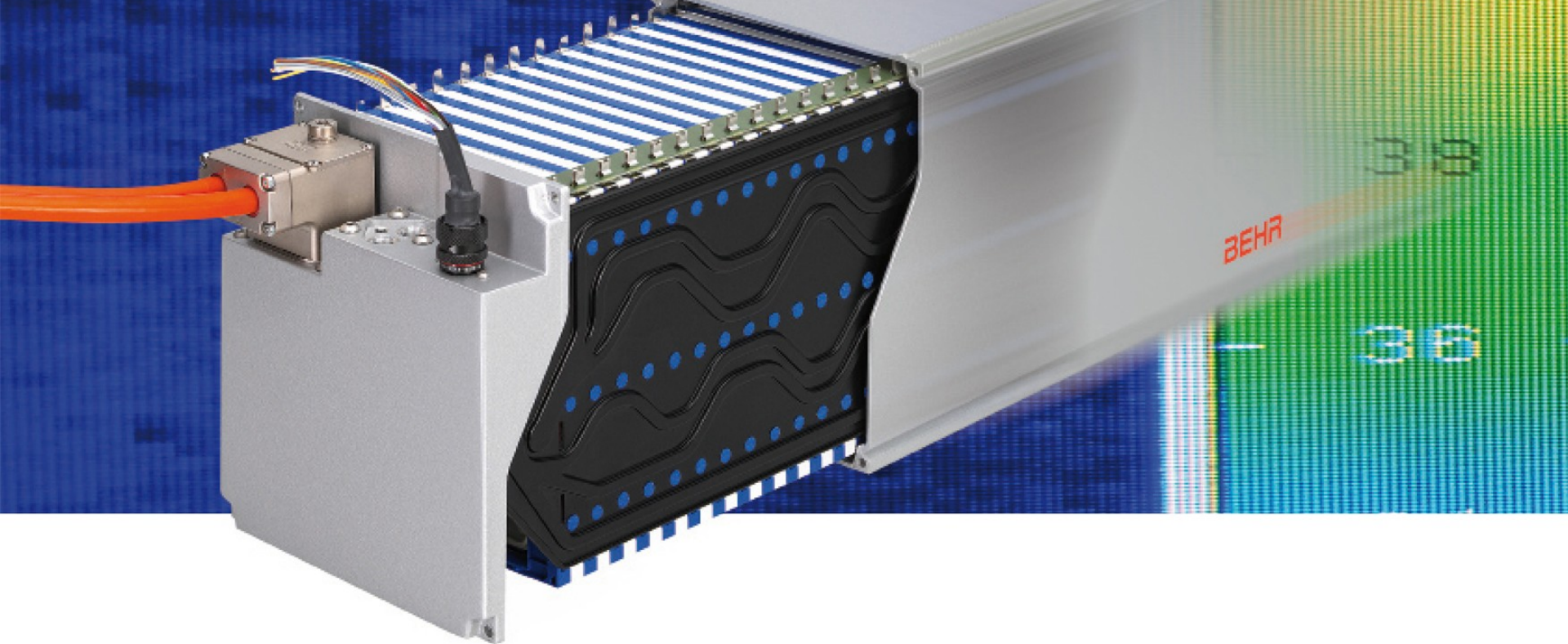


Technical Press Day 2009 | Stuttgart, May, 20<sup>th</sup> 2009

**Li-ion battery cooling:  
more than just another cooling task**

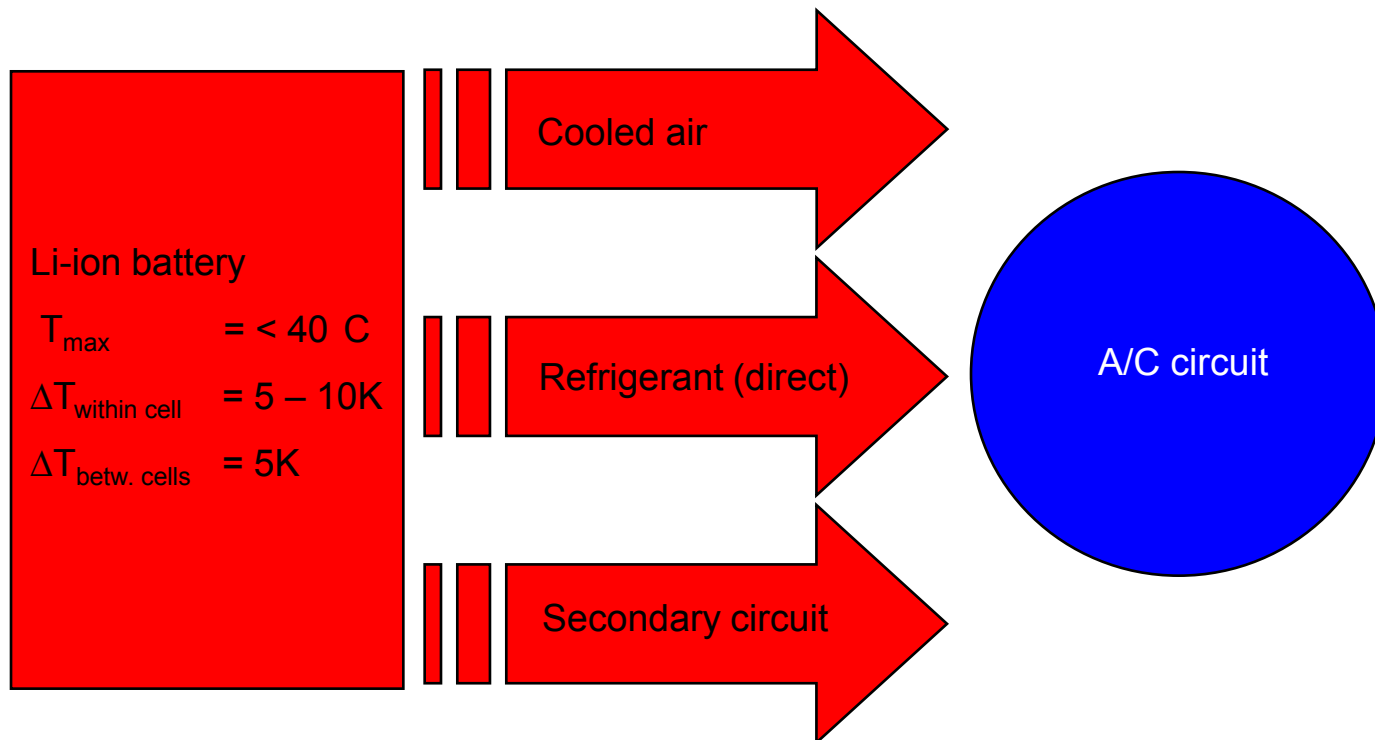
Dr. Thomas Heckenberger  
Director Technology and Methods Center



Heat up. Cool down.

**BEHR**

# Li-ion battery cooling



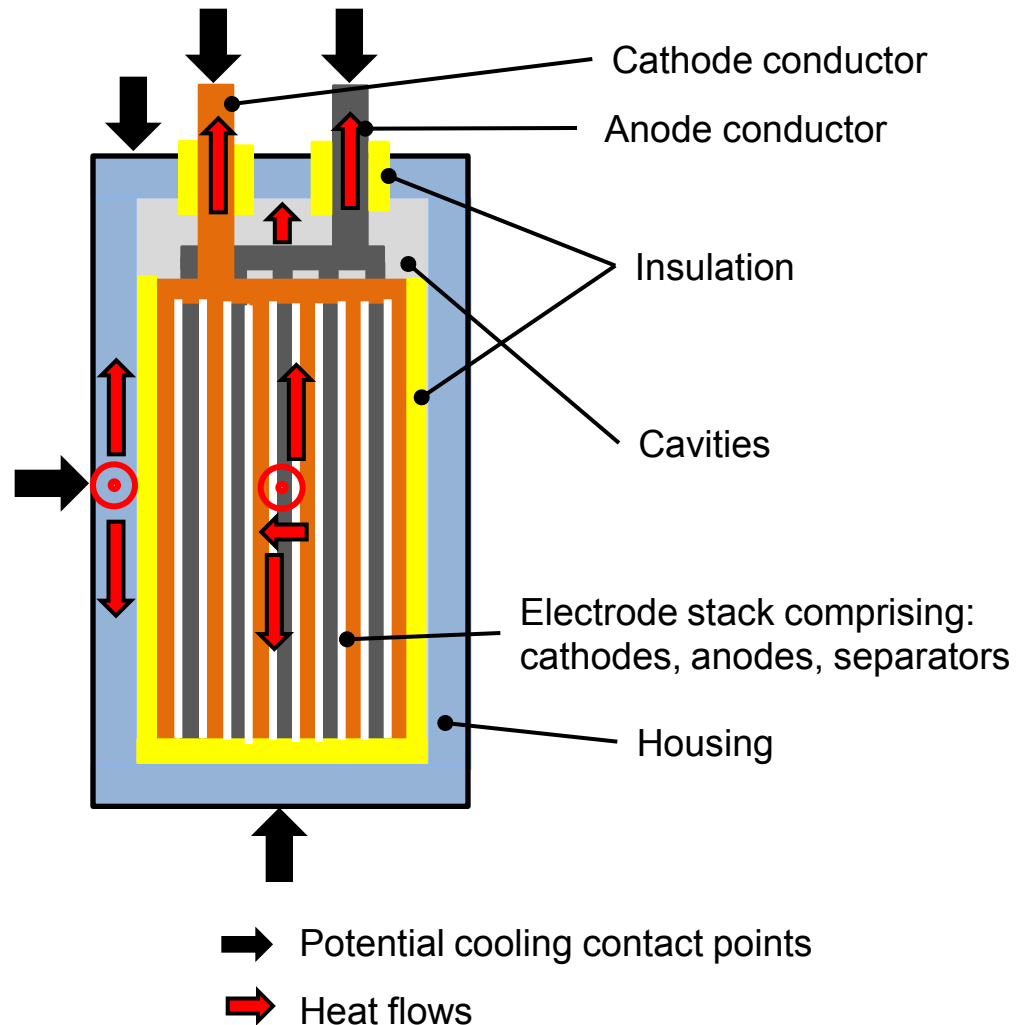
# Cell structure and cooling paths

## Good thermal conductivity:

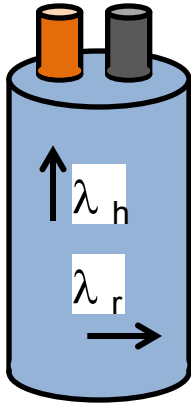
- Along electrodes
- In the conductors
- In the metallic housing

## Low thermal conductivity:

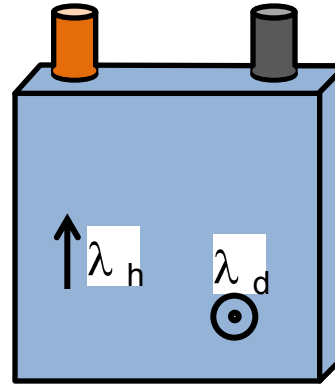
- Perpendicular to the electrodes
- In cavities



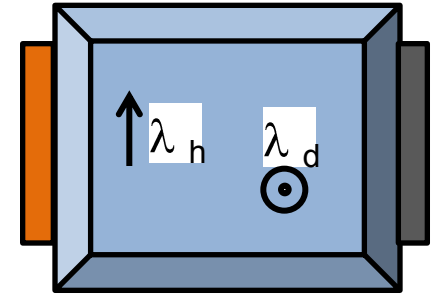
# Cell types



Cylindrical



Prismatic



Pouch ("coffee bag")

## Assessment with regard to cooling:



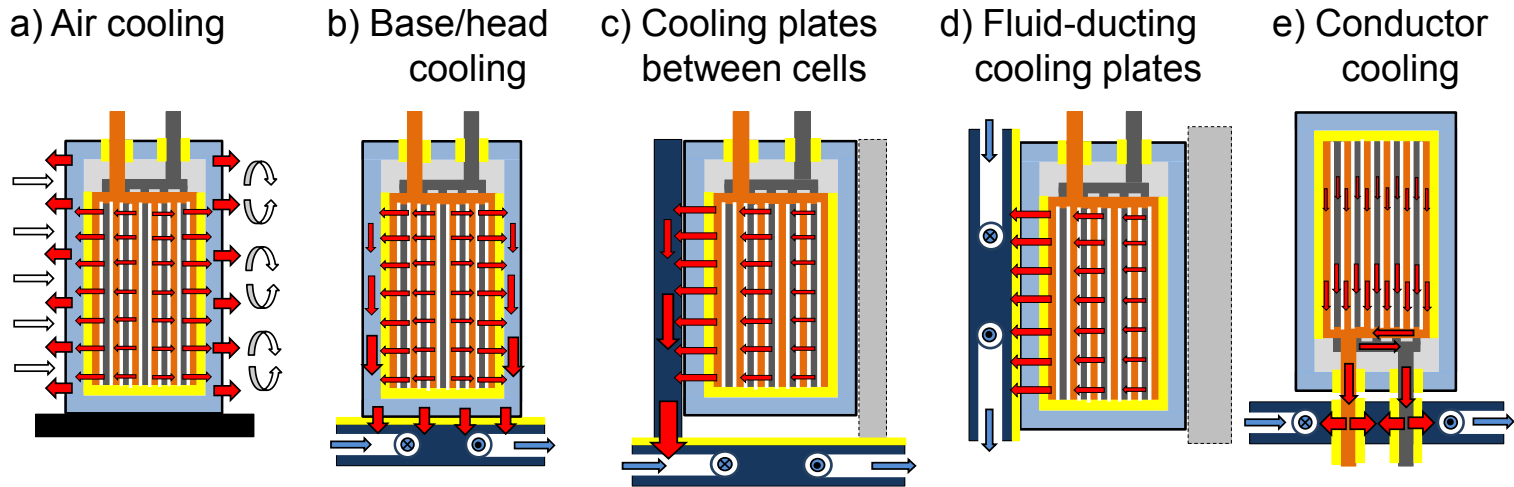
- Unfavorable surface/volume ratio
- Curved external surface unfavorable for contact with heat-conducting elements



- Aerodynamic when air-cooled
- Favorable surface/volume ratio
  - ➔ Level external surface favorable for contact with heat-conducting elements
- Pouch cells: efficient conductor cooling producible



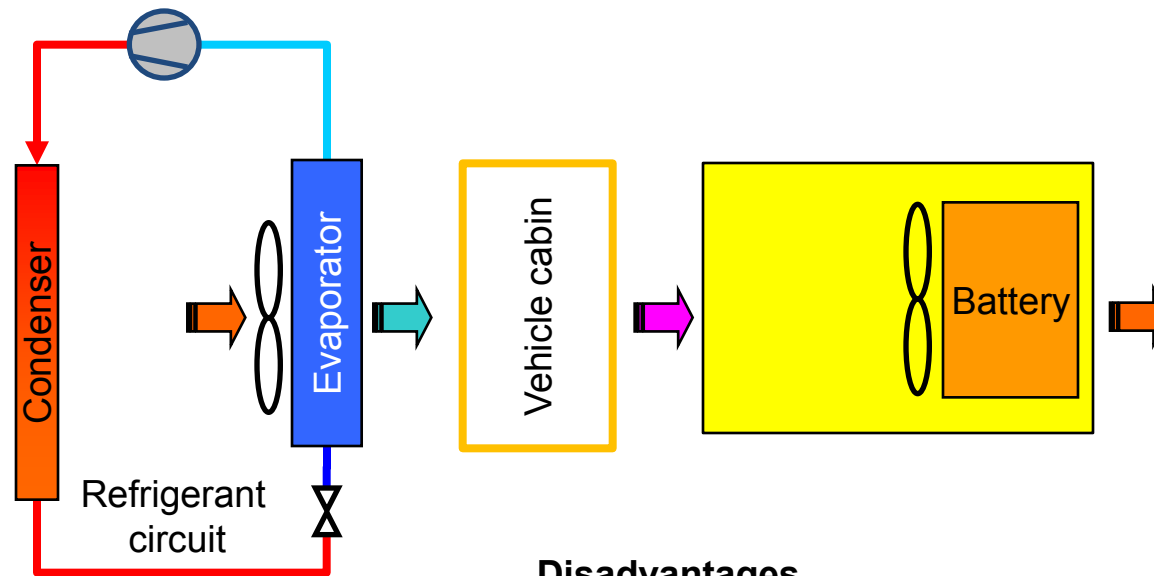
# Cooling concepts for cells



Cell assembly in battery	++	+	0	-	+
Cooling effectiveness	0	+	+	++	+
Package space required in battery	-	++	+	-	++

# Cooling systems for batteries

## Cabin air cooling



### Advantage

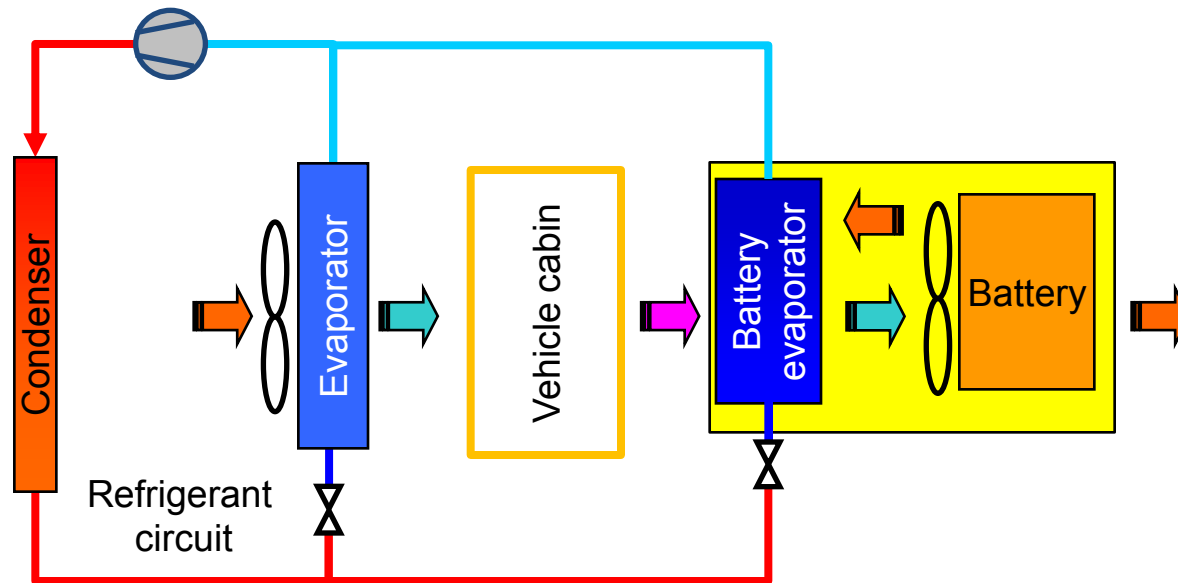
- Low complexity

### Disadvantages

- Package space requirement of entire system
- Dependence on vehicle cabin air temperature
- Low cooling performance
- Inhomogeneous temperature distribution within battery
- Risk of fouling
- Potential safety concerns

# Cooling systems for batteries

## Independent air cooling



### Advantages

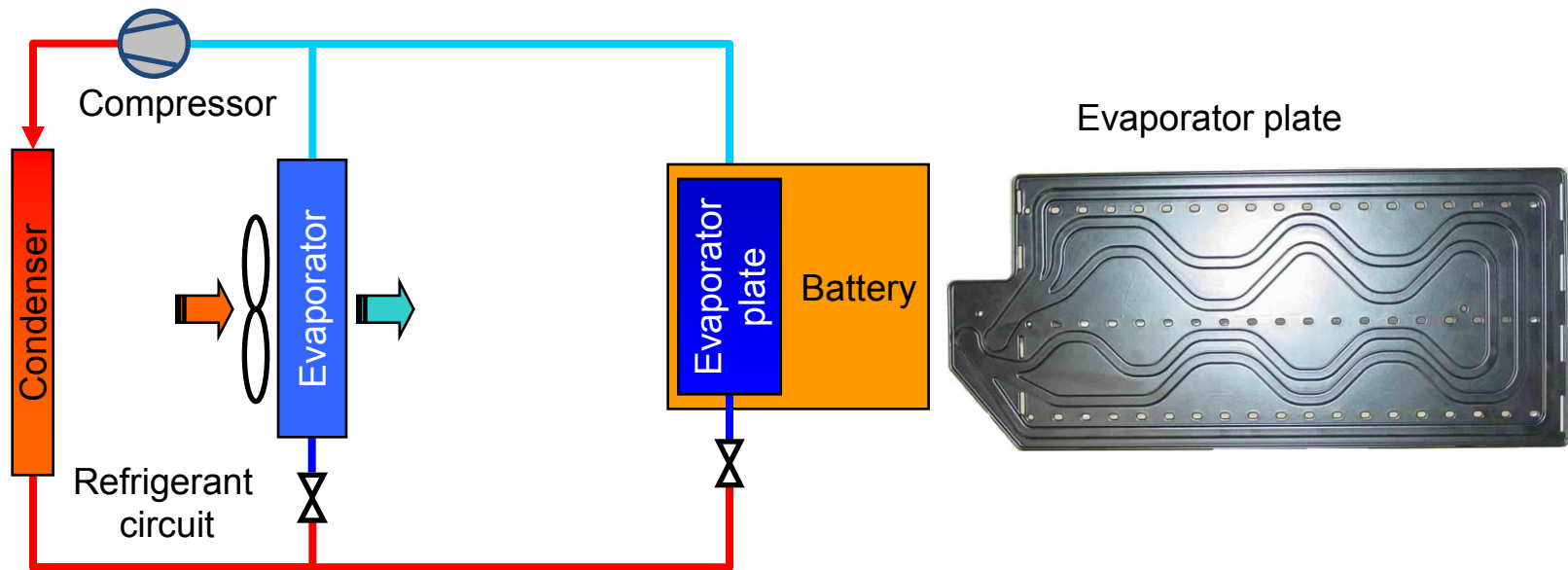
- Independent of vehicle cabin air temperature
- High cooling performance

### Disadvantages

- Package space requirement of entire system
- Inhomogeneous temperature distribution within battery
- Risk of fouling

# Cooling systems for batteries

## Direct refrigerant-based cooling



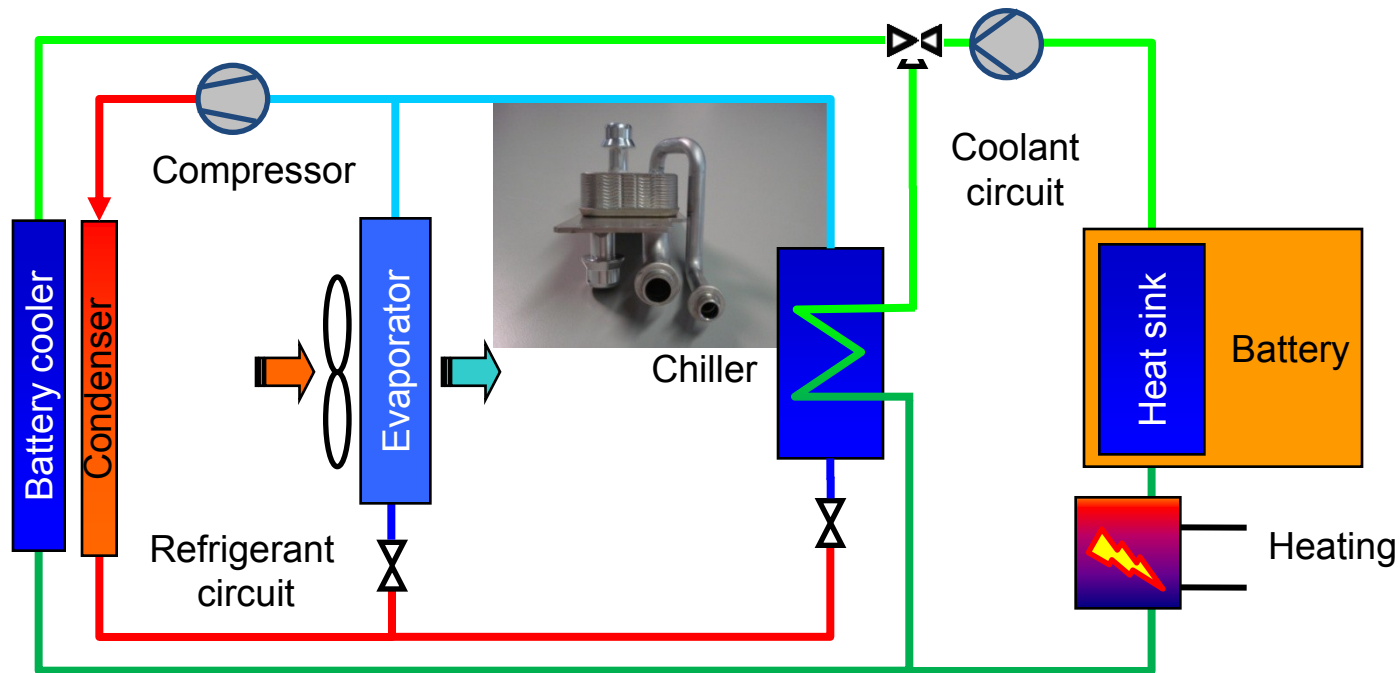
### Advantages

- Bauraum of entire system
- Homogeneous temperature distribution
- High cooling performance

### Disadvantages

- Battery cooling possible only when A/C circuit operating
- Heating cannot be integrated

# Secondary circuit with chiller and heat sink in battery



## Advantages

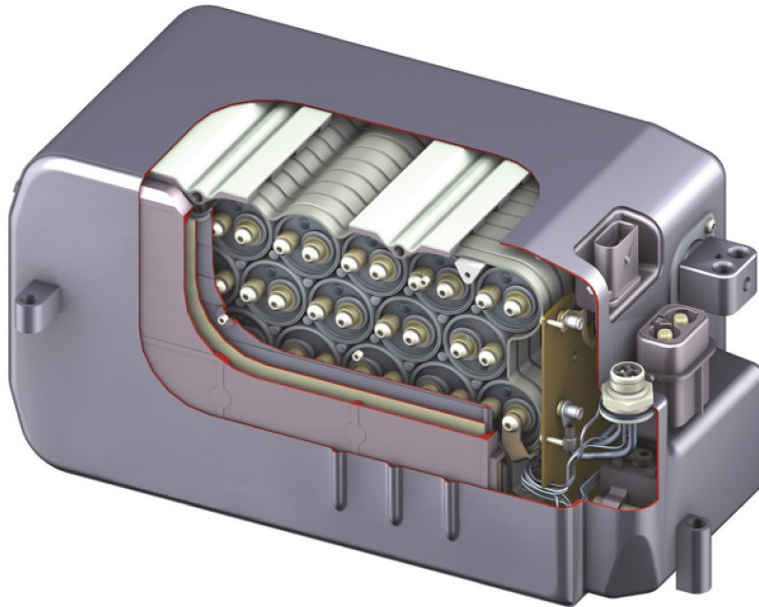
- Energy efficiency (annual average)
- Compact battery module
- High cooling performance
- Battery heating can be integrated

## Disadvantages

- Package space and weight of entire system
- Cost
- Inertia due to high thermal mass

## Current examples

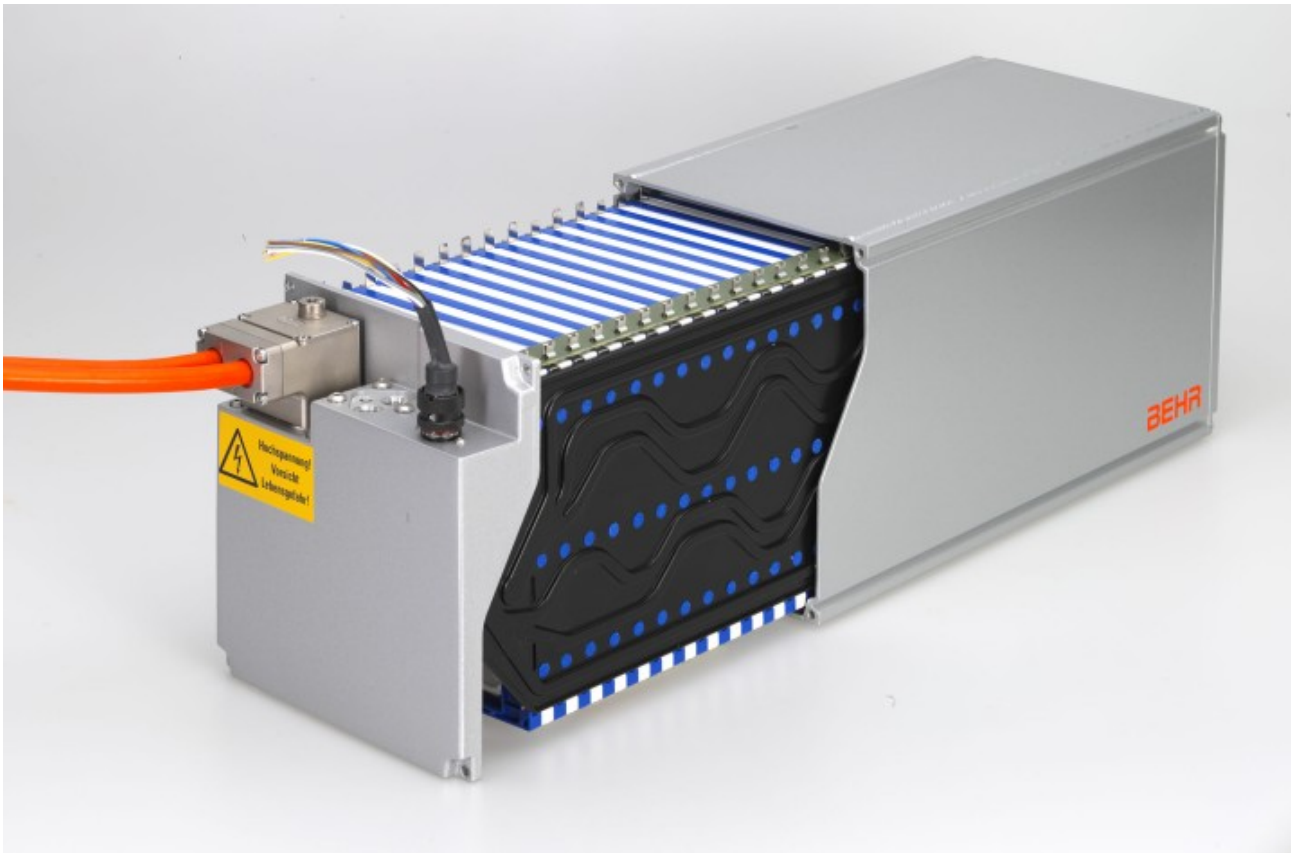
Direct refrigerant-based cooling in Mercedes S400 BlueHYBRID



First Li-ion battery to be cooled directly by refrigerant in series production 2009

# Current examples

Direct refrigerant or coolant-based cooling and conductor cooling

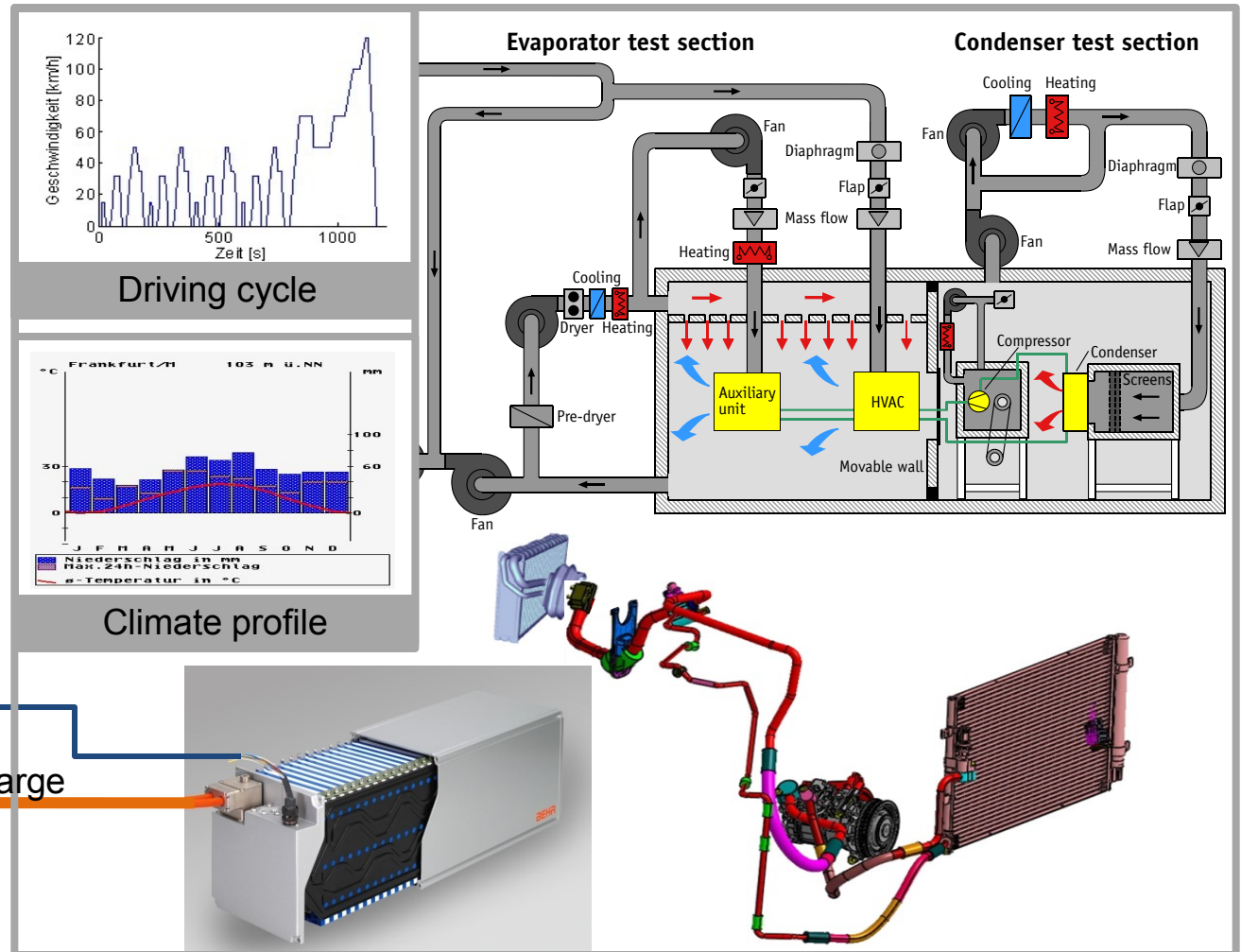


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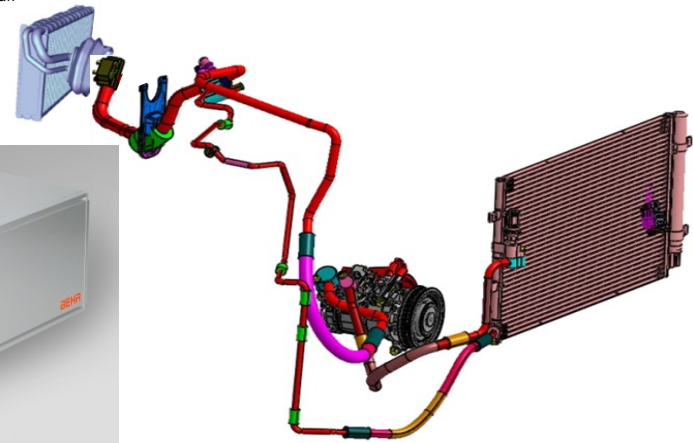
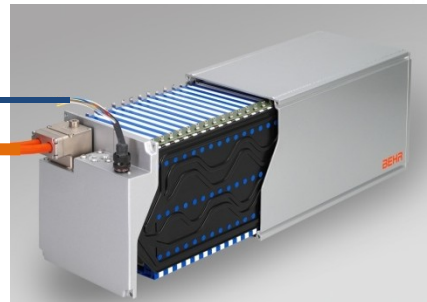
# HVAC/battery system test bench

Battery, A/C circuit/secondary circuit under real operating conditions

- Voltage:  $\leq 500 \text{ V}$
- Current:  $\leq 300 \text{ A}$
- Output:  $65 \text{ kW}$



CAN  
Charge/discharge



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# Summary

- The approach to Li-ion battery cooling depends on the cell type and application.
- Behr has over 4 years' experience in battery cooling and provides a tightly-knit development process from simulation through validation.
- The world's first direct refrigerant-based cooling system for Li-ion batteries will go into series production in the Mercedes S400 BlueHYBRID in 2009.
- Additional series production orders for battery cooling components have been received.
- Behr has successfully developed various battery cooling systems for mild and full hybrids, plug-in hybrids, and electric vehicles, and supplies the necessary associated components.
- Direct refrigerant-based cooling is the compact solution for mild and full hybrids.
- We favor secondary circuit cooling for plug-in hybrids and electric vehicles. This enables valuable electric energy for powering the refrigerant compressor to be saved when outside temperatures are low.