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Digital twin for heat pump systems - Description of a holistic approach consisting of numerical models and system platform

J. Seifert[a], L. Haupt[a], L. Schinke[a], A. Perschk[a], Th. Hackensellner[b], S. Wiemann[a], M. Knorr[a]

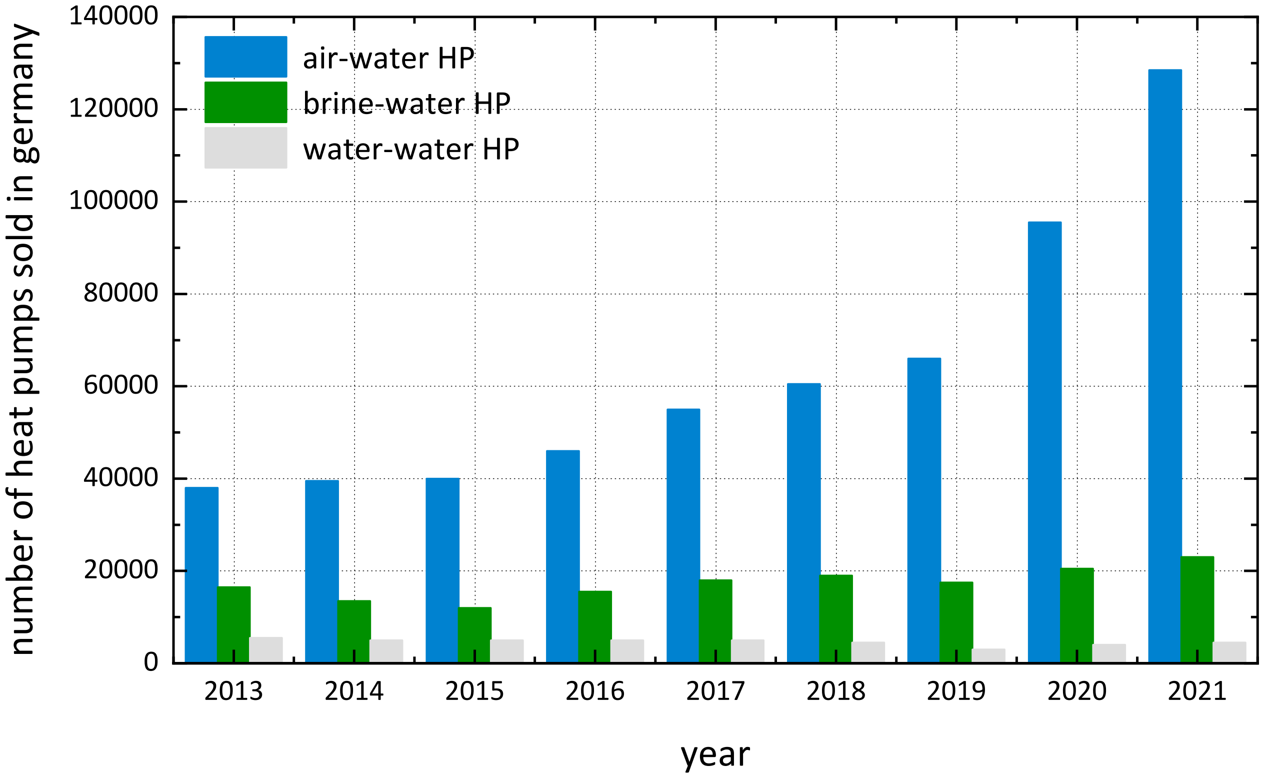
[a] Technical University of Dresden
[b] Glen Dimplex Deutschland GmbH, Germany

Introduction

- CO_2-reduction in the building sector is necessary
- In Germany, systems based on oil and gas are currently dominant
- From 2025, no new heat generators based on fossil fuels are to be installed

- Heat pump system and fuel cells will become the dominant system for buildings

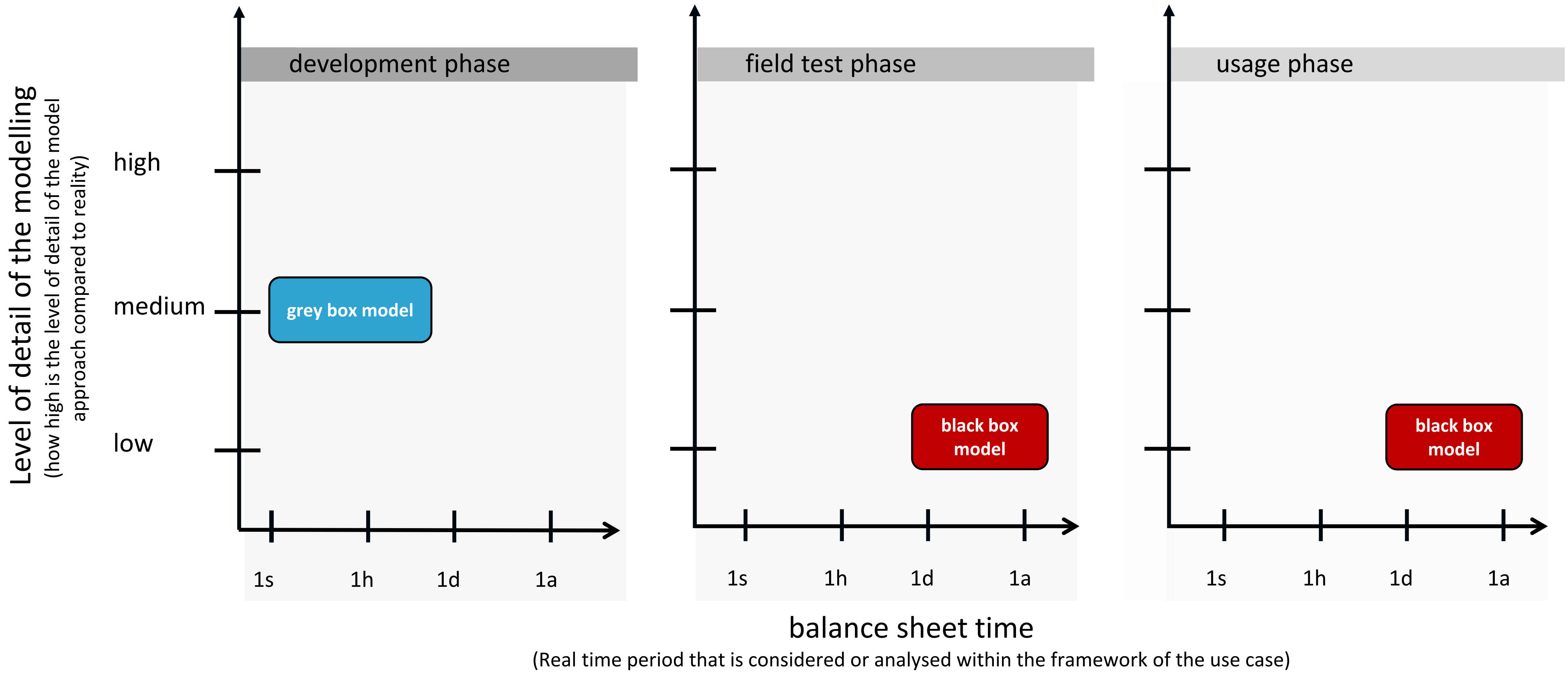
Models for the complete life cycle are needed



sales figures for heat pumps in recent years - Germany

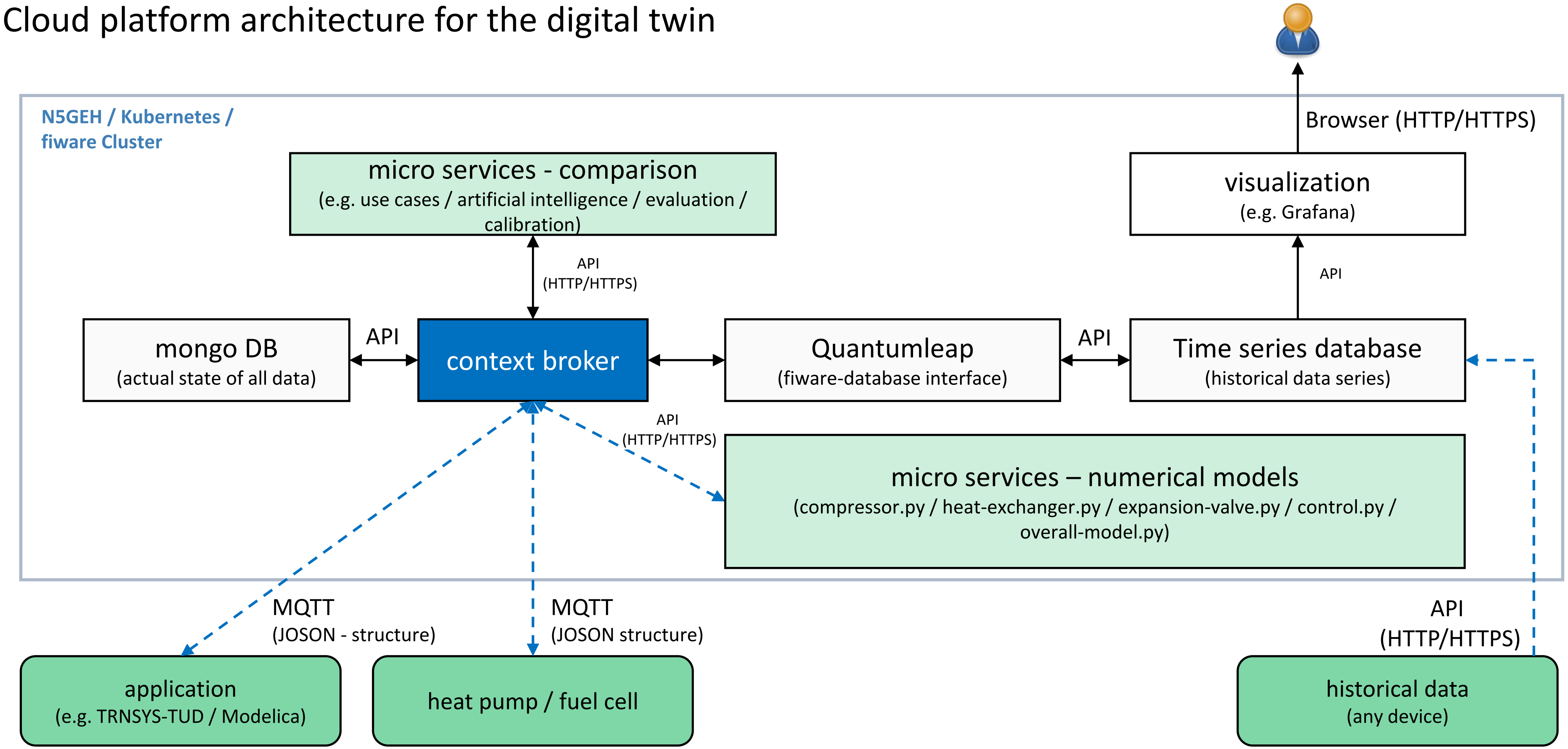
Introduction

- Differentiation of development / field test and usage phase



The concept of the digital twin

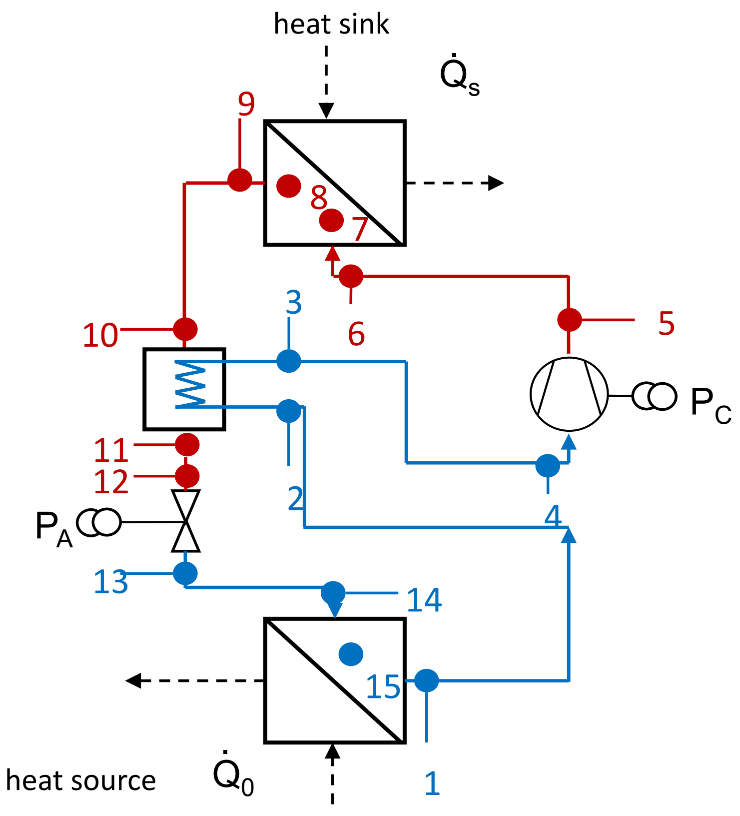
- Cloud platform architecture for the digital twin



System architecture of the digital twin platform

The concept of the digital twin

- Detailed models are developed for all components of the refrigeration circuit

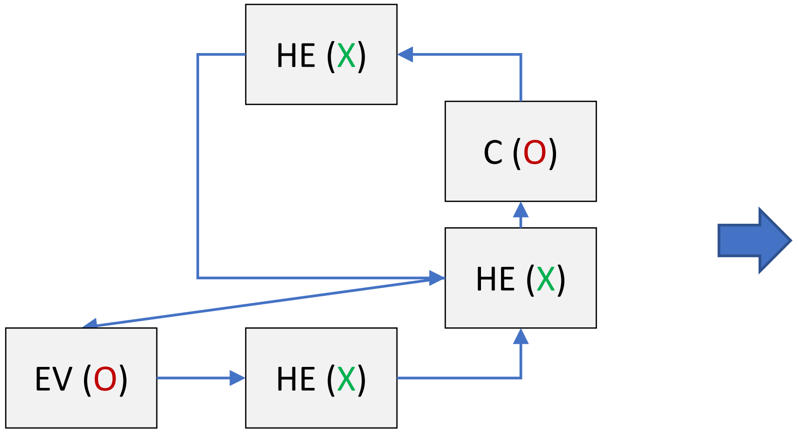


air-to-water heat pump refrigeration circuit

static and dynamic sub-models

component	model 1	model 2	model 3
heat exchanger	X	O	...
compressor	X	O	...
expansion valve	X	O	...

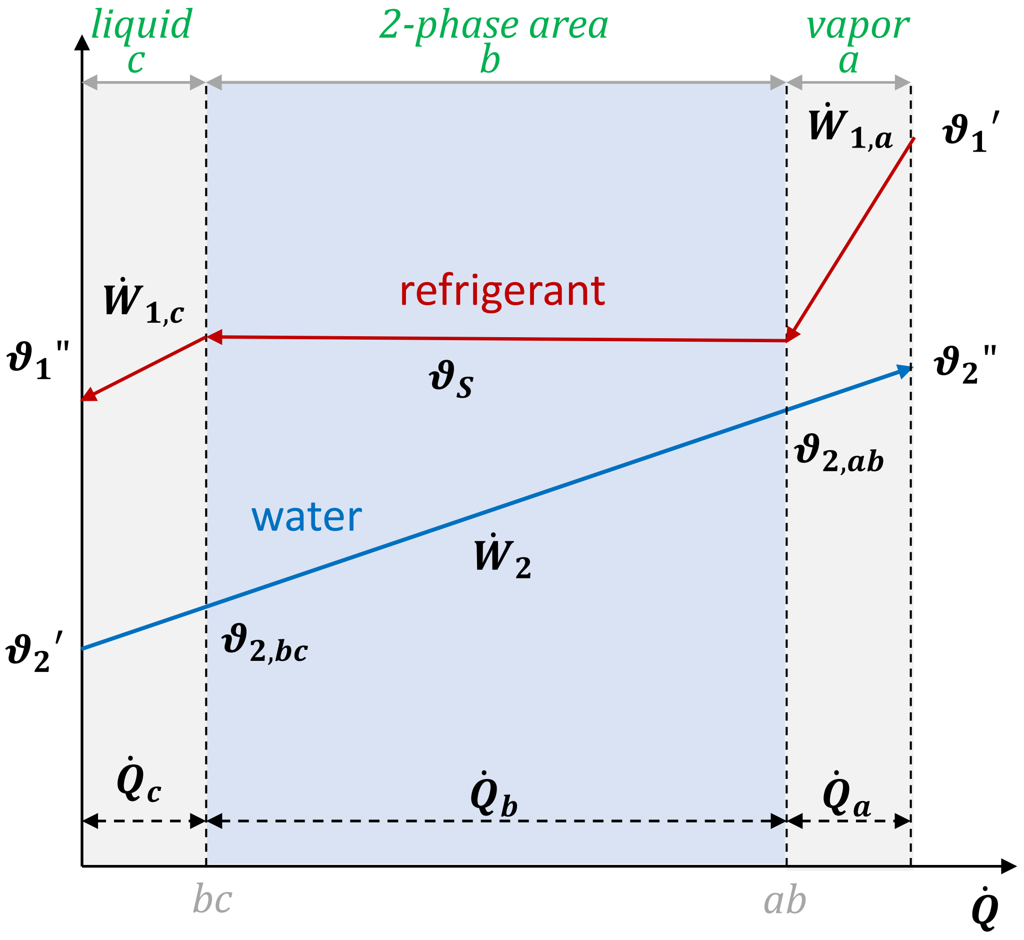
X grey (white)-box model O grey (black) - box model



Examples for different component models

The concept of the digital twin

- Heat exchanger (stationary model) – condenser: **Effectiveness-NTU method** with trisection



simplified model of the condenser (heat exchanger)

Basic balance equations for the description of the heat transfer conditions

$$\vartheta_{2,bc} = \vartheta_2' + \frac{\dot{W}_{1,c}}{\dot{W}_{2,c}} \cdot (\vartheta_S - \vartheta_1")$$

$$\vartheta_{2,ab} = \vartheta_{2,bc} + \frac{\dot{m}_1 \cdot (h_{1,ab} - h_{1,bc})}{\dot{W}_{2,b}}$$

$$\vartheta_2" = \vartheta_{2,ab} + \frac{\dot{W}_{1,a}}{\dot{W}_{2,a}} \cdot (\vartheta_1' - \vartheta_S)$$

$$\dot{W}_{1,i} = \dot{m}_1 \cdot c_{1,i} \qquad \dot{W}_{2,i} = \dot{m}_1 \cdot c_{2,i}$$

$\dot{W}$	flow stream heat capacity rate	W/K
$\dot{m}$	mass flow	kg/s
ϑ_1'	inlet temperature - refrigerant	°C
ϑ_1''	outlet temperature - refrigerant	°C
ϑ_2'	inlet temperature - water	°C
ϑ_2''	outlet temperature - water	°C
ϑ_S	boiling temperature – refrigerant	°C

The concept of the digital twin

- Several static models for the compressor are currently available
- Mass flow rate of refrigerant is determined via a polynomial approach

$$\dot{m}_{refrigerant} = c_0 + c_1 \cdot \vartheta_{ev} + c_2 \cdot \vartheta_{con} + c_3 \cdot \vartheta_{ev}^2 + c_4 \cdot \vartheta_{con} \cdot \vartheta_{ev} + c_5 \cdot \vartheta_{con}^2 + c_6 \cdot \vartheta_{ev}^3 + c_7 \cdot \vartheta_{con} \cdot \vartheta_{ev}^2 + c_8 \cdot \vartheta_{ev} \cdot \vartheta_{con}^2 + c_9 \cdot \vartheta_{con}^2$$

- Electrical Power is also determined via a polynomial approach

variable	explanation
ϑ_{ev}	evaporating temperature
ϑ_{con}	condensing temperature
$c_0 \ldots c_{19}$	Parameters of the model
h_{in}	Inlet enthalpy compressor
$h_{out,is}$	Isentropic outlet enthalpy compressor

1. **Simplified model (001)** in which the efficiency is determined via a polynomial approach.

$$\eta_{compr} = c_0 + c_1 \cdot \vartheta_{con} + c_2 \cdot \vartheta_{con}^2 + c_3 \cdot \vartheta_{con}^3 + (c_4 + c_5 \cdot \vartheta_{con} + c_6 \cdot \vartheta_{con}^2 + c_7 \cdot \vartheta_{con}^3) \cdot \vartheta_{ev} + (c_8 + c_9 \cdot \vartheta_{con} + c_{10} \cdot \vartheta_{con}^2 + c_{11} \cdot \vartheta_{con}^3) \cdot \vartheta_{ev}^2 + (c_{12} + c_{19} \cdot \vartheta_{con} + c_{14} \cdot \vartheta_{con}^2 + c_{15} \cdot \vartheta_{con}^3) \cdot \vartheta_{ev}^3 + (c_{16} + c_{17} \cdot \vartheta_{con} + c_{18} \cdot \vartheta_{con}^2 + c_{19} \cdot \vartheta_{con}^3) \cdot \vartheta_{ev}^4$$

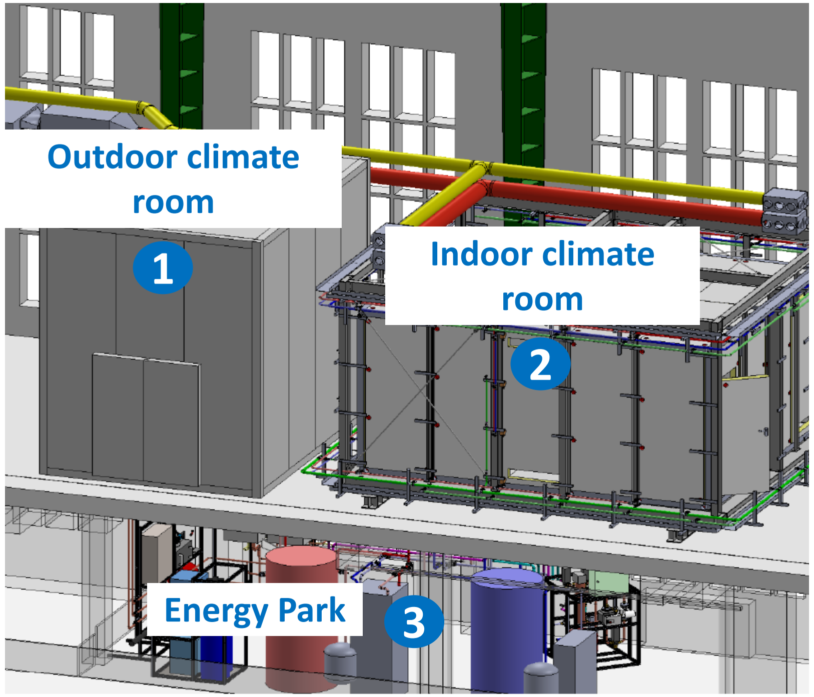
2. **Simplified model (002)** in which the efficiency is determined as ratio to isentropic compression

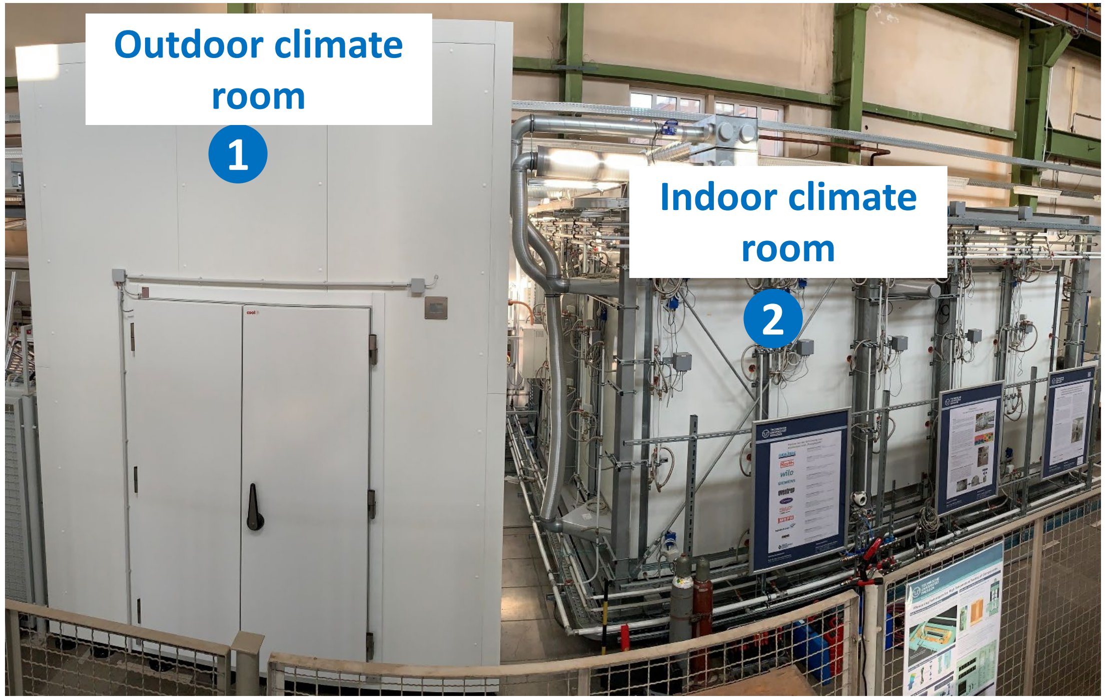
$$\eta_{compr} = \frac{P_{isentropic}}{P_{electrical}}$$

$$P_{isentropic} = \dot{m}_{refrigerant} \cdot (h_{out,is} - h_{in})$$

Measurement / Validation

- Measurement were carried out at the test facility’s of the TU Dresden and the test facility’s from Glen Dimplex
- Test facility's of the TU Dresden are able to represent the entire building including the entire plant technology





Combined energy Lab 2.0 of the Technical University of Dresden

Measurement / Validation

- The validation is carried out with measurement data
- Data measurement in the laboratory
- Reference measuring point: Heat pump in steady state for a period of 15 minutes

variable	Unit	measured data	Simplified model 001 Simulation results	Simplified model 002 Simulation results
$P_{el,compressor}$	kW	1,637	1,649 (+ 0,73 %)	1,677 (+ 2,44 %)
p_{out}	bar	20,99	20,93 (- 0,29 %)	20,93 (- 0,29 %)
ϑ_{out}	°C	74,36	84,4 (+ 13,5 %)	88,9 (+19,55 %)
$\dot{m}_{refrigerant}$	kg/s	0,03*	0,0261 (- 13,0 %)	0,0261 (- 13,0 %)

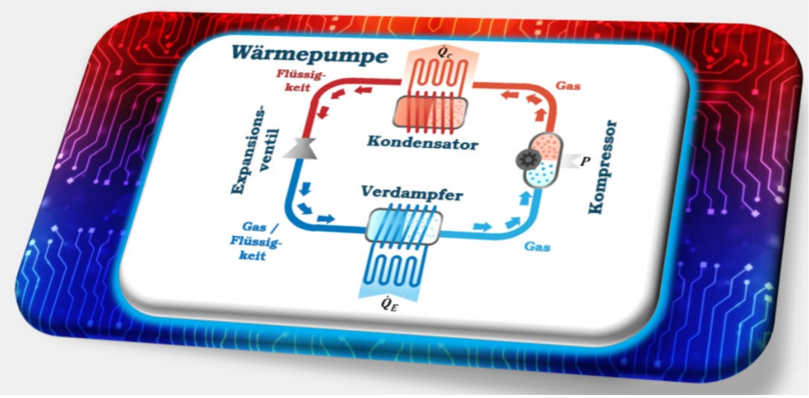
* calculated value: volume flow, temperature and pressure were measured

- small deviations in mass flow in the current model
- **Note:** Measuring of small mass flows is very difficult (non invasive ultrasonic measurement, refrigerant)

Conclusions / Outlook

- Digital twin of an energetic system is more than just a numerical simulation model
- Essential components are also
  - Data comparison
  - Fault detection
  - Optimization of the operating behavior
- Modular structure of the numerical model (subdivision into sub-models that can be combined in different ways)
- acceptable agreement between numerical values and measured values - **first validation**

https://dzwi-waerme.de/



Transfer of the structure of the digital twin to other technical systems (air conditioning systems / solar systems / PV systems / CHP systems) --- entire building energy systems

End of the presentation

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[a] Technical University of Dresden

[b] Glen Dimplex Deutschland GmbH, Germany

corresponding address:

Prof. Dr.-Ing. habil. J. Seifert / TU Dresden / Helmholtzstraße 14 / 01062 Dresden / E-Mail: joachim.Seifert@tu-dresden.de

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