DRESDEN

Design and development process for rapid charge storage heaters for electric city buses

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OVERVIEW

- **Motivation**
- Heat demand simulation
- Electric heating systems
- Rapid charge storage heater
  - Concept
  - Design process
  - Prototype
- Outlook

Motivation

objective:
Realization of **emission-free** and **economic** heating for full electric urban buses

to date:
diesel bus: engine waste heat (+ fuel auxiliary heater)
hybrid bus: fuel auxiliary heater (+ engine waste heat)

→ energy demand secondary

available solutions for e-buses:

fuel auxiliary heater	→ not emission-free
electric heater (PTC)	→ reduced range or increased battery capacity
(heatpump)	→ in development/limited availability

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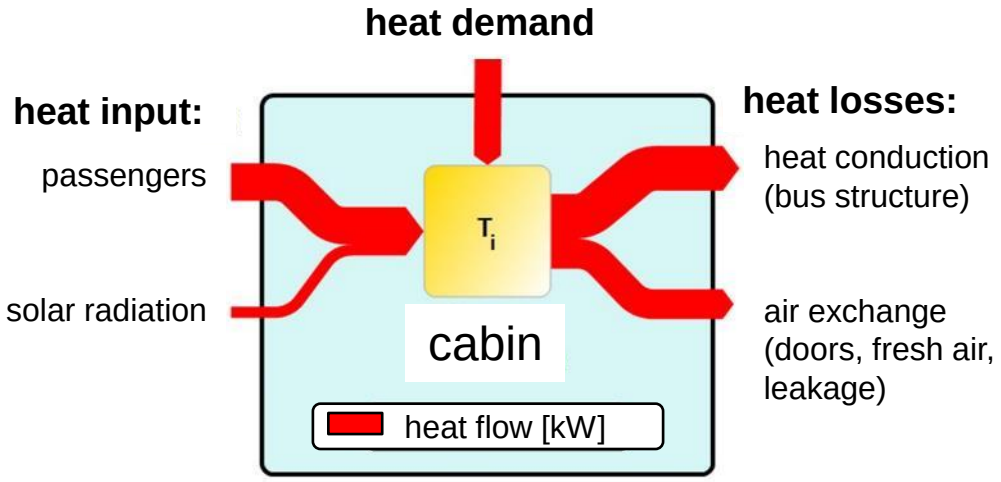
Heat demand simulation

Simulation tool HVACCO2SIM:

- Energy-balance based 1-zone-model
- Simulation step wide 1-5 min
- Simulated timeframe 1 year
- expandable bus und climate database (currently 160 / 41 data sets)

considered boundary conditions:



result: temporal course of heat demand

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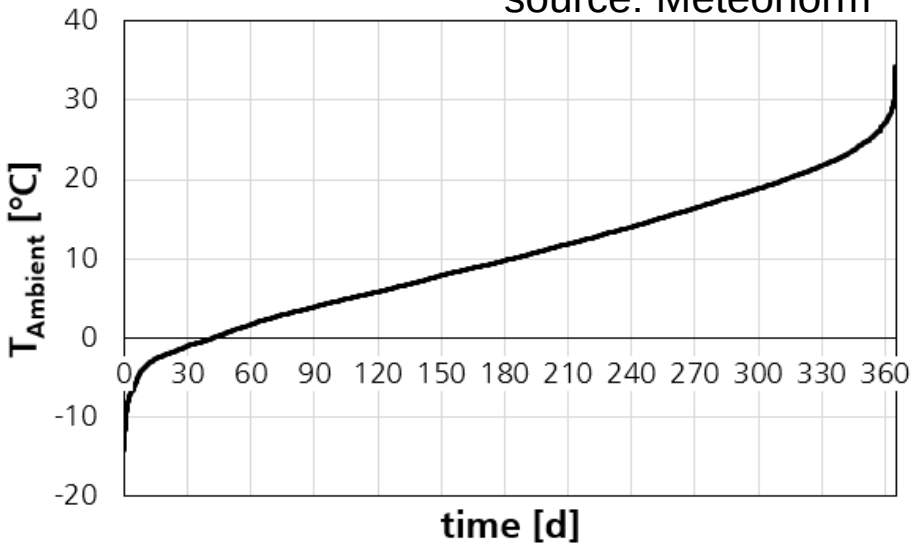
Heat demand simulation

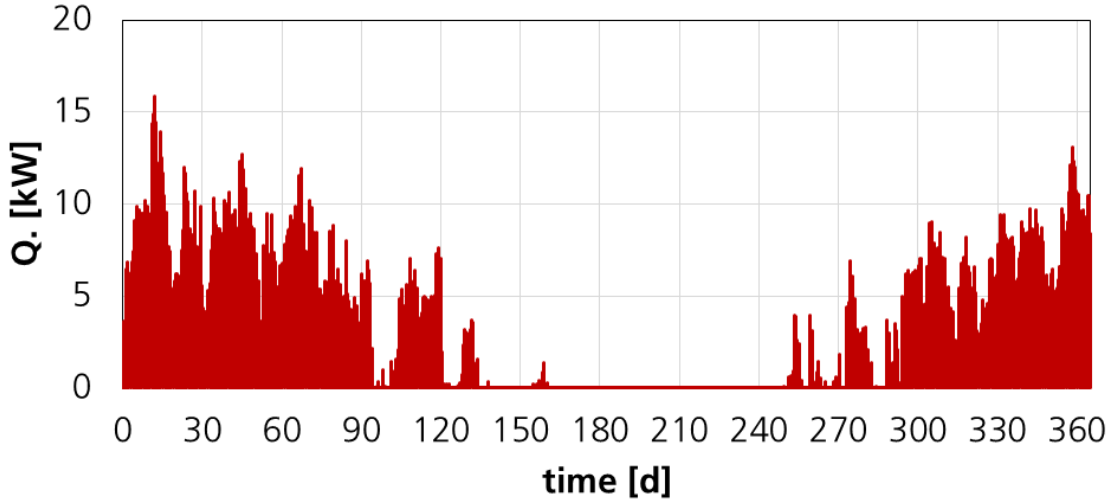
Reference scenario:

Location:	Berlin
Vehicle:	12 m urban bus
Operation time:	06:00-22:00 (5840 h/a)
Passengers:	43
Set value heating:	18 °C
Air circulation rate:	7 h^{-1}
Fresh air rate:	20 %

source: Meteonorm



temporal course of heat demand:



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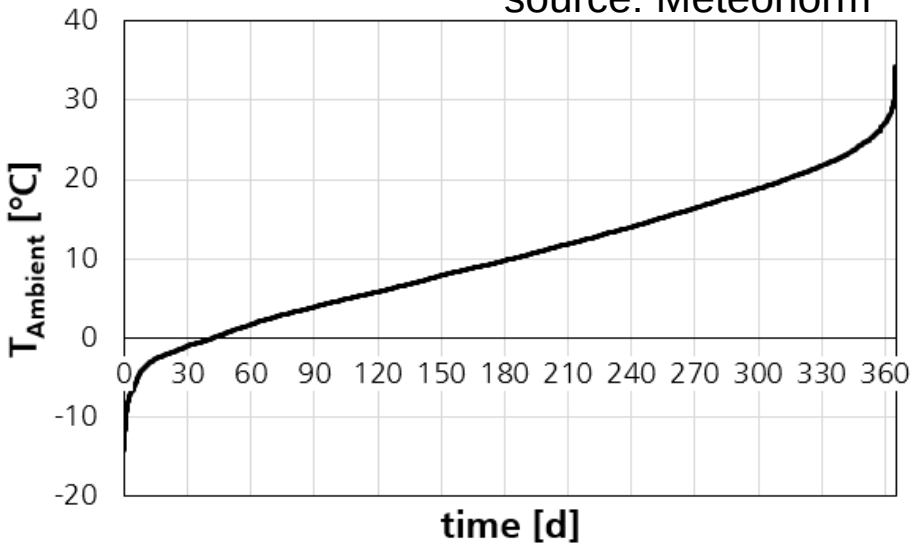
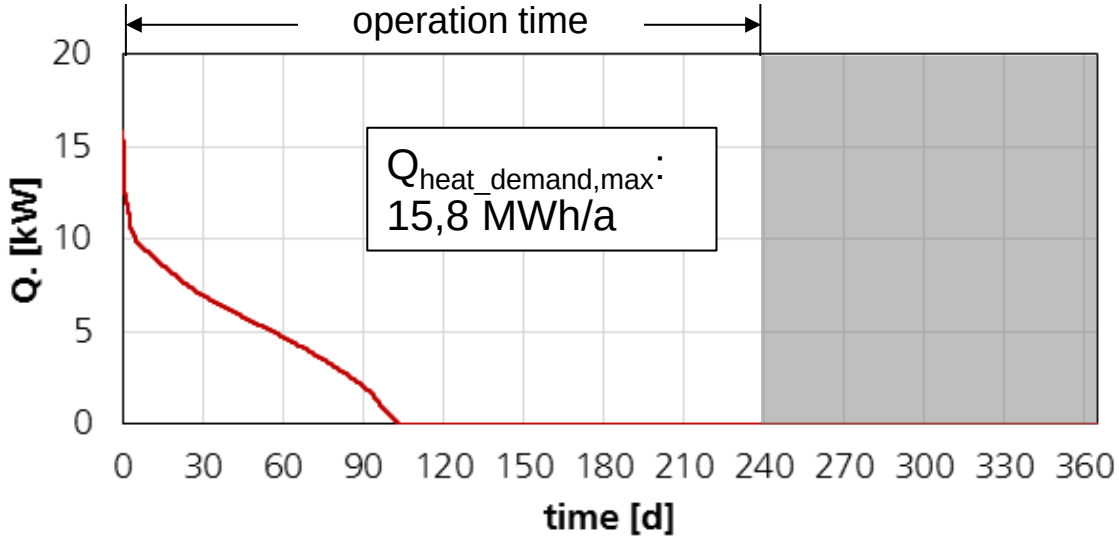


temporal course of heat demand:

(annual load duration curve):



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Electric heating systems

Charging concepts for electric urban buses

	depot charging	opportunity charging
charging interval	**1 day**	**1 h** (16 cycles/day)
battery technology	LiFePo	Li-NMC
system energy density **usable**	(90 Wh/kg) **80 Wh/kg**	(60 Wh/kg) **20 Wh/kg**
energy demand without heating	360,0 kWh (300 km)	22,5 kWh (18,75 km)
battery weight without heating	4.500 kg	1.125 kg

Electric heating systems

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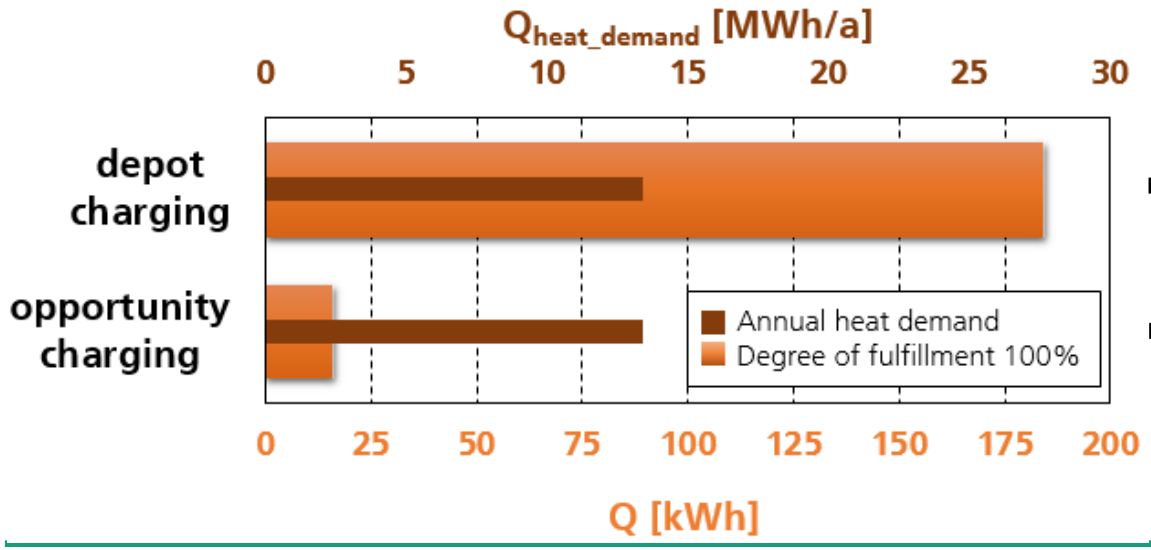

→ Q_{Max}=184,0 kWh/d

→ Q_{Max}=15,7 kWh/h

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Electric heating systems

Charging concepts for electric urban buses

Assumption: loss-free heat transfer to cabin

battery weight (heating**, total)**	**depot charging**	**opportunity charging**
electrical PTC-Heater (efficiency = 0,98)	2.350 kg (188,0 kWh) **6.850 kg (548,0 kWh)**	795 kg (15,9 kWh) **1.920 kg (38,4 kWh)**
Heat pump, (COP = 3,5)	660 kg (52,6 kWh) **5.160 kg (412,6 kWh)**	220 kg (4,5 kWh) **1.350 kg (27,0 kWh)**

Heat pumps with required performance at lower ambient temperatures in development – to date only limited availability

→ only broadly available emission-free heating solution:
electric PTC-Heater + opportunity charging

→ alternative solutions have to be advantageous regarding system and energy costs

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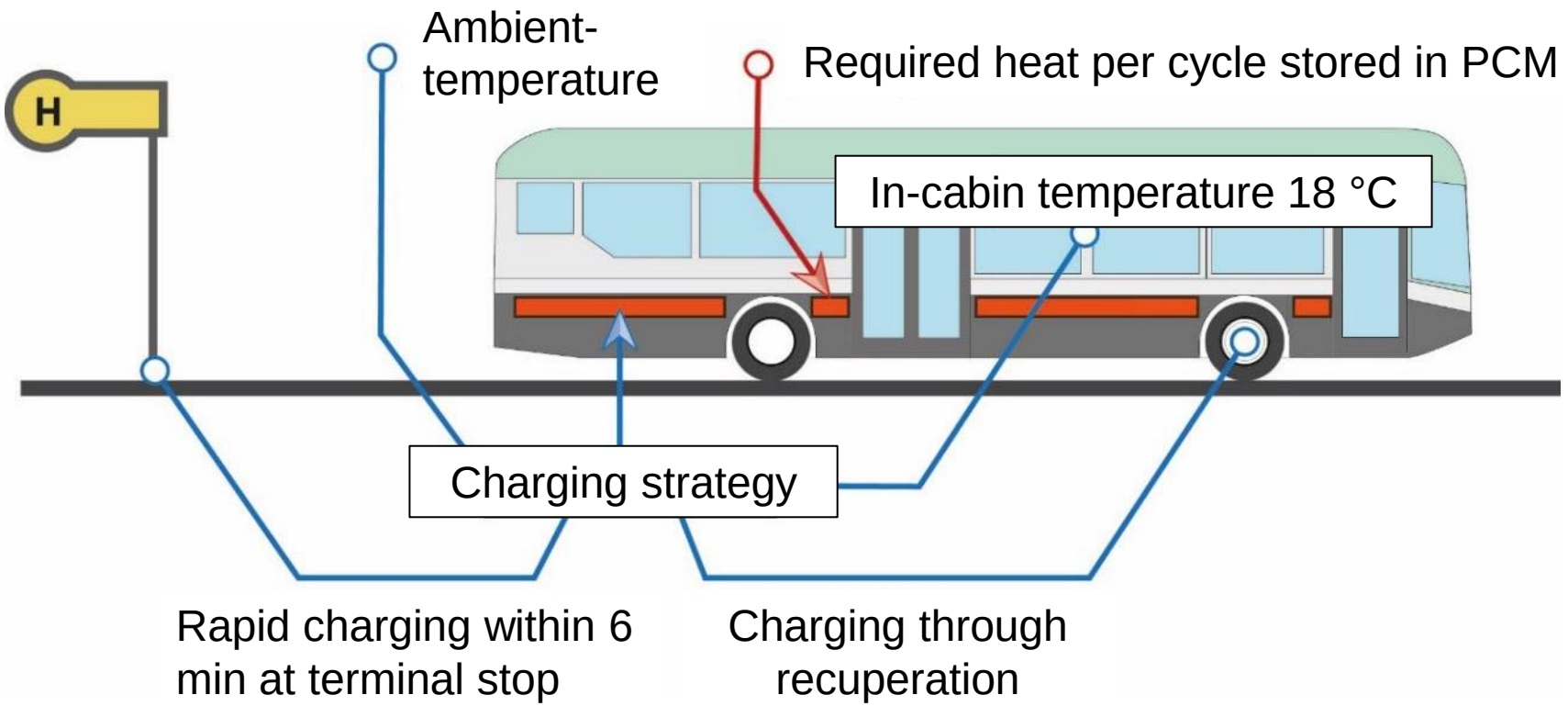
Rapid charge storage heater

Concept



Project: Heat2Go 10/2016-09/2019

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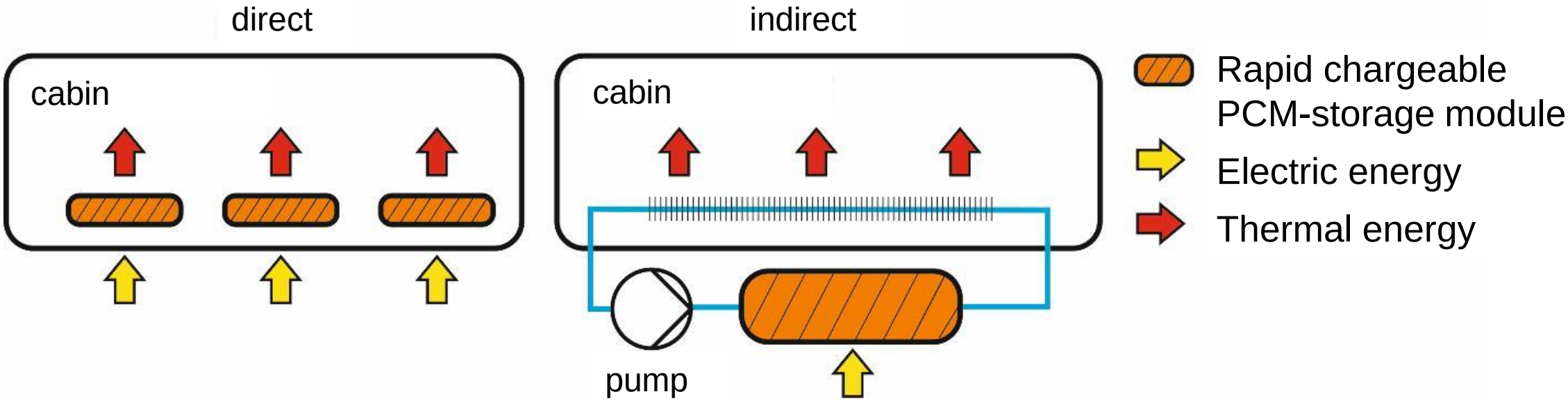
Rapid charge storage heater

System variants



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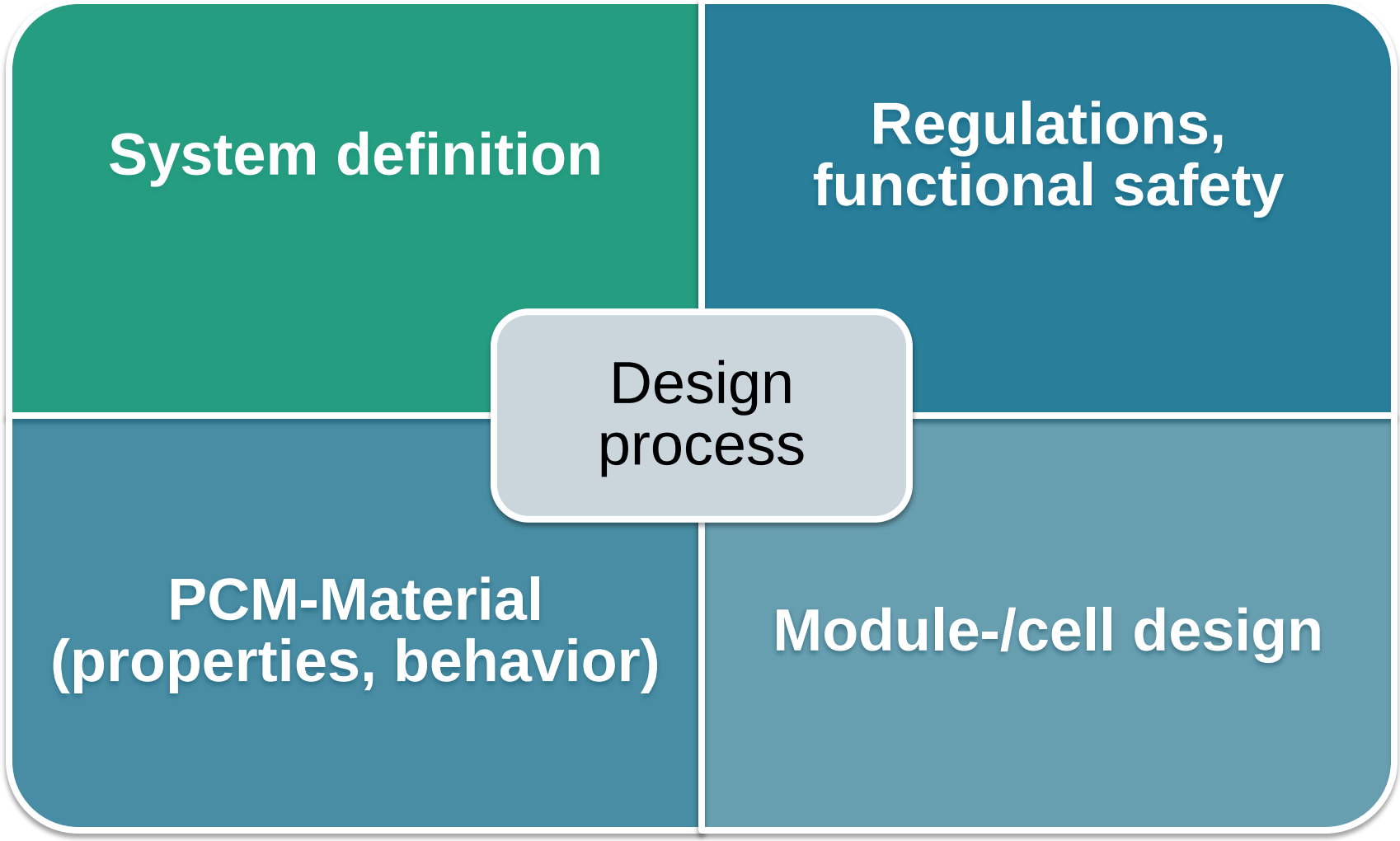
Rapid charge storage heater



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Rapid charge storage heater

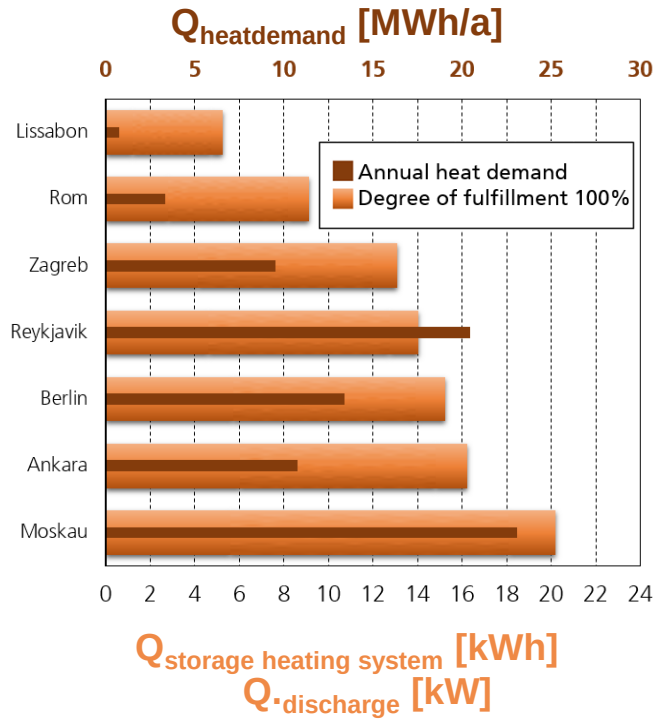
Design process: System definition

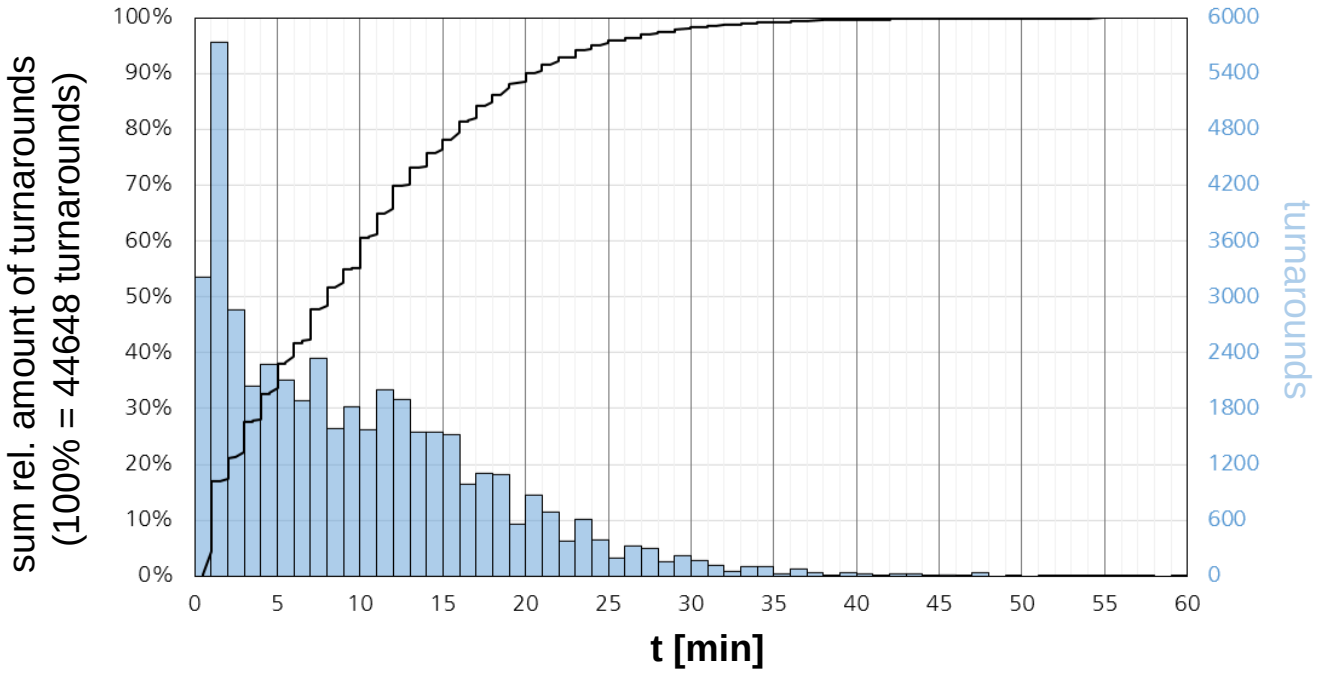
Capacity, charging time, charging and discharging power

→ heat demand simulation for 40 European cities and different bus sizes

→ heat supply measurement 12 m urban bus 5000+ operation hours

→ analyzation of 3000+ real city bus cycles from different German cities





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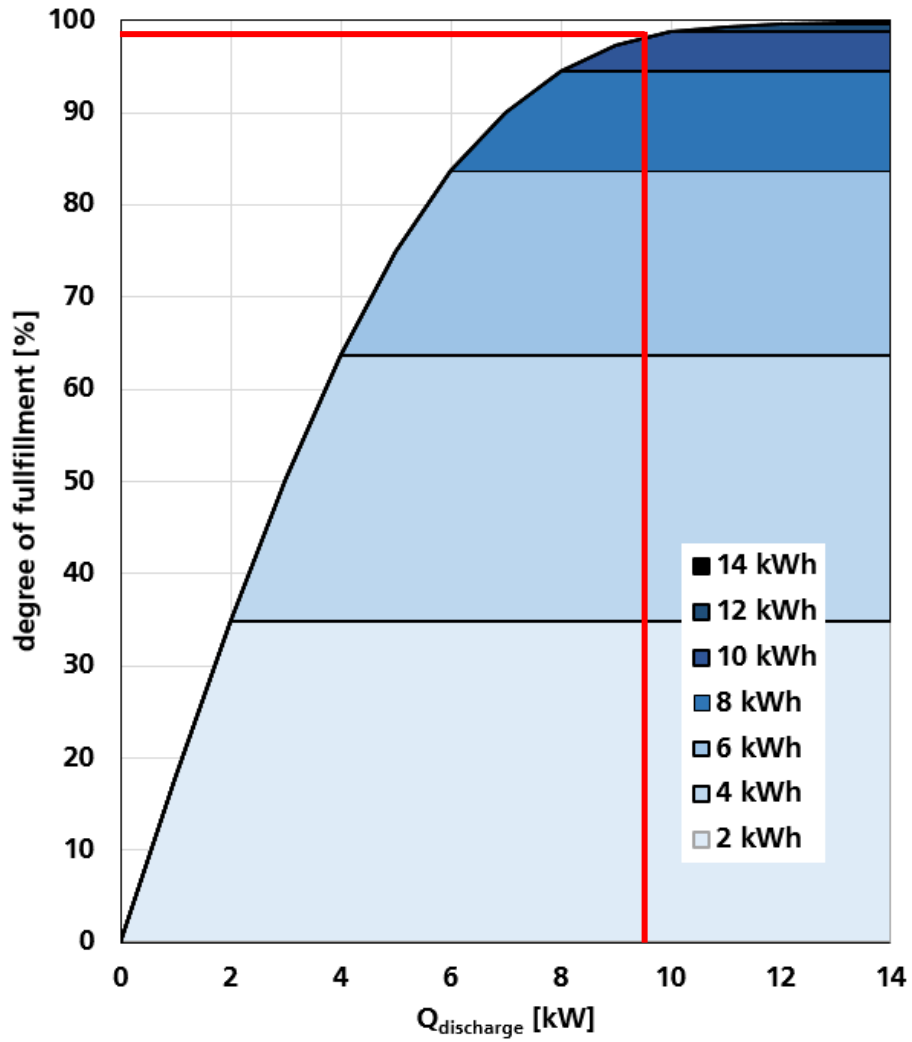
Rapid charge storage heater

Design process: System definition

12 m urban bus, Berlin
degree of fulfillment 100%
≙ 13,4 MWh/a

98,0 % → 9,5 kW @ 9,5 kWh

≙ 132 kg PCM



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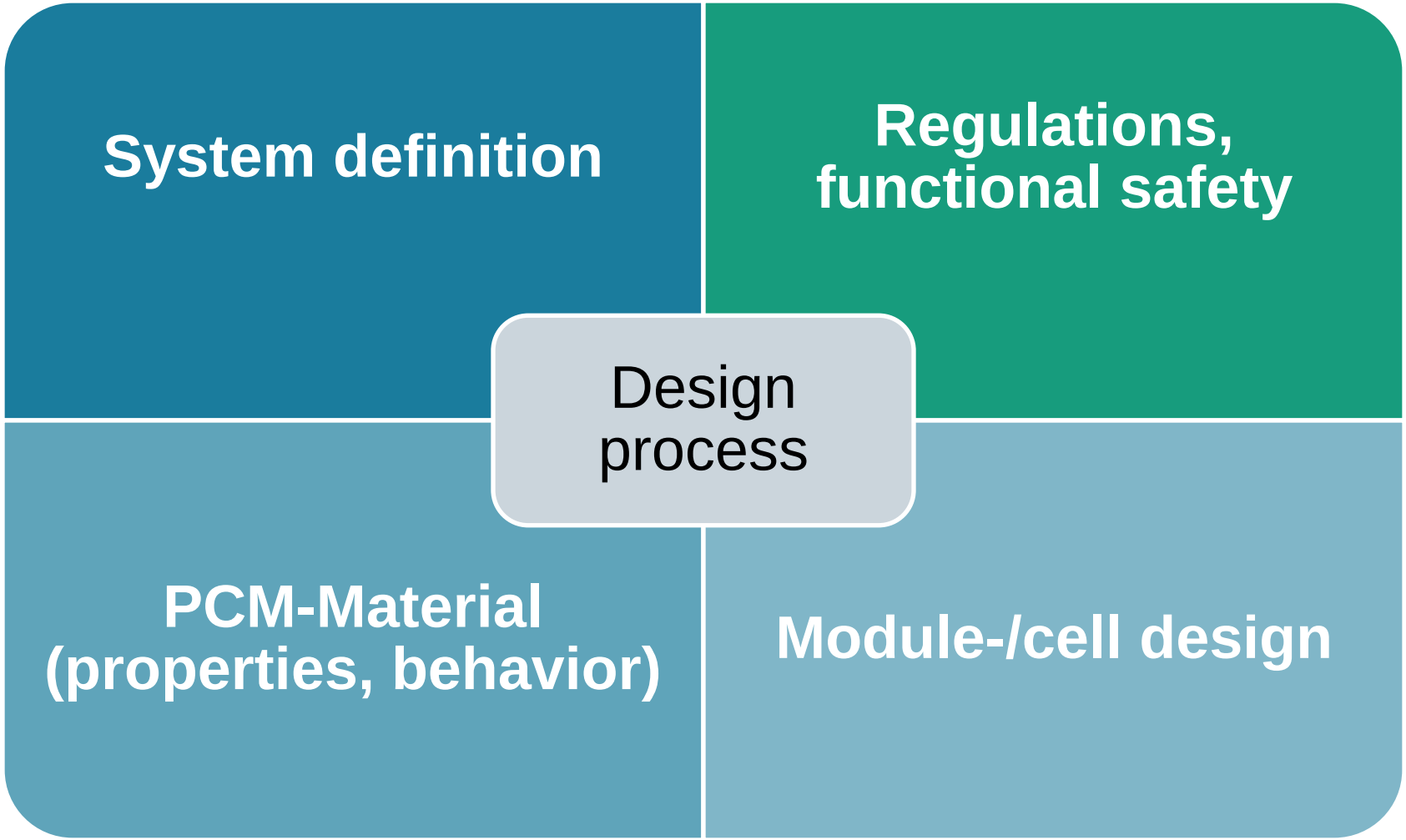
Rapid charge storage heater



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Rapid charge storage heater

Design process: Regulations, functional safety

Considered regulations: ECE R100, ECE R107, ECE R122,
VDV 230, VDV 236, VDV 236/1
DIN 71460

Requirements regarding:

- Room temperature, Air quality
- Maintenance
- Environmental noise
- Safety (Construction, electrical safety, control, fire protection)

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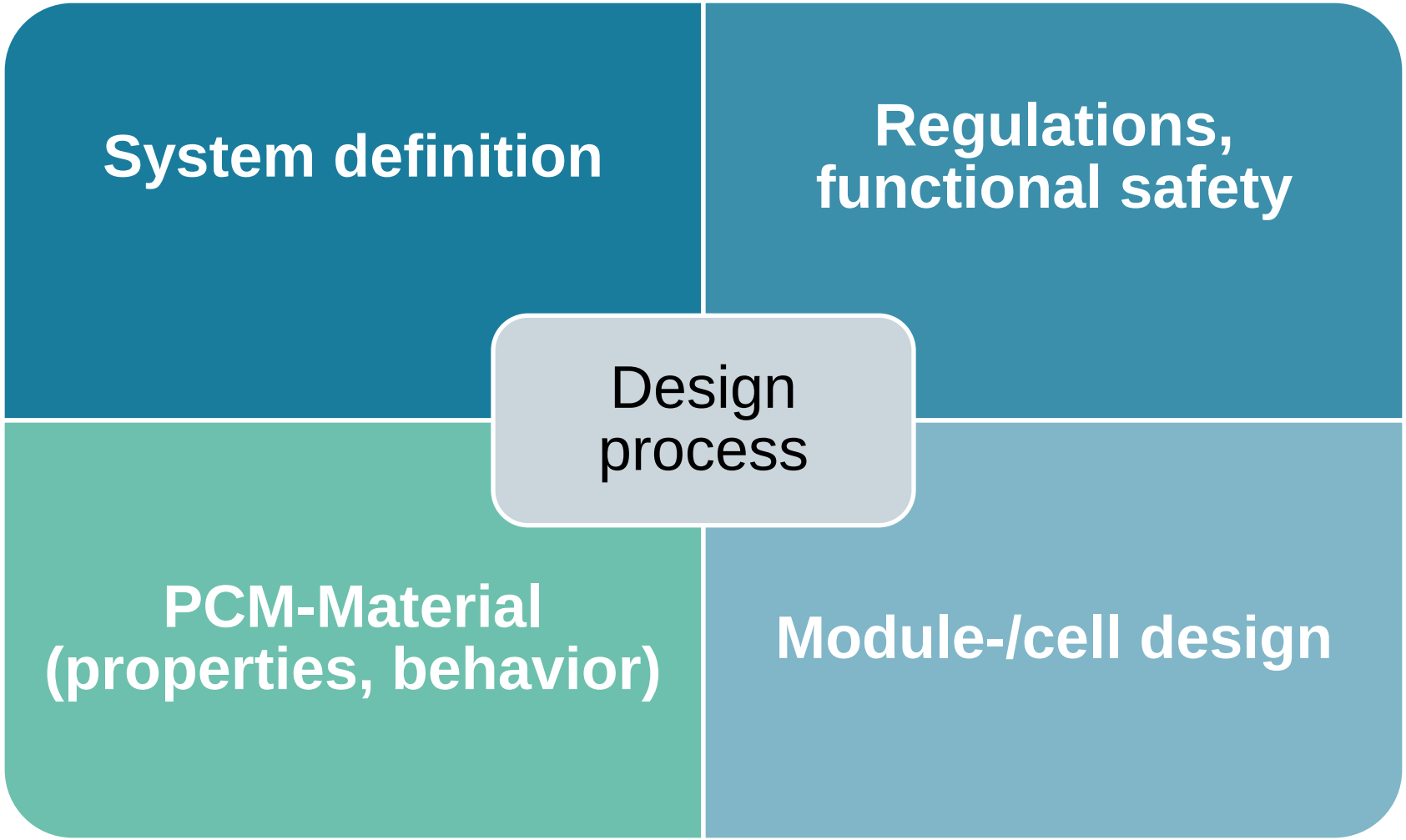
Rapid charge storage heater



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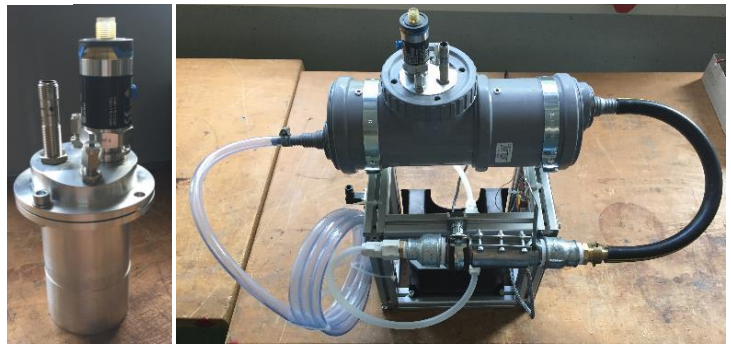
Rapid charge storage heater

Design process: PCM-material (properties, behavior)

Rapid charging capabilities, charging and discharging behavior, SOC determination,
Evaluation of heating elements (flat, cylindrical) and heat conduction elements

test benches

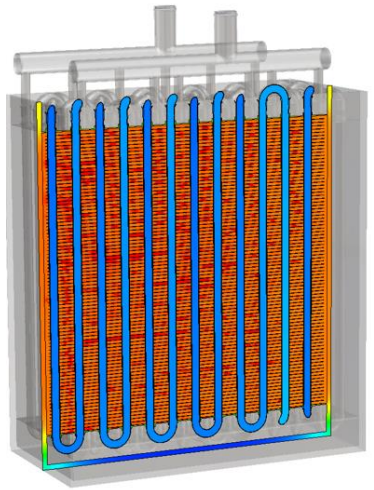
SOC

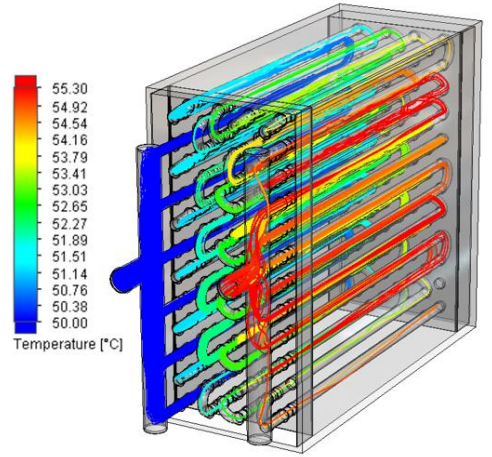


cylindrical

flat

simulation





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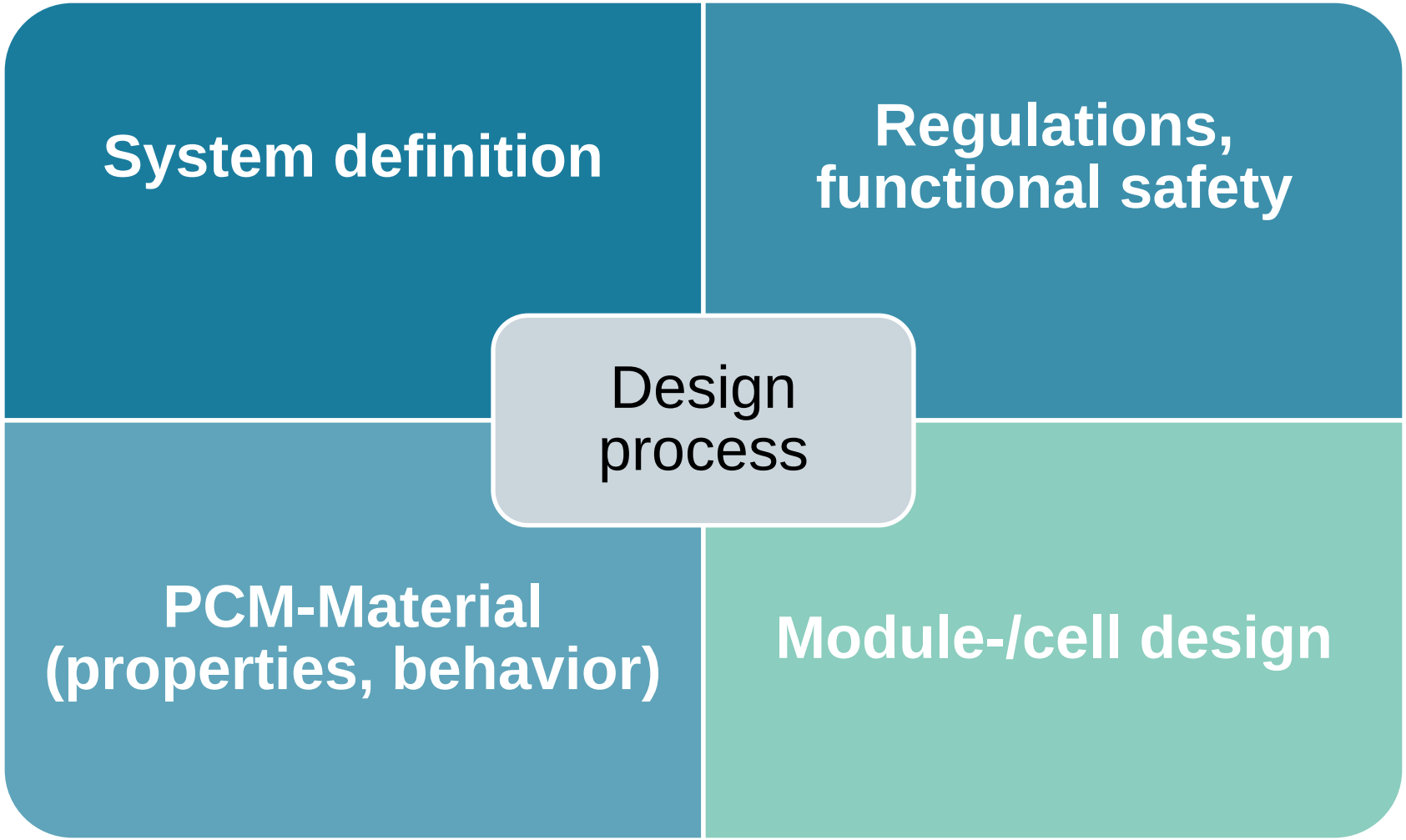

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Rapid charge storage heater

Design process: Module-/cell design

Multi-parameter optimization problem:

Boundary conditions:

- Spatial restrictions
- Production process restrictions
- eCity bus compatible electric layout
- Material properties (PCM, heating elements)
- Safety requirements

optimization goals:

- High storage density (kWh/kg, kWh/m³)
- Rapid charging capability
- Practical modularization (thermal, electric)
- Low connection effort
- Low costs

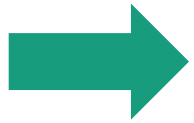
Rapid charge storage heater

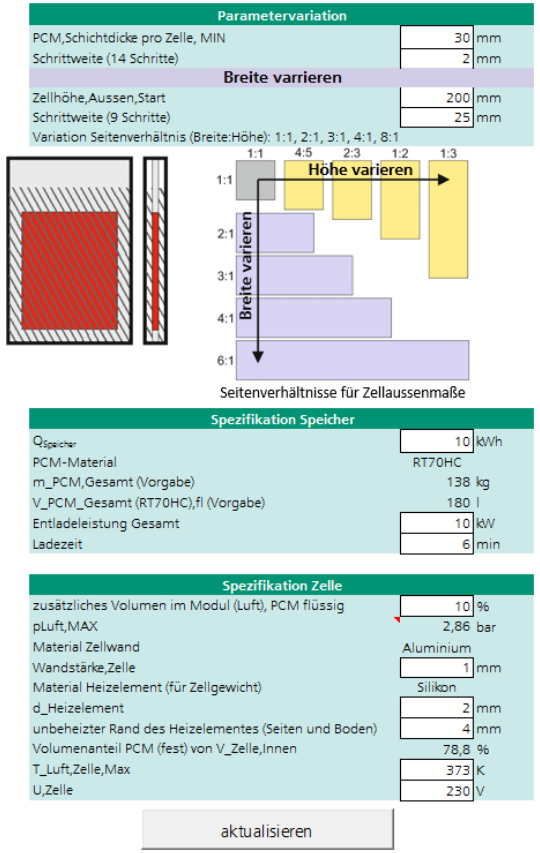
Design process: Module-/cell design

Multi-parameter optimization problem:
Solution → Designtool - Determines properties for a huge variety of possible systems

Example (cell based system):
system specification:

- Capacity
- Charging duration (charging power)
- Discharging power
- Heating element voltage
- Cell dimension variation (height, wide, depth)





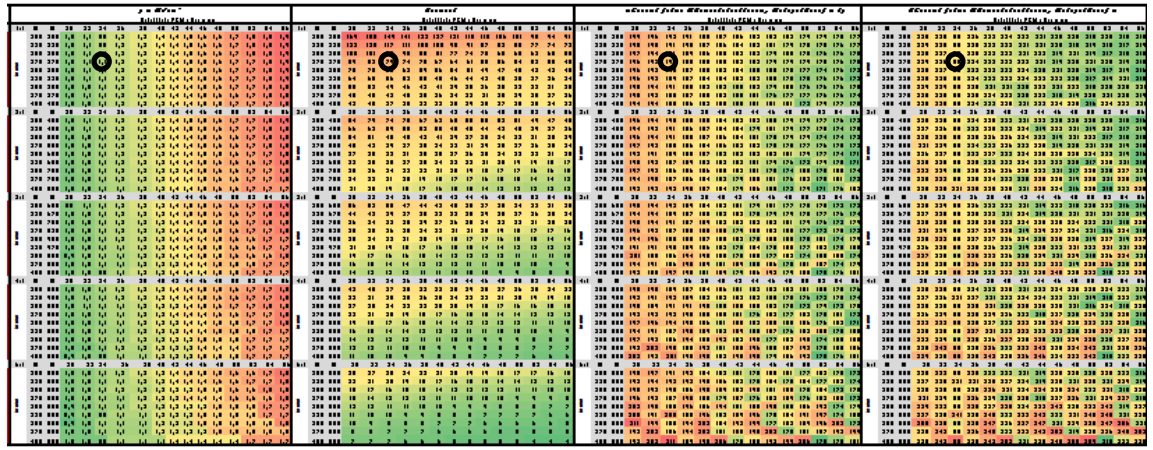
Rapid charge storage heater

Design process: Module-/cell design

Multi-parameter optimization problem:
Solution → Designtool - Determines properties for a huge variety of possible systems

Example (cell based system):

→ determination of **system properties** for systems based on 630 different cells



- System properties for one system based on one specific cell

Rapid charge storage heater

Design process: Module-/cell design

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Example (cell based system):

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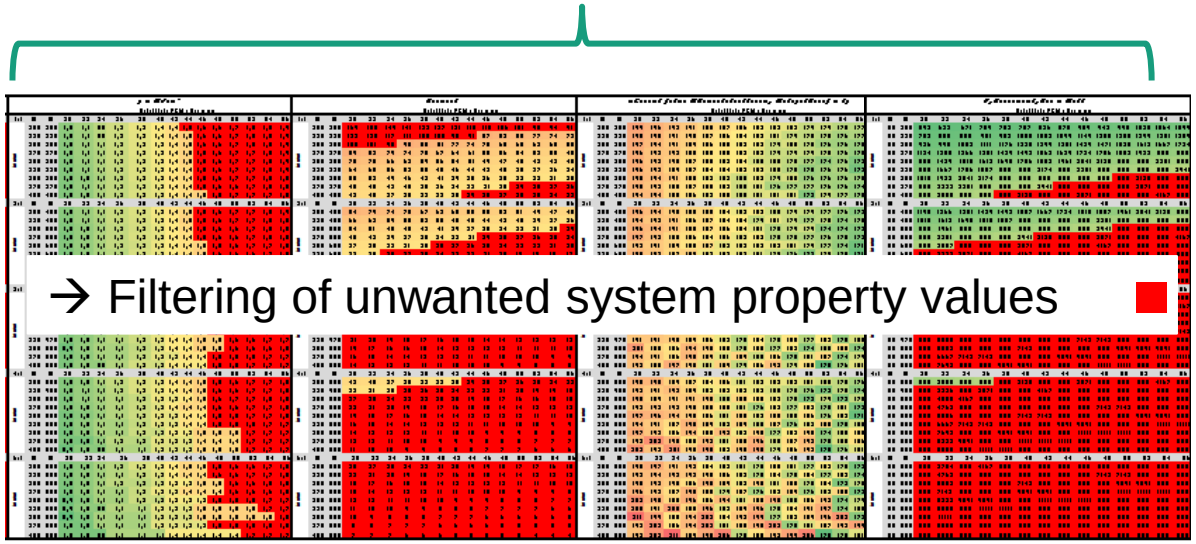

Rapid charge storage heater

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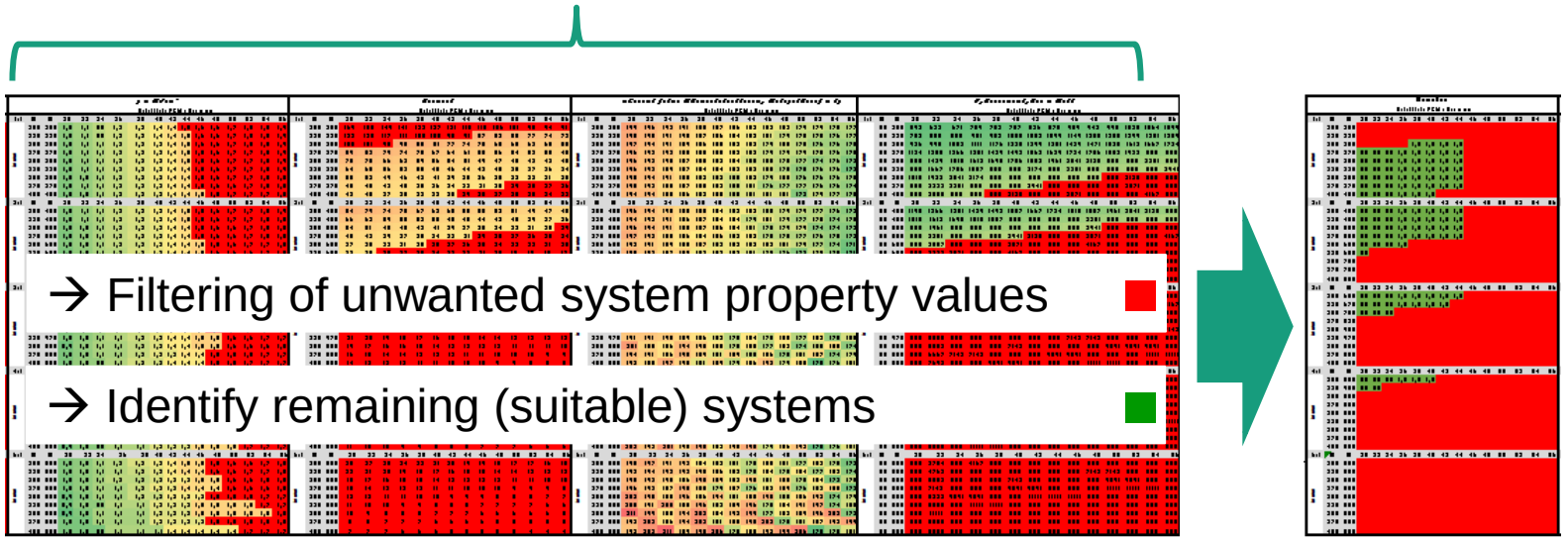

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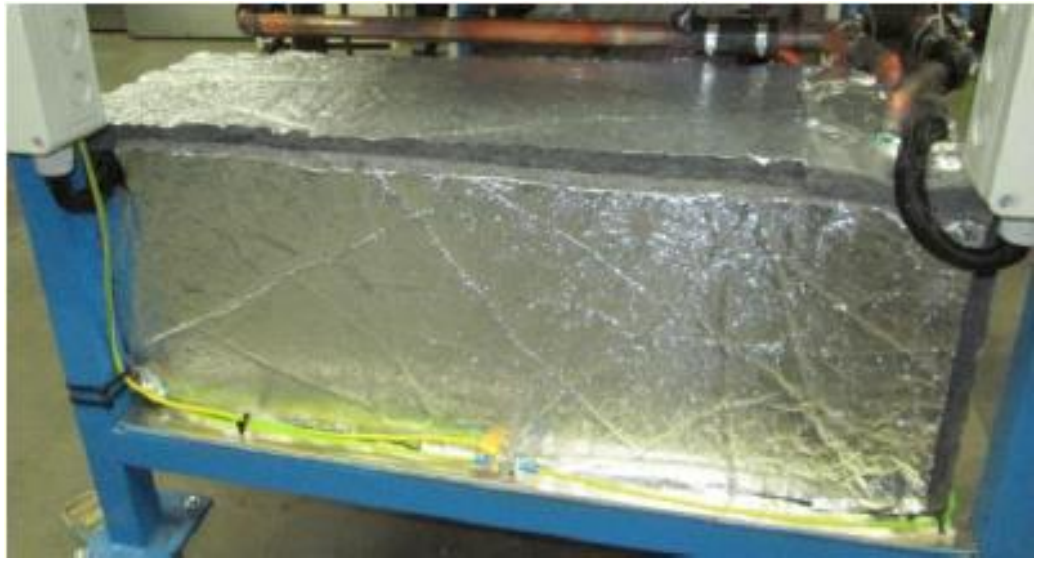
Rapid charge storage heater

Prototype

Prototype indirect system (realization Konvekta AG): discharging through water circuit

Capacity[1]:	0,76 kWh
PCM:	Paraffin, T_{Melt}=70 °C
El. charging power:	11,0 kW (720 VDC)
Charging time:	316 s
Energy density:	30 Wh/kg
Charging-/Discharging cycles:	2500



storage module prototype

[1] discharged heat per cycle

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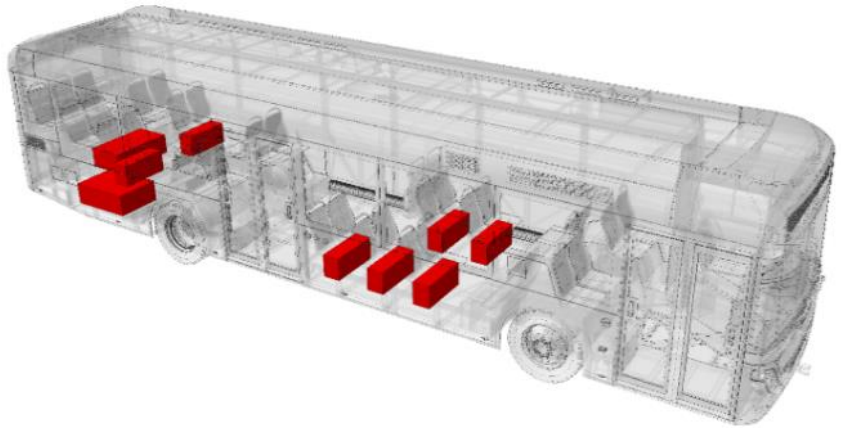
Outlook

Heat2Go project goals:

- Realization rapid charge thermal storage heating system

- el. charging (HV) within 6 min
- storage capacity & discharging power for 1 h operation time



- Functionality:
  - Recharging through recuperation
  - Separate charging of single modules
  - Cell-/module monitoring
- Integration in test vehicle (EDDA Bus, 12 m city bus; FEV)
- Demonstration in drive operation and climate hall

Project progress

Start 10/2016 — End (09/2019)

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