Workshop “SunPeek Open-Source Software for Monitoring of Large-Scale Solar Thermal Plants”

Daniel Tschopp (AEE INTEC) & SunPeek Team

Welcome!

Online Workshop

SunPeek Open-Source Software for Monitoring of Large-Scale Solar Thermal Plants

28 February 2024, 2 – 4 pm (UTC+1)

Co-funded by the European Union
Grant Agreement #101083940
EDIH
European Digital Innovation Hubs Network
APPLIED CPS

ORGANIZED BY

IN COLLABORATION WITH
SUNPEEK DEVELOPMENT TEAM

FUNDED BY
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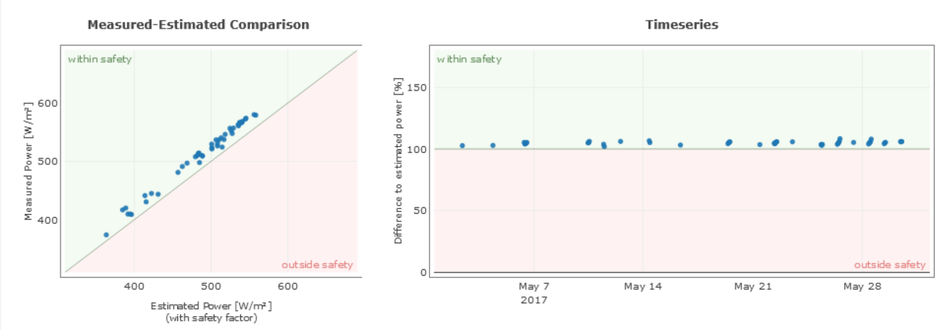
Agenda



1 Demonstration of SunPeek open-source software

AEE INTEC – Marnoch Hamilton-Jones & Philip Ohnewein

2 ISO 24194 & SunPeek Software

AEE INTEC – Philip Ohnewein

3 SunPeek use cases

SOLID – Lukas Feierl

4 Q&A Session

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Workshop Series „Digitalization of Solar Thermal Plants"

- **Focus**: Demonstrate how to use **digital tools** and **methods** for the monitoring of (large-scale) solar thermal plants & give support for SunPeek users
- **Target group**: Operators of large-scale solar thermal plants and associated compagnies and stakeholders

28 February, 2024

SunPeek Open Source Software (Online)

SunPeek

10 - 11 April 2024

SunPeek Exhibition Stand at ISEC 2024

June 2024

Guide to ISO 24194:2022 + Handbook „Digital Tools for Solar Thermal Plant Monitoring" + SunPeek

+ tailored, free workshops for compagnies! Please contact us!

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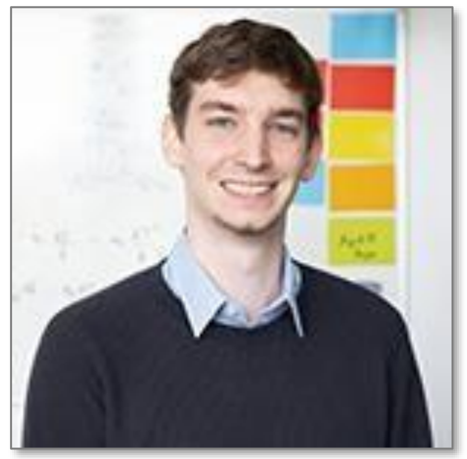
SunPeek Development Team

AEE INTEC




SOLID solar energy systems



GASOKOL Solar. Seit 1981.

SCHNEID

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Applied CPS Project

Project partners

- The project **Applied-CPS (Applied Cyber-Physical Systems)** is an Austrian research project of the Digital Europe Programme, funded by the European Commission and the Austrian Research Promotion Agency
- **Project duration**: 2022/09 to 2025/08
- Applied-CPS offers **tailored services for SME within the European Union** to support the implementation of cyber-physical systems (CPS)
- **Services up to 40 k€ are** fully funded! Please contact us if you are interested!

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Organizational issues

- The workshop will **not** be recorded.
- **Slides** and **additional material** will be distributed after the workshop. Please feel free to share them!
- After each session, there is some time for **longer questions** and **discussion**.
- You may ask **shorter questions** during the sessions directly to the presenter or using the “Chat” function in MS Teams
- Please register through the Applied CPS website if you haven’t done this yet: https://www.applied-cps.at/event_kalender/sunpeek-open-source-software-for-monitoring-of-large-scale-solar-thermal-plants/

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Contact

- For questions regarding Applied CPS (in particular Service Offers), please contact **Daniel Tschopp** (d.tschopp@aee.at)
- SunPeek General Questions: sunpeek@sunpeek.org
- SunPeek Support: support@sunpeek.org
- For specific requests / problems / bugs, please open issues in https://gitlab.com/sunpeek/

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AEE INTEC

IDEA TO ACTION

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+43 (0)3112 5886-252

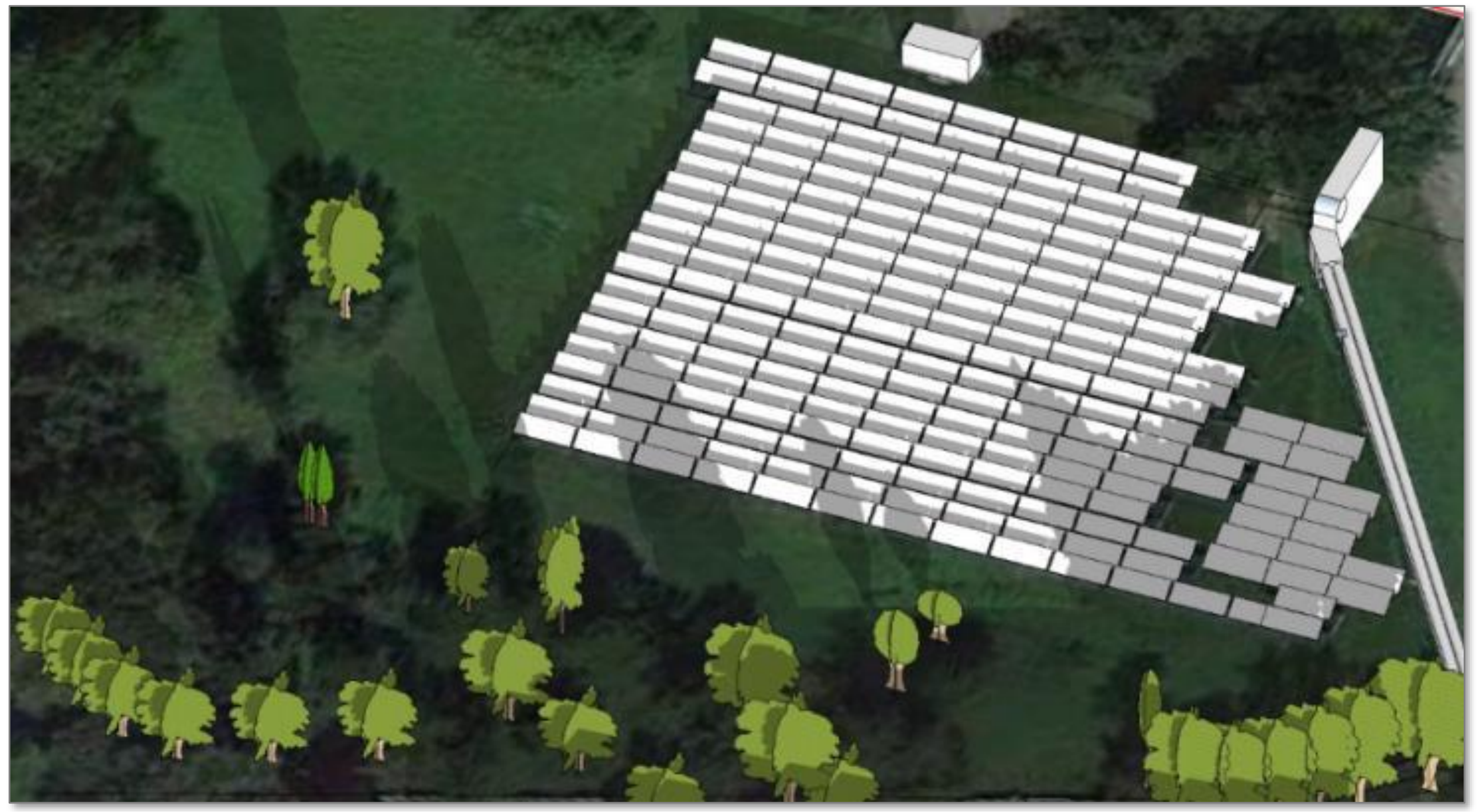
https://www.applied-cps.at/
https://demo.sunpeek.org/
https://gitlab.com/sunpeek

ISO 24194 & SunPeek Software

Monitoring and Guarantees for solar thermal plants with open-source software

Philip Ohnewein, Daniel Tschopp & SunPeek-Team

Influences on Solar Thermal Yield / Performance



- **Collectors**
  - Efficiency parameters, Heat capacity
  - Collector soiling, degradation
- **Plant design**
  - Row distances, tilt angle, plant hydraulics
  - Shading: row-to-row and external
- **Plant control, operational strategies**
  - Volume flows, system temperatures
- **Secondary side, external influences**
  - Temperature levels, heat storages,…
  - Weather, solar radiation
- **Measurements**
  - Data quality, missing data, inconsistencies
  - Representativity of solar radiation & wind
  - Measurement uncertainty

Challenges Monitoring Solar thermal plants

Design | Commissioning & Operation | 20-30 years

ISO 9806
EN 12975
EN 12976

ISO 24194

Challenges

1) CAPEX: Solar thermal has **high initial investment**.
2) OPEX & payback: Operator needs to ensure **high solar yield** long-term.
3) New ISO 24194! But requires **data analysis** → tedious & time-consuming.
4) High-quality performance assessment is **challenging**, even for experts.
5) **No standard software** on the market for ISO 24194 automated performance monitoring.

ISO 24194:2022

Solar energy — Collector fields — Check of performance

(ISO 24194:2022)

Sonnenenergie — Kollektorfelder — Überprüfung der Leistungsfähigkeit (ISO 24194:2022)

Energie solaire — Champs de capteurs — Vérification de la performance (ISO 24194:2022)

General information

Status : Published
Publication date : 2022-05
Stage : International Standard published [60.60]

Edition : 1
Number of pages : 30

Technical Committee : ISO/TC 180/SC 4
ICS : 27.160

Life cycle

Now

Published
ISO 24194:2022
Stage: 60.60

Corrigenda / Amendments

Under development
ISO 24194:2022/Amd 1

- Defines **2 methods** on paper:
  - ✓ Thermal Power Check
  - ✓ Daily Yield Check
- **Collector types**:
  - ✓ Applicable to glazed flat plate collectors, evacuated tube collectors, and/or tracking, concentrating collectors

Usages & Application Areas

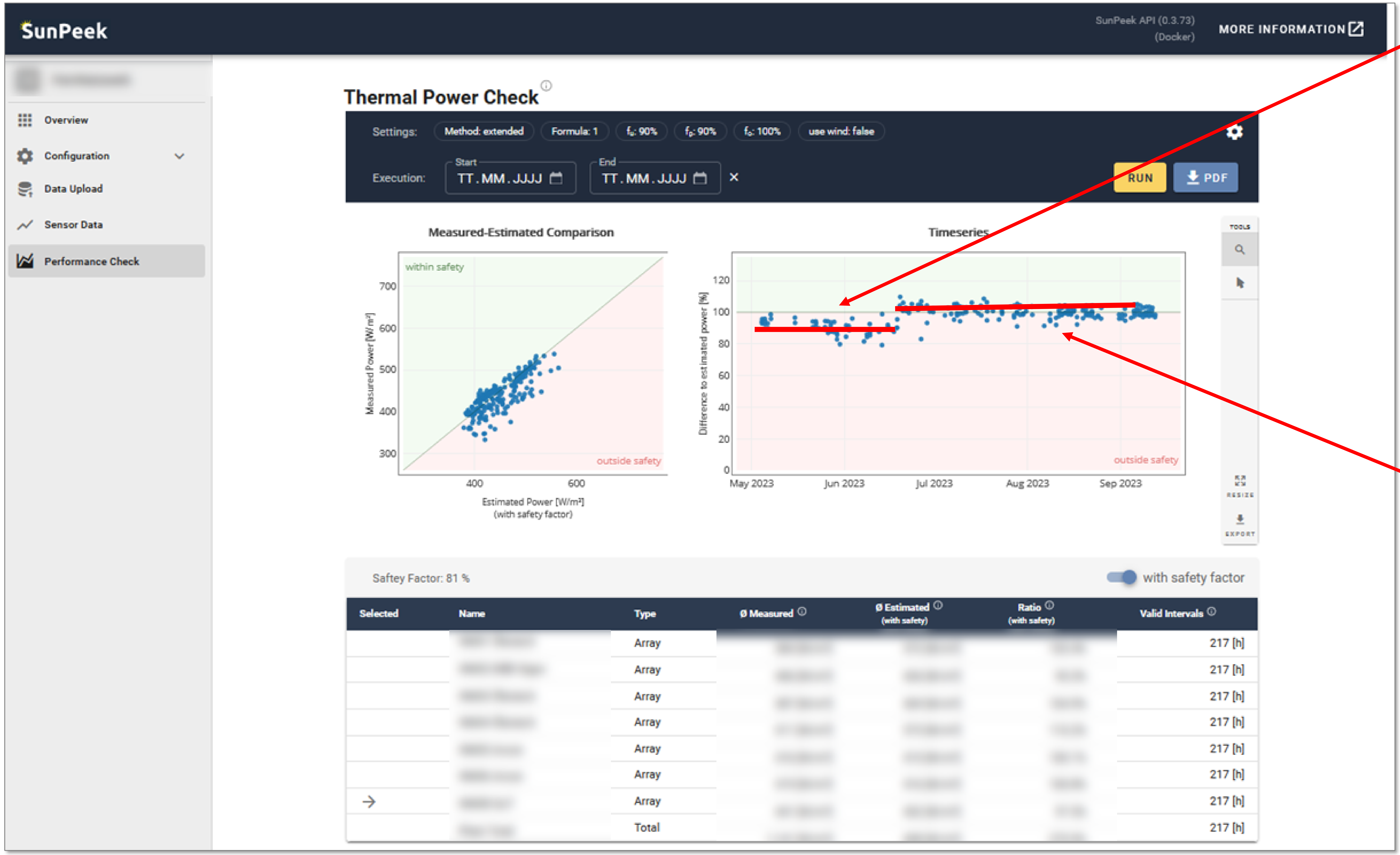
of ISO 24149 Thermal Power Check

- Usage1: **Guarantee Procedure**
  - E.g. at plant commissioning
  - Question: "Does the plant meet the guaranteed performance?"
- Usage 2: **Performance Monitoring during operating phase**
  - Ongoing evaluation performance under field conditions
  - Detect performance degradation or plant problems

- **Answer** the fuzzy question
  „How good is a solar thermal plant working?“
- **Quantitative answer**:
  - Percentage “ratio measured – estimated output”
  - Compare absolute plant performance (geography, temperatures, technologies)

Example Results

Collector Performance Before / After Cleaning



Before cleaning

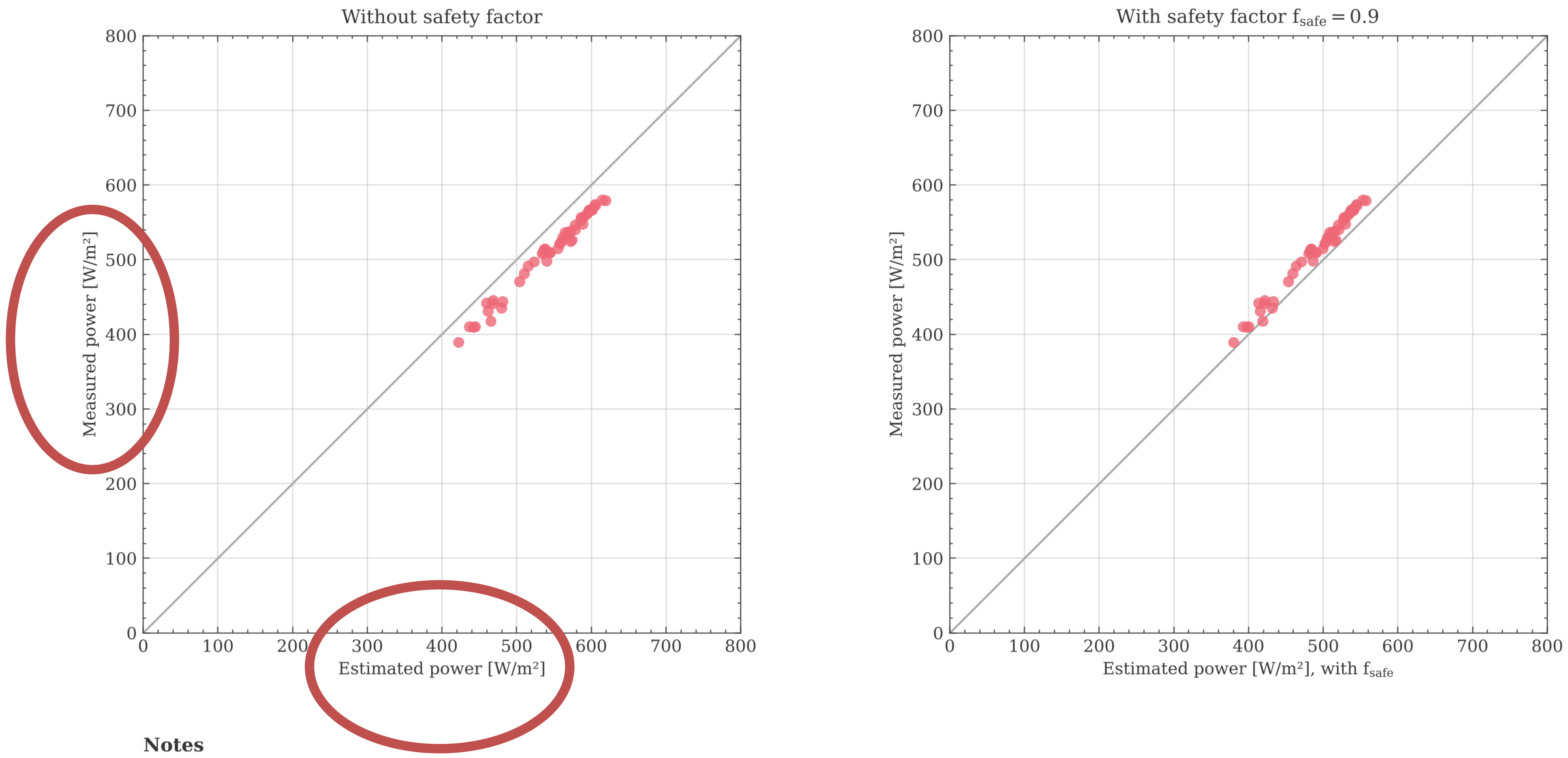
After cleaning

Measured vs. Estimated Power

ISO 24194 Thermal Power Check

Thermal Power Output: Measured vs. Estimated

Plant FHW Arcon South _Test_
Included arrays Arcon South



Notes

Each dot in the plots is the average thermal power output of a 1 hour interval.
The left plot is based on unaltered estimated and measured data, without safety factor.
The right plot takes the combined safety factor $f_{safe} = 0.9$ into account.

Calculation Estimated Power: 3 Models

ISO 24194 Thermal Power Check

Formula (1): Non-concentrating collectors

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

Formula (2): Non- or low-concentrating collectors

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

Formula (3): Focussing collectors with high concentration ratio

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

Data Selection Criteria

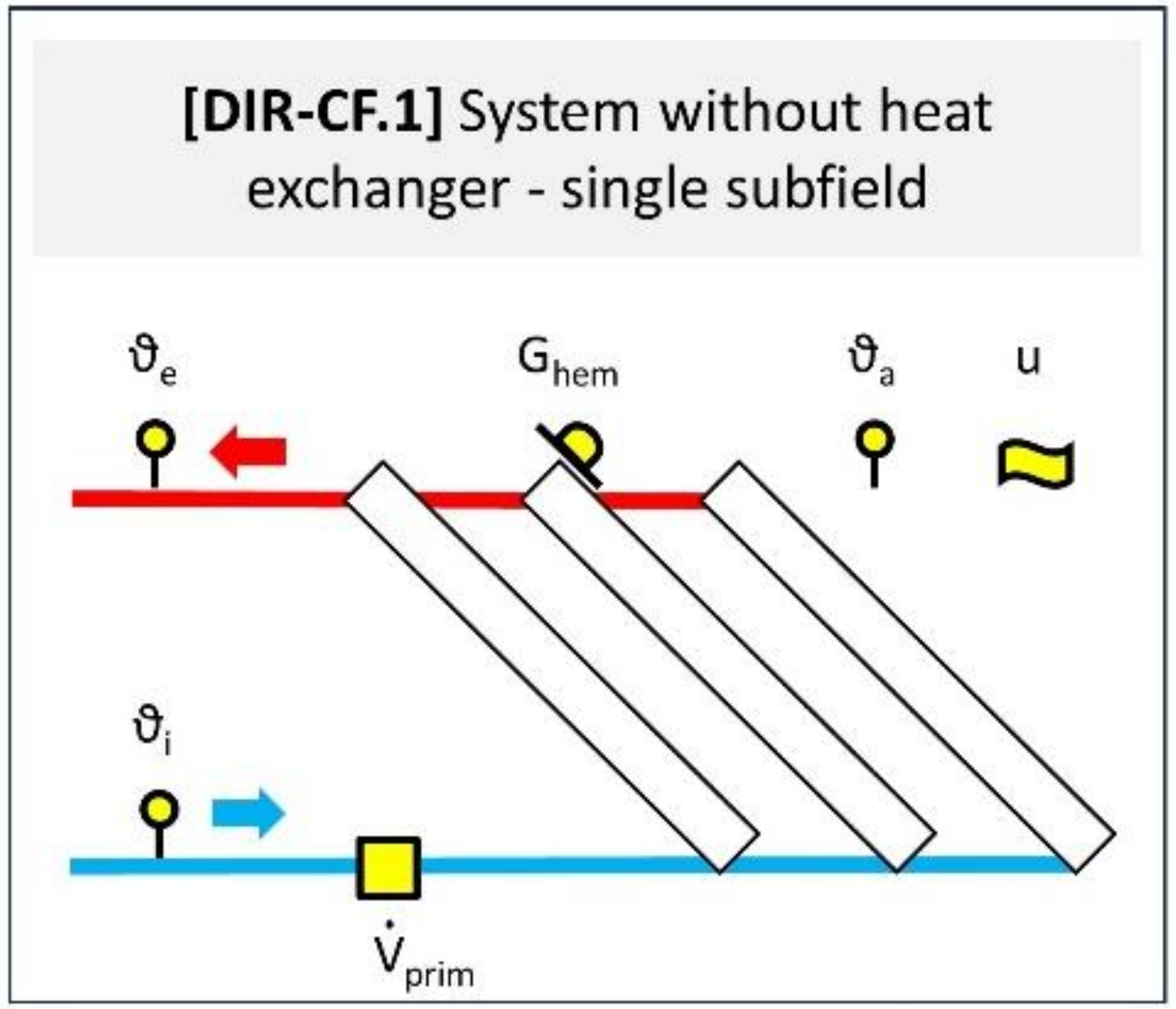
ISO 24194 Thermal Power Check

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	

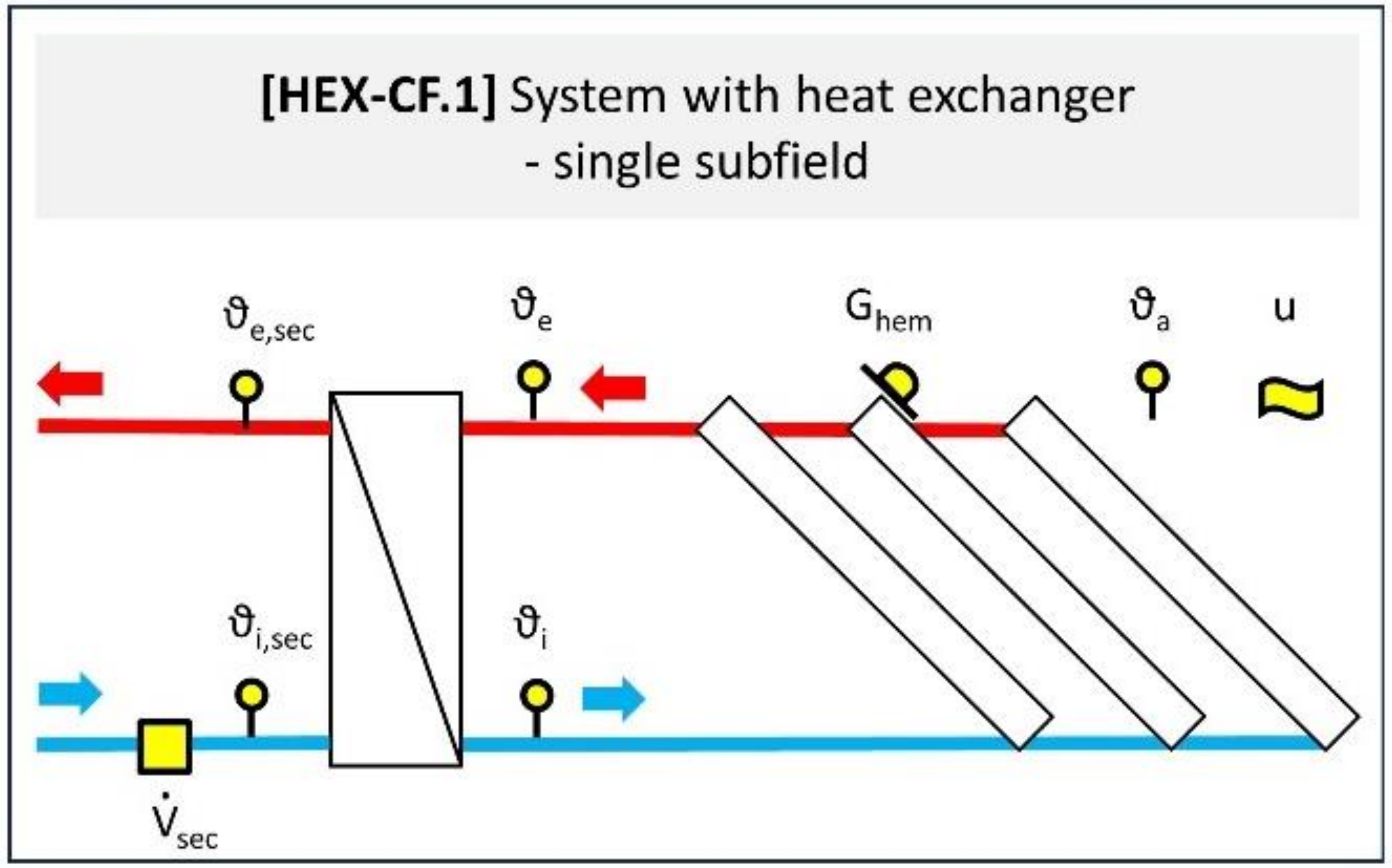
Measurement Operating Data

for ISO 24194 Thermal Power Check

Measurement on **primary** side



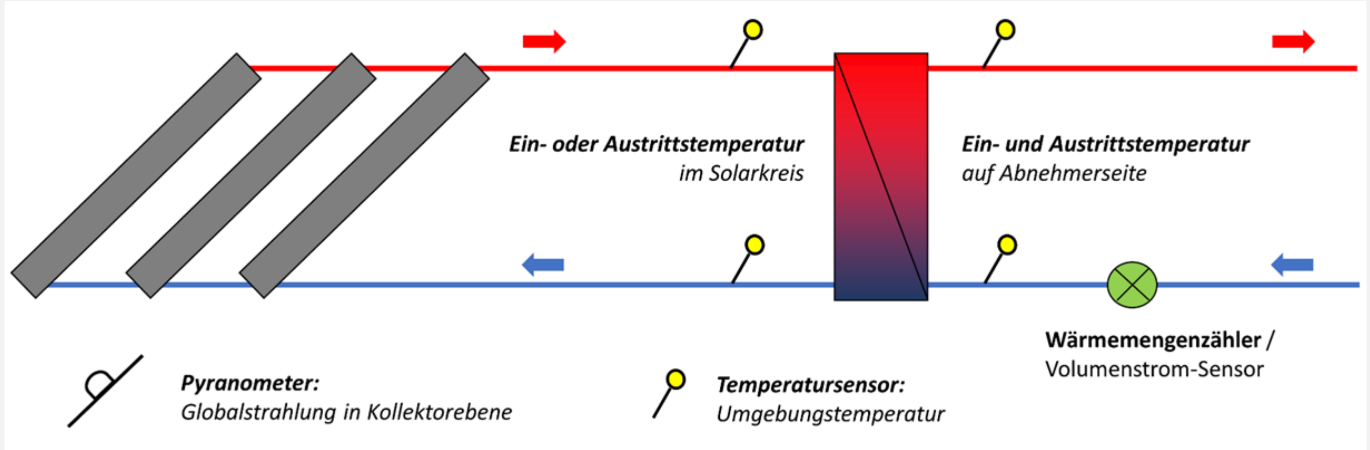
Measurement on **secondary** side



+ Solar Radiation global or direct / diffuse (optional)
+ Wind velocity

Calculation Estimated Power

ISO 24194 Thermal Power Check



1 Measurement Data

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
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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/m²	-	-	
G_b	-	≥600 W/m²	≥600 W/m²	

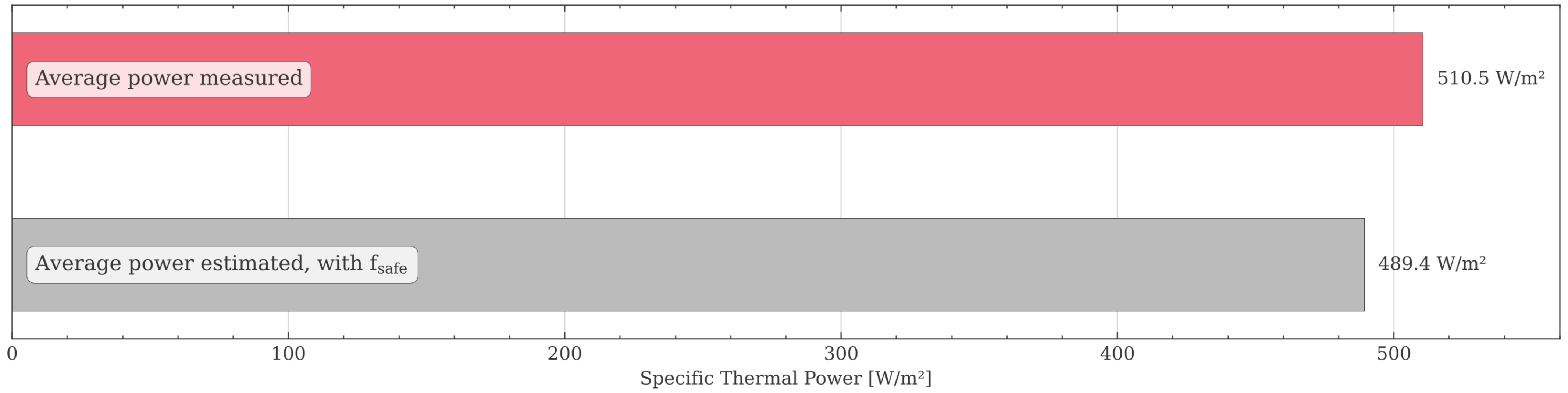
2 Data selection / filtering

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

3 Averaging

$$\dot{Q}_{estimate} = A_{GF} \cdot \left[\eta_{0,hem} K_{hem}(\theta_L, \theta_T) G_{hem} - a_{1,\Delta Q}(\vartheta_m - \vartheta_a) - T_{\Delta Q}(\vartheta_m - \vartheta_a)^2 - a_5(\mathrm{d}\vartheta_m/\mathrm{d}t)\right] \cdot f_{safe}$$

4 Calculation Estimated Power/ 3 Models



Thermal Power Check:
Performance Assessment corrected for

- Operating temperatures
- Weather (Solar radiation, ambient temp., wind)
- Components (Collectors, heat transfer fluids)

„Safety Factor“

Treatment of Uncertainties in ISO 24194 Thermal Power Check

$$\dot{Q}_{estimate} = A_{GF} \cdot \left[\eta_{0,hem} K_{hem}(\theta_L, \theta_T) G_{hem} - a_{1,\Delta Q}(\vartheta_m - \vartheta_a) - T_{\Delta Q}(\vartheta_m - \vartheta_a)^2 - a_5 (d\vartheta_m / dt)\right] \cdot f_{safe}$$

f_{safe} Combined safety factor:

$$f_{safe} = f_P \cdot f_U \cdot f_O$$

f_P: Safety factor considering heat losses from pipes etc. in the collector loop. To be estimated based on an evaluation of the pipe losses (e.g. by Formula (23))

f_U: Safety factor considering measurement uncertainty. To be estimated - with the requirements given in 7.2, a factor of 0,95 (level I) and 0,9 (level II and III) can be used – or detailed documentation for the uncertainty calculation is required according to ISO/IEC Guide 98-3.

f_O: Safety factor for other uncertainties e.g. related to non-ideal conditions such as:

— non-ideal flow distribution. To be estimated - should be close to one.

— unforeseen heat losses. To be estimated - should be close to one.

SunPeek Summary

https://demo.sunpeek.org/





Demo server: https://demo.sunpeek.org/

GitLab project: https://gitlab.com/sunpeek/

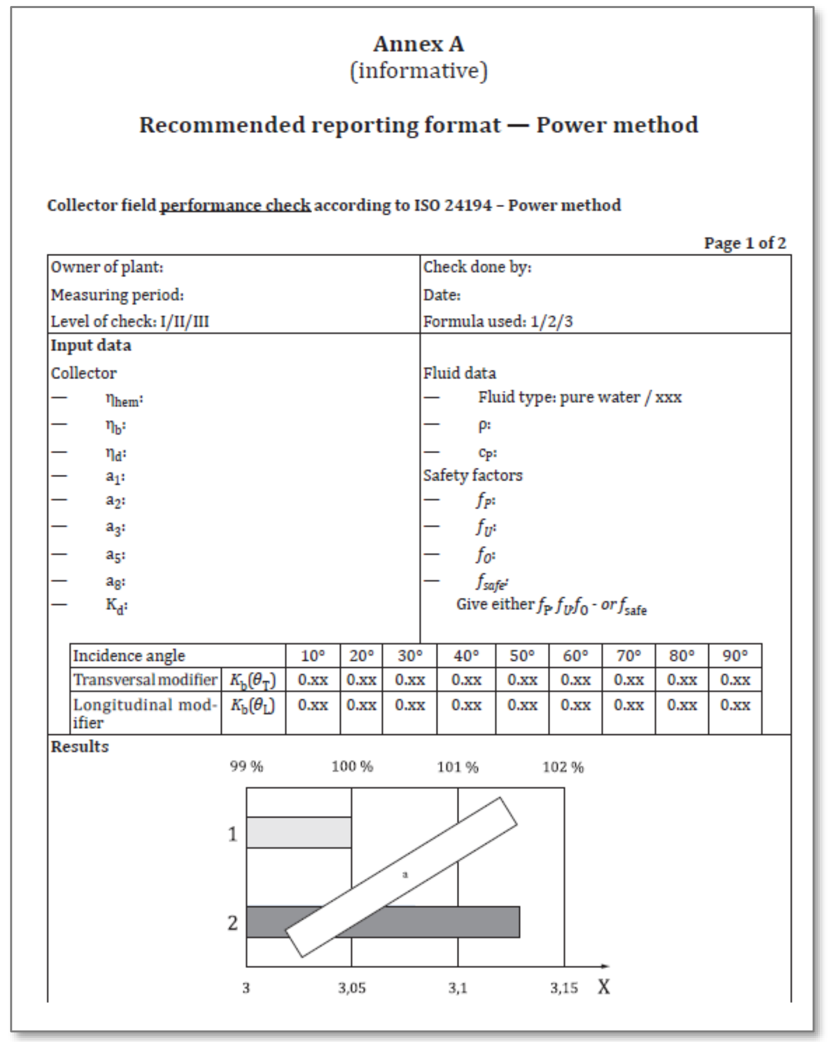
- SunPeek is an open-source software for **automated performance monitoring** and **guarantee procedures** of solar thermal plants.
- The SunPeek licenses (LGPL, BSD-3) explicitly allow **commercial usage**.
- SunPeek is intended as an **industry solution and reference implementation** of the **ISO 24194** performance check standard.
- Project governance is defined, contributions are welcome.
- SunPeek was developed with a network of leading academic and industry experts in the field. Partners: AEE INTEC, SOLID, GASOKOL, Schneid.

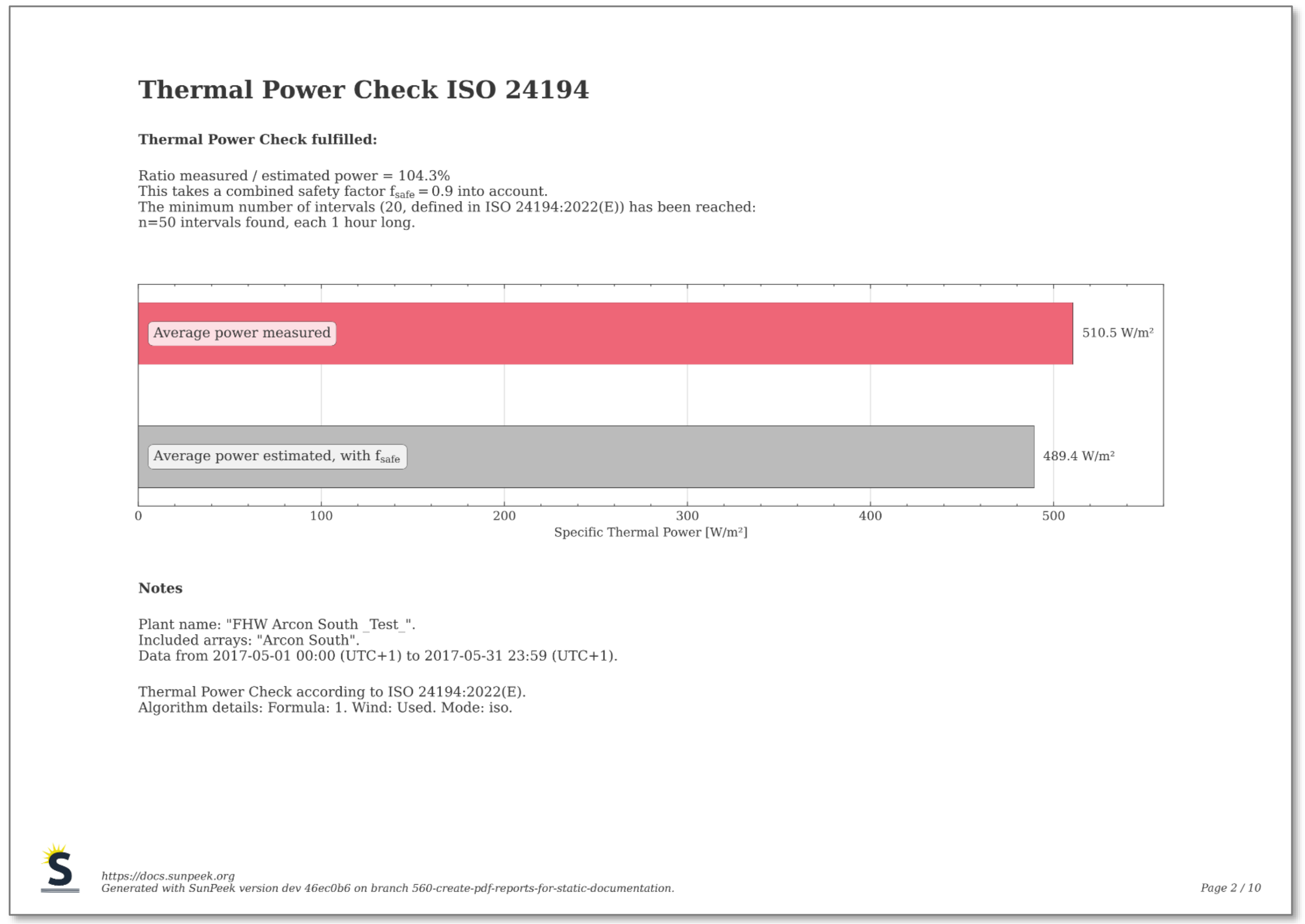
SunPeek as Reference Implementation for ISO 24194

https://demo.sunpeek.org/

- First **Open-Source Implementation** of ISO 24194:2022
  - Transparence, easy access to ISO methods, integration with own tools
- **Open-Source Hub** / Development Platform parallel to ISO standard
  - Community Building research & industry
  - Possible Extension of methods & technologies, software features
- **Implement & Extend** ISO Standard
  - Extend ISO 24194 where necessary
  - Automate the ISO methods, web API

ISO 24194 pdf → **Thermal Power Check Report via API**

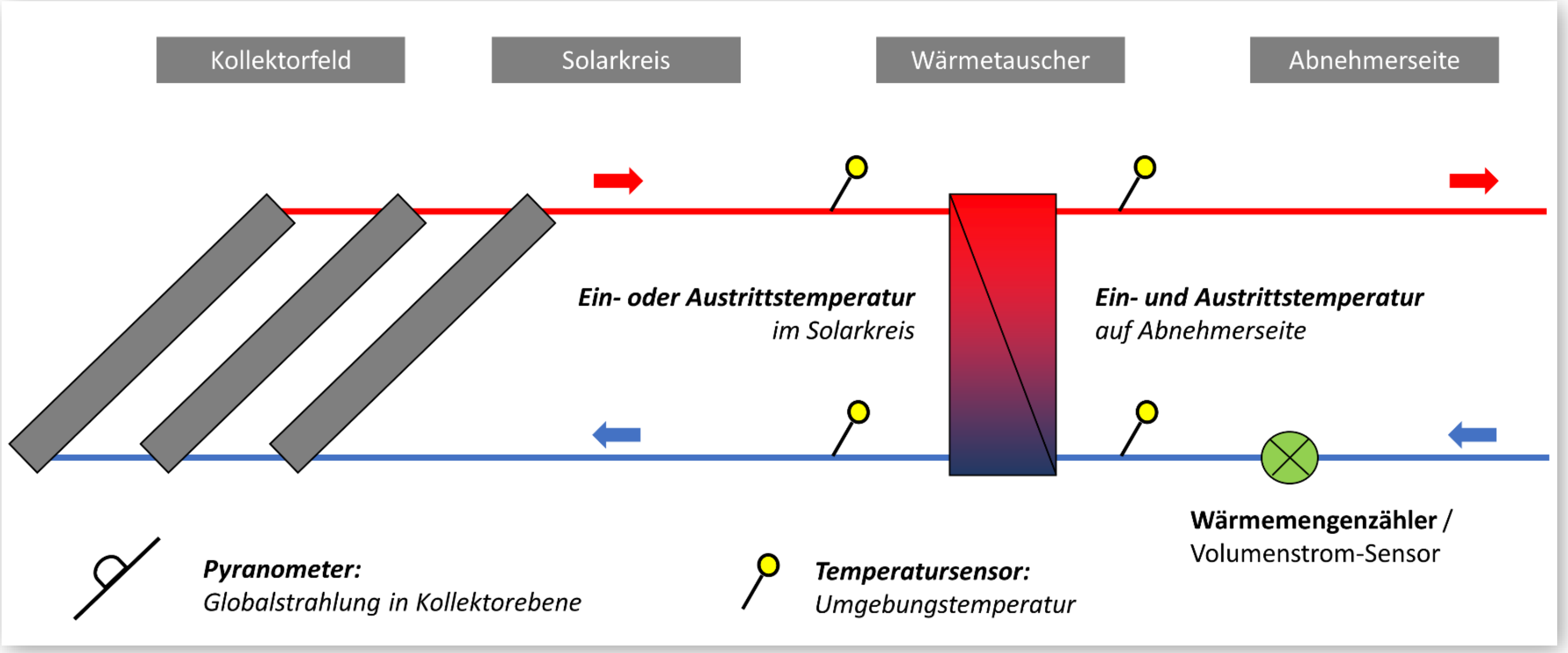




SunPeek Practical Adaptations

to ISO 24194:2022

https://demo.sunpeek.org/



1) **More than 1 collector field / array**
   - ✓ Data treatment & estimated power per array
2) **Mixed collector types**
   - ✓ E.g. single & double glazed, flat-plate & concentrating
   - ✓ Differences in collector data sheets (SST/QDT, IAM,…)
3) **Non-standardized measurements**
   - ✓ Virtual sensors, Fluids Database
4) **Nasty data**
   - ✓ Auto-treat data formats, valid data, time zones, …
5) **Extended filtering → more data**
   - ✓ Extend TPC with more information in partial load

AEE INTEC

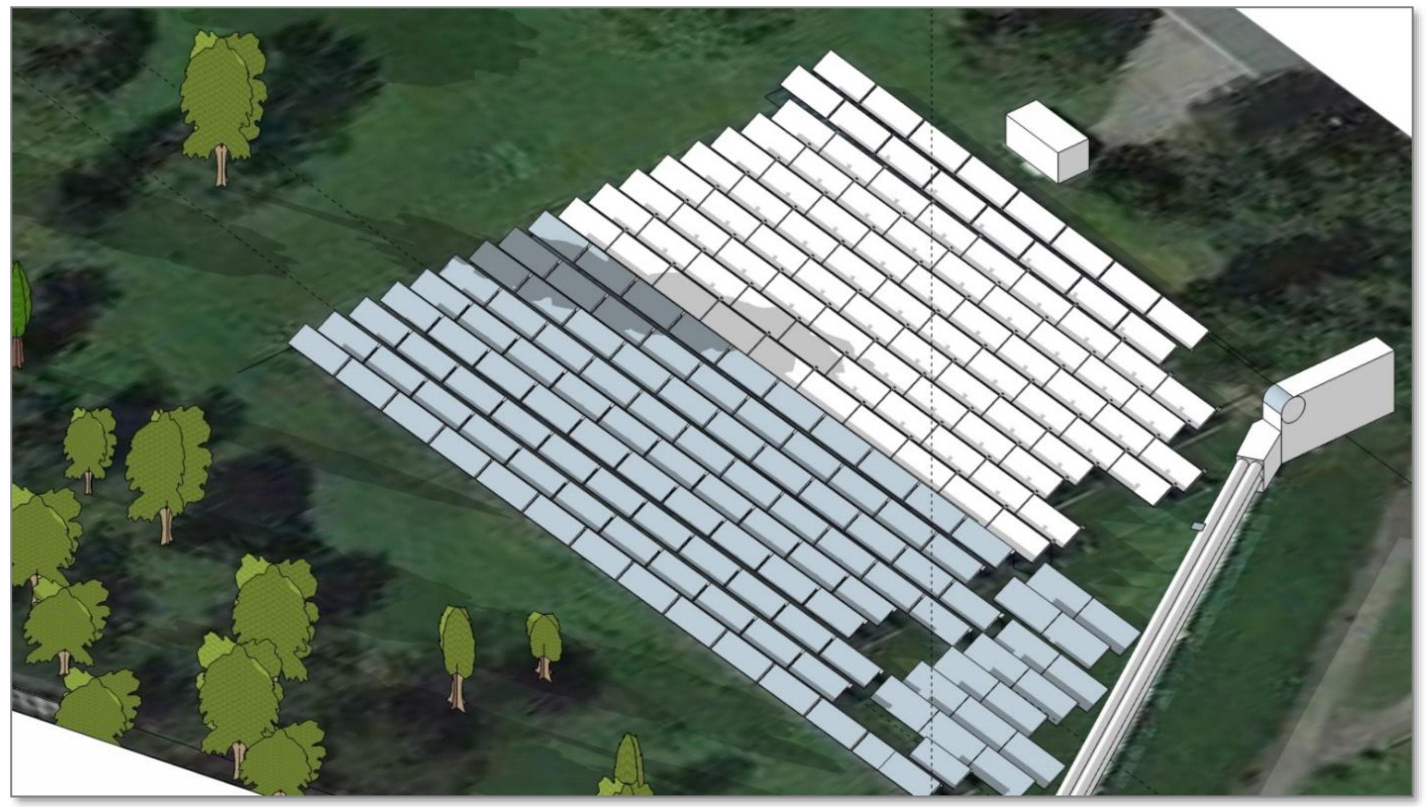
SunPeek Planned Features

to ISO 24194:2022

https://demo.sunpeek.org/

1) Radiation modelling

- ✓ Internal Shading (done)
- ➢ Multiple collector arrays with different orientation
- ➢ Tracking collectors
- ➢ Correction of diffuse radiation for fair assessment



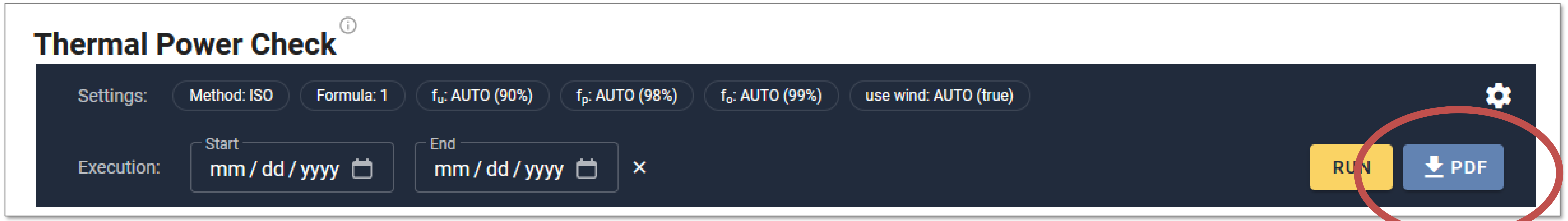
2) Predefined Collectors

- ➢ Link to Solar Keymark Database

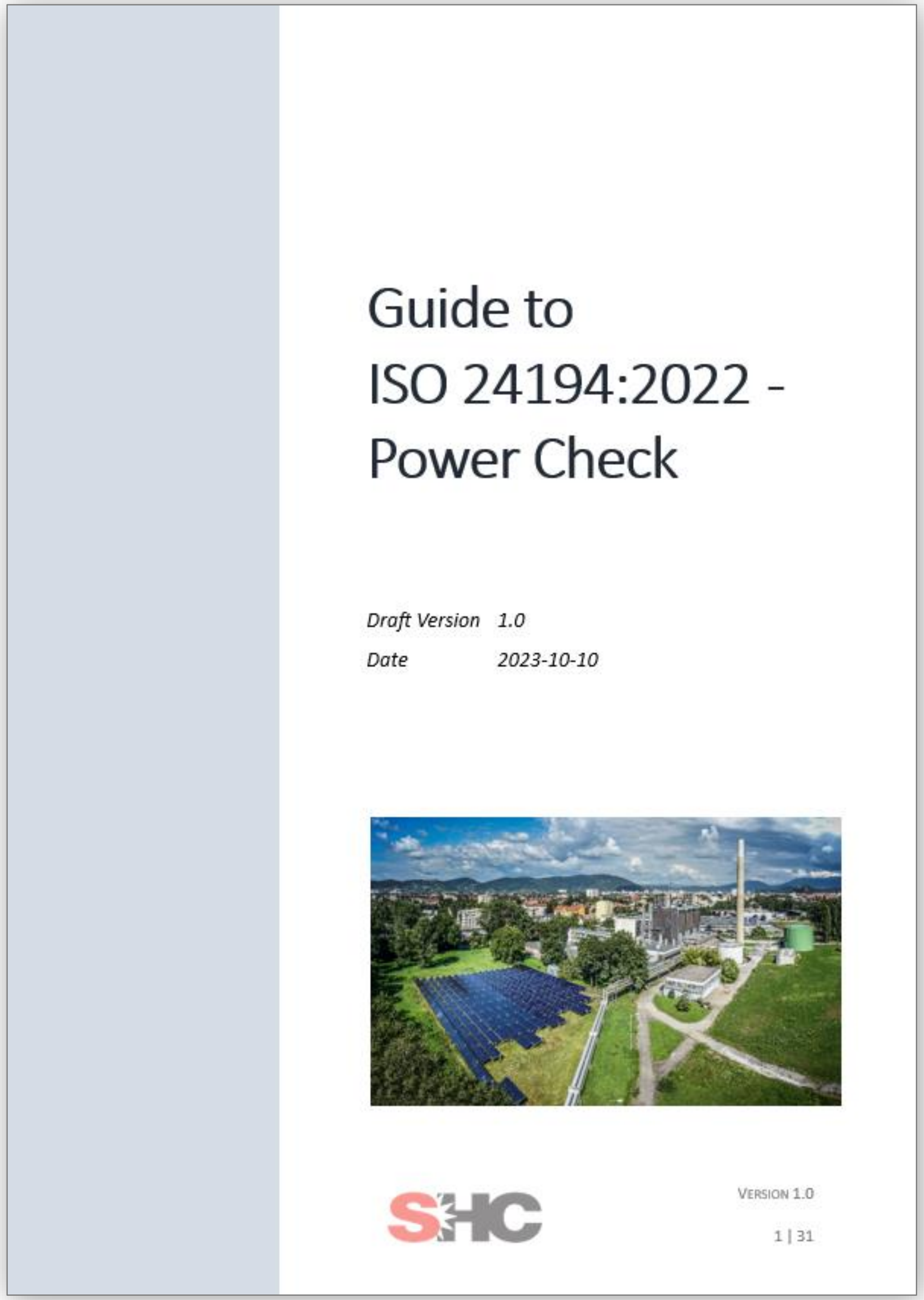
The Solar Keymark
CEN Keymark Scheme

3) Further Automation

- ➢ Automatic data upload, Automatic sending of reports



“Task 68 Guide” to ISO 24194 Thermal Power Check


Guide to
ISO 24194:2022 -
Power Check

Draft Version 1.0
Date 2023-10-10

VERSION 1.0
1 | 31

Cooperation from „IEA SHC Task 68“ Efficient Solar District Heating Systems

- Application of ISO 24194 underpins the need for clarification, background information and some practical amendments / tweaks.
- Software implementation SunPeek, for automated and transparent ISO 24194 Thermal Power Check.
- Main target groups: plant operators, plant designers, collector manufacturers, researchers.

Inputs from industry & research welcome!

“Task 68 Guide”

Interpretation of ISO 24194 Practice

Conversion of collector data sheets

Collector test	Source
QDT (Quasi-dynamic test) Given parameter: $\eta_{0,b}, K_b, K_d$ Derived parameter: $\eta_{0,hem}, K_{hem}$	
$\eta_{0,hem} = \eta_{0,b}(0.85 + 0.15\,K_d)$	ISO 9806:2017 Annex B, Formula (B.2), (B.5)
$K_{hem}(\theta_L,\theta_T) = \frac{\eta_{0,b}}{\eta_{0,hem}}(0.85 K_b\,(\theta_L,\theta_T) + 0.15\,K_d)$	Derived from ISO 9806:2017 Annex B Formula (B.2), (B.5)
SST (Steady-state test) Given parameter: $\eta_{0,hem}, K_{hem}$ Derived parameter: $K_b, K_d, \eta_{0,b}$	
$K_b(\theta_L,\theta_T) = K_{hem}(\theta_L,\theta_T)$	ISO 9806:2017 Annex B, Formula (B.1)
$K_d = \frac{1}{W}\sum_{\theta,\gamma=0^{\circ}}^{90^{\circ}} K_b(\theta,\gamma)\sin(\theta)\cos(\gamma)$ $W = \sum_{\theta,\gamma=0^{o};\ steps=10^{o}}^{90^{o}} \sin(\theta)\cos(\gamma)$	ISO 9806:2017 Annex B, Formula (B.3), (B.4)
$\eta_{0,b} = \frac{\eta_{0,hem}}{0.85 + 0.15\,K_d}$	ISO 9806:2017 Annex B (B.5)

Automated Data Filtering

SensorType	Com-patilbe Unit	Associated datapoints	Replacement values: LOWER_REPLACE_MIN	LOWER_REPLACE_MAX	LOWER_REPLACE_VALUE	UPPER_REPLACE_MIN	UPPER_REPLACE_MAX	UPPER_REPLACE_VALUE
Fluid temperature	°C	ϑ_i, ϑ_e	-20	-	-	-	200	-
Ambient temperature	°C	ϑ_a	-30	-	-	-	60	-
Global radiation	W/m²	G_{hem}	-10	0	0	-	1700	-
Direct radiation	W/m²	G_b	-10	0	0	-	1400	-
Diffuse radiation	W/m²	G_d	-10	0	0	-	1110	-
DNI	W/m²	I_{DN}	-10	0	0	-	1400	-
Thermal power	W	$\dot{Q}_{pri}$, $\dot{Q}_{sec}$	-10	0	0	-	-	-
Mass flow	kg/s	$\dot{m}_{pri}$, $\dot{m}_{sec}$	-100	0	0	-	-	-

SunPeek Licenses

open source initiative Approved License®

SunPeek Backend
LGPL (GNU General Public License)

- Free commercial usage
- „Weakly Protective“
- Integration with proprietary code is possible
- Changes to the LGPL part must be made publicly available

SunPeek Web-UI
BSD-3 Clause

- Free commercial usage
- „Permissive“
  Virtually no restrictions, simple license text
- Used in similar open-source projects (e.g. pvlib)

✓ Open-source approach ensures **transparency** in yield guarantee procedures and fosters **use and distribution**

✓ **LGPL** ensures consistent implementation of ISO 24194

✓ **BSD-3** enables code integration with own software / visualization

✓ Open data is optional. No need to share measurement data!

AEE INTEC

SunPeek Software Outcomes

web UI

Grafische Oberfläche, Interaktive Nutzung

web API

Restful API. Integration in eigene Software Tools.

Python package

Nutzung mit anderen Projekten. Weiterentwicklung

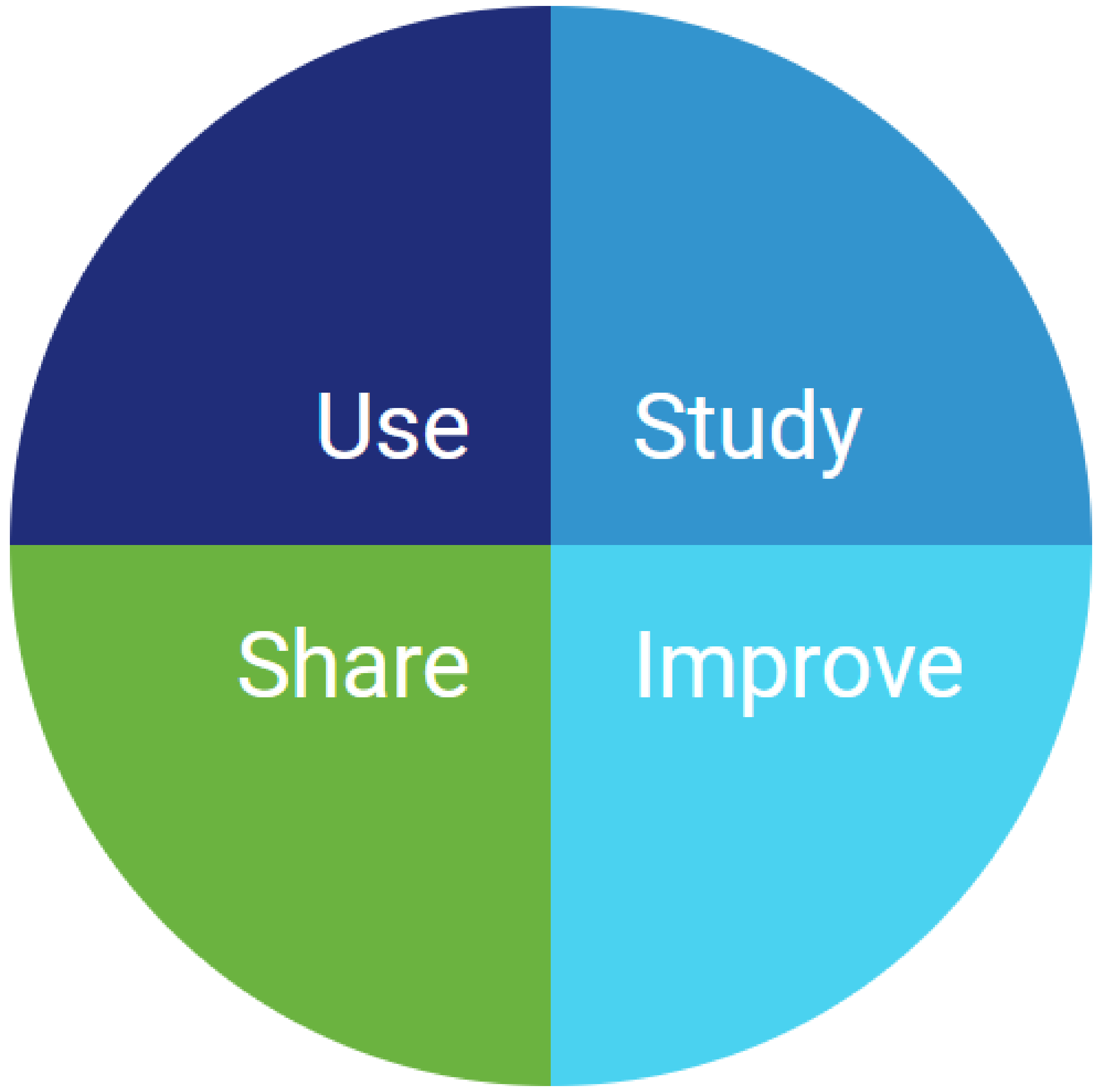
open source initiative Approved License®

Encourage commercial use.

docker

Standardized distribution.

Open-Source Software

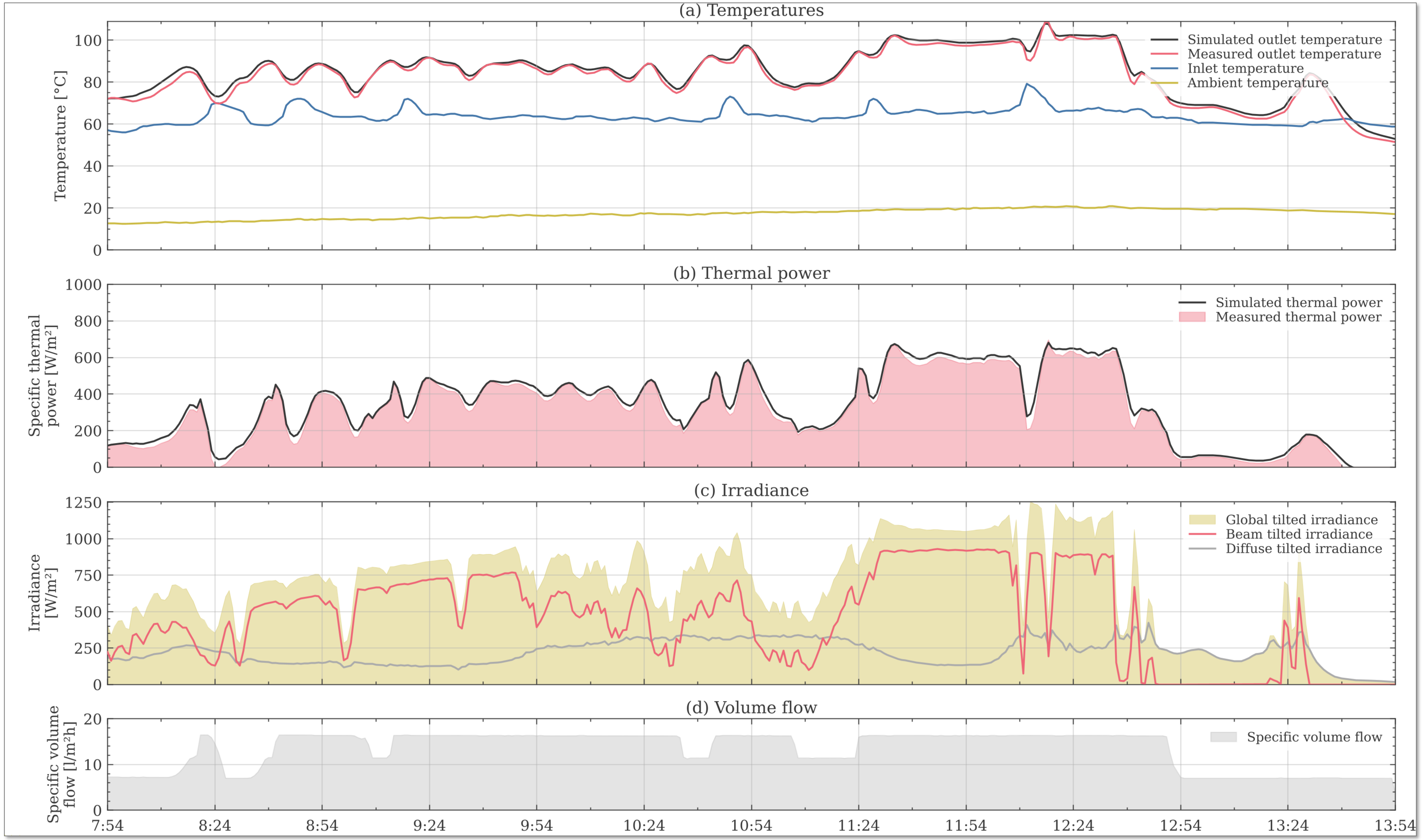


- Autonomy
- Reuse Code
- Collaboration
- Innovation
- Share & Copy
- Competition
- No Lock-In
- Security

Source: https://fsfe.org/

SunPeek: D-CAT Method

Energy Yield Check & more. Status: pending



SunPeek

Current Status

https://demo.sunpeek.org/

- ✓ Simple system configuration, ~10 minutes
- ✓ Automated evaluation, Interactive analysis, pdf report
- ✓ For Windows / Mac / Linux
- ✓ Beta Release Planned

1) SunPeek implements ISO 24194 Thermal Power Check.
2) Fully automatic data processing & Thermal Power Check.
3) Proven software, SunPeek is tested with around 10 LST plants.
4) Applicable to any plant size and to most ST collectors on the market.
5) Compare absolute plant performance (geography, temperatures, technologies).

SunPeek

Further Information

https://demo.sunpeek.org/

- ✓ **Hub** https://sunpeek.org/
- ✓ **Demo Site** https://demo.sunpeek.org/
- ✓ **Software Repository** https://gitlab.com/sunpeek/
- ✓ **Open Dataset** https://doi.org/10.5281/zenodo.7741083
- ✓ **Data-in-Brief Article** https://doi.org/10.1016/j.dib.2023.109224
- ✓ **JOSS Article** in preparation
- ✓ **Visit us** ISEC Graz, Bad Staffelstein, EuroSun Cyprus

Zenodo Community https://zenodo.org/communities/sunpeek

March 16, 2023 (1.0) | Dataset | Open

One year of high-precision operational data including measurement uncertainties from a large-scale solar thermal collector array with flat plate collectors, located in Graz, Austria

Tschopp, Daniel; Ohnewein, Philip; Stelzer, Roman; and 4 others

Highlights: High-precision measurement data acquired within a scientific research project, using high-quality measurement equipment and implementing extensive data quality assurance measures. The dataset includes data from one full operational year in a 1-minute sampling rate, covering all seasons. Measured data channels include global,...

Uploaded on March 16, 2023 — 429 — 355

February 3, 2023 (v1) | Report | Open

Dynamic Collector Array Test (D-CAT)

Ohnewein, Philip; Tschopp, Daniel; Hausner, Robert; and 1 other

Final report of the research project "MeQuSo, Development of methods for quality assurance of large-scale solar thermal plants under real operating conditions". The project MeQuSo was supported by the Austrian Climate and Energy Fund and carried out as part of the Energy Research Program (FFG 848 766). Project start 2015-08-01, project end 2019-...

Uploaded on February 7, 2023 — 90 — 98

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https://www.sunpeek.org

SOLID
solar energy systems

SunPeek

at SOLID Solar Energy Systems

Lukas Feierl, Maria Moser

28.02.2024 @Applied CPS SunPeek Workshop

Who is SOLID?

solar energy systems

~30 Employees

~300 solar thermal plants worldwide

Connection to SunPeek

Background

- One of the developers of SunPeek (HarvestIT project)
- One of the active maintainers

Why SunPeek?

- Collector guarantees
- Monitoring collector performance

SunPeek Contributors

AEE INTEC

SOLID solar energy systems

GASOKOL Solar. Seit 1981.

SCHNEID

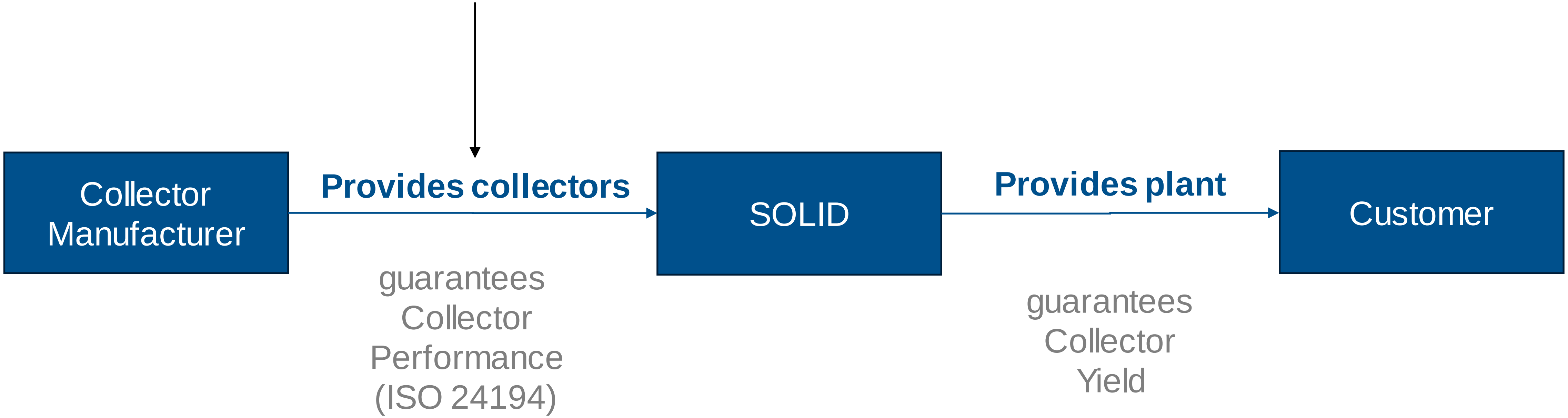
Use-Cases

Collector Guarantees

Performance Monitoring

Collector Guarantees

Aim: Check if collector performance is as specified.



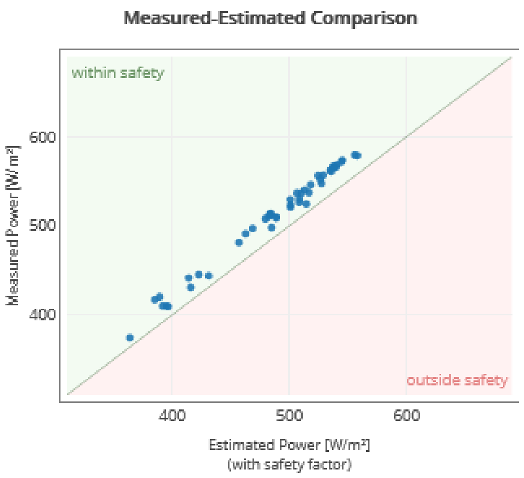
Collector Guarantees

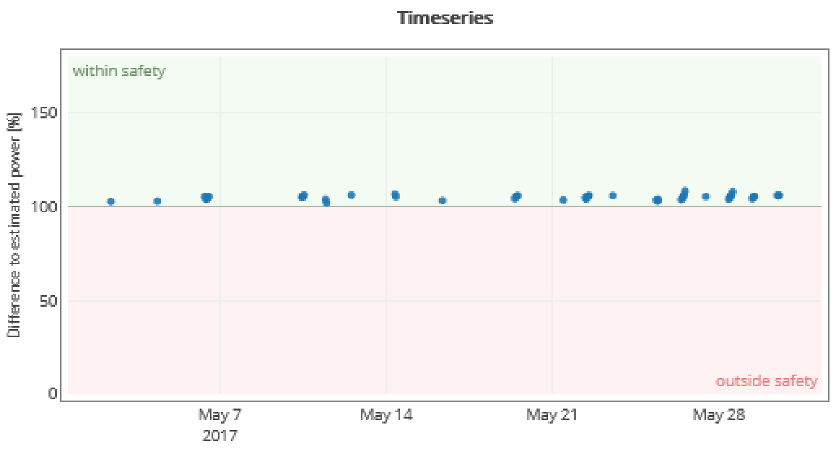
Thermal Power Check

Settings: Method: ISO | Formula: AUTO (2) | f_U: 90% | f_p: 100% | f_o: 100% | use wind: AUTO (true)

Measurement Period: Start 30 / 04 / 2017 End 01 / 06 / 2017

RUN | PDF





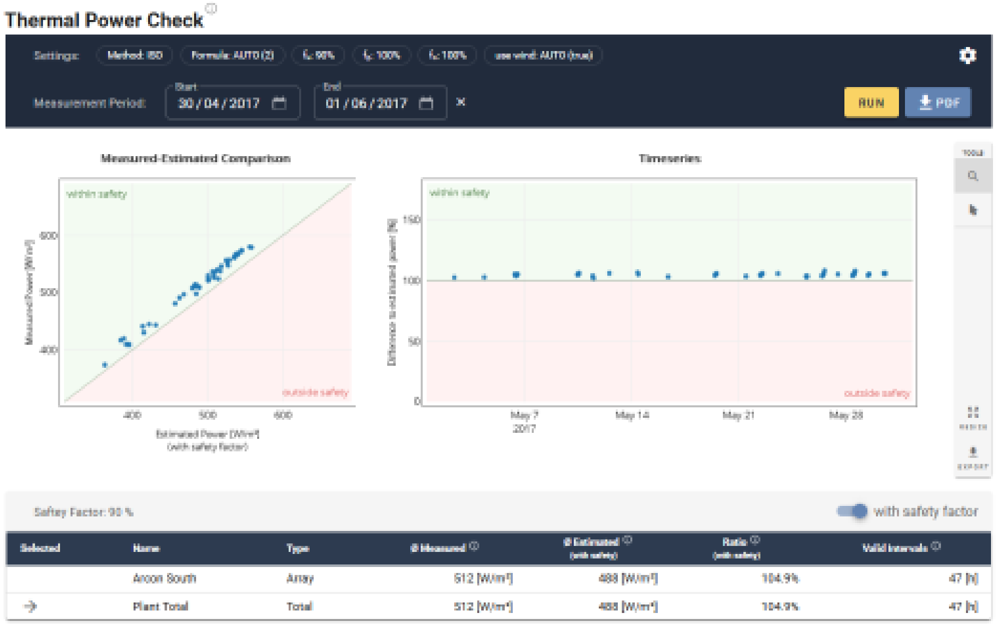
Saftey Factor: 90 %

with safety factor

Selected	Name	Type	Ø Measured	Ø Estimated (with safety)	Ratio (with safety)	Valid Intervals
	Arcon South	Array	512 [W/m²]	488 [W/m²]	104.9%	47 [h]
→	Plant Total	Total	512 [W/m²]	488 [W/m²]	104.9%	47 [h]

Use Case: Guarantees

Aim: Check if collector performance is as specified.



SunPeek advantages:

- Fast evaluation
- Transparent calculation
- Easy to export and share results

Use-Cases

Collector Guarantees

Performance Monitoring

Performance Monitoring

Aim: Is there any change in collector performance?

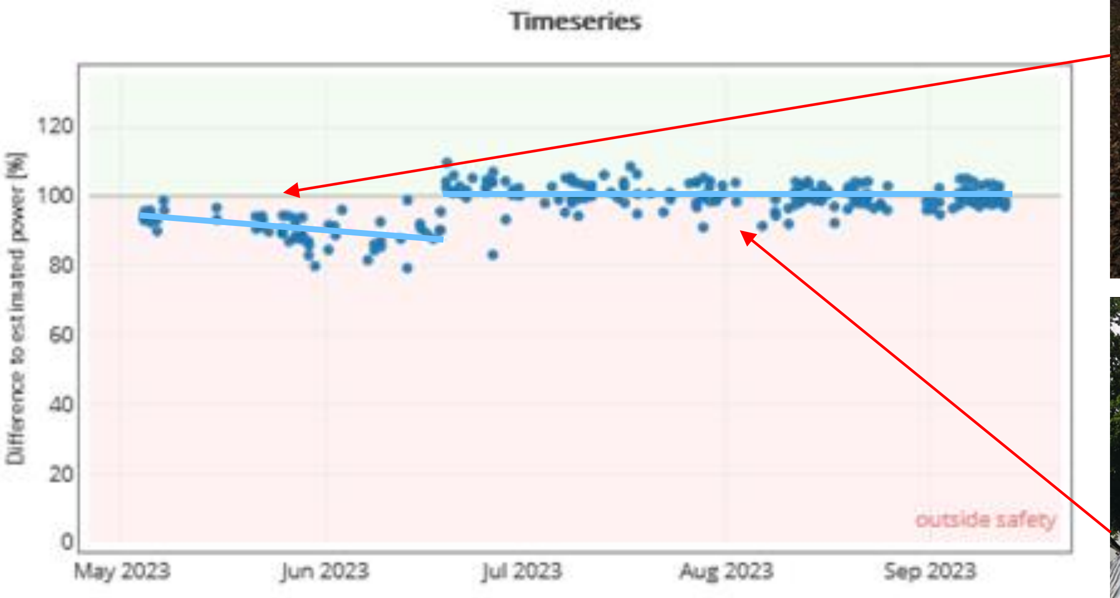
Examples:

- Dirt on collectors?
- Broken collector foils?
- Effect of collector cleaning?

Problem:

- Need to factor out operating conditions (irradiation, operating temperature, …)

Example: Collector Cleaning



Experiences

- SunPeek saves a lot of time (only data needs to be updated).
- Refering to a open-source software creates more trust in results.

Open Topics for SOLID:

  - Radiation conversion would be nice to have!

SOLID
solar energy systems

Thank you!

Take action today for a better tomorrow