BS 2019 2-4 SEPT ROME
16th IBPSA INTERNATIONAL CONFERENCE AND EXHIBITION

INTERNATIONAL BUILDING PERFORMANCE SIMULATION ASSOCIATION

Numerical Simulation of a Magnetocaloric Heat Pump for Domestic Hot Water Production in Residential Buildings

Speaker:

Hicham Johra
Aalborg University
Denmark

AALBORG UNIVERSITY DENMARK

ENOVHEAT

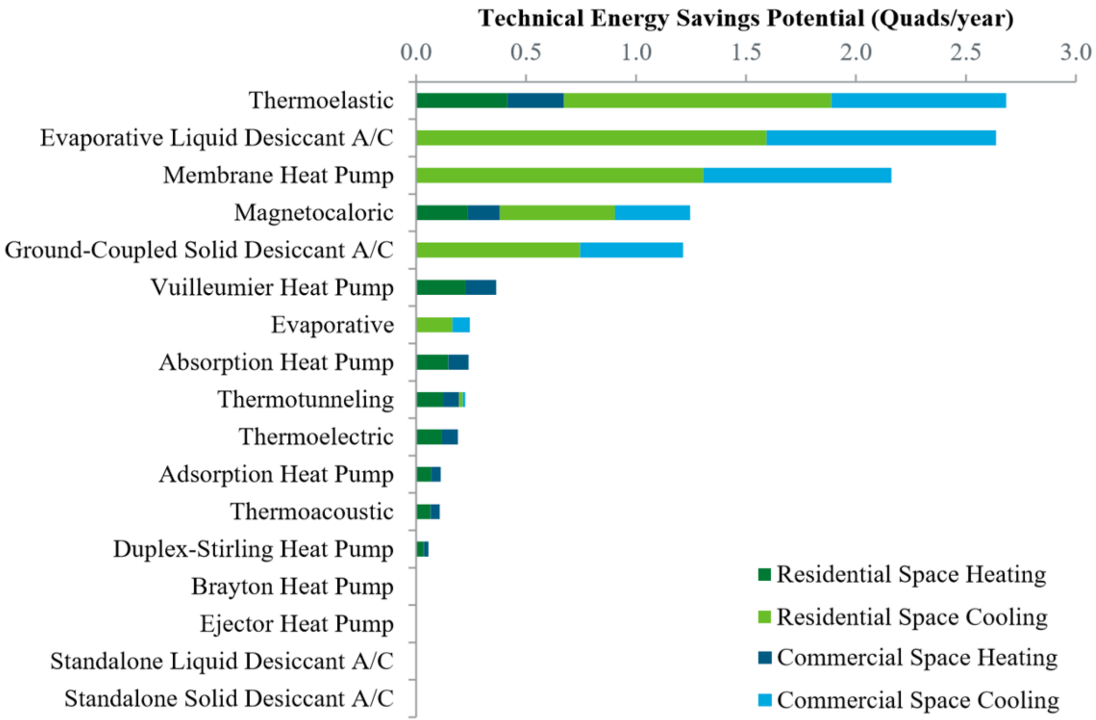
Authors:

Hicham Johra, Aalborg University, Denmark
Konstantin Filonenko, University of Southern Denmark
Anna Marszal-Pomianowska, Aalborg University, Denmark
Per Heiselberg, Aalborg University, Denmark
Christian Veje, University of Southern Denmark
Stefano Dall'Olio, Technical University of Denmark
Kurt Engelbrecht, Technical University of Denmark
Christian Bahl, Technical University of Denmark

Motivations

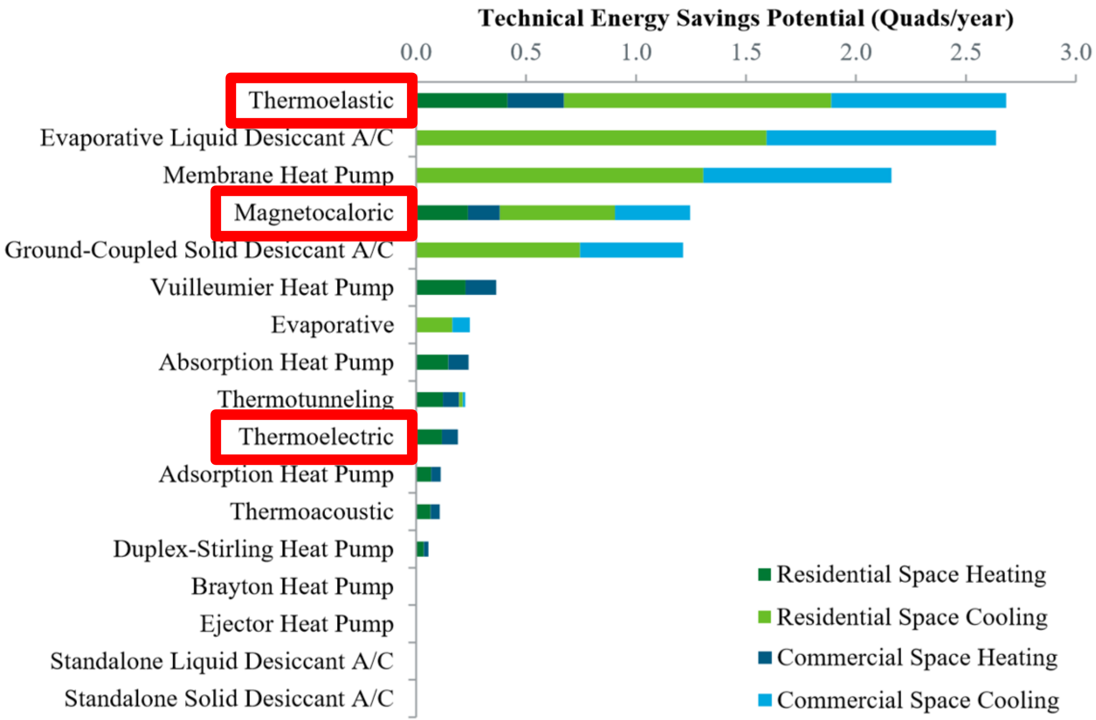
- Large increase of market demand for heat pumps
- Need to develop cost effective heating / cooling systems
- Problems with use of liquid / gas refrigerant:
  - F-gas
  - Flammability
  - Toxicity
  - Greenhouse gas effect
  - …

Potential of innovative systems



Comparison of technical energy savings potential. U.S. Department of Energy, 2014.

Potential of innovative systems



Comparison of technical energy savings potential. U.S. Department of Energy, 2014.

Caloric effects

Large adiabatic temperature change when varying a specific environment parameter of a material:

- Electrocaloric effect: variation of electrical field
- Barocaloric effect: variation of hydrostatic pressure
- Elastocaloric effect: variation of uniaxial mechanical stress
- Magnetocaloric effect: variation of magnetic field

Potential of caloric effects

- Thermodynamic cycle to transfer heat from cold source to warmer heat sink
- Large COPs (in theory) because (nearly) reversible caloric effects
- Solid refrigerant + sustainable heat transfer fluid
- Active regenerator cycle to achieve temperature span above adiabatic temperature change of caloric effects

Challenges

- Not mature technologies compared to vapor-compression

- Has to prove its competitiveness

Objectives of the ENOVHEAT project

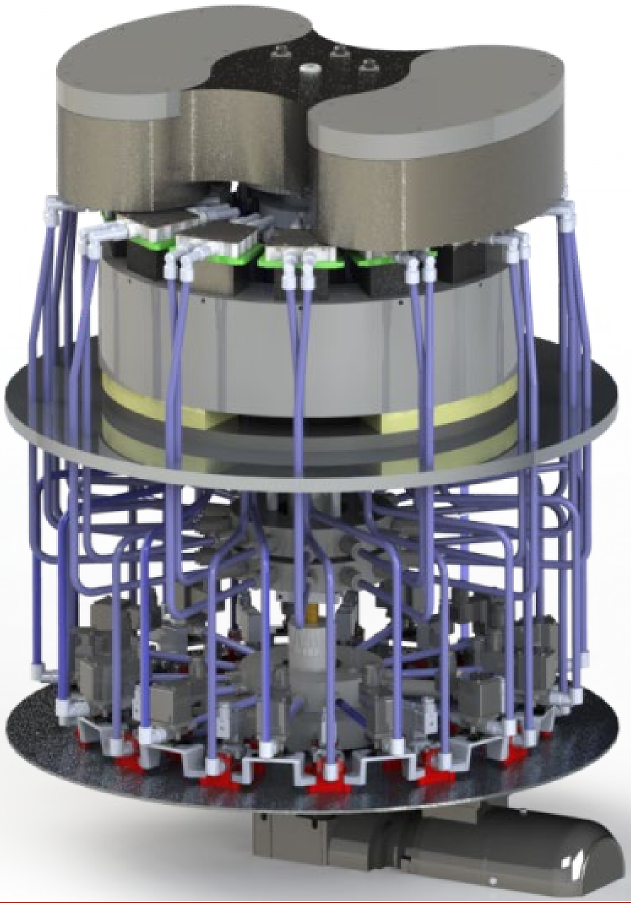
Create a magnetocaloric heat pump prototype for a single-family house in Denmark:

- Provide indoor space heating
- 1 - 1.5 kW of heating power
- 20 - 25 K of temperature span
- COP of 5

Magnetocaloric heat pump

The ENOVHEAT magnetocaloric heat pump prototype:

”*MagQueen*”



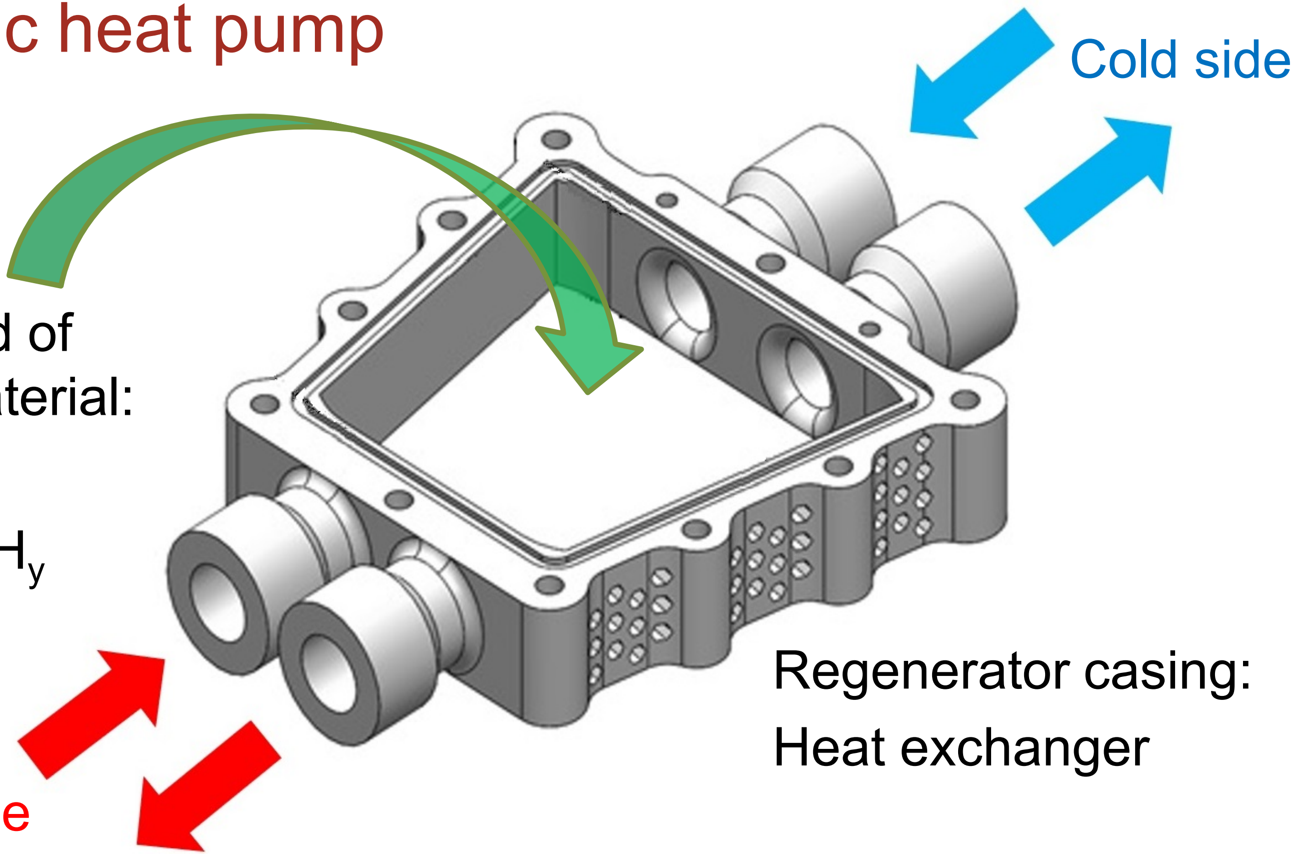
Magnetocaloric effect

- The most studied and developed of all caloric effects
- Reversible temperature change in a magnetocaloric material magnetized or demagnetized:
  - Warms up when magnetic field is applied
  - Cools down when magnetic field is removed
- Thermodynamic cycle to transfer heat from cold source to warmer heat sink: active magnetic regenerator cycle

Magnetocaloric heat pump

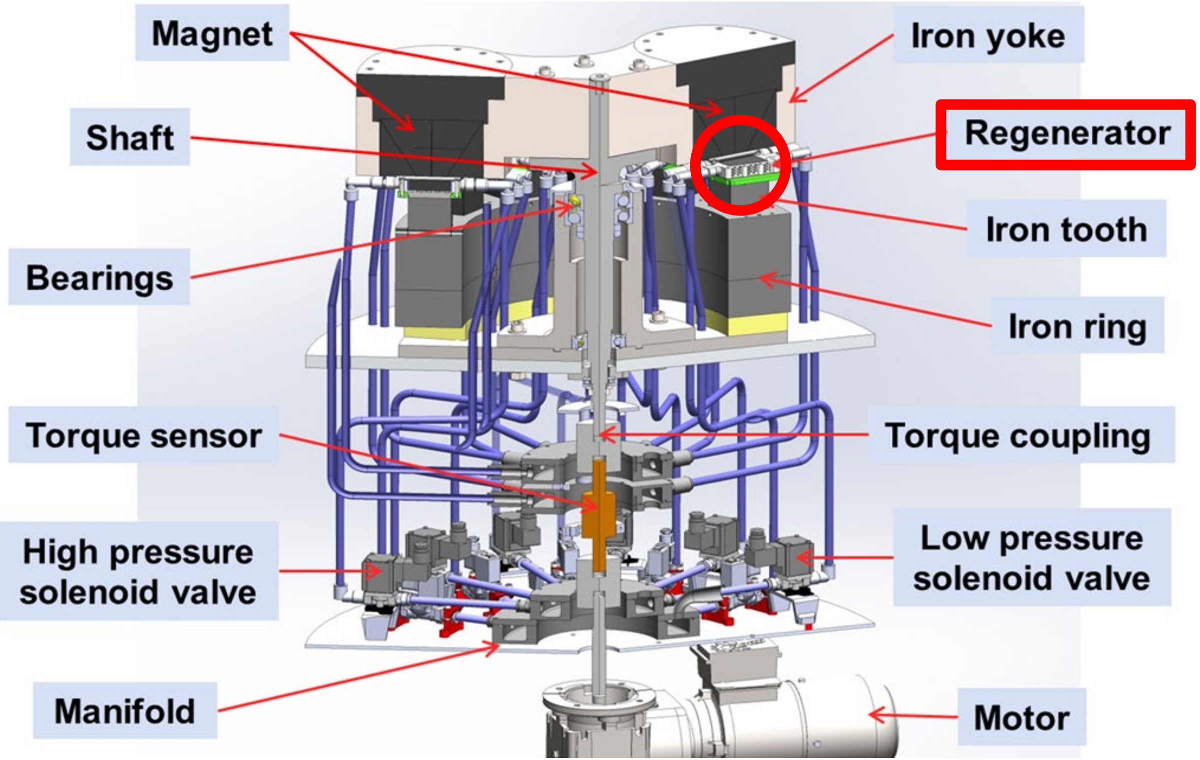
Packed sphere bed of magnetocaloric material:

- Gadolinium
- $La(Fe,Mn,Si)_{13}H_y$



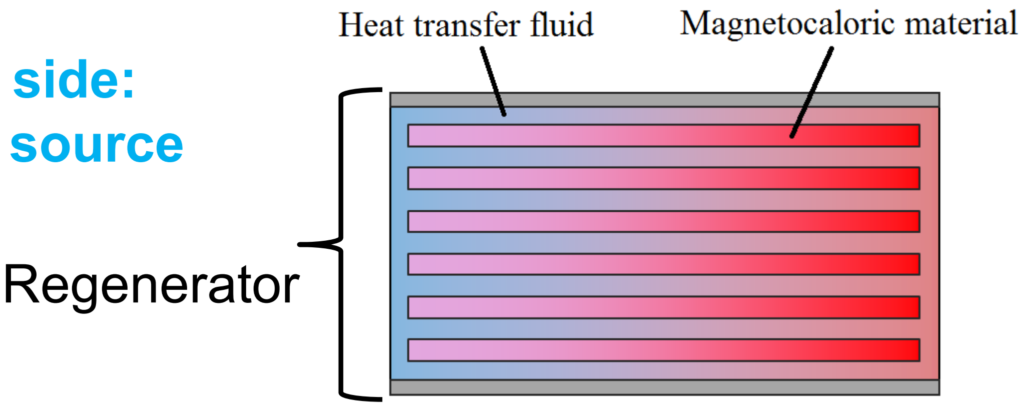
Regenerator casing:
Heat exchanger

Magnetocaloric heat pump

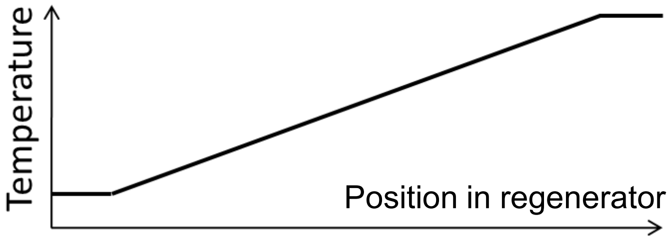


Active magnetic regenerator cycle

Cold side:
Heat source

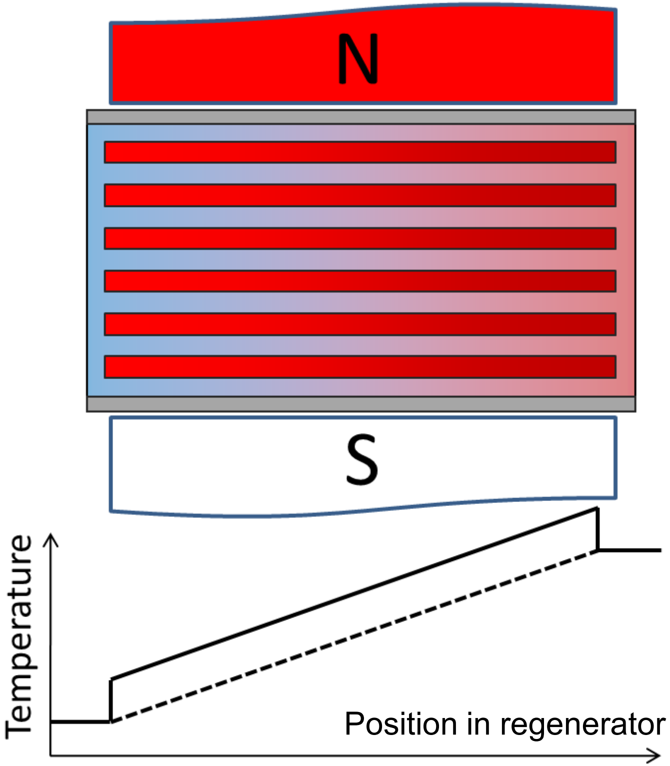


Hot side:
Heat sink



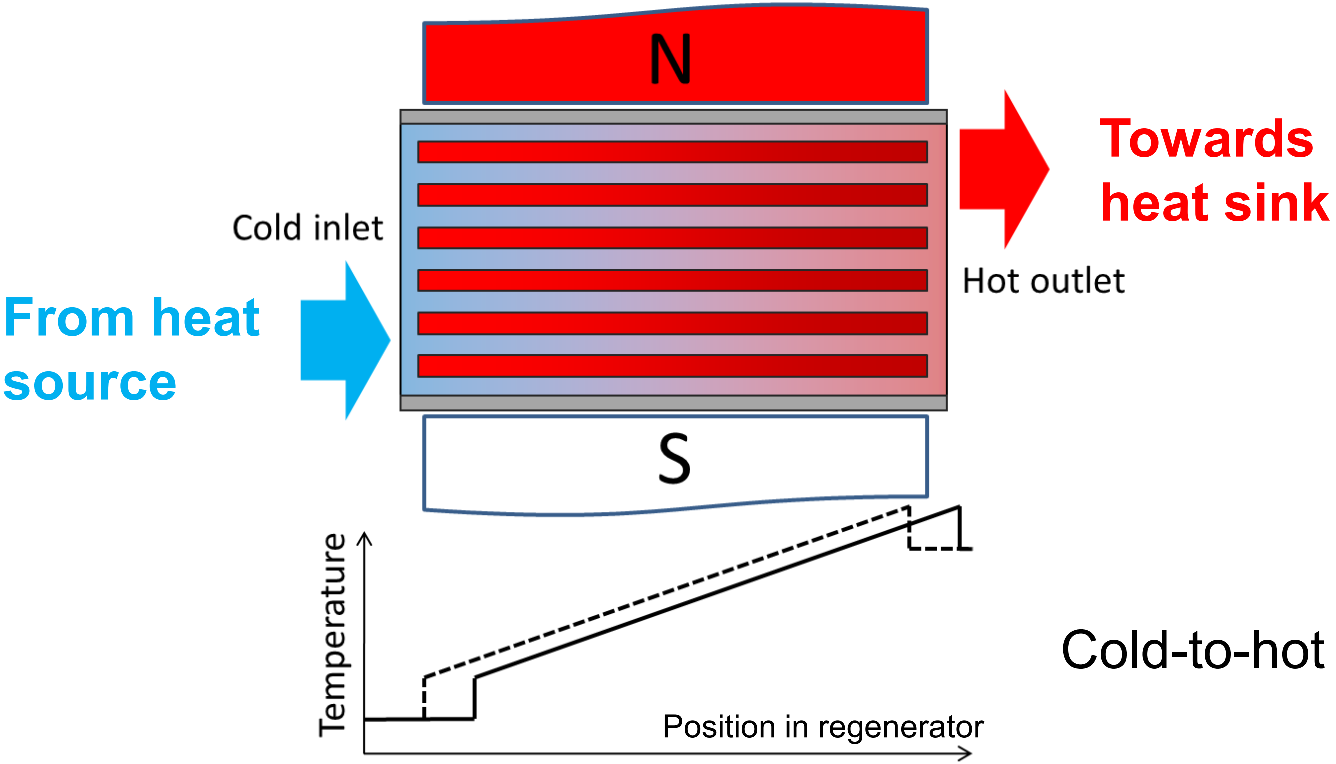
Initial state with temperature gradient

Active magnetic regenerator cycle



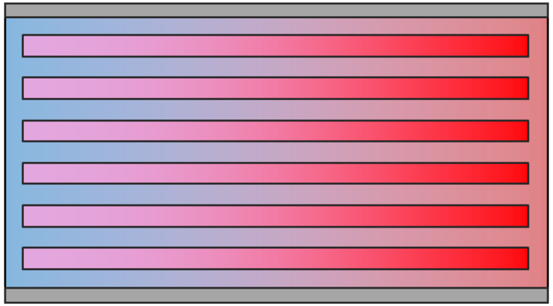
Adiabatic magnetization

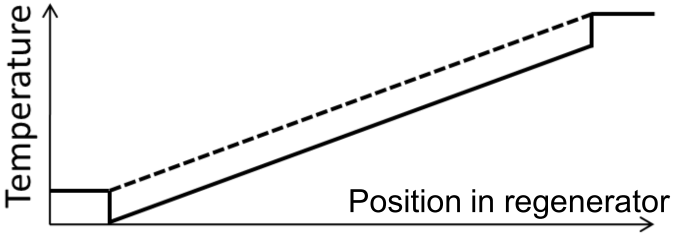
Active magnetic regenerator cycle



Cold-to-hot blow

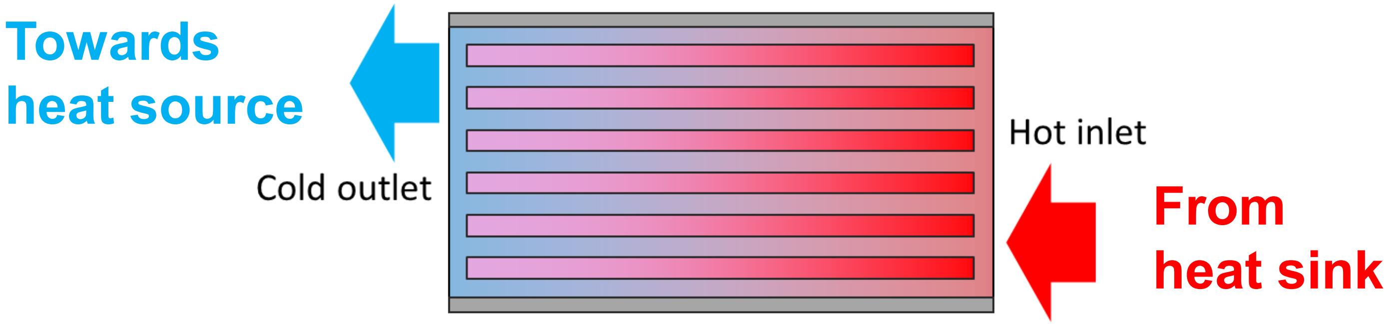
Active magnetic regenerator cycle

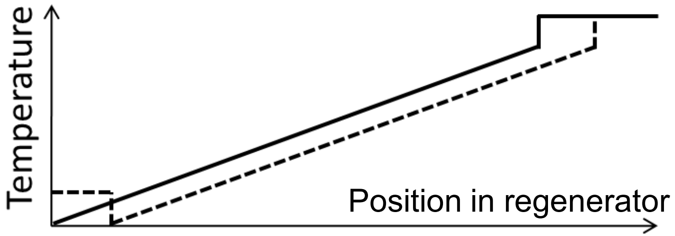




Adiabatic demagnetization

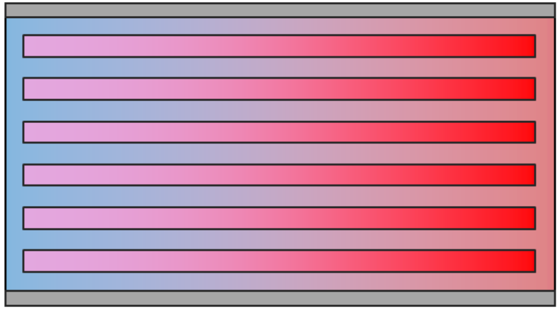
Active magnetic regenerator cycle

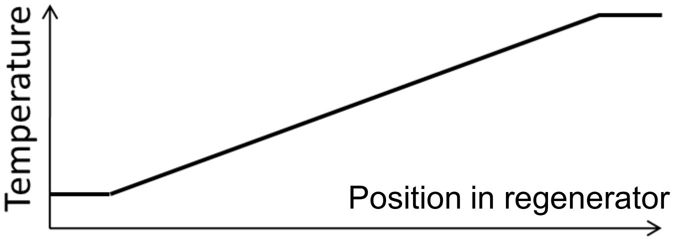




Hot-to-cold blow:
heat regeneration

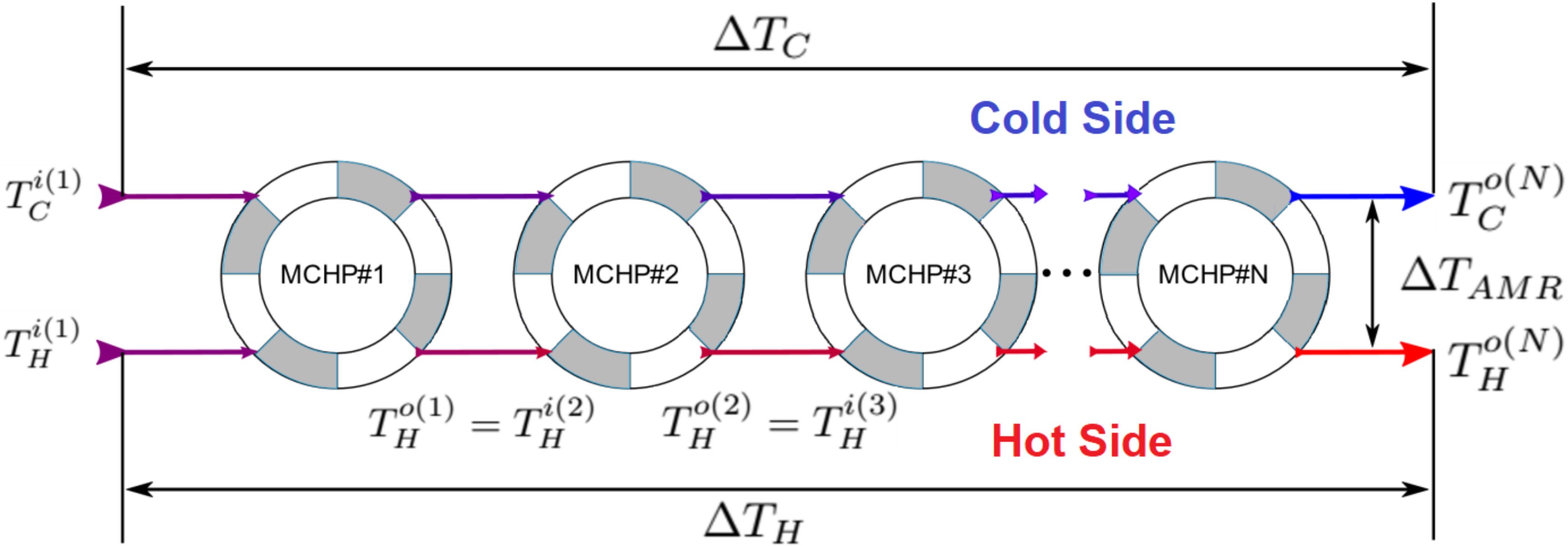
Active magnetic regenerator cycle





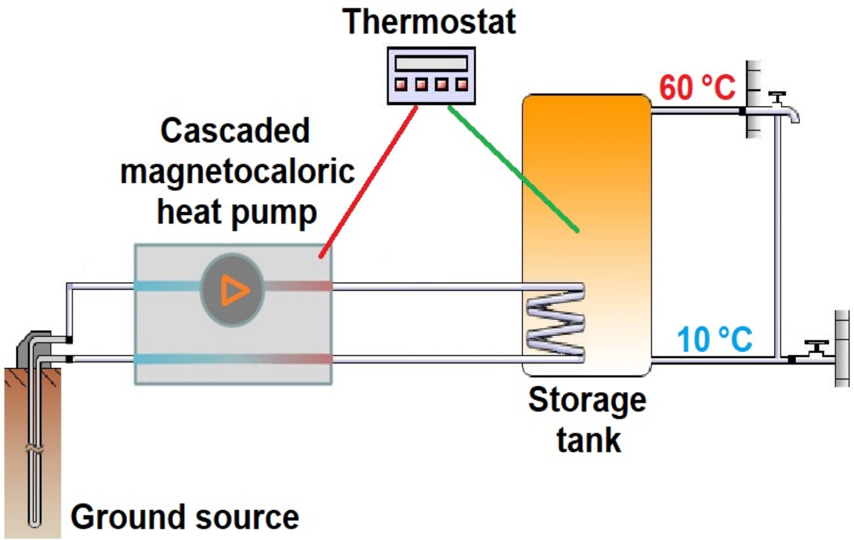
Back to initial state

Cascading regenerators: increase temperature span



Objectives of this numerical study

Test different cascading configurations for higher temperature span for Domestic Hot Water production in a Danish single-family house.



Study case

- Hot water draw-off profile from a single-family house in Denmark: 60 °C
- 250 L hot water storage tank
- 5 cascaded heat pump configurations:
  - 2 – 24 cascaded heat pumps
  - 1 – 12 regenerators each
- Magnetocaloric material: $La(Fe,Mn,Si)_{13}H_y$
- Vertical borehole ground source

Numerical modelling

$$\frac{\partial}{\partial x}\left(k_{\text{disp}}A_c\frac{\partial T_f}{\partial x}\right)-\dot{m}_f c_f\frac{\partial T_f}{\partial x}-\frac{Nuk_f}{d_h}a_s A_c\left(T_f-T_s\right)+\left|\frac{\partial P}{\partial x}\frac{\dot{m}_f}{\rho_f}\right| = A_c\varepsilon\rho_f c_f\frac{\partial T_f}{\partial t}$$

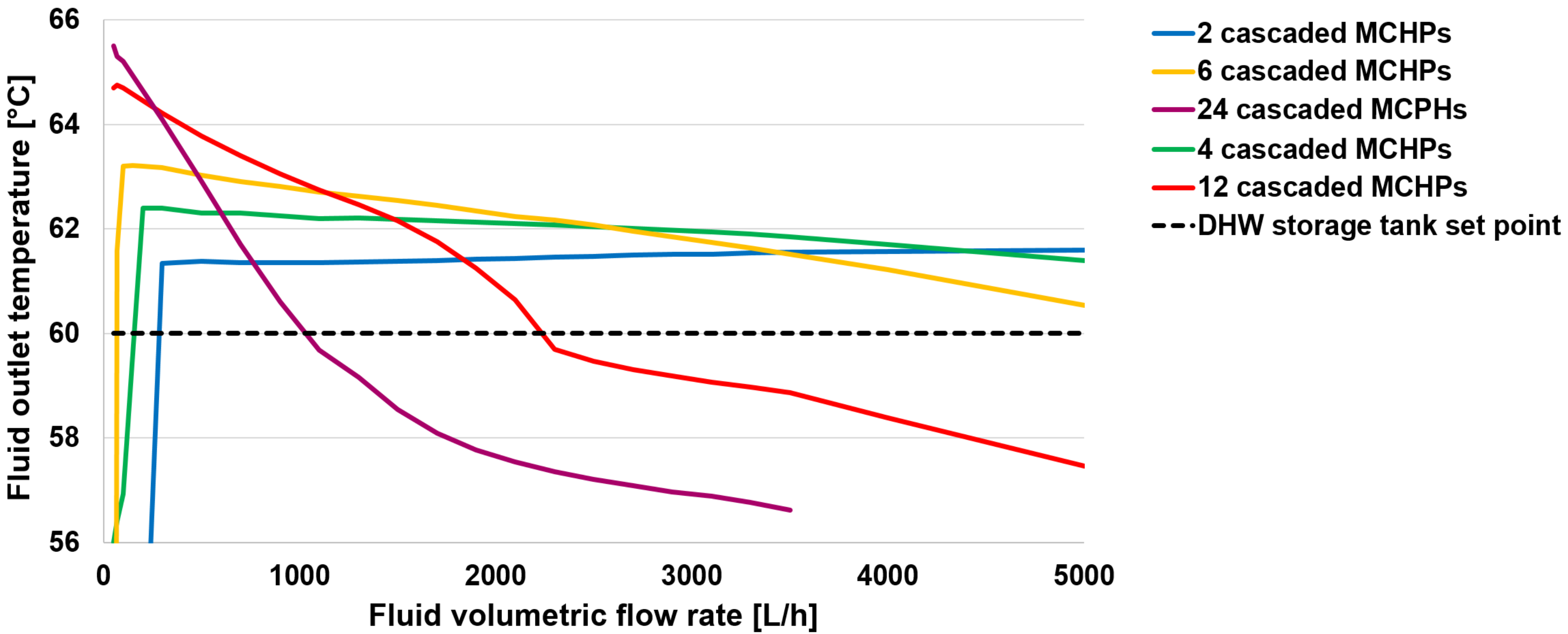
$$\frac{\partial}{\partial x}\left(k_{\text{stat}}A_c\frac{\partial T_s}{\partial x}\right)+\frac{\text{Nu}k_f}{d_h}a_s A_c\left(T_f-T_s\right) = A_c(1-\varepsilon)\rho_s\times\left[c_H\frac{\partial T_s}{\partial t}+T_s\left(\frac{\partial s_s}{\partial H}\right)_{T_s}\frac{\partial H}{\partial t}\right]$$

Detailed heat pump model [Engelbrecht and Lei]

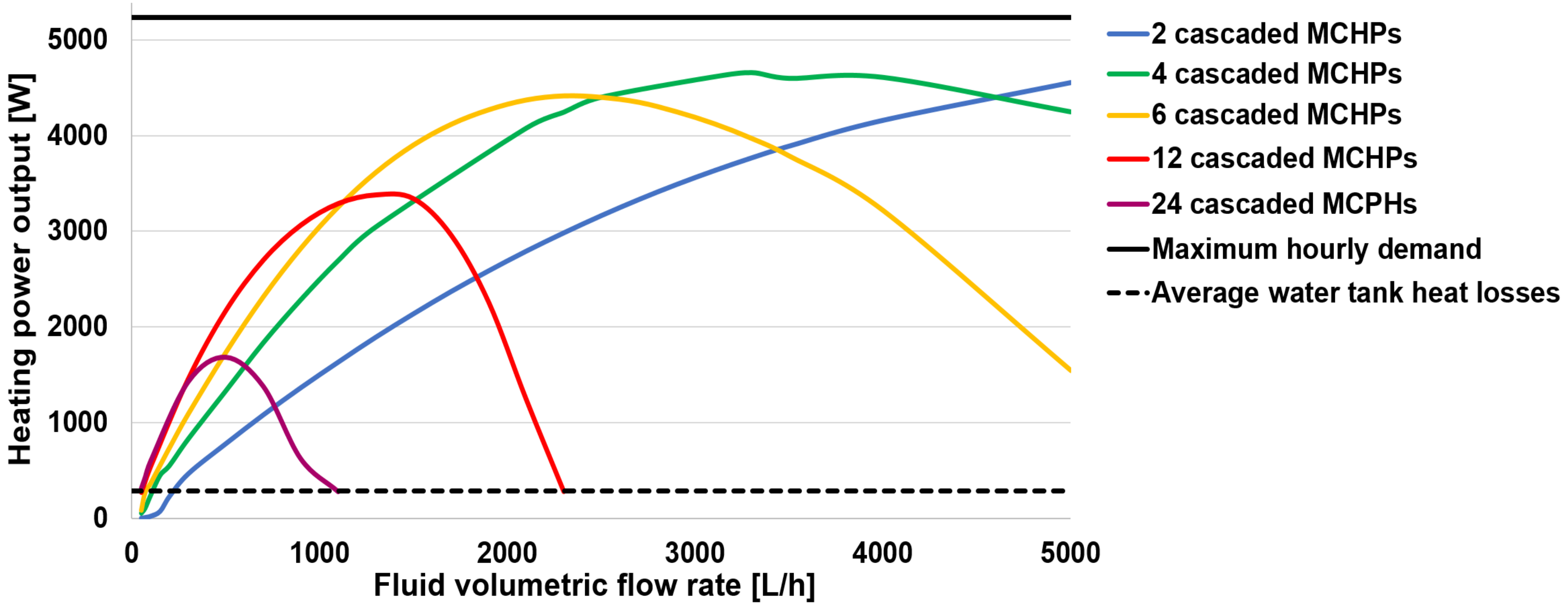
5-dimensional lookup tables (1600 points)

MATLAB-Simulink model of ground source, storage tank and piping

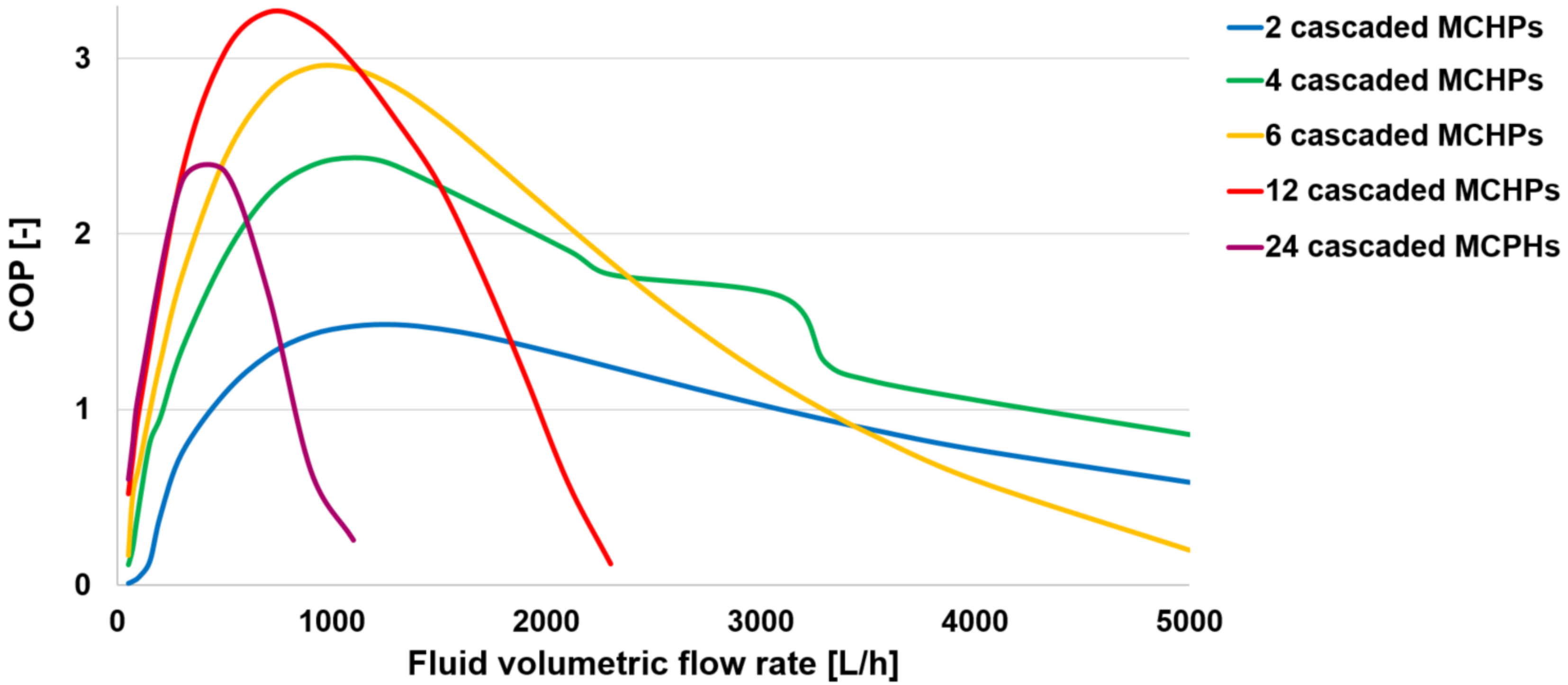
Results: outlet fluid temperature



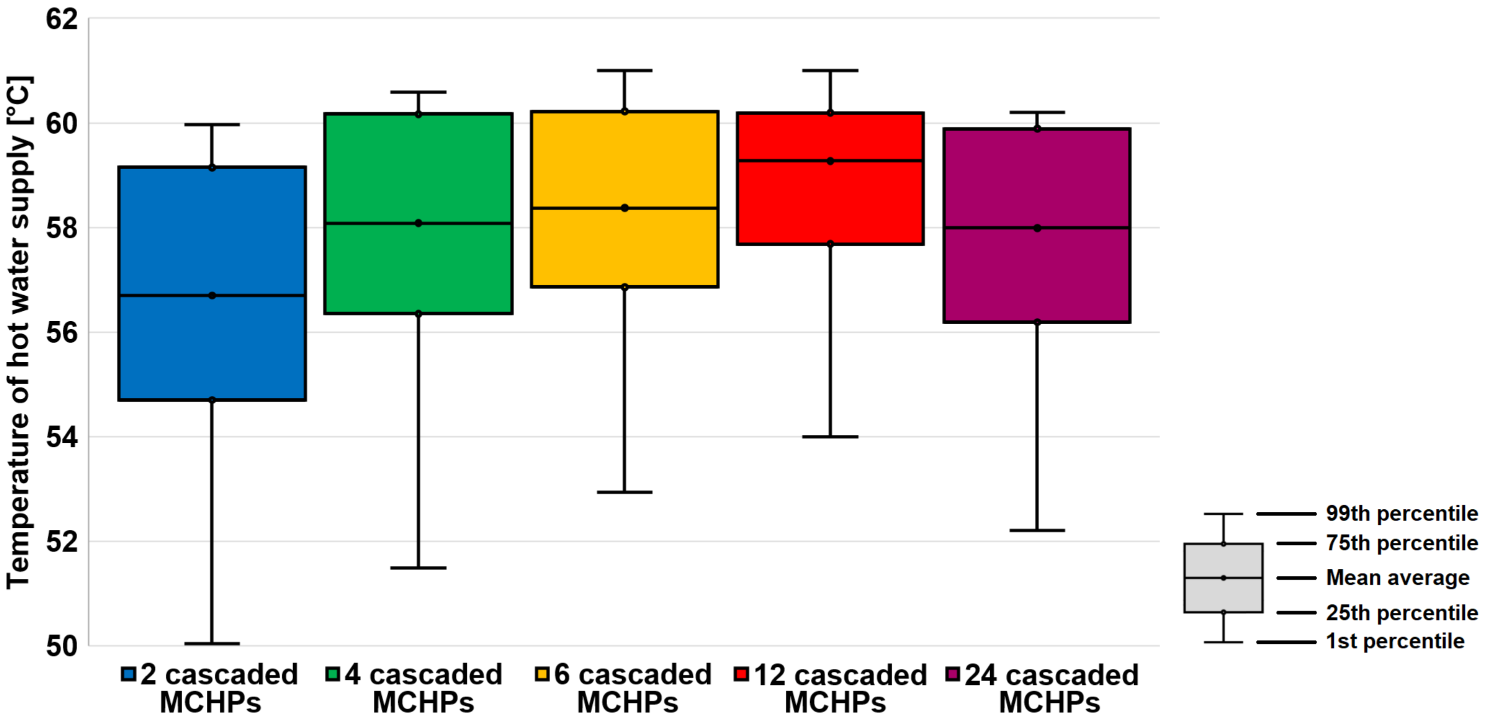
Results: useful heating power output



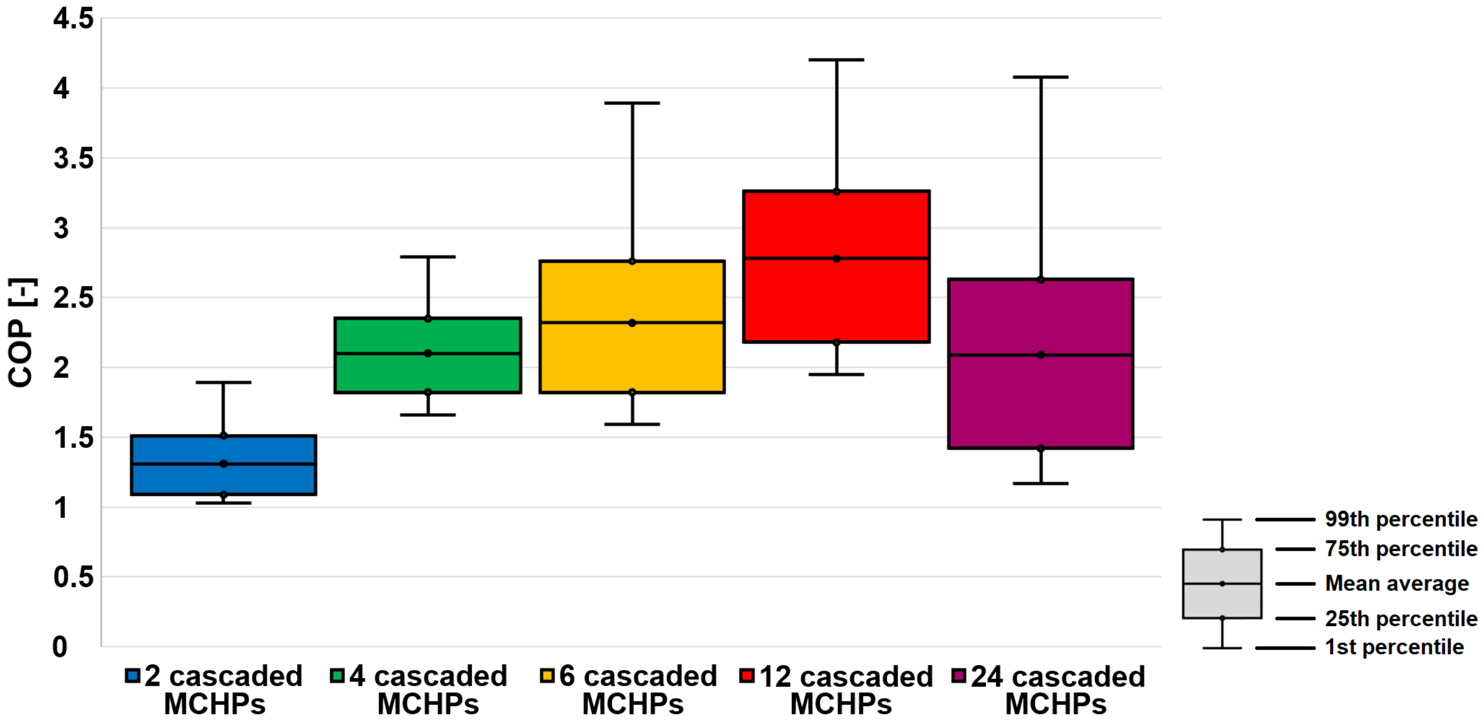
Results: system COP



One-month test results: hot water draw-off temperature



One-month test results: COP



Conclusion

- A cascaded magnetocaloric heat pump system can produce a sufficient temperature span for the production of domestic hot water at 55 °C – 60 °C
- Possible to produce hot water need for a single-family house
- Monthly average COP up to 2.78

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Questions and Comments

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Speaker:

Hicham Johra
Aalborg University
Denmark

Contacts:

hj@civil.aau.dk

linkedin.com/in/hichamjohra

ENOVHEAT

www.enovheat.dk