Improving EV Efficiency by Battery Thermal Insulation

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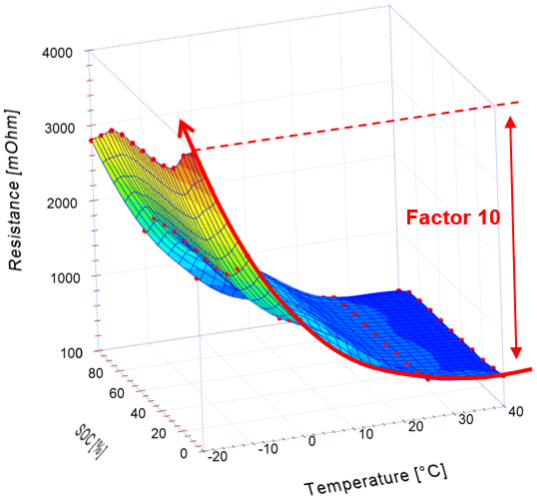
Introduction: Battery Cells and Cold Temperatures

Cold battery cells cause several problems in electric vehicles…

1) Very high inner resistance

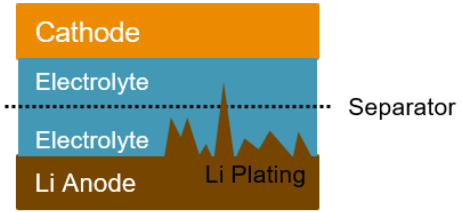
Example Inner Resistance
(6 Li Ion cells in series)



2) Damage from Lithium plating

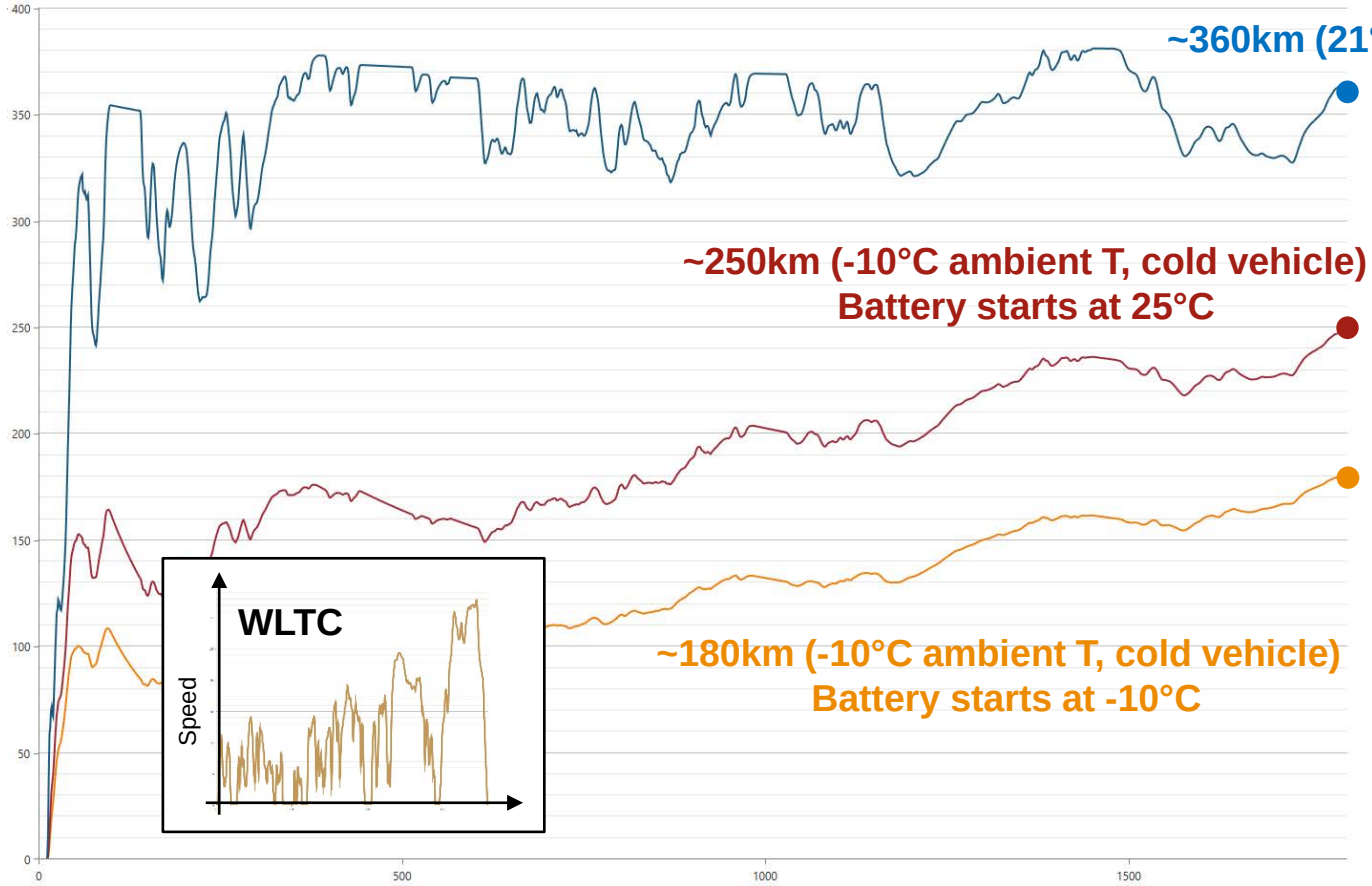
Lithium plating:

- Irreversible cell damage (reduced efficiency)
- Can even cause short circuit (if separator punctured)
- Effect increased, if charging in low T (<0°C) occurs…



- Cold battery cells severely reduce vehicle **efficiency** (range!) and **performance** (acceleration!)
- Cold battery cells limit (fast) **charging** and **recuperation** capacities
- But: Cold cells also reduce **calendaric aging** (e.g. in standing vehicles…)

WLTC at -10°C Ambient Temperature
Warm vs. Cold Battery Pack (example Magna E1)



-50%

Improvement Potential!

How much potential can be realized by improved battery pack **insulation**?

Introduction: Content of this Investigation

- Baseline Study: Impact of cold battery cells on a car
  - Investigated Car: Magna E1 (based on Tesla S)
  - Vehicle Class: Full size luxury (F)
  - Peak power: 420kW
  - What is the “cost” of a cold battery?
- Thermal insulation technology (Evonik)
- Benefits of battery thermal insulation
  - Cool-down times… overnight or within some hours
  - Impact on vehicle range
- Summary

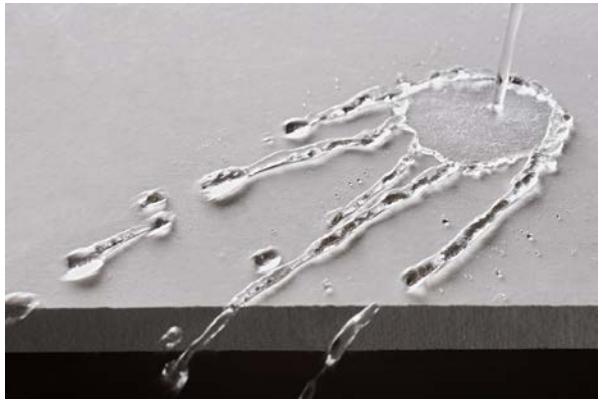
Magna E1

CALOSTAT® Granules

New high-performance insulation material by Evonik

EVONIK
Leading Beyond Chemistry

CALOSTAT® is a innovative high-performance material with a combination of outstanding properties



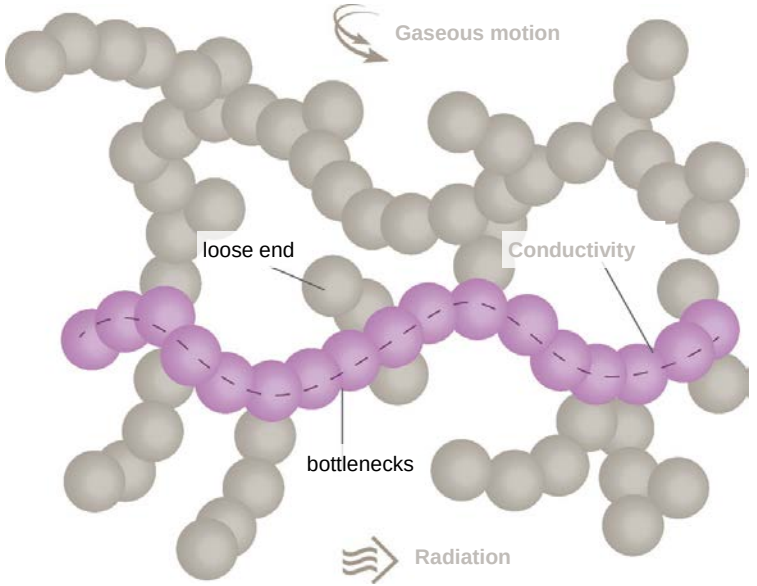
Core hydrophobic

Non combustible

Super insulating

CALOSTAT® is …

- Based on mineral silicon dioxide (SiO_2)
- An specially engineered material with a microporous structure
- Formulated to reach an outstanding thermal insulation value
- Started as ready to use boards for the construction industry
- Now available as granule for further processing in coatings, mortars or similar



EVONIK
Leading Beyond Chemistry

CALOSTAT® Granules can be used in Thermal Insulation Composites (TIC) in which they are the main ingredient to lower the thermal conductivity

What are CALOSTAT® Granules?

CALOSTAT® is a specially engineered **microporous material based on silica** with a defined pore structure, density, and formulation used mainly in thermal insulation applications.

Granules made of CALOSTAT® are produced in a grain size distribution between 1000 and 4000 µm. They can fill hollow structures or act in TIC as thermal insulation ingredient.

What is a TIC?

TICs containing CALOSTAT® granules are liquid or semi-liquid and suitable for spray application in a certain thickness (up to 10 mm). They provide not only thermal insulation properties, but also a protective and flame retardant finish.

Typical binders of TICs are acrylics, poly-siloxanes (silicones), or epoxies.

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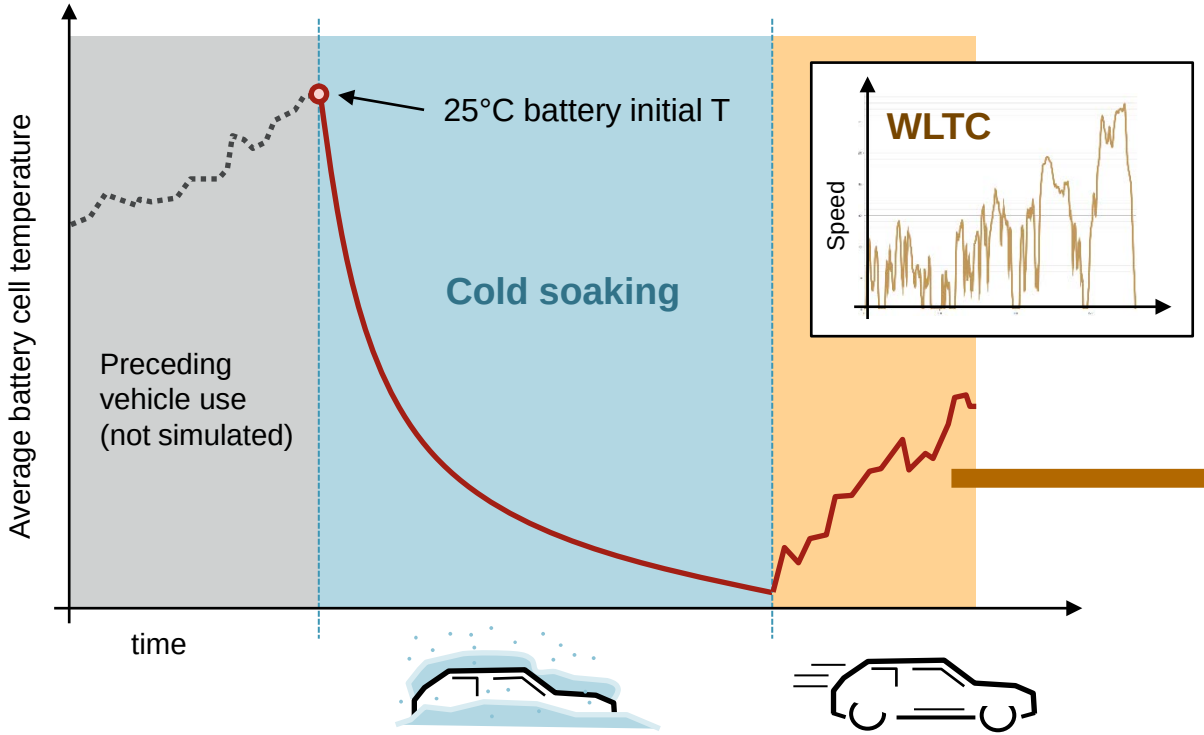
Benefit Study:
Thermal Insulation of Battery Packs

Simulated Conditions:
Cold day with WLTC after cold soaking phase…

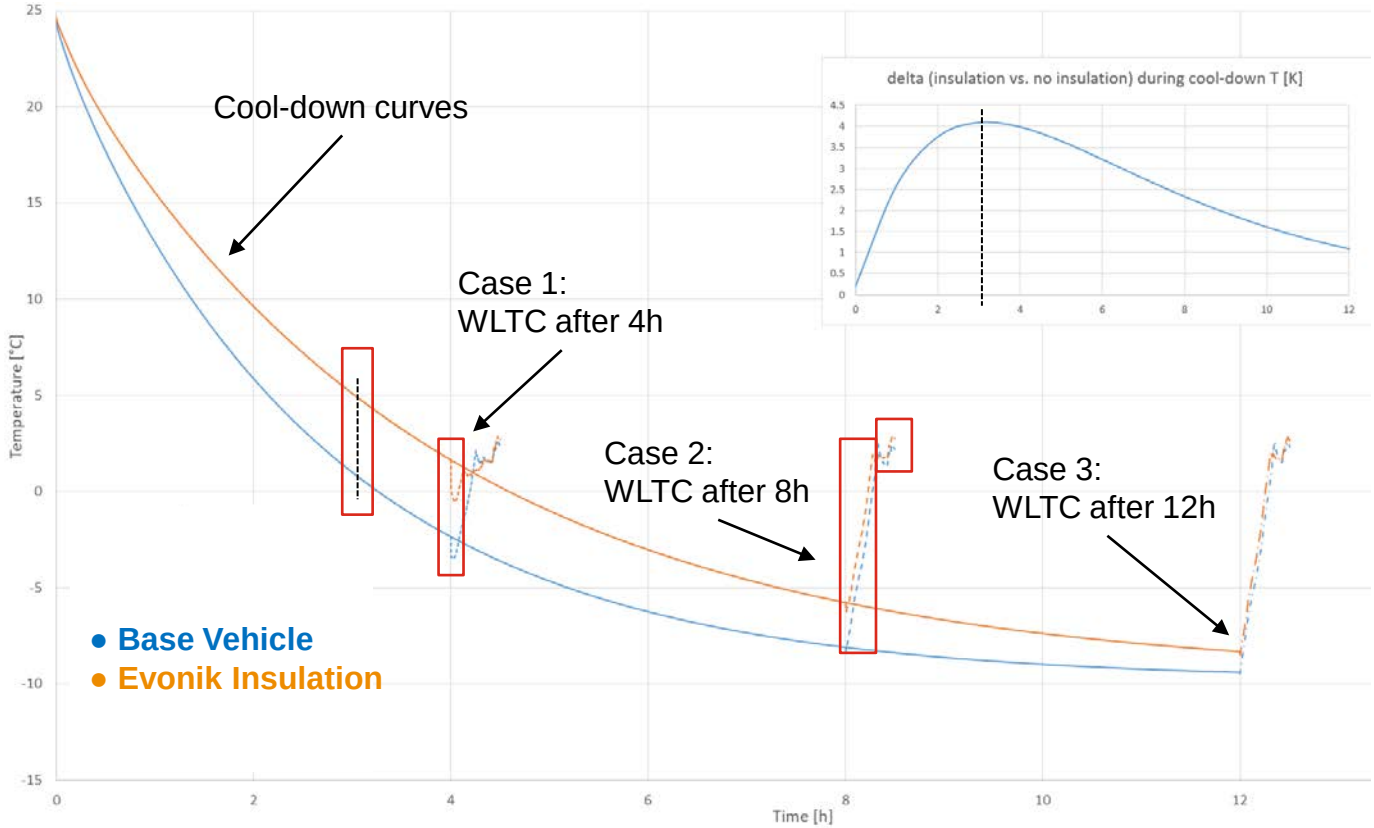


- **Different ambient T:**
  - 0°C, -10°C, -20°C
- **Different soaking time:**
  - 4h, 8h, 12h
- **Comparison of WLTC range:**
  - Base vehicle vs. improved insulation

Further Boundary Conditions of the Following Simulations ("The fine print")

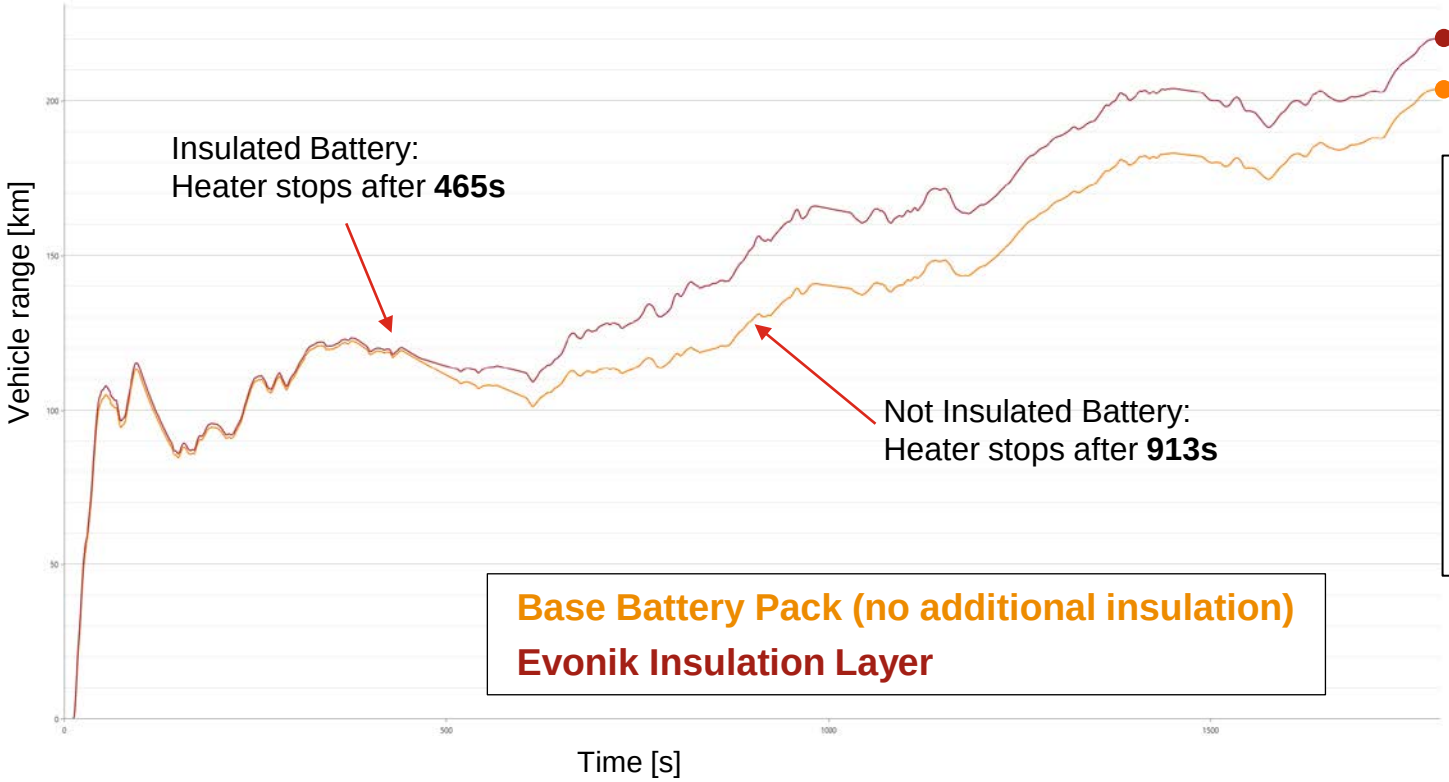
- Battery heating by 3kW coolant heater
  - Heating only below 0°C minimum battery cell temperature
- Regenerative braking used, but only when the coldest cell is warmer than 0°C (lithium plating!)
  - Efficiencies are considered (motor/generator, inverter, transmission…)
- Simulations were done for dry air and without passengers in the vehicle, fresh air mode used.
  - Cabin heating provides a constant offset to all cases; therefore it is considered, but was not the focus of this investigation
- Simplified generic HVAC controls
  - Based on state machine

Battery Temperatures (Ambient T -10°C, Cool-Down + WLTC)



1. Biggest delta T (4.1°C) after ~3h
2. Initial cool-down effects in battery from cold coolant in ducts
3. Initial rapid warm-up from 3kW coolant heater
4. Slower warm-up due to internal resistance of battery cells
5. Range impact is shown in more detail for 4h and 12h use-case…

Vehicle Range
Case 1 (Ambient T -10°C, WLTC after 4h Cool-Down)

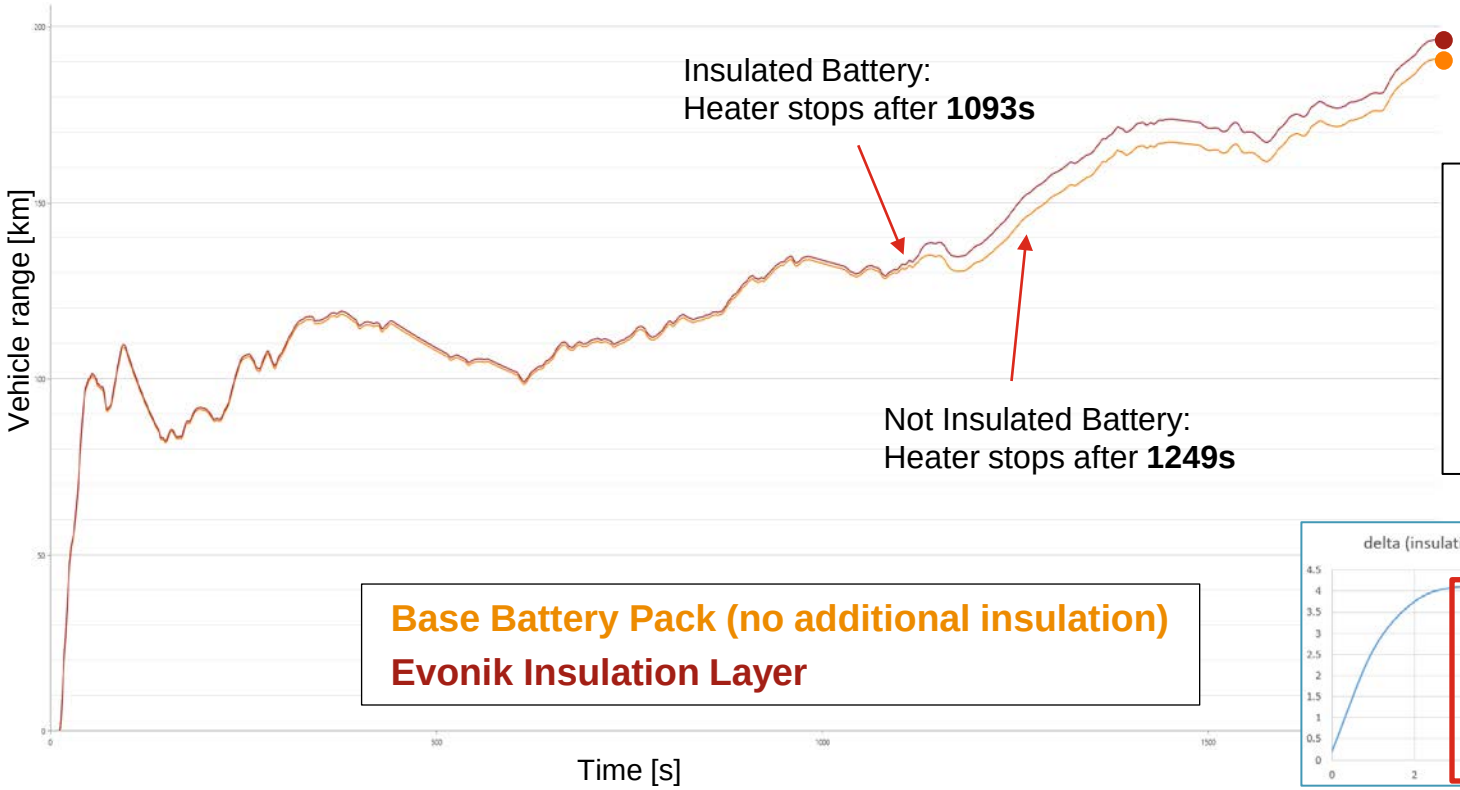


- Range improvement **~8%**
- Main impact from battery heating
- Further contributors are
  - Earlier availability of recuperation
  - Reduced internal resistance of cells

Base Battery Pack (no additional insulation)

Evonik Insulation Layer

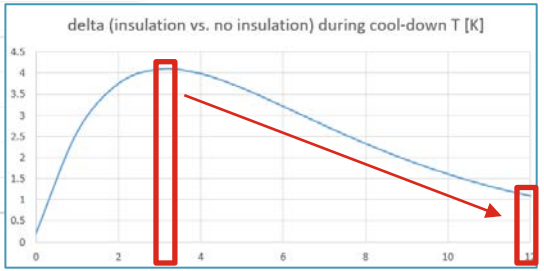
Vehicle Range
Case 3 (Ambient T -10°C, WLTC after 12h Cool-Down)



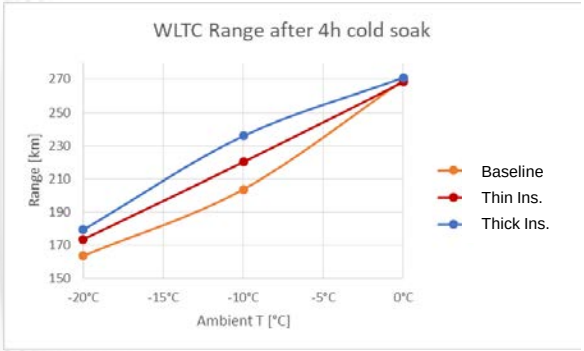
- Range improvement **~3%**
- Long cool-down reduces benefit from insulation (homogenization of temperature levels).

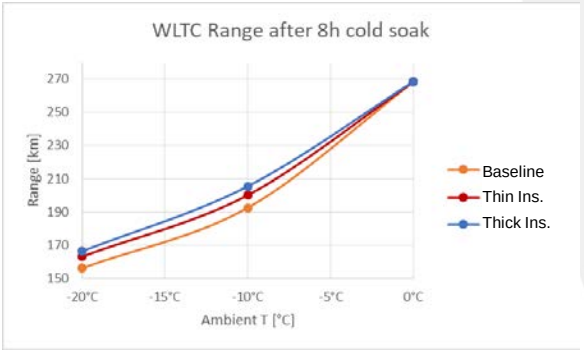
Base Battery Pack (no additional insulation)

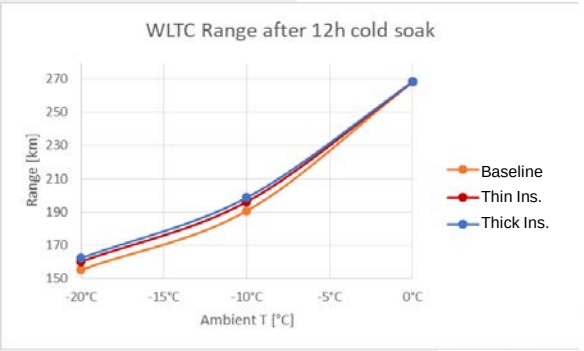
Evonik Insulation Layer



Summary: Comparison of WLTC Range







Range Benefits Thin Insulation

WLTC-Range [km]	4h	8h	12h
0°C	-0.4%	0.0%	0.0%
-10°C	8.0%	3.9%	2.9%
-20°C	6.0%	4.5%	3.2%

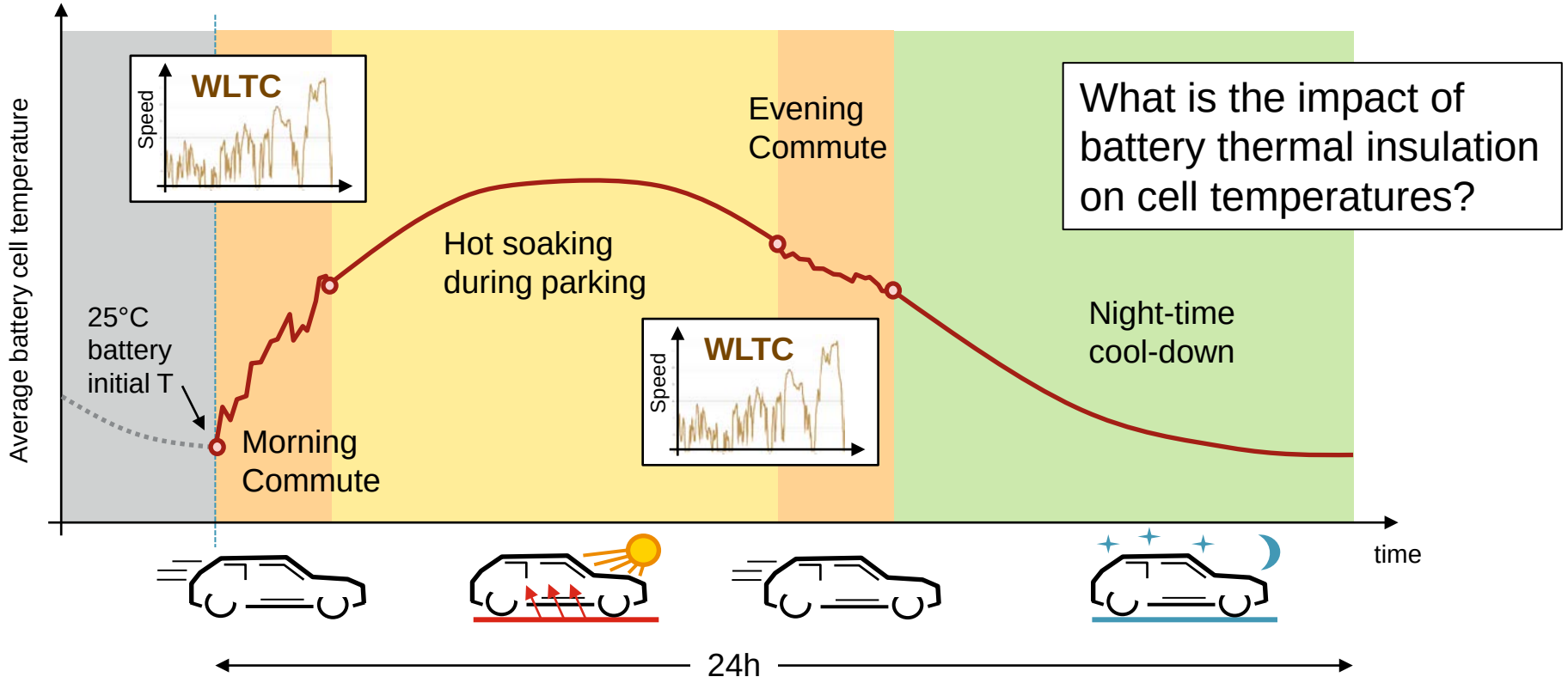
Range Benefits Thick Insulation

WLTC-Range [km]	4h	8h	12h
0°C	0.56%	0.07%	0.04%
-10°C	15.75%	6.70%	4.20%
-20°C	9.59%	6.53%	4.51%

- Improved performance for thicker insulation layer
- Best benefits at -10°C
- Very little benefit at 0°C
- Longer cold soak reduces benefits of insulation
- Best benefits after 3-4h

But what about summer conditions?

Simulated Conditions:
A hot summer working day



Model adaptations for hot soaking

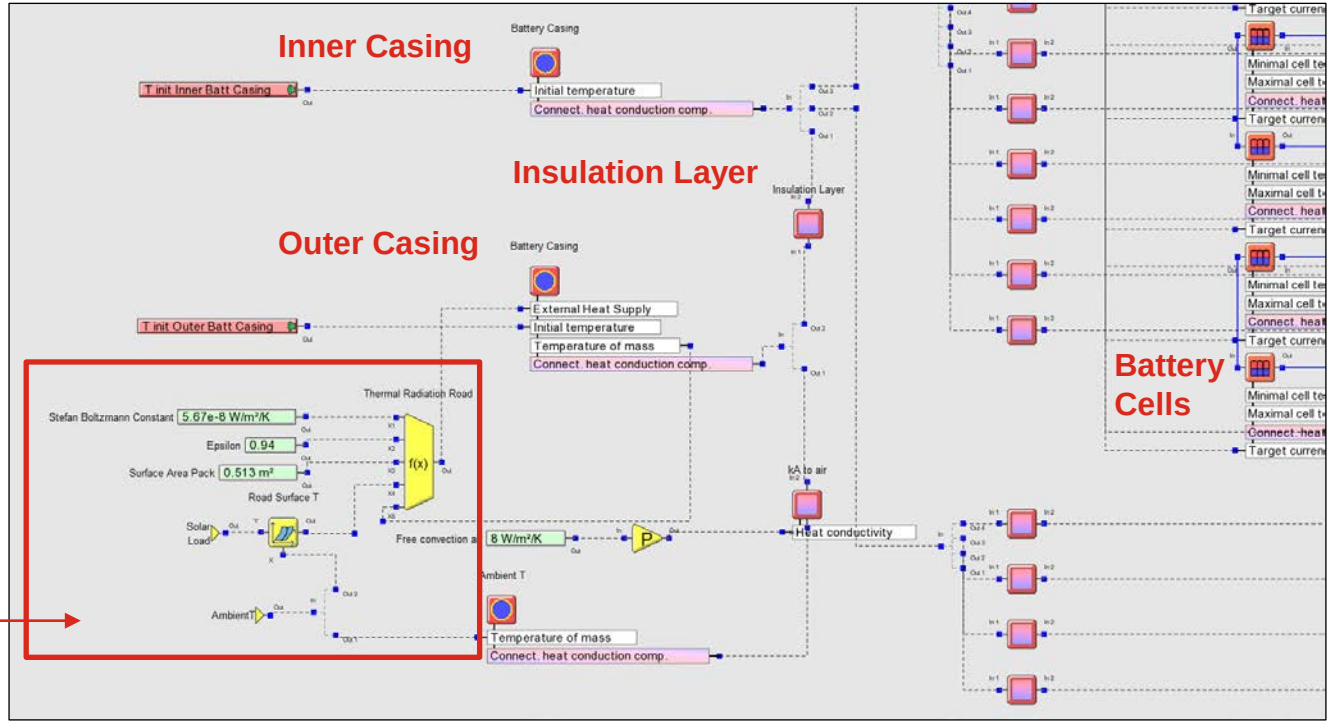
Influence of hot road surface needs to be considered…

Air temperature 20cm above ground is already very close to general ambient T…

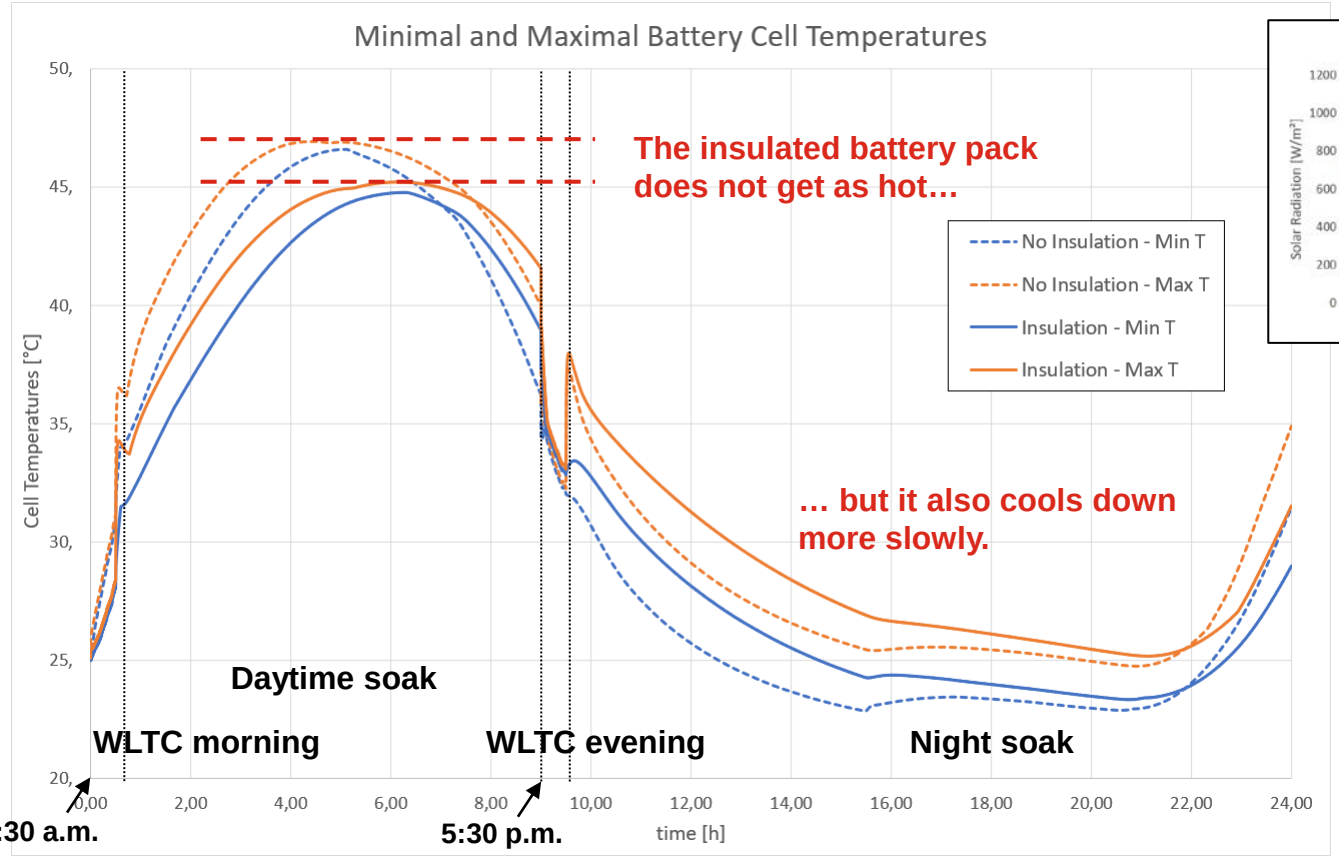
➡ **little influence!**

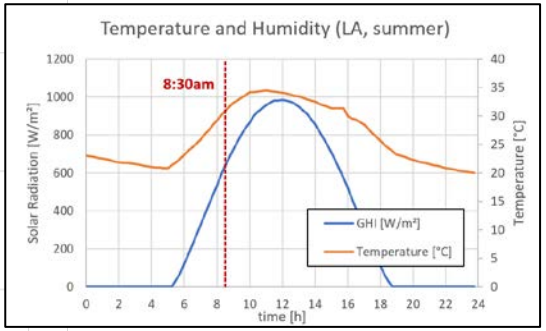
Radiation from the hot road surface needs to be simulated, though…

➡ **heats up outer casing layer**



Simulation Results – Battery Cell Temperatures





Weather data (ambient T and solar radiation) for summer day in Los Angeles

Analysis of Summer Results

Average cell temperatures

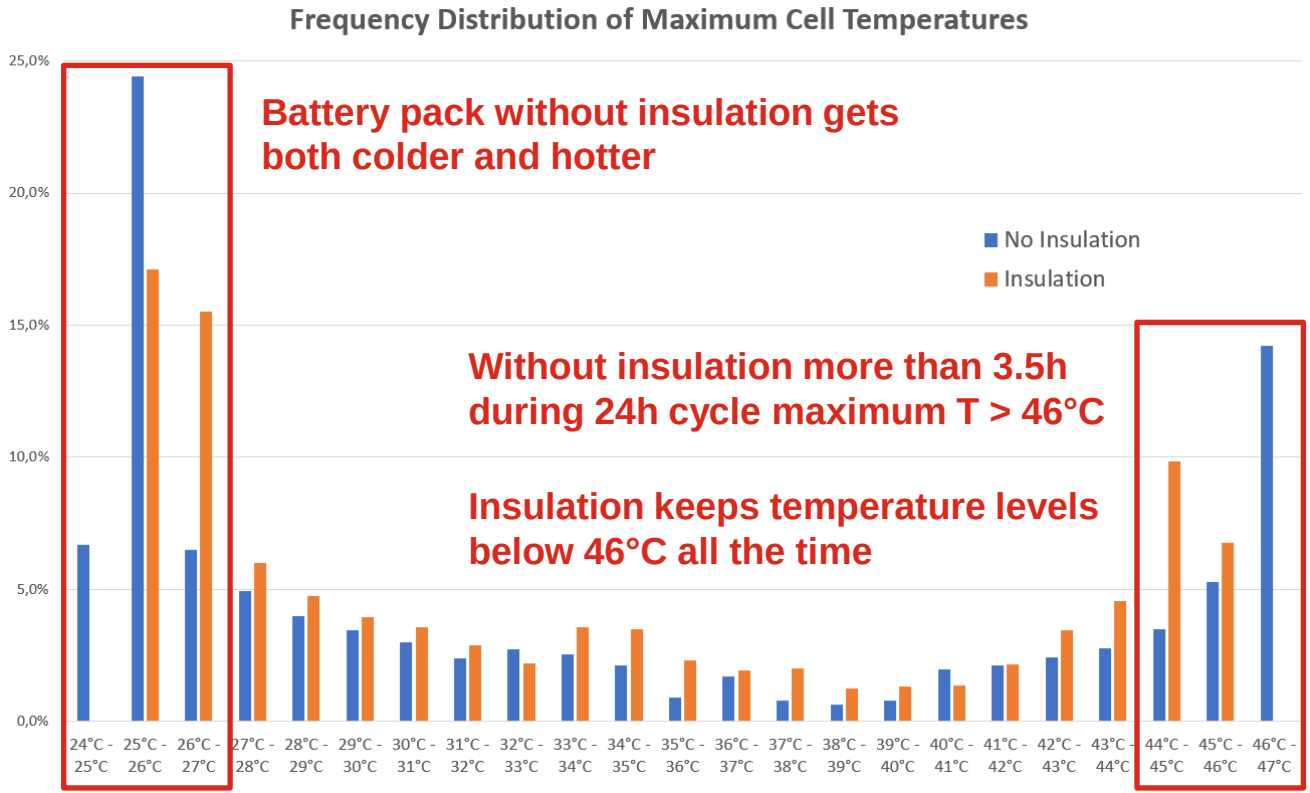
- No insulation: **32.49°C**
- Insulation: **32.37°C**

Average cell temperatures for 24h period are **very similar…**

Maximum cell temperatures

- No insulation: **46.93°C**
- Insulation: **45.22°C**

Maximum cell temperature is **more than 1.5K lower** for insulated battery



Summary

Summary

- Thermal insulation of battery packs can contribute significantly to EV winter range
  - Reduced effort for battery heating
  - More benefit from regenerative braking
  - Reduced internal resistance of battery cells
- Biggest impact (in this example) for
  - 3-4h cold soak
  - At very cold ambient temperatures
  - When insulation can reduce heating effort!
- This is also influenced by
  - Battery heating strategy (optimized for performance or energy saving?)
  - Recuperation strategy (direct use of recuperated energy for heating?)
  - Cell chemistry
- In hot summer conditions, thermal insulation reduces the impact of temperature extremes
  - Average temperatures stay very similar (slower warm-up, but also slower cool-down)
  - Phases with very high temperature levels are reduced significantly by thermal insulation!

DRIVING **EXCELLENCE.**
INSPIRING **INNOVATION.**