20th Aachen Colloquium "Automobile and Engine Technology" 10th – 12th October 2011

Holistic Method of Thermal Management Development Illustrated by the Example of the Traction Battery for an Electric Vehicle

Aachen, 12. October 2011

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Agenda

- Motivation
- Holistic Method (modelling principle)
- Exemplary applications
  - Thermal behaviour of different battery design approaches
  - Control strategies for battery preheating
- Summary

Motivation
Shuichi Nishimura, Nissan Motor Company

„Current chaos of technologies has to be well managed“

20th Aachen Colloquium „Automobile and Engine Technology“

Introduction
Motivation

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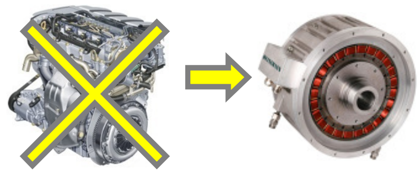
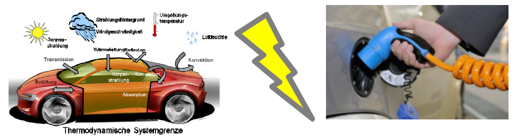
Higher number of new components

Substitution of the combustion engine



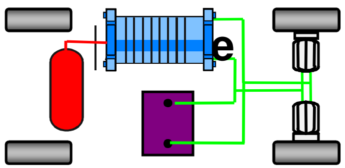
Challenge between climatisation and range



Different operating temperatures (heat recovery)

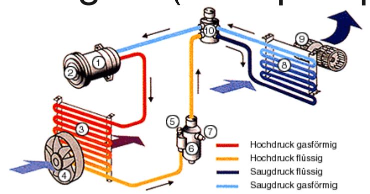
20 °C 120 °C

Decentralised package

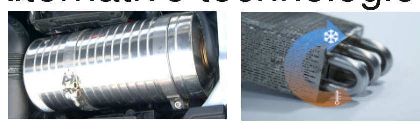


Increasing efficiency by electrification the power train

Alternative climatisation strategies (heat pump)



Alternative technologies



Higher overall system complexity

Holistic development / simulation tool is necessary

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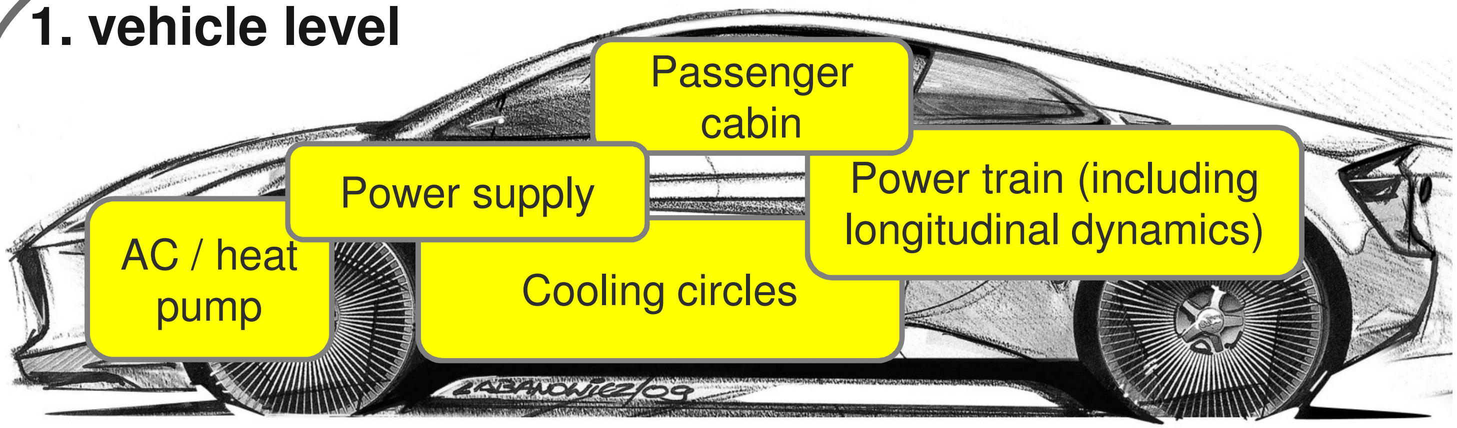
Modelling principle
1. vehicle level

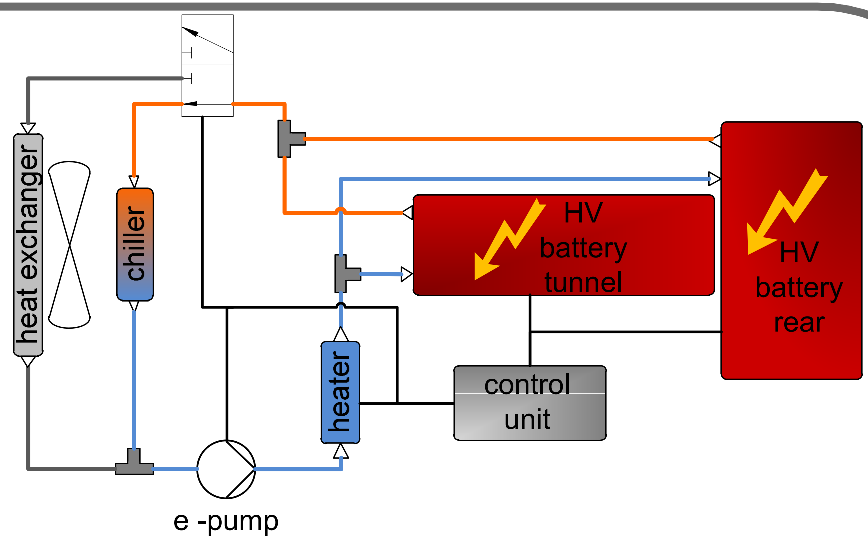
1. vehicle level



- Combines all vehicle submodels
- Definition of global boundary conditions
  - driving cycle
  - route profile
  - ambient conditions, initial conditions

Modelling principle
2. energy flow level

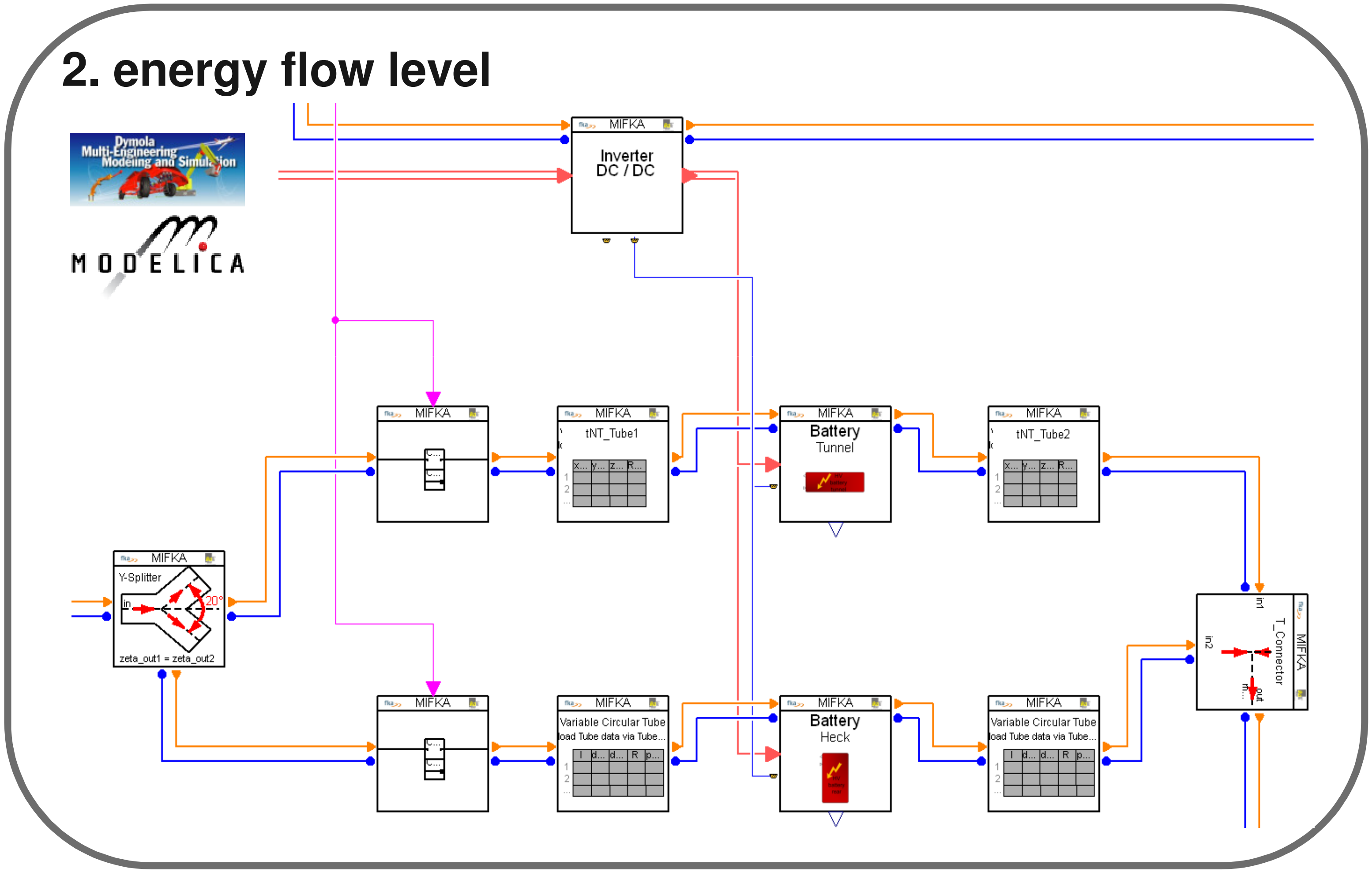
2. energy flow level



- Combines all component models
- Definition of circuit respectively control loops
  - mechanics (power train, lungitudinal dynamics)
  - thermal (AC, heat pump, cooling circuits)
  - electrics (high voltage and low voltage power supply)

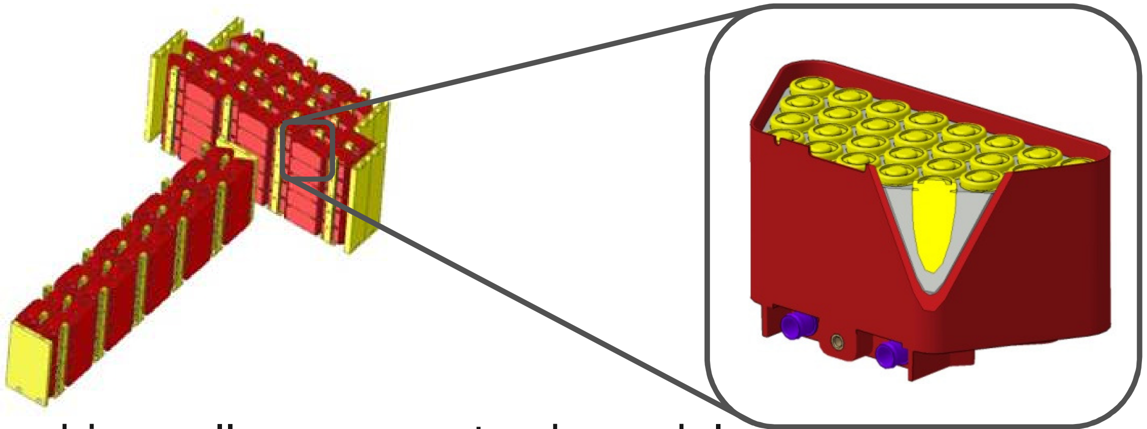
Modelling principle

2. energy flow level – simulation example



Modelling principle
3. component level

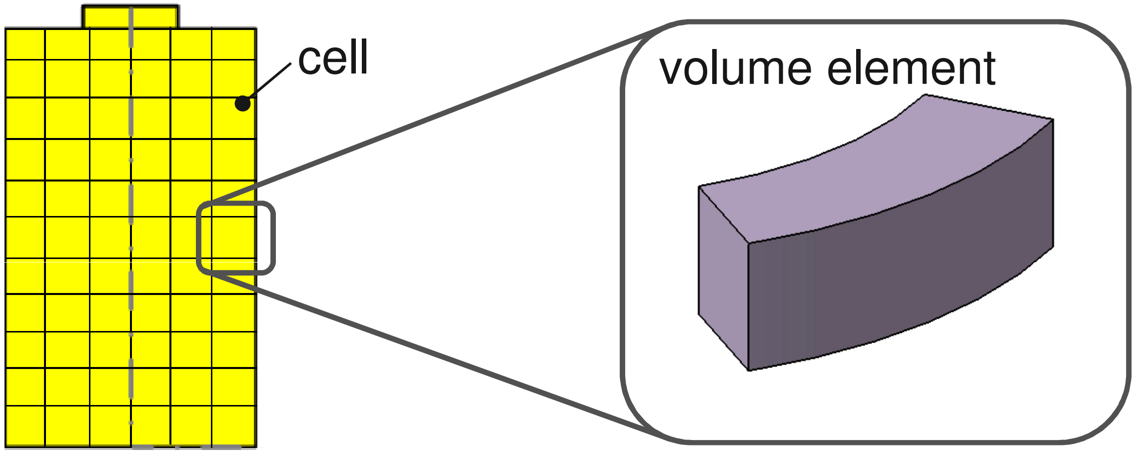
3. component level



- Combines all component sub-models
  - mechanics (e.g. power loss calculation)
  - thermal (heat flows via a 3D-disceret volume model)
  - electrics (e.g. cell characteristics)
  - signals (component internal control units)

Modelling principle
4. physical base level

4. physical base level



- Describes all physical laws
  - differential energy and mass balance
  - differential linear force and torque balance
  - material properties

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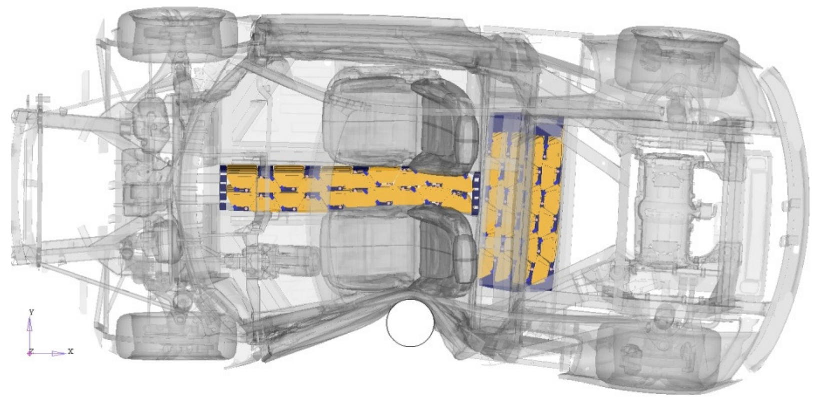
Exemplary applications
Vehicle information

1. Thermal behavior of different battery design approaches.
2. Control strategies for battery preheating.

vehicle information:	e performance Forschungsprojekt
vehicle class	two seated sports car
vehicle mass	1400 kg
electric machine	▪ 1 x ASM: 45 kW, 172 Nm (peak performance) ▪ 2 x PMSM: 45 kW, 150 Nm (peak performance)
battery system ▪ type of cells ▪ number of cells ▪ performance ▪ energy content ▪ mass	 ▪ 18650 Li-Ion-Cell ▪ 2080 cells (tunnel battery) / 3120 cells (rear battery) ▪ appr. 220 kW ▪ appr. 42 kWh ▪ appr. 310 kg

Exemplary applications
Requirements and limits

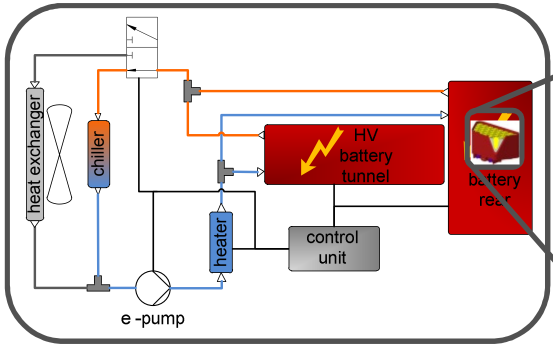
requirements
deformable and energy absorbing battery system
low overall system weight
low installation space



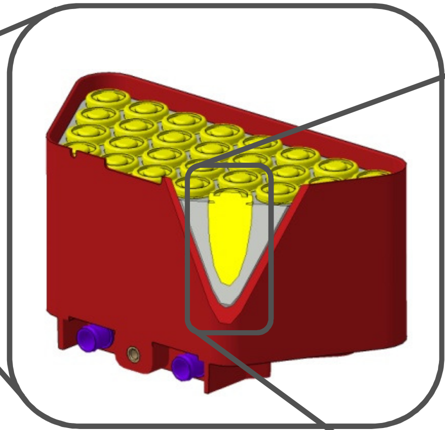
thermal requirements / limits	
maximum operating temperatures	< 40 °C
maximum axial cell temperature gradient	< 4 K
maximum temperature difference between two cells	< 4 K
minimum cell temperature for charging	5 °C

Exemplary application I
Influences of different design approaches

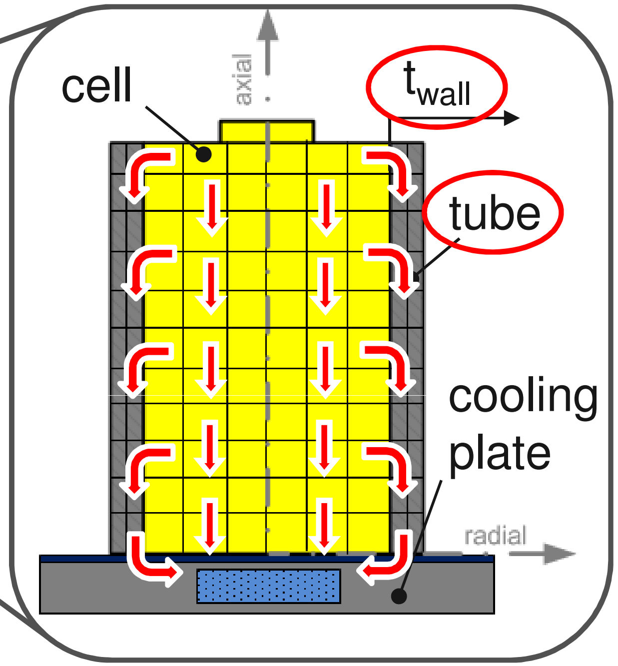
energy flow level

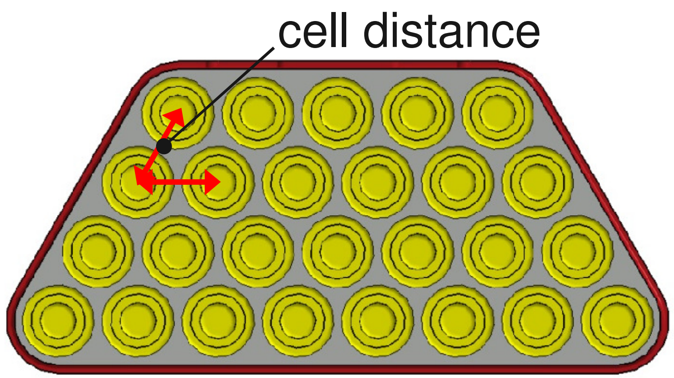


component level



base level





Variations:

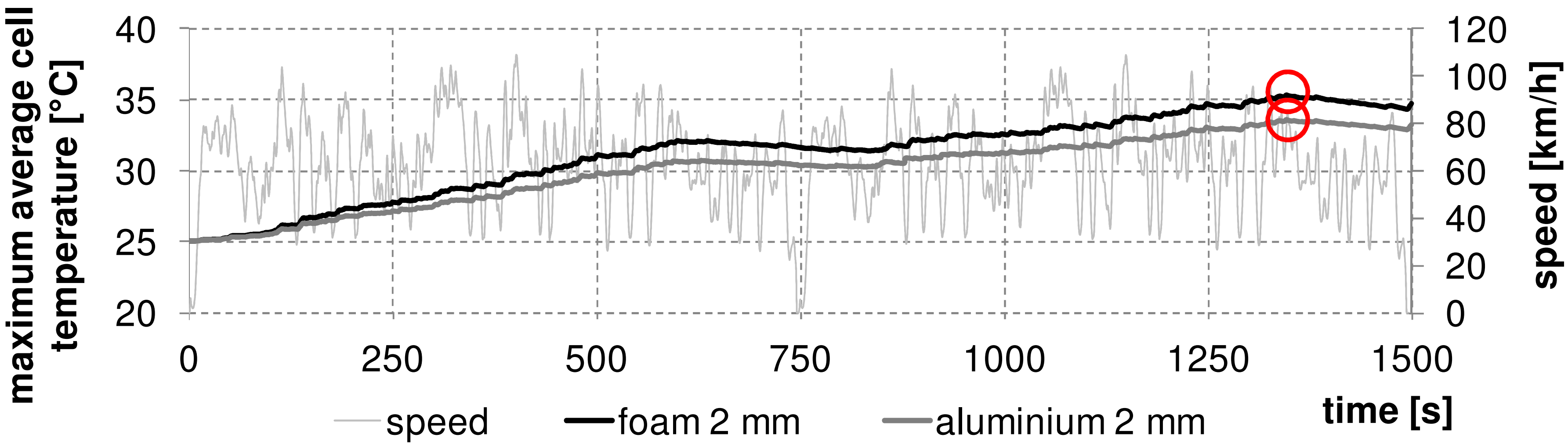
- material of the cell reinforcement to improve battery crash safety (foam, aluminum, copper)
- thickness of the reinforcement (0,5 mm up to 2,5 mm)

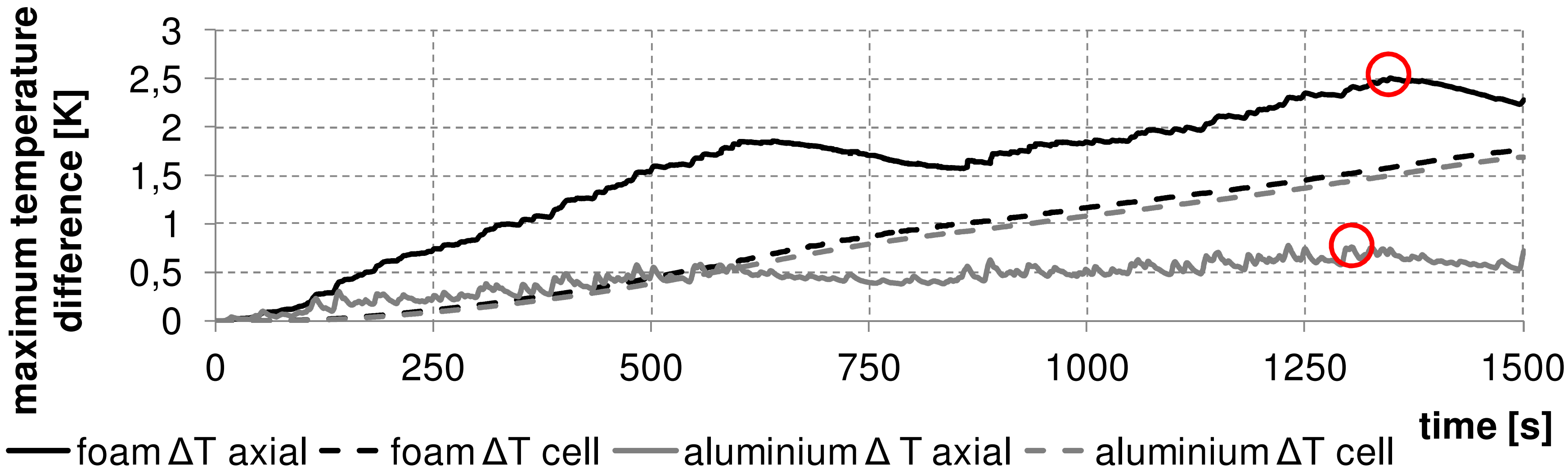
Assumptions:

- thermal equilibrium at the beginning
- starting temperature is 25℃
- adiabatic battery system behavior
- thermal contact of the cells only via the cooling plate

Influence of different design approaches

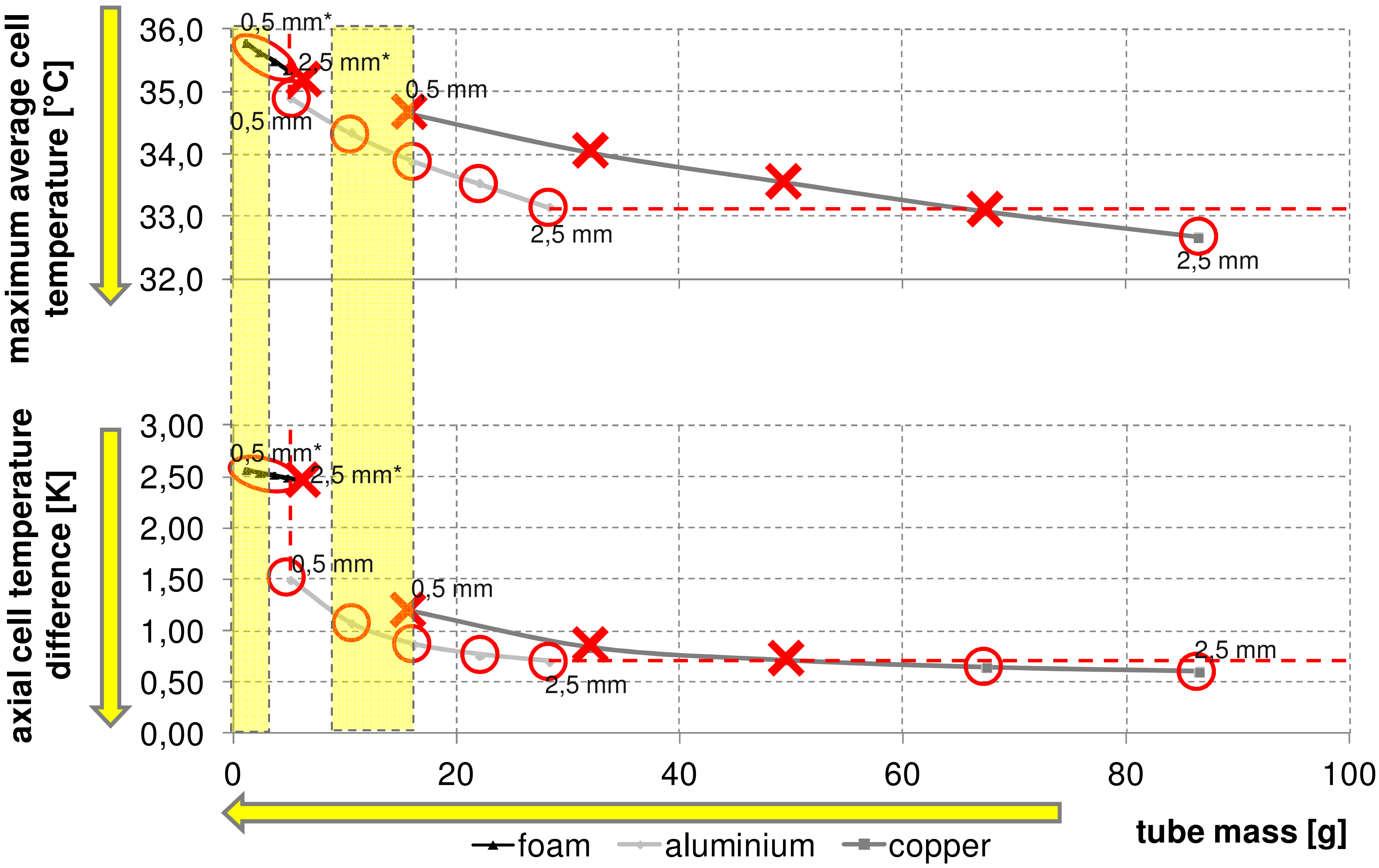
Maximum temperatures & temperature differences





Influence of different design approaches

Multi-criteria analysis



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Exemplary application II

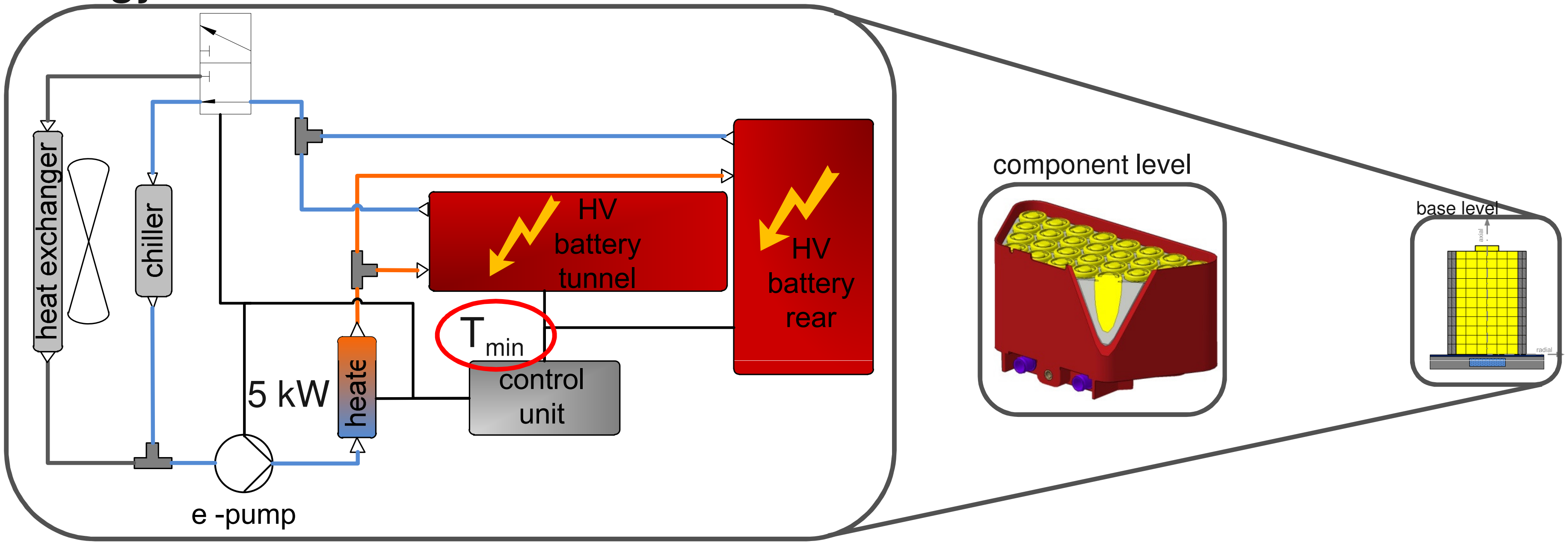
Battery preheating strategies / opposite effects

1. Could a realistic drive cycle be driven without preheating?
2. If not which preheat temperature should be chosen to get a good compromise between
   - potential start time
   - vehicle performance
   - overall energy demand

criteria	low (preheat) temperature		high (preheat) temperature		
battery / vehicle performance	↓	−	↑	+	surplus power
internal cell resistance / battery losses	↑	−	↓	+	energy demand
recuperation potential	↓	−	↑	+	
energy demand for heating period	↓	+	↑	−	
potential start time	↓	+	↑	−	start time

Exemplary application II
Battery preheating strategies

energy flow level



Variations:

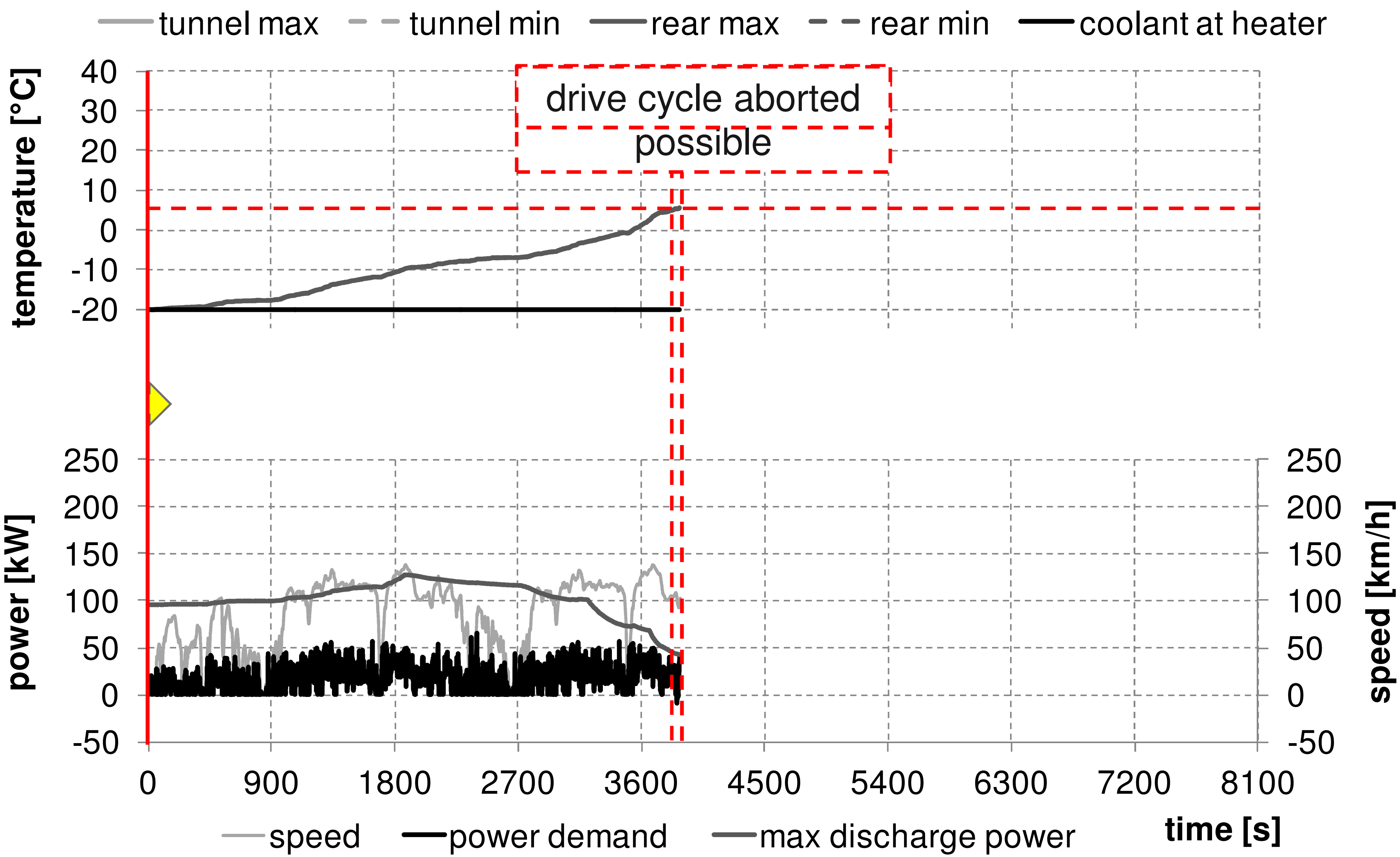
- switch off temperature of the coolant heater (from -15°C up to +25°C)

Assumptions:

- strong winter scenario, starting temperature is -20°C
- thermal equilibrium at the beginning
- adiabatic battery system behavior (form is used for the reinforcement)

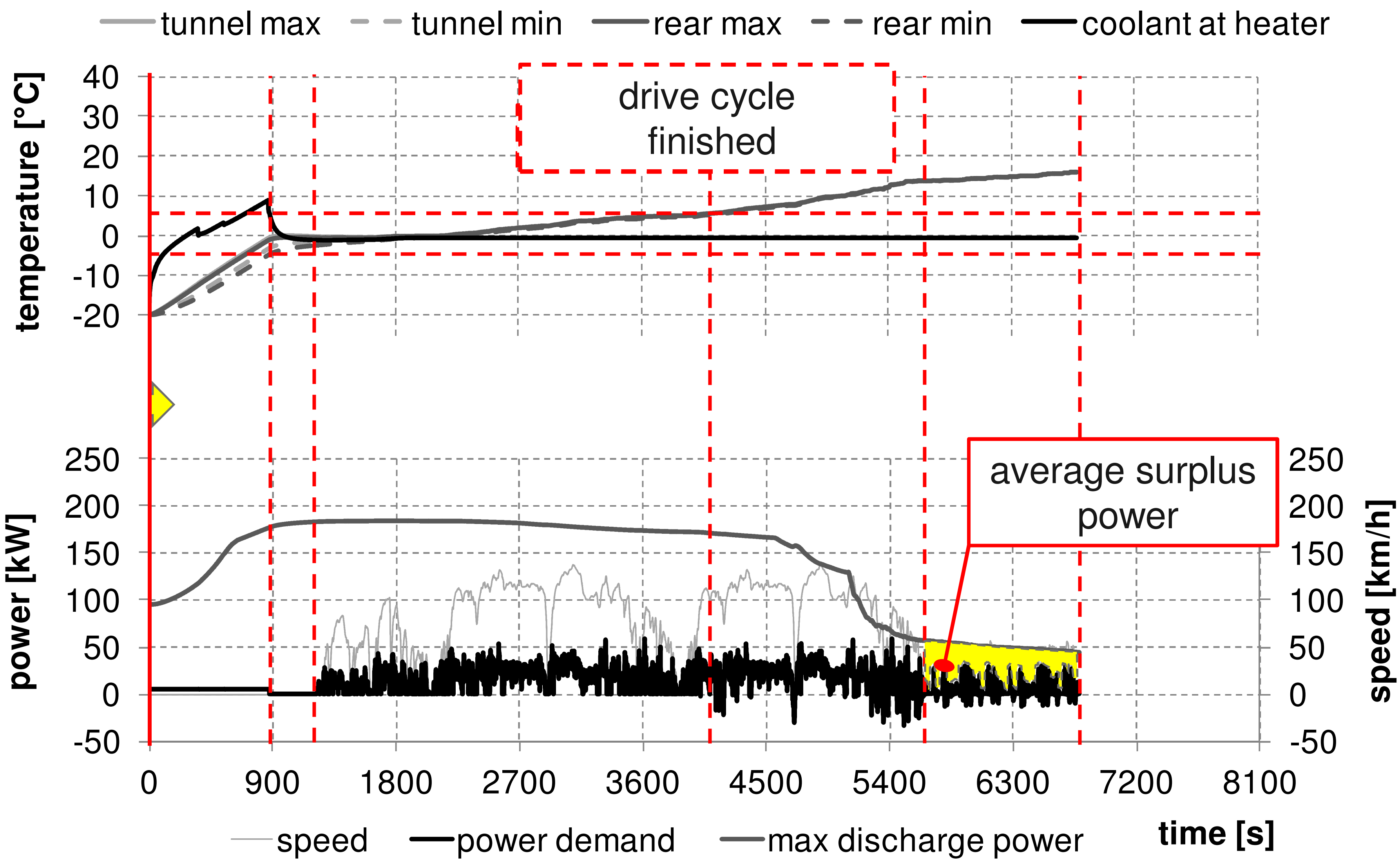
Without battery preheating

T_{start} = -20°C



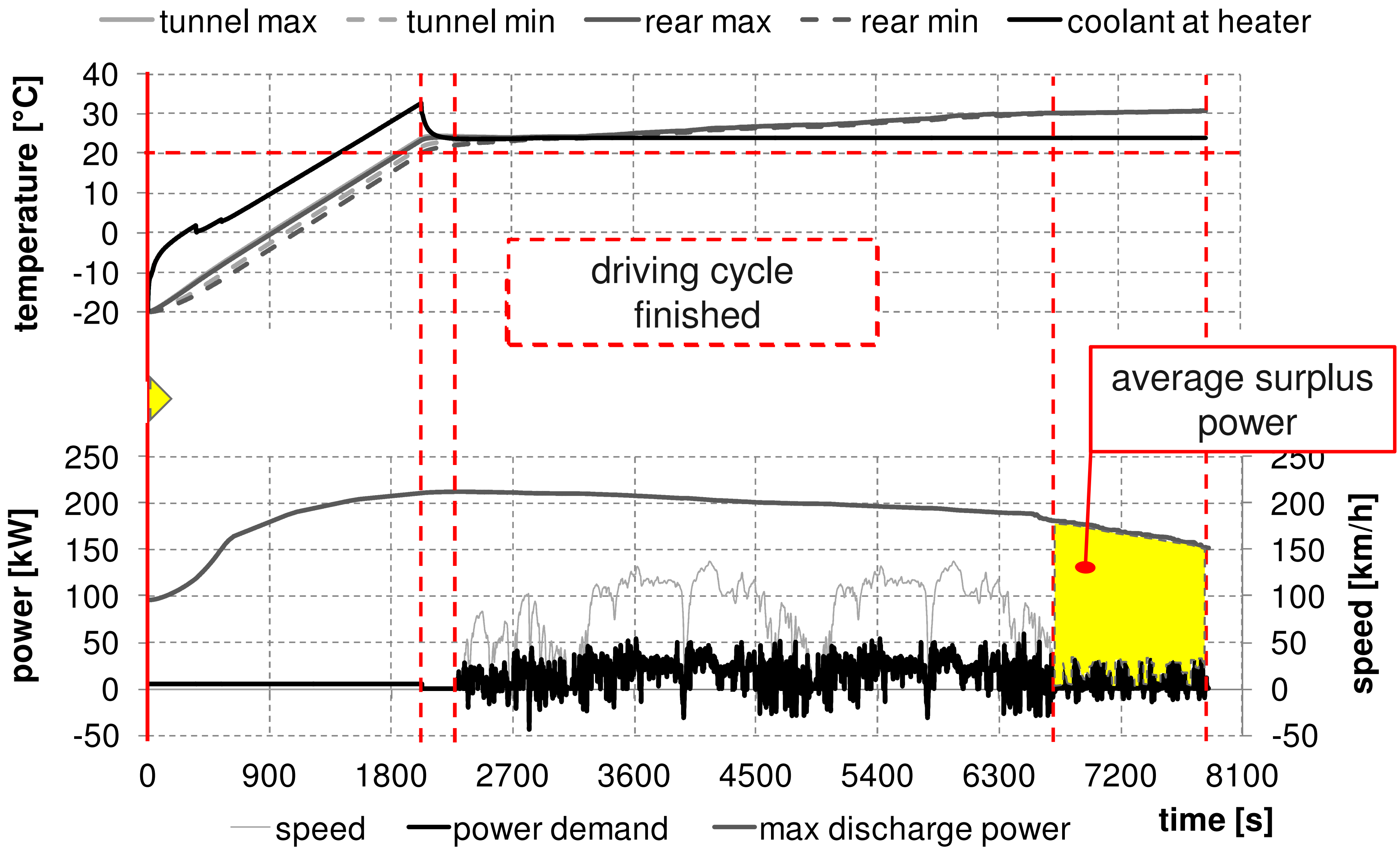
Battery preheating

$T_{heater,off}$ = -5°C

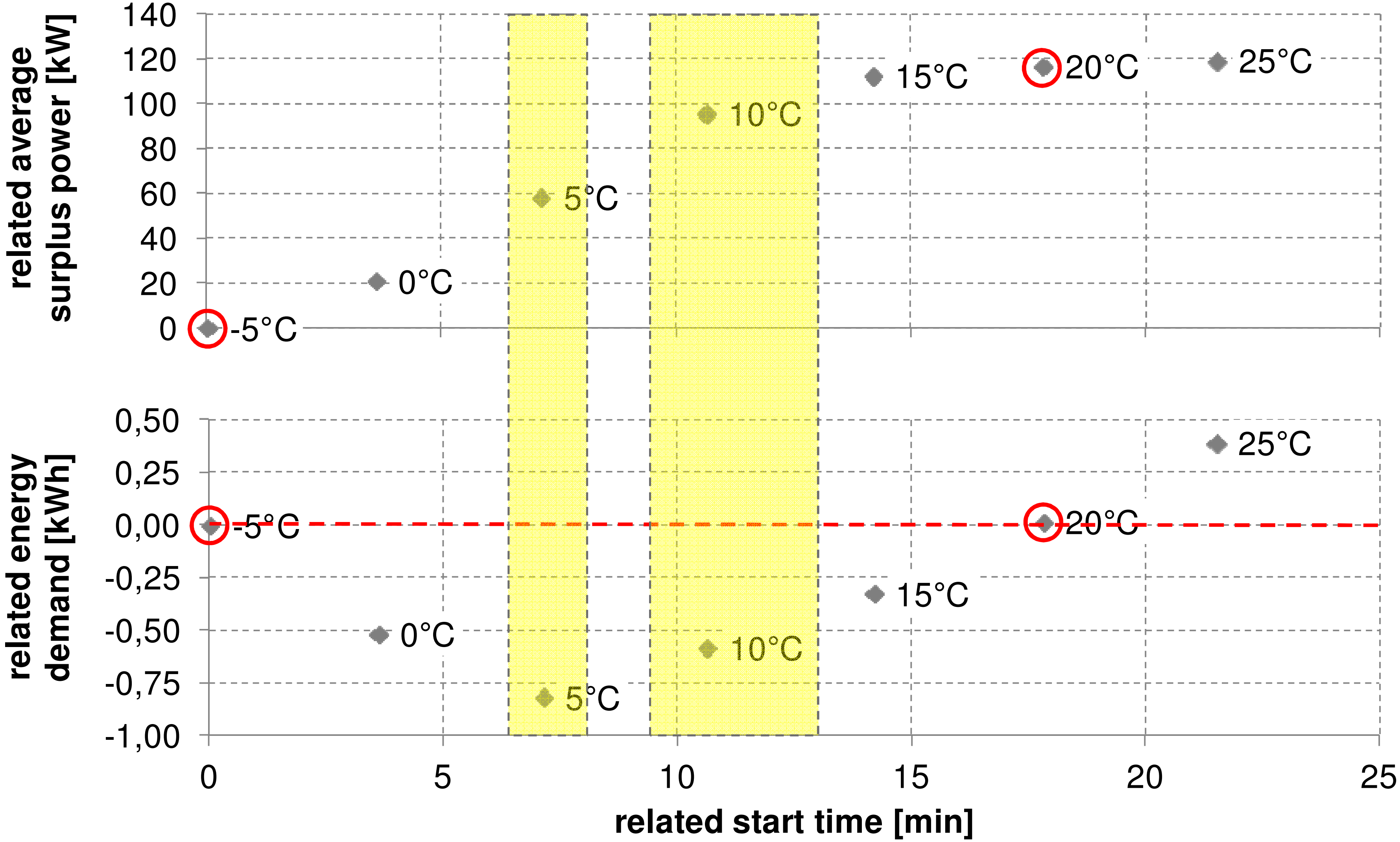


Battery preheating

$T_{heater,off}$ = 20°C



Battery preheating
Multi-criteria analysis



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Summary

- Increasing overall system complexity
- Holistic simulation tool is necessary
  - Simulation of mechanical, electrical and thermal energy flows
  - Support the design process (e.g. functional or structural development)
- Flexible holistic support tool is been developed at ika/fka
- Exemplary applications demonstrate the benefit of the holistic approach

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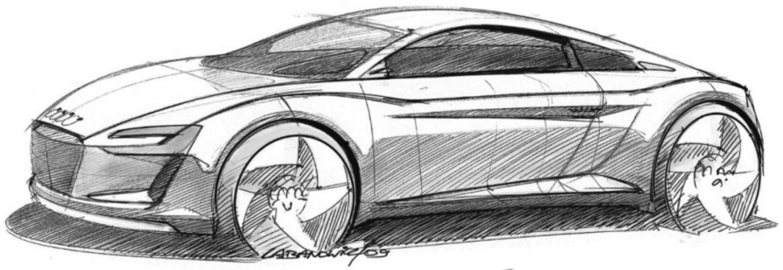
Thank you for your attention.



eperformance
Forschungsprojekt

Many thanks also to all team members of the project eperformance

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