Steam Drum Design for Direct Steam Generation

Experience from the TSE1 Kanchanaburi

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solarlite
plugged to the sun

TSE1 Plant Kanchanaburi

- First power plant with direct steam generation (DSG) and superheating in parabolic troughs

- Owner & Operator: Thai Solar Energy
- Planning and Solar field: Solarlite CSP Technology GmbH; T&N
- Operated since 2012
- First CSP in Southeast Asia
- Nominal power: 19,5 $MW_{thermal}$ / 5 MW_{el}
- Superheated steam: 30 bar/ 330 °C

- ~500 sensors installed
- Time resolution of about 1 minute
- A time span of 18 (2012/2013) months has been investigated by DLR within the KanDis project (funded by German BMWi)

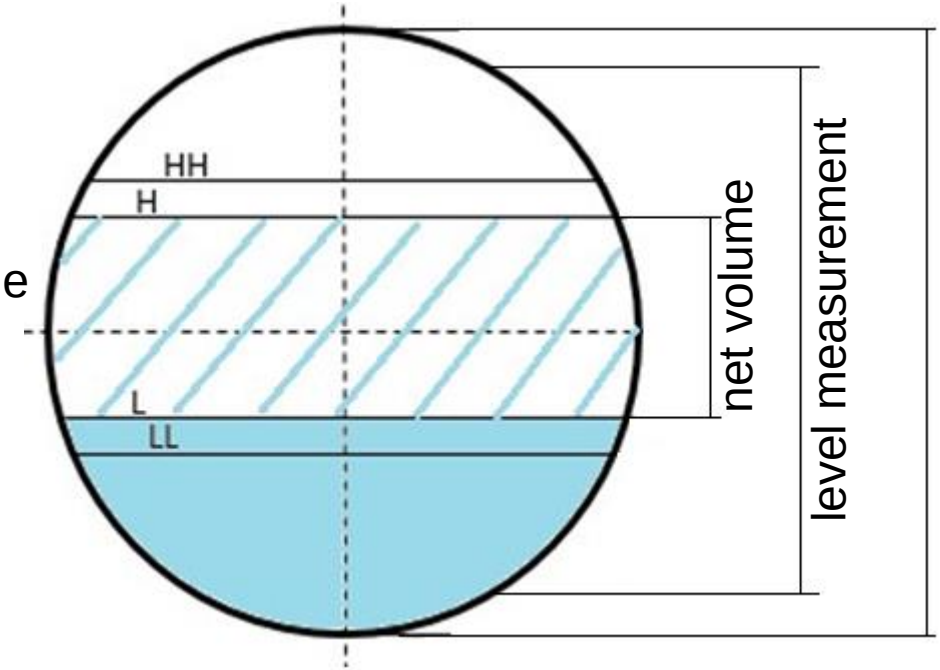
TSE1 Plant Kanchanaburi

Operational Experience of TSE 1 within the KanDis Project

- Stable operation was demonstrated
- Knowledge about flow behavior in DSG generated
- Superheating events in the evaporator could be observed and several factors were detected which might cause or prevent superheating in the evaporator
- The implemented control strategies were evaluated
- From the experiences with the TSE1 power plant conclusions could be drawn to improve the layout and control of future DSG plants
- Focus of this presentation: Steam Drum

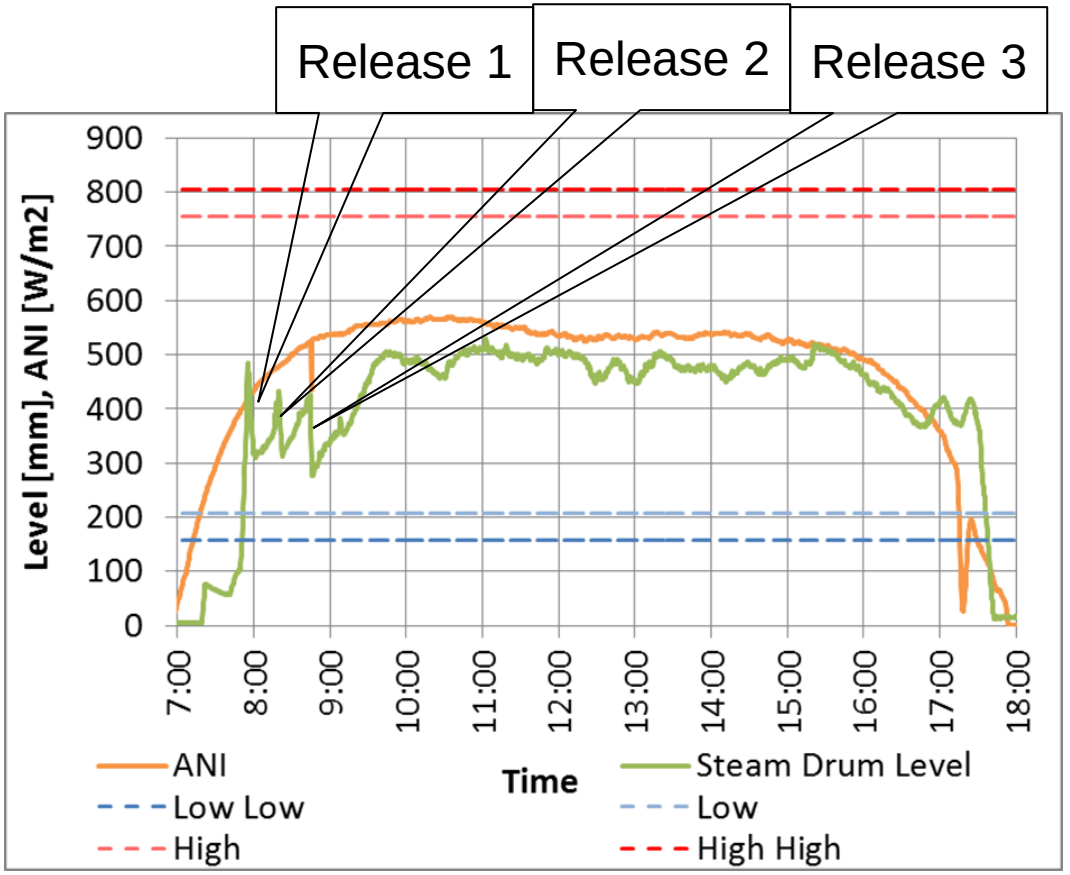
TSE1 Steam Drum Design

- Dynamic simulation to dimension the steam drum
  - Question: Surplus of water in the evaporator during start-up
  - Result: 54 % of the volume in the SF (absorber tubes and the outlet header pipes) at a mass flow of 16 kg/s
- Greater mass flows => smaller water surplus
- Additional space for control
- TSE1 SD is smaller to reduce costs
  - Additional atmospheric tanks
- Net volume 29 % of the SF volume
- Gross volume 74 % of the SF volume



Evaluation of Steam Drum Levels

During Start-up



Start-up:

- Evaporator is filled with water
- Within ~15 min. increasing volume of steam pushes water into SD

=>Raise of SD-level expected to be highest for start-ups

E.g. 14th of January 2013

- Saw-shaped profile

=>Water from SD is released to drain tank (3 times)

- 23 % water / 16 min
- > 48 % water / 2 h

Evaluation of Steam Drum Levels

Constant Irradiance

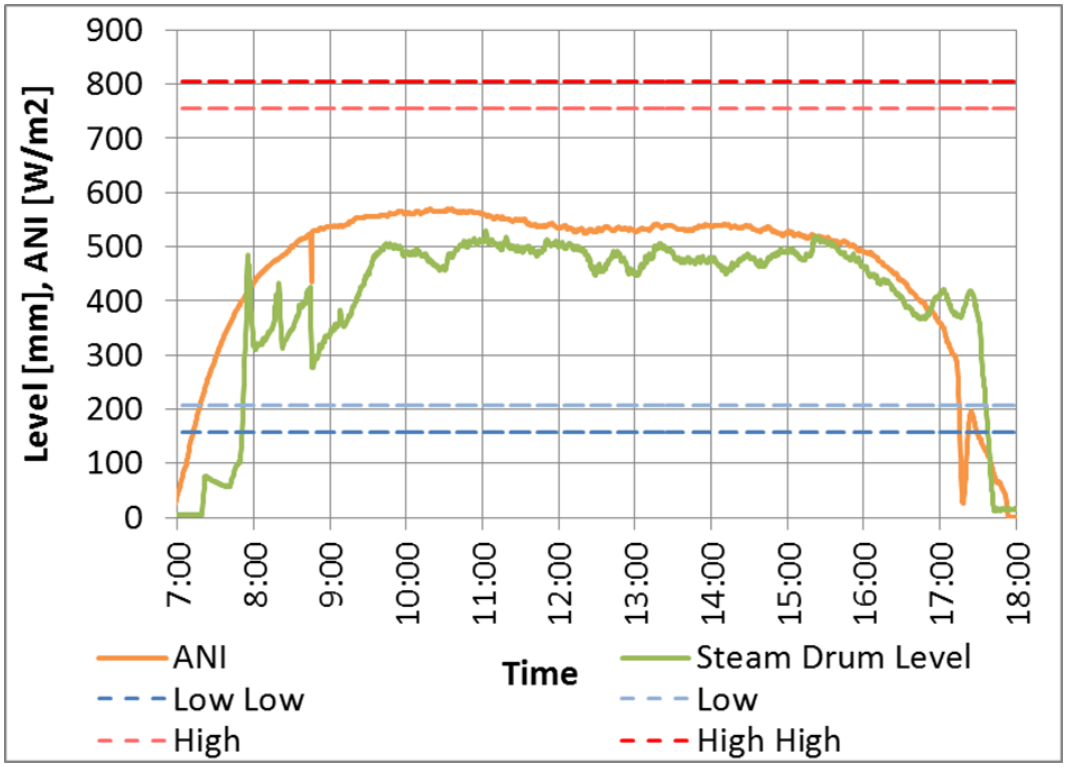
Expectation:

- Constant irradiance

=> Constant SD level

E.g. 14th of January 2013

- Good control
- Level relatively stable at about 500 mm



Evaluation of Steam Drum Levels

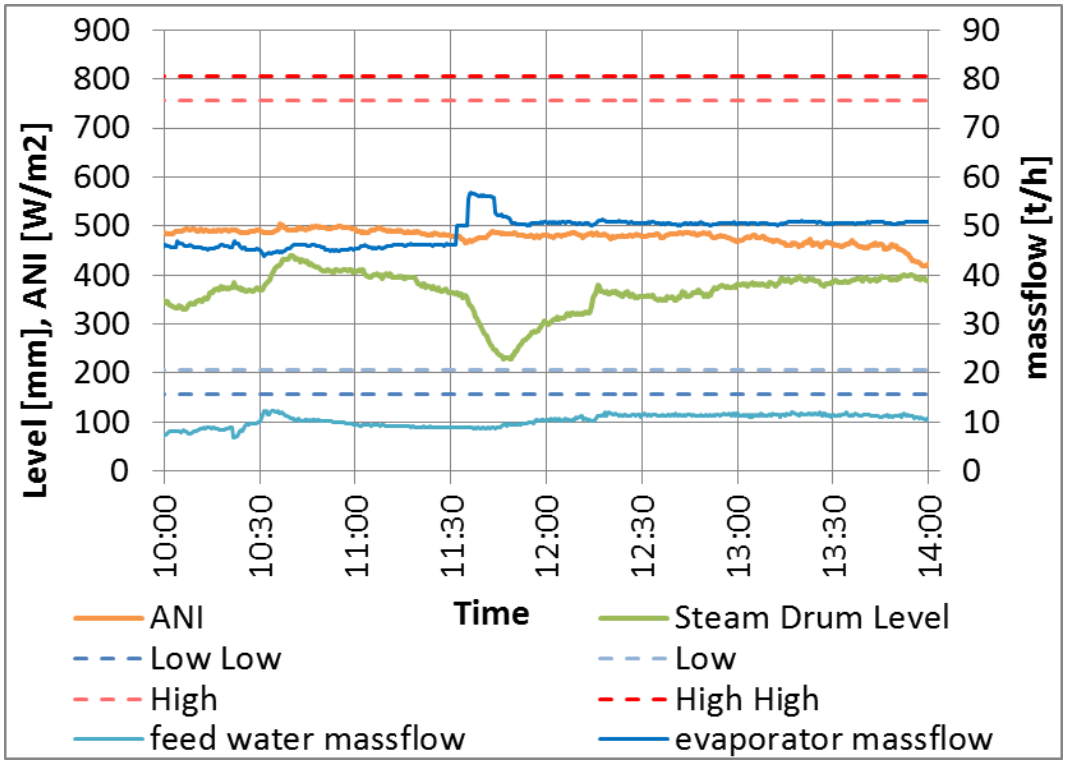
Constant Irradiance

On other days

- Level varies strongly
- Sometimes exceeds boundaries
- Caused by incorrect operation

E.g. 2nd of January 2013

- 11:30: recirculation mass flow 12.5 kg/s -> 15.3 kg/s
- Feed water mass flow const.
- Extra water taken from SD
- Level already low
  =>Low limit almost crossed



➢ Important lesson: SD volume depends strongly on recirculation mass flow

Evaluation of Steam Drum Levels

Constant Irradiance

Causes for level change during constant irradiation:

- Changes in the supply of feed water
- Changes in the number of focused mirrors
- Changes in the mass flow recirculating from steam drum to evaporator

Limits can be exceeded depending on:

- State of the steam drum
- Gradient of the changes

➢ An improved operation strategy thus shall consider the actual status of the steam drum and the related changes in the solar field.

Evaluation of Steam Drum Levels

Fluctuating Irradiance

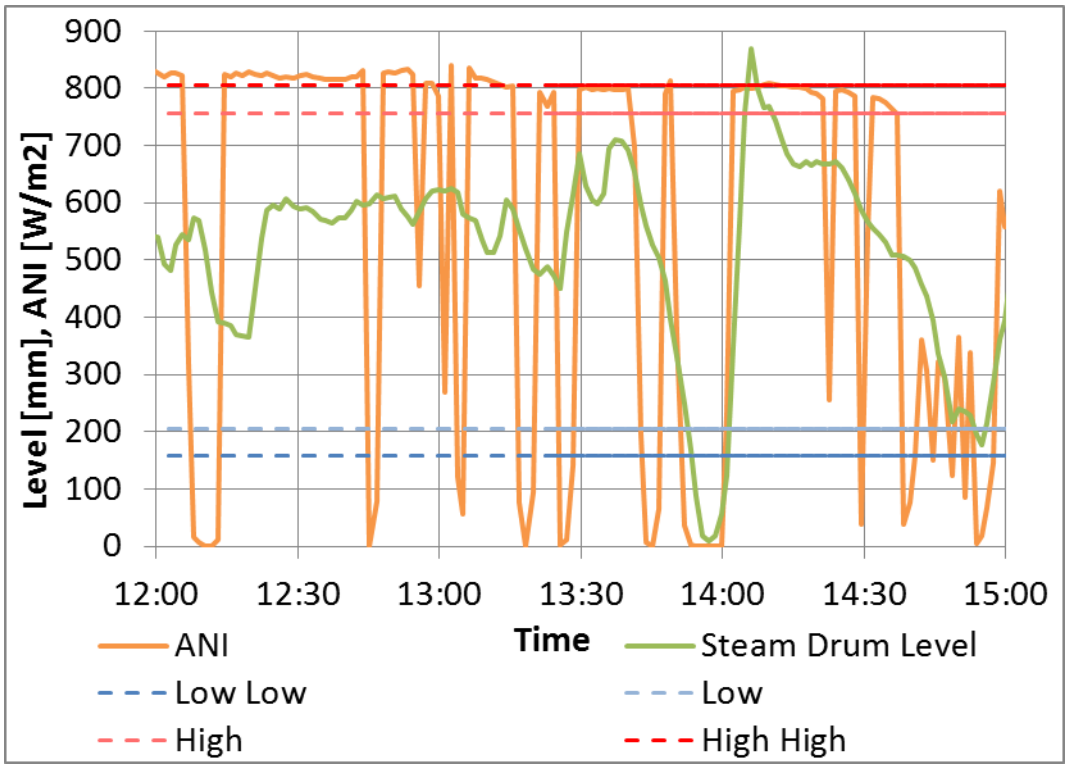
Varying evaporation conditions

=> Varying steam volume fraction

=> Limits often exceeded

E.g.13th of July in 2012

- Good operation until 13:45
- 13:45 o`clock: SD at high level
  - ANI: 800 W/m² -> 0 W/m²
  - SD level: -> 0 mm
    =>Limits crossed
- 14:05: ANI back to 800 W/m²
  - SD level overshoots
  - 870 mm/ 9 minutes
  - 45 % of overall water



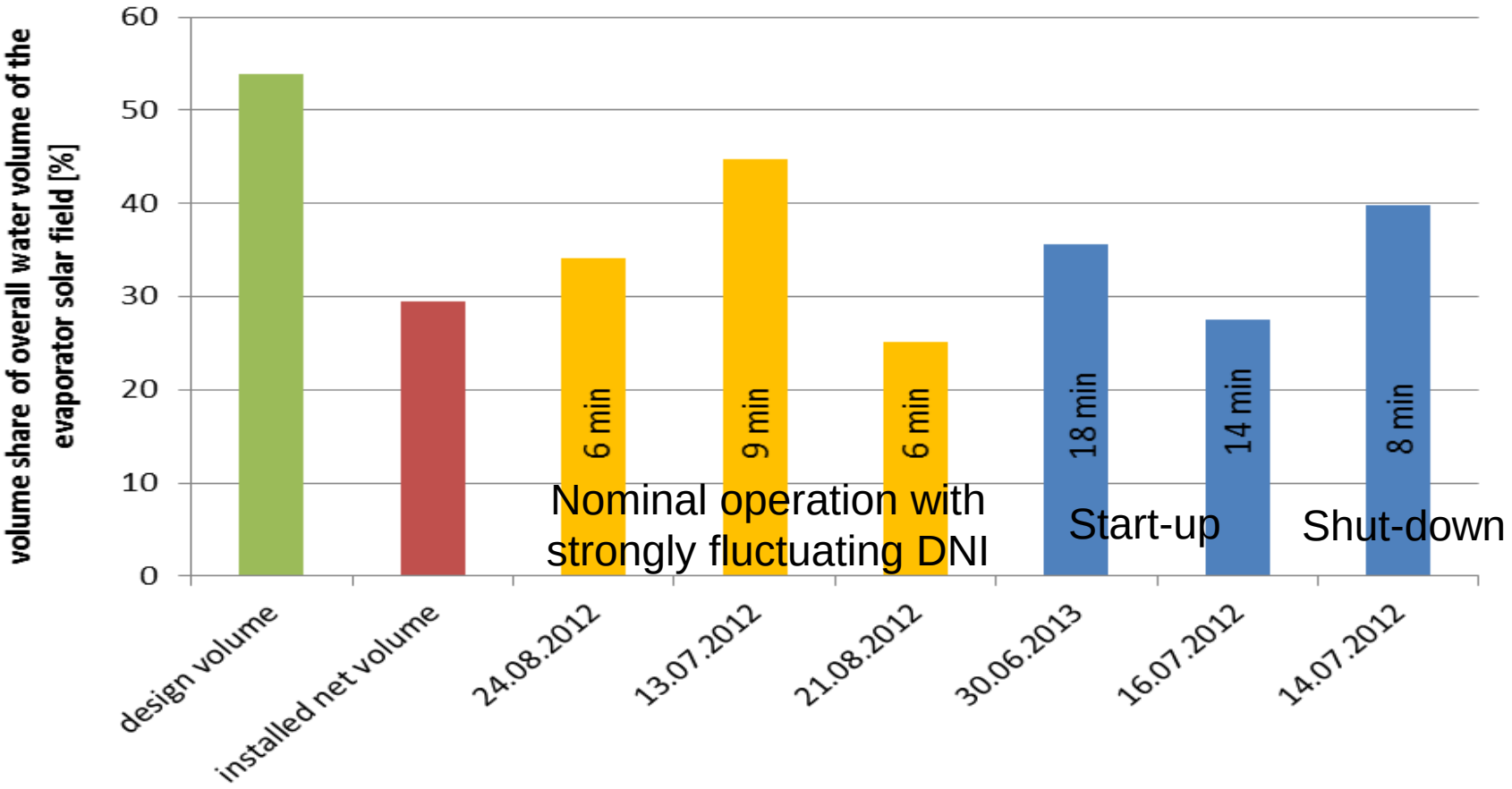
Evaluation of Steam Drum Levels

Fluctuating Irradiance

- Buffer function works well
- But high number of incidents with limits exceeded due to poor operation
- Crossing the steam drum level limits could be prevented by:
  - A bigger steam drum volume
  - A higher recirculation rate
  - An improved automatic control
  - A better educated operation personal

➢ One criterion for the design of the drum size is thus what kind of irradiance disturbances shall be buffered securely and what kind of disturbances and related ‘off-design’ operations can be accepted.

Evaluation TSE1 SD Design



Events with high transients and without water release to other tanks

Evaluation TSE1 SD Design

- Installed TSE1 SD with 29% of SF volume is only sufficient in combination with additional tanks

- Additional control strategies should be implemented:
  - Recirculation mass flow control should consider steam drum level
  - Set level value should be determined regarding the operating stage:
    - SD level should be low before start-up
    - SD level should be high before shut-down
  - Control of draining SD to other tanks needs to be automated and to depend on the SD level and its gradient

Conclusion for Future SD Design

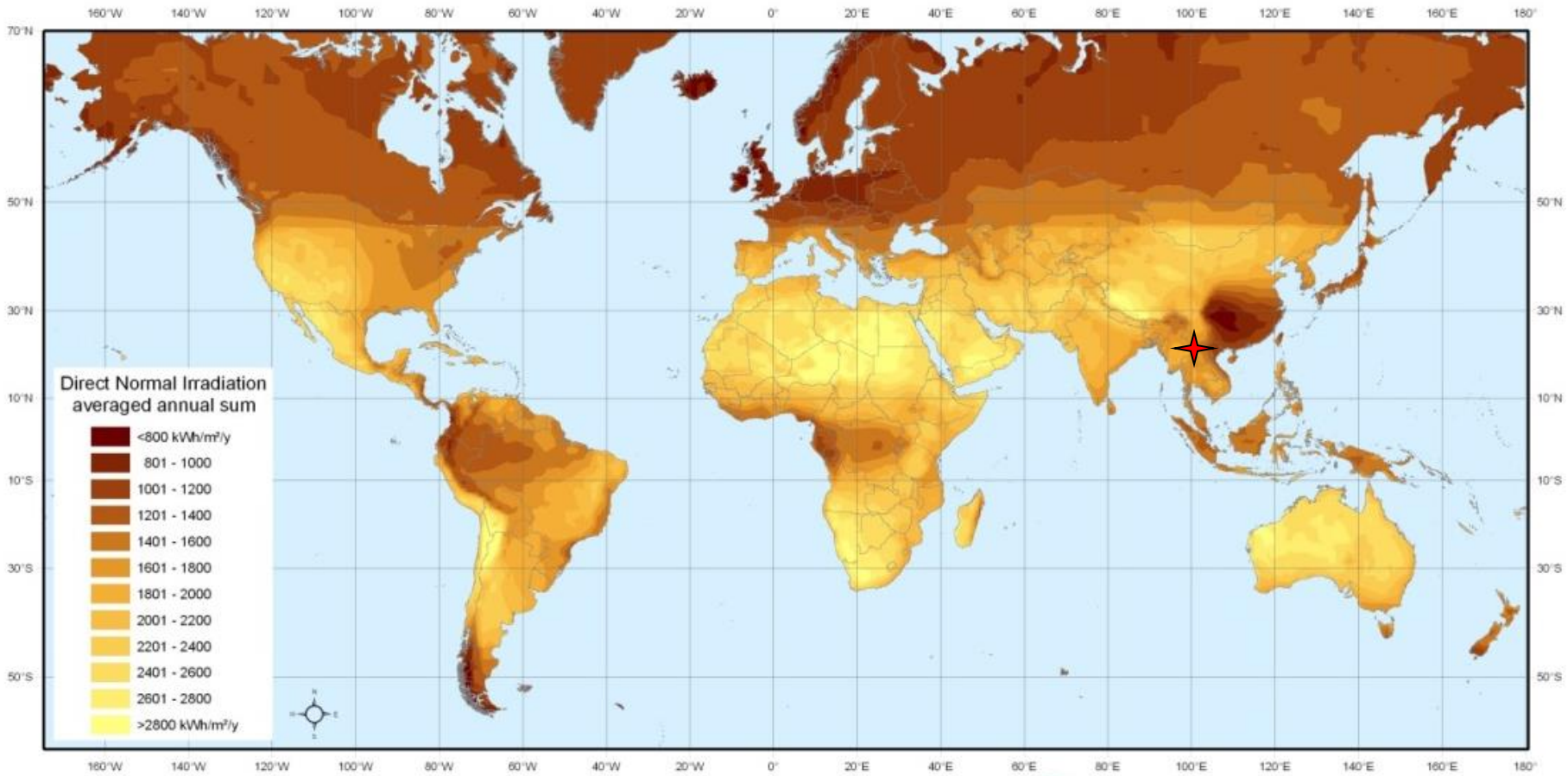
- TSE1 SD design of 54 % of the overall solar field volume is sufficient
- Volume cannot simply be extrapolated to future plants
  - Design depends on:
    - steam parameters (pressure, design steam quality etc.)
    - feed water temperature
    - various dynamic interactions
  - ➢ Dynamic simulation
- Volume can be reduced when combined with other tanks

- SD level during operation is highly dependent on fluctuating DNI and control strategy
  - ➢ At sites with many clouds and fluctuating DNI SD should be larger

Thank you for your attention

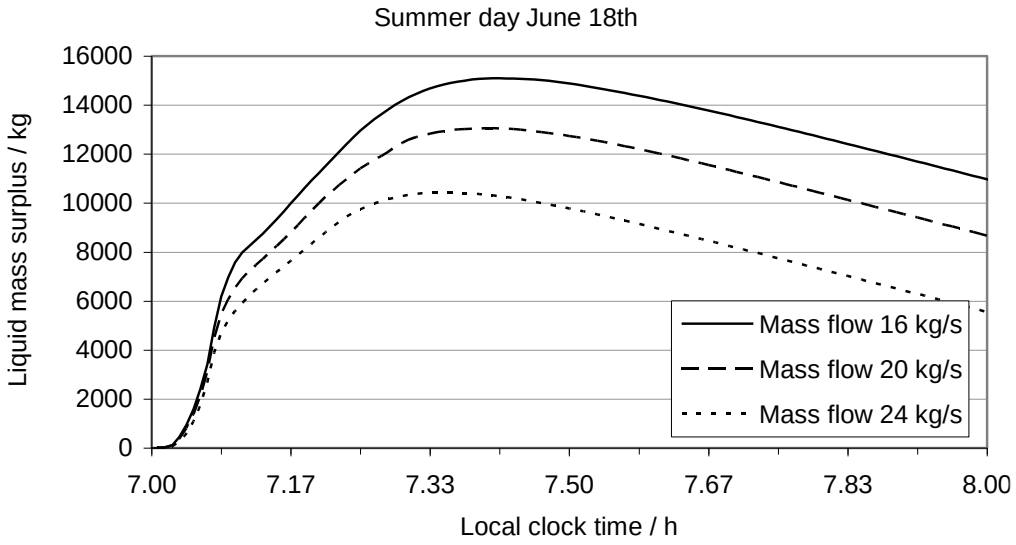
The *KanDis* project has been funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestag.

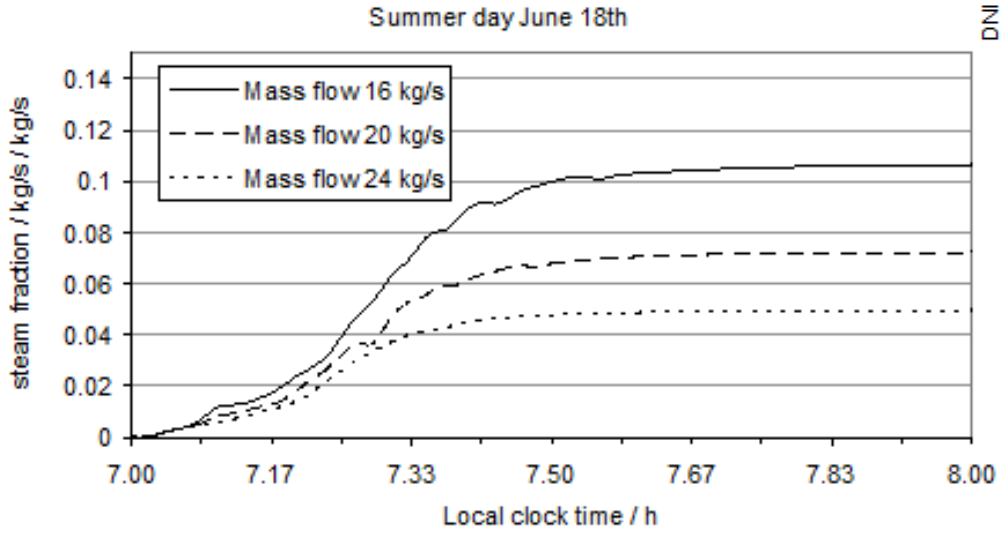
Direct Normal Irradiation (DNI)

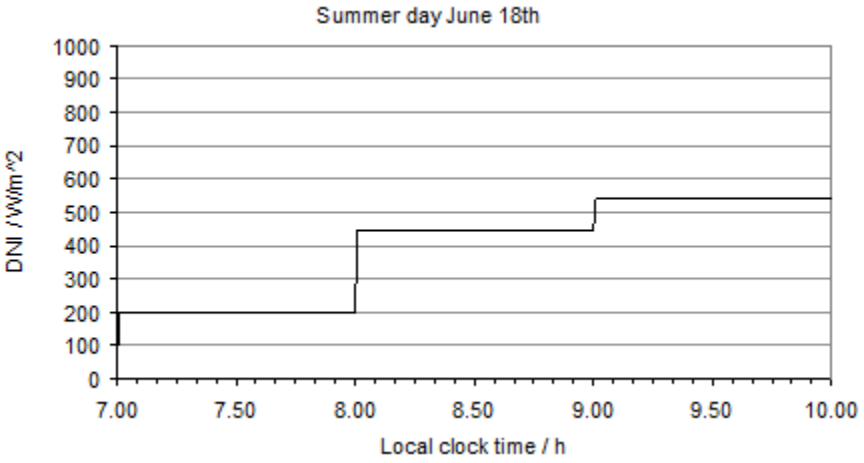


Data based on SSE 6.0 dataset for a 22-year period (July 1983 - June 2005)
(http://eosweb.larc.nasa.gov/sse/)

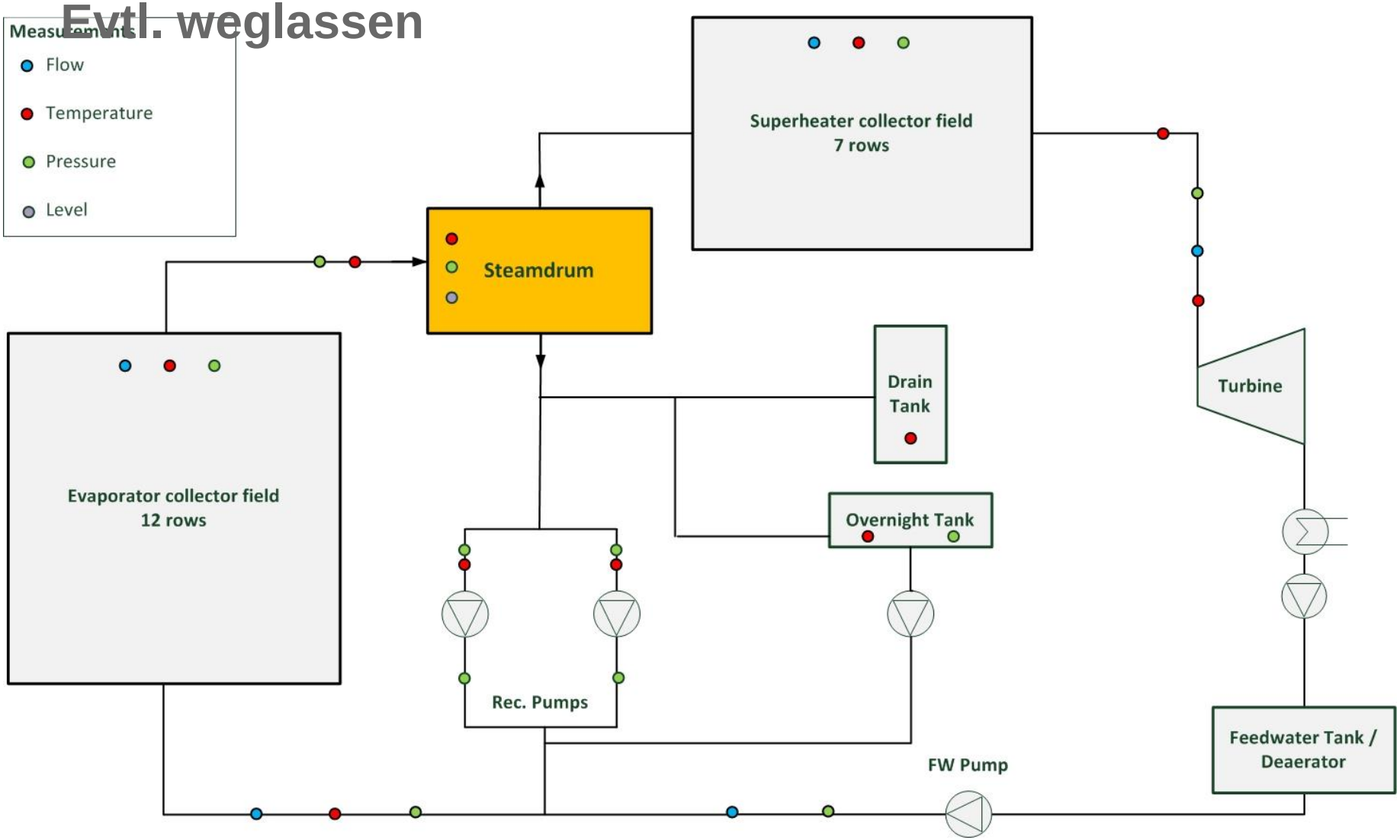
Map created and map layout by DLR 2008
(http://www.dlr.de)


Summer day June 18th
Liquid mass surplus / kg
16000
14000
12000
10000
8000
6000
4000
2000
0
7.00
7.17
7.33
7.50
7.67
7.83
8.00
Local clock time / h
Mass flow 16 kg/s
Mass flow 20 kg/s
Mass flow 24 kg/s


Summer day June 18th
steam fraction / kg/s / kg/s
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
7.00
7.17
7.33
7.50
7.67
7.83
8.00
Local clock time / h
Mass flow 16 kg/s
Mass flow 20 kg/s
Mass flow 24 kg/s


Summer day June 18th
DNI / W/m^2
1000
900
800
700
600
500
400
300
200
100
0
7.00
7.50
8.00
8.50
9.00
9.50
10.00
Local clock time / h

Evtl. weglassen



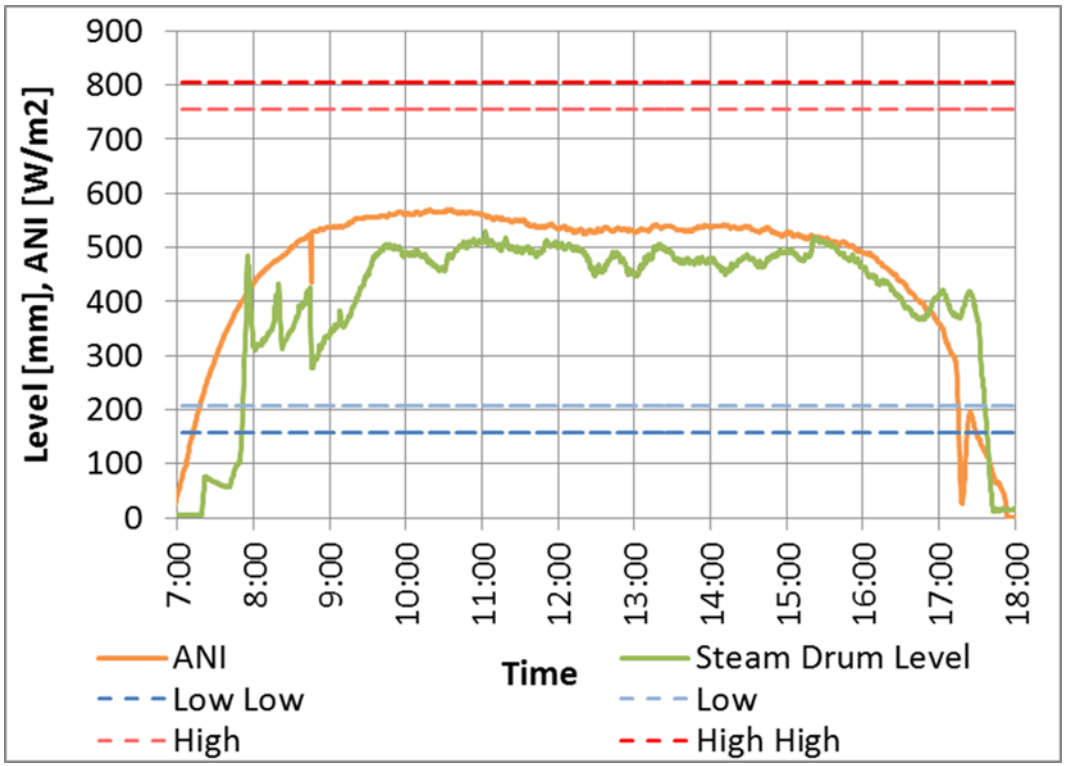
Evaluation of Steam Drum Levels

Fluctuating Irradiance

- Shut-down:
- At evening evaporation stops
- Decreasing volume of steam
- Draws water from SD
- Level decreases rapidly

E.g. 14th of January 2013

- 21 % /18 min.



➢ Feed water control has to provide sufficient water to fill the evaporator field for the night.