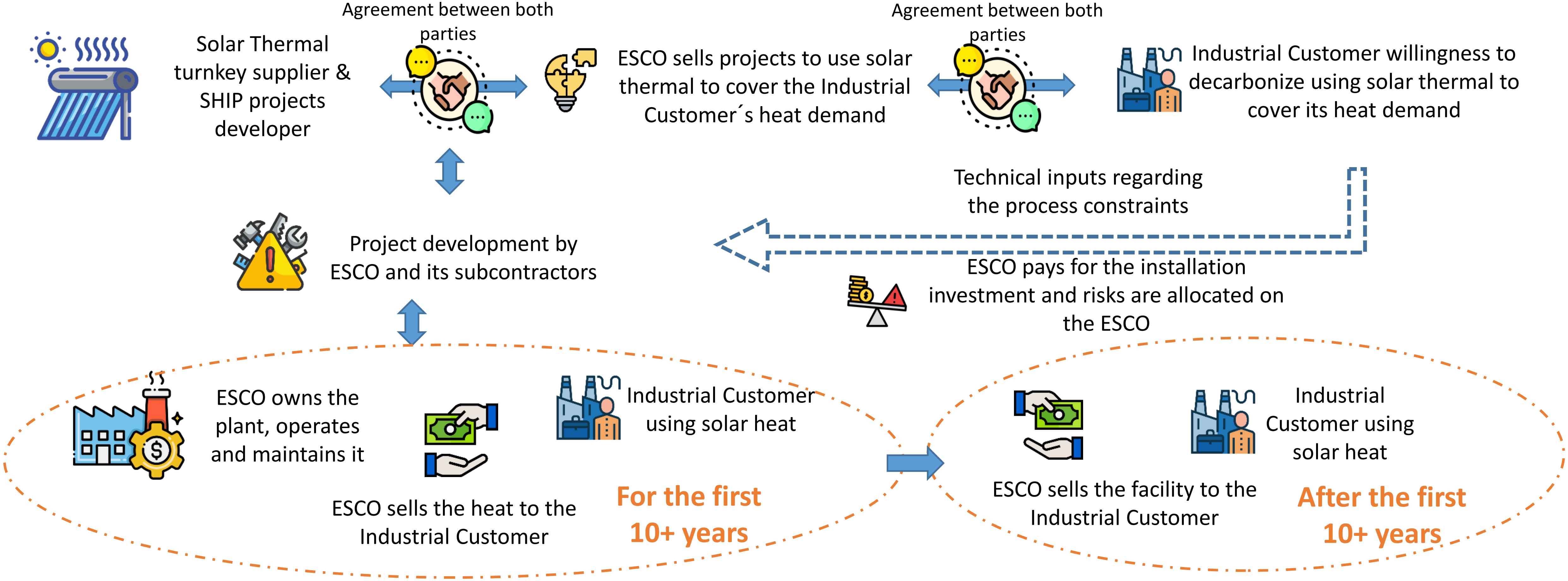


Energy as a Service - ESCO



SHIP2FAIR Business Model

Business Model – Hybrid



Solar Heat for Industrial Process towards Food and Agro Industries commitment in Renewables

Funding Programmes & Incentives

Incentives for Solar Thermal

Overview of funding schemes in Europe

European Funding Programmes

- Innovation Fund
- LIFE

Type of funding: grants as a % on the project eligible cost

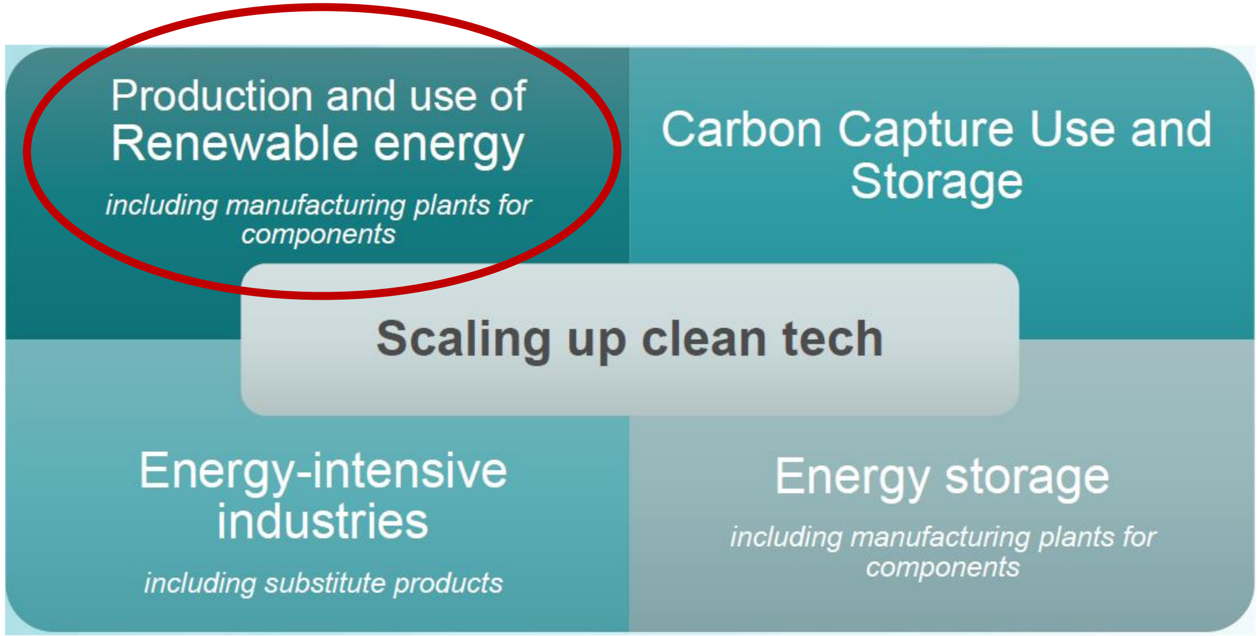
National/ Regional Funding Programmes / Subsidies

- Using national financial resources
- Using a mix of national & European financial resources

Type of funding: grants or subsidies on the capital expenditure, tax exemptions, loans under advantageous conditions, feed in tariffs, etc.

Incentives for Solar Thermal

The Innovation Fund

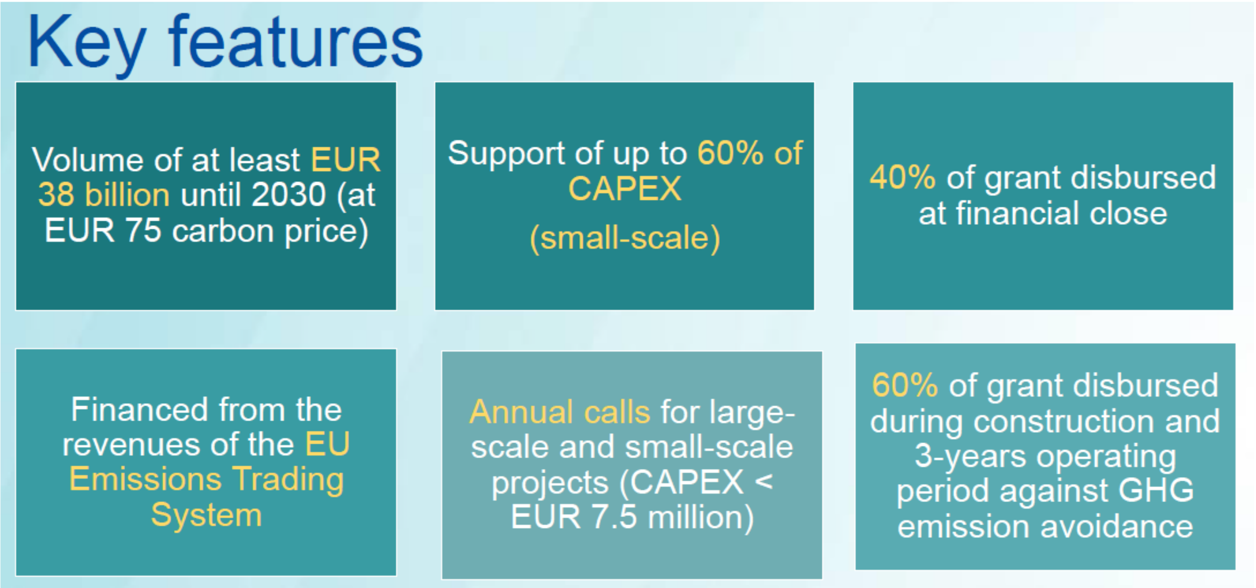


The IF supports:

- ❑ Highly innovative technologies
- ❑ Sufficiently mature
- ❑ With strong potential to reduce GHG emissions

Funding available for:

- ❑ Small-scale projects: projects with a capital expenditure between €2.5 and 7.5 million
- ❑ Large-scale projects: > €7.5 million



Details here

Incentives for Solar Thermal

National funding institutions – EU examples

Austria: BMK (Bundesministerium für Klimaschutz, Umwelt, Energie, Mobilität, Innovation und Technologie

France: ADEME

Germany: BAFA (Federal Office for Economic Affairs and Export Control)

Italy: MISE (Ministero Sviluppo Economico)

Spain: IDEA (Institute for Diversification and Energy saving)

Further fundings for commercial and R&D projects

IEA Task 64: Collection of available solar process heat related national and trans-national research and funding programs

Final Remarks

Business models in SHIP – Main challenges

- Planning is more complex (e.g. compared to photovoltaics)
- Data availability for good planning is often limited
- Excess production can not be sold & storage is limited & costly
- Fuel prices cause fluctuating cashflows

Business models in SHIP – Economic advantages

- Addresses process heat (most relevant energy form)
- Highest conversion efficiencies (solar energy –> useful energy)
- No requirement for approval from grid operators
- Well-proven technology
- Fuel prices already increased over time & higher prices are expected
- Strong impact on CO_2 emissions

Thank you for your attention.

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Motivation for Energetic Process Optimization

- **Climate Protection**
  - Reduction of CO2-Emission
- **Cost Reduction**
  - Reduction of energy related cost of production
- **Risk Minimization**
  - Reduction of the dependence on fossil energy ressources

Energy Optimization in the Context of Industrial Processes

- How efficient is the relevant process?
- How big is the potential of heat recovery?
- What is the minimum heat demand of the processes?
- How can renewable energies be used in the process in an useful way?
- Where is the economic optimum of heat recovery measures and renewable energies?
- How can such an optimum be achieved?

Energy Optimization in the Context of Industrial Processes

Renewable Energy Technology

Replacement of fossil fuel based energy production by renewables

Energy integration

sector coupling, heat recovery on system level

Optimize Unit Operation

reduce energy consumption of each unit operation and building

Energetic and Economic Optimum

Approach: Energy Integration using the Pinch Method

Systemic method for determining the optimal energy use and system design for thermal processes

- Economically optimal energy recovery approaches
- Energetically and economically sensible integration options for alternative energy technologies such as heat pumps, solar thermal energy, CHP, etc.
- Optimal configuration of thermal storage systems

Result of a Pinch Analysis

- The minimum energy requirement if fully optimized integrated processes were in place
- Information on the maximum possible energy saving potential
- Economically optimized heat recovery and energy supply
- Correct integration of building heating as a waste heat user, heat pumps, solar thermal energy, CHP, etc.
- Catalog of measures with cost/benefit analysis (payback per measure)
- Strategic planning of implementation ("You don't mess anything up")
- Reduction in energy demand typically 10-40%

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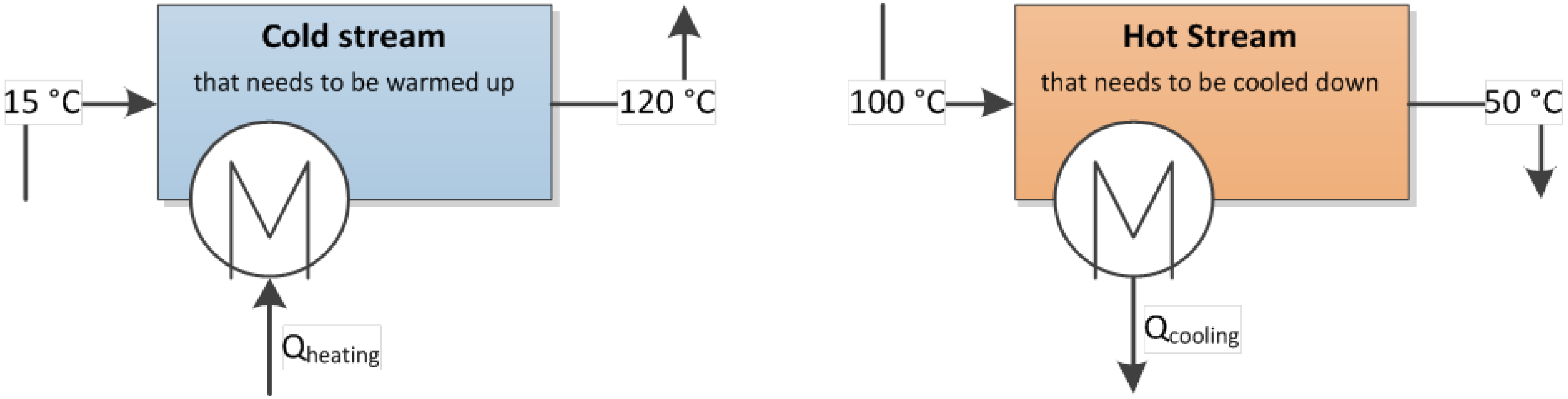
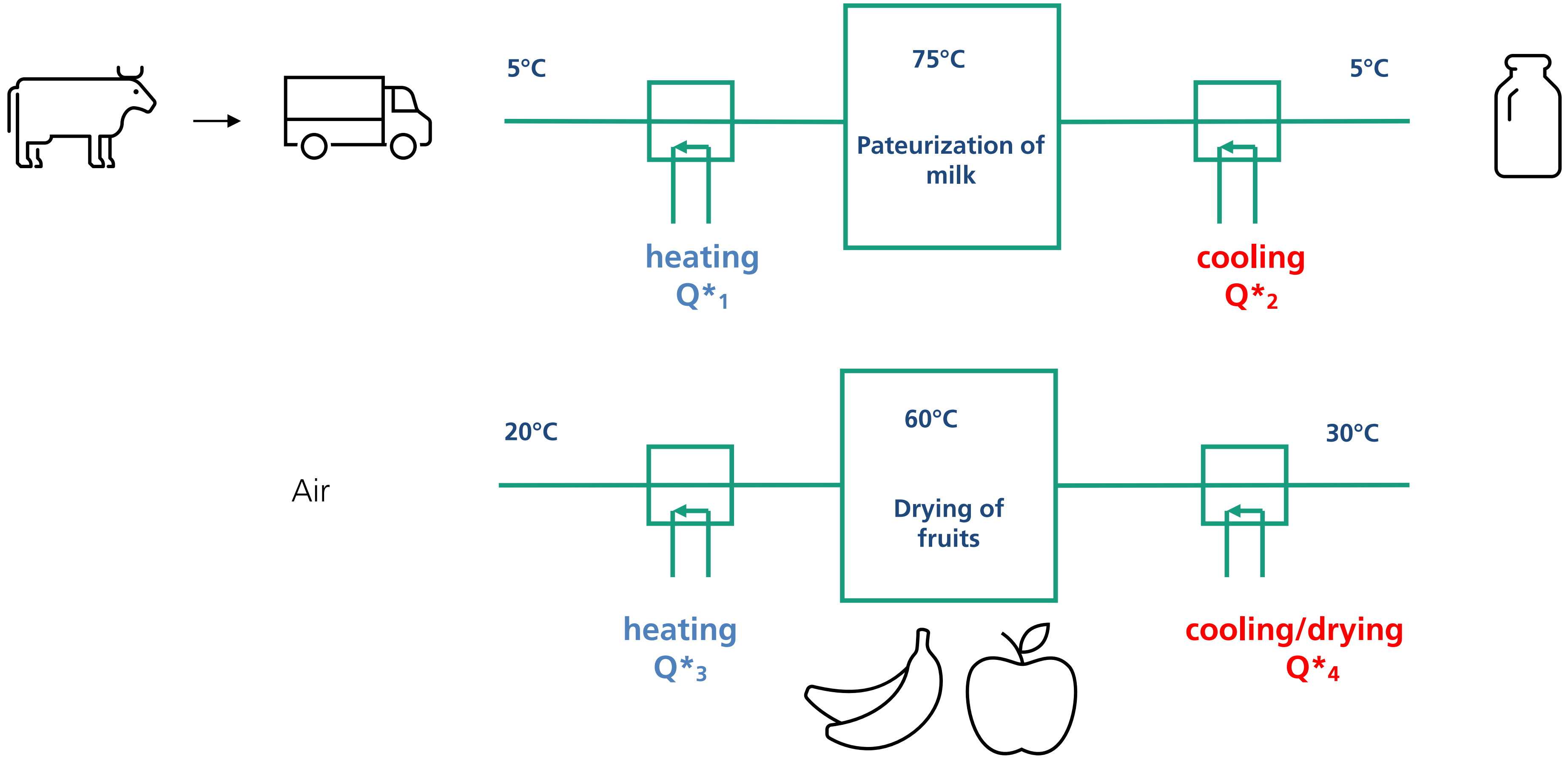
Introduction Pinch Method

- Method for determining the heat recovery potential of (originally) continuous and (now also) discontinuous batch processes
- Requires detailed knowledge of the heating and cooling requirements of all energy-relevant processes
- Each flow is defined by mass flow, specific heat capacity and necessary inlet and outlet temperatures

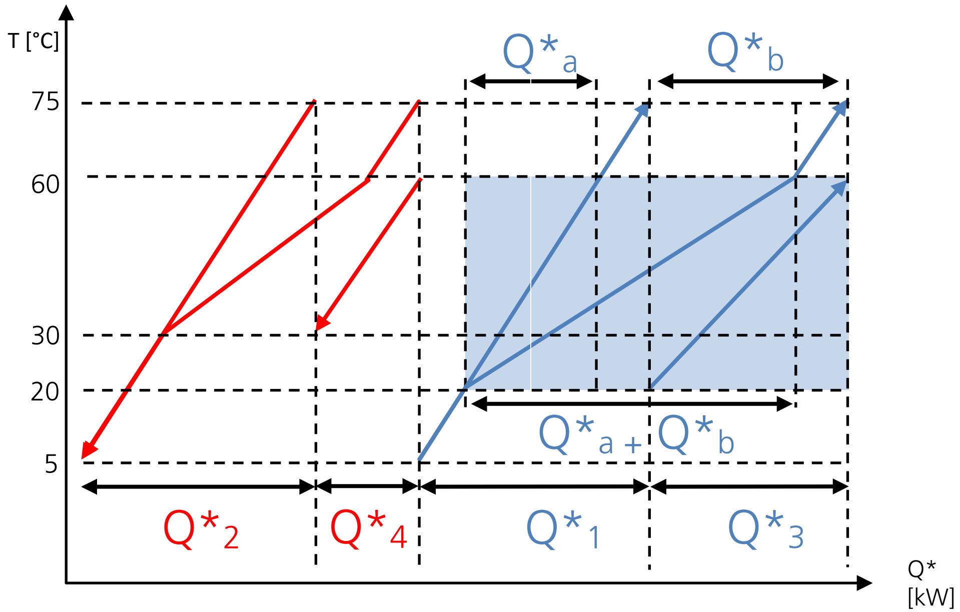


Introduction Pinch Method



Introduction Pinch Method- Example

T_{start} [°C]	T_{end} [°C]	Q* [kW]	Medium
5	75	Q^*_1	milk
75	5	Q^*_2	milk
20	60	Q^*_3	air
60	30	Q^*_4	air

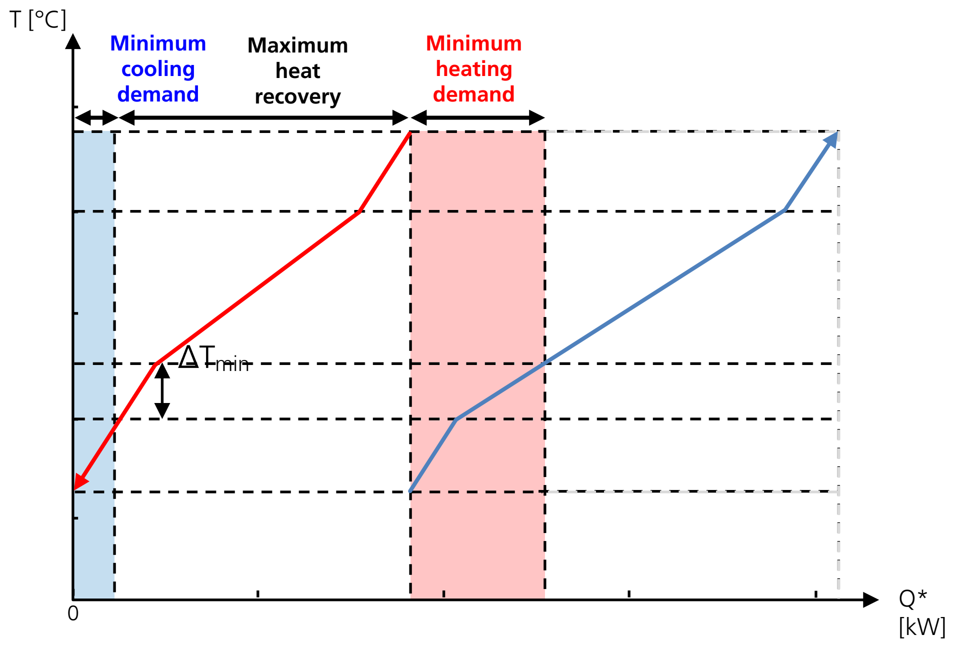


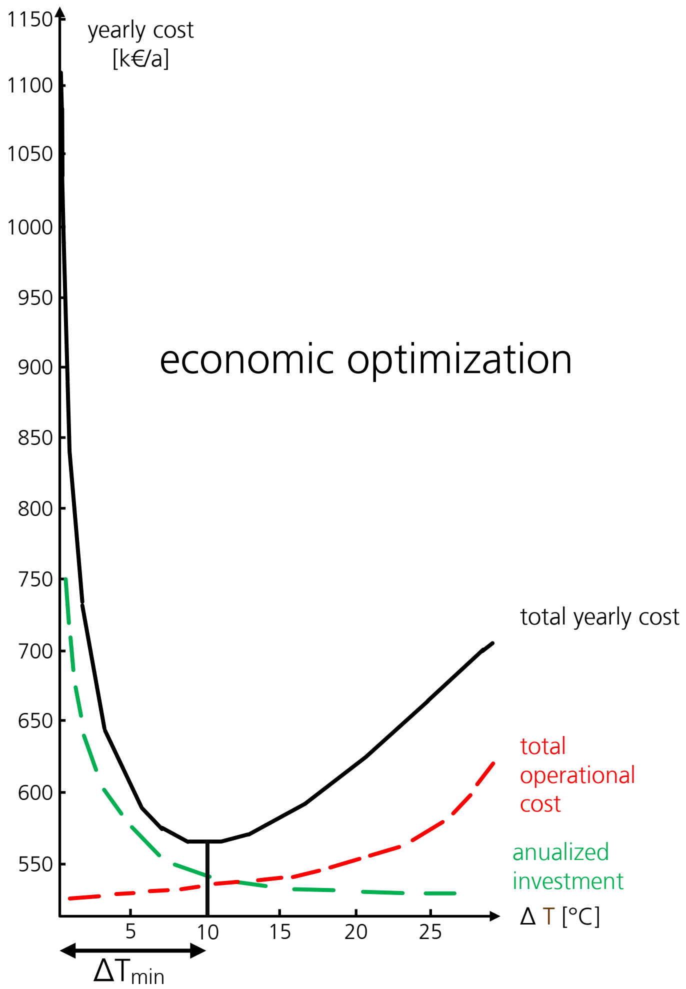
- Consideration of all flows to be heated up (cold streams)
- Consideration of all to be cooled down (hot streams)

Design of the Composite Curve

- Mapping of all heat flows to be heated up and cooled down
- Addition of all heat flows in the same temperature window (superposition)
- Only differences between initial and final state are relevant
- Structure of the composite curves

Introduction Pinch Method - Example





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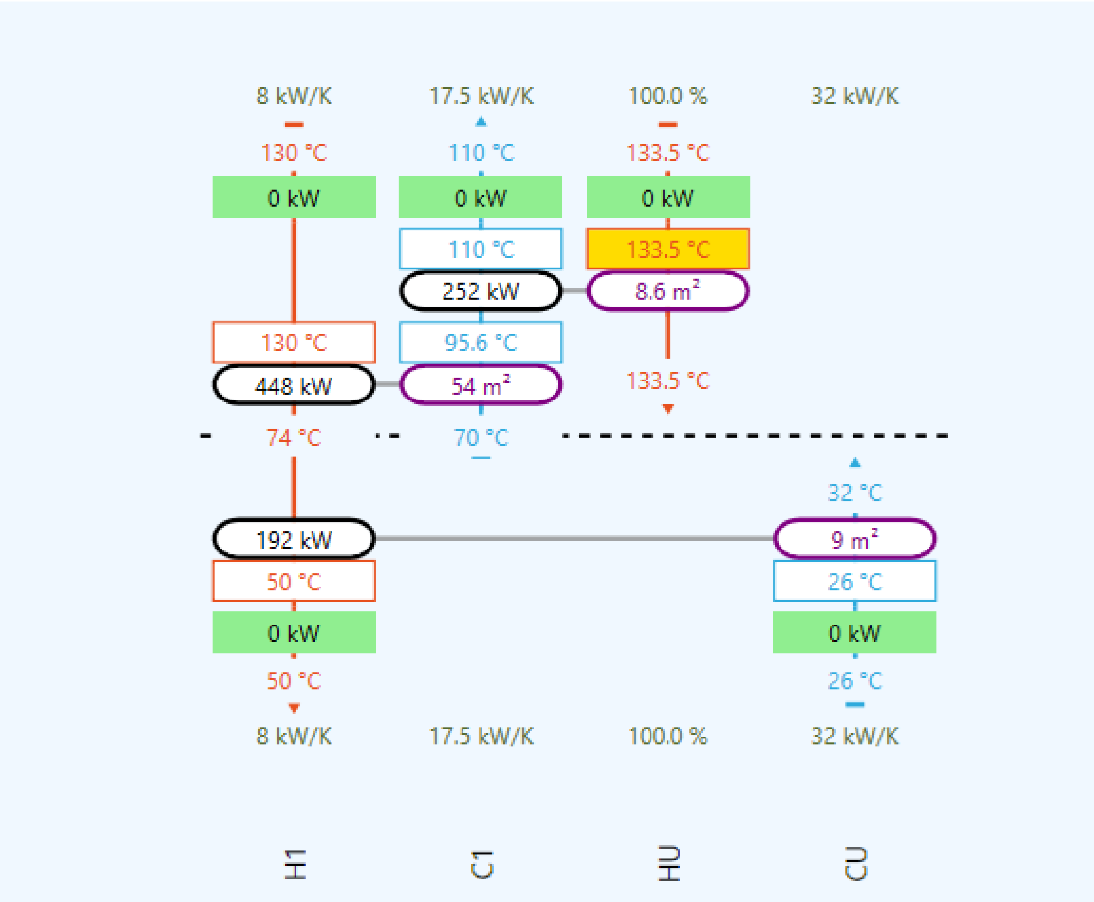
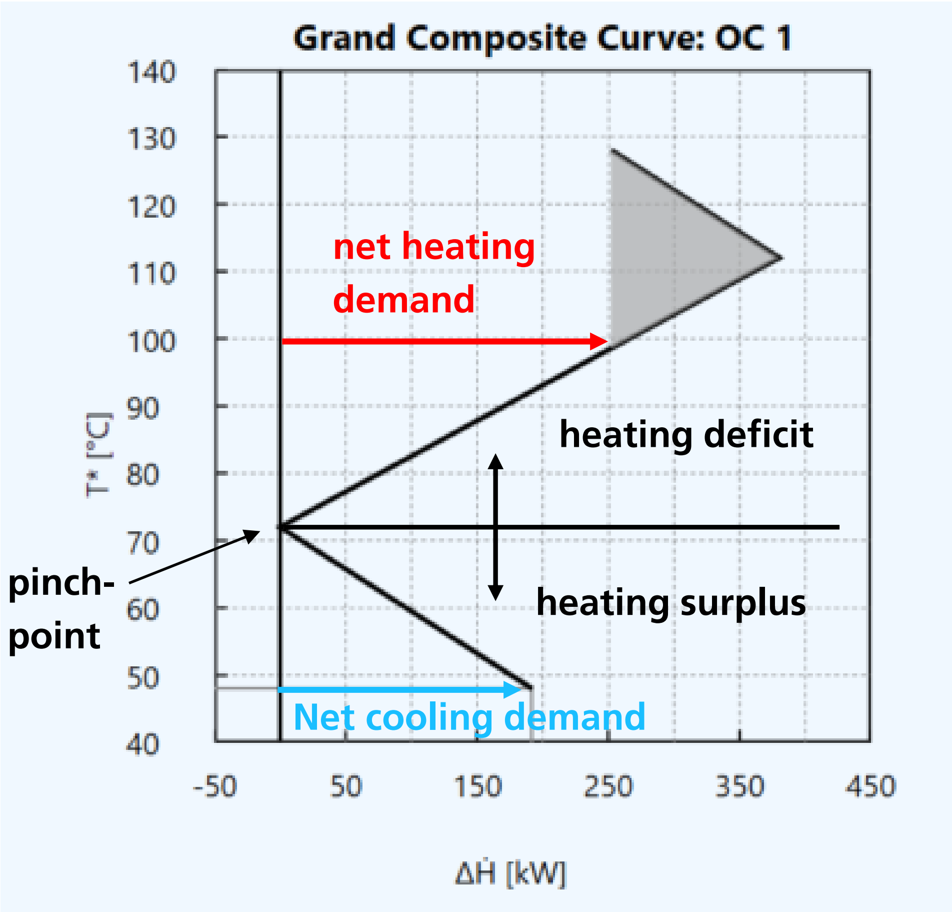
Introduction Pinch Method : Heat Exchanger Network

- A heat exchanger network is designed using the pinch method
- The heat exchanger network shows which flows should ideally be thermally coupled via heat exchangers
- Simplification approaches allow a real heat exchanger network to be generated



Introduction Pinch Method: Grand Composite Curve

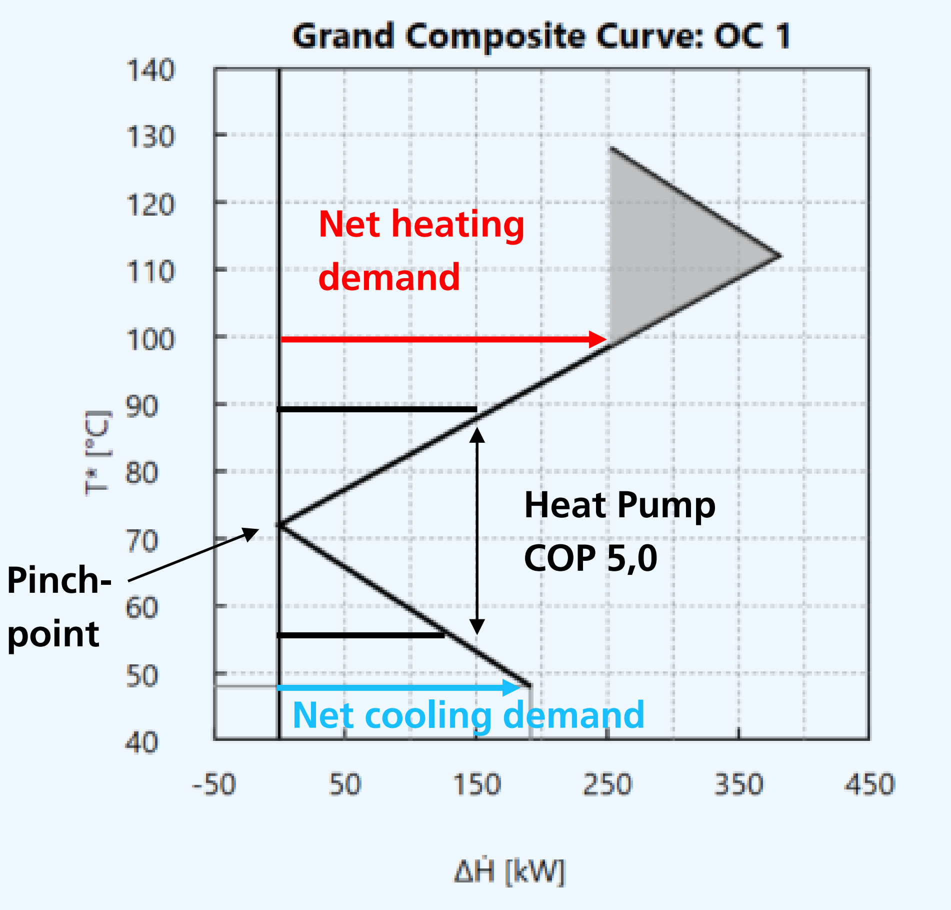
- The "Grand Composite Curve" shows the net heating or cooling demand of the overall system as a function of temperature
- Above the pinch point there is a net heating requirement
- Below the pinch point, there is a net cooling requirement
- Enabling of optimization of the energy supply



Introduction Pinch Method: : Grand Composite Curve – Heat Pump

- **The "Grand Composite Curve" shows the net heating or cooling demand of the overall system as a function of temperature**

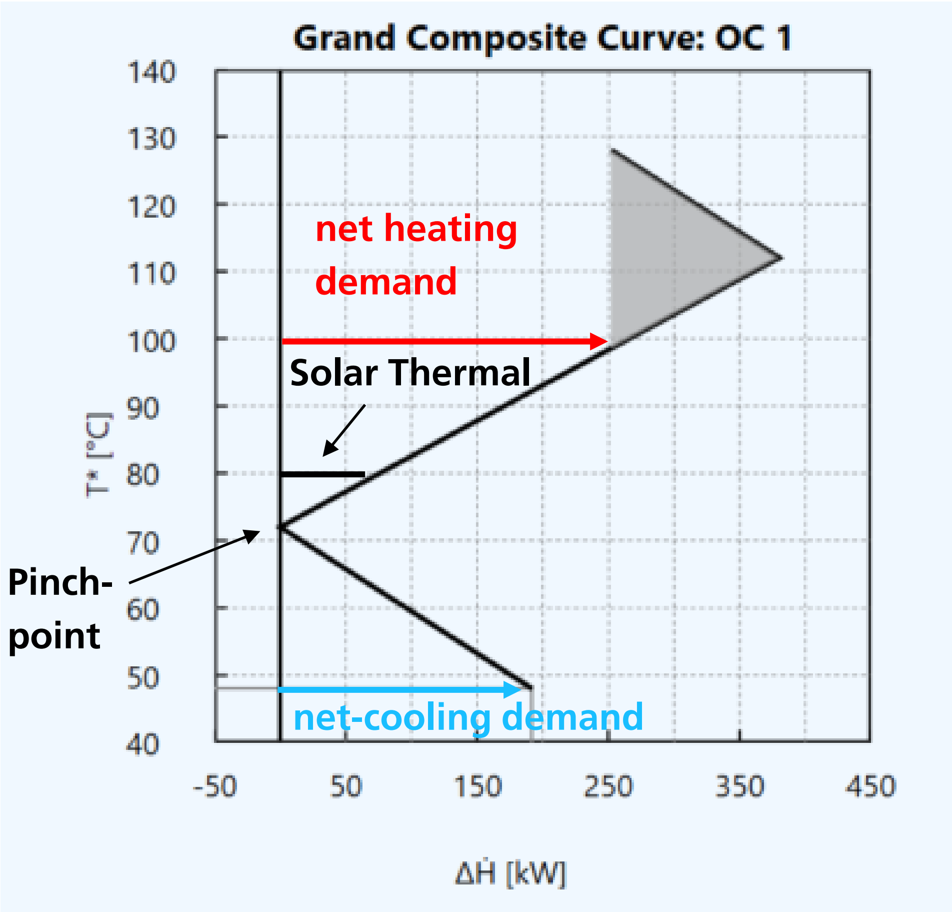
- **Application of a heat pump**
  - Source always below pinch point
  - Sink always above pinch point
  - Source and sink capacity can be read
    - source 54°C, 125kW; sink 90°C, 150 kW
  - Maximum output can be read
    - maximum source output 190 kW at 46 °C,
    - maximum sink output 250 KW at 102 °C



Introduction Pinch Method: Grand Composite Curve – Solar Themal

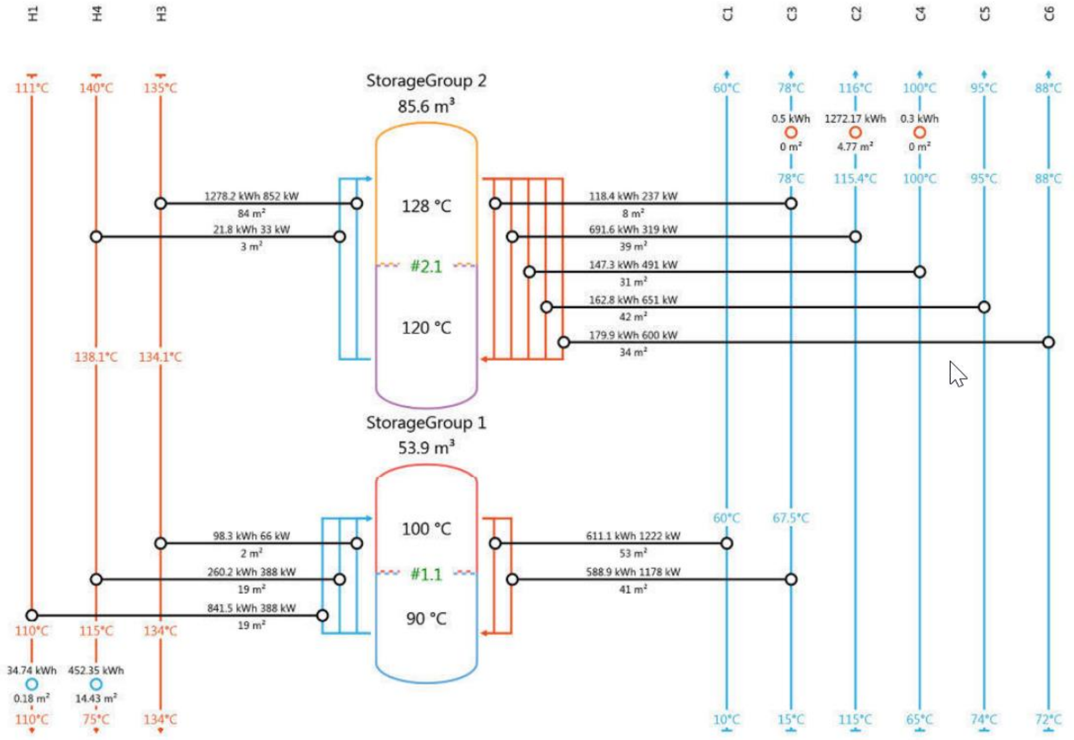
- **The "Grand Composite Curve" shows the net heating or cooling demand of the overall system as a function of temperature**

- **Application Solar Thermal**
  - Additional heat generator always above pinch point
  - e.g. solar thermal 80°C, 70 KW



Introduction Pinch Method: Batch Processes und Thermal Storage

- **The pinch analysis also allows the conceptual design of the integration of batch processes**
- **Determination of heat recovery taking into account simultaneities**
- **Determination of maximum heat recovery using a time-average model**
- **Conceptual design of storage integration**



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Procedure of a Pinch Analysis

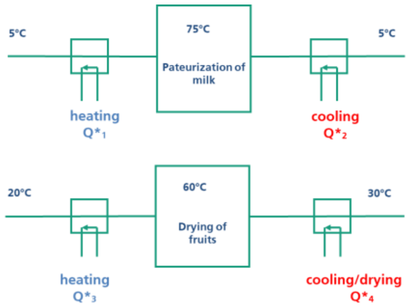
Effort

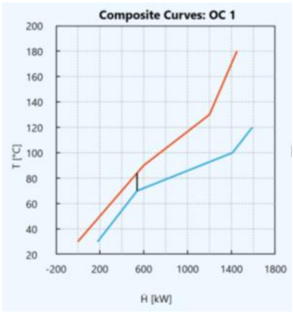
60-80% | 10-20% | 10-20%

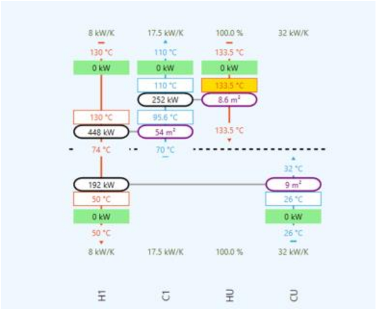
Data collection, process flow diagram with temperatures, mass flows, time sequences

Pinch Analysis

Feasibility analysis, plausibility check, simplification







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Conclusion Pinch Analysis

The pinch analysis allows

- Systematic exploitation of economically optimized heat recovery potential
- Integration of heat pumps, solar thermal energy and thermal storage into industrial processes in a meaningful way
- Development of sustainable concepts for energetic process integration

Now your questions

contact

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