Flow Determination in Parabolic Trough Power Plants using Temperature Signals

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MOTIVATION

Alex Brenner, Institut of Solar Research (DLR), 22.06.2023

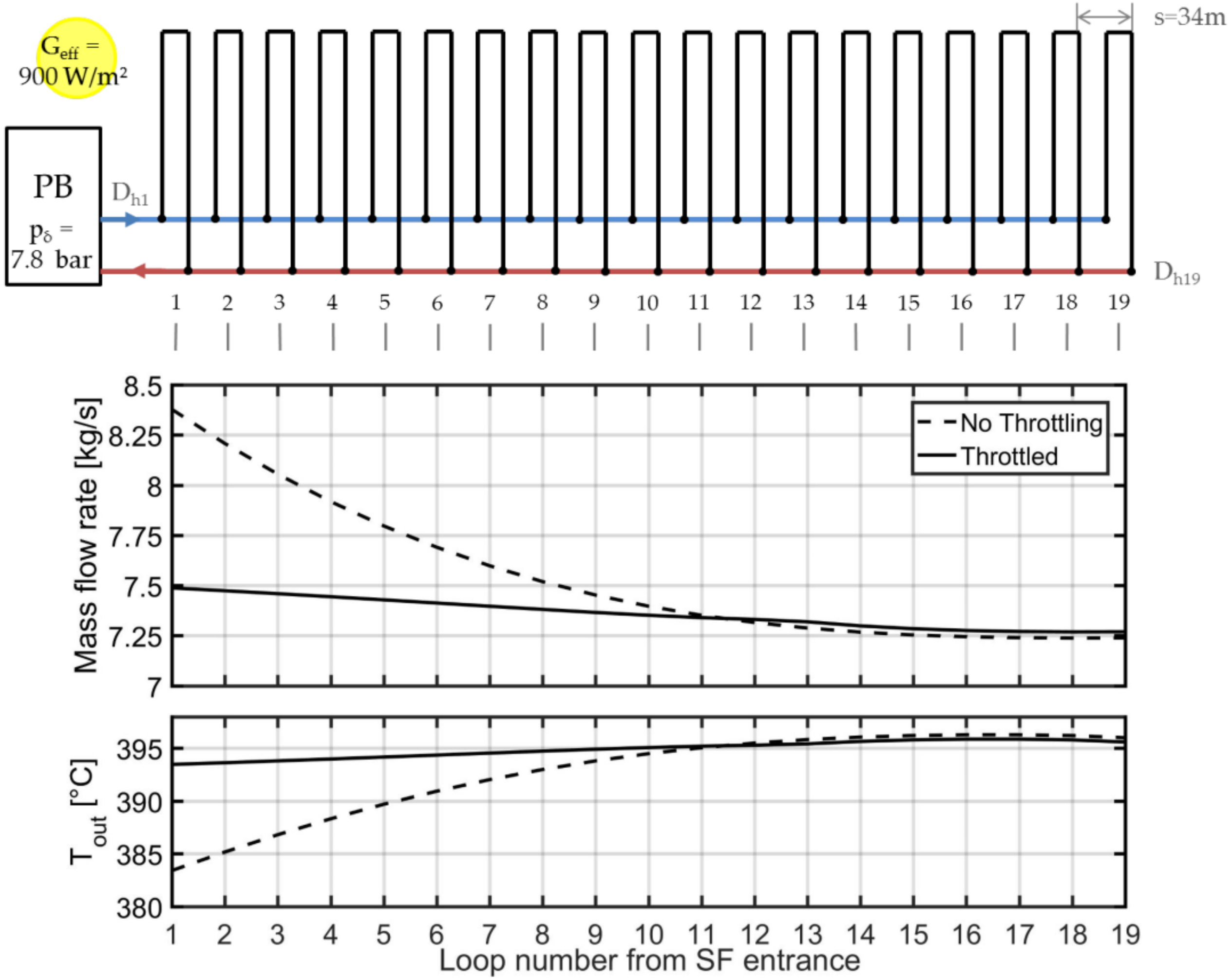
Motivation
Hydraulic balancing and performance monitoring

Application 1: Hydraulic balancing

- Relative flow distribution necessary
- Initial hydraulic balancing during commissioning
  - Aim: Equal loop outlet temperatures under nominal conditions
- Throttle valves available for each loop
- Adjustments during operation also possible

Application 2: Performance monitoring

- Absolute values of loop mass flow is necessary
- So far, evaluation of loop performance not possible without additional measurement equipment



From: Noureldin, Kareem (2019): Modelling and Control of Transients in Parabolic Trough Power Plants with Single-Phase Heat Transfer Fluids. Dissertation. University, RWTH Aachen. Faculty of Mechanical Engineering. Available online at https://publications.rwth-aachen.de/record/771557/files/771557.pdf

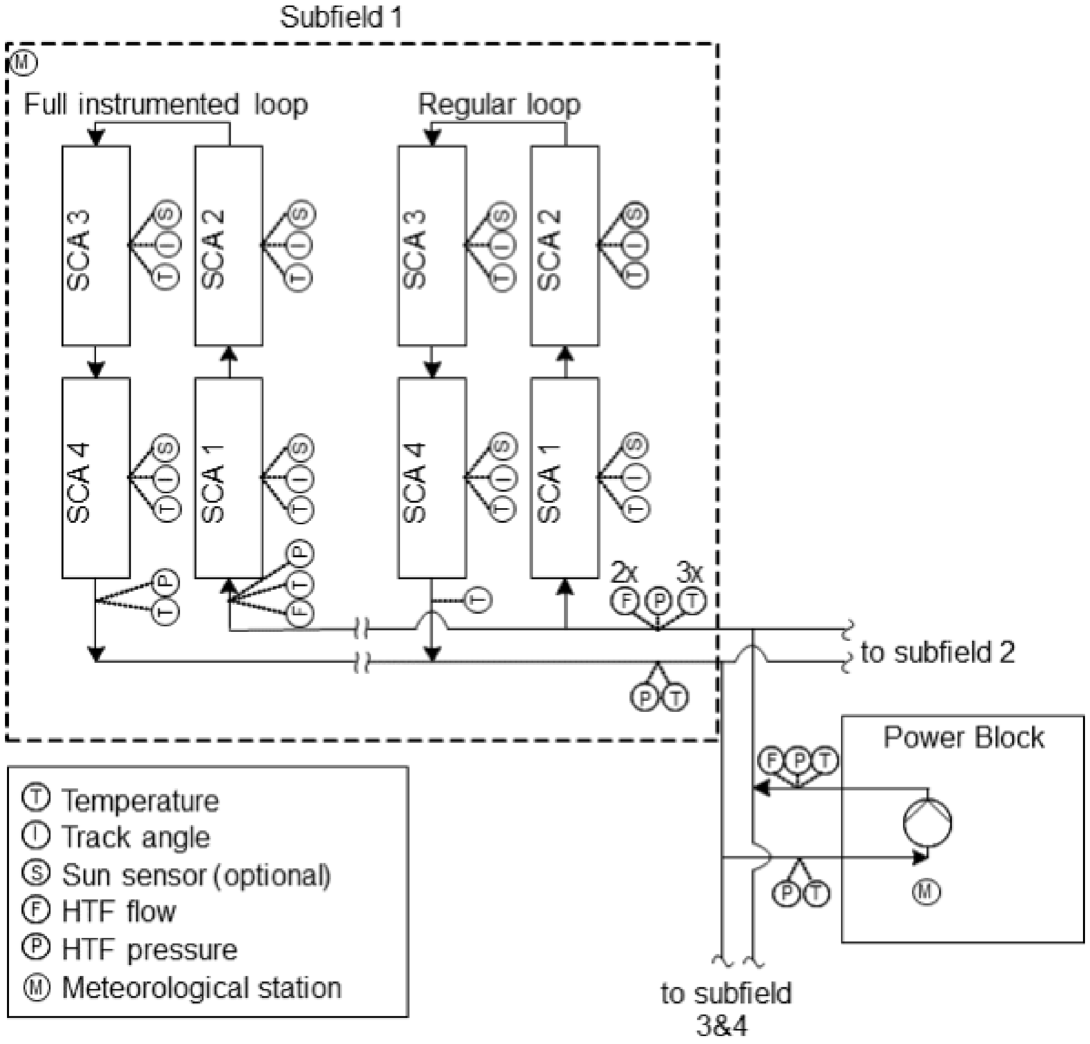
Motivation
Available measuring equipment

What we do not have:

- Loop (mass)flow is usually not determined
- Measurements only available at certain positions in the field
- Retrofitting is often expensive, or not possible
  - Numerous measuring instruments would be required

What we have:

- Temperature sensors are often already installed at collectors
- Collector can change heat input to HTF by adjusting focus, thus temperature can also be changed



From: Brenner, Alex; Hirsch, Tobias; Röger, Marc; Pitz-Paal, Robert (2021): State-of-the-Art Measurement Instrumentation and Most Recent Measurement Techniques for Parabolic Trough Collector Fields. In *Energies* 14 (21), p. 7166. DOI: 10.3390/en14217166.

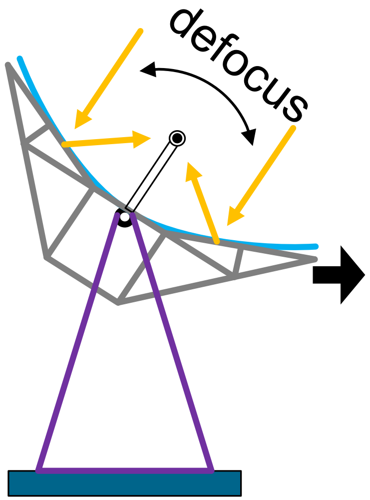
APPROACH

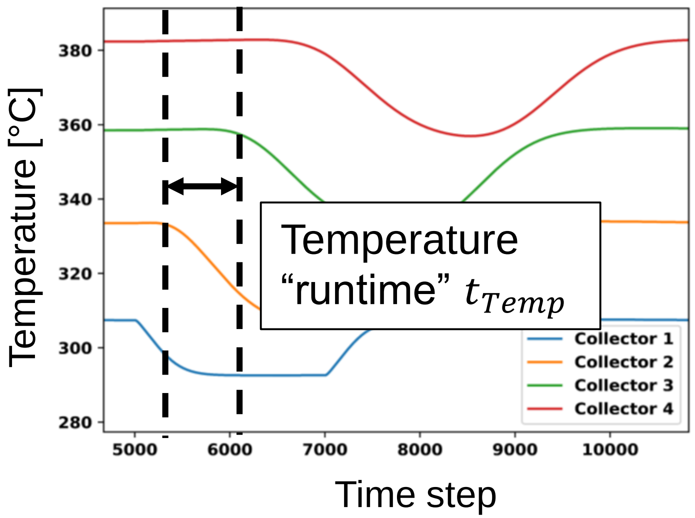
Approach
Using temperature gradients as tracer to determine fluid flow

Challenge:

- Thermal interaction with pipe shifts fluid runtime and runtime of temperature signal
  - Correction is required

Generated temperature gradients:





- First collector is defocused: Temperature gradient "flows" through loop
- Gradient measurable at following sensors
- Repeating signal is also possible
- Goal of this procedure: Generation of clearly recognizable temperature gradients with a small disturbance to plant operation

- **Proof-of-concept study with Virtual Solar Field (VSF)**

Approach
Using temperature gradients as tracer to determine fluid flow

Relative flow distribution

- Only relative flow to each loop of a subfield is determined

$$\text{ratio}_{loop,i} = \frac{\dot{m}_{loop,i}}{\dot{m}_{subfield}} = \frac{\dot{m}_{loop,i}}{\sum_{i=1}^{n_{loops}} \dot{m}_{loop,i}}$$

- Requirements:
  - Subfield consists of identical loops: Geometry, components, defocus procedure
  - Simultaneous defocusing to ensure constant conditions
- Due to identical conditions in the loops the temperature runtime can be used directly to infer relative flow:

$$\text{ratio}_{loop,i} = \frac{\frac{1}{t_{Temp}}}{\sum_{i=1}^{n_{loops}} \frac{1}{t_{Temp,i}}}$$

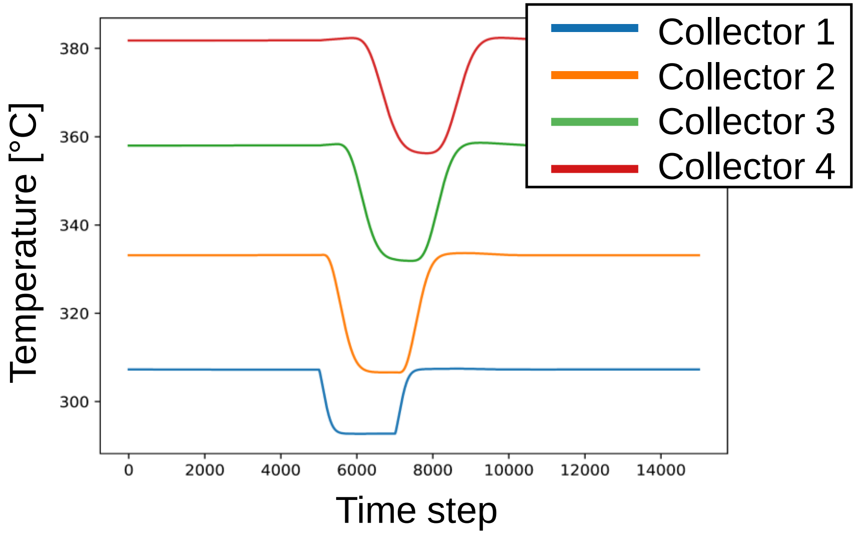
RESULTS

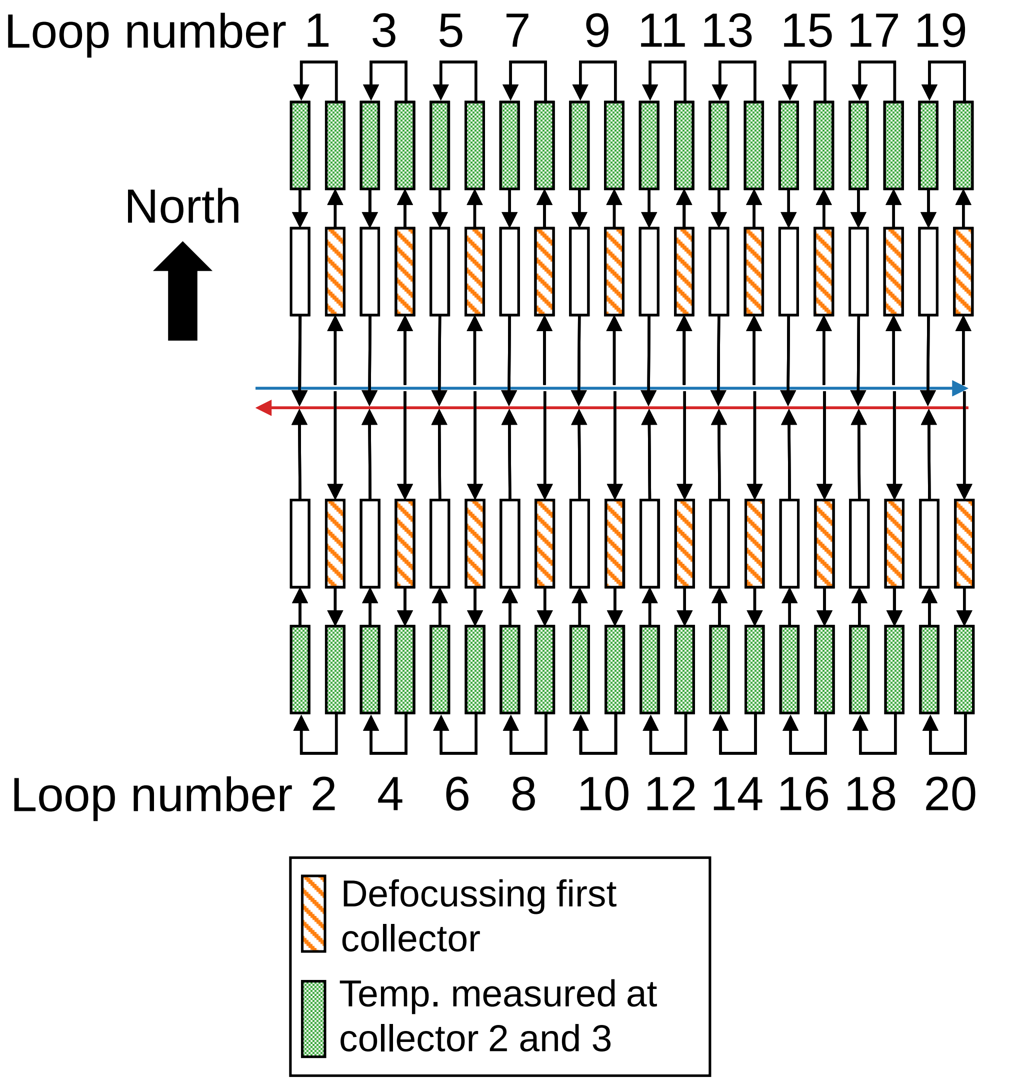
Results

Determine relative flow distributions: Simulation setup

Aim: Relative flow within subfield using temperature gradients

- Subfield with 20 <u>identical</u> loops facing north and south
- First collectors are <u>simultaneously</u> defocused
  - Approximately constant irradiance and constant flow conditions
- Temperature signals from collector 2 and 3 taken for analysis



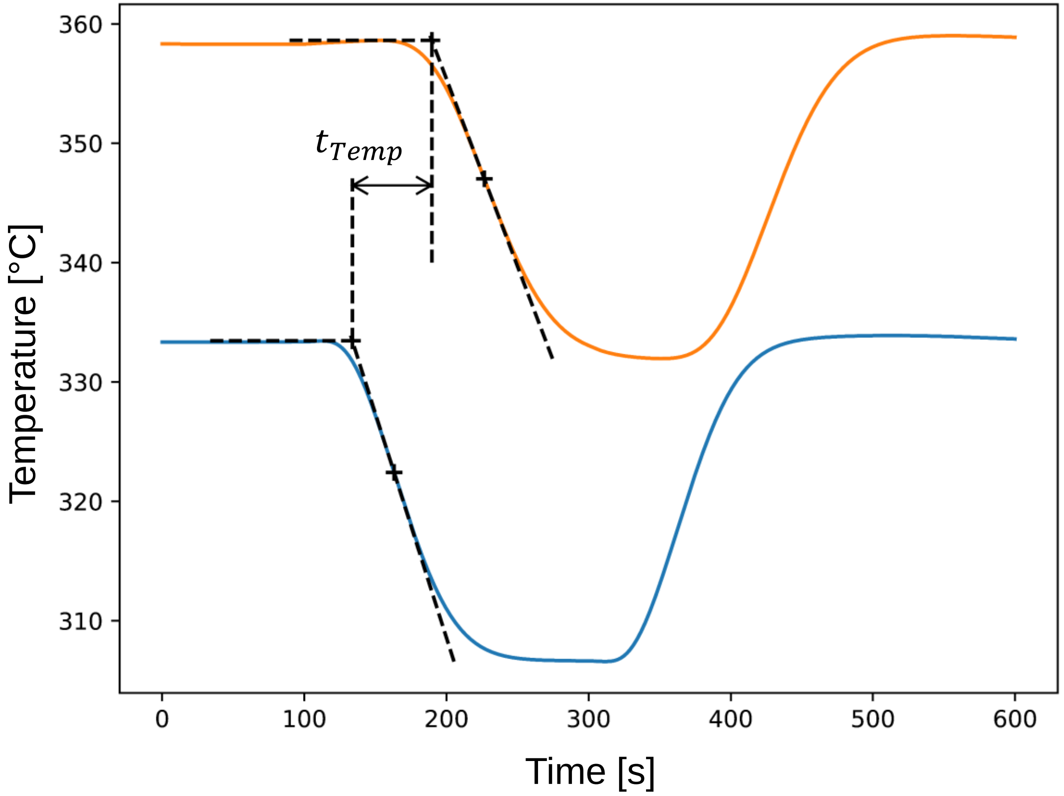


Results

Determine relative flow distributions: Temperature runtime

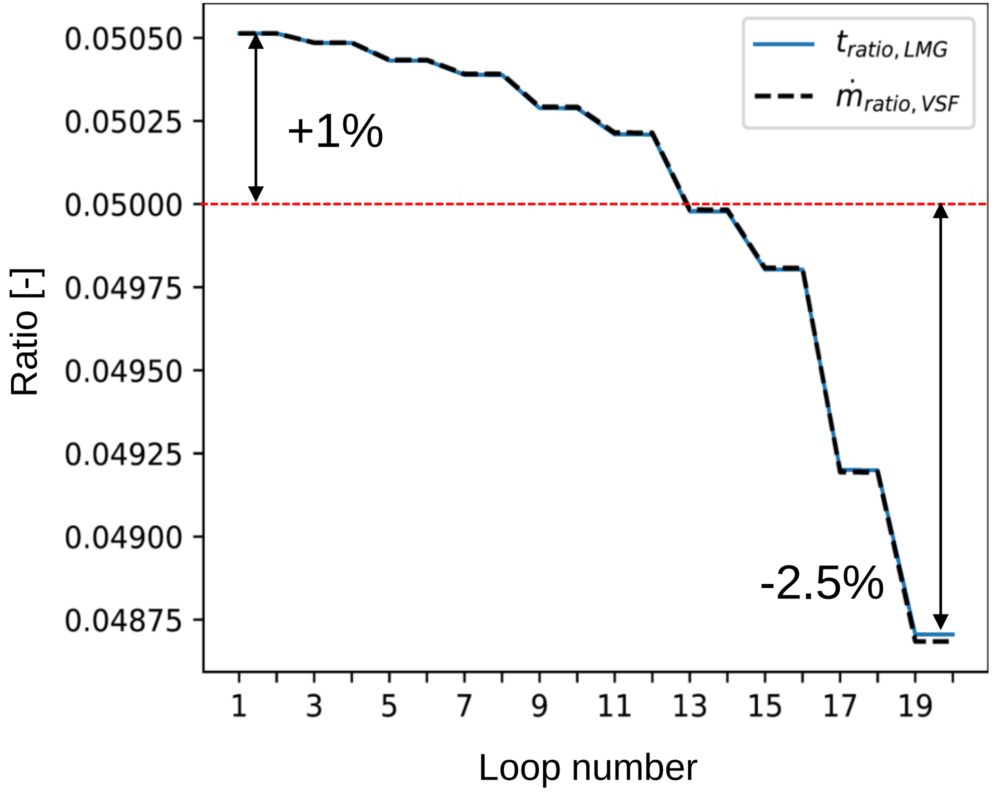
Minimum gradient method

- Position of minimum gradient of two temperature signals are taken
- Linearization around this point
- Intersection with undisturbed temperature signal is taken for calculation of temperature runtime t_{Temp}
- Method takes only one part of the signal
  - reduces the duration when conditions must be constant
- Signals do not need to be scaled or normalized
- Very simple method, which showed good results for signals without noise



Results
Determine relative flow distributions

- Challenging case for determination of relative flow is a nearly balanced field
- Simulations with remaining flow imbalances of 3.5% from loop 1 to loop 20
- Relative flow distributions can be accurately determined
  - Calculated $t_{ratio,LMG}$ nearly perfectly fits the reference results $\dot{m}_{ratio,VSF}$ from the VSF simulation
- **Challenges:**
  - Assumption of identical loops may not be 100% true in a real field



CONCLUSION + OUTLOOK

Conclusions

Relative flow distribution

- Relative flow distribution can be determined very accurately
- Procedure could be used during hydraulic balancing
- Assumption of identical loops may not be 100% true in a real field

- Only built-in instrumentation is used
- Publication of procedure in preparation
- Patent pending

Outlook

- Influence of defocusing procedure on plant operation needs to be investigated
- Procedure for determining absolute values of fluid runtime is also developed
  - Correction function taking into account:
  - $t_{Fluid} = f(t_{Temp}, l, \Delta T, C_{vol})$

t_{Temp}	Temp. runtime
l	Distance between sensors
ΔT	Temp. drop due to defocus
C_{vol}	Vol. heat capacity pipe

- So far only proof-of-concept study: Approach needs to be tested under real conditions

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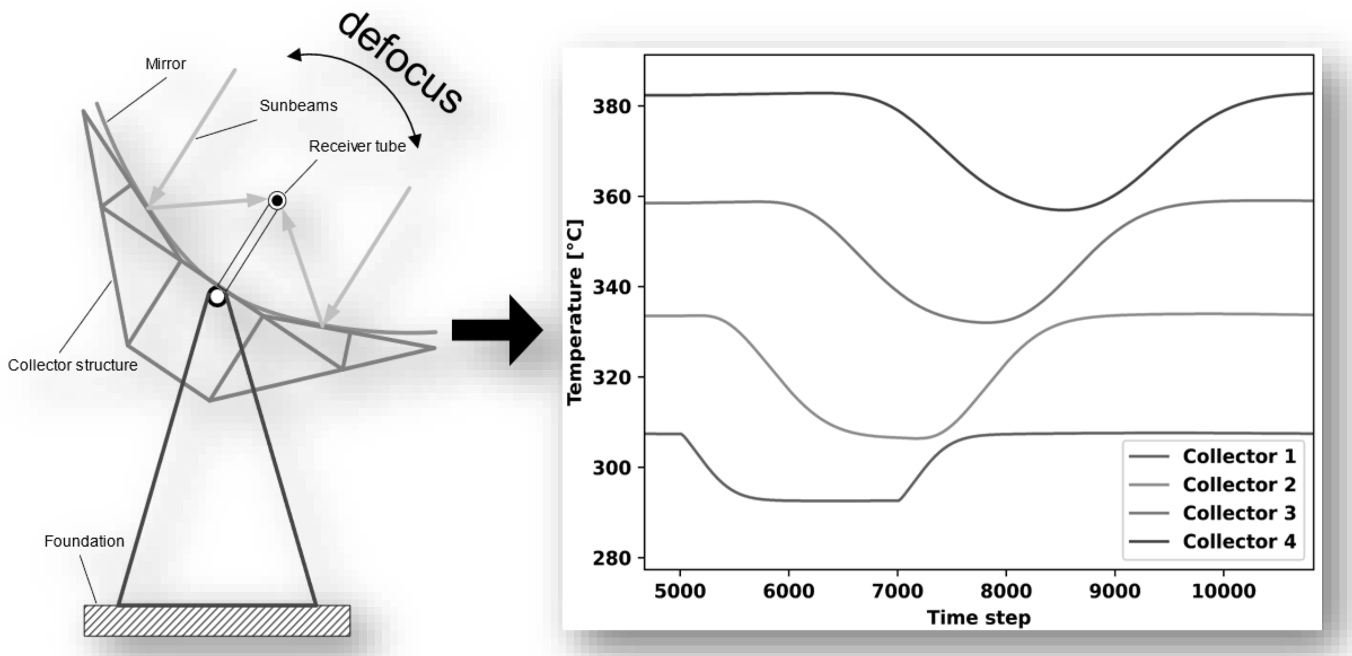
Thank you for your attention.

Any Questions?



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Impressum

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