CLIMA 2022
REHVA 14th HVAC World Congress
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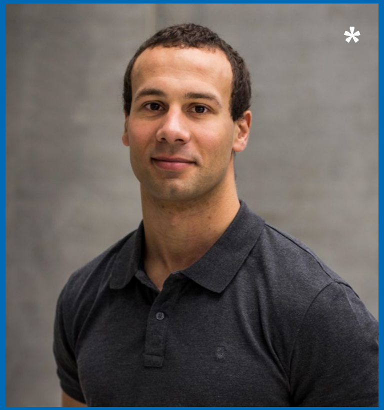
AALBORG UNIVERSITY
DENMARK

Innovative Heating and Cooling Systems Based on Caloric Effects
A Review



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Motivations

To save the world !... we need to:

- Increase efficiency of heating and cooling systems for building space conditioning and production of domestic hot water.
- Improve sustainability of heat pump systems.
- Improve cost effectiveness of heat pumps.

Motivations

Heat pumps are great at providing heating and cooling to buildings.

Large continuous increase of heat pump market.

Vapour-compression systems dominate the market.

But certain challenges with current liquid/gas refrigerants:

- F-gas
- Flammability
- Explosivity
- Toxicity
- Greenhouse gas effect

Innovative heating and cooling systems

Innovative non-vapour compression heat pump systems for building applications are being developed.

Some are very promising:

- Very high COP (coefficient of performance)
- Miniaturization
- Silent operation
- No liquid/gas refrigerant issues

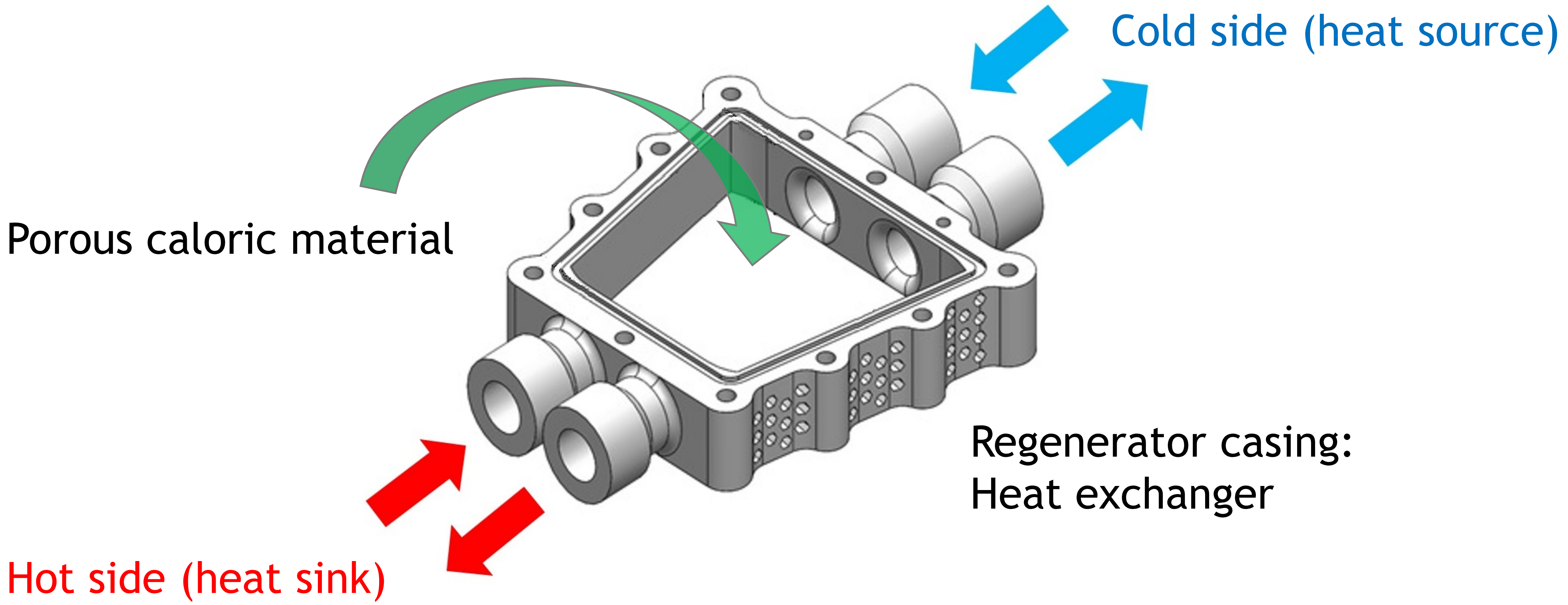
The caloric effects

Caloric effects: Large adiabatic temperature change in certain materials when a specific external field is applied or removed.

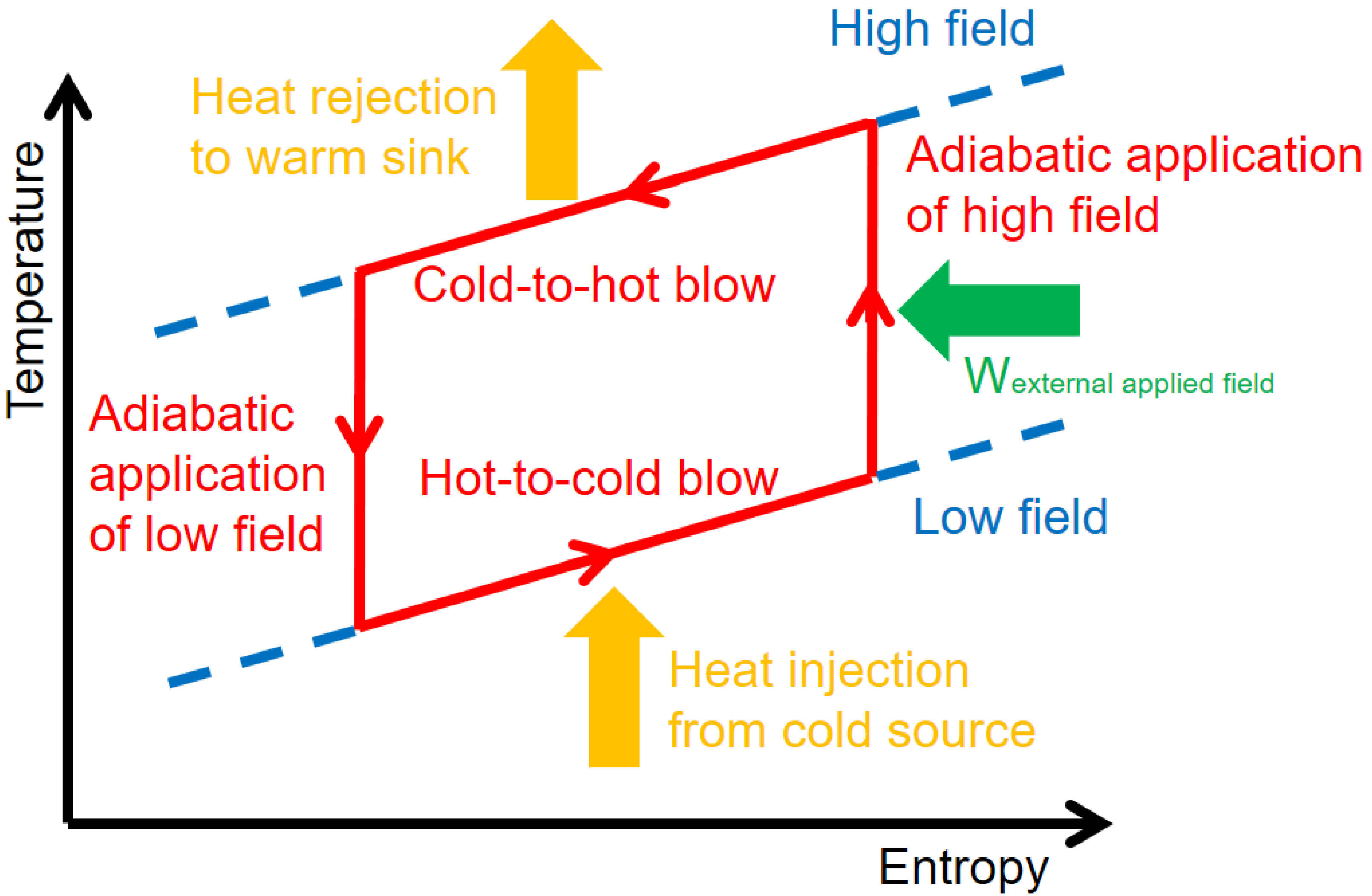
4 main caloric effects:

- Electrocaloric effect: variation of electrical field (polarization)
- Barocaloric effect: variation of hydrostatic pressure (compression)
- Elastocaloric effect: variation of uniaxial mechanical stress (stretching)
- Magnetocaloric effect: variation of magnetic field (magnetization)

Innovative heating and cooling systems based on caloric effects



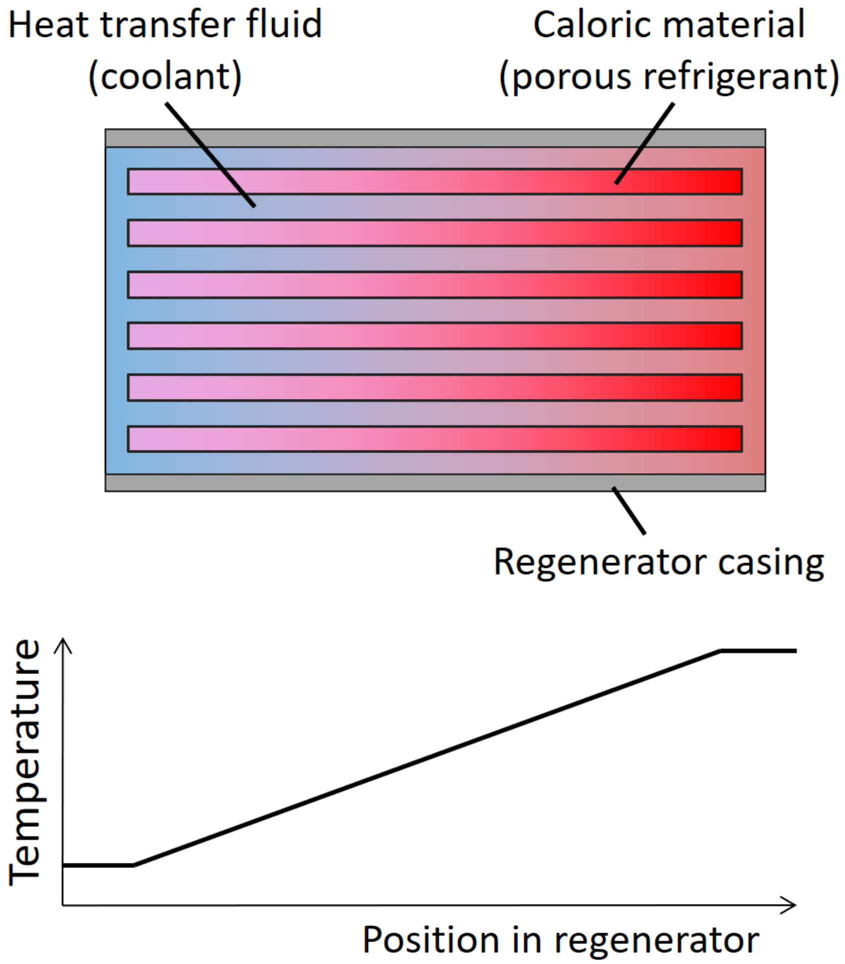
Innovative heating and cooling systems based on caloric effects



Bi-directional fluid flow and adiabatic temperature change (caloric effect):

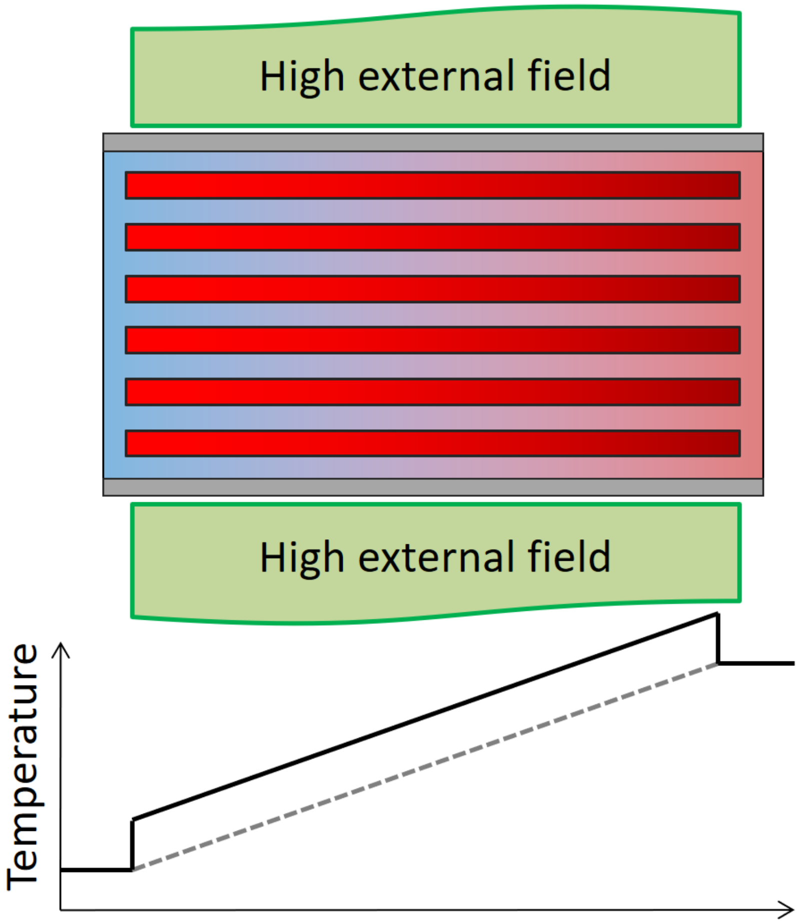
The caloric Brayton cycle:
An active caloric regenerative cycle for heat pumps.

Innovative heating and cooling systems based on caloric effects



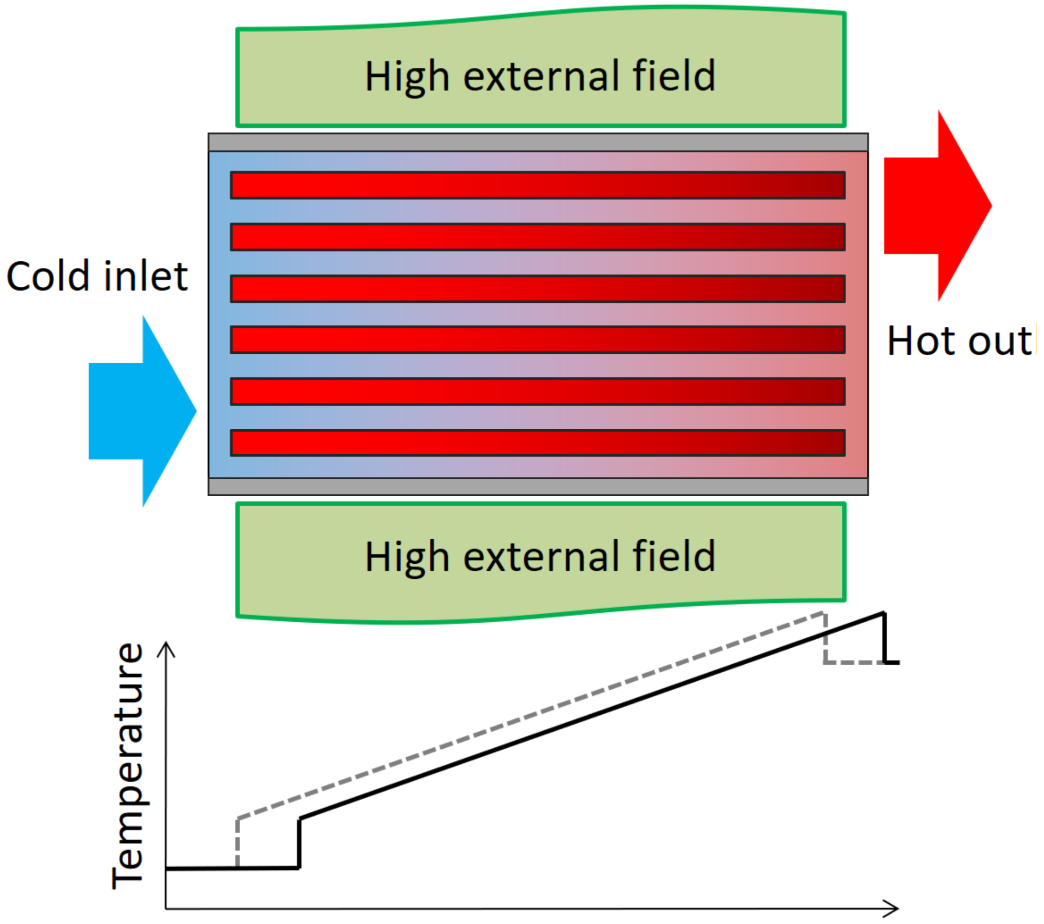
Initial state with temperature gradient

Innovative heating and cooling systems based on caloric effects



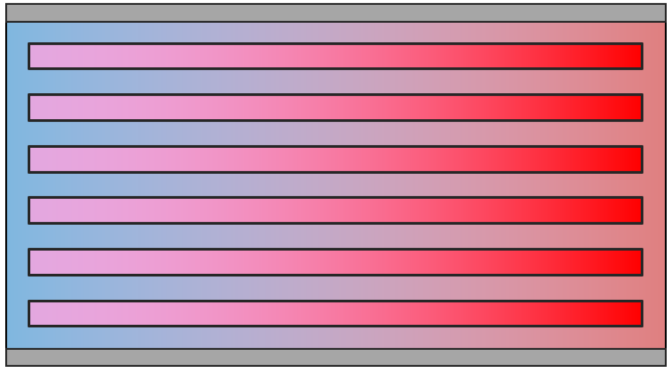
Application of high external field

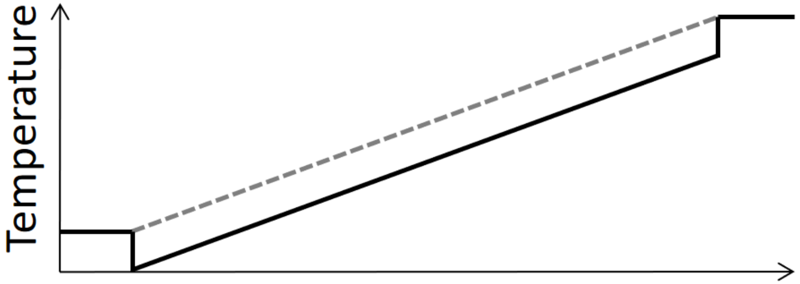
Innovative heating and cooling systems based on caloric effects



Cold-to-hot blow

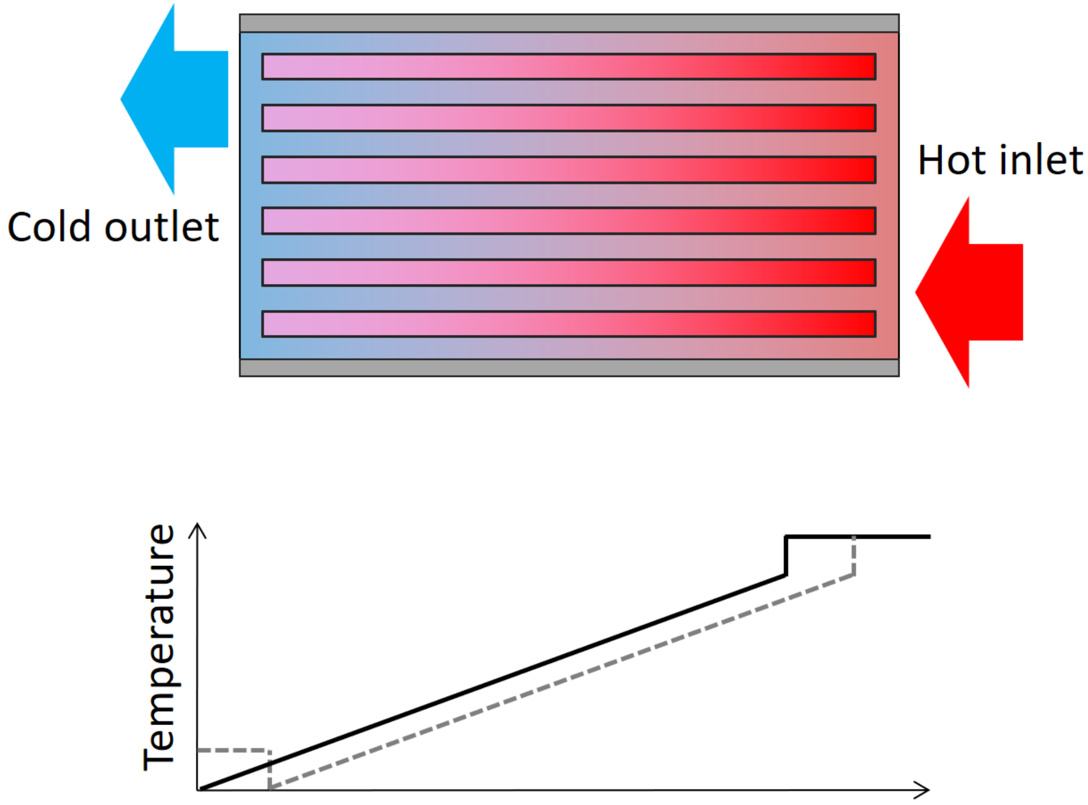
Innovative heating and cooling systems based on caloric effects





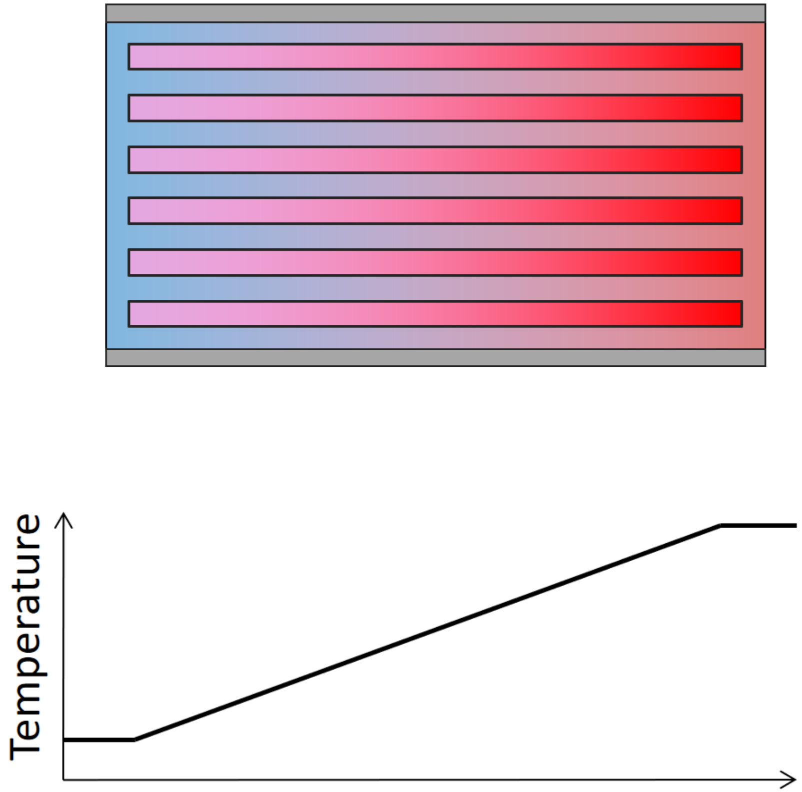
Application of low external field

Innovative heating and cooling systems based on caloric effects



Hot-to-cold blow

Innovative heating and cooling systems based on caloric effects



Back to initial state

Innovative heating and cooling systems based on caloric effects

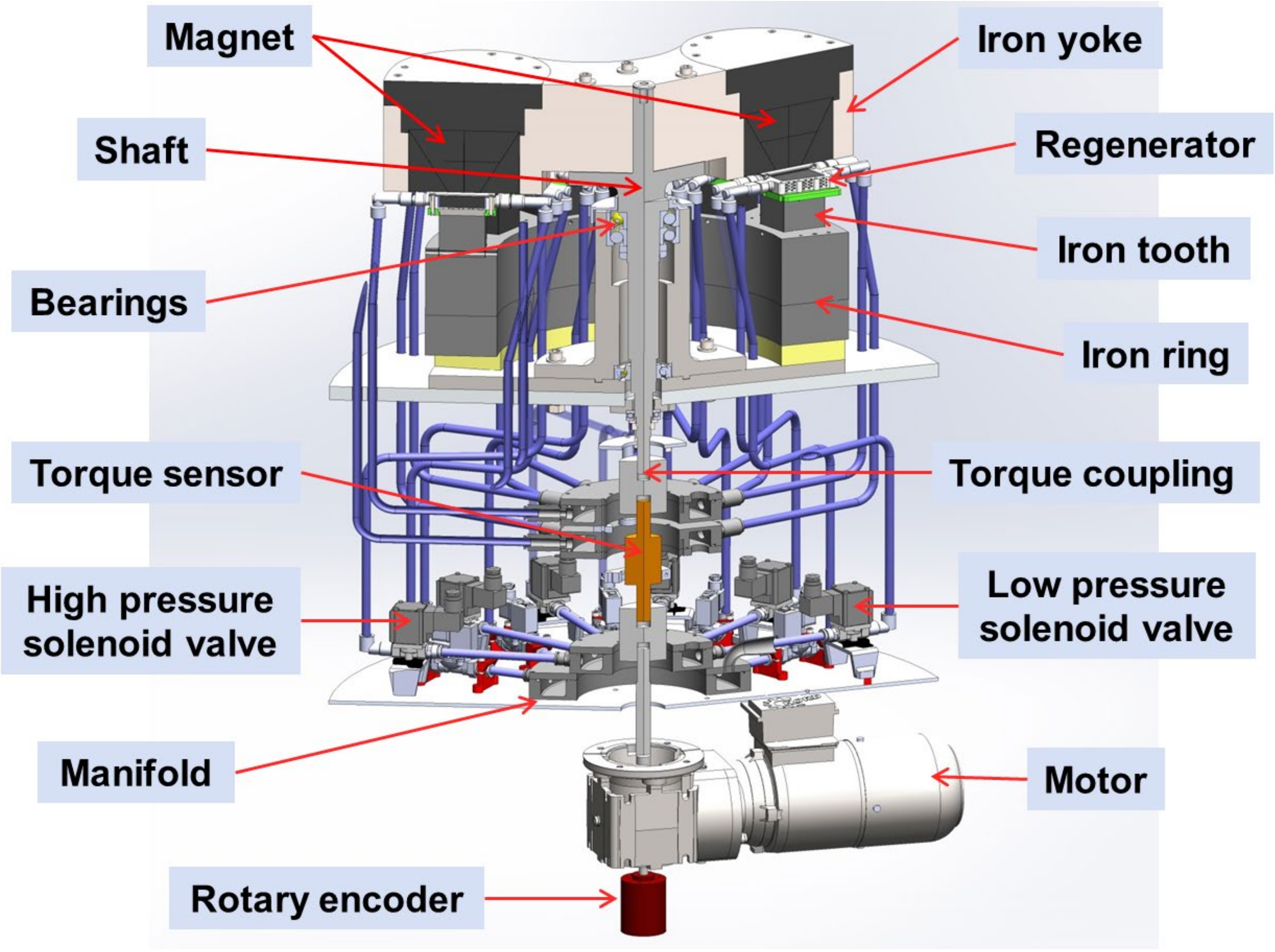
- Caloric effect-based systems are relatively new technologies.
- Only a limited number of research groups are working on this topic.
- Caloric effect-based heat pump technology does not have the same degree of maturity as conventional vapour-compression systems.
- Reversible nature of caloric effects allows for very high theoretical COPs.
- Potential for quiet and low vibration level operation, miniaturization, part-load control, no use of harmful or greenhouse effect refrigerant.

Magnetocaloric heat pumps

- The magnetocaloric effect was the first caloric effect to be observed.
- Most mature of the caloric technologies.
- Recently gained a lot of popularity.
- 100 prototypes built and tested in the last 30 years.

Magnetocaloric heat pumps

Current best prototypes are rotary systems with a permanent magnet assembly rotor and a fixed regenerator.



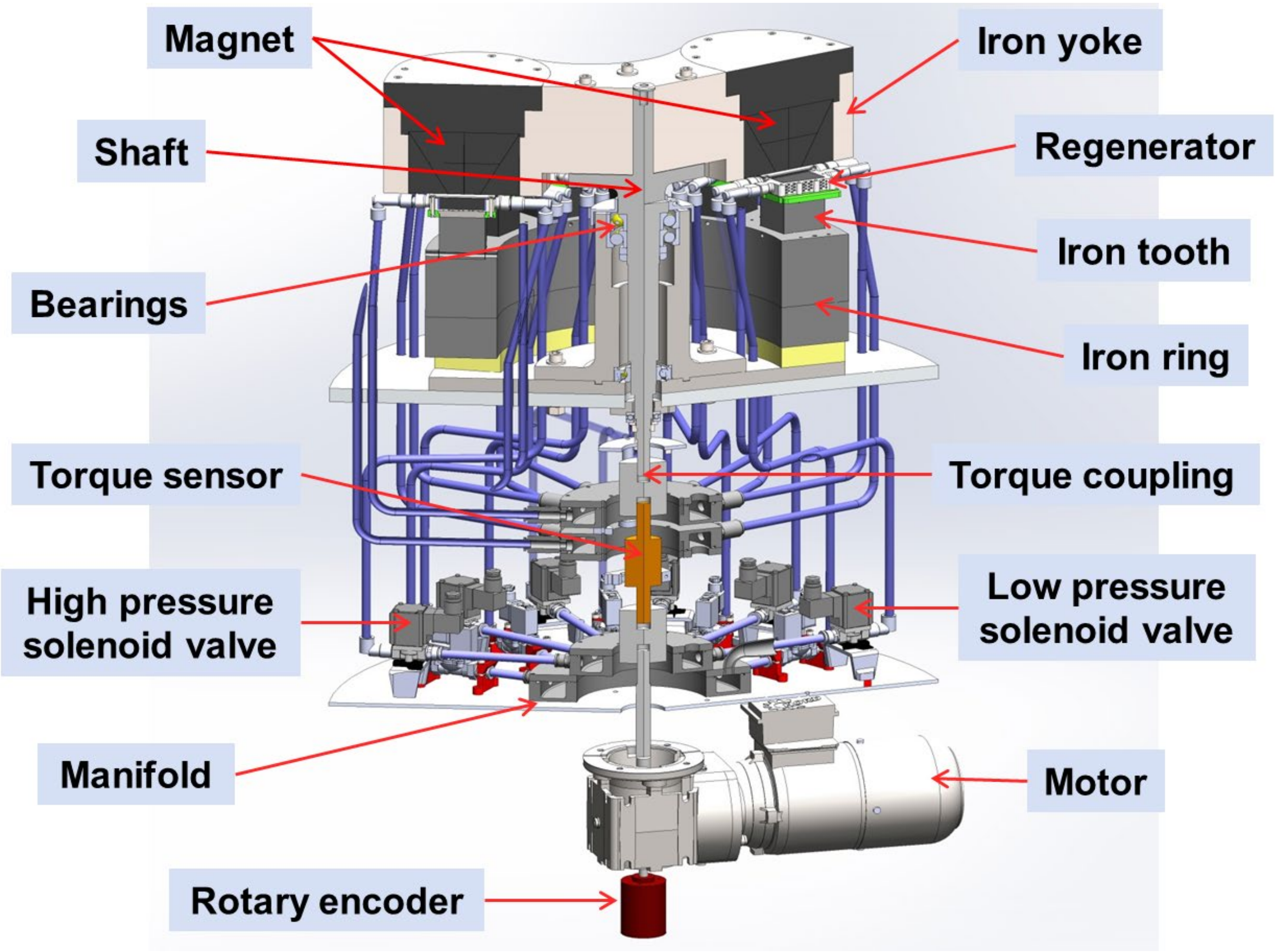
Magnetocaloric heat pumps

2021:

- 340 W - 10.3 K temperature span - COP of 6.7
- 950 W - 5.6 K temperature span - COP of 7

2022:

- 265 W - 14.8 K temperature span - COP of 3.97
- 445 W - 7.3 K temperature span - COP of 15.9



Elastocaloric heat pumps

- Elastocaloric systems are more recent technology.
- Elastocaloric systems are recently gaining a lot of attention.
- They are considered to be the most promising alternative to vapour-compression heat pumps.
- Use of metallic superelastic shape-memory alloys without rare earth materials.

Elastocaloric heat pumps

- Very new technology: first prototype presented in 2012.
- Good potential for miniaturized cooling systems.
- 2018: direct active heat recovery system for ventilation:
  - 250 W
  - 10 K temperature span
  - COP of 9.5

Electrocaloric heat pumps

- Very new technology: still at the proof of concept stage.
- 20 small-scale prototypes have been built.
- Currently, very small cooling power at temperature span below 10 K.
- Possibility to create miniaturized cooling systems without moving parts.
- 2017: miniature electrocaloric cooling:
  - 0.64 W – 1.4 K temperature span – COP of 13
- 2020: miniature cascaded electrocaloric cooling:
  - 0.8 W – 2.7 K temperature span – COP of 9

Barocaloric heat pumps

- Embryonic stage technology.
- No functional barocaloric heat pump prototype at the moment.
- Barocaloric effect is observed in many materials.
- But practical applicability has yet to be proven.
- Potential for multicaloric systems: coupling barocaloric effect with other caloric effets.

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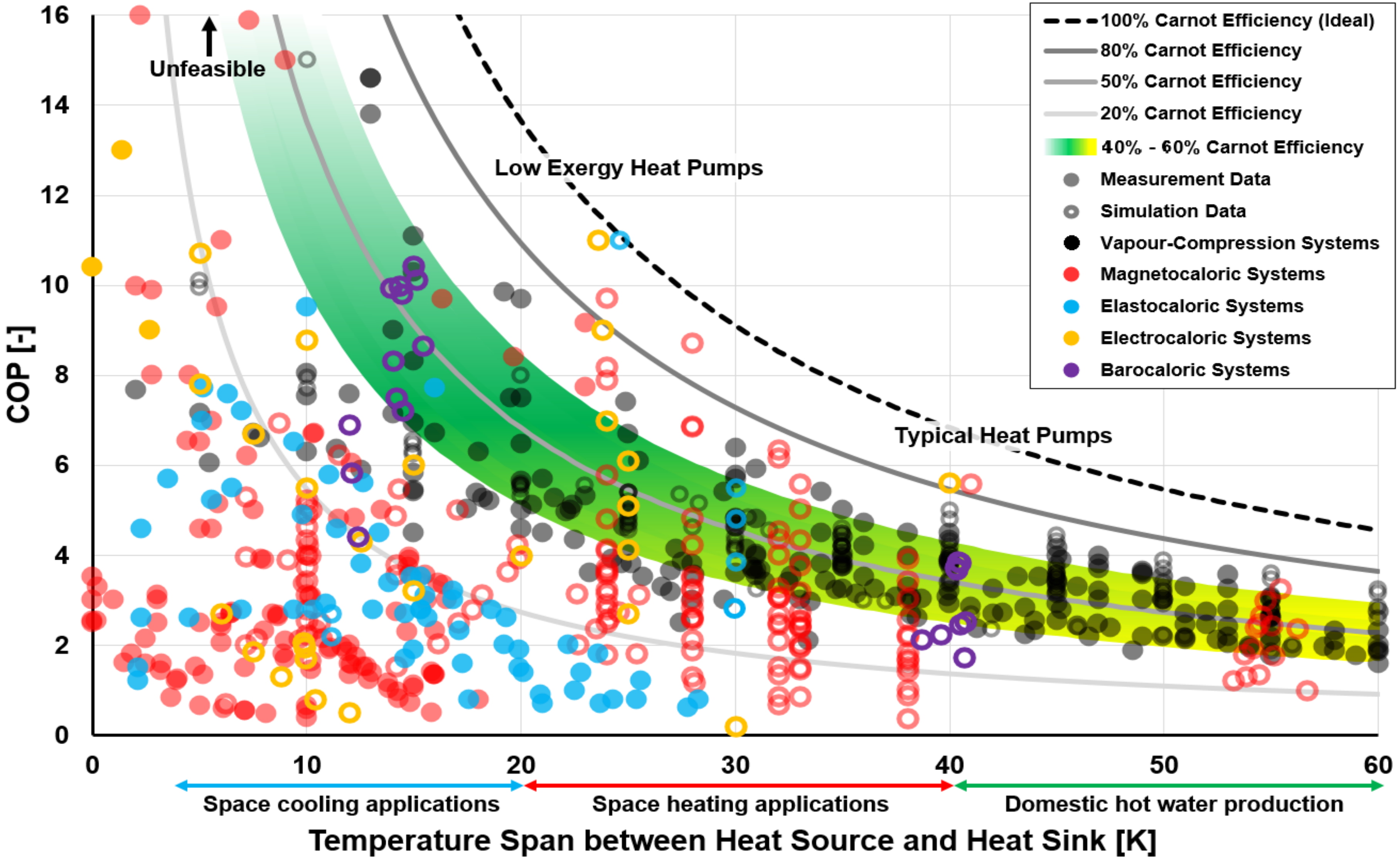
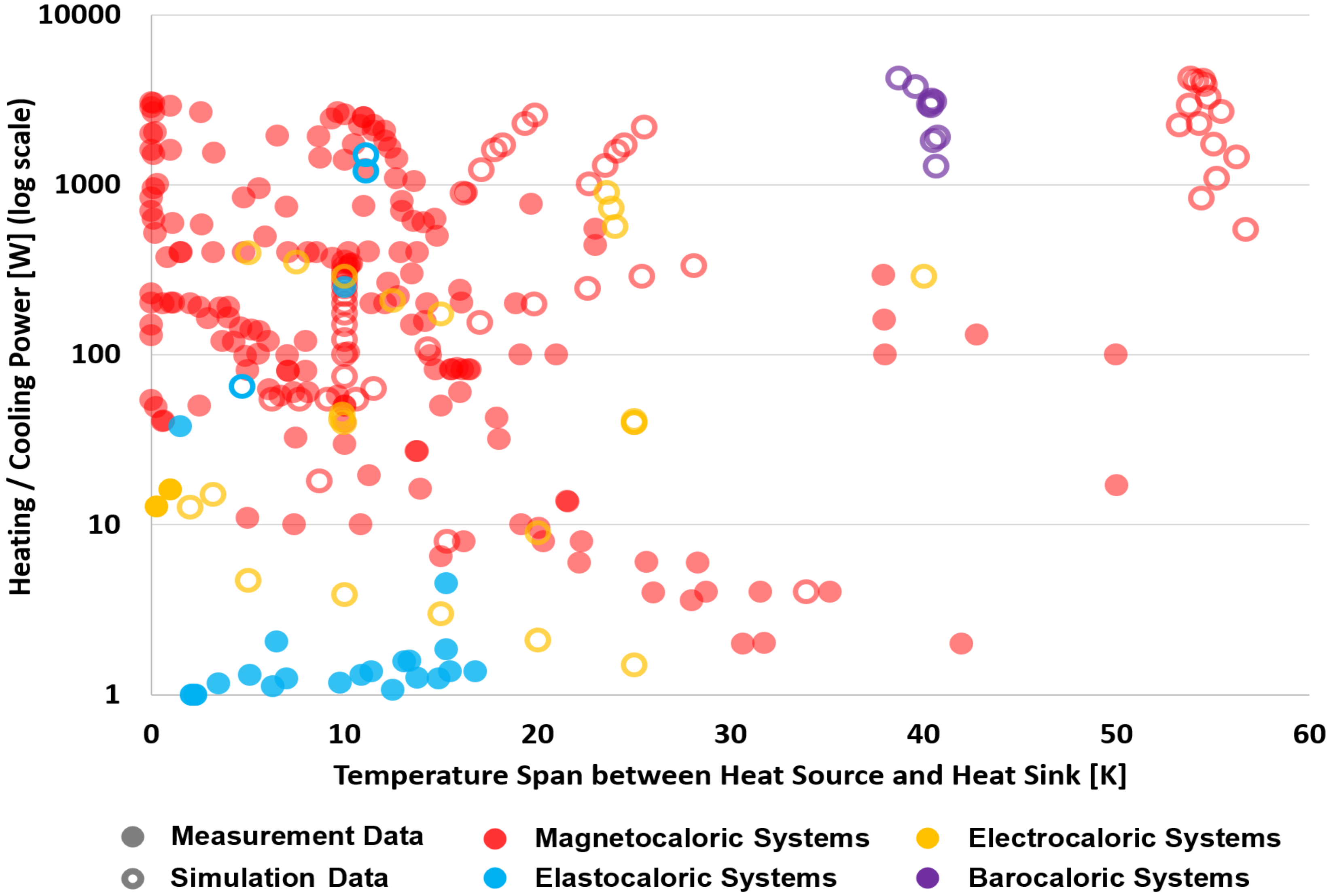
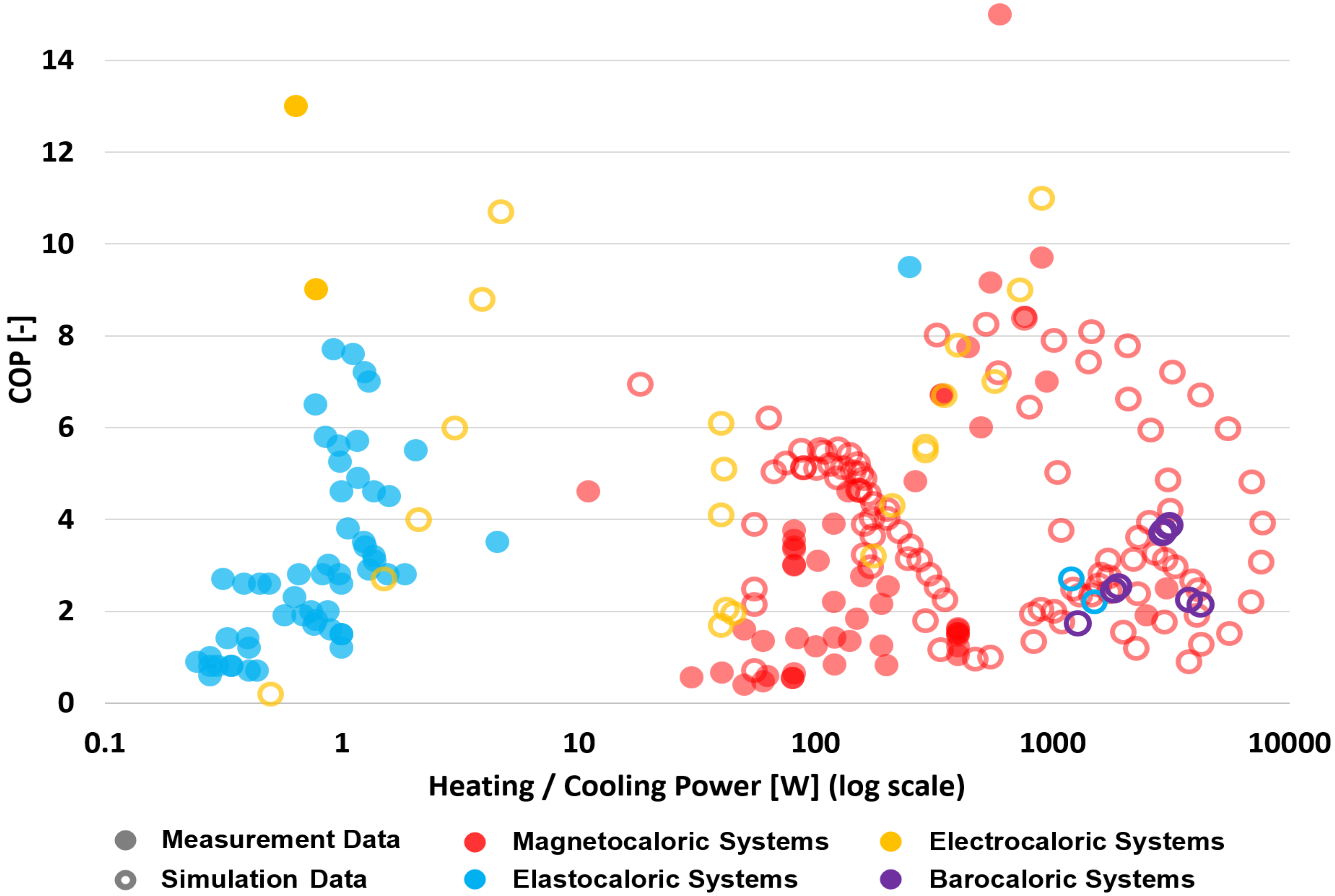
Performance overview of caloric heat pumps



Performance overview of caloric heat pumps



Performance overview of caloric heat pumps



Conclusions

- Caloric heat pump technology has made tremendous progress in the last decade.
- The large-scale magnetocaloric prototypes show performances that are similar or superior to conventional vapour-compression systems.
- However, caloric heat pumps have yet to prove cost competitiveness and sustainability superiority against mature vapour-compression systems.

Conclusions

- Only magnetocaloric systems have been experimentally proven suitable for high-COP low-temperature space heating and cooling in buildings.

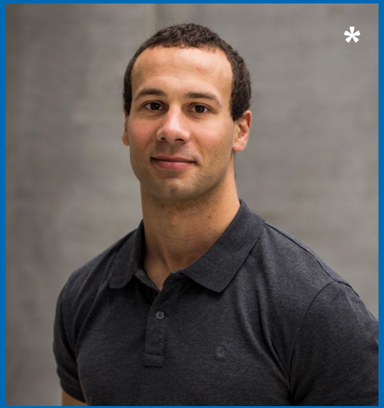
- However, elastocaloric and electrocaloric systems are very promising.

Future work to be done

- New caloric materials with large adiabatic temperature change and long-term durability.
- New manufacturing processes for caloric solid refrigerants.
- New active regenerator geometries.
- New specific engineering design of actuators, pumps and auxiliary systems for caloric systems.
- Reduction of parasitic energy and heat losses.
- Improvement of energy recovery systems.
- Coupling multiple caloric effects.

Thank you for your attention !

Any questions or comments ?



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