Hochschule Düsseldorf
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ZIES

Efficiency studies on a heat pump system with a stratified storage tank for space heating and domestic hot water based on hardware in the loop tests

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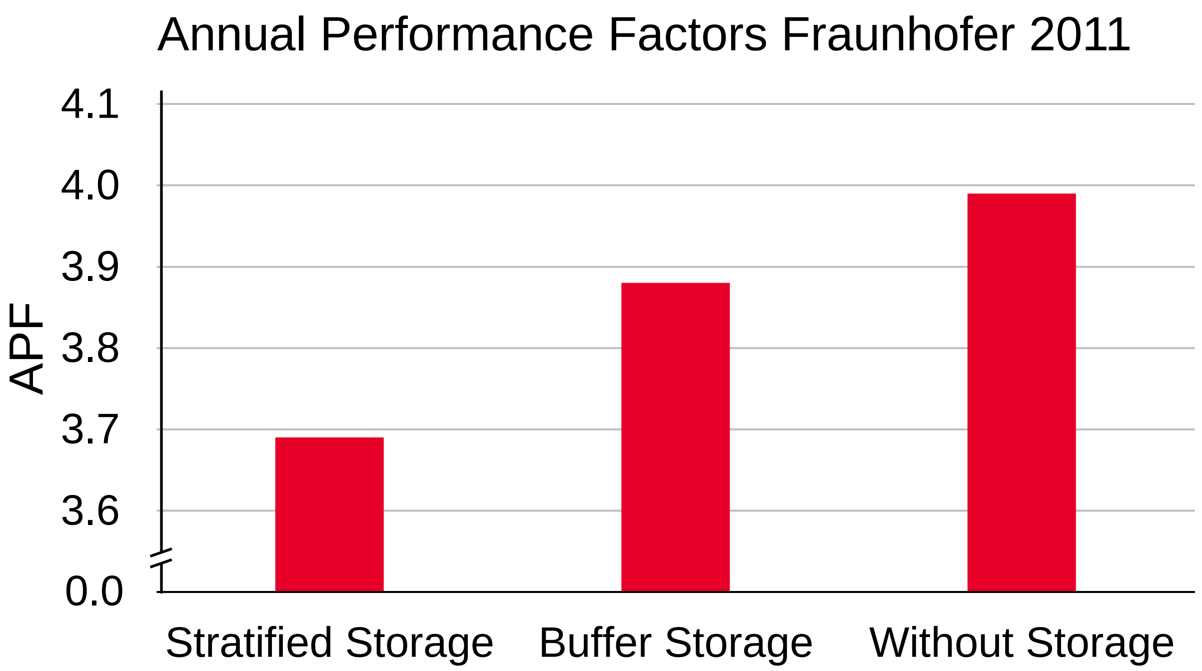
Introduction

Background of the work

Fraunhofer study from 2011 (Miara et al. 2011): Stratified storage systems in building heat supply (for about 200 m² living space) comparatively inefficient - reasons:

- Incorrect positioning of temperature sensors
- Inaccurate control parameters
- Inadequate loading strategy



Introduction

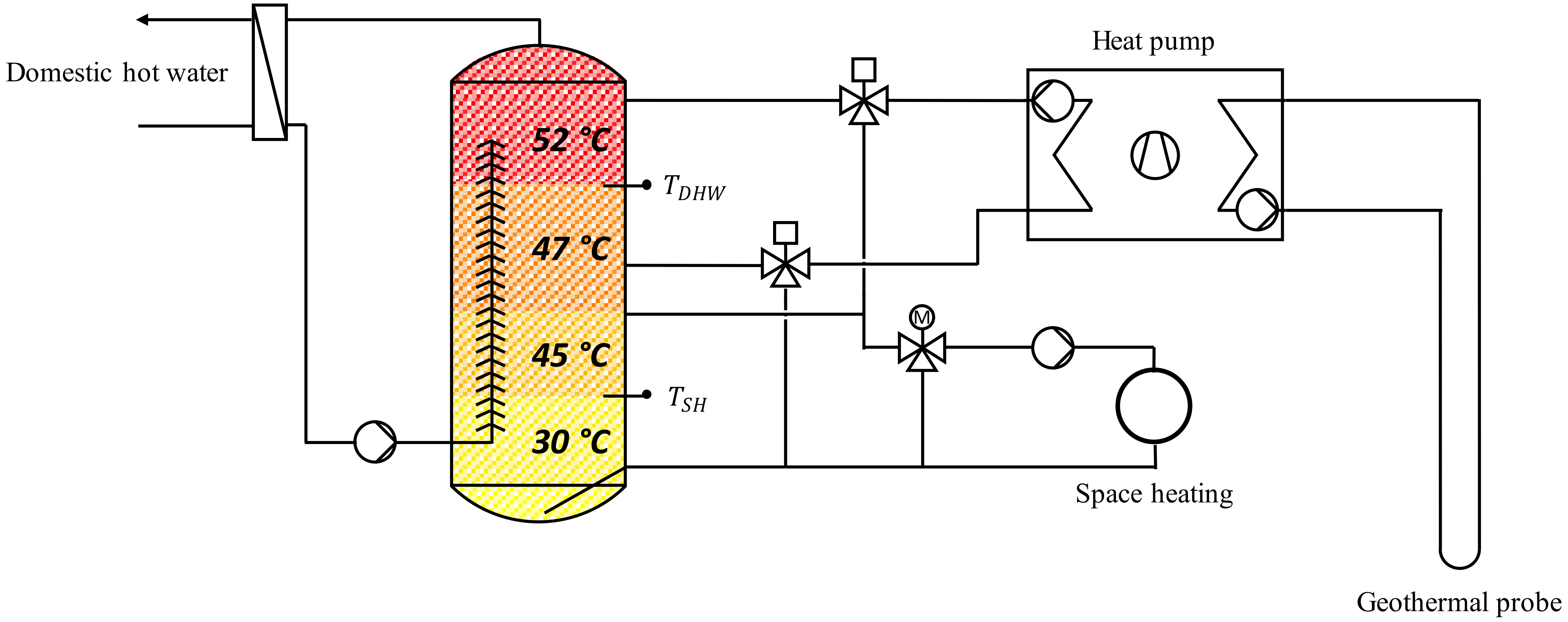
Aim of the investigation

- Elaboration of an efficient loading management of stratified storage systems
- Investigation of efficiency parameters
- Investigation of the heat pump cycle rate (compressor lifetime and grid flexibility)
- Elaboration of interactions of the variables

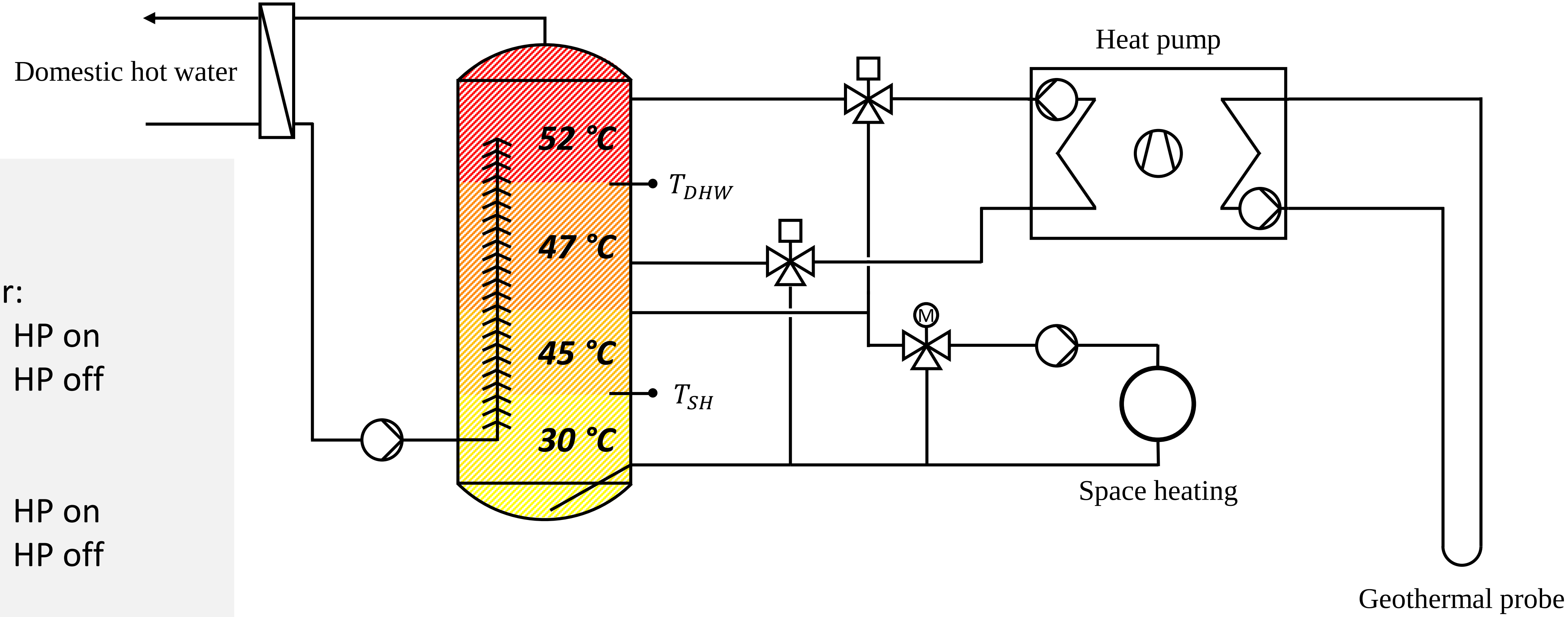
HiL-experiments are carried out with the heat pump

Influences of the transient behavior on the stratified storage loading

Heat Supply System



Heat Supply System



Control

Domestic hot water:

$T_{DHW} < 47\,°C$ HP on

$T_{DHW} > 52\,°C$ HP off

Space heating:

$T_{SH} < 35$ °C HP on

$T_{SH} > 45$ °C HP off

(Nominal supply temperature of space heating: 35 °C)

Heat Supply System

Heat sinks (IEA Annex 38 Task 44)

Building (SFH 45):

- Single family house with 140 m²
- Heat demand: 6500 kWh/a
- Renovated building with good thermal quality (Dott et al. 2013)

Domestic hot water:

- 2130 kWh/a or 140 liters of DHW per day
- Corresponds to a household with approx. 3 to 4 persons

Weather data (IEA Annex 38 Task 44)

Central European climate (Strasbourg weather data)

Heat source

Geothermal probe dimensioned according to VDI guideline 4640

Storage

Sailer stratified tank, parameter estimation according to DIN EN 12977-3

Heat pump

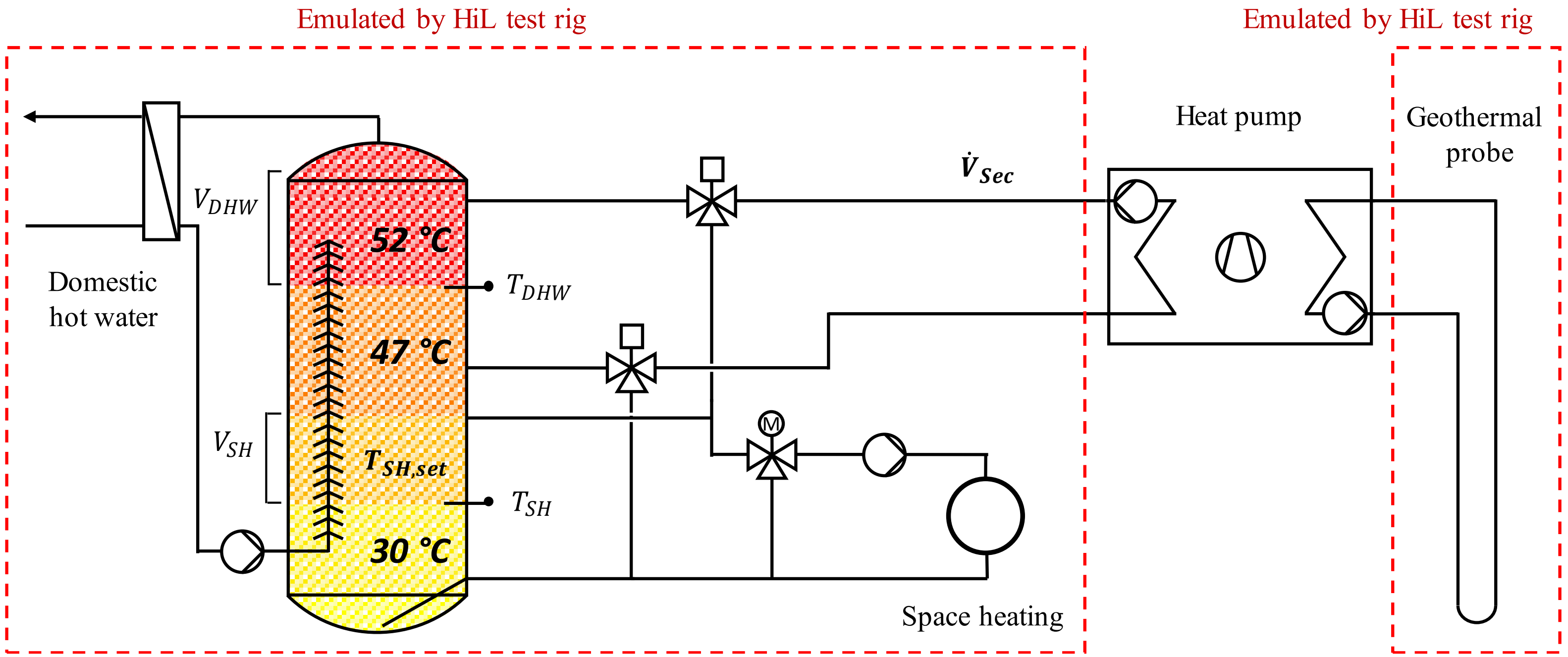
Viessmann Vitocal 300-G
(Year of manufacture 2014)
Nominal power about 5.5 kW

Models from CARNOT-toolbox 7.0 (© Solar-Institut Jülich) in Simulink

Experimental design

Tests on a hardware in the loop test bench

- Heat pump as real component
- Rest of the system is modeled (Simulink - Carnot Toolbox)



Test scope: 24-hours

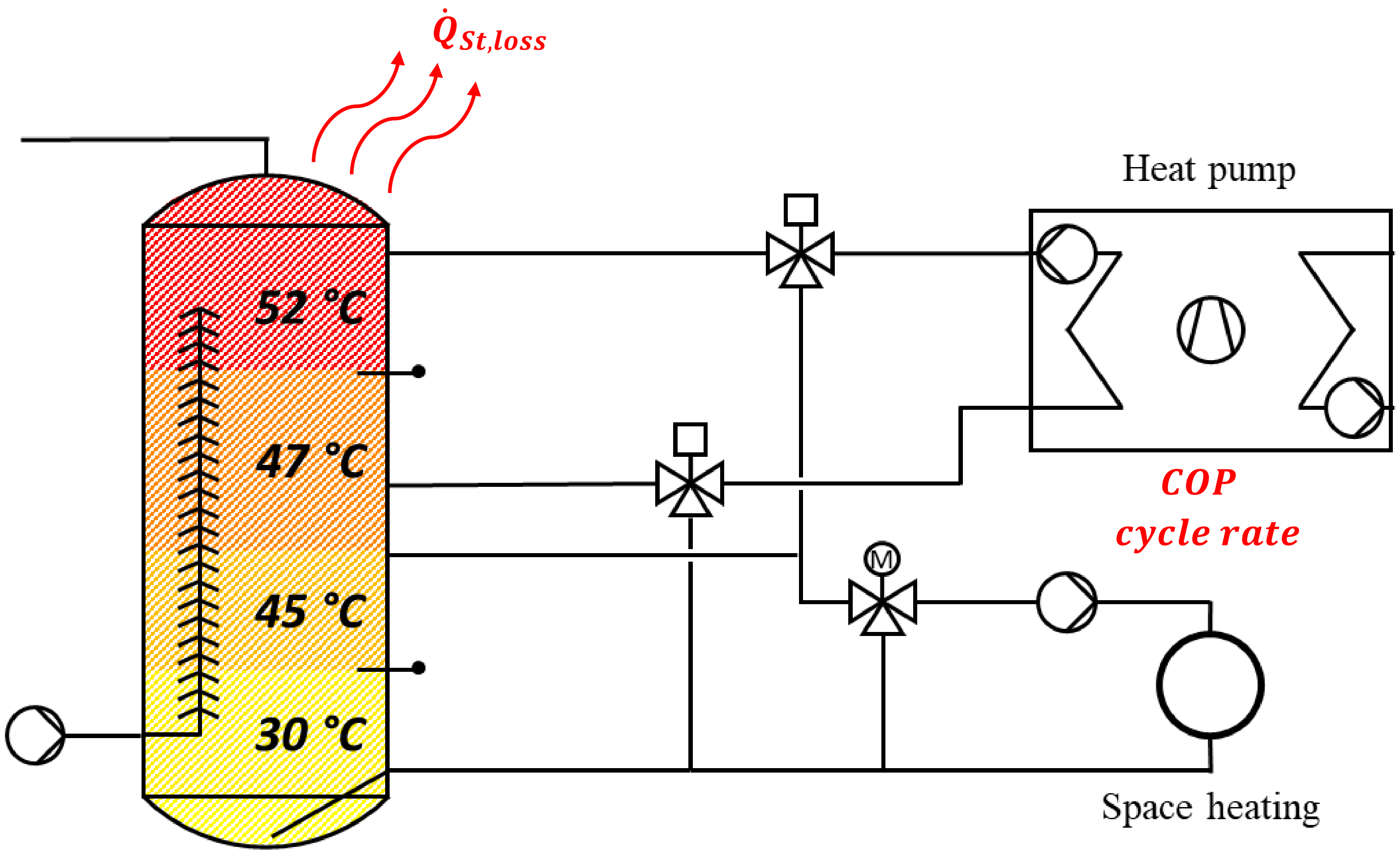
Constant boundary conditions for each test – typical day for the heating period

Typical day derived from an annual simulation of the system

Outside temperature:	9 °C
Space heat demand:	35 kWh (86 %)
Domestic hot water:	6 kWh (14 %)

Targets

- **COP of the Heat pump**
- **Storage heat loss**
- **Heat pump cycle rate**



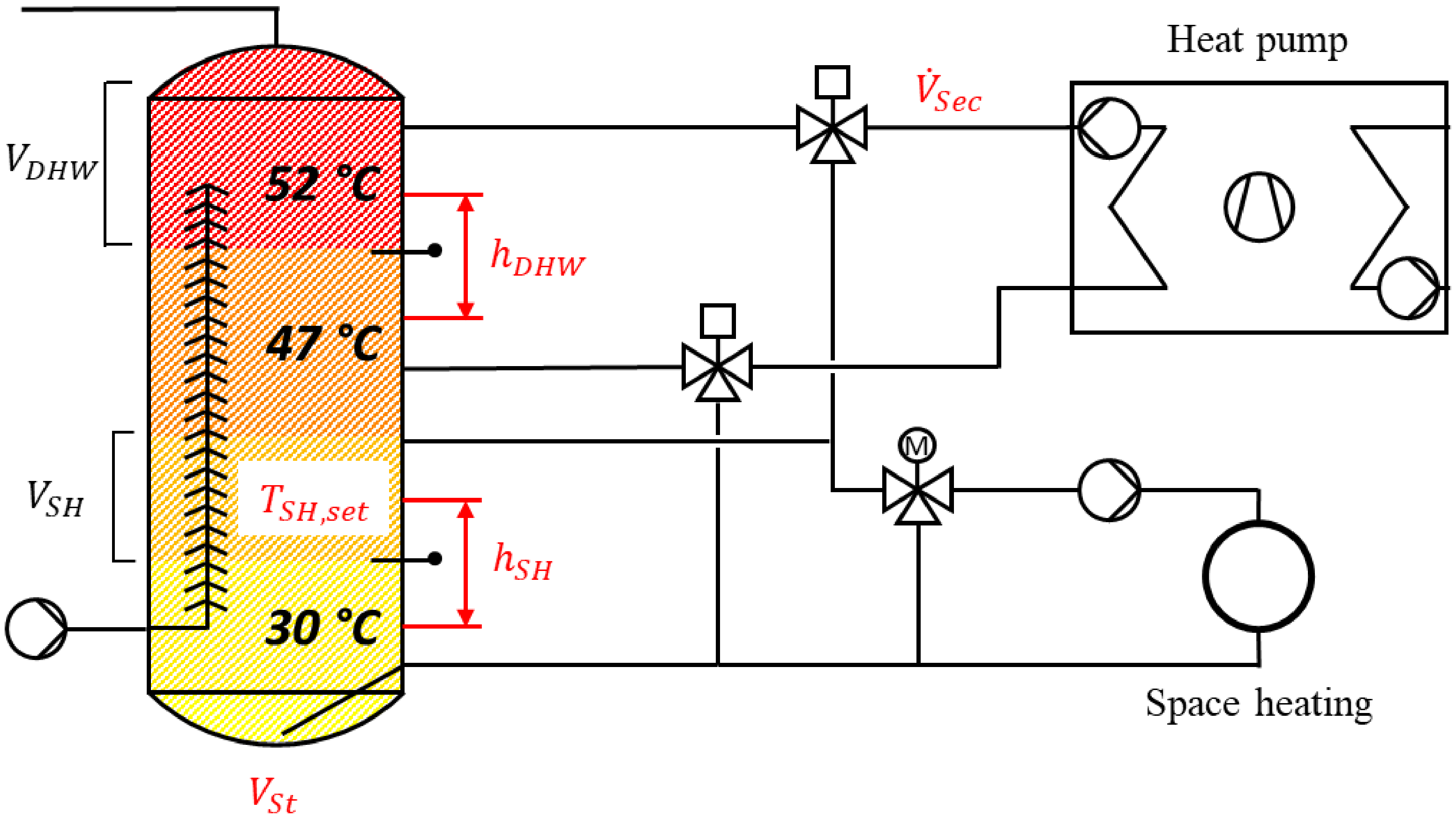
Influencing variables

Parameters

- Relative sensor heights for SH and DHW zone
- Set temperature of the SH zone
- Flow rate in the secondary circuit (heating circuit) of the HP
- Storage volume

Limits

Symbol	Limits		Unit
	Min	Max	
h_{SH}	0,125	0,312	-
h_{DHW}	0,625	0,812	-
V_{St}	531	731	l
$T_{SH,set}$	40	45	°C
$\dot{V}_{Sec}$	800	1250	l/h



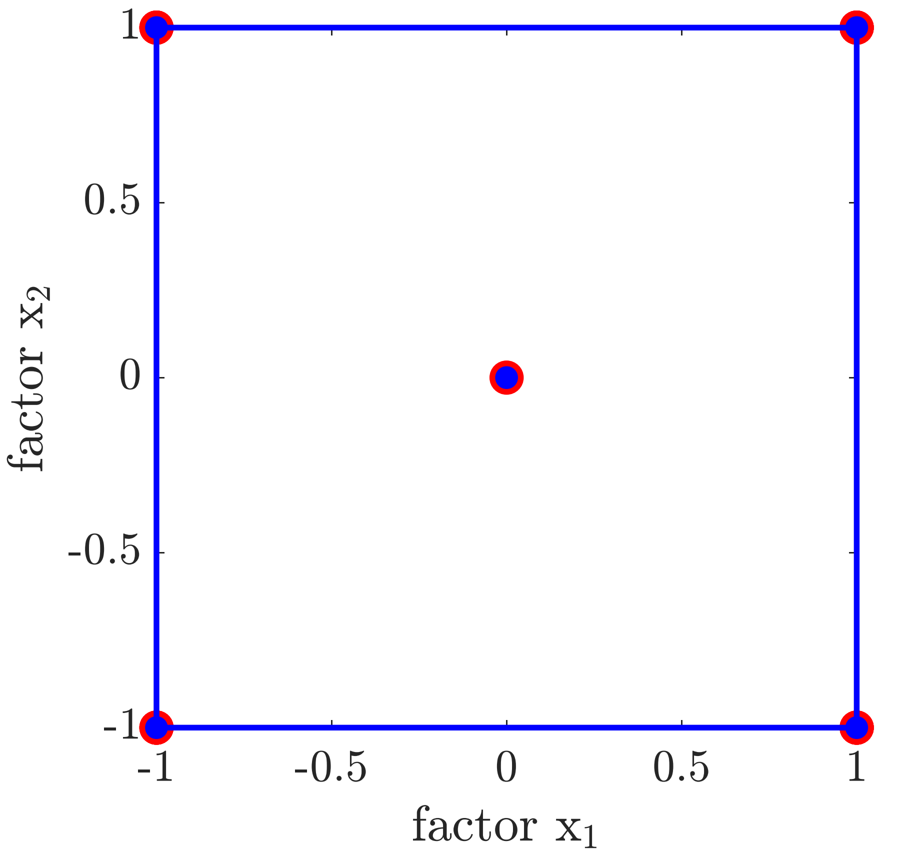
Design of experiments (DoE)

Fractional factorial experimental design
(as little experimental effort as possible)

- Targeted omission of corner points to shorten the experimental design (knowledge gain remains almost the same)
- $2^{5-1} = 16$ experimental points

Central point (measured 5 times in total)

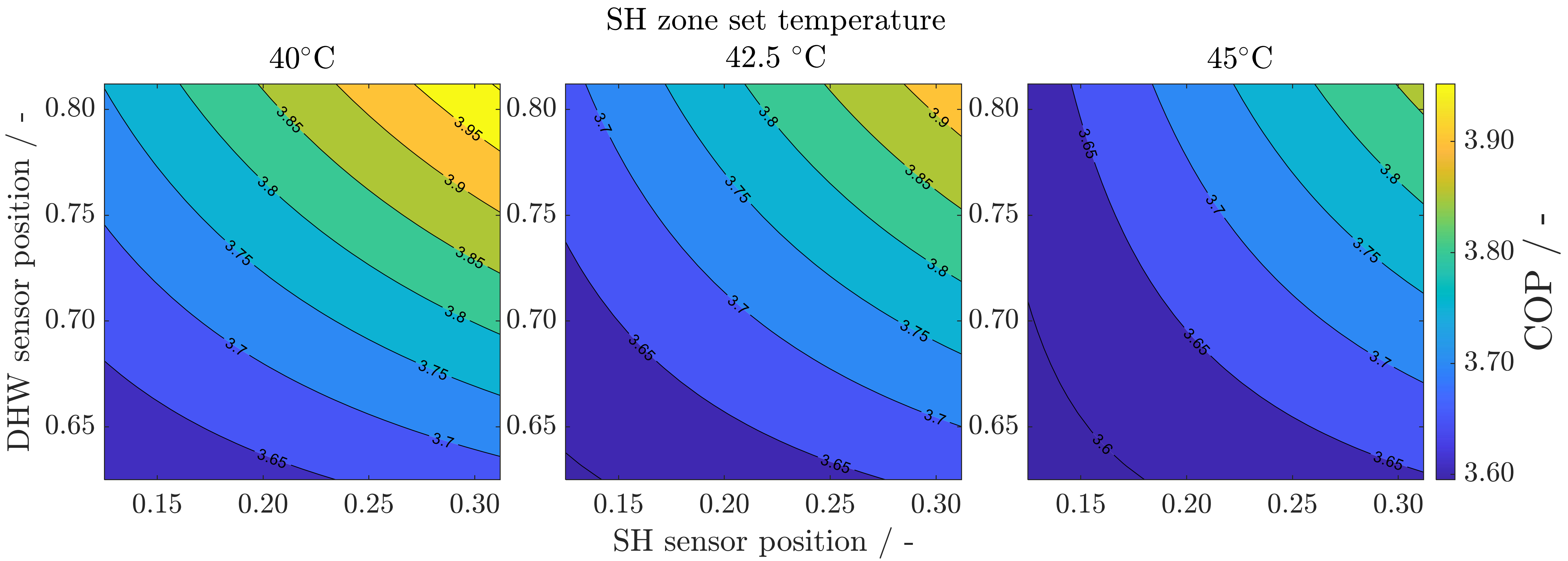
- Control of the regression
- Scattering of the test points



Regression function

$$Target = c_0 + \underbrace{\sum_{i=1}^{n_f} c_i x_i}_{\text{Linear effects}} + \underbrace{\sum_{i=1}^{n_f-1} \sum_{j=i+1}^{n_f} c_{ij} x_i x_j}_{\text{2-way interactions}} + \varepsilon$$

Results COP



Bandwidth COP: ± 5%

in absolute values. 3,6 … 3,95

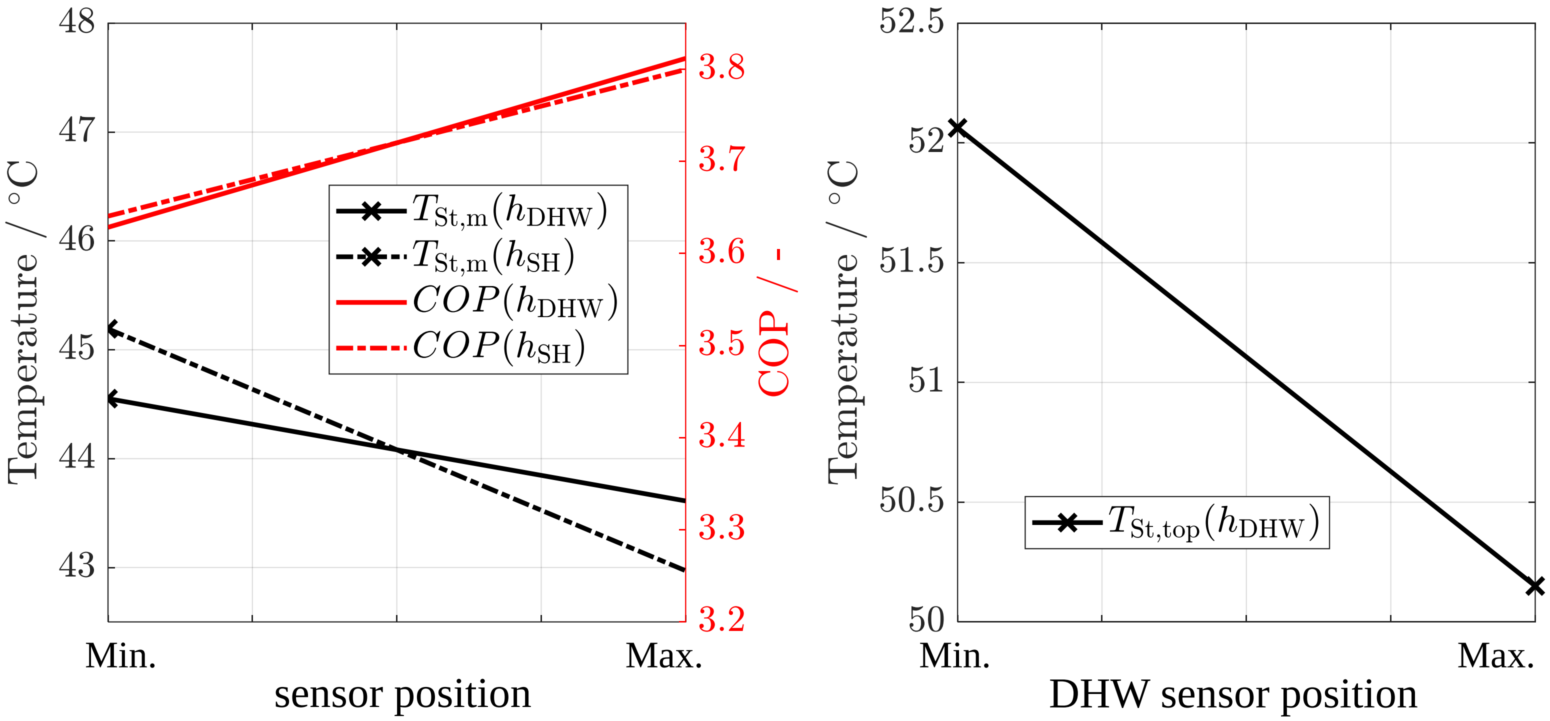
Results COP

Sensor positions:

High positioning decreases mean storage tank temperature

Decreases upper storage tank temperature

→ tap temperature remains > 45 °C

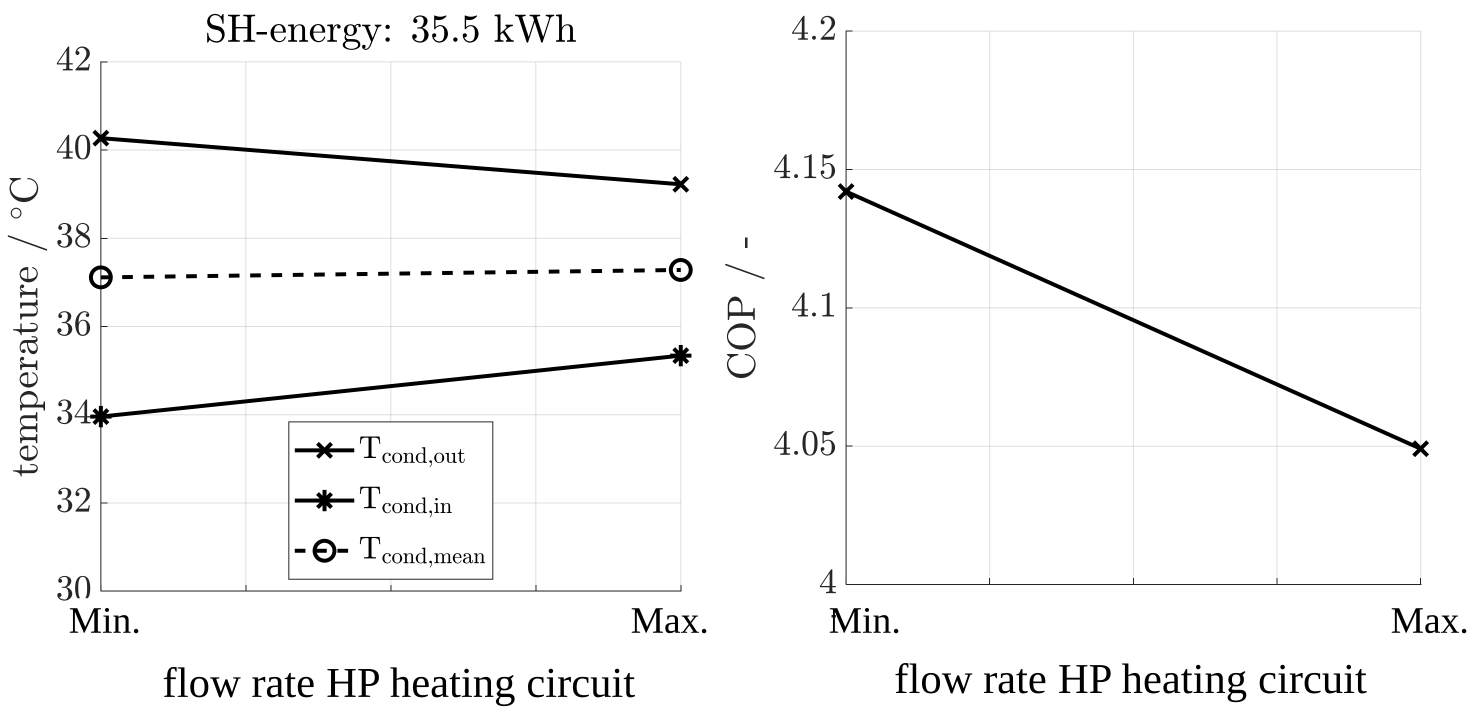


Results COP

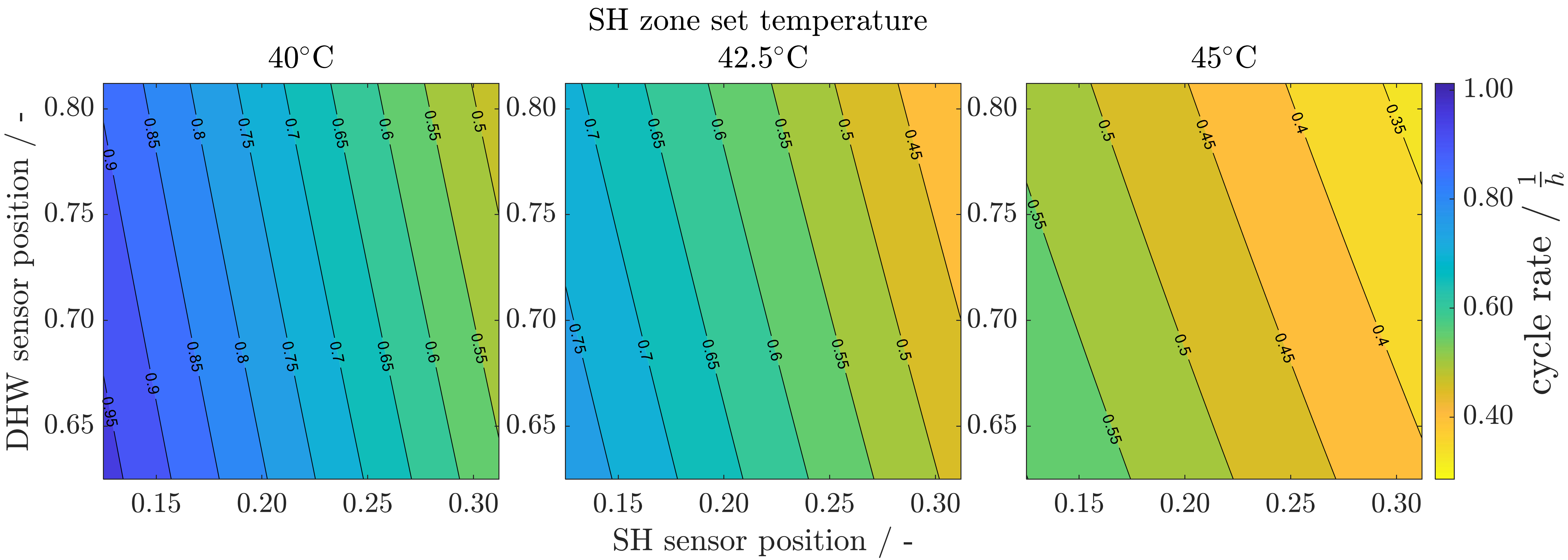
Flow rate of the HP (secondary/heating circuit):

High flow rate creates mixing in the storage tank (Glembin et al. 2015)

Higher mean condenser temperatures increase HP temperature lift slightly



Results Cycle rate



Bandwidth cycle rate: **± 50%**

in absolute values: **0,35 … 0,95 1/h**

Cycle rate in contour plot scales with storage volume: ± 100 l correspond to ± 0.15 1/h

Conclusion

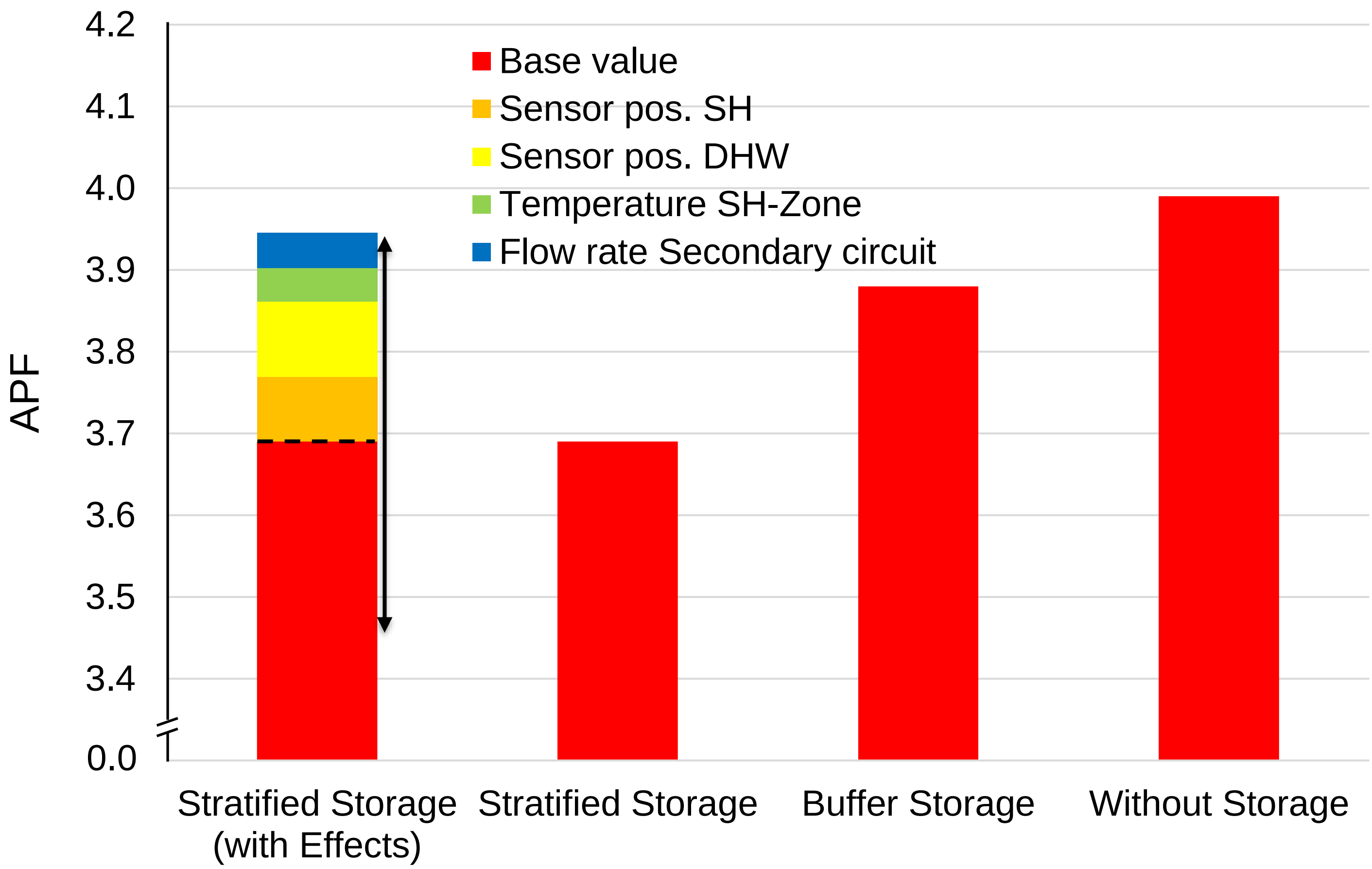
Application of the determined effects to the annual performance factor

Range of the effects of the variables: ± 0.25

- COP and APF comparable in both investigations:

$$\frac{heating\ energy\ of\ the\ HP}{el.\ energy\ of\ compressor, pumps, control}$$

- Time periods different: day vs. year
- Particularly poor settings of the influencing variables not tested here
- Measured baseline value in (Miara et al. 2011) low, due to several systems operating incorrectly



Conclusion

Set sensor positions high if possible

Positive effects on COP, cycle rate and storage heat loss

Temperature of the SH-zone

- High temperature lowers the HP cycle rate
- High temperature has negative impact on COP and storage heat loss
- Hence: use high sensor positions to lower the cycle rate and choose a low storage temperature if possible

Storage volume

- Rises the storage heat loss and lowers the HP cycle rate
- Dimension the storage tank to the required heat demand

Small flow rate in the HP secondary circuit

Sources

M. Miara, D. Günther, T. Kramer, T. Oltersdorf und J. Wapler, “WP Effizienz - Messtechnische Untersuchung von Wärmepumpenanlagen zur Analyse und Bewertung der Effizienz im realen Betrieb,” Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg, 2011.

J. Glembin, C. Büttner, J. Steinweg und G. Rockendorf, “Thermal Storage Tanks in High Efficiency Heat Pump Systems – Optimized Installation and Operation Parameters,” *Energy Procedia*, Jg. 73, S. 331–340, 2015, doi: 10.1016/j.egypro.2015.07.700.

J. Glembin, C. Büttner, J. Steinweg und G. Rockendorf, “Optimal Connection of Heat Pump and Solar Buffer Storage under Different Boundary Conditions,” *Energy Procedia*, Jg. 91, S. 145–154, 2016, doi: 10.1016/j.egypro.2016.06.190.

M. Y. Haller, R. Haberl, I. Mojic und E. Frank, “Hydraulic Integration and Control of Heat Pump and Combi-storage: Same Components, Big Differences,” *Energy Procedia*, Jg. 48, S. 571–580, 2014, doi: 10.1016/j.egypro.2014.02.067.

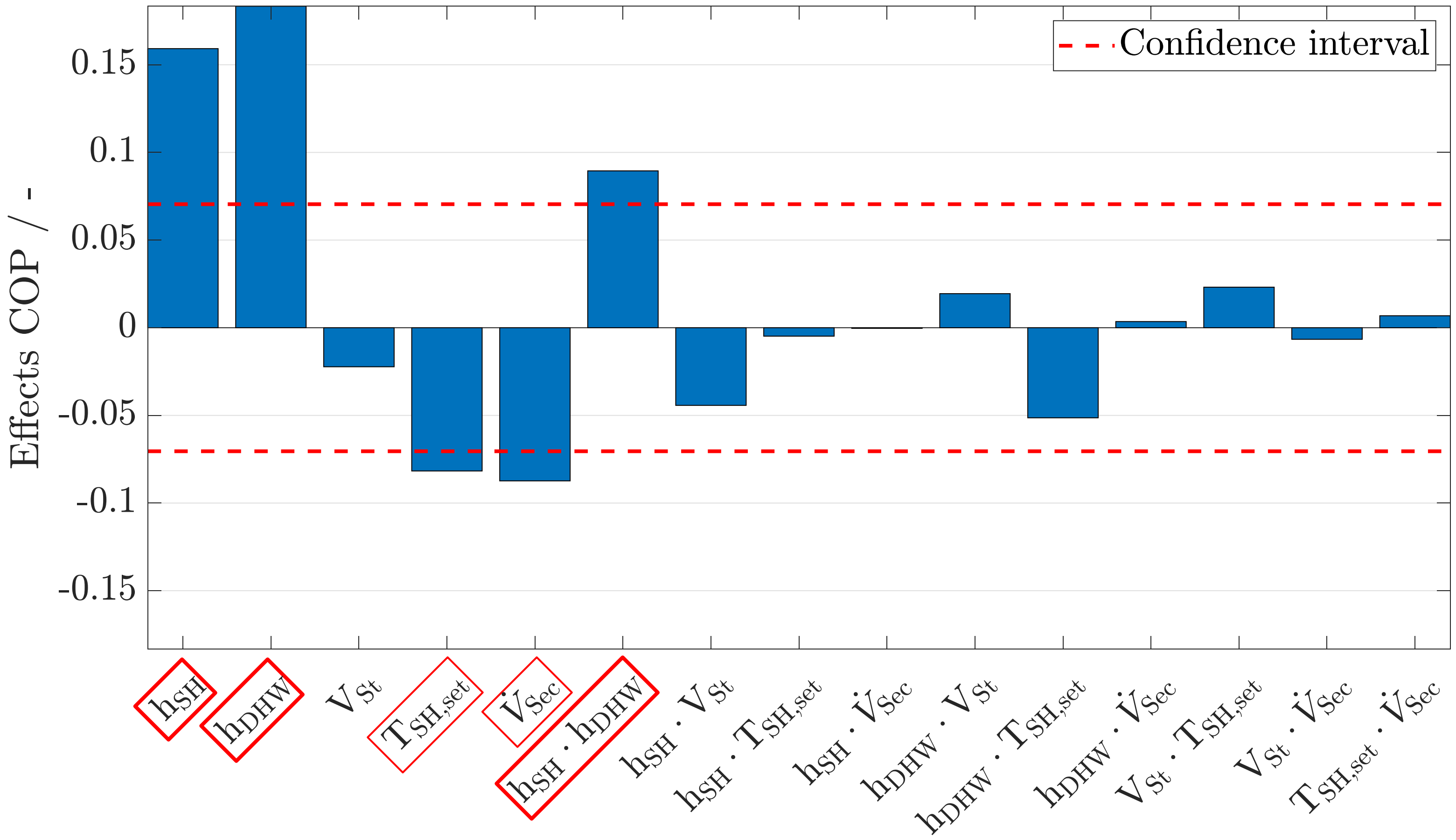
W. El-Baz, P. Tzscheutschler und U. Wagner, “Experimental Study and Modeling of Ground-Source Heat Pumps with Combi-Storage in Buildings,” *Energies*, Jg. 11, Nr. 5, S. 1174, 2018, doi: 10.3390/en11051174.

R. Dott, M. Y. Haller, J. Ruschenburg, F. Ochs und J. Bony, “The Reference Framework for System Simulations of the IEA SHC Task 44 / HPP Annex 38: Part B: Buildings and Space Heat Load,” Institut Energie am Bau - Fachhochschule Nordwestschweiz, Muttenz, Schweiz, 2013.

Haberl, Robert; Haller, Michel Y.; Papillon, Philippe; Chèze, David; Persson, Tomas; Bales, Chris (2015): Testing of combined heating systems for small houses: Im-proved procedures for whole system test methods. Institut für Solartechnik SPF, Hochschule für Technik HSR. Rapperswil, Schweiz.

Questions?

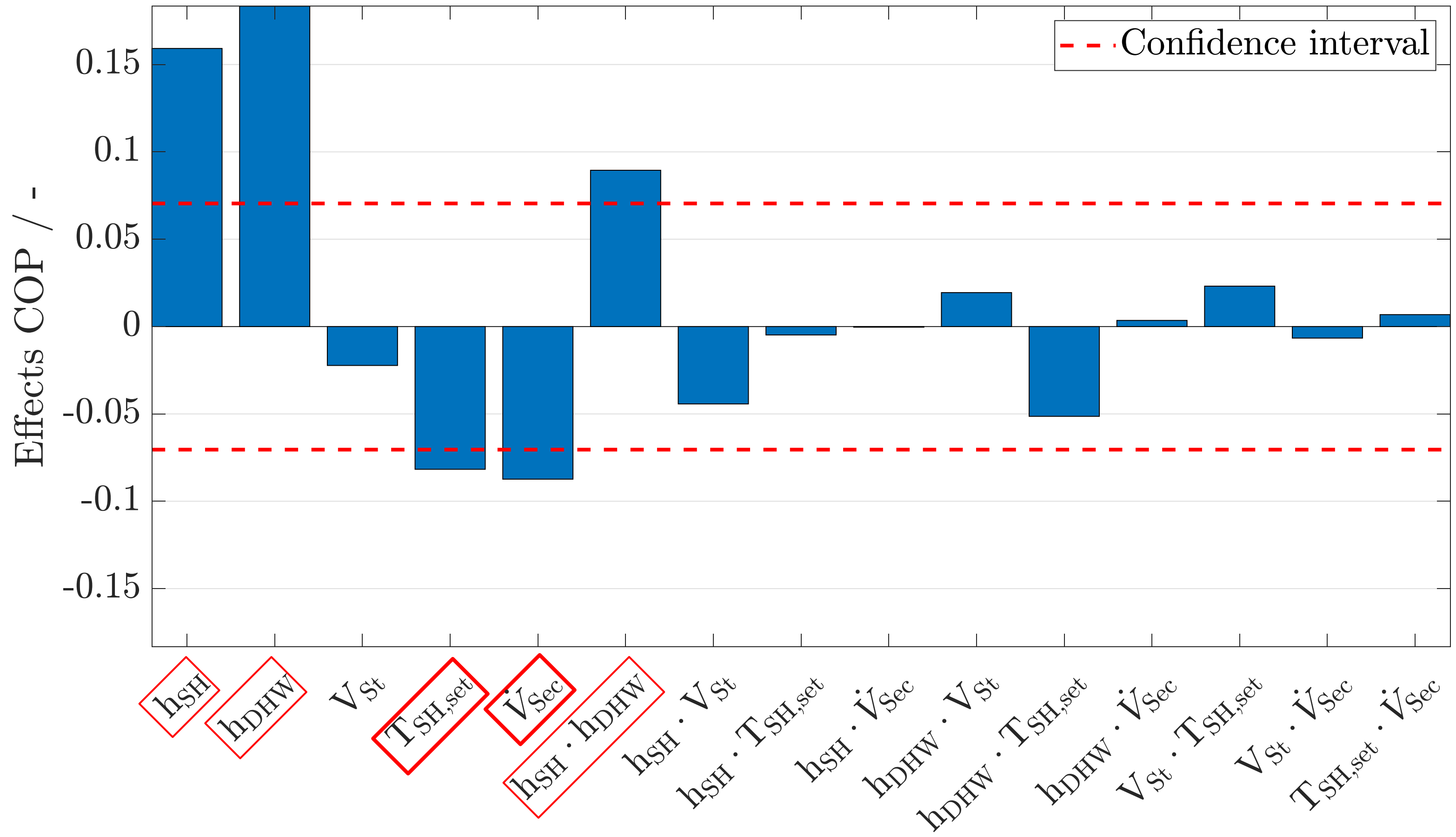
Results COP



<u>Legend</u>:

h_{SH} - Sensor position SH-Zone
h_{DHW} - Sensor position DHW-Zone
V_{St} - Storage volume
$\dot{V}_{Sec}$ - Flow rate secondary circuit
$T_{SH,set}$ - Set temperature SH-Zone

Results COP



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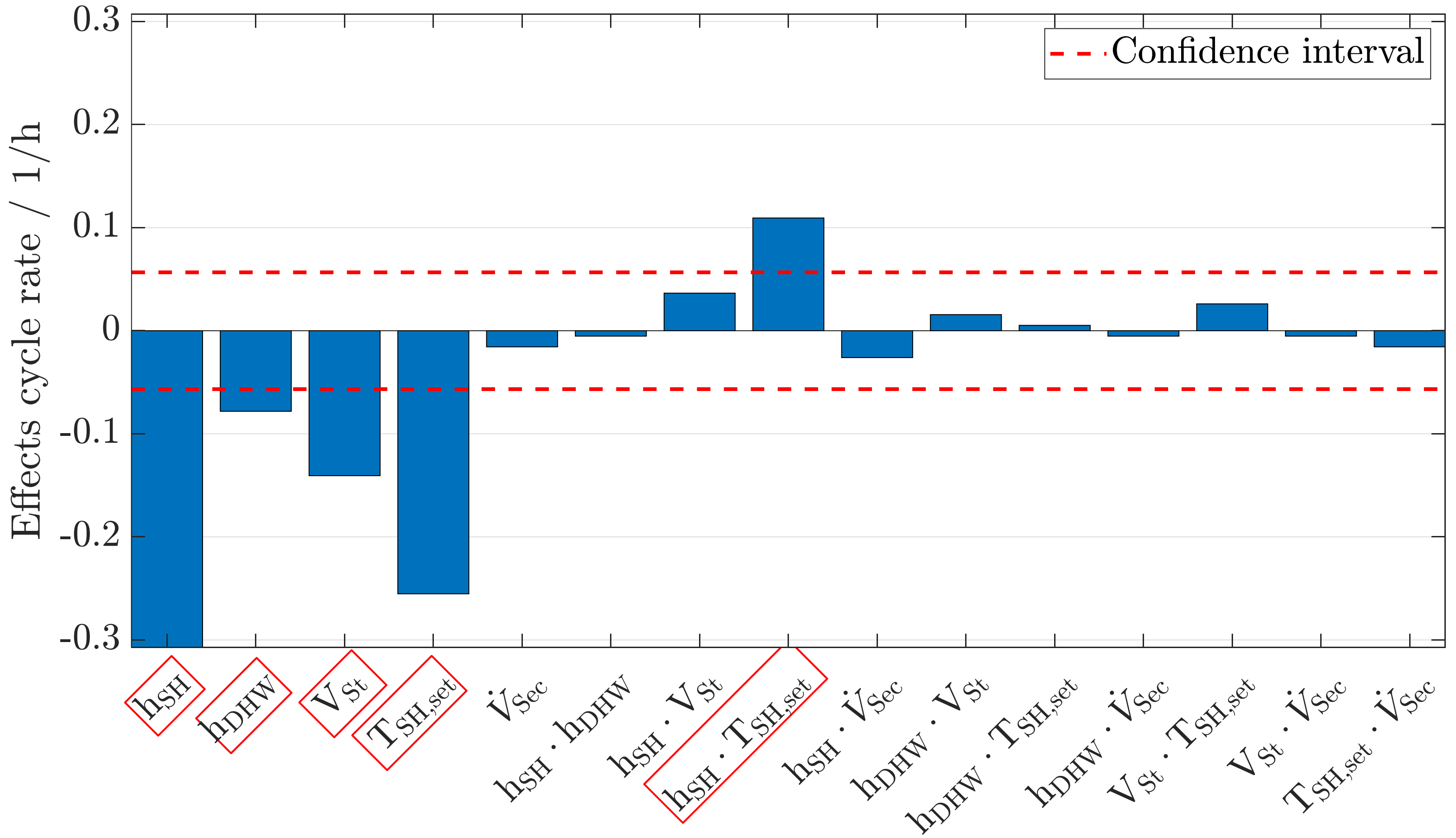
Results Cycle rate



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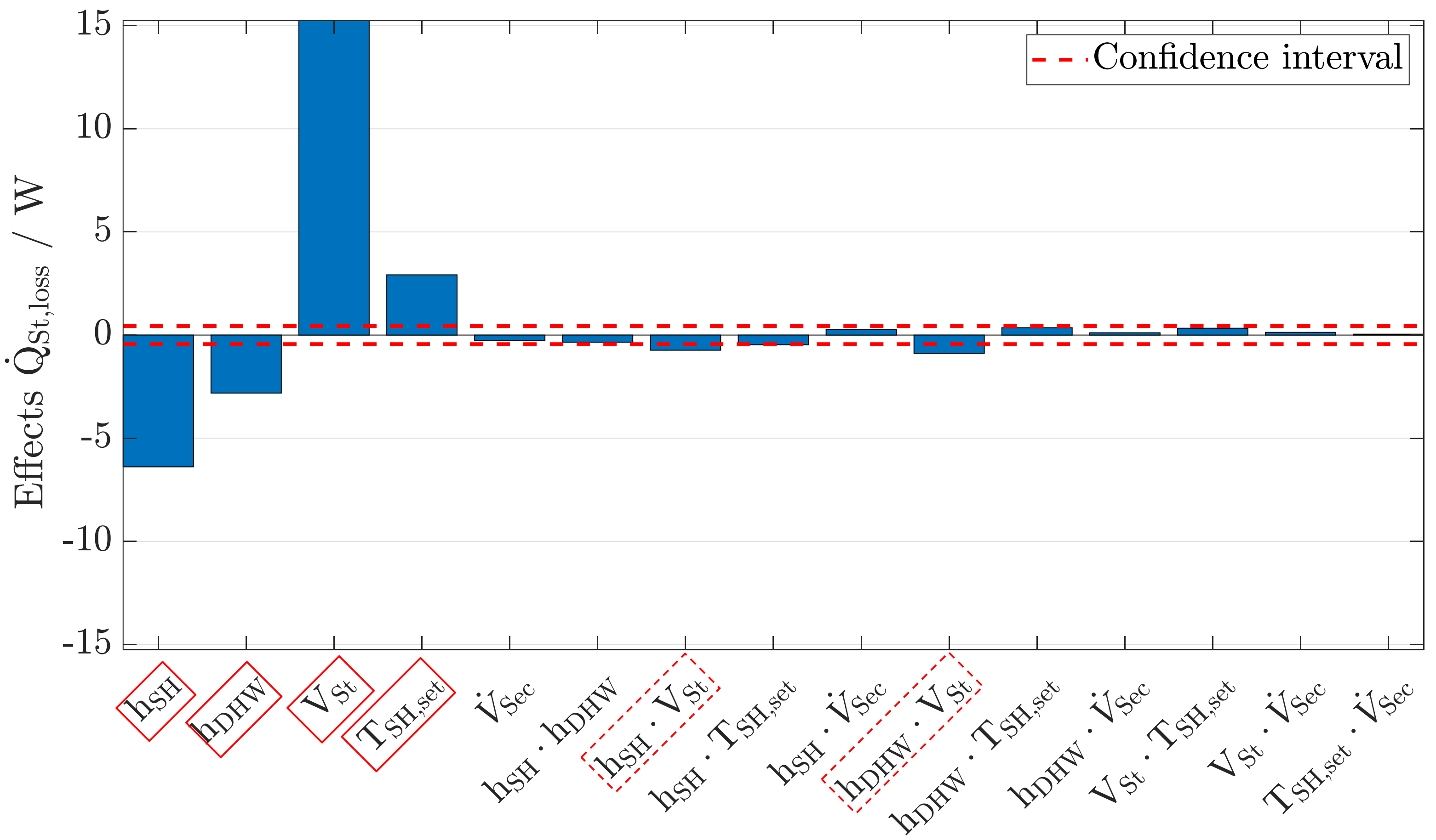
Results Storage heat loss



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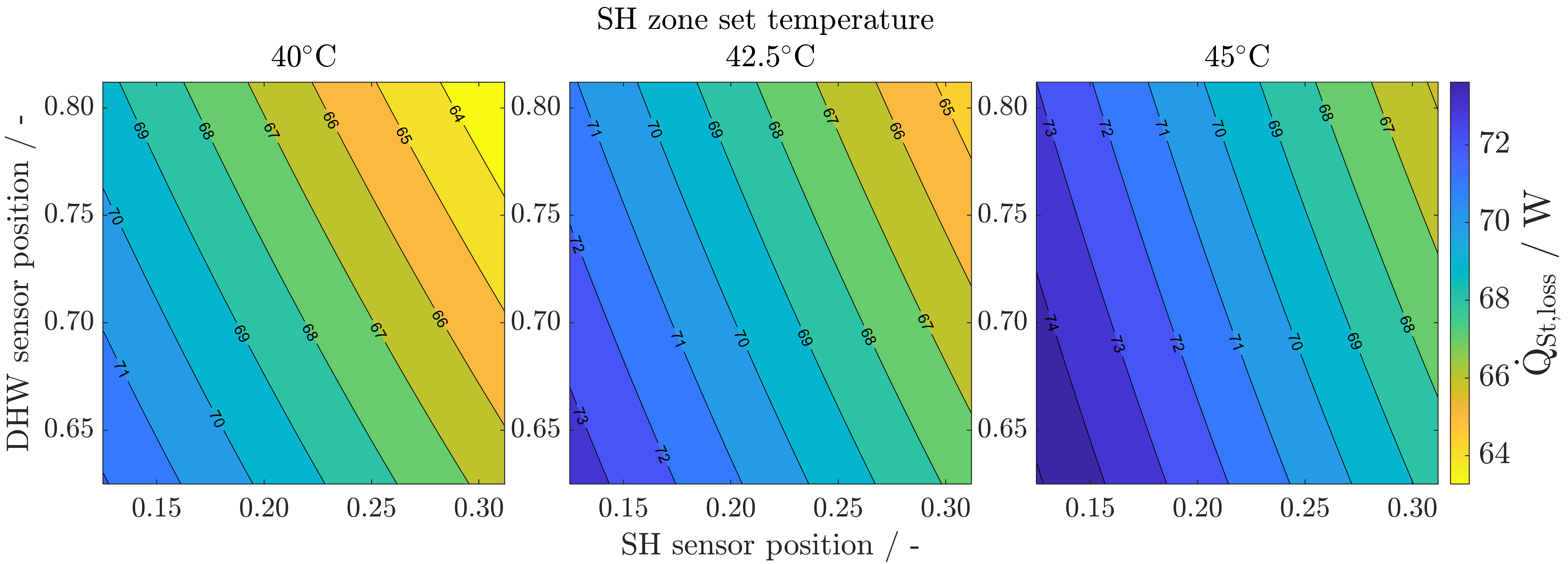
Results Storage heat loss



Bandwidth storage heat loss: ± 7%
in absolute values 64 … 74 W

Heat loss in contour plot scaled with storage volume: ± 100 l correspond to ± 7,5 W