„Free cooling reduces energy consumption of cold water systems“

iSEnEC Conference 2018

Philipp Puls

Fraunhofer Institute for Integrated Systems and Device Technology (IISB)

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Overview

1. Motivation

2. Modelling of cooling components
    a. Reference components
    b. Model design
    c. Results

3. Technical Implementation at IISB
    a. Installation scheme
    b. Experimental profiles
    c. Results

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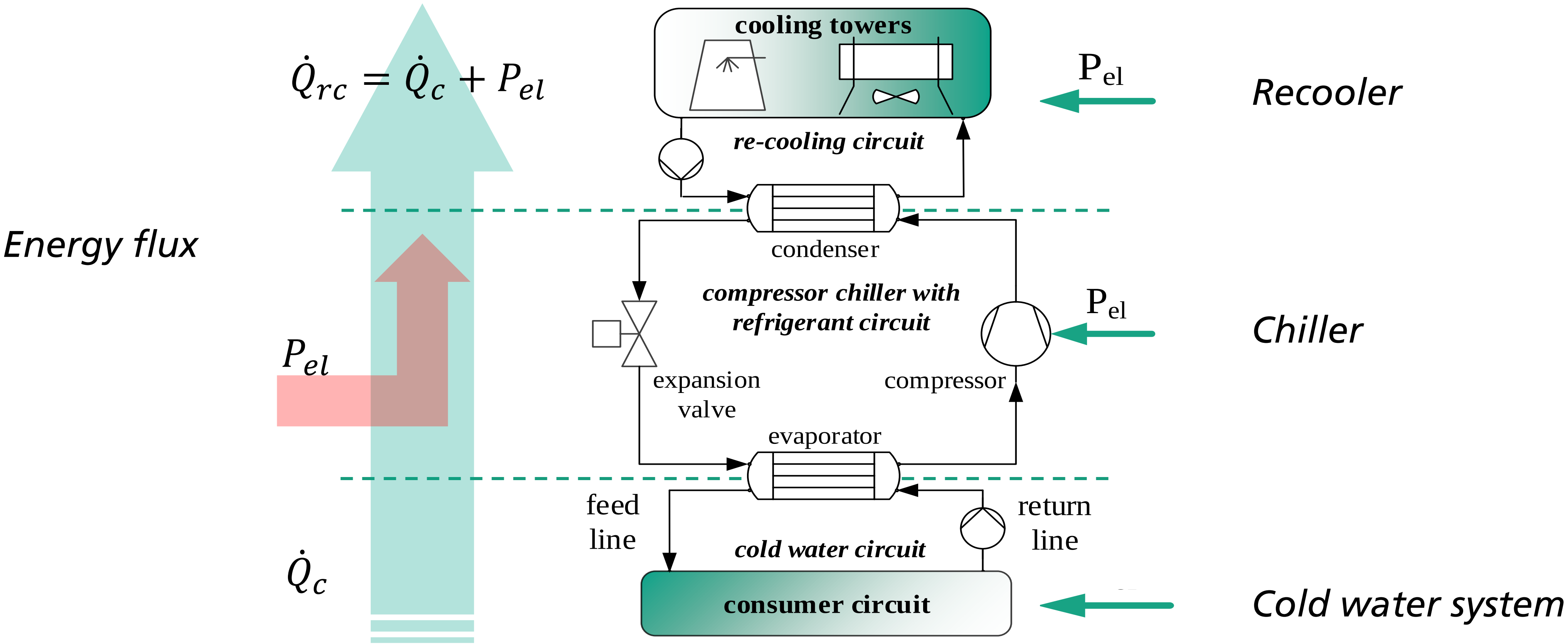
Motivation
Cooling without a chiller



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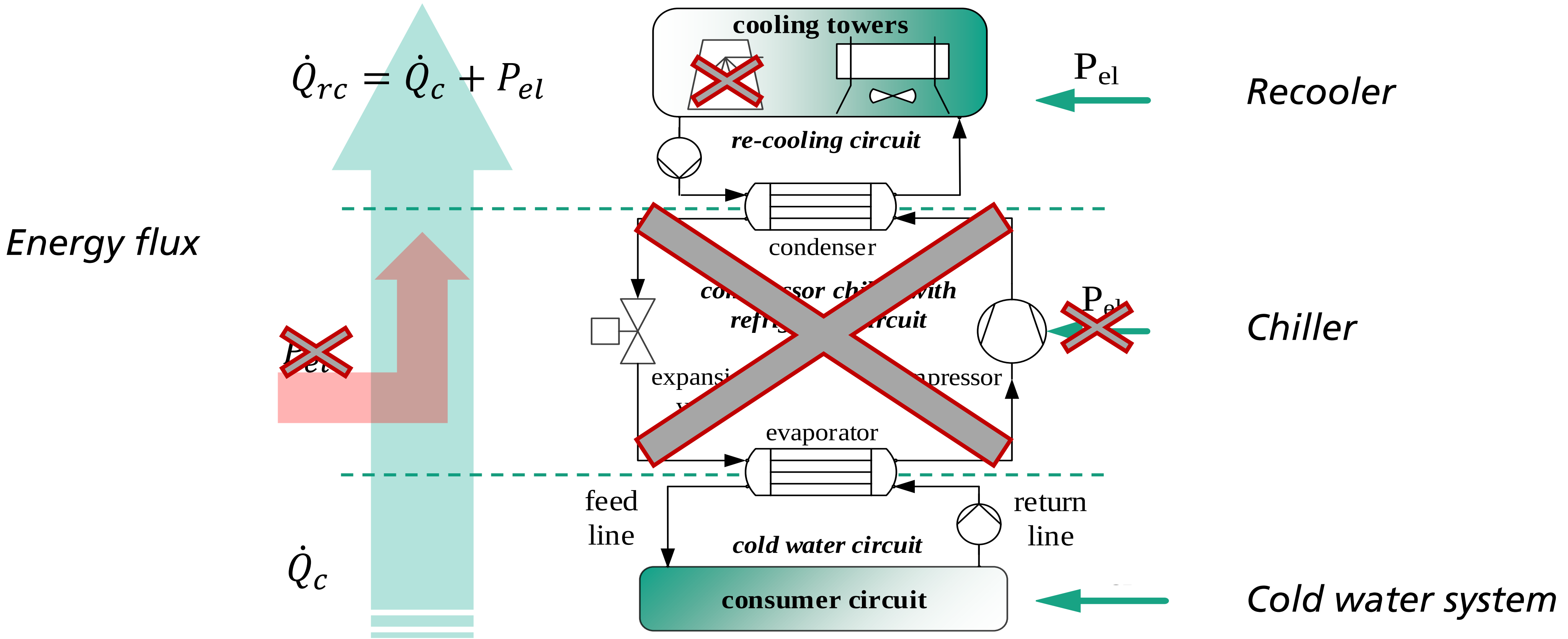
Motivation

Cooling without a chiller



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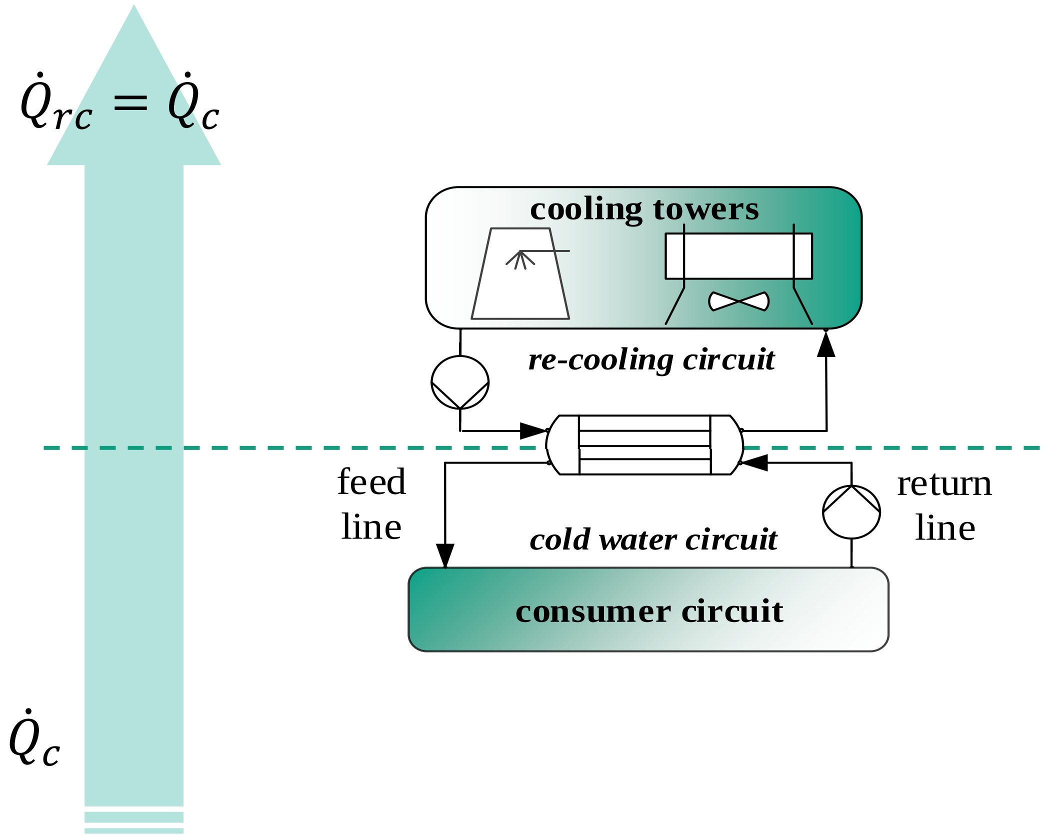
Motivation

Cooling without a chiller



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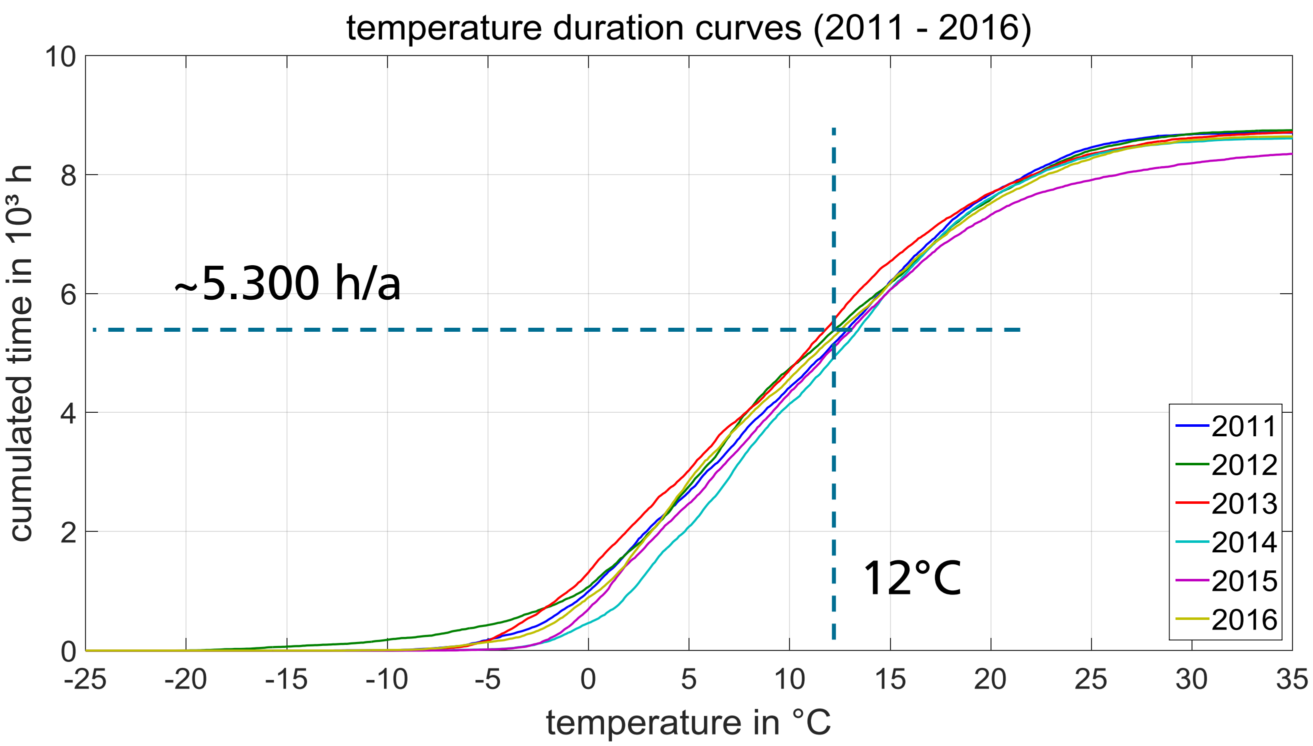
Motivation

Estimation of operating hours

- In Germany the **ambient temperatures is often below** the temperature of the cooling system



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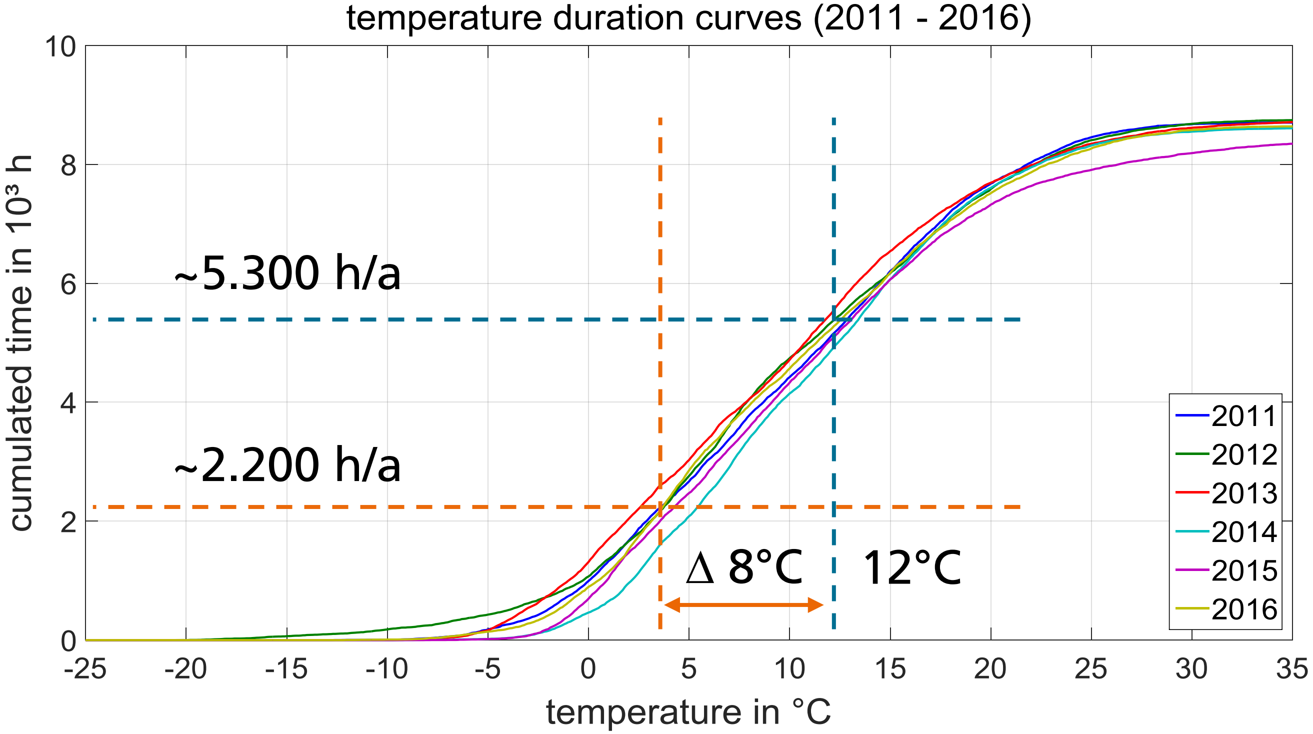
Motivation

Estimation of operating hours

- **Rule of thumb**: dry cooling is economically feasible if the temperature difference between ambient air and the cooling application is at least 6 to 8 °C (Reference system: 13 °C)



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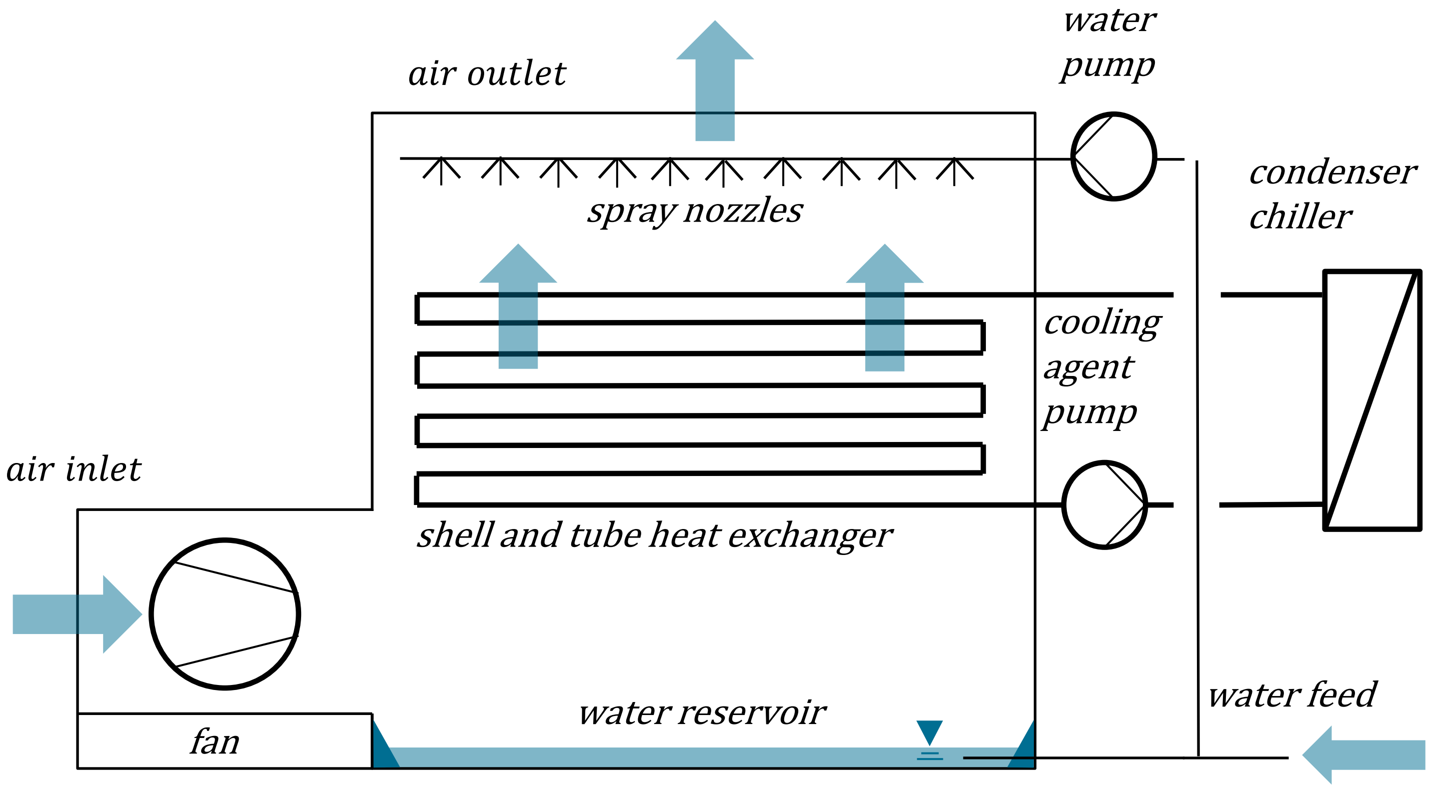
Model design
Hybrid recooler

- Diagram of a hybrid recooler



Recooler data	
technology	hybrid
fan stages	0/1/2
irrigation stage	0/1
max. power consumption	50 kW

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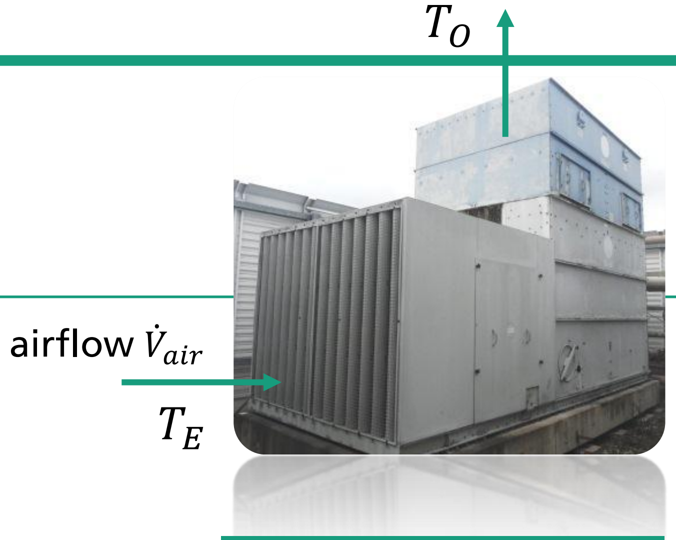
Model design
Hybrid recooler



- Modelling of operating strategies
  - Dry operation
    - Estimation auf air temperature at outlet T_O
    - $\dot{V}_{air}, T_E \rightarrow \alpha_i(Nu, Re, T_m), \alpha_o(Nu, Re, T_m) \rightarrow k \rightarrow \dot{Q}_{rc} \rightarrow T_{O,new}$
    - Repeat process until T_O matches $T_{O,new}$
    - Known <u>iterative</u> procedure for calculation of heat exchangers
  - Wet operation
    - No closed calculation methods for heat and mass transport
    - Manufacturers use experimental humidification curves
    - <u>Time-saving</u> model for energy system simulations is needed!

Explanation of parameters
α_i and α_o for shell and tube heat exchanger
heat exchanger with countercurrent principle
temperature-dependent physical properties
empiric air velocities at different fan stages

Nu = Nusselt number — *Re = Reynolds number*

α = heat transfer coefficient — *k = heat transmission coefficient*

i, o = inner / outer — *$\dot{Q}$ = cooling capacity*

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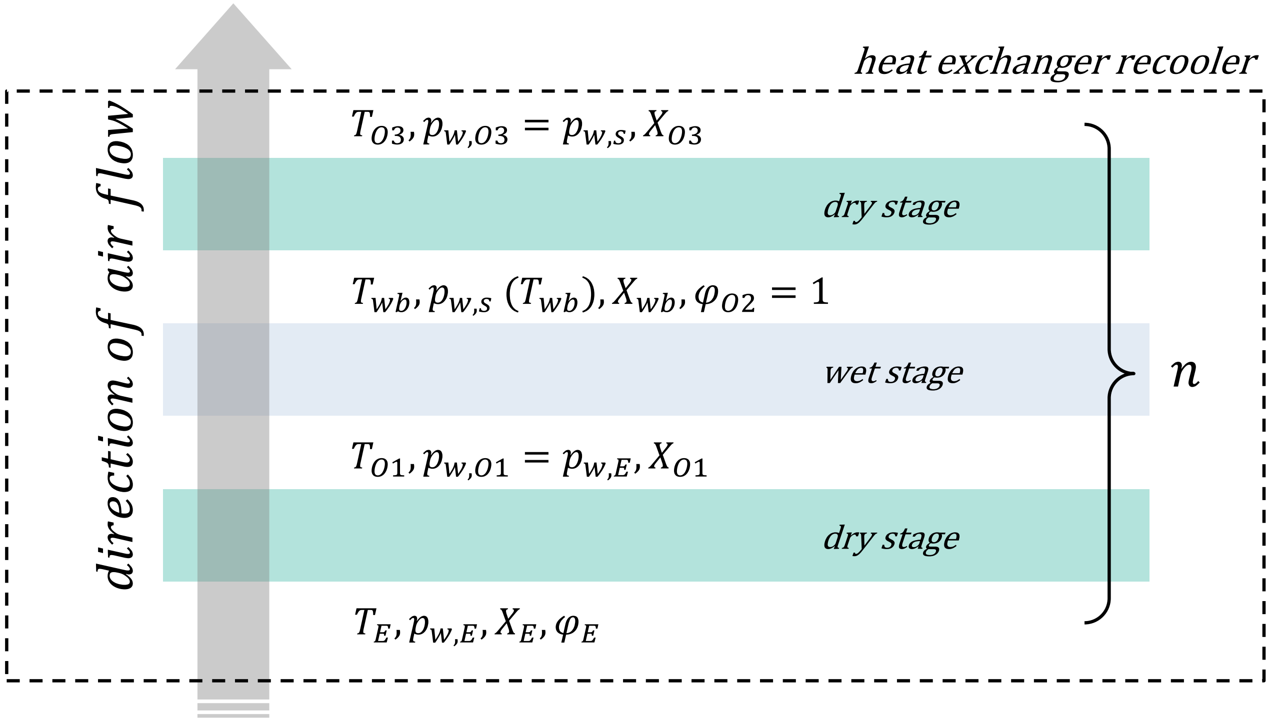
Model design

New model for wet operation

- Modelling of mass transfer and humidification for wet operation
  - Separating the heat exchanger into virtual segments (dry and wet)



Assumptions

- *ambient temperature* T_{amb} *equals inlet temperature* T_E
- *relative humidity* φ_E*, water content* X_E *and partial pressure* $p_{w,E}$ *of water are known*
- *n defines extent of discretization*
- T_{wb} *is the wet bulb temperature*

E,O = Entrance, Outlet | *φ = relative humidity* | *X = water content (in air)*

n = discretization number | p_w *= part. pressure of water in air* | *T = Temperature*

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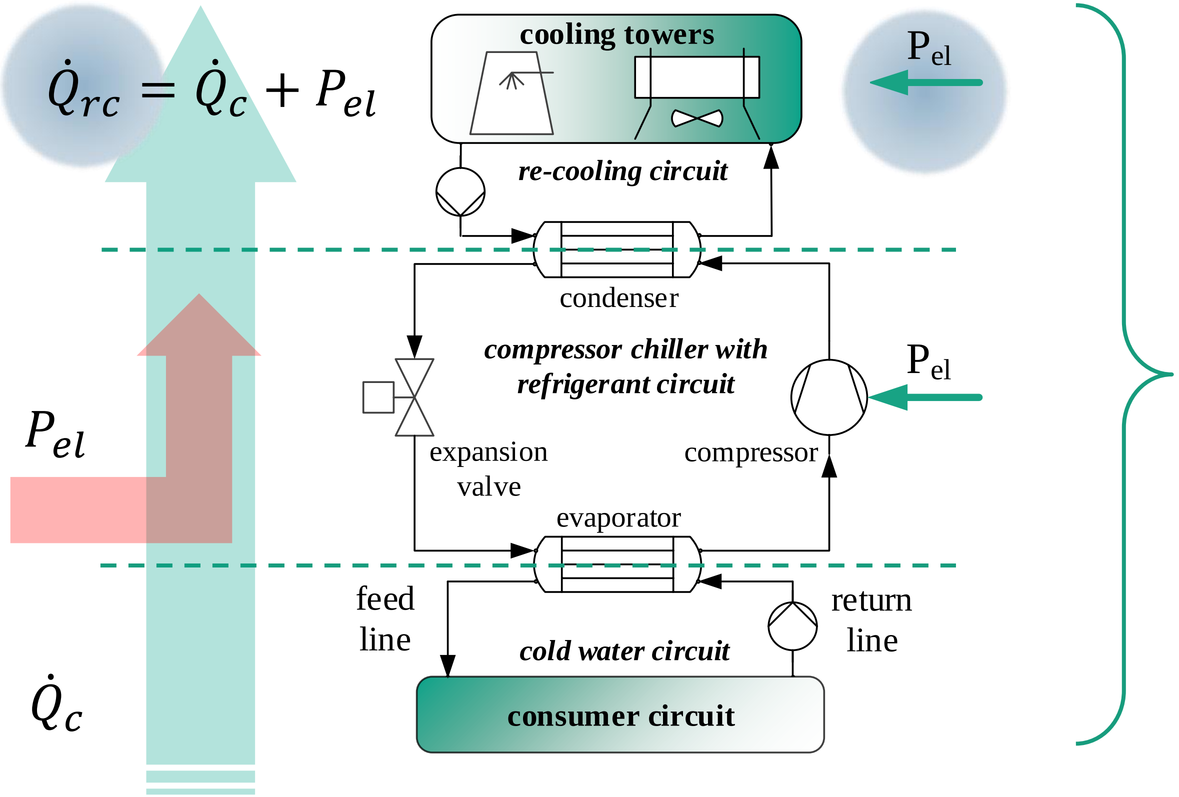
Model design

New model for wet operation

- Modelling of mass transfer and humidification for wet operation



P_{el}, $\dot{Q}_{rc}$ → *find n*

Model tuning

n defines the degree of interaction between dry and wet stages

n can be determined when $\dot{Q}_{rc}$ and P_{el} are known

task: Find n which suits best the experimental data

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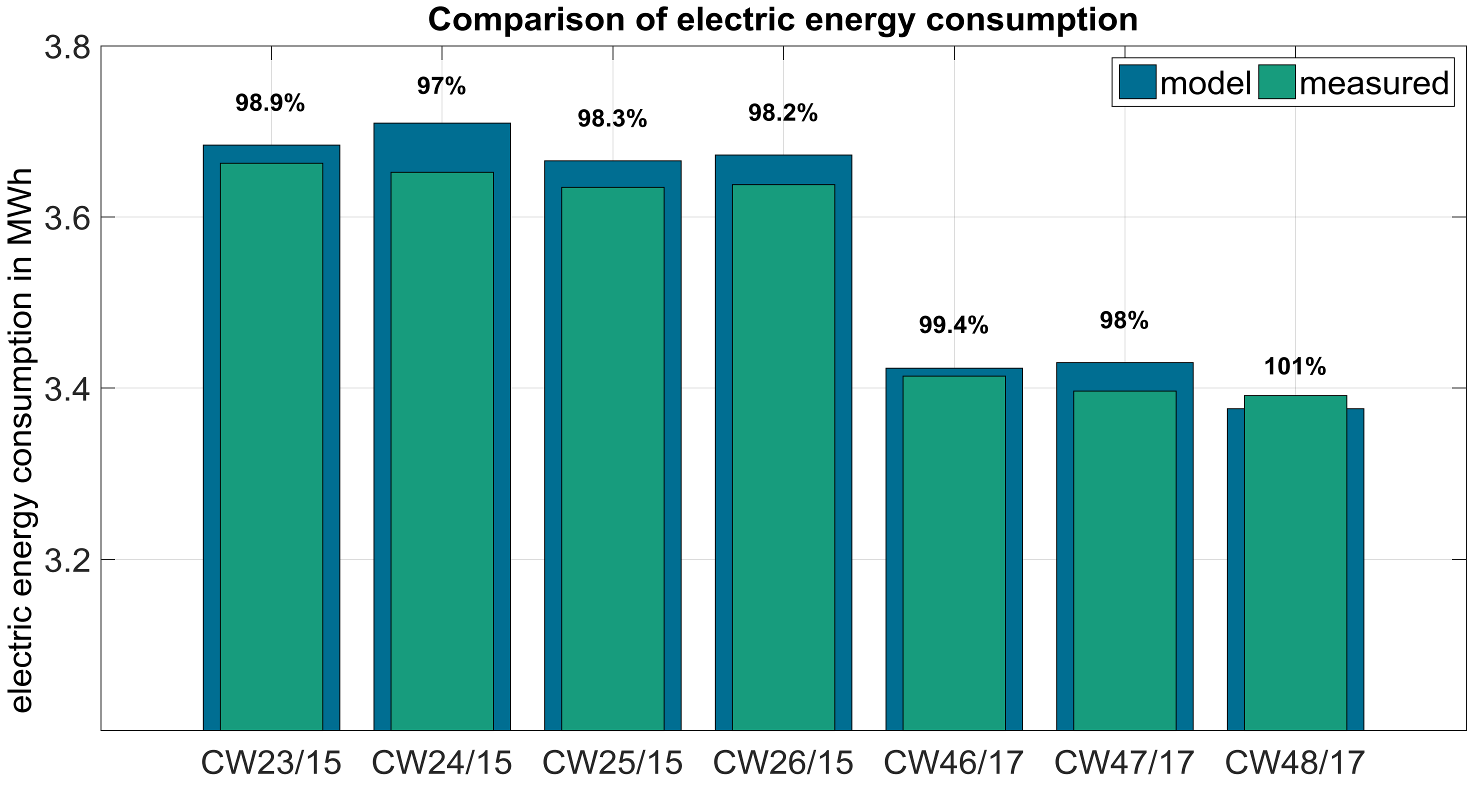
Model design
Model verification

- Modelling of important system variables



Boundary conditions
4 weeks with summer profile
3 weeks with winter profile
existing heat recovery from chiller condenser was shut down
benchmark variable is electric energy consumption

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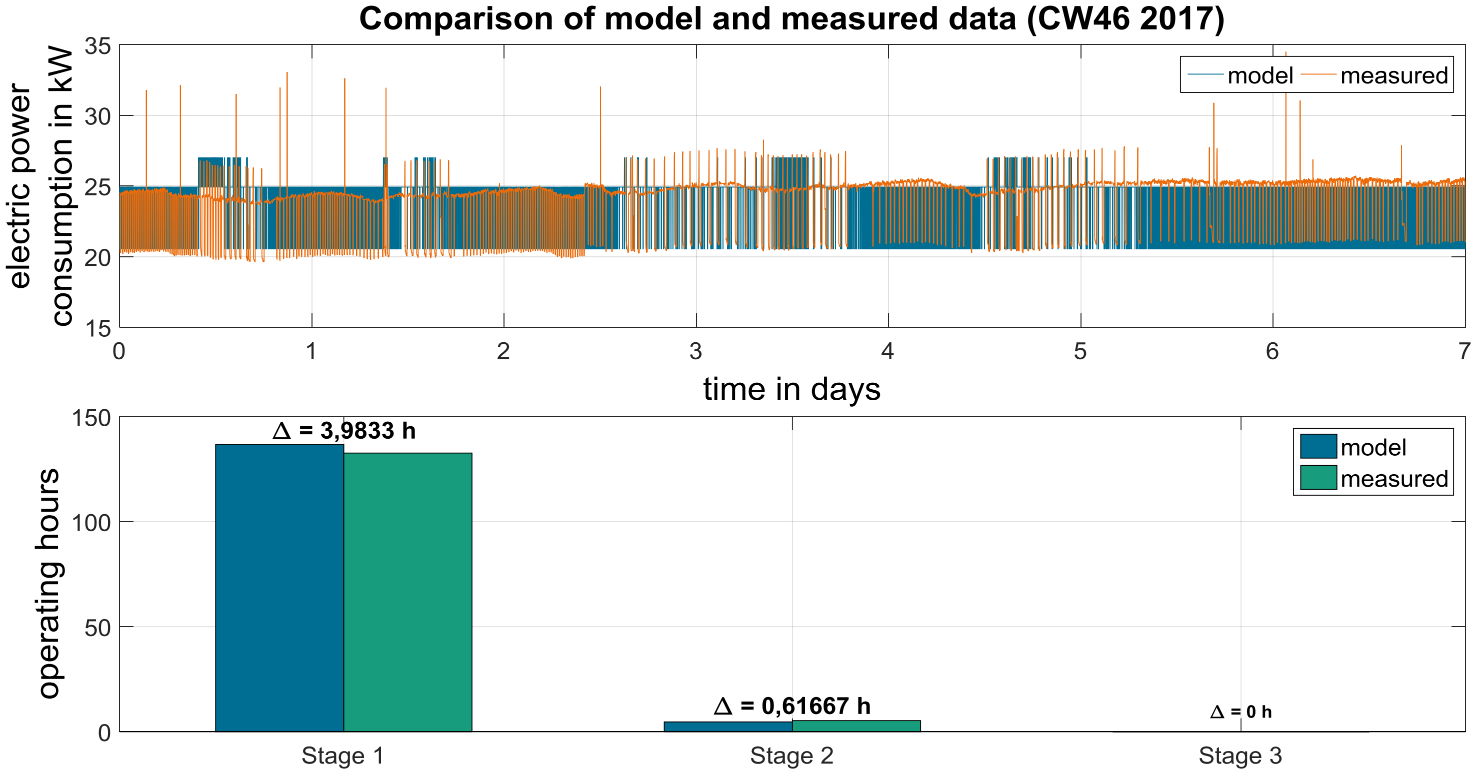
Model design
Model verification

- Modelling of important system variables



Fan stage usage

temporal progression of fan stage activation

electric power consumption of recooler gives away the active fan stage

total duration of individual stages can be used for model verification

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P. Puls, 18.07.2018

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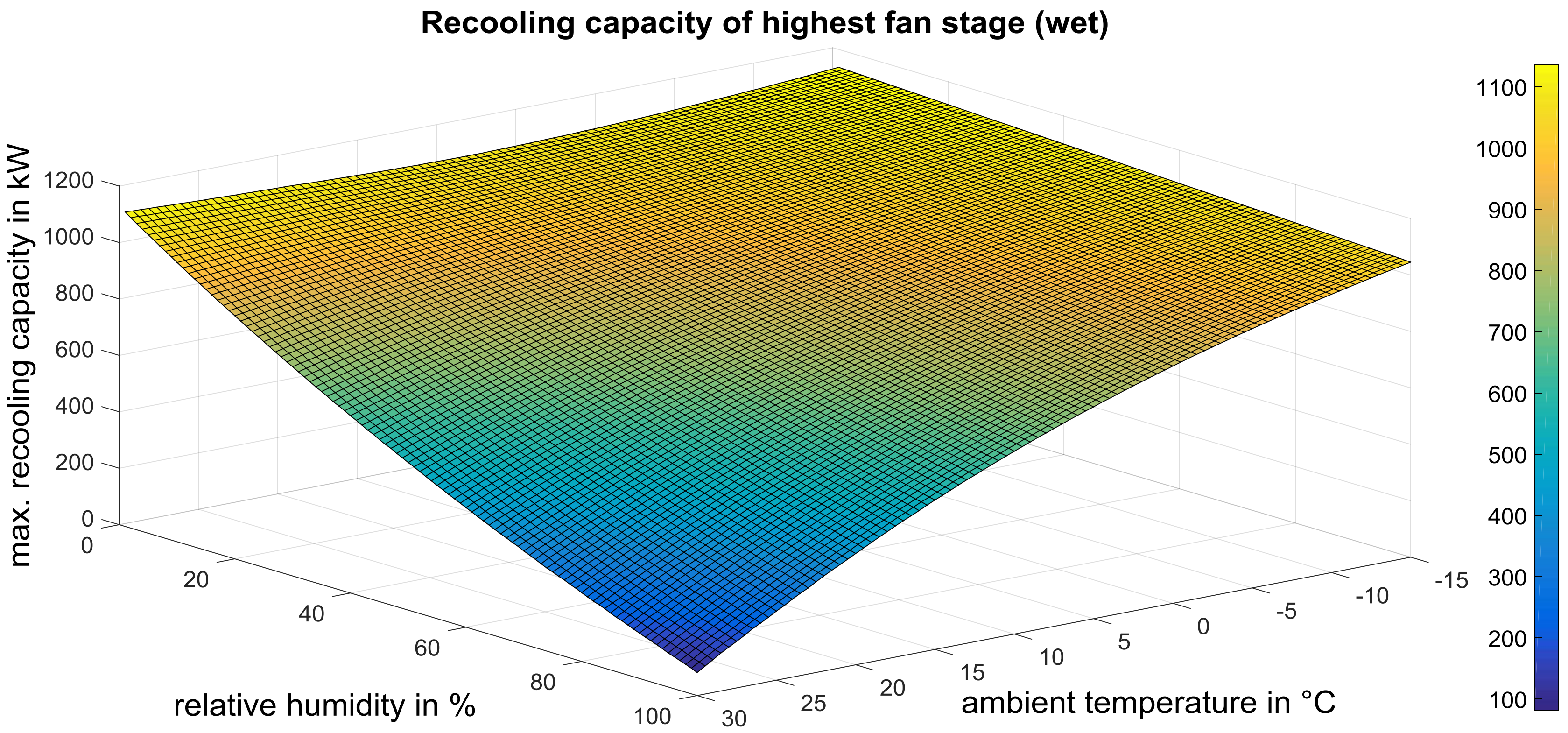
Model design

Simulation results

- Wet operation (highest fan stage)



Main impacts
ambient temperature
relative humidity
fan stage (air mass flow)
temperature level of the recooling-application (32 °C)

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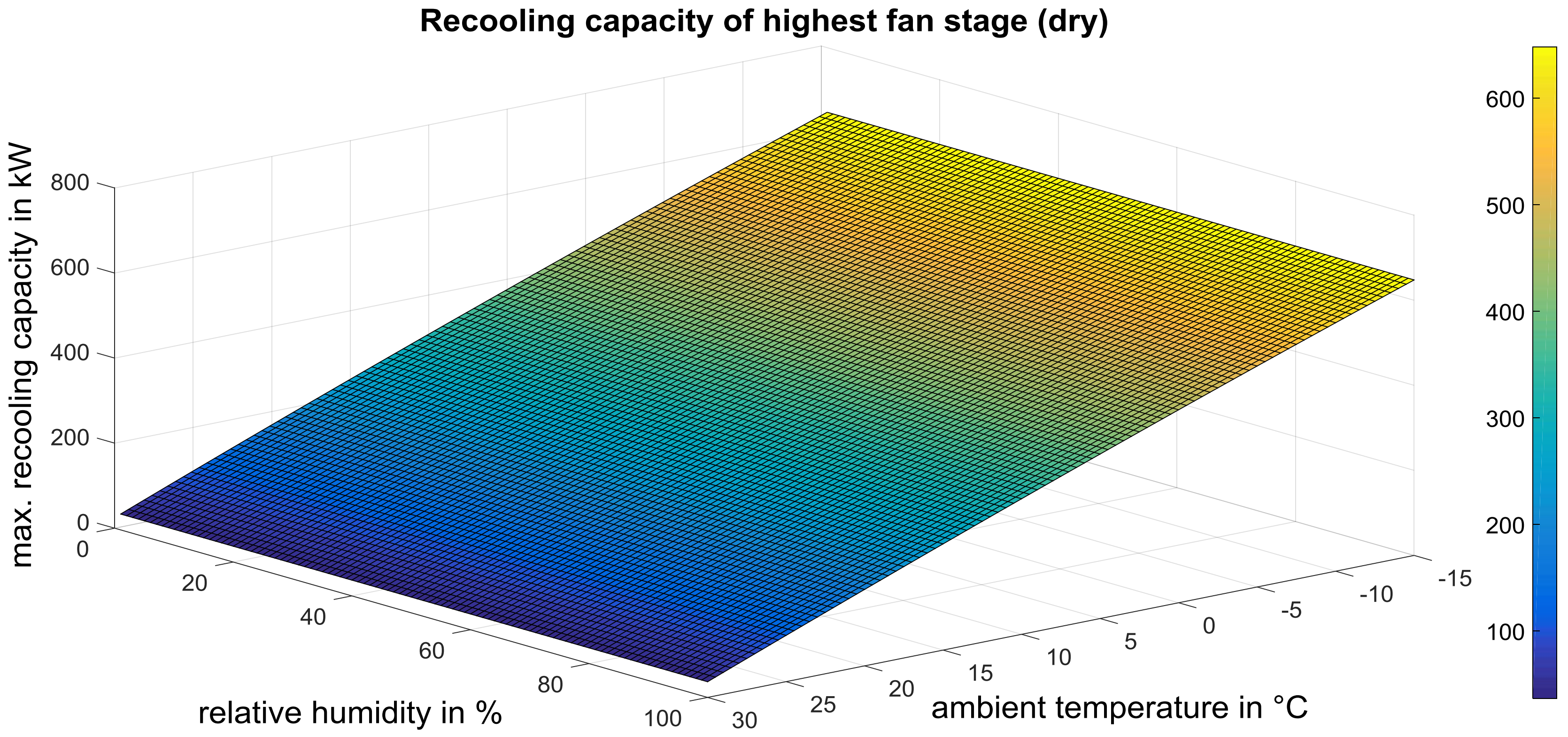
Model design
Simulation results

- Dry operation (highest fan stage)



Main impacts
ambient temperature
fan stage (air mass flow)
temperature level of the recooling-application (32 °C)

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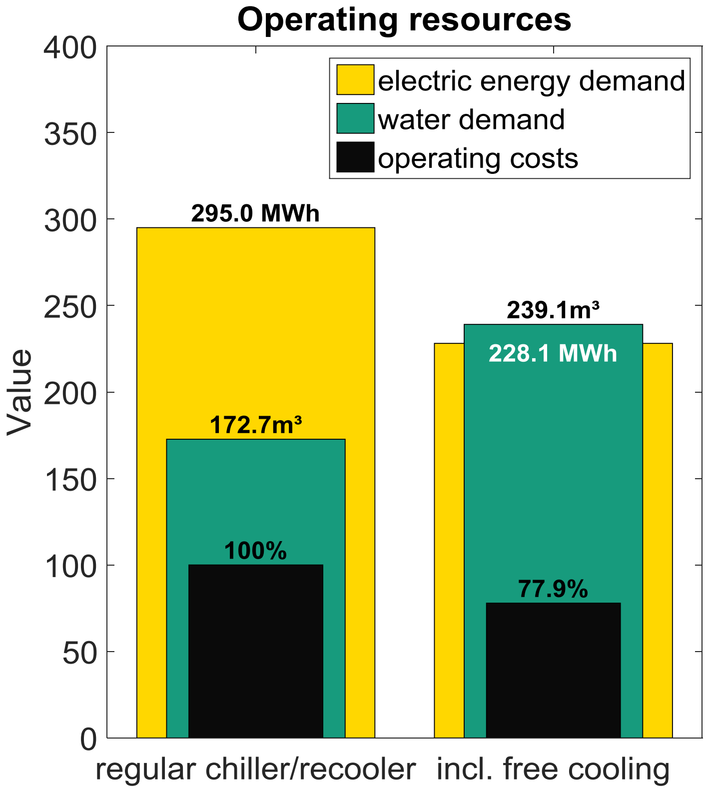
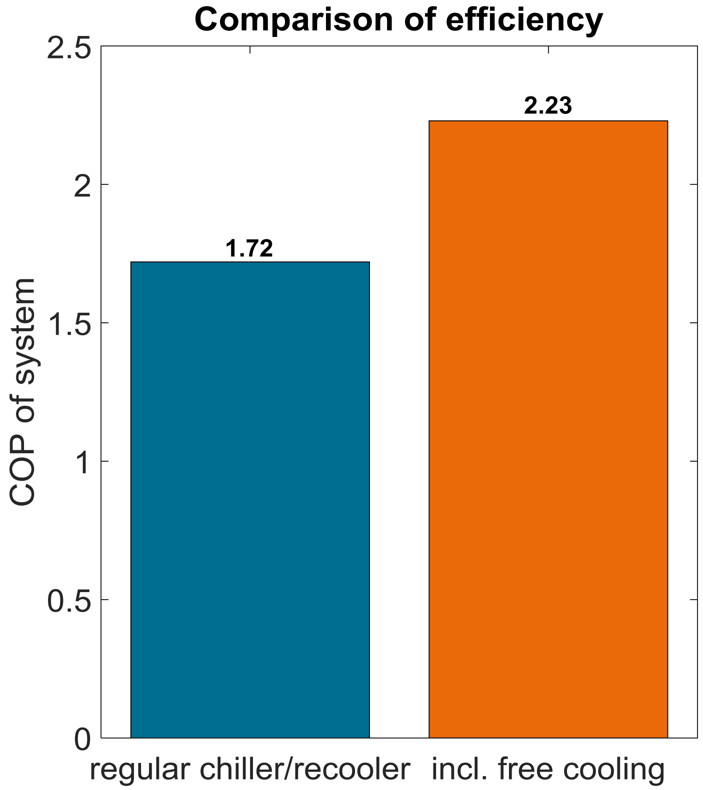
Model design
Simulation results

- Efficiency forecast via simulation of cold water system





Forecast for energy efficiency
time frame: 24 weeks (Nov. 2015– Apr. 2016)
seasonal efficiency is ~22% higher compared with chiller
annual efficiency is raised by ~12%
$\overline{T}_{amb} = 4.4°C$, $\dot{\overline{Q}}_c = 126\ kW$

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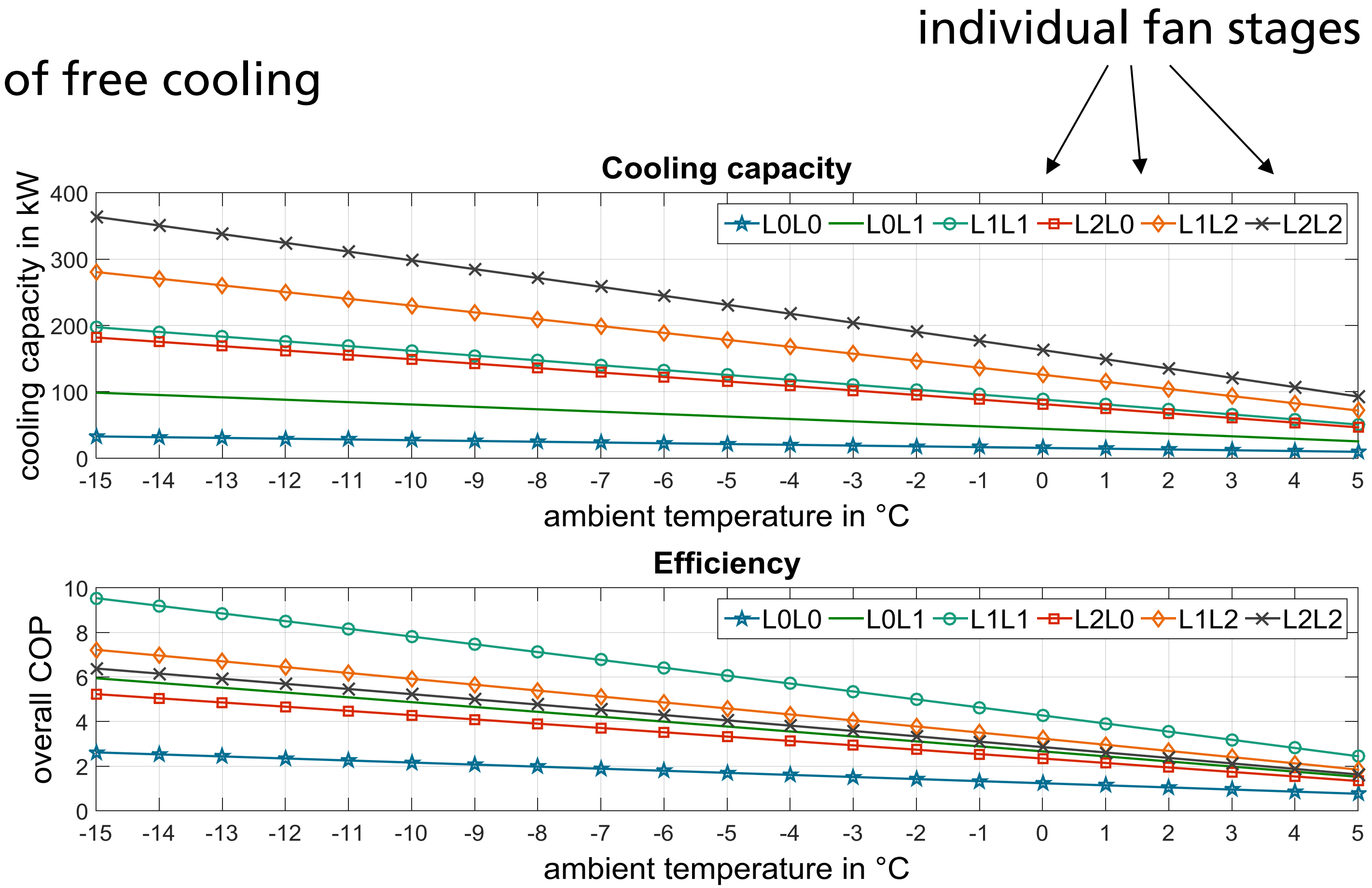
Model design

Simulation results

- Boundary conditions for utilization of free cooling

→ load dependency!

→ temperature dependency!



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Overview

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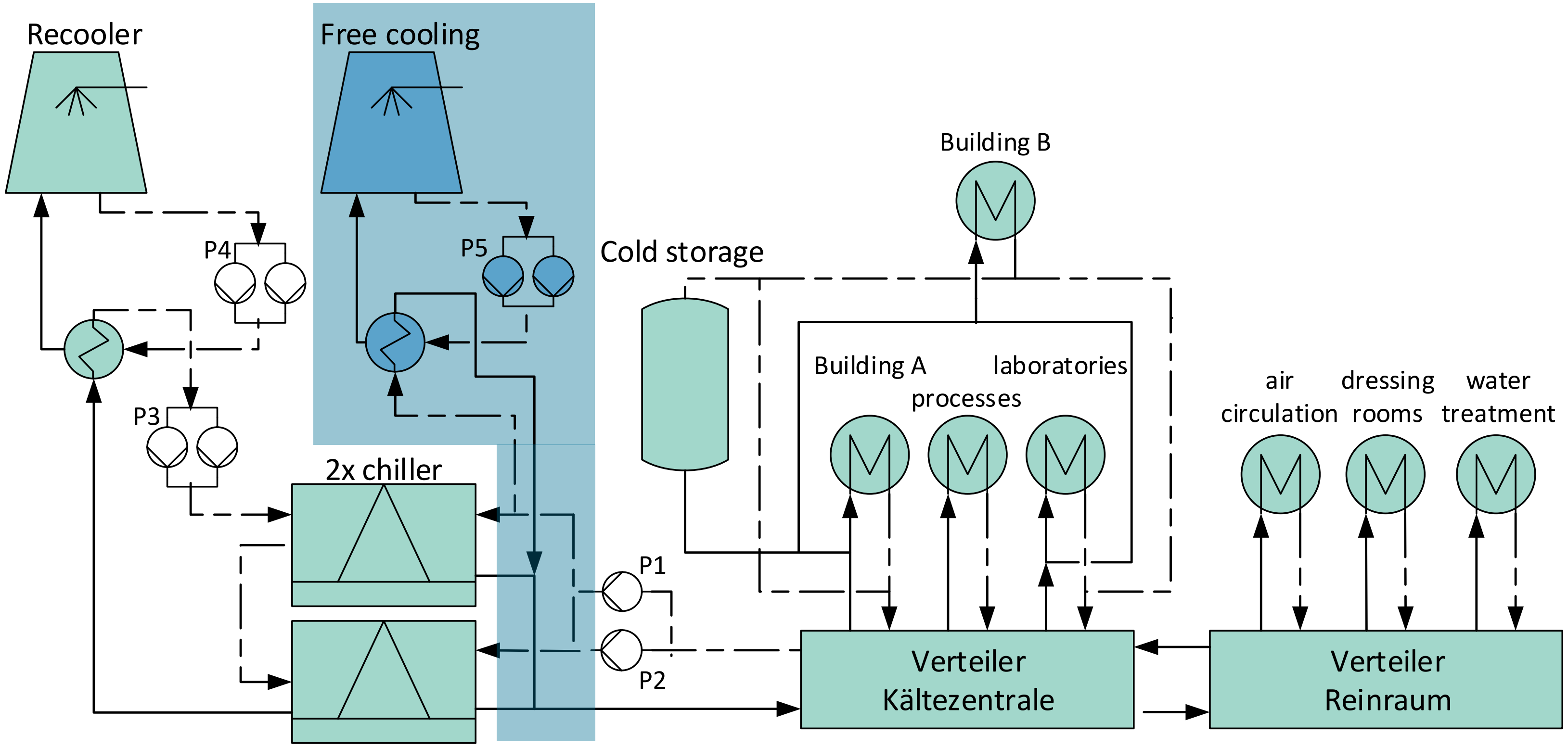
Technical implementation
Integration of components

- Integration into existing cooling system
  - **Blue**: free cooling components
  - **Green**: regular cooling components



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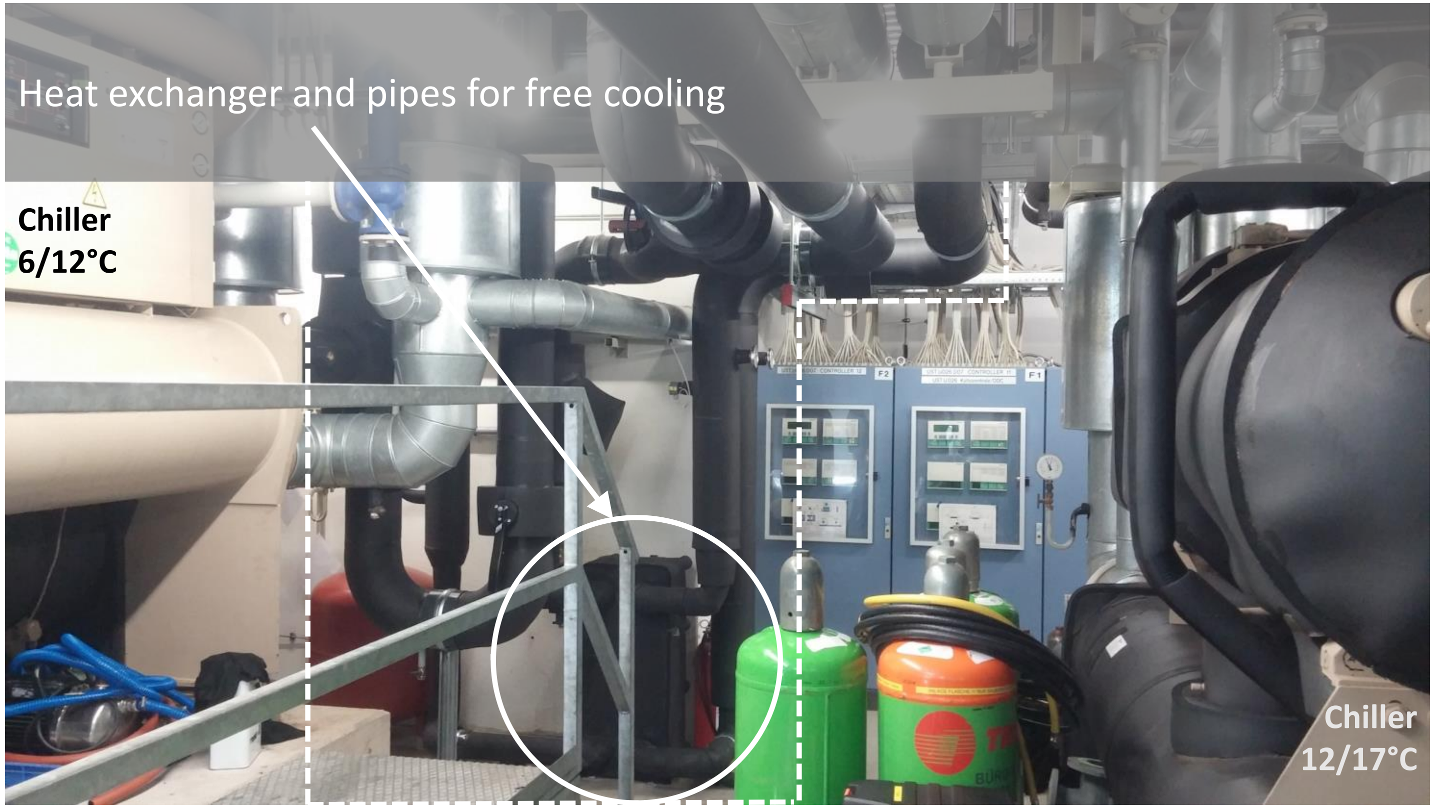
Technical implementation
Central chiller station

- Installation of new pipes and heat exchanger
  - Plate heat exchanger (nominal capacity of **250 kW**)
  - **Several valves** for switching flow directions and bypassing the chiller 6/12°C
  - **Temperature sensors** for controlling the cooling capacity



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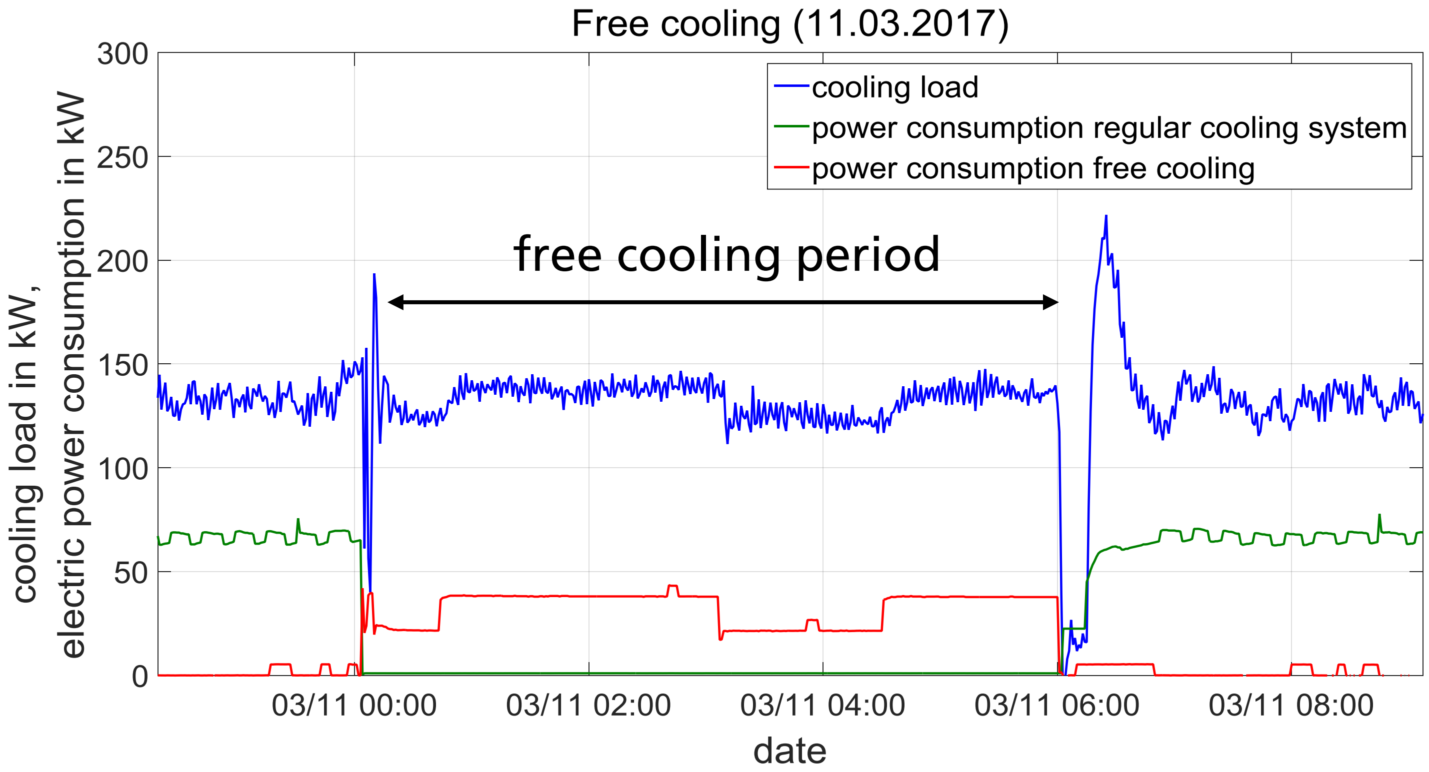
Technical implementation
Field test on 11.03.2017

- Boundary conditions:
  - mean ambient temperature -2.5 °C
  - mean cooling load ~131.5 kW



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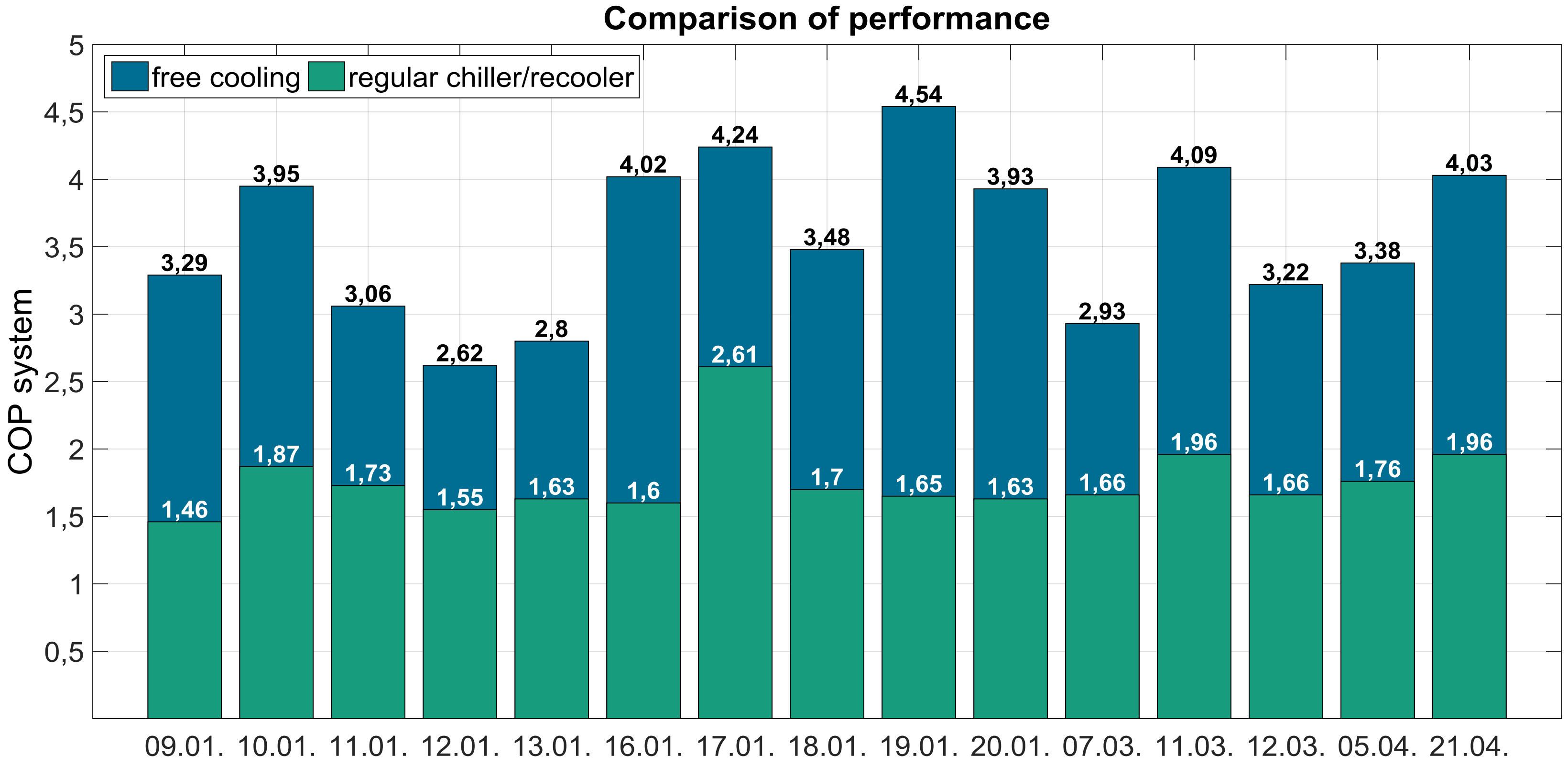
Technical implementation
Overview on results

- Overview of all field tests in 2016/17
  - mean ambient temperature -0.24 °C
  - mean cooling load ~115 kW



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Results and summary
Energy saving potentials

- Model design
  - New model for hybrid recoolers was developed and verified
  - Model integration in energy system simulations is easy and time saving
  - Just the electric power demand and the recooling power is needed for model tuning

- Simulation results
  - **Seasonal cooling efficiency** (winter period) **is 22 % higher** than regular chiller/recooler combination
  - Simulation indicates **annual energy savings of 12 %** related to the electric energy demand of the cooling system

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Results and Summary
Energy saving potentials

- Technical implementation
  - Technical implementation indicates **significant cost savings**
  - Simulation results are in good agreement with experimental results
    - Simulation forecast of energy savings were ~47 % during free cooling
    - Technical implementation yielded ~50 %
  - The operating parameters (e.g. size of heat exchanger, temperature limits) were taken from the simulation

- Outlook
  - In 2017/18 the plant was shut down due to building measures; more operational experience is planned for 2018/19 as well as a combined operation with cold storage

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Thank you for your attention!

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Additional information
Free cooling

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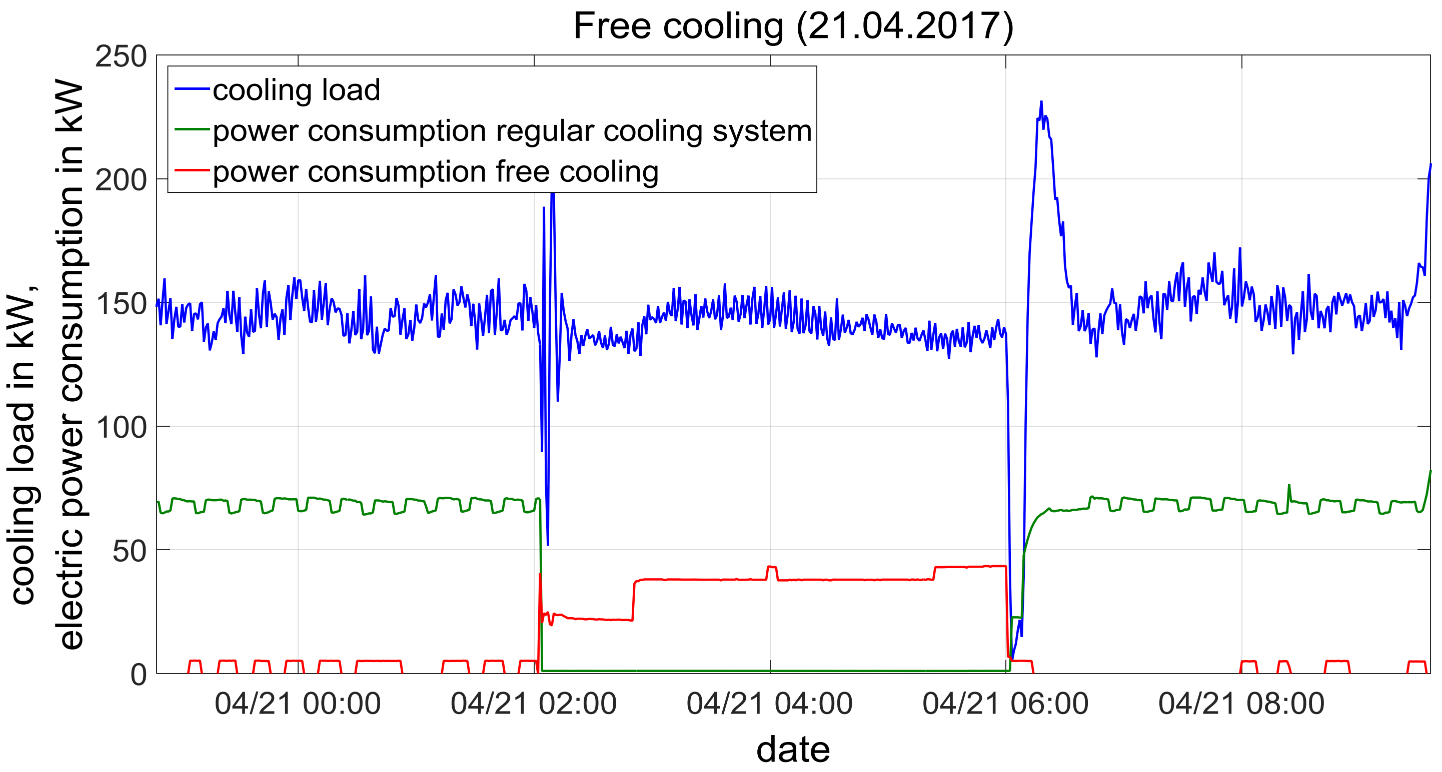
Technical implementation
Field test on 21.04.2017

- Boundary conditions
  - mean ambient temperature -2.6 °C
  - mean cooling load ~137.5 kW



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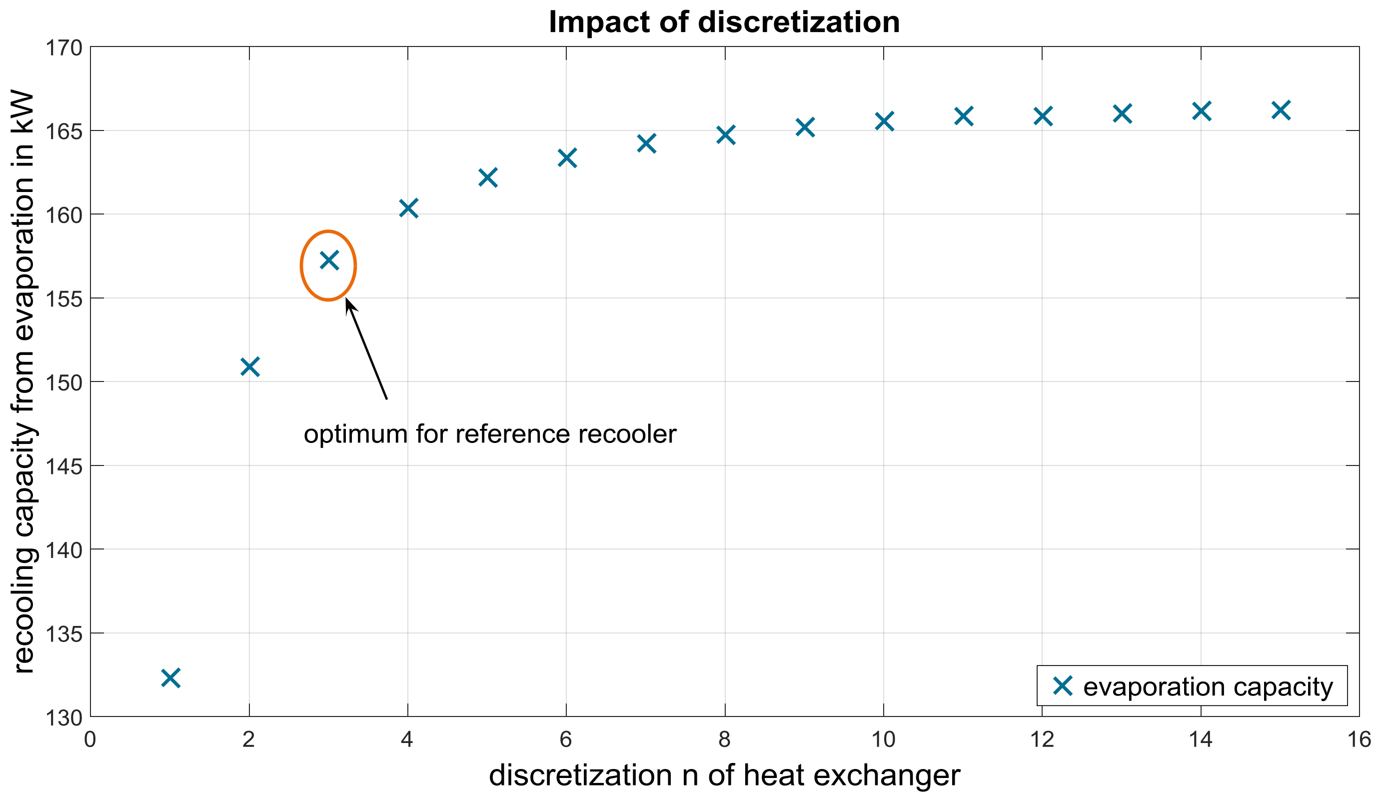
Technical implementation
Discretization and model tuning

- Evaporation capacity in dependence of the discretization parameter n:



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