Institute of Thermal Engineering

TU Graz
Graz University of Technology

SCIENCE ▪ PASSION ▪ TECHNOLOGY

Sector Coupling Potentials

of a 5th Generation District Heating and Cooling Network

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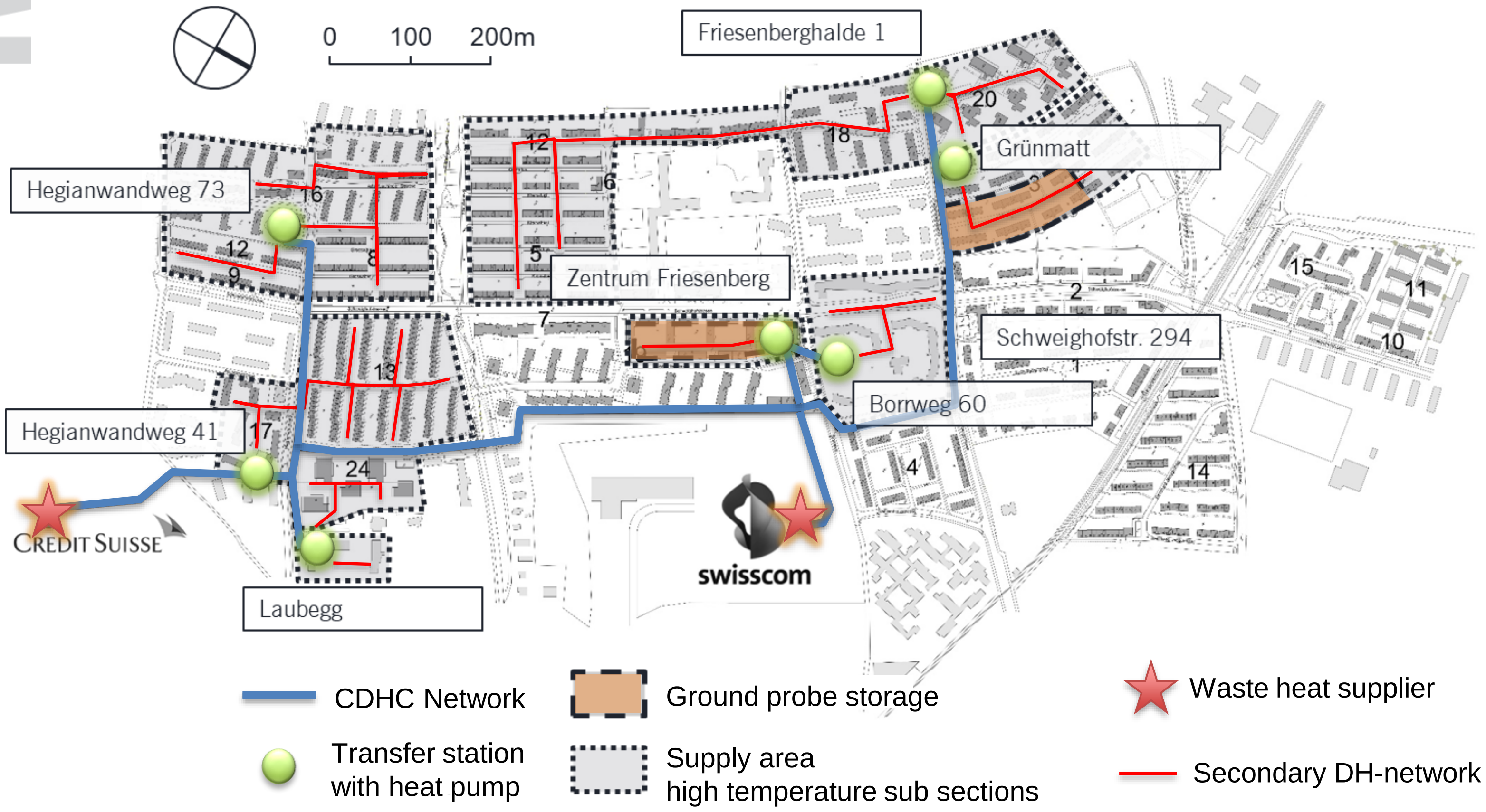
6th International Conference on Smart Energy Systems, 6-7 October 2020, Aalborg, Denmark

The FGZ CDHC-network

Status quo 2020

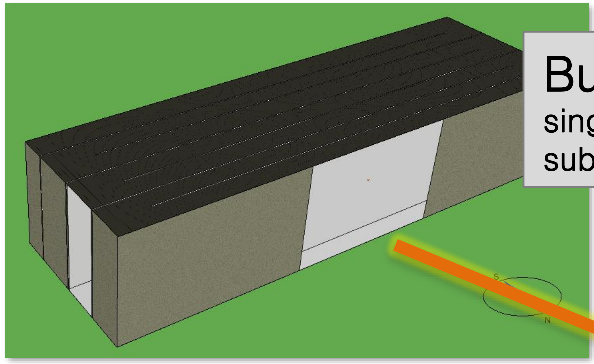


Location: Friesenberg, Zürich, Switzerland
Owner: Familienheim-Genossenschaft Zürich
Total nr. of housing units: 2200
Total nr. of residents: 5500

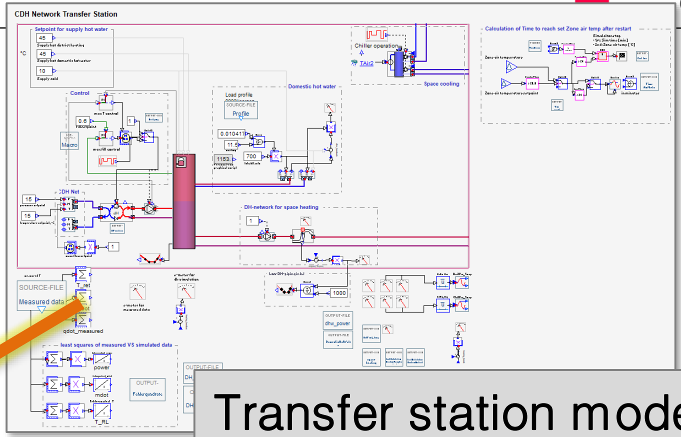
Connected housing units: 1000
Installed heat pump power: 9 MW
Nr. of ground probes installed: 266 at 250m

Start of operation:
2014 with 400 hu, 3,4 MW hpp, 153 probes
Final completion planned:
2050, with 2200hu, 14 MW hpp, 453 probes

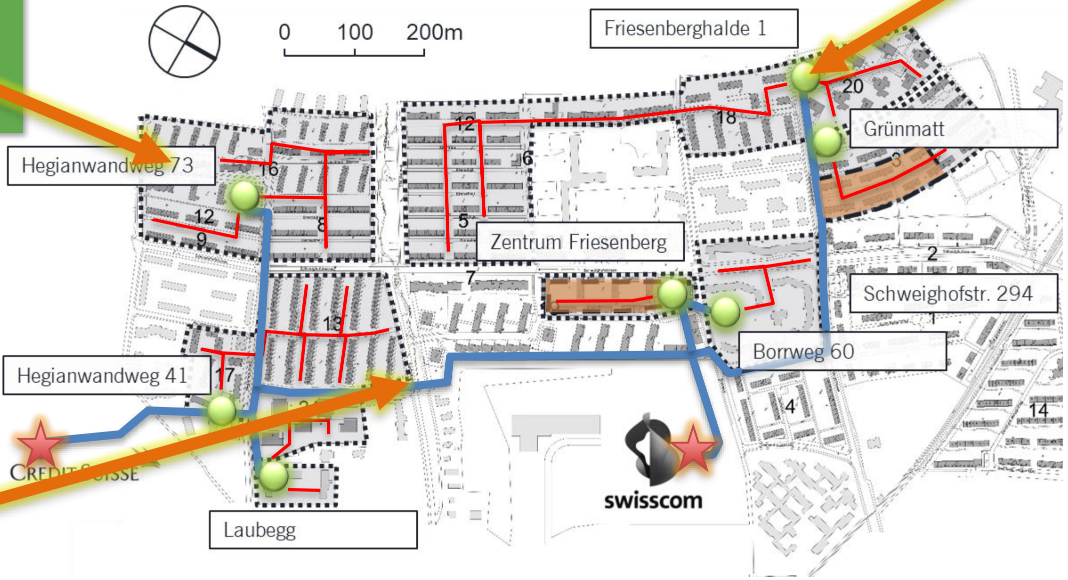
Co-simulation framework in IDA ICE



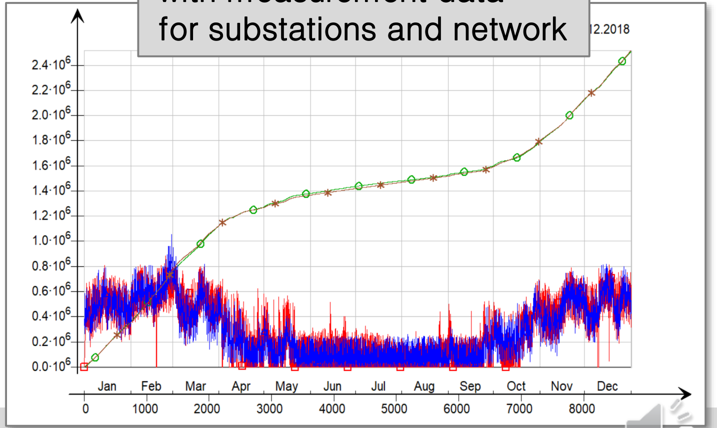
Building model
single building
substitute for sub area

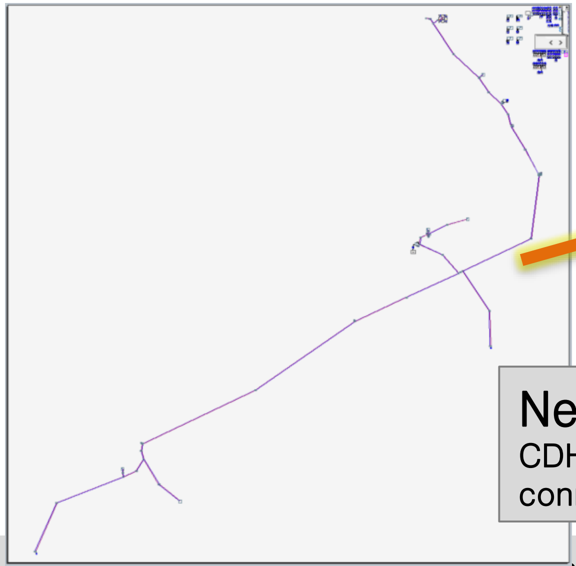


Transfer station model
heat pump, hot water storage,
domestic hot water, space heating
secondary side dh–network



Model validation
with measurement data
for substations and network





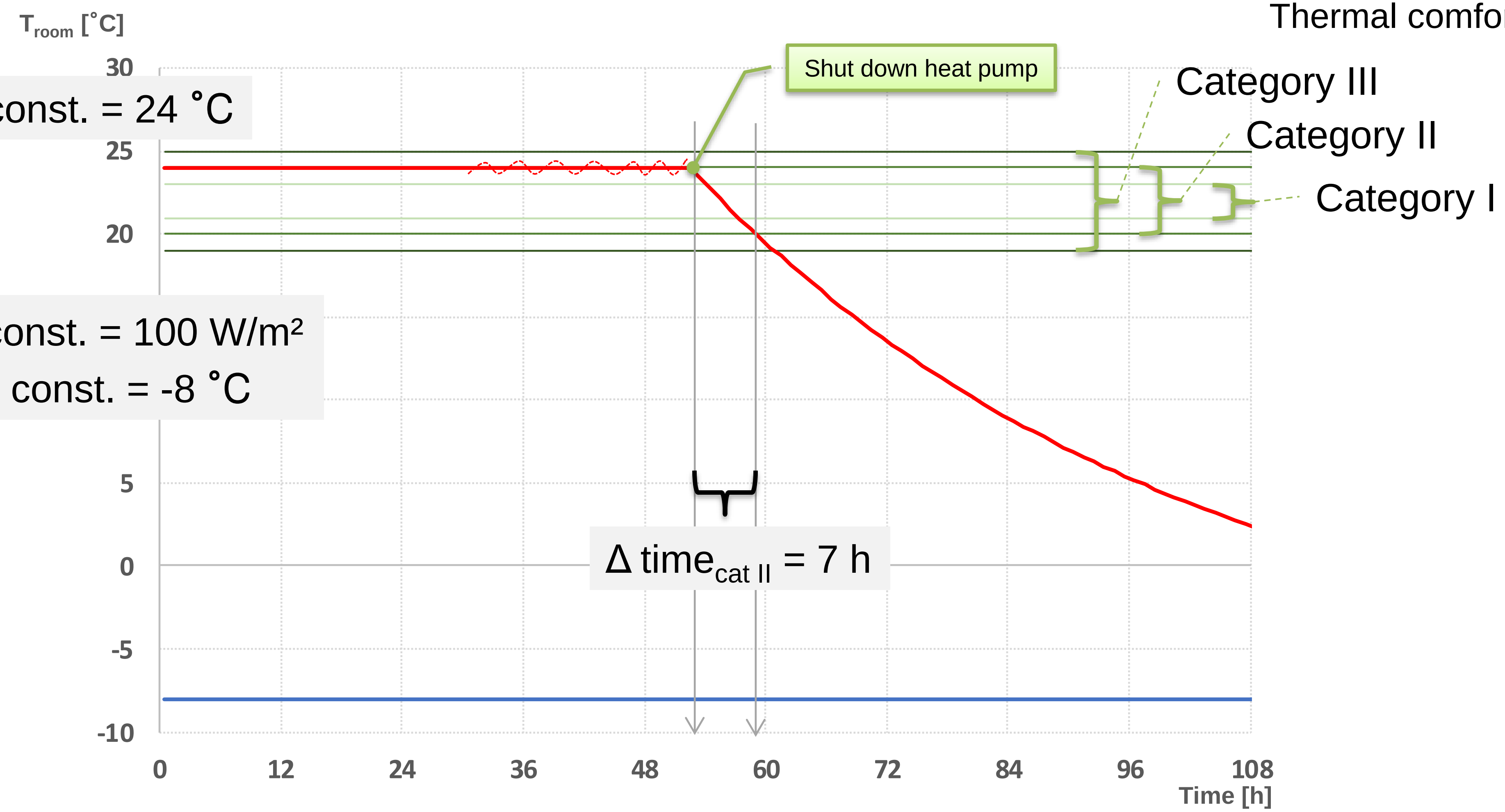
Network model
CDHC network
connecting transfer stations

Step response test with constant boundary conditions

DIN EN ISO 7730
Thermal comfort in buildings

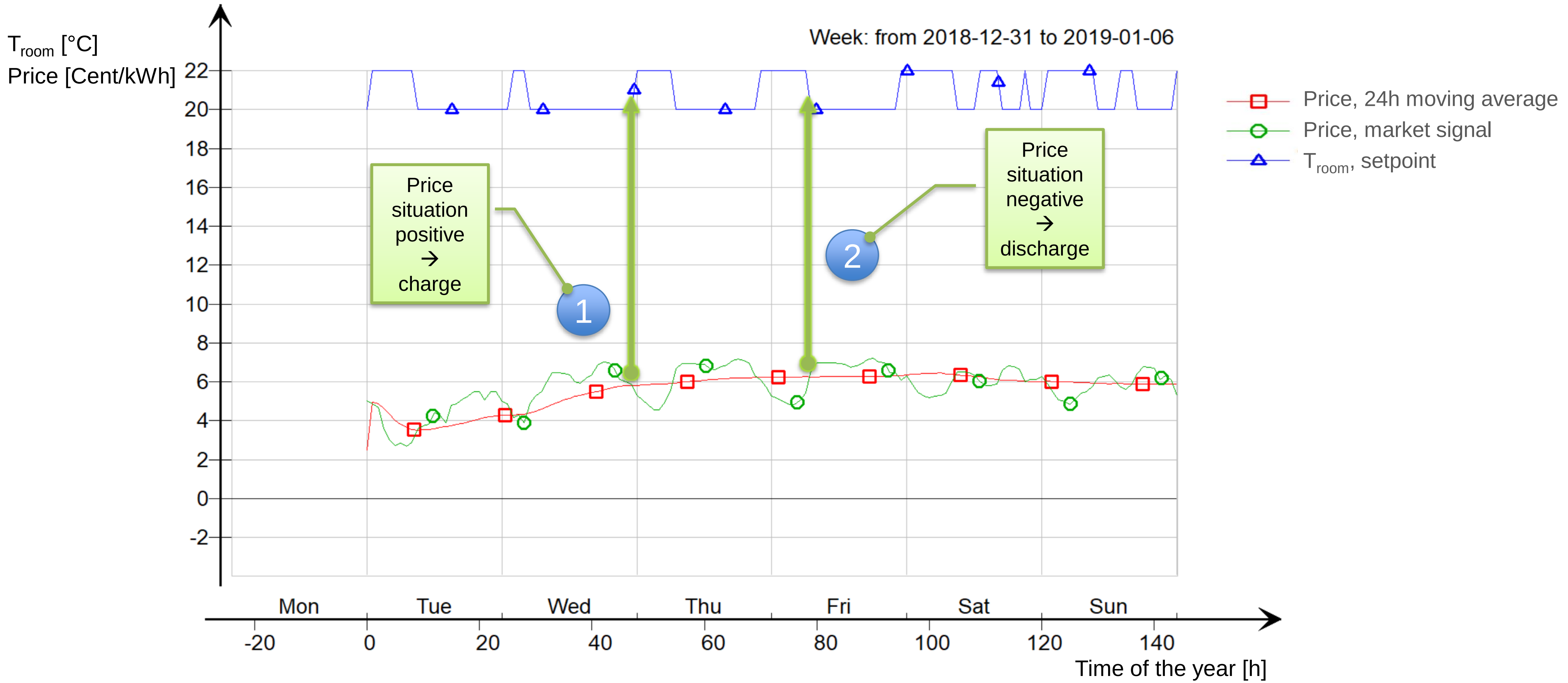
T_{room} = const. = 24 ˚C

I_{global} = const. = 100 W/m²
$T_{amb\text{-}air}$ = const. = -8 ˚C

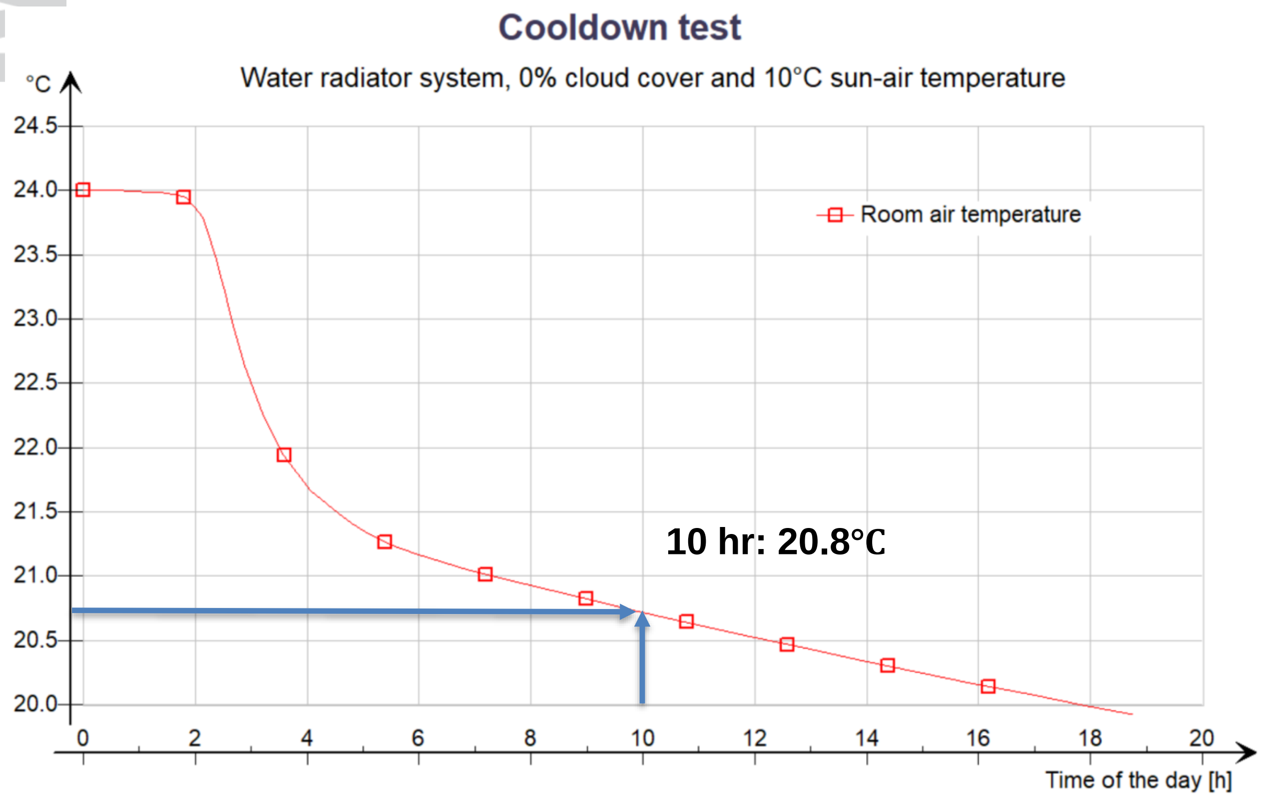


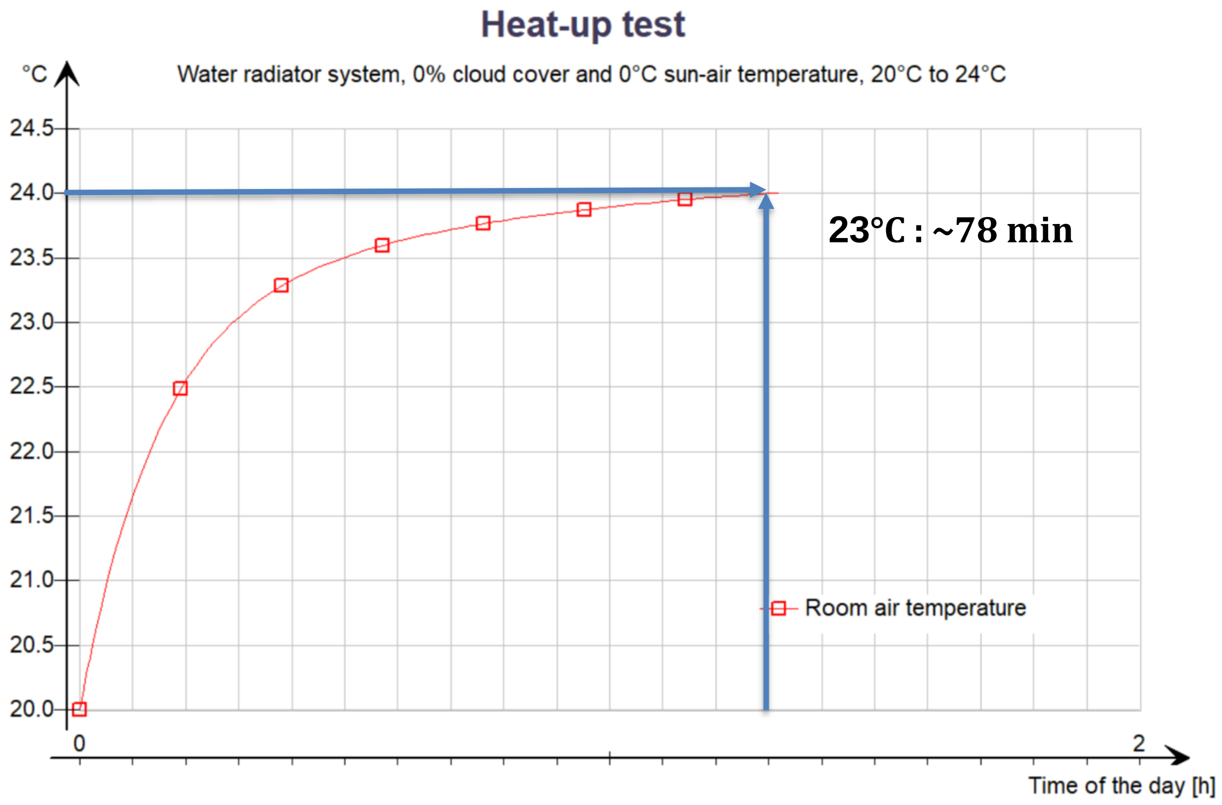
Dynamic network simulation with energy market price signal

24h moving average control

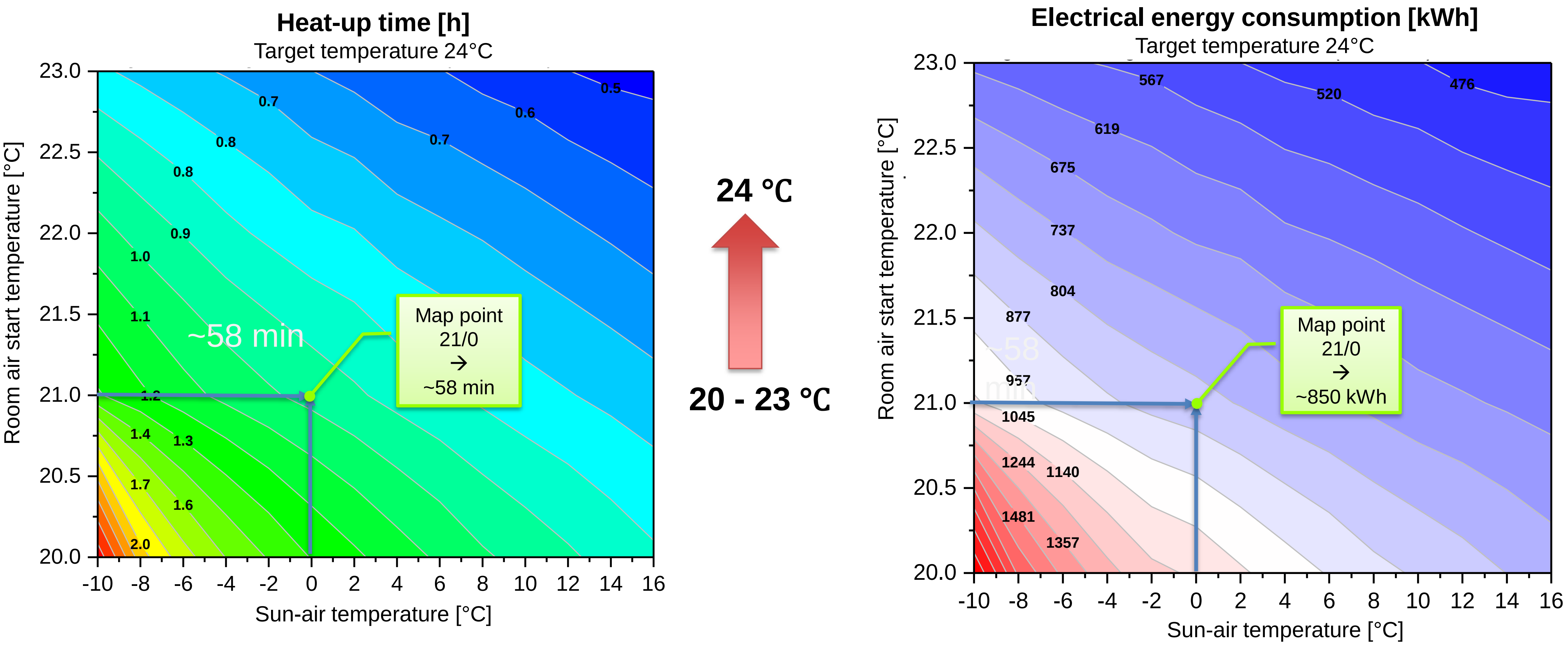


Step response test, 20°C and 24°C





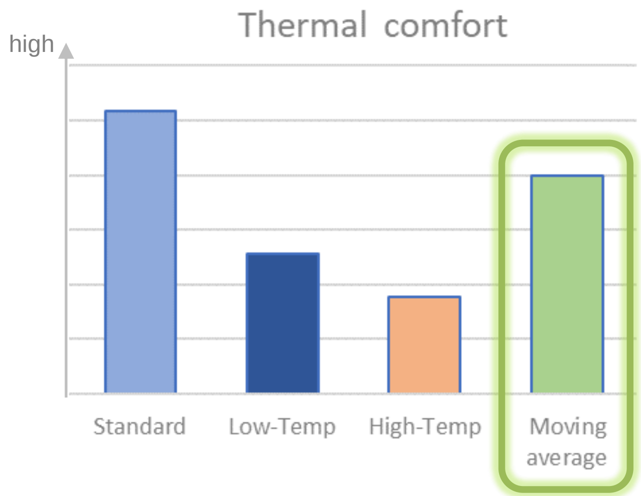
Characteristic diagrams of the step response test

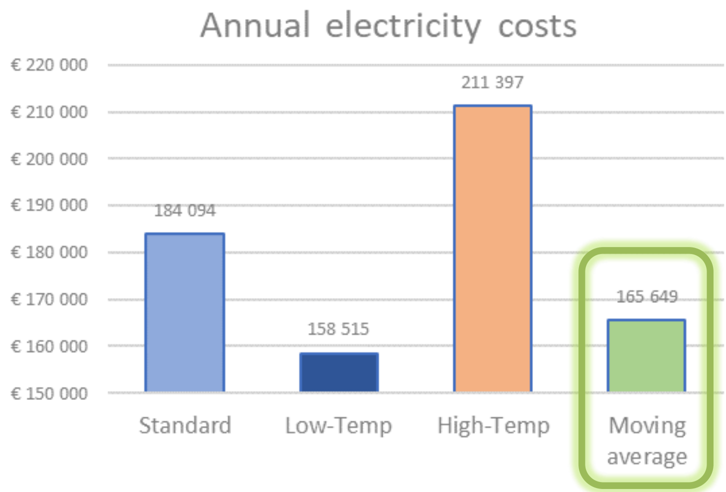


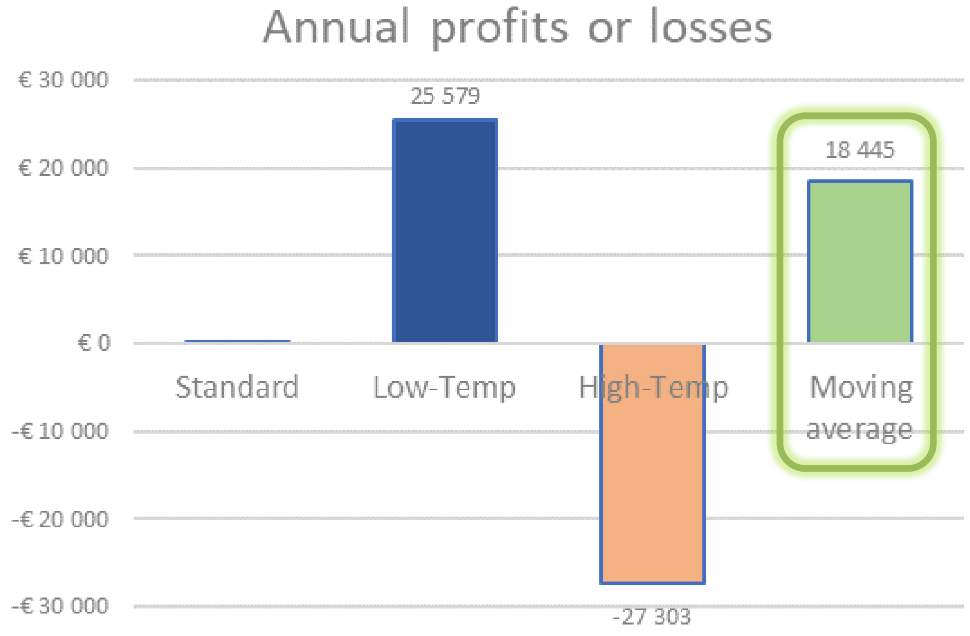
Revenue potentials of the network

Investigation of different control strategies with energy spot market tariff

Szenario	Room air temperature setpoint
Standard	constant 22°C
Low-Temp	constant 20°C
High-Temp	constant 24°C
Moving average	variable: if 24h MA > tariff then 22°C else 20°C







Possibilities & challenges

Possibilities

- System **flexibilities** available
- **Extra revenues** with existing system topology possible
- Numerous **optimisation possibilities** of the network
- **Simulation model** for further investigation/optimisation available

Challenges

- System **complexity** for 5GCDH-networks
- Large number of **influencing variables** on the system behavior
- **Modelling** of undirected thermal networks
- Still **high work effort** for detailed simulation needed

Thank you for your attention!

Contact

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Links

The research project *'DeStoSimKaFe'*

- TU Graz
- AEE Intec
- Researchgate
- Austrian funding organisation FFG

Project partners

- AEE Intec
  http://www.aee-intec.at
- anex Ingenieure AG
  https://www.anex.ch/de/
- Energieinstitut Vorarlberg
  https://www.energieinstitut.at/
- Ochsner Process Energy Systems
  https://processenergysystems.com/
- 3F Solar Technologies
  https://www.3f-solar.at/

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Sector coupling with CDHC Networks

Heat pump operation strategy

- Installed electrical power & systems thermal flexibility
- Large industrial heat pumps → no pooling necessary

Power to heat potentials

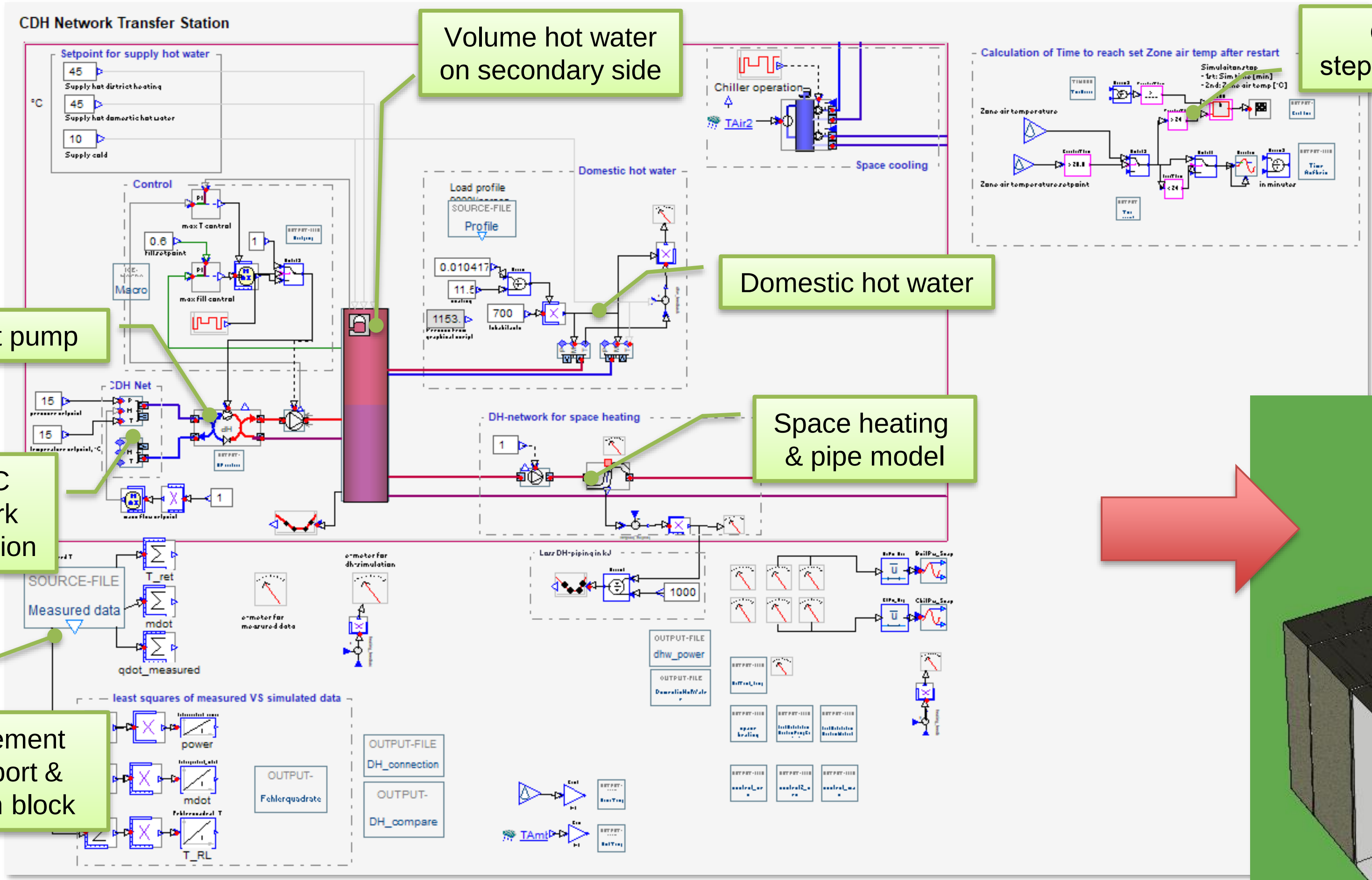
- Energy spot market
  - Use combination of cheap market prices and heat storage capacities
- Grid stability services
  - Use installed electrical heat pump power and heat storage capacities

Flexibility potentials

- Peak clipping
  - Lower the costs of peak power contract
- Peak power for other applications
  - Utilise unused peak power possibilities for e.g. charging stations

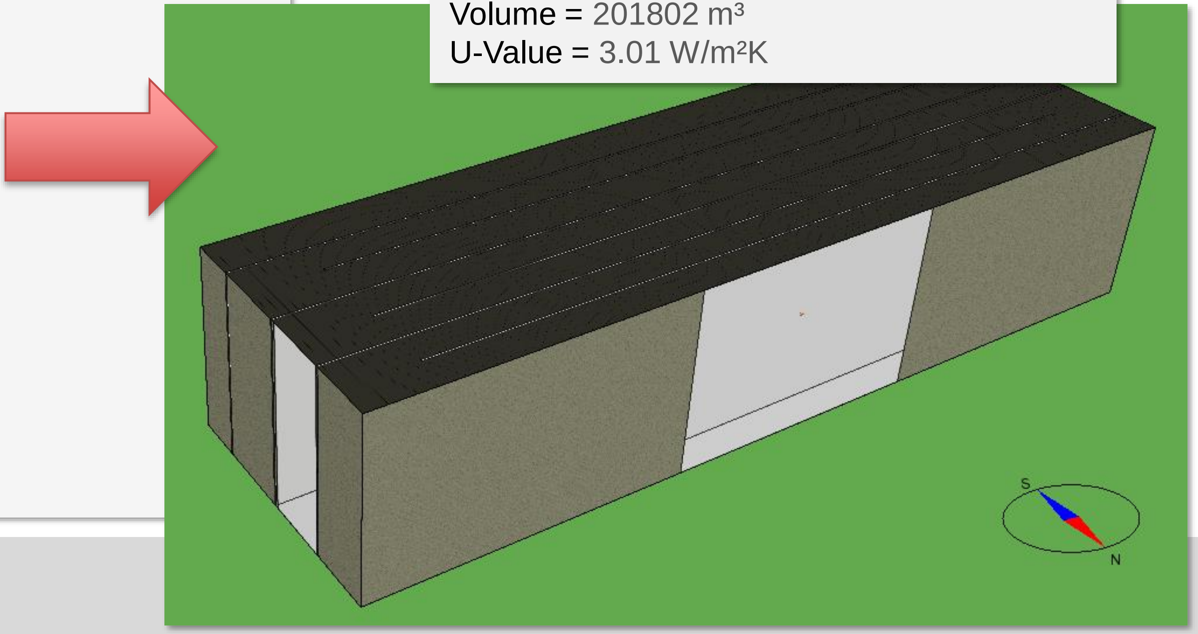
Simulation framework - IDA ICE model

Sub section with transfer station and substitute building

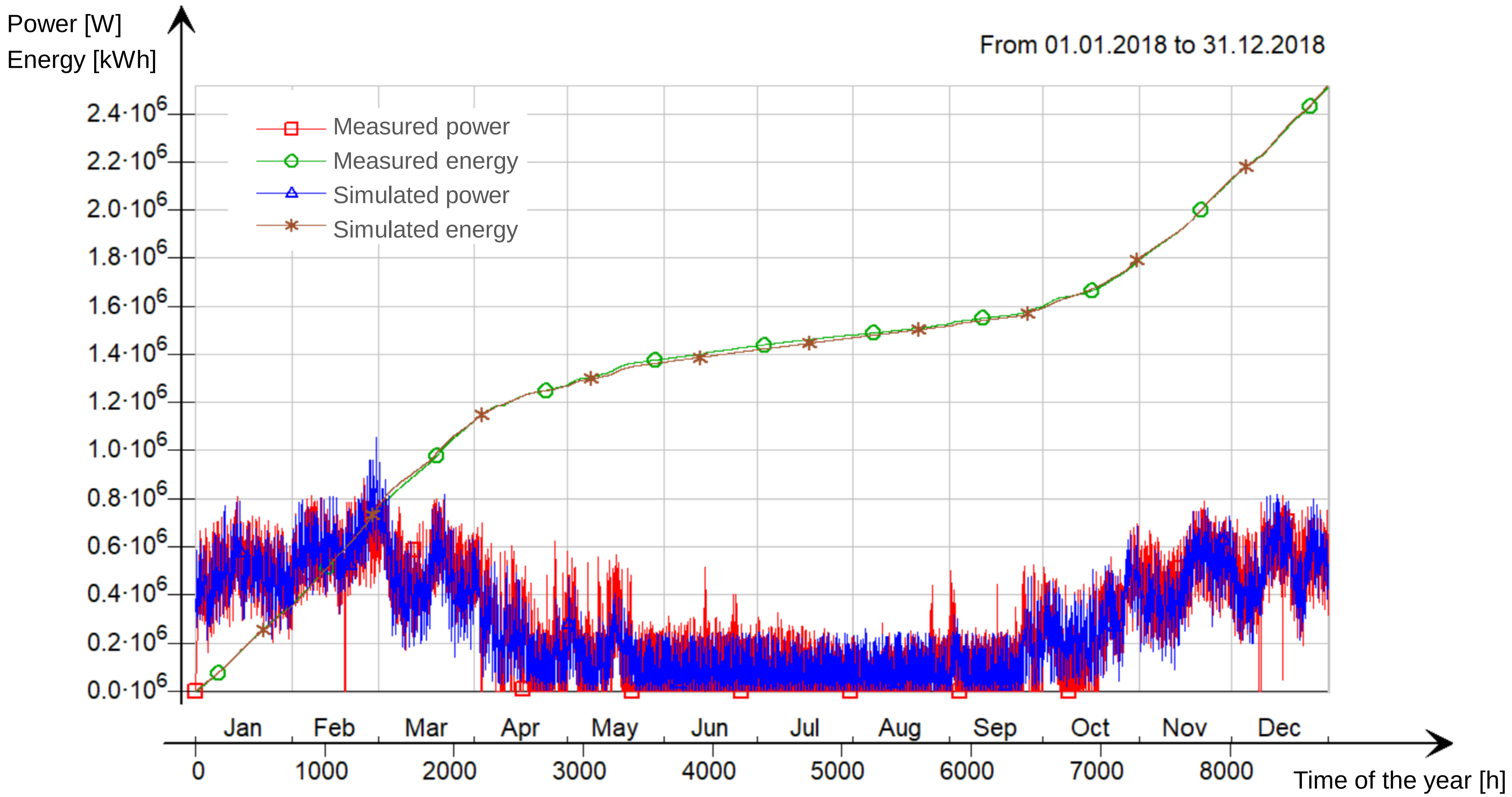


Substitute building for sub section *'Hegianwandweg 41'*

Length depth height = 147.0 x 44.0 x 31.2 m
Gross floor area = 58212 m²
Stories = 9
Volume = 201802 m³
U-Value = 3.01 W/m²K



Validation of substitute building with measurement data



Regression analysis of the step response

Heat-up, cooldown & energy consumption of the water radiator system

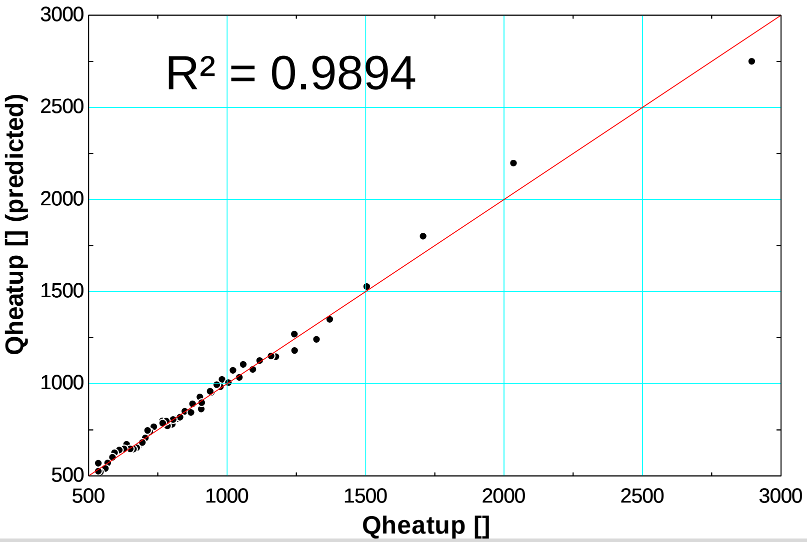
Polynomial fit → forecast function

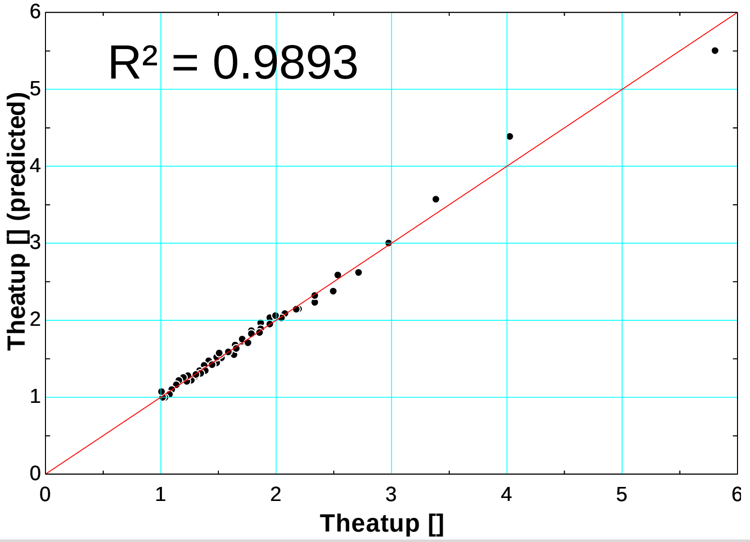
QheatUp= 2.15584648E+06-3.52022706E+04*TsolAir+1.07826465E+04*TsolAir^2-5.92177380E+02*TsolAir^3+8.19349342E-03*TsolAir^4-3.97306055E+05*Troom+2.74946888E+04*Troom^2-8.46062071E+02*Troom^3+9.76334511E+00*Troom^4+4.76106227E+03*TsolAir*Troom-2.14744593E+02*TsolAir*Troom^2+3.22977908E+00*TsolAir*Troom^3-1.47390145E+03*TsolAir^2*Troom+6.71208306E+01*TsolAir^2*Troom^2-1.01838421E+00*TsolAir^2*Troom^3+8.10630646E+01*TsolAir^3*Troom-3.69752707E+00*TsolAir^3*Troom^2+5.61868526E-02*TsolAir^3*Troom^3

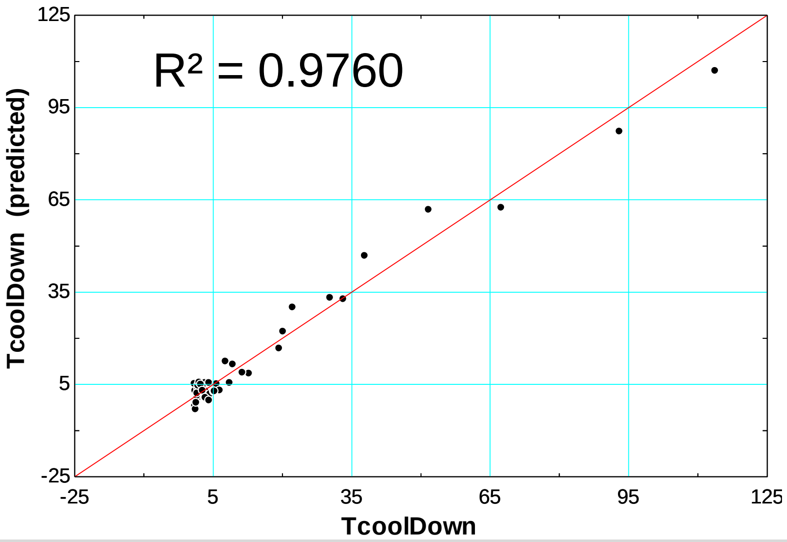
TheatUp= 2.37653466E+03-4.21996850E+01*TsolAir+1.10213082E+01*TsolAir^2-5.88336497E-01*TsolAir^3+8.02085476E-06*TsolAir^4-4.37793363E+02*Troom+3.02760977E+01*Troom^2-9.30876559E-01*Troom^3+1.07321624E-02*Troom^4+5.72553903E+00*TsolAir*Troom-2.59091343E-01*TsolAir*Troom^2+3.90956877E-03*TsolAir*Troom^3-1.50624143E+00*TsolAir^2*Troom+6.85831635E-02*TsolAir^2*Troom^2-1.04042710E-03*TsolAir^2*Troom^3+8.05082754E-02*TsolAir^3*Troom-3.67088949E-03*TsolAir^3*Troom^2+5.57612325E-05*TsolAir^3*Troom^3

TcoolDown= 3.47464244E+03-3.06620129E+02*TsolAir-3.60096982E+01*TsolAir^2+2.89460565E+00*TsolAir^3+1.70047946E-03*TsolAir^4-5.64658560E+02*Troom+3.39920929E+01*Troom^2-8.94212139E-01*Troom^3+8.63073547E-03*Troom^4+4.75577965E+01*TsolAir*Troom-2.43993288E+00*TsolAir*Troom^2+4.14605840E-02*TsolAir*Troom^3+5.20100536E+00*TsolAir^2*Troom-2.49862326E-01*TsolAir^2*Troom^2+3.97571792E-03*TsolAir^2*Troom^3-4.37429828E-01*TsolAir^3*Troom+2.21301355E-02*TsolAir^3*Troom^2-3.74178008E-04*TsolAir^3*Troom^3

To forecast (e.g. MPC)







ToDo's

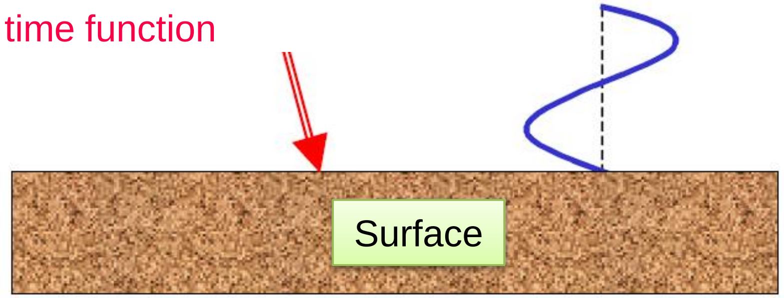
- Simplified model needs to be assed
  - Comparison of high and low detail simulation → how much simplification is possible?
- Work flow needs to be optimized
  - Raise degree of automatization
  - Improve simulation model for applied studies
- Further investigations regarding system flexibilities
  - Evaluation of the determined KPIs
  - Future design of 5GDHC-networks
  - Forecasts on revenues & possibilities of business models
- Implementation of Model Predictive Control
  - Application of characteristic diagrams and forecast functions

Sun-air temperature

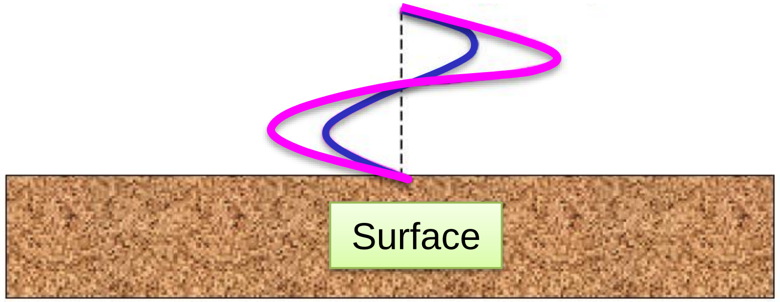
Super positioning of horizontal global irradiation & ambient air temperature

Solar irradiation on horizonal surface as time function

Ambient air temperature as time function



Super positioning
Sun-air temperature as time function



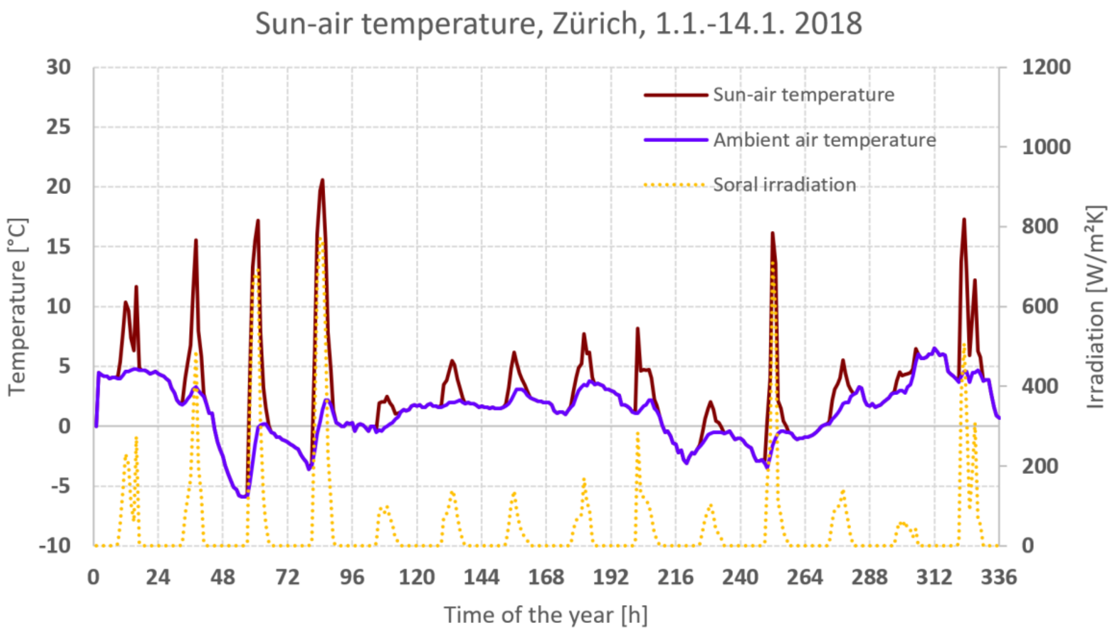
$$t_{out}(\tau) = t_L(\tau) + \frac{a\,\dot{I}_{total}(\tau)}{\alpha_a}$$

a = 0.5 –

α_a = 20 W/m²K

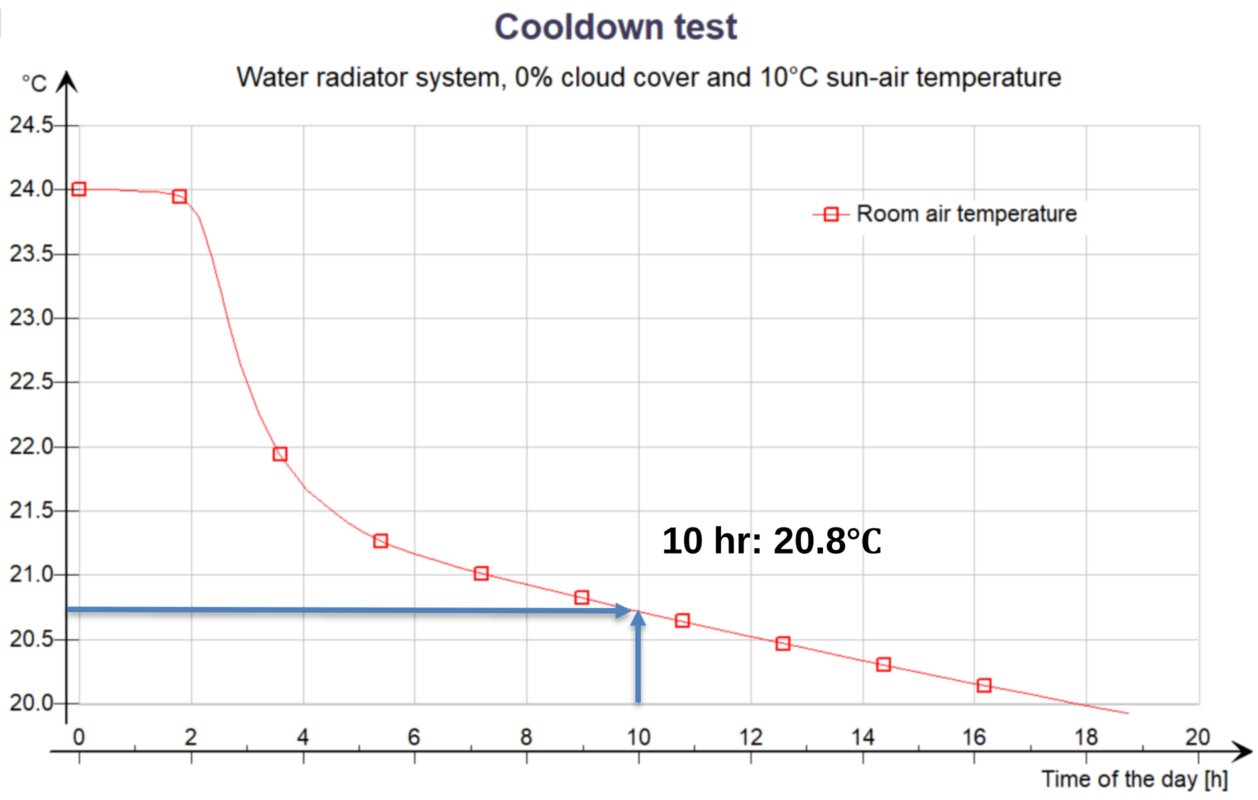
$t_{out}(\tau)$	°C	Ambient temperature as sun-air temperature
$t_L(\tau)$	°C	Ambient air temperature
a	-	Absorption coefficient of surface
$\dot{I}_{total}$	W/m²	Horizontal global irradiation
α_a	W/(m²K)	Heat transfer coefficient of surface

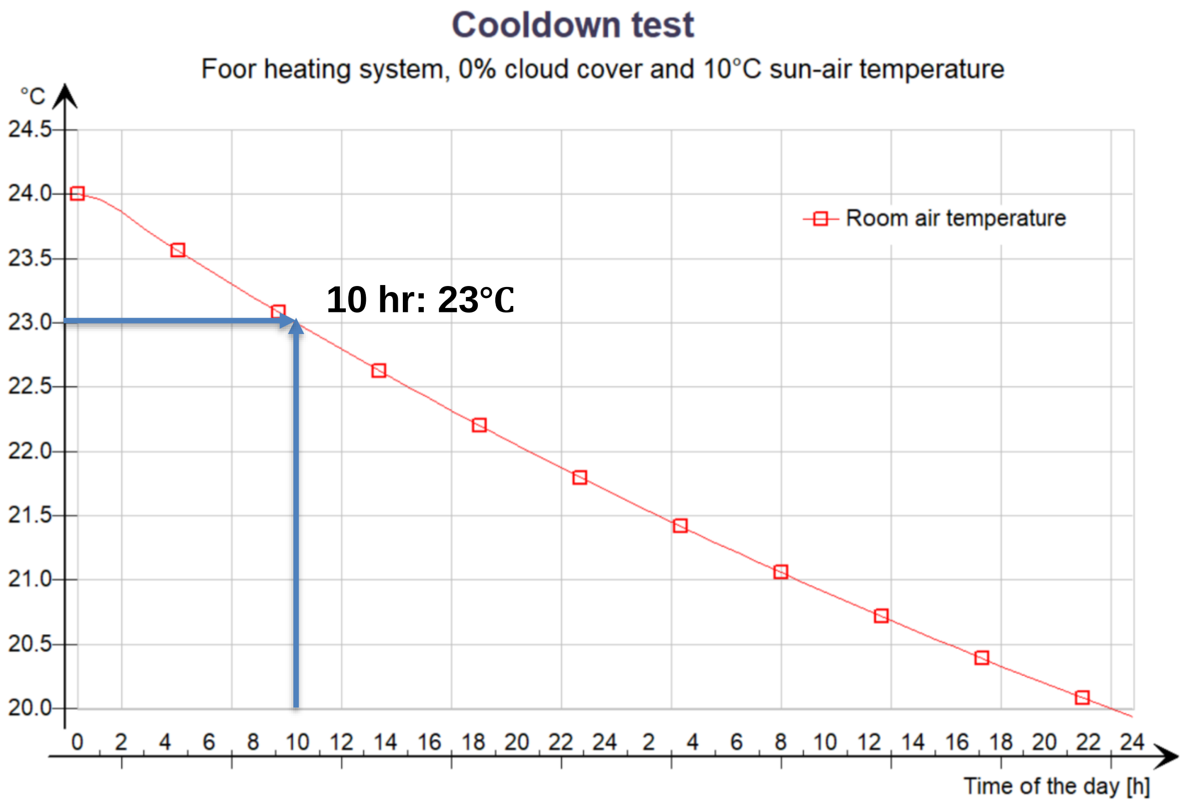
Based on source:
Bernd Glück, 2018: Wärmetechnische Vorgänge in einer Außenwand ohne und mit Dämmung sowie Anwendung des U-Wertes
www.berndglueck.de



Results of the step response test

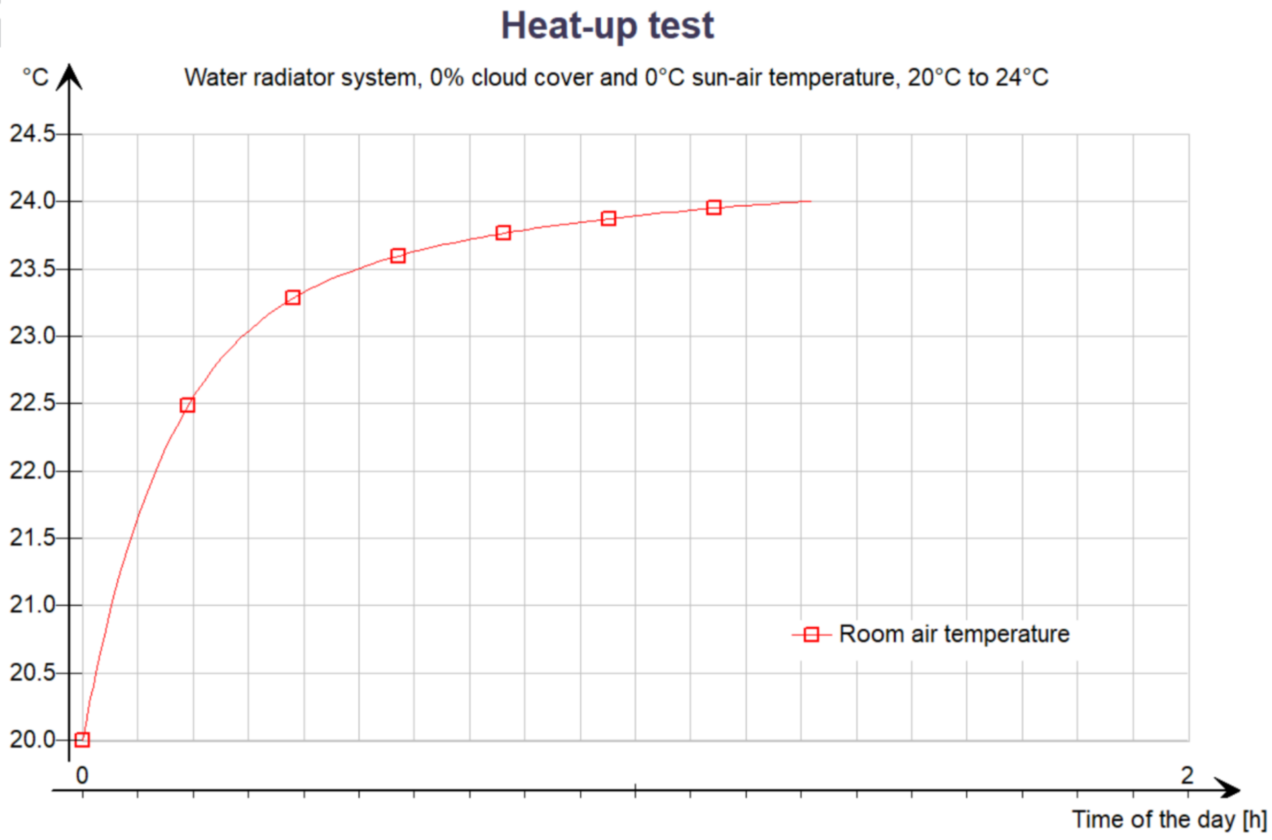
Cool down test, 24°C to 20°C, varying heating systems

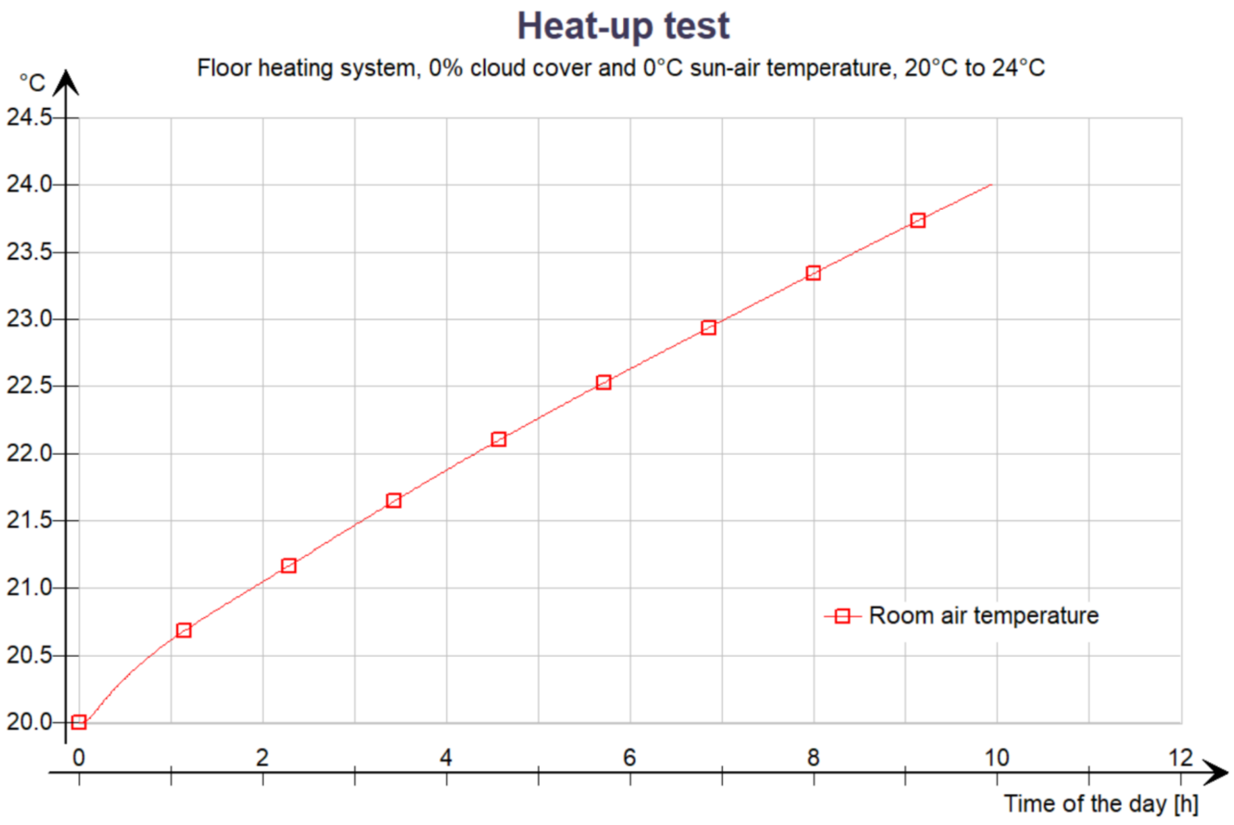




Results of the step response test

Heat up test, 20°C to 24°C, with varying heating systems

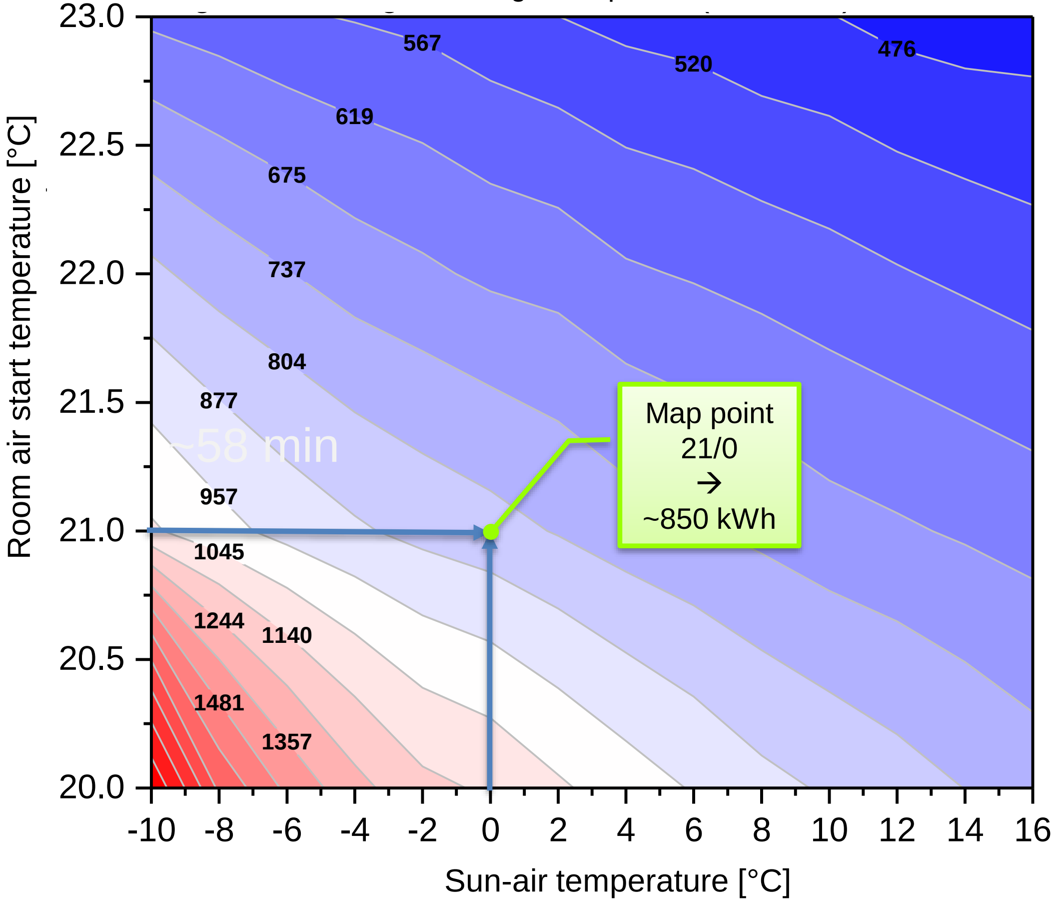




Characteristic diagrams of the step response test

Heat-up, electrical energy consumption of the heat pump

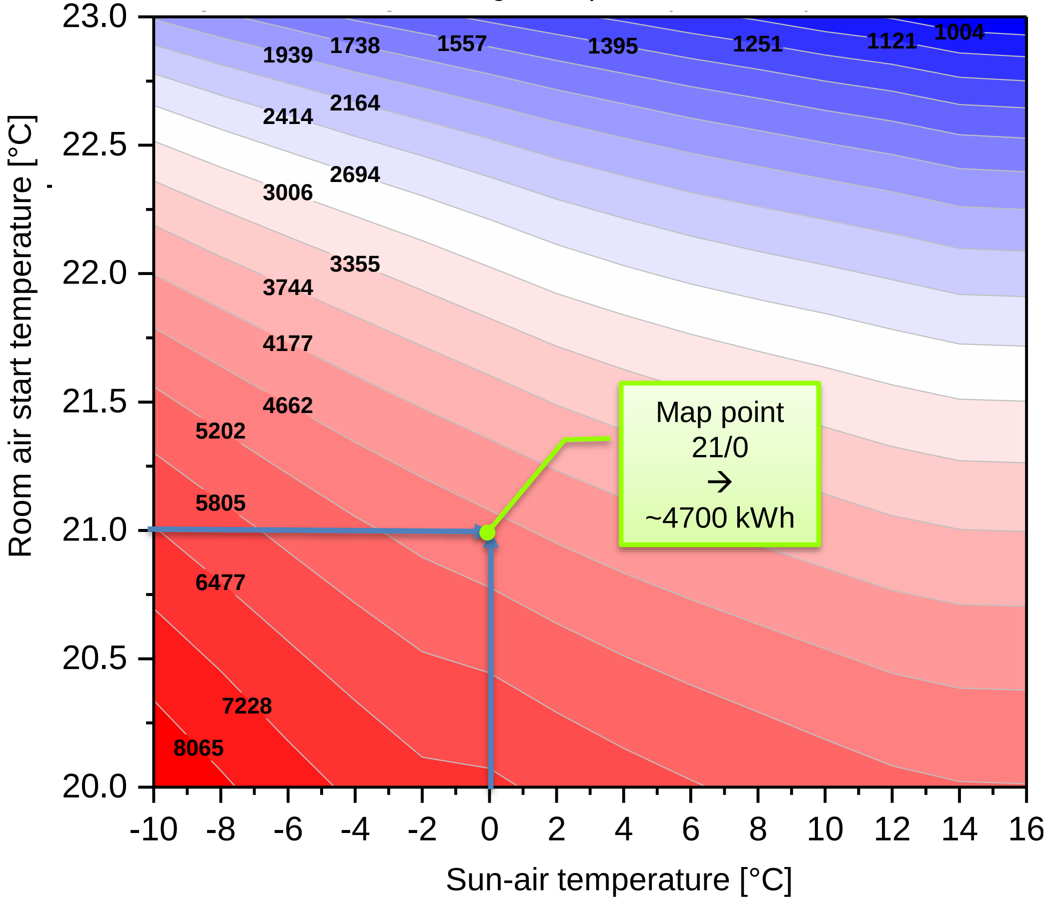
Water radiator system, electrical energy consumption [kWh]
Target temperature 24°C



24 °C

20 - 23 °C

Floor heating system, electrical energy consumption [kWh]
Target temperature 24°C



Characteristic diagrams of the step response test

Water radiator system, heat-up and cooldown time