magneto caloric refrigeration for efficient electric air conditioning

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SEVENTH FRAMEWORK PROGRAMME

ICE Project: Magnetocaloric Refrigeration for Efficient Air Conditioning

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Cooltech Applications

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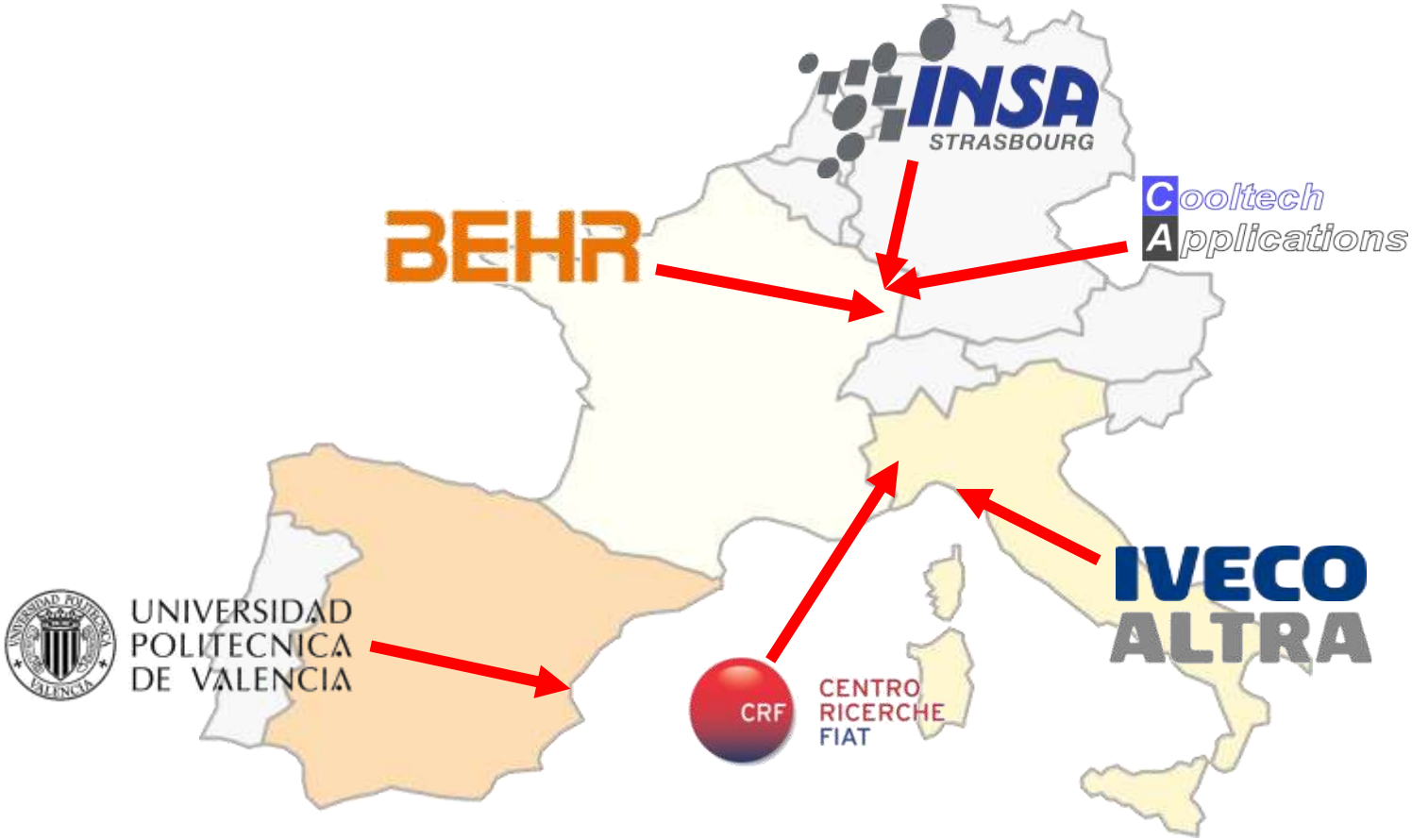
Cooltech Applications

IVECO ALTRA

INSA STRASBOURG

FIAT CRF CENTRO RICERCHE FIAT

The ICE Consortium



The ICE Consortium

Project full title:	**ICE – Magnetocaloric Refrigeration for Efficient Air Conditioning**
Starting date	1st December 2010
Ending date	30th April 2014
Budget total/funding	4’428’550 Euro/2’993’540 Euro
Type of project	Collaborative project

Centro Ricerche Fiat, Italy

Project coordinator
Control strategies
Exploitation

Cooltech Applications, France

Magnetocaloric heat pump design and realization
Exploitation

Behr, Germany (French division)

Heat exchangers development
Exploitation

Un. Politecnica de Valencia, Spain

Mathematical modeling
Dissemination

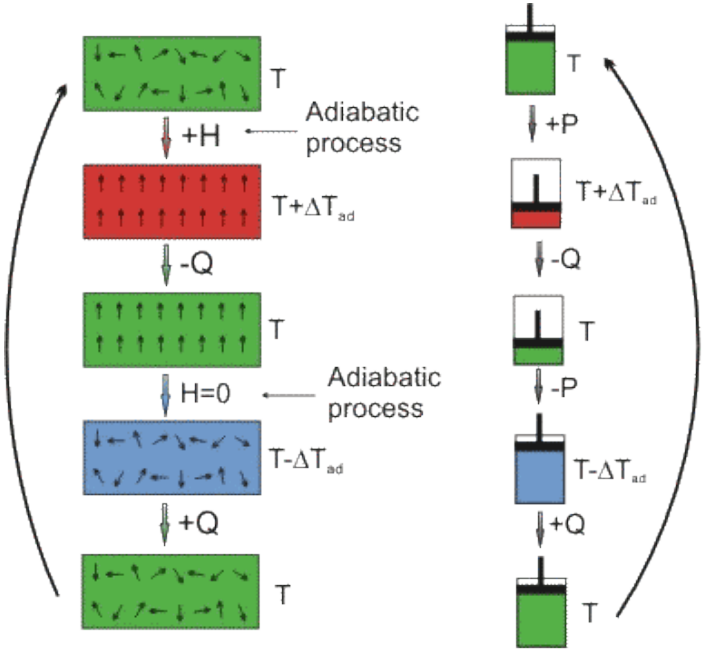
INSA Strasbourg, France

Magnetocaloric refrigeration concept development and basics

Iveco ALTRA, Italy

Vehicle integration
Exploitation

The Magnetic Refrigeration



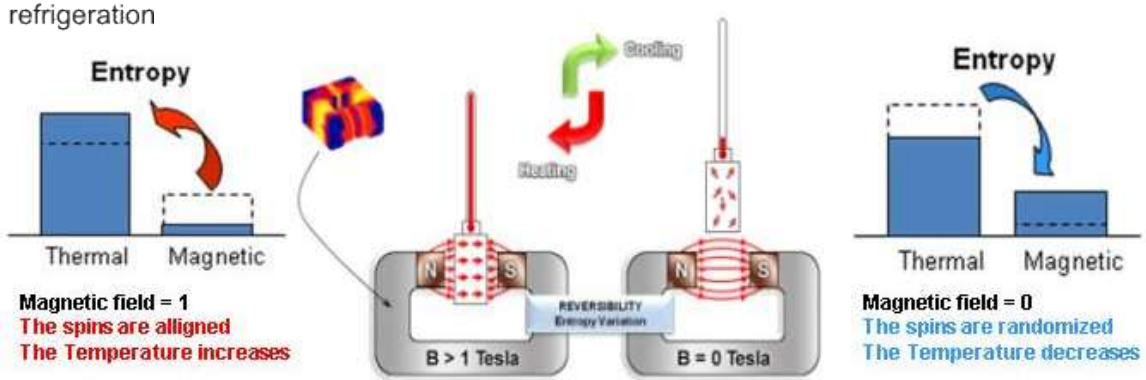
Magnetic refrigeration

Vapor cycle refrigeration

1881: observed in iron by Warburg
1926-1927: explained by Debye and Giauque

The Magnetocaloric Effect is an **intrinsic property of magnetic materials** which results in a **reversible variation of temperature** of the material when submitted to a magnetic field.

This phenomenon is maximal in the vicinity of the ordering temperature of the magnetic material (the Curie or the Néel temperature).



ICE Project: the goal

The proposal is the development of a industrial prototype level **magnetocaloric heat pump for automotive application**, realizing a really new generation system able to replace the vapor compression systems.

Heat Pump Unit main features:

COP: 5

Temperature span: 5 °C – 60 °C

Cooling power: 5 kW

Heating power: 6 kW

Compact packaging

Electrically driven

No refrigerant, no GHG problems

Low working pressure (< 2 bar)

IVECO Daily Electric

A complete air conditioning system will be realized, installed and validated on a IVECO Daily fully electric **minibus** (already commercialized)

ICE Project: main contents

Efficient automotive electrical compact heat pump

- COP > 5 in cooling mode
- based on magnetocaloric effect using high efficiency magnetic materials, smart design and specific microchannel heat exchangers.

Redesign of the vehicle thermal systems

- to distribute locally the thermal power
- to regulate the batteries and electronic temperature also in very hot climate

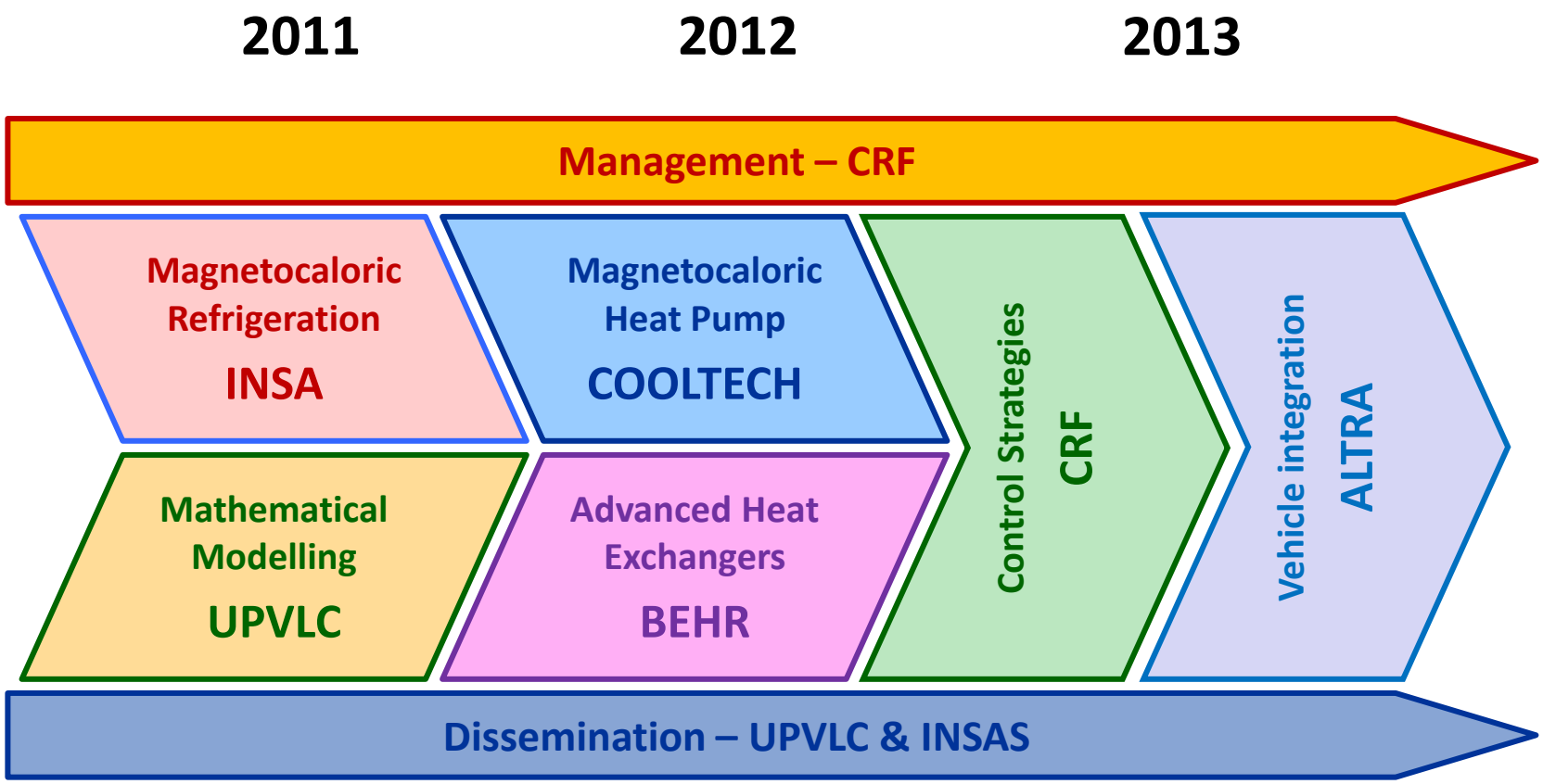
Microclimate control system based on thermal comfort

- to limit the thermal power generation only to the really required quantity
- to adapt the system to the occupants' number

Sustainable Cost thanks to

- the innovative technical solutions that will be adopted
- the thermal systems resize and their integration

Project Scheduling



System requirements – Summer

Maximum average power consumption: 1.5 kW (all included but the fan and blower**)**

Maximum peak power: < 10 kW for 10' (accumulated energy in the batteries max 80 kWh)

Reference ambient conditions: 35 ° C – 60% R.H. – no solar irradiation

Occupation (only for modelling and system sizing): driver + 7 passengers

Cabin Target: –10 ° C in respect to external temperature and R.H. < 50%

The driver area should be considered with priority

In case of minibus (e.g. shuttle) it is better to **avoid too large temperature gap** so to limit the passenger thermal stress guaranteeing **acceptable comfort conditions**. In case of extreme summer conditions the ventilation and the low R.H. will guarantee an acceptable comfort level not increasing too much the energy demand and the consequent negative impact on the vehicle range.

Cool down time – summer operation: 60' – not relevant performance

Assumption: When the vehicle is parked it is plugged ➔ the cool down time performance is not relevant.

System requirements – Winter

Maximum average power consumption: 1.5 kW (all included but the fan and blower)

Maximum peak power: < 10 kW for 10' (accumulated energy in the batteries max 80 kWh)

Reference ambient conditions: 0 ° C – no solar irradiation

Occupation (only for modelling and system sizing): driver + 7 passengers

Cabin Target:

Passenger :	**+10 ° C in respect to external temperature**
Driver:	**+20 ° C in respect to external temperature**

In case of minibus (e.g. shuttle) it is better to **avoid too large temperature gap** so to limit the passenger thermal stress guaranteeing **acceptable comfort conditions** without limiting too much the vehicle range.

Dehumidification is not relevant.

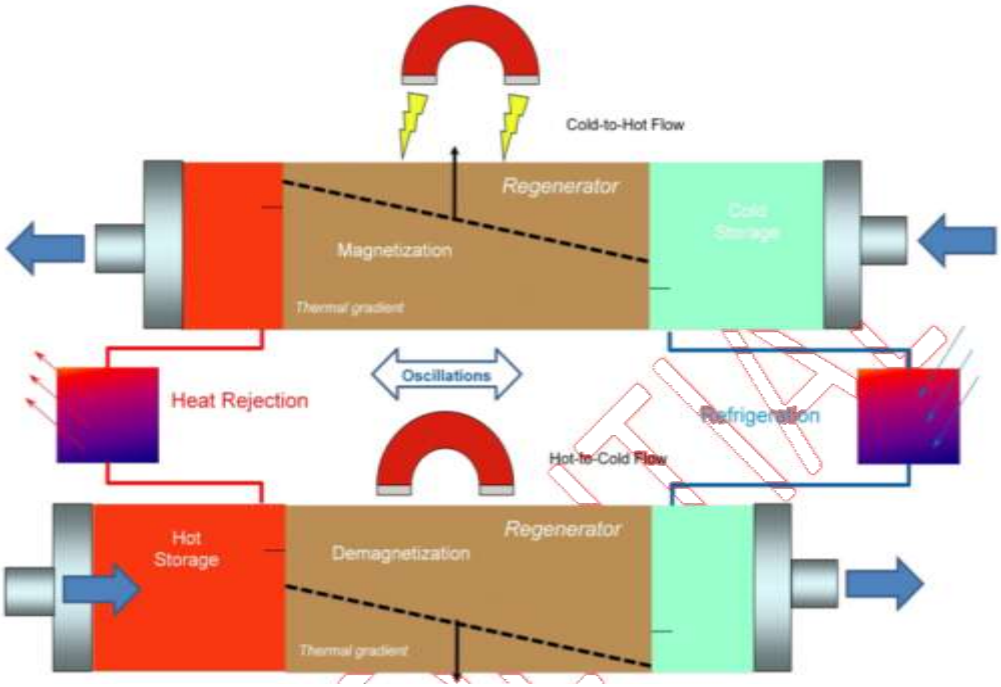
Warm up time: 60' even if it not a relevant performance

Assumption: When the vehicle is parked it is plugged ➔ the warm up time performance is not relevant.

Defogging and Deicing: an electrified windshield can be adopted

The magnetocaloric unit: how it works

A **magneto caloric pump** is based on active magnetic regenerative (**AMR**) cycle, used to adapt the basic cycle of the material to the required temperature difference imposed by the sink and source temperatures on a vehicle which are much larger (10 to 30 K).



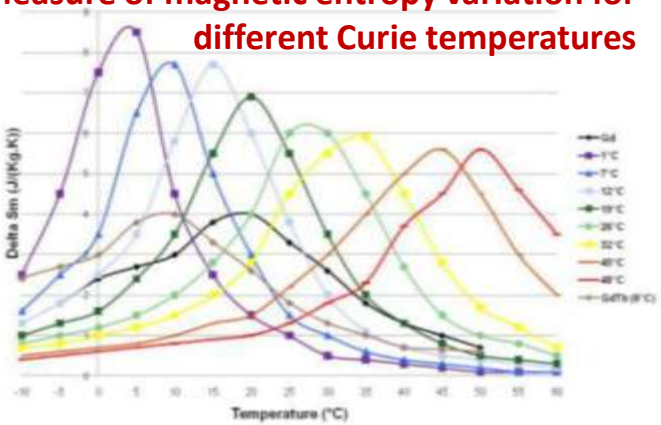
The AMR cycle consists in 4 phases:

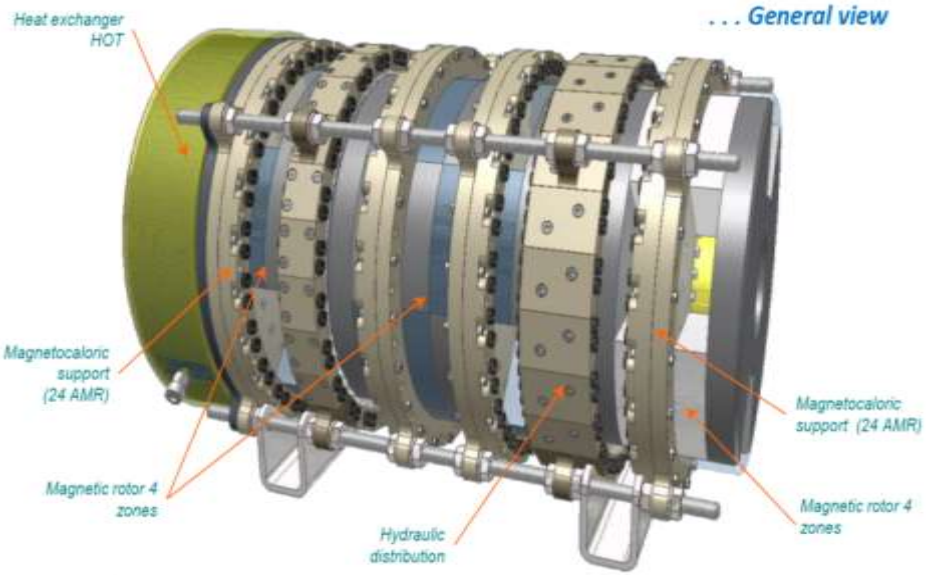
1. **Magnetization:** the active material is forced to pass through a high magnetic field and **warms up** due to its magneto caloric effect (MCE)
2. **Material cooling:** the fluid is pushed through the regenerator from the cold to the hot side, warming up and cooling down the active material
3. **Demagnetization:** the active material exits the magnetic field and **cools down** because of the MCE
4. **Material heating:** the fluid is pushed through the regenerator from the hot to the cold side, cooling down and warming up the active material.

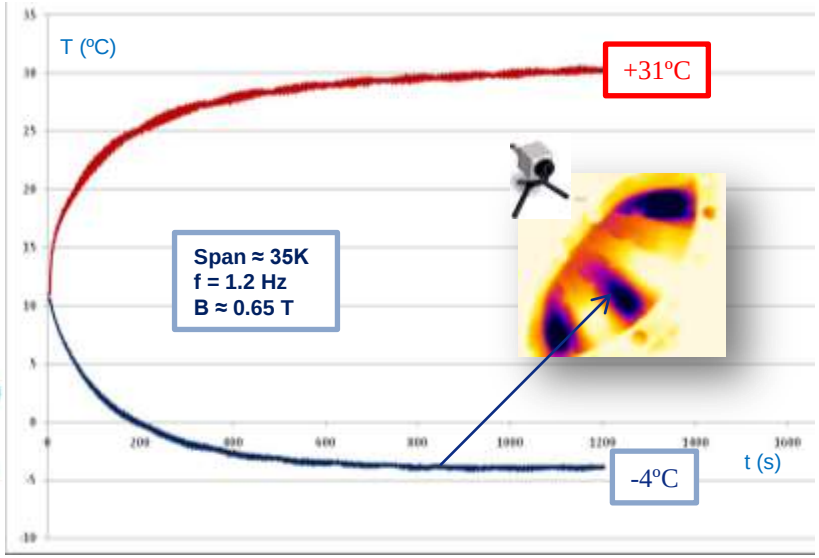
The magnetocaloric heat pump

To increase the temperature span between hot and cold ends, a multistage prototype has been designed and a proper sequence of magnetocaloric material has been selected.

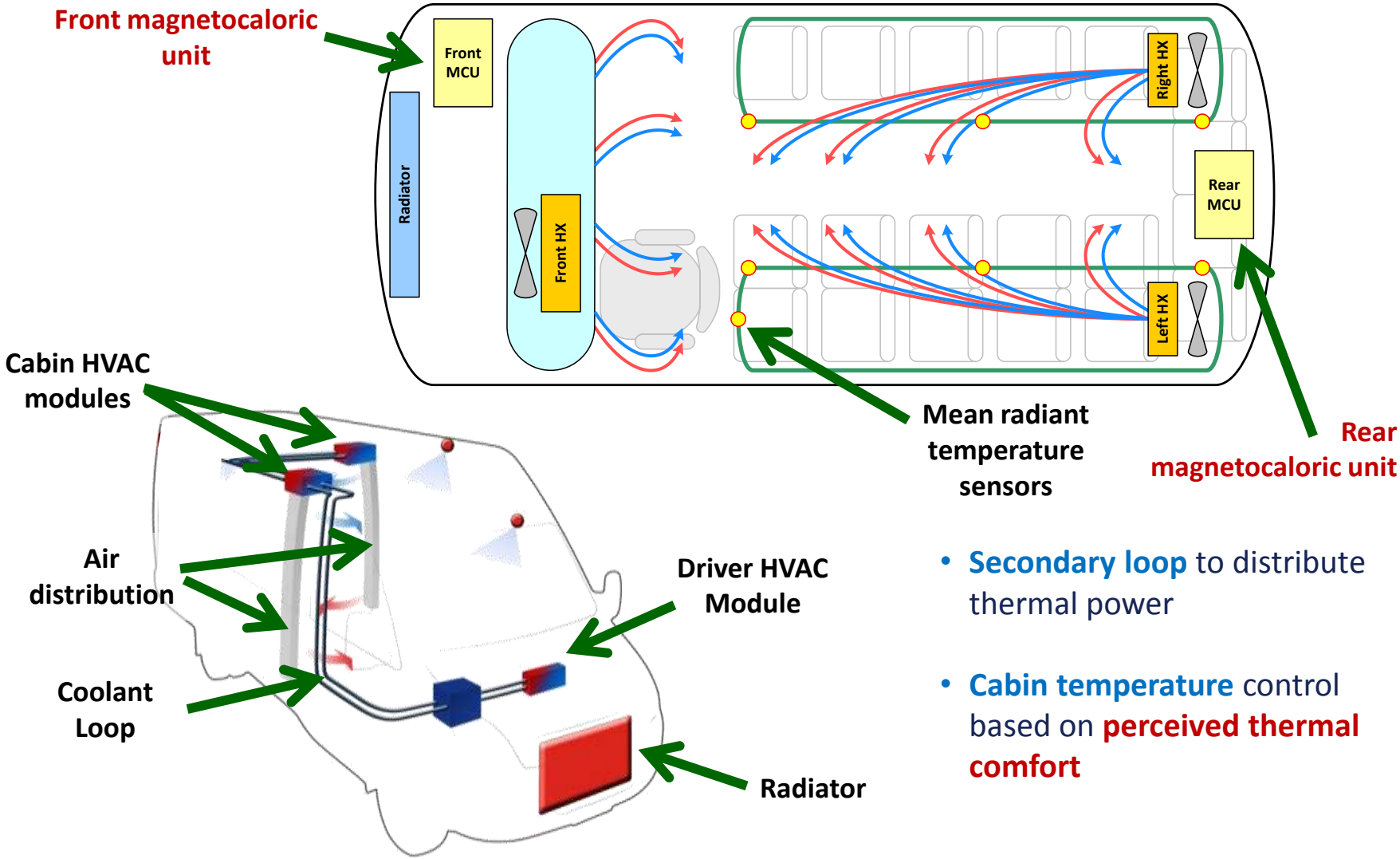
Measure of magnetic entropy variation for different Curie temperatures





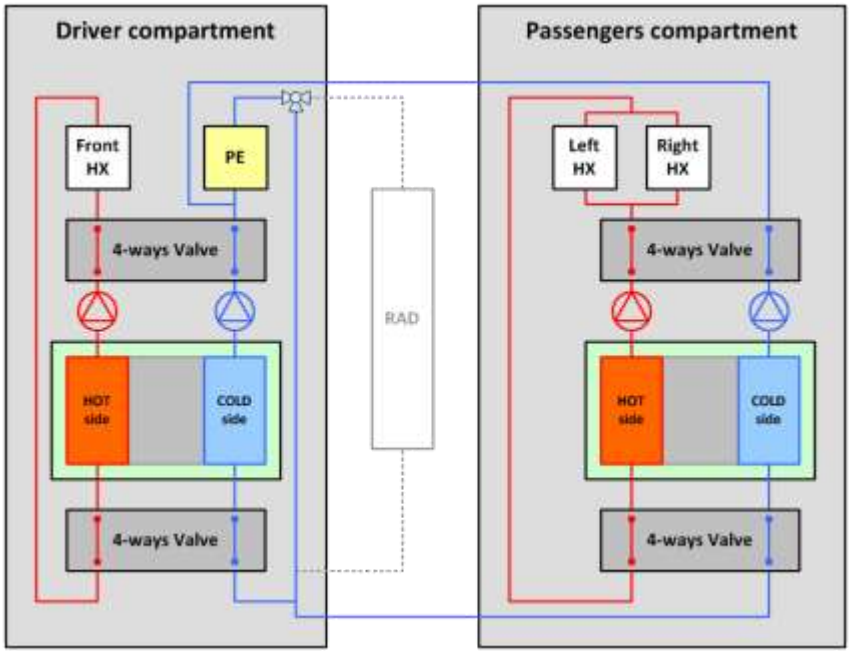


Thermal power distribution system outline



- **Secondary loop** to distribute thermal power
- **Cabin temperature** control based on **perceived thermal comfort**

Summer vs Winter operation

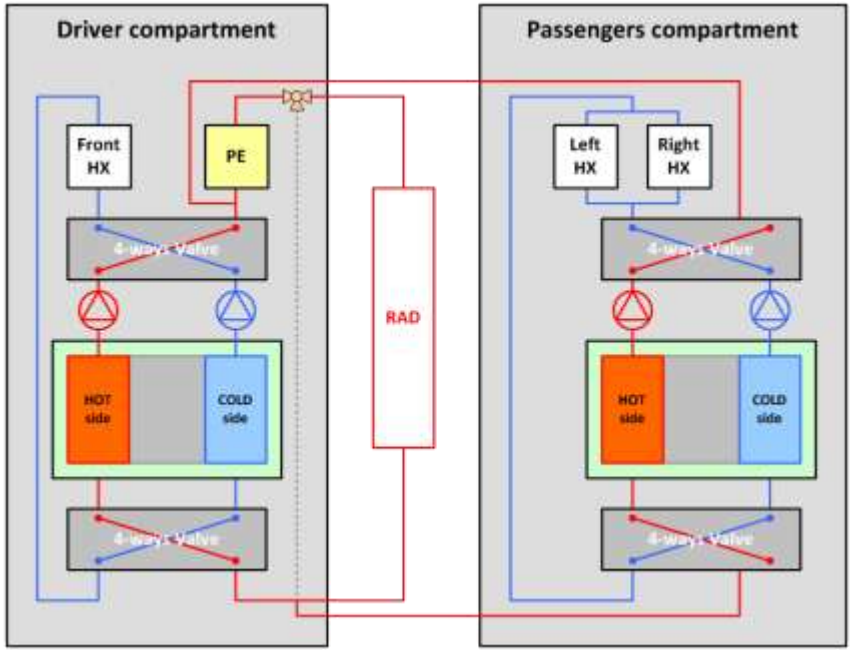


Summer mode

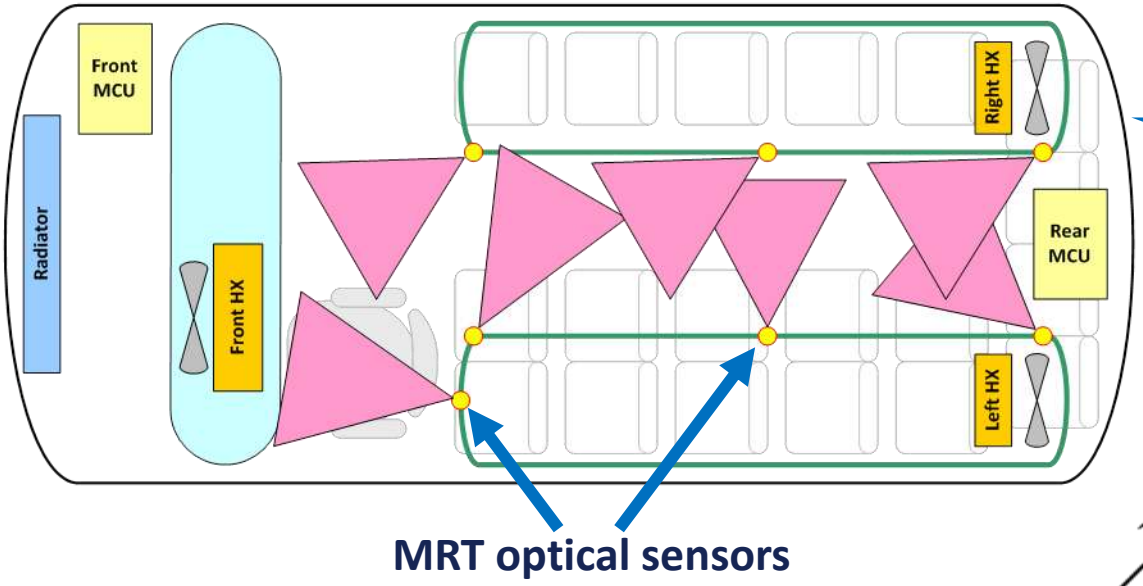
Cold side of the MCU is connected to the cabin heat exchangers. *Power electronics* is cooled thanks to the hot MCU end.

Winter mode

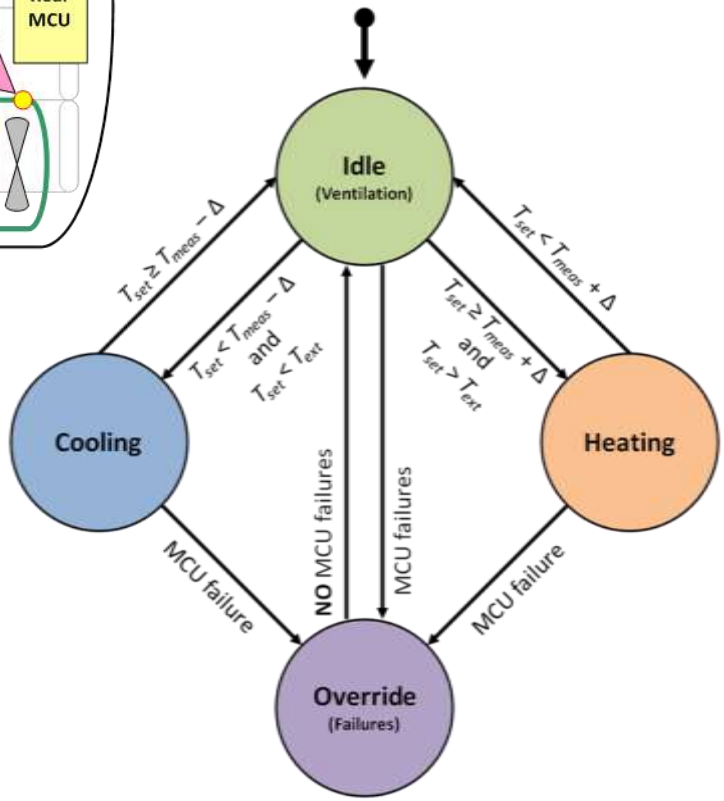
Hot side of the MCU is connected to the cabin heat exchangers. ***Power electronics*** is cooled thanks to the cold MCU end.



Cabin temperature control system



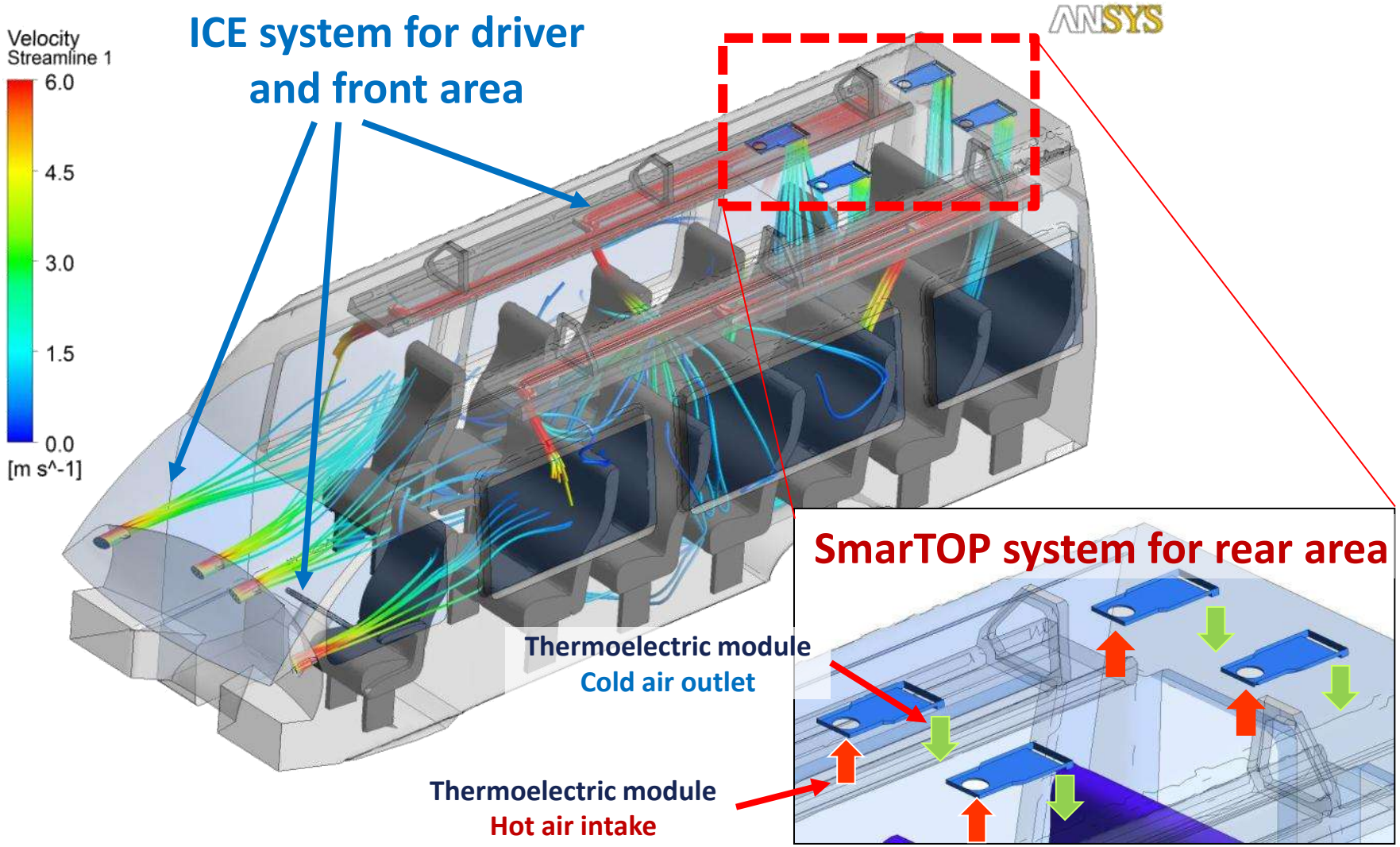
State machine controlling the system operation



The cabin temperature control is based on **mean radiant temperature** (MRT) measurement, to guarantee thermal comfort.

Strategy and operation thresholds are defined after the **overall vehicle mathematical model**

ICE and SmarTOP integration



Other Features

Weight of ICE system: **+20 kg max (ref. standard electric heat pump)**

Expected lifetime (in operation): **15,000 hours (approx. 300,000 km)**

Noise level: **≤ standard system**

Cost estimation (for 1000 pcs/year):

	Magnetocaloric	Vapor Compression
Heat pump unit	2.0 k€	1.5 to 2.5 k€ (*)
HVAC system	2.5 k€	3.0 k€
Electronics & Sensors	500 €	500 €

The ICE target cost have to be intended after having completed the industrial development, the initial production phase and a final system optimization.

(*) depending on size and component quality

THANK YOU!

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