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CARNOT User Meeting, Innsbruck, 2022-07-01

Development of control concepts for heat exchangers for highly flexible usage in the test facility “District LAB” with the CARNOT blockset

Dennis Lottis

Supported by:

Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

»

Low temperature district heating is one of the most efficient technology solutions to achieve 100% renewable and GHG emission-free energy systems on a community level. «

Final Report of IEA DHC Annex TS1,
FUTURE LOW TEMPERATURE DISTRICT HEATING DESIGN GUIDEBOOK

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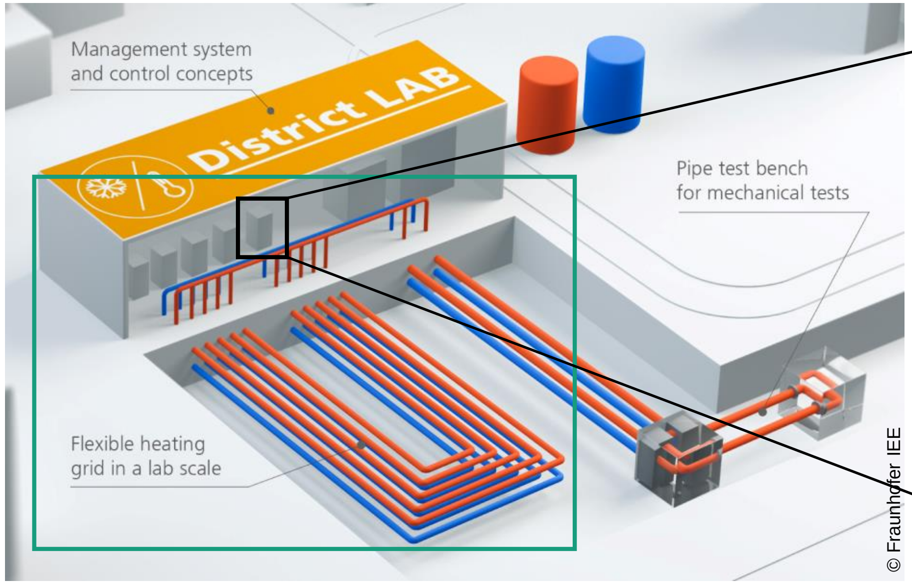
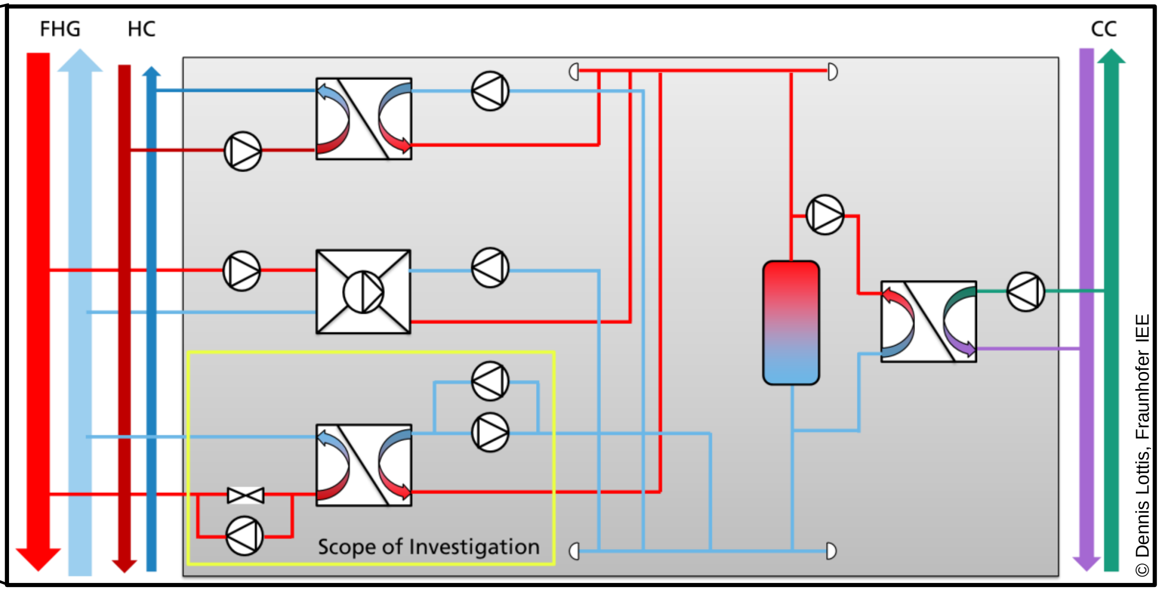
Scope of the Investigation





- Joint project "UrbanTurn“ funded by the Federal Ministry for Economic Affairs and Climate Action: suitable transformation measures for existing district heating (DH) networks
- For this: Experimental facility for DH applications "District LAB" by Fraunhofer IEE in Kassel
- In this work: Focus on the flexible heating grid (FHG)

- Hardware-in-the-loop (HIL) units should map producer, consumer or prosumer in the FHG
- Heat removal or supply via secondary circuits: Hot Circuit (HC), Cold Circuit (CC)
- Interaction with the FHG via heat exchanger
- **Necessary: Control of heat flow and secondary side outlet temperature simultaneously**

More information to the District LAB: https://www.iee.fraunhofer.de/en/laboratories/District_LAB.html

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Related Approaches

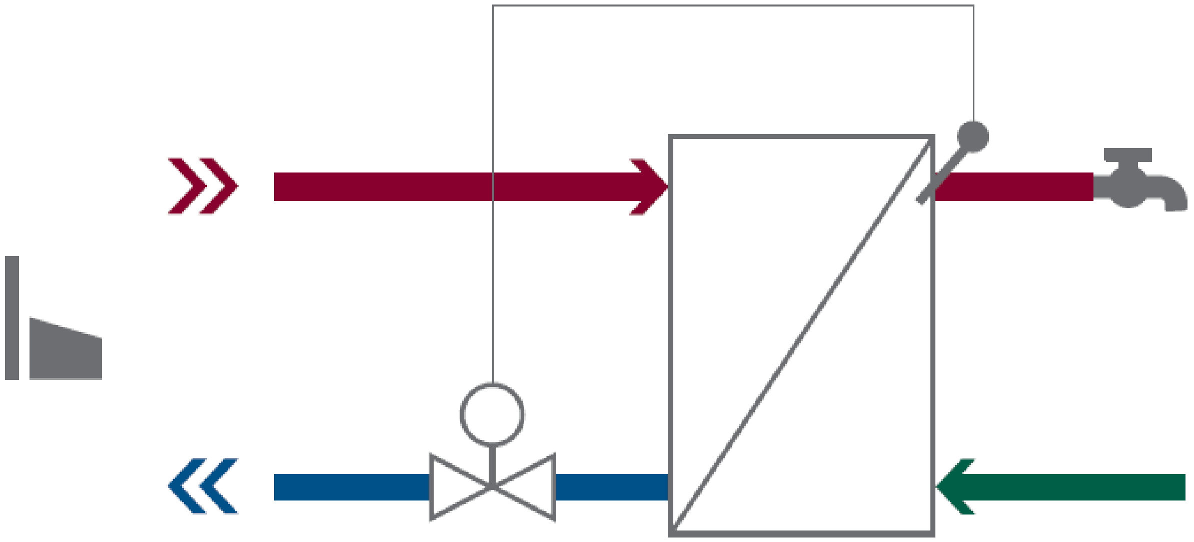
Special Control Task for Heat Exchangers (HEx)

- Typically only one outlet temperatures is controlled
- Commercial DH house transfer stations: Secondary side outlet temperature is controlled by a primary side valve
- Scientific literature: No solution for a comparable control task found; only for temperature controls

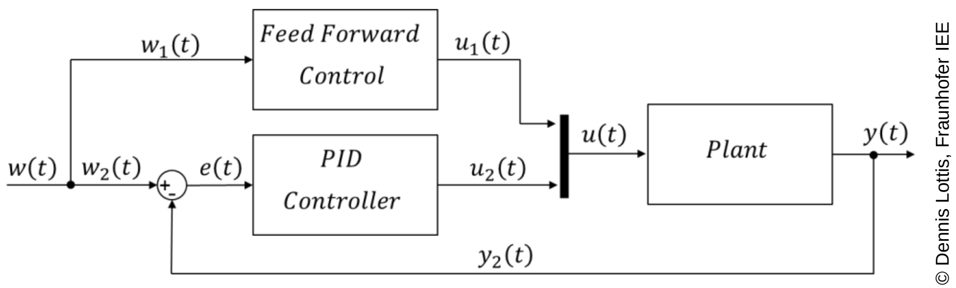
Development of own two variable control

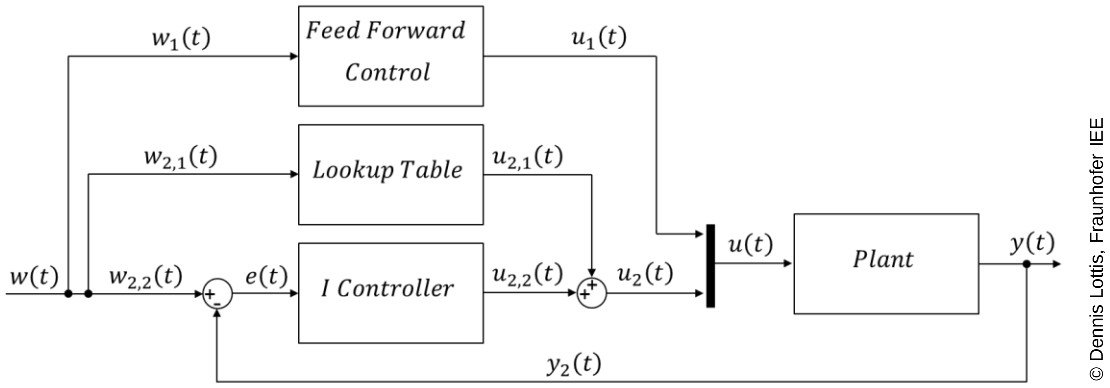
- Cascaded Control?
  - Similar time behaviour of the two control circuits because of their dependency on the heat capacity of the HEX => Does not work
- Idea: Decoupling with a Feed Forward Control based on:

$$\dot{Q} = \dot{m}_{sec} \cdot c_{p,sec} \cdot \Delta T_{sec}$$



Developed Control Concepts





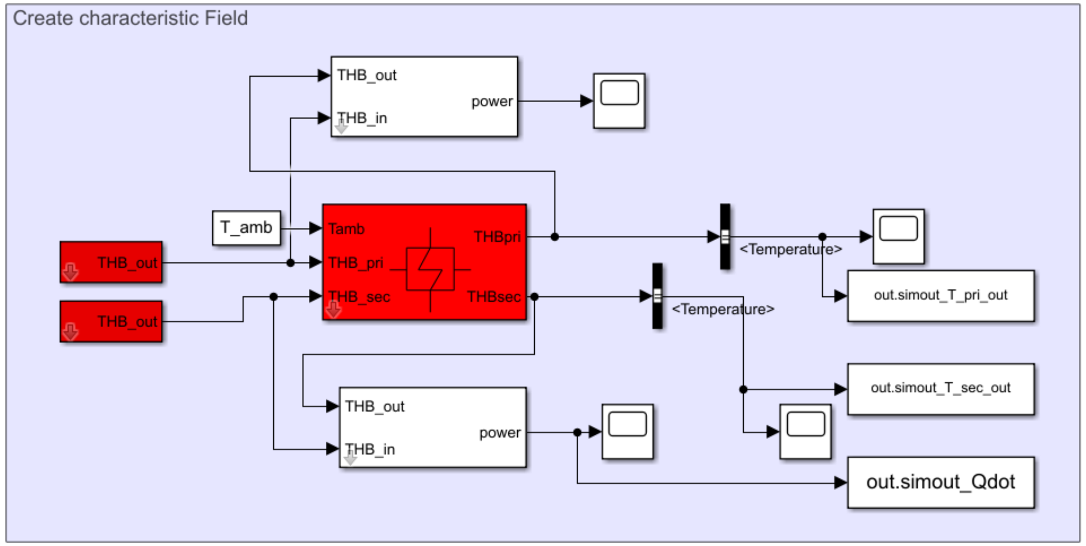
Control Concept: “Decoupled PID Controller”

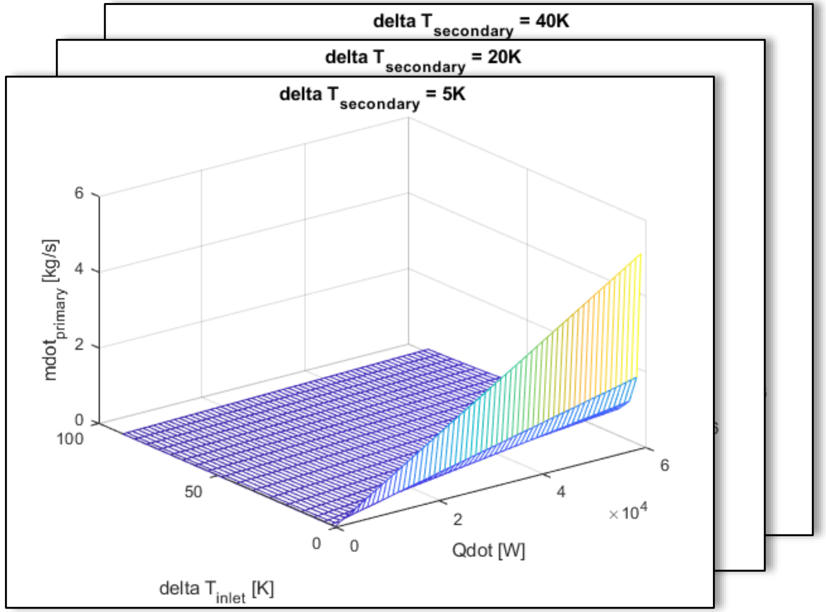
- Secondary side mass flow $u_1(t)$ is manipulated by Feed Forward Control (decoupling)
- Primary side mass flow $u_2(t)$ is manipulated by PID-Controller
- Secondary side outlet temperature $y_2(t)$ is the controlled variable

Control Concept: “Characteristic Field Based Control”

- PID controller is replaced by a lookup table with a characteristic Field (CF)
- Weak parameterised I controller for the final correction
- Other allocation of the vectors $w(t)$ and u(t) necessary

Determination of the Characteristic Field

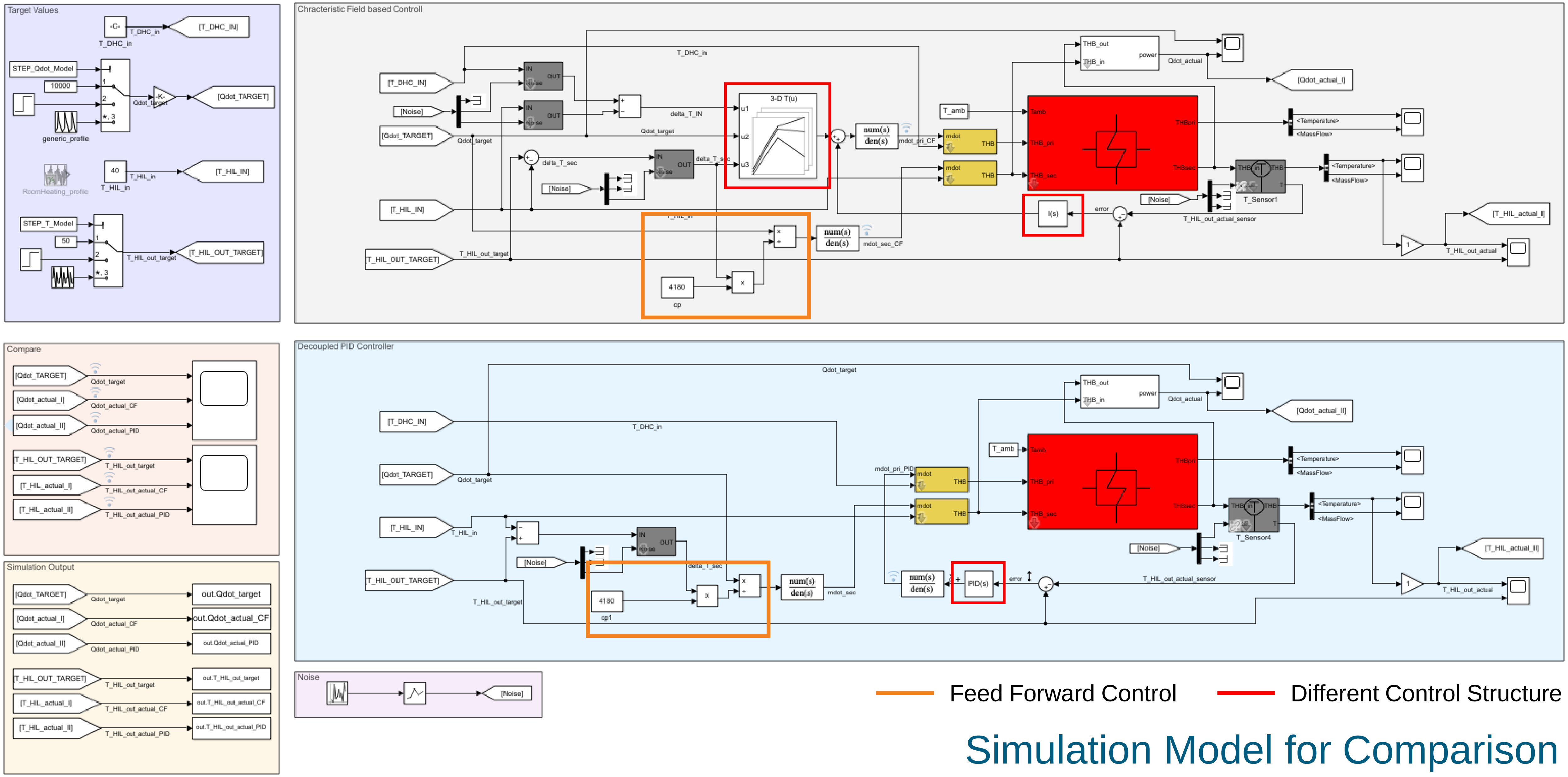




Reduction of the number of dimensions: $\dot{m}_{pri} = f\left(\dot{Q}, \Delta T_{in}, \Delta T_{sec}\right)$

Variable	Min.	Max.	Step Size	Step Number
$\dot{Q}$	100 W	60000 W	1000 W	60
ΔT_{in}	5 °C	90 °C	5 °C	18
ΔT_{sec}	5 °C	40 °C	5 °C	8

8640 Simulation runs



Feed Forward Control   Different Control Structure

Simulation Model for Comparison

Investigation Scenarios

48 different Scenarios for Simulation:

- Step response type:
  - Heat Flow step
  - Temperature step
  - Both steps together
- Temperature Level:
  - Conventional grid: 130 °C
  - Low-temperature grid: 80 °C
- Heat Flow Level:
  - low: ~ 10 kW
  - high: ~ 50 kW
- Time constant of PT1 elements:
  - 1 s
  - 2 s
- Factor for heat exchanger model parameters:
  - 1
  - 1.5

Scenario Name	Step Type	Temperature Level	Power Level	Parameter Factor	Time Constant PT1
1-Q	Power	80	Low	1	1
1-T	Temperature	80	Low	1	1
1-TQ	Temperature & Power	80	Low	1	1
2-Q	Power	130	Low	1	1
2-T	Temperature	130	Low	1	1
2-TQ	Temperature & Power	130	Low	1	1
3-Q	Power	80	Low	1	2
3-T	Temperature	80	Low	1	2
3-TQ	Temperature & Power	80	Low	1	2
4-Q	Power	130	Low	1	2
4-T	Temperature	130	Low	1	2
4-TQ	Temperature & Power	130	Low	1	2
5-Q	Power	80	Low	1,5	1
5-T	Temperature	80	Low	1,5	1
5-TQ	Temperature & Power	80	Low	1,5	1
6-Q	Power	130	Low	1,5	1
6-T	Temperature	130	Low	1,5	1
6-TQ	Temperature & Power	130	Low	1,5	1
⋮	⋮	⋮	⋮	⋮	⋮
13-Q	Power	80	High	1,5	1
13-T	Temperature	80	High	1,5	1
13-TQ	Temperature & Power	80	High	1,5	1
14-Q	Power	130	High	1,5	1
14-T	Temperature	130	High	1,5	1
14-TQ	Temperature & Power	130	High	1,5	1
15-Q	Power	80	High	1,5	2
15-T	Temperature	80	High	1,5	2
15-TQ	Temperature & Power	80	High	1,5	2
16-Q	Power	130	High	1,5	2
16-T	Temperature	130	High	1,5	2
16-TQ	Temperature & Power	130	High	1,5	2

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Results

Comparison Factor

Based on Root Mean Square Error (RMSE):

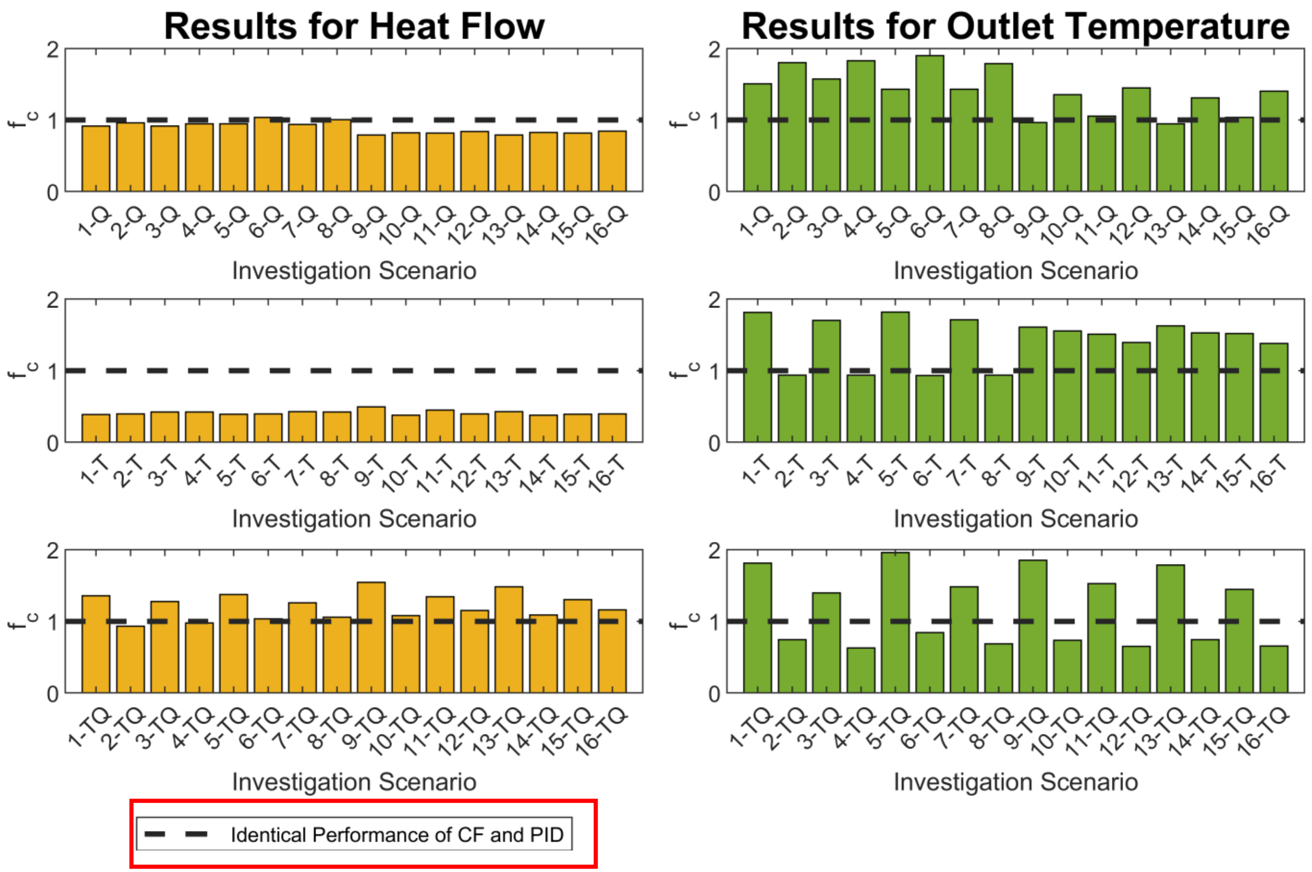
$$RMSE_{j,k}(x) = \sqrt{\frac{\sum_{i=1}^{n}\left(x_{actual,j,k,i} - x_{target,k,i}\right)^2}{n}}$$

$$j \in \{CF, PID\}, k \in \{1-Q, \dots, 16-TQ\}, x \in \{\dot{Q}, T_{sec,out}\}$$

$$f_{c,k} = \frac{\overline{RMSE}_k(x) + RMSE_{CF,k}(x)}{\overline{RMSE}_k(x) + RMSE_{PID,k}(x)}$$

=> $f_{c,k} < 1 \Rightarrow$ CF performes better and vice versa

No concepts outperforms the other, but very different performance based on scenario!



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Results

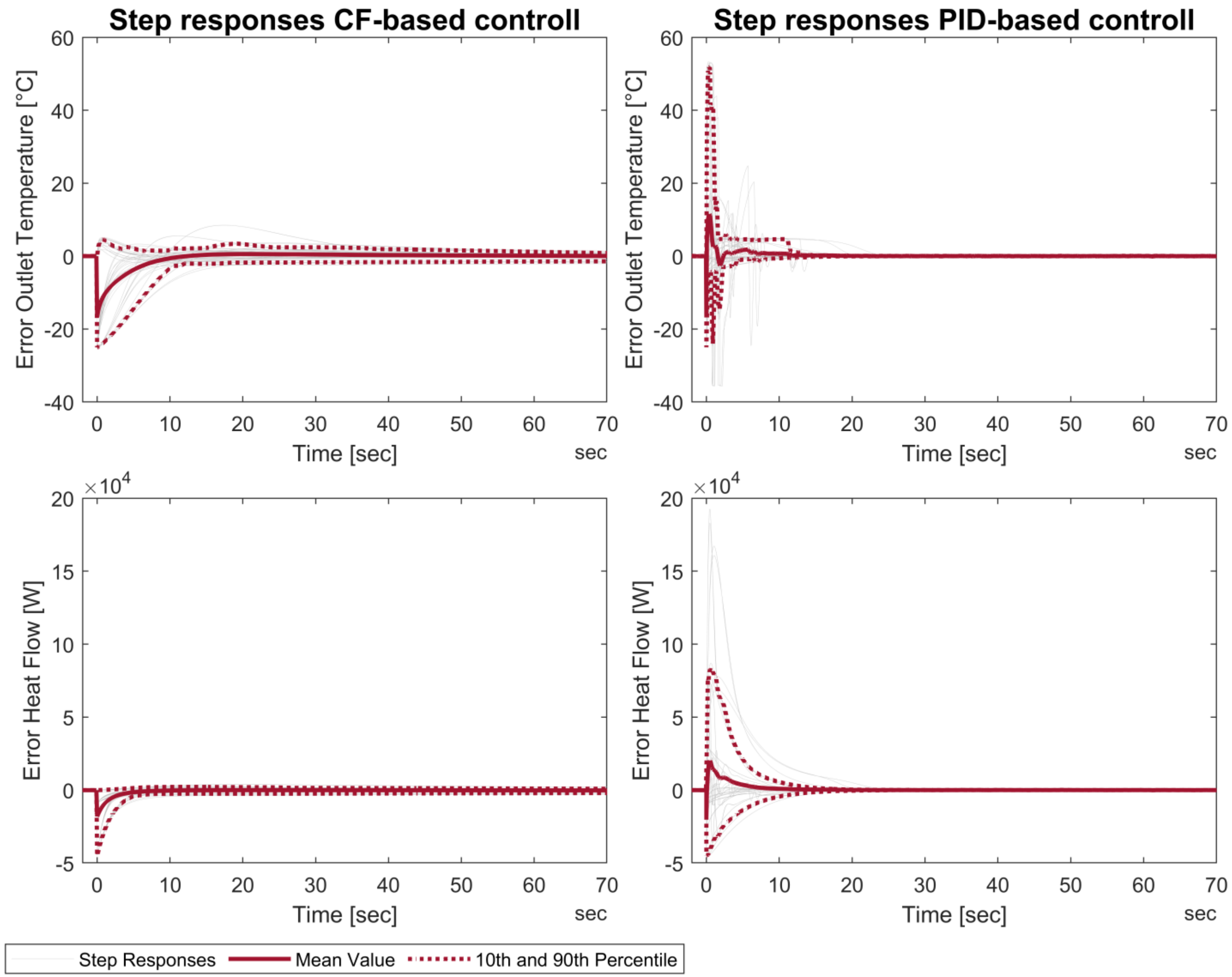
Step Response Error Plots

CF-based control:

- Slow reaction to the step
- Few overshoots or oscillatory behavior
- Moderate influence of scenarios (mean values vs percentiles)

PID-based control:

- Fast reaction to the step
- A lot of overshoots and oscillatory behavior
- Large influence of scenarios (mean values vs. percentiles)



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Conclusion and Outlook

CF-based control concept seams better suited for the District LAB

- No concept outperforms based on the compare factor
- Planned at District LAB: Solar thermal or room heating profiles
- Very slow changes compared to the steps in this investigation
- Lesser overshoots but slower reaction time is favourable

Further investigation planned when more precise knowledge of the components is available

Shown methods might be useful for other test facilities

Contact

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Thank you for your attention!