Modeling and analyzing solar heating plants to predict thermal performance

2nd International Conference on Smart Energy Systems and
4th Generation District Heating, Aalborg, 27-28 September 2016

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In cooperation with Rambøll and OE3i

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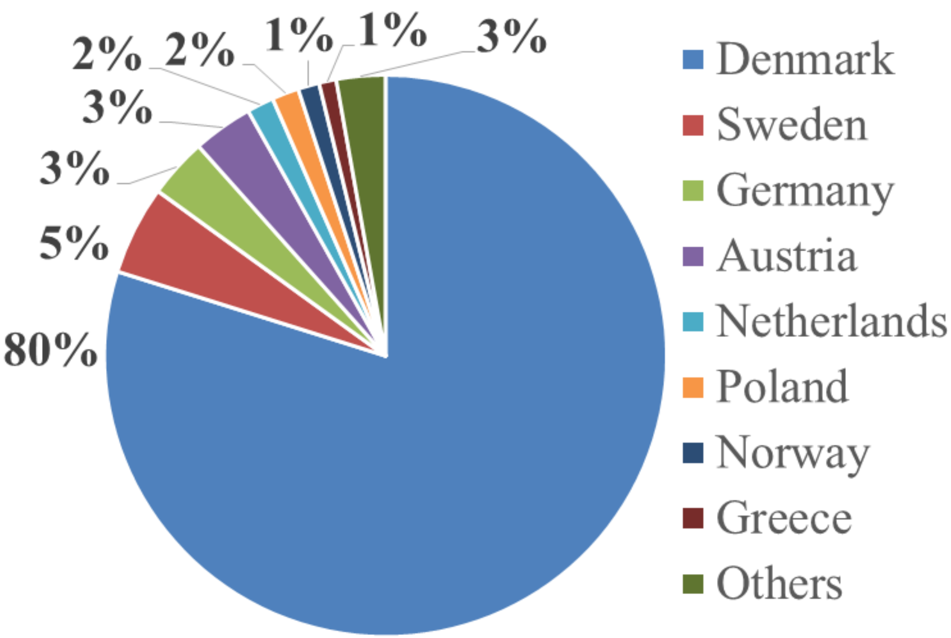
Agenda

I. Introduction
  – Solar heating plants in EU
  – Aim of the study
II. Method
  – Reference system
  – Modeling approach
III. Results
  – Validation model
  – Prediction model
  – Optimization
IV. Discussion

I. Installed solar collector area in Europe until 2015



Solar heating plants higher than 700 kW_{th}

Facts of solar heating plants

- >1,000,000 m² in EU
- >800,000 m² in DK
- 1.3 mio. m² in DK expected until end of 2016

- 29 out of 31 plants ≥ 10,000 m² in DK
- Economy of scale: build large
  - 156,694 m² (110 MW_{th}) planned in Silkeborg

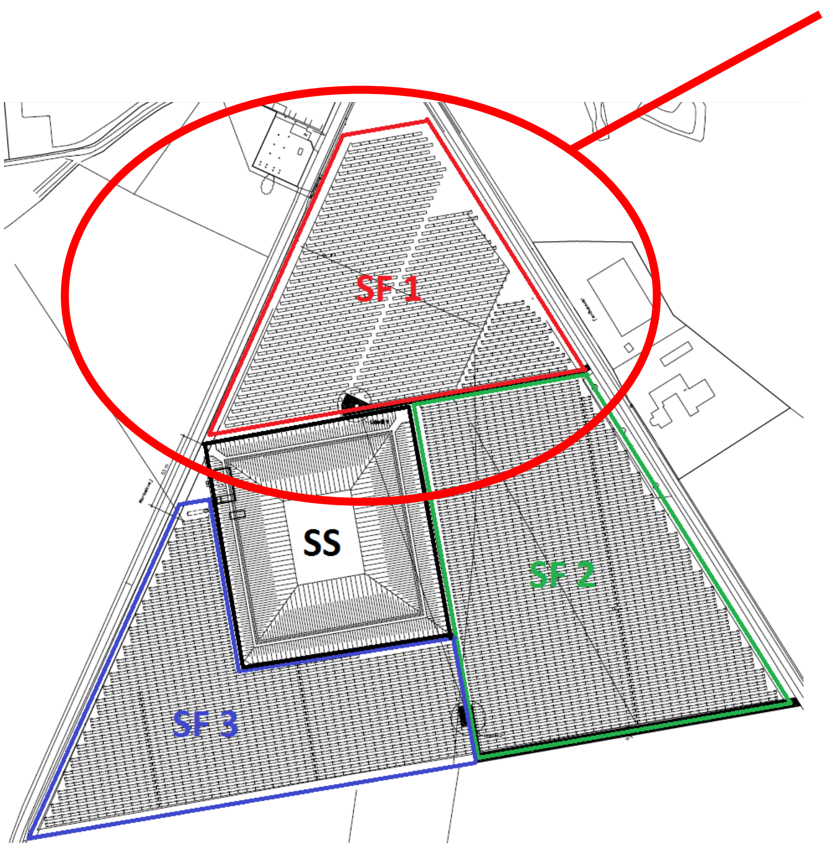
I. Aim of the study

<u>Model development</u>

- Predict thermal performance of solar heating plants
- Based on weather data
  - solar irradiation, ambient temperature and wind speed
- Efficient and flexible
- Compatible with energy system optimization tools
  - e.g. Mentor Planner

<u>Overall aim: optimize energy system</u>

II. Reference System: Gram



Facts of solar field 1

- 7 MW_{th} - 10,073 m²
- 802 solar collectors (Arcon HT-SA)
- 13 collectors in a row
- 15 % solar fraction in DH system

Available data

- 08.05. - 29.09.2015
- 10 min time step
  - $\dot{Q}_{u,tot}$ Total energy output
  - $\dot{V}_{tot}$ Total volume flow rate
  - T_{in} Inlet temperature
  - T_{out} Outlet temperature
  - T_a Ambient temperature
  - G_{sun} Solar irradiation on collector tilt

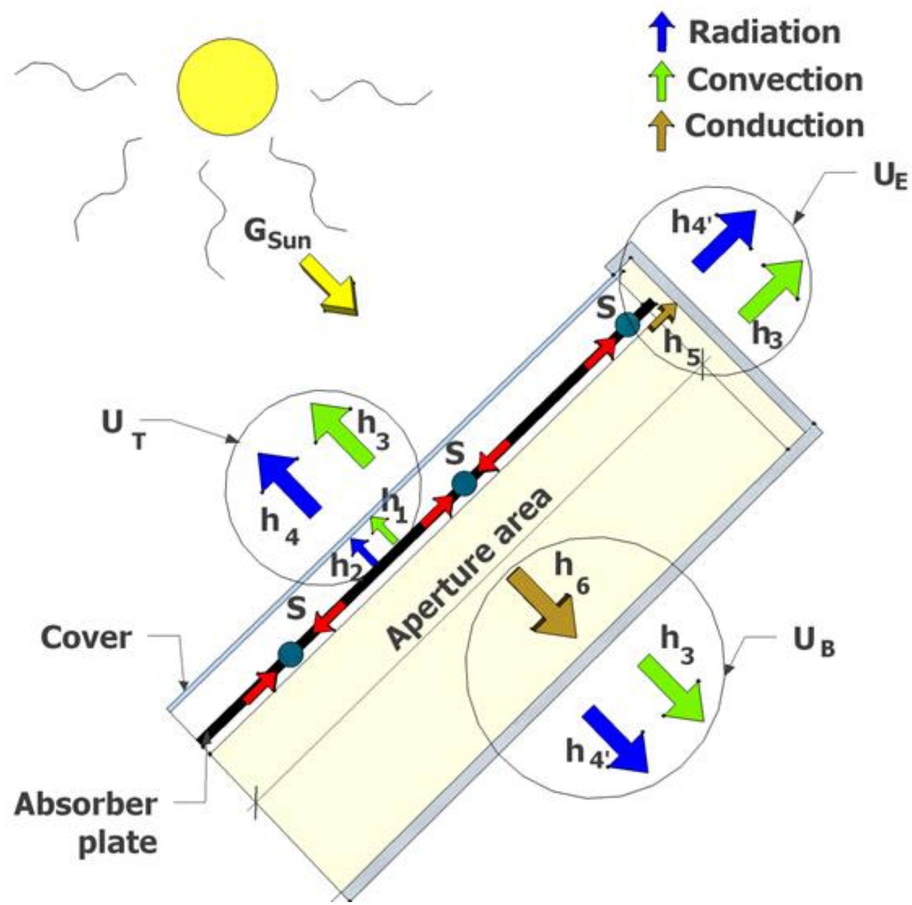
II. Modeling approach

Weather data

Plant data

Model

Calculation of thermal performance



Model:

- Single solar collector

$$\dot{Q}_{u,tot} = \dot{Q}_{u,col} * n_{col}$$

- Basic heat transfer

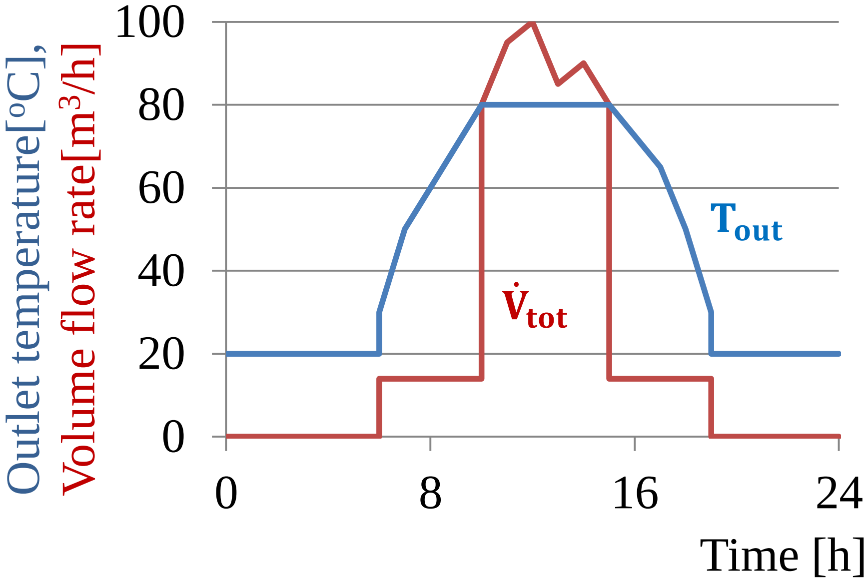
II. Modeling approach

Validation model

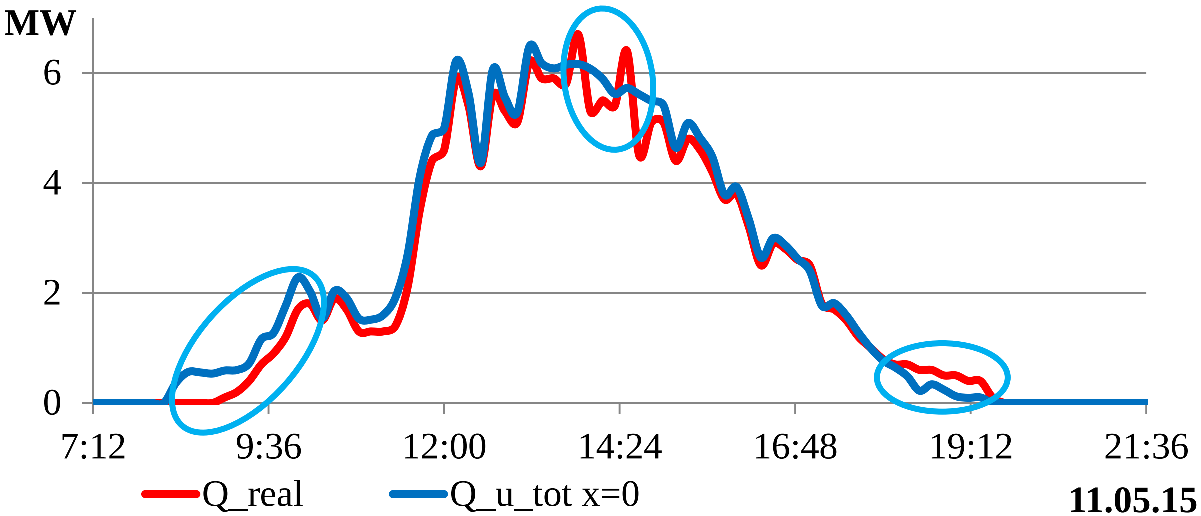
- Inputs: $\dot{V}_{tot}$, T_{in}, G_{Sun}, T_a, u_{wind}
- Outputs: $\dot{Q}_{u,tot}$, T_{out}
- Representation of system inertia
  - Constant time delay x for T_{out}
  - Variation of delay
    - 0-70 min
    - Best fit at 40 min (x=4)
- Modeling of entire period
  - Comparison with measurements

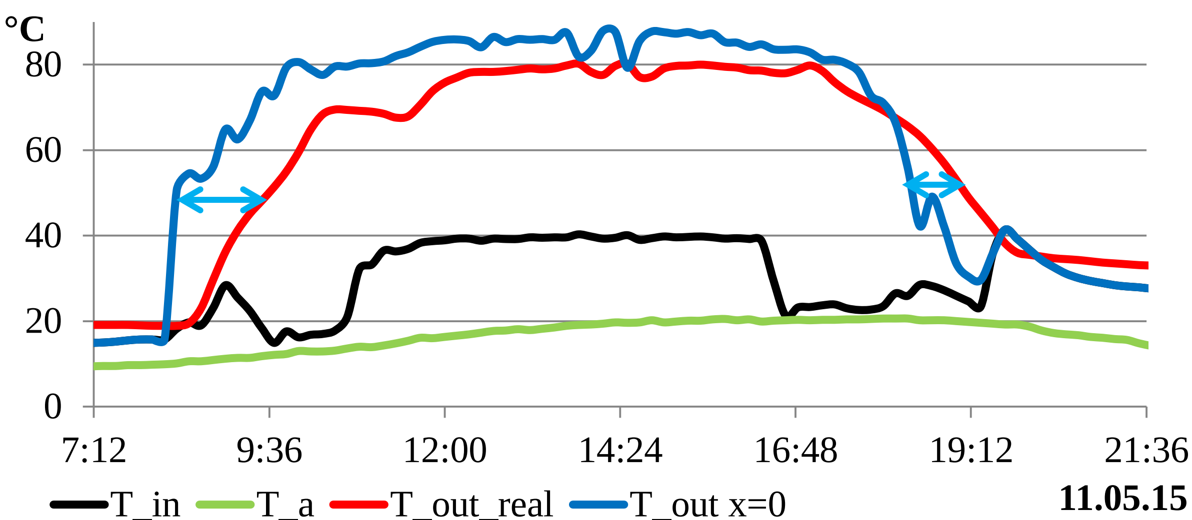
Prediction model

- Inputs: ~~$\dot{V}_{tot}$, T_{in}~~, G_{Sun}, T_a, u_{wind}
- Instead: $\dot{V}_{min}$, $T_{out,max}$, $T_{in,24h}$, $T_{in,24h,real}$
- Outputs: $\dot{Q}_{u,tot}$, T_{out}, $\dot{V}_{tot}$, T_{in}



III.Validation model - no time delay

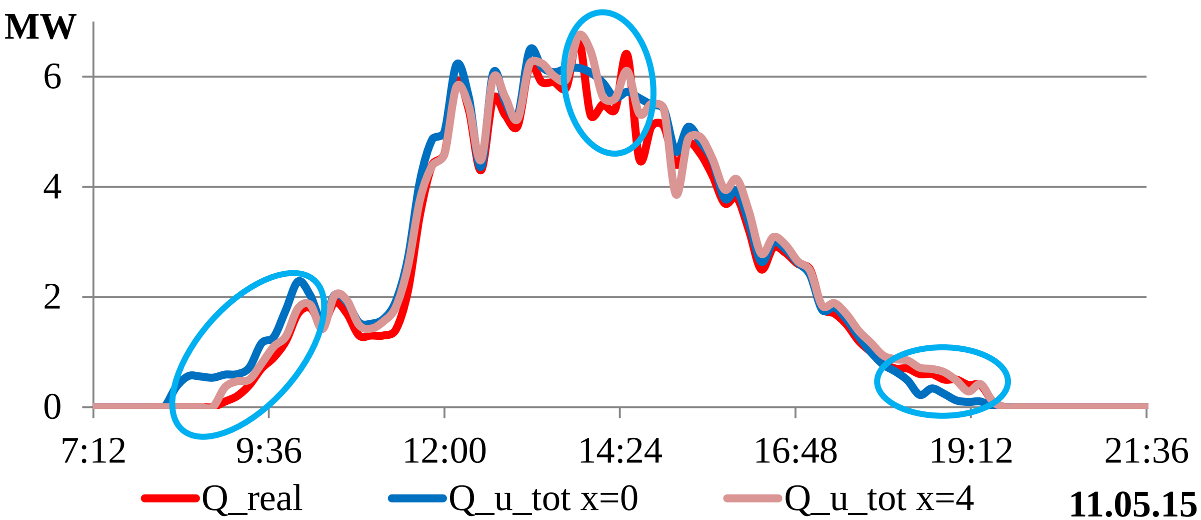


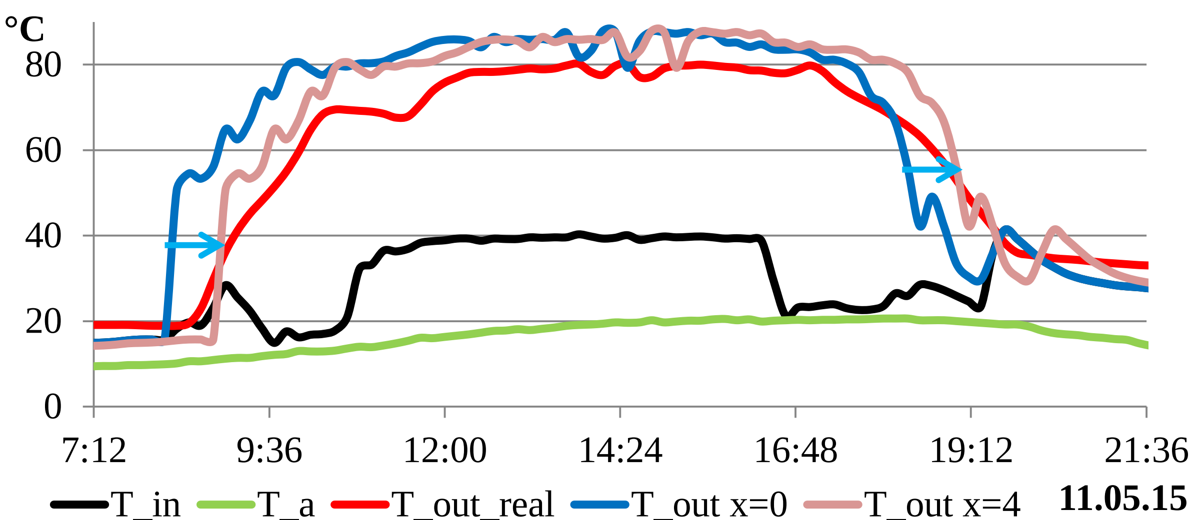


Findings

- Good representation
- Too high in the morning
- Too low in the evening
- Not all peaks
- Temperature increases and decreases too early

III.Validation model – 40 min time delay





Findings

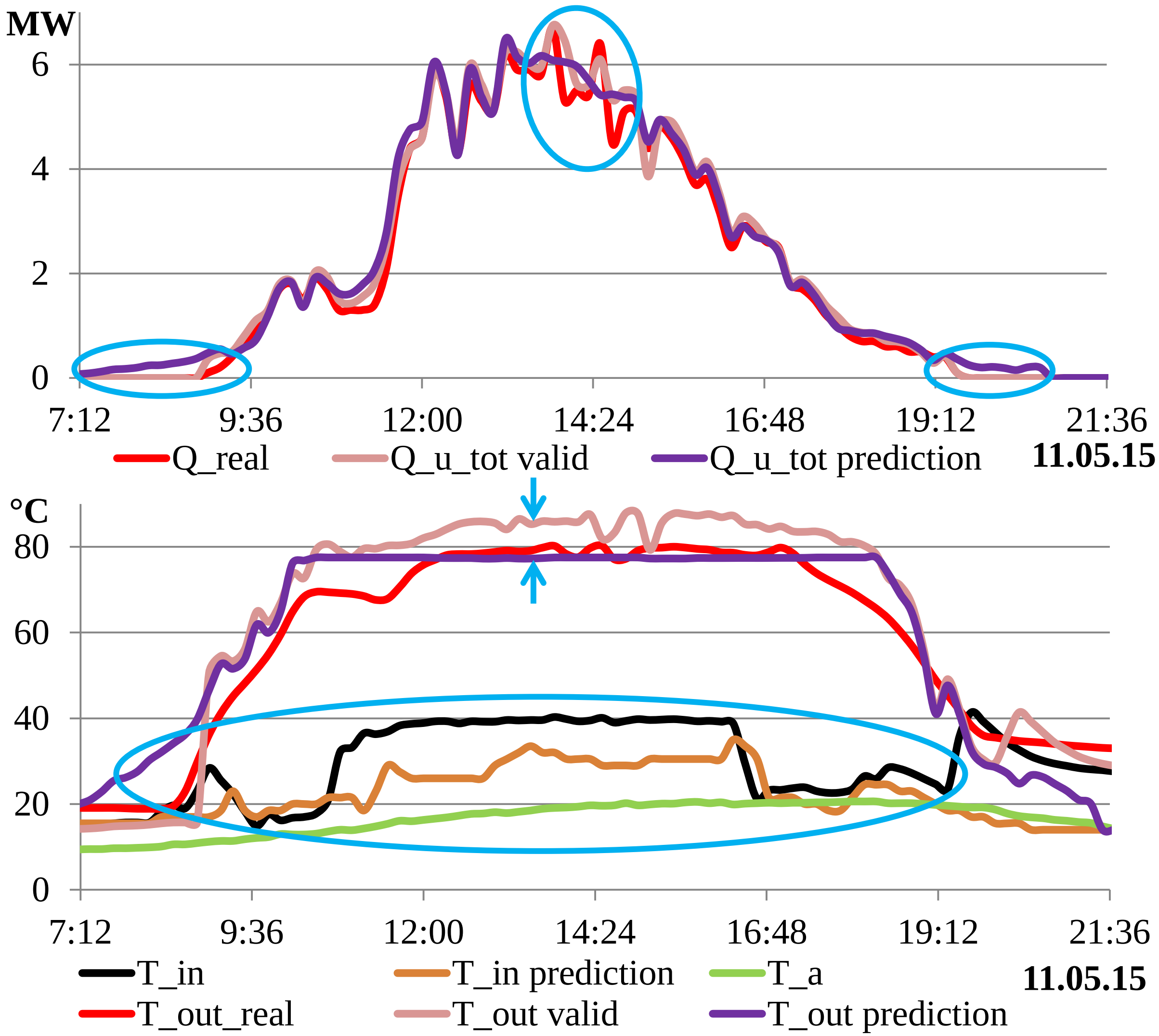
- Good representation
- Too high in the morning
- Too low in the evening
- Not all peaks
- Temperature increases and decreases too early

Time delay of 40 min

- Morning and evening better represented
- Peaks better represented

R^2	$\dot{Q}_{u,tot}$	T_{out}
x=0	0.980	0.565
x=4	0.989	0.915

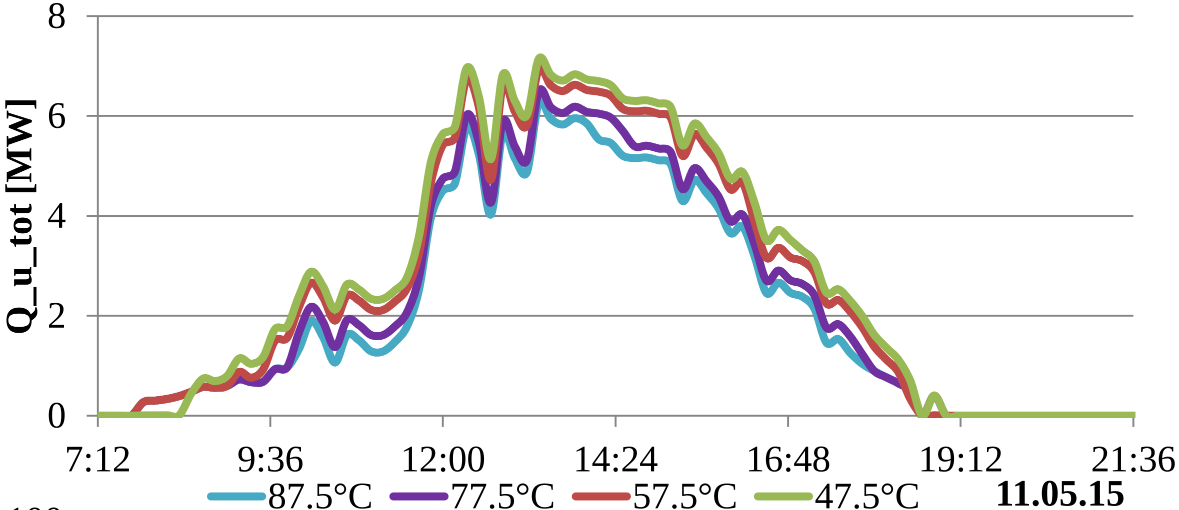
III.Prediction model

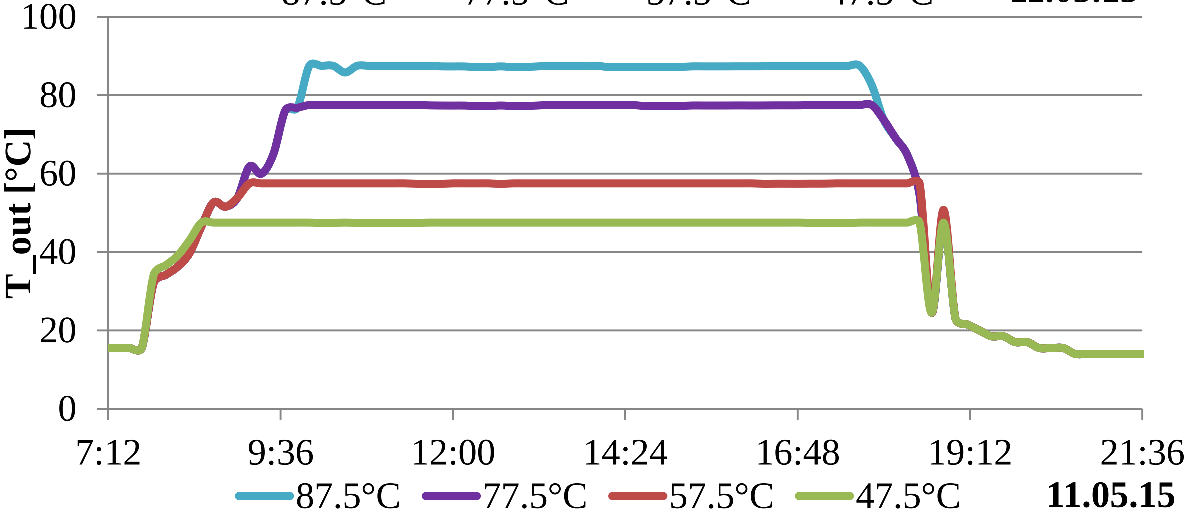


Findings

- Good representation
- Not all peaks
- Morning/evening slightly too high energy output
- Lower max. temperature than validated model
- Inlet temperature follows similar trend (beginning of period)

III.Optimization





Approach

- Vary $T_{out,max}$

Findings

T_{out} [°C]	Q_sum [MWh]	η [%]
47.5	40	63
57.5	38	59
77.5	33	52
87.5	31	48
G_sun	63	

- Optimize energy output based on demand
- Higher efficiency at lower temperature

IV.Discussion

Summary

- Solar heating plant modelled by single collector
- Considering system inertia is important
- Prediction of thermal performance possible
- Advantages for energy system
  - Lower heat production
  - Higher flexibility
  - Optimization of flow temperature

Challenges

- Prediction of solar irradiation (cloud covers)
- Improve system inertia representation based on irradiation, volume flow rate
- Apply model to other solar heating plants

Thank you for your attention

Questions?

References

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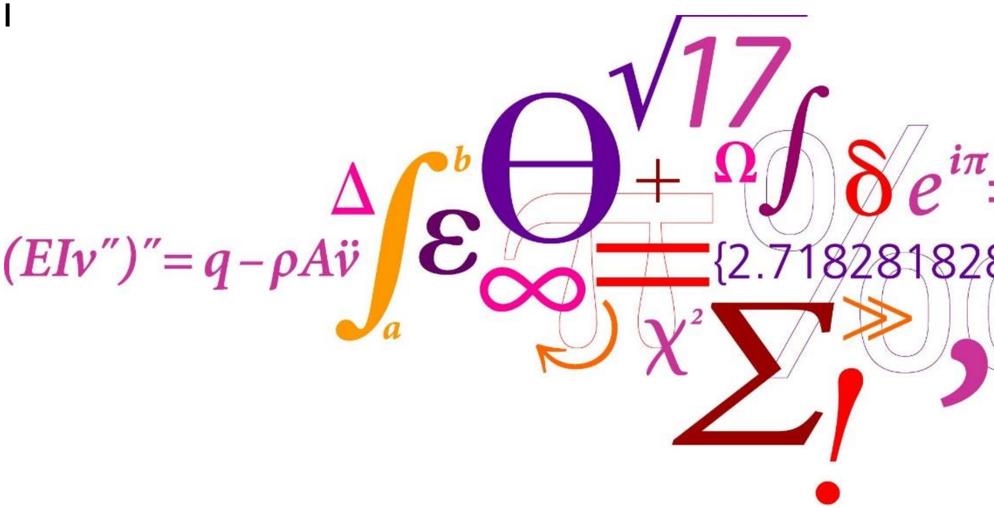

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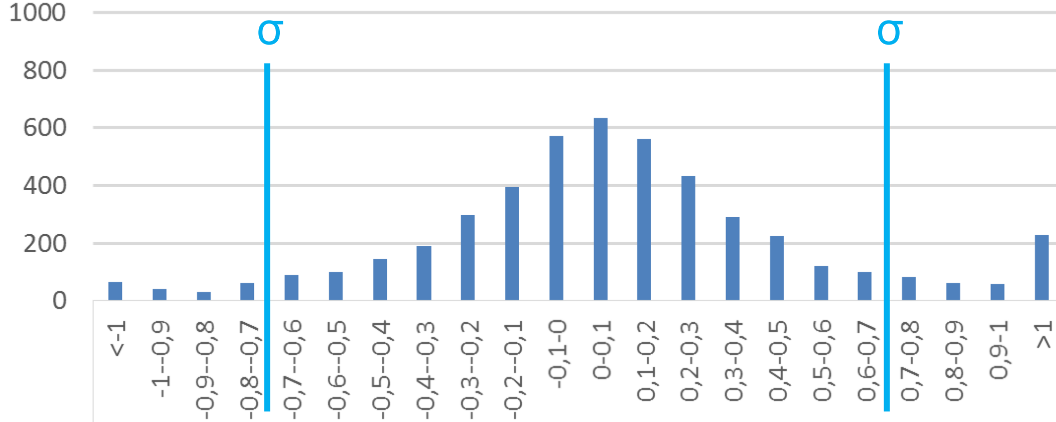
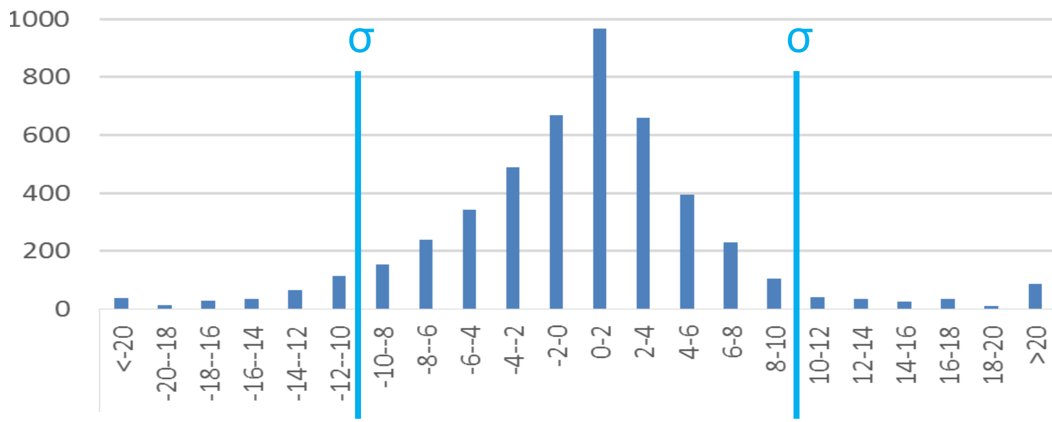
III.Prediction model – deviation ≥ 1 MW

Frequency of deviation



Deviation compared to measurements [MW]



Deviation compared to measurements [^oC]

Findings

- Good distribution for entire period (4774 data points)
- Some extreme values

- $\sigma(\Delta\dot{Q}_{u,tot,\geq 1MW})=0.643$ MW
- $\sigma(\Delta T_{out,\geq 1MW})=9.349$ ^oC

- Measurement error
  - $\dot{V}_{tot}$ ≈ 0.2 %
  - T_{in} ≈ 2 %
  - G_{sun} ≈ 5 %