IBPSA-NORDIC
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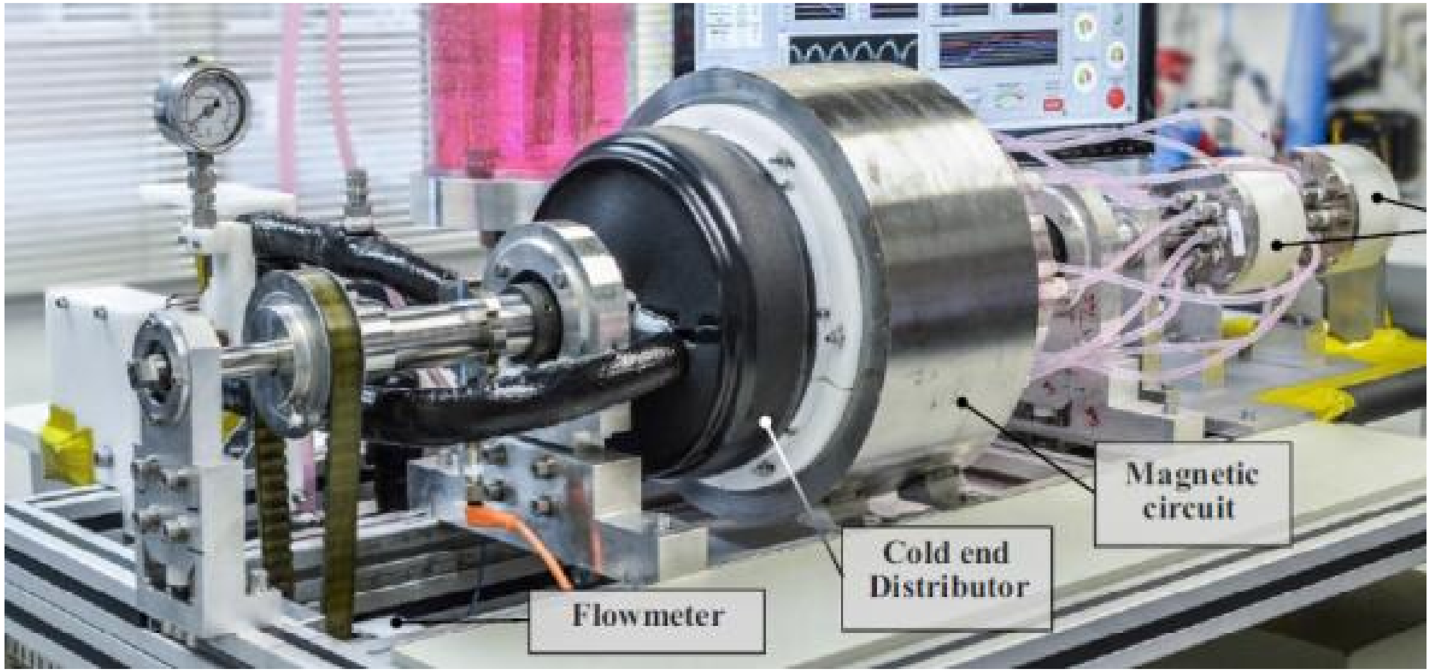
Integration of a magnetocaloric heat pump in a low-energy residential building

BuildSim-Nordic 2017



Aalborg University
Civil Engineering Department

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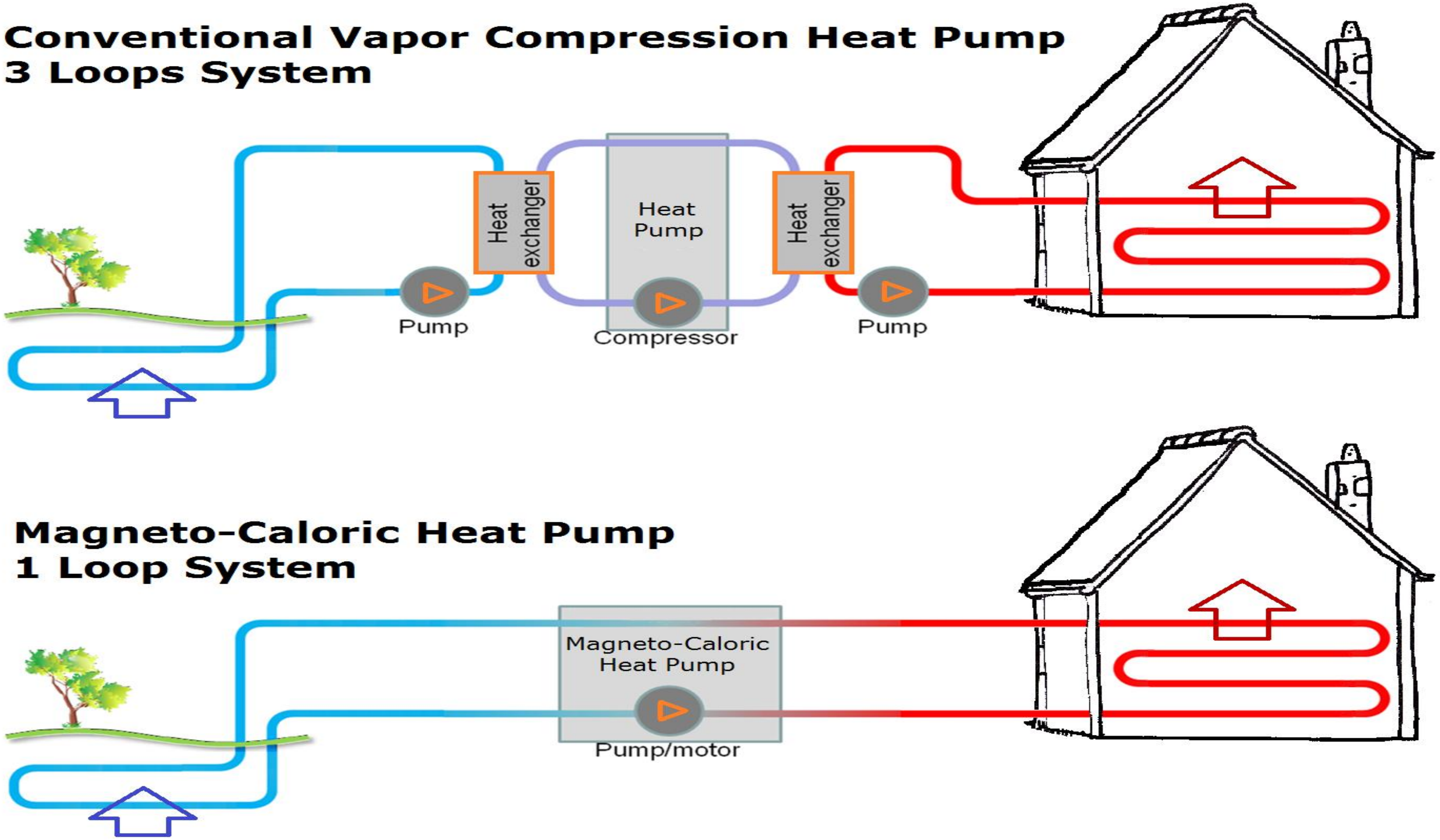
21 September 2017

EnovHeat Project

EnovHeat Project: creation of an innovative and efficient magnetocaloric heat pump for a single family house:

- COP of 5 or more
- 2.5 kW of heating power
- 30 K of temperature span between heat source and heat sink

EnovHeat Project



Possibility for a single hydronic loop integration

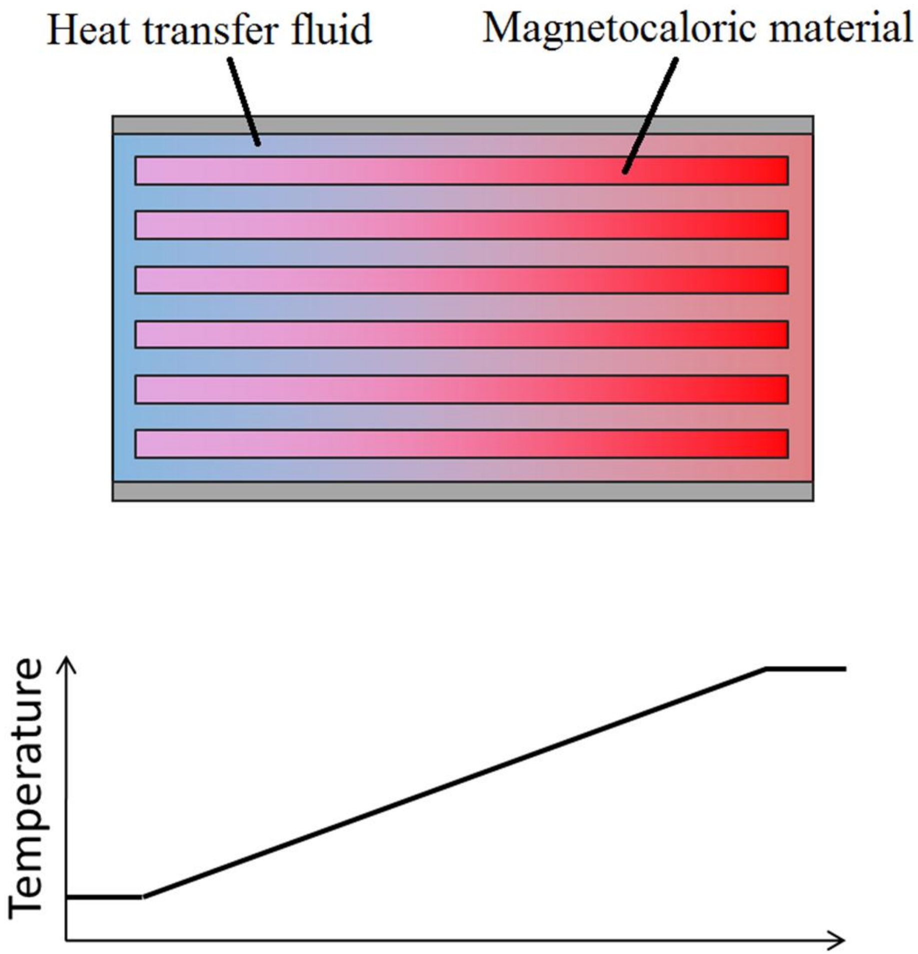
Magnetocaloric Heat Pump

- System based on the **magnetocaloric** effect and active magnetic regenerator (AMR) technology

- Use reversible magnetocaloric effect of solid refrigerant to build a cooling / heating cycle

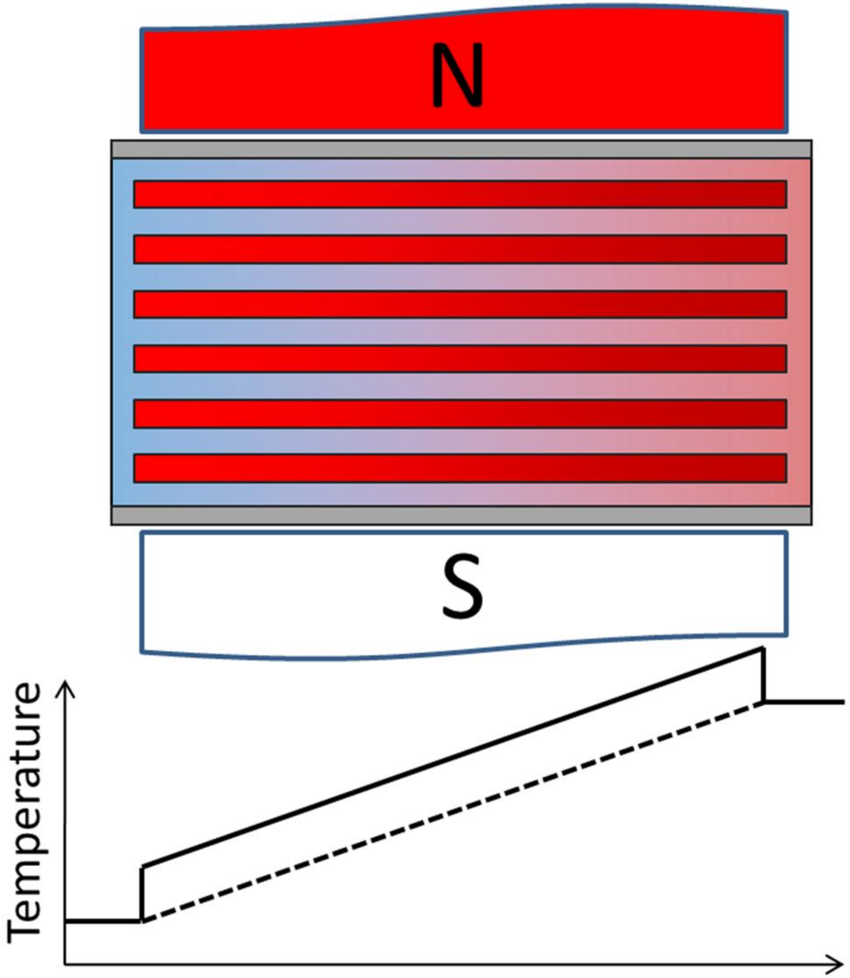
- Potential for high coefficient of performance, more silent operation and efficient part-load control.

Magnetocaloric Heat Pump Cycle



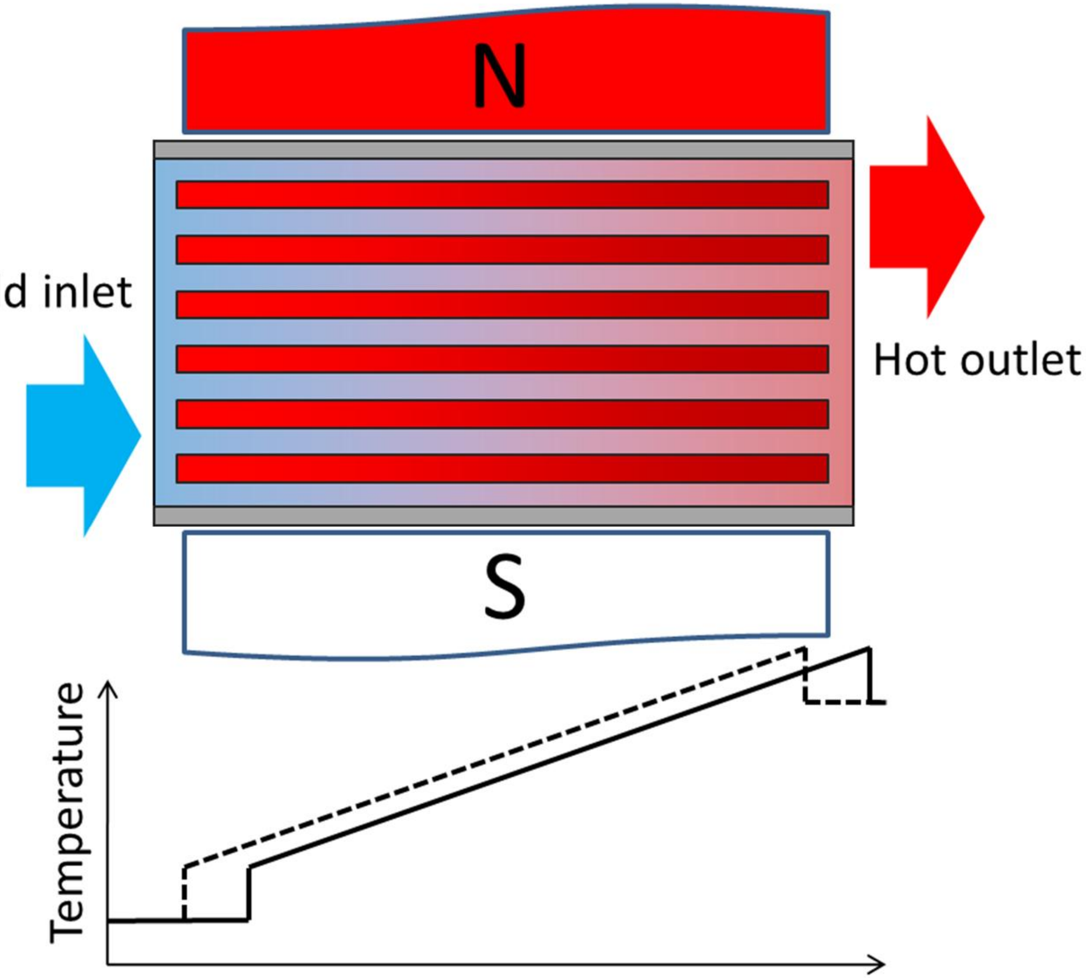
(a) Initial state with temperature gradient

Magnetocaloric Heat Pump Cycle



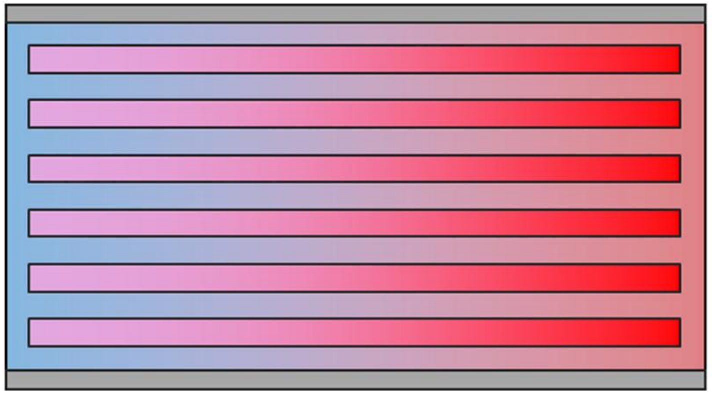
(b) Adiabatic magnetization

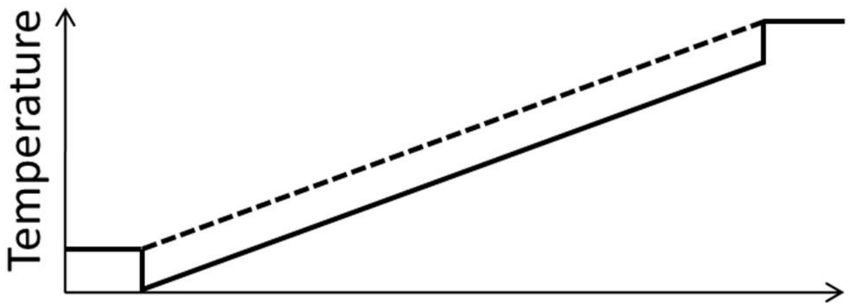
Magnetocaloric Heat Pump Cycle



(c) Cold-to-hot blow

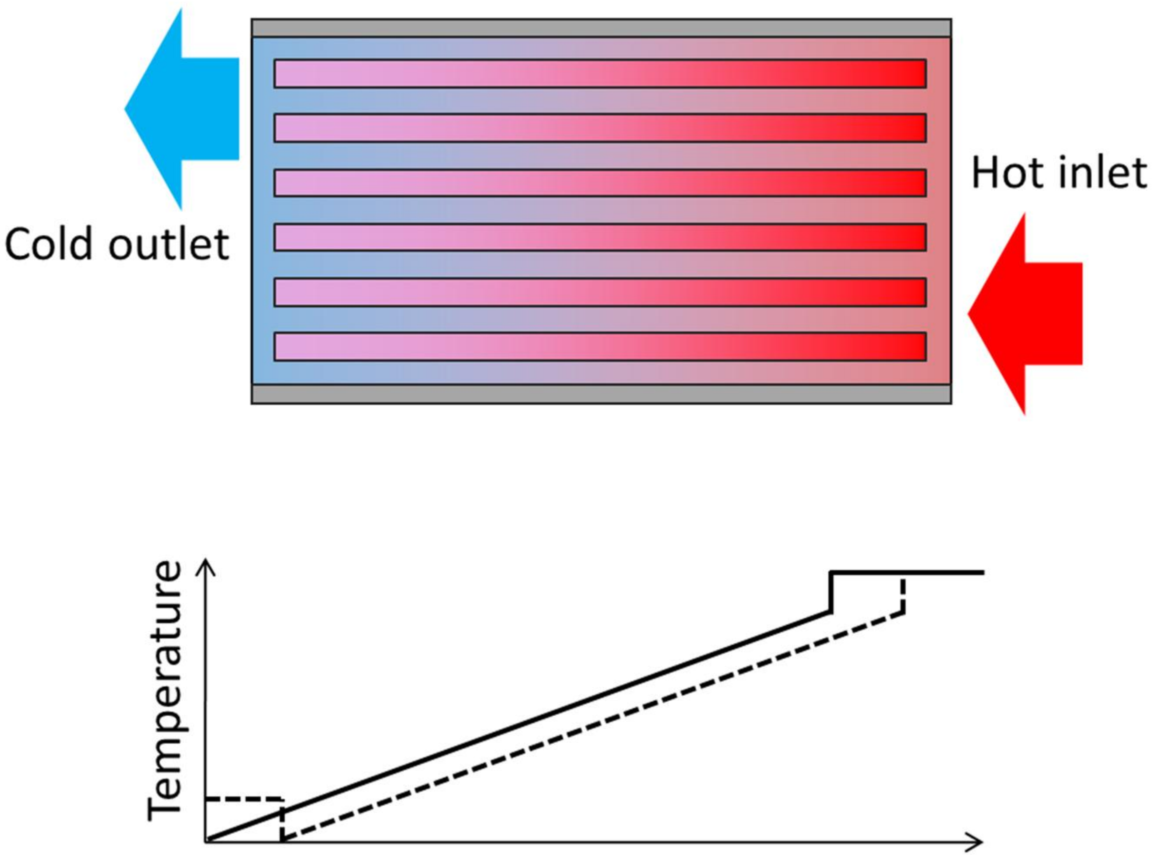
Magnetocaloric Heat Pump Cycle





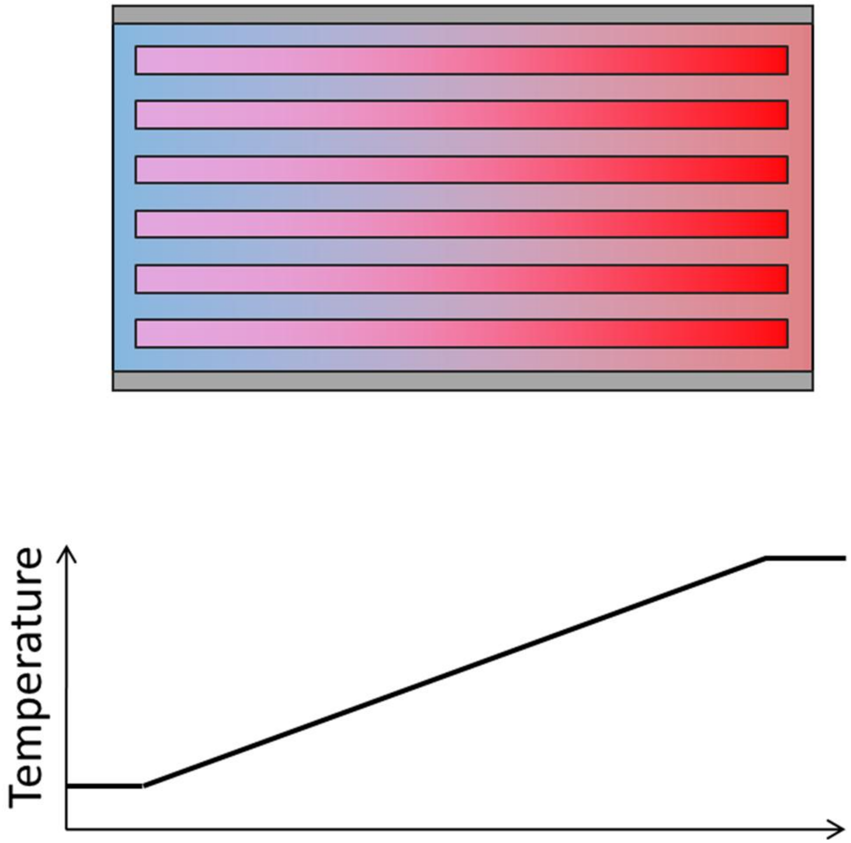
(d) Adiabatic demagnetization

Magnetocaloric Heat Pump Cycle



(e) Hot-to-cold blow

Magnetocaloric Heat Pump Cycle

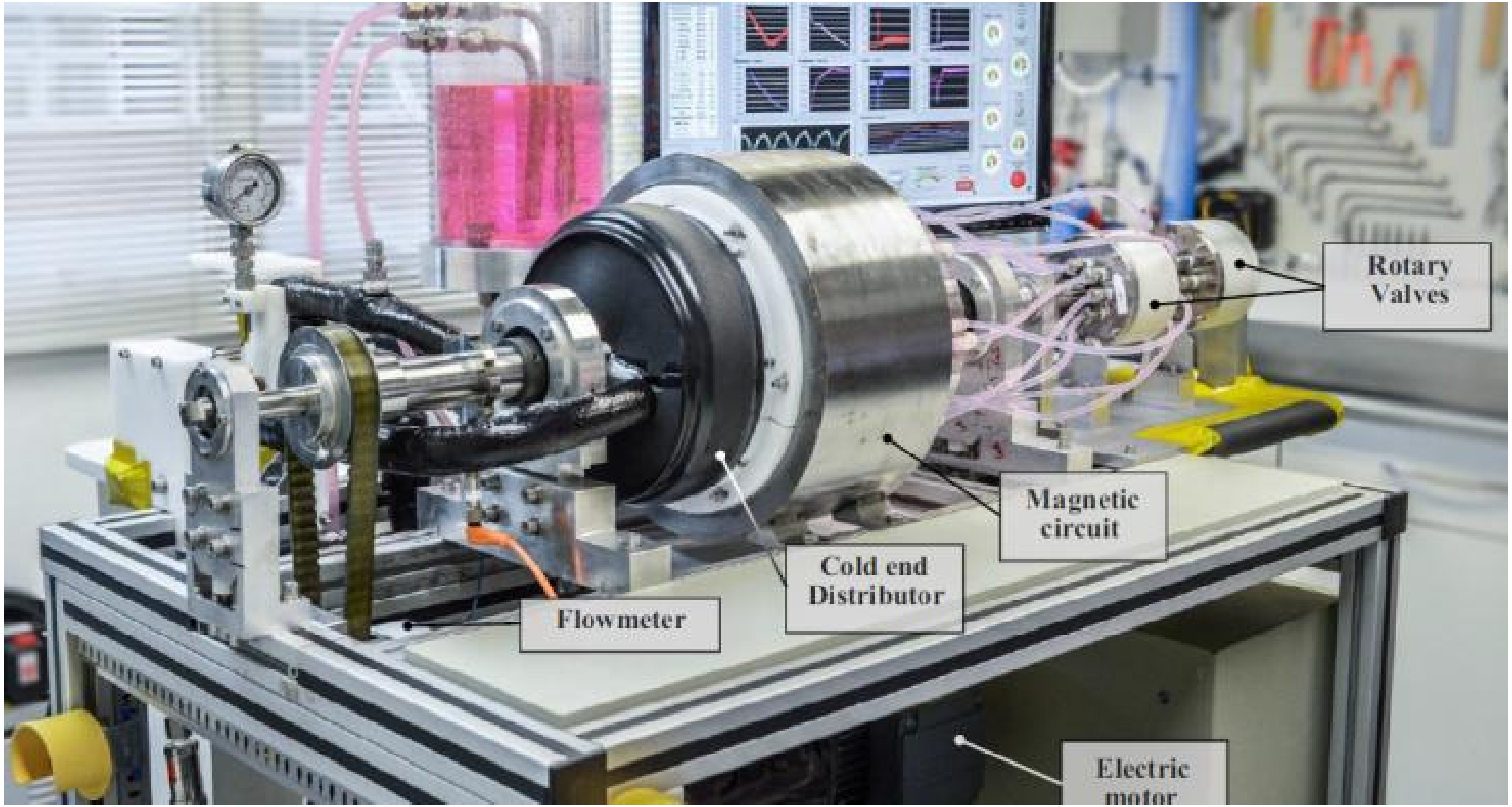


(f) Back to initial state

Magnetocaloric Heat Pump

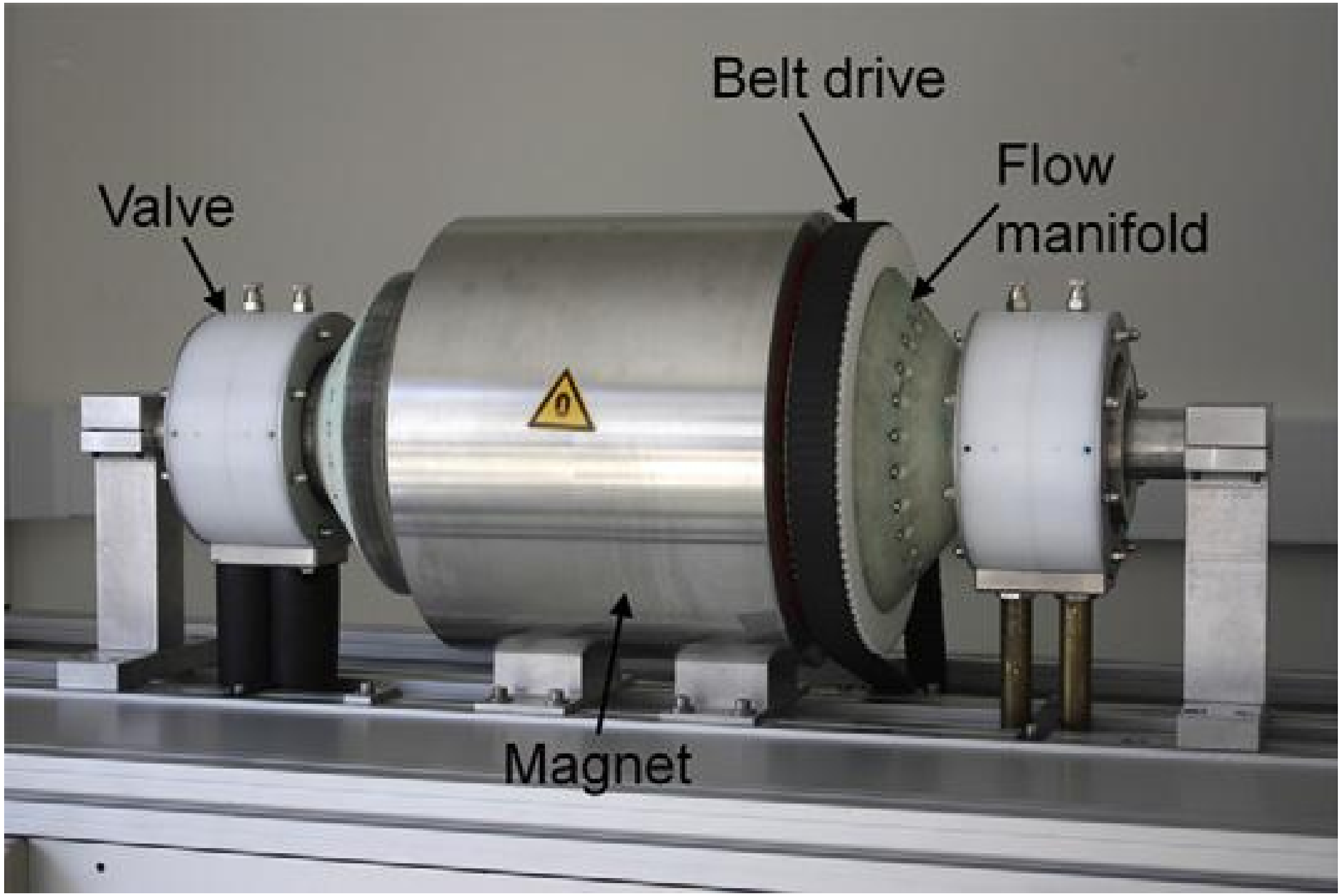
- 40 different lab prototypes of magnetocaloric devices in the world
- We have the best ones ! (at DTU Risø, collaboration of the project)
- Only magnetocaloric device used as a heat pump

Magnetocaloric Heat Pump: Examples



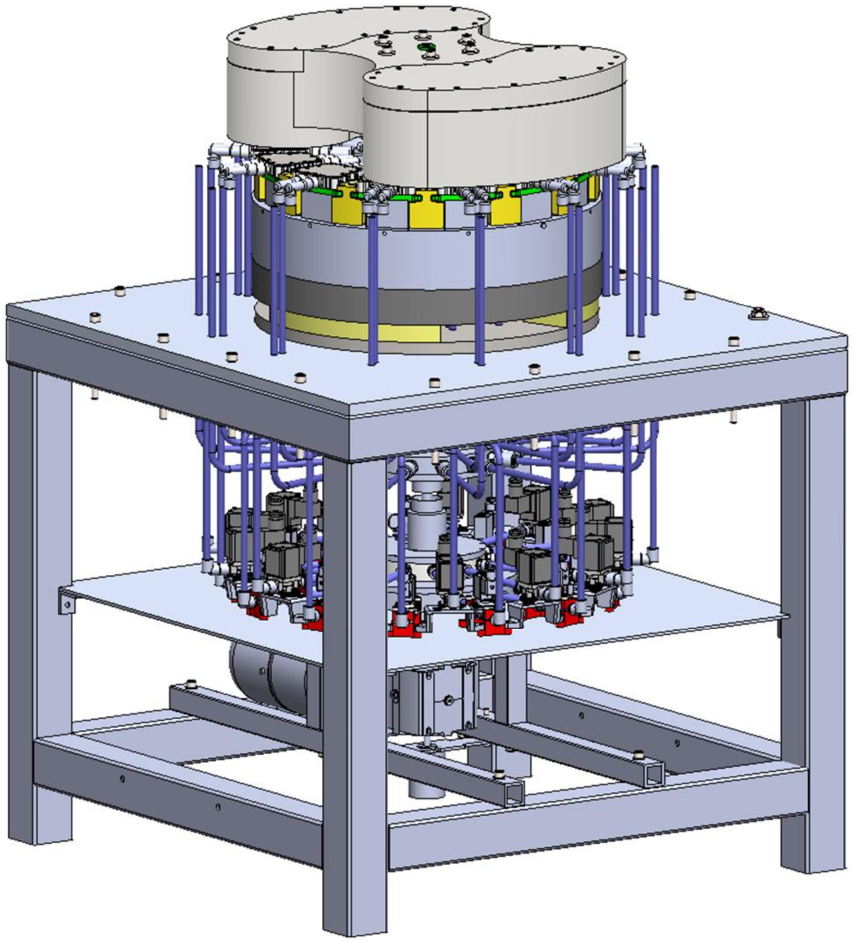
POLO – UFSC – Brazil (collaboration with DTU Risø)

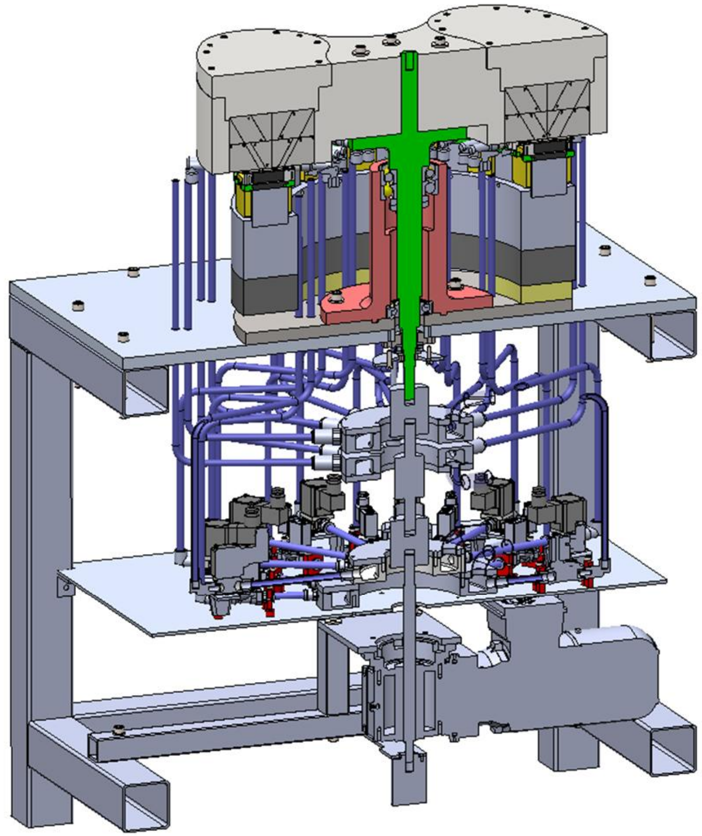
Magnetocaloric Heat Pump: Examples



"Maggi" (second prototype of DTU Risø)

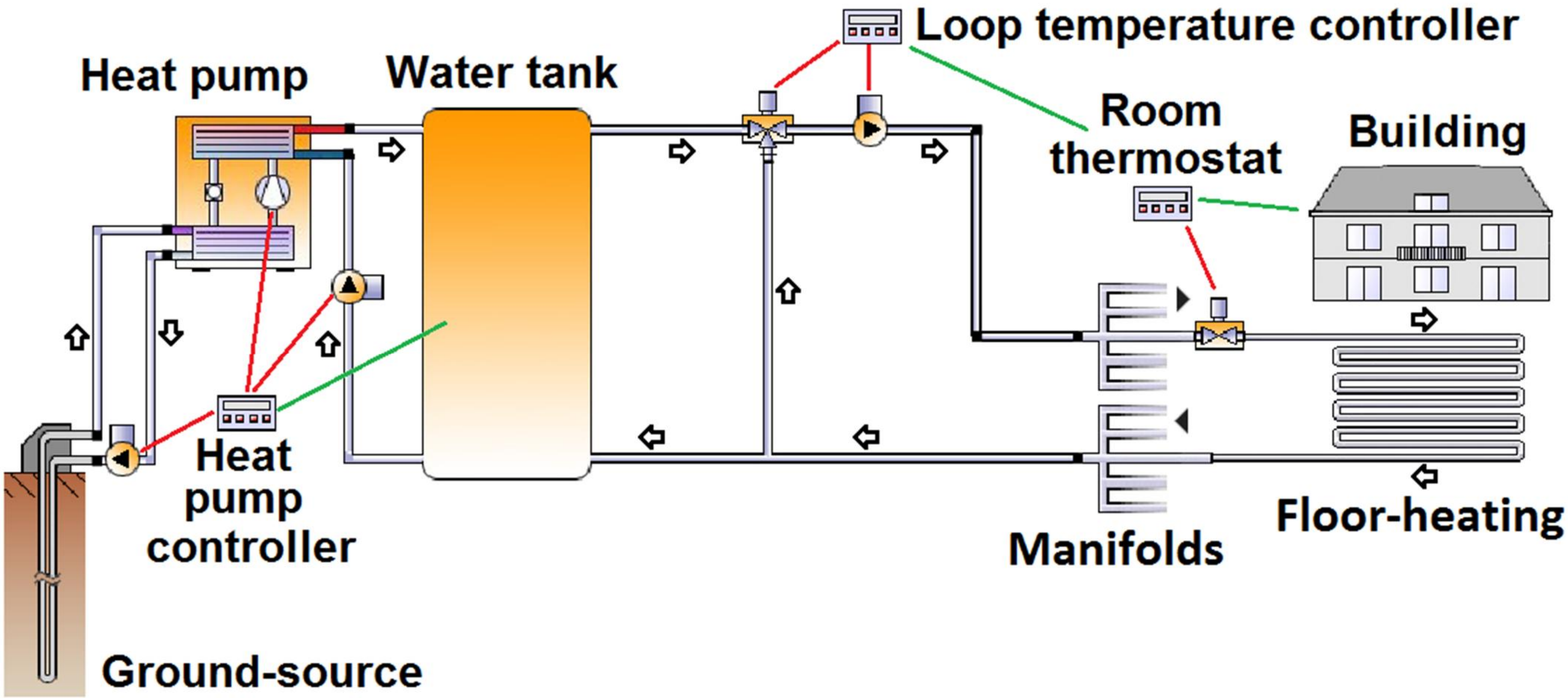
Magnetocaloric Heat Pump: Examples





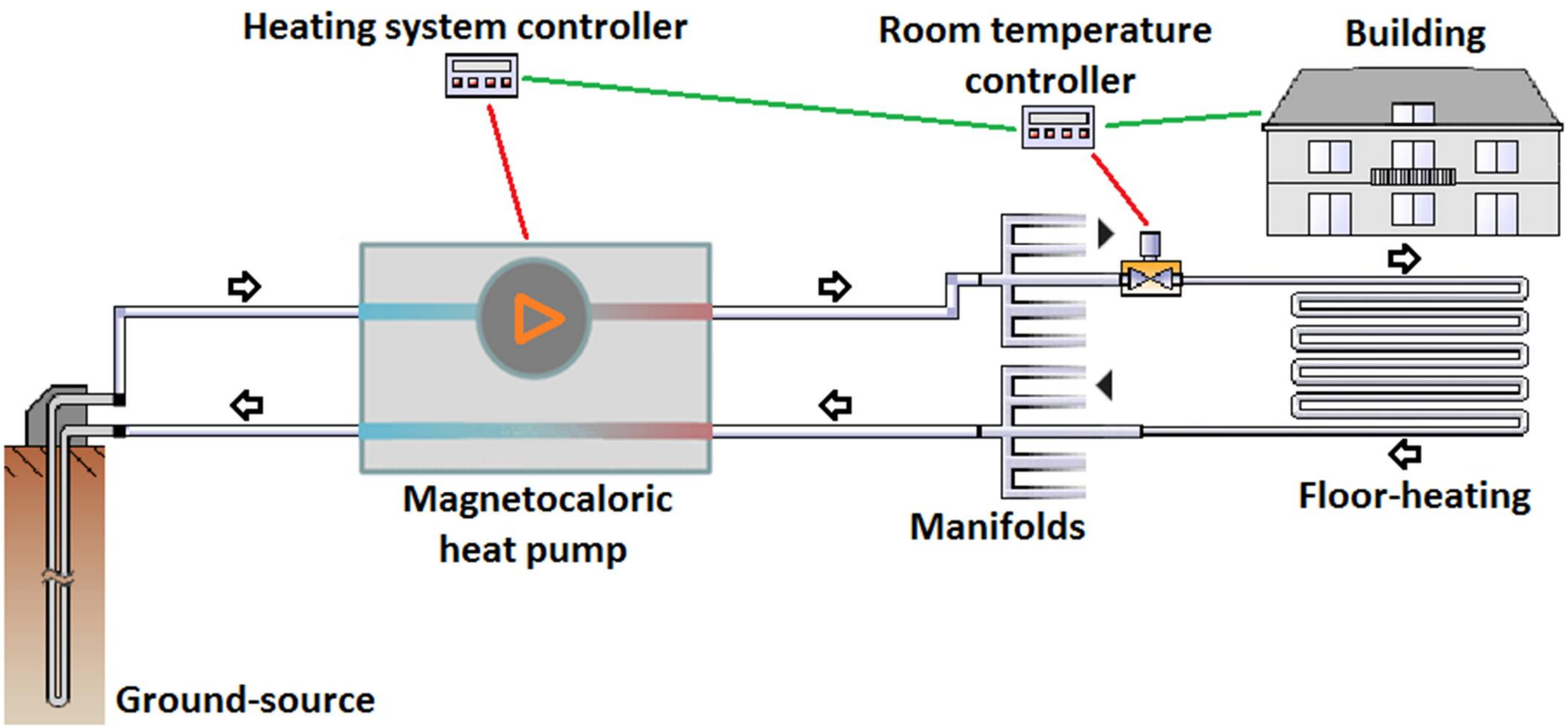
" MagQueen" (new prototype of DTU Risø for EnovHeat project)

Integration of the Vapor-Compression Heat Pump in a Single Family House in Denmark



Integration of a vapor-compression heat pump

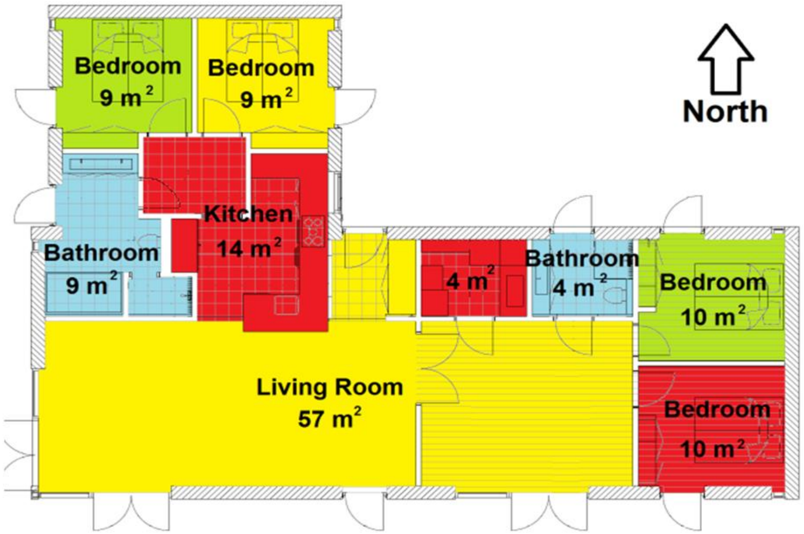
Integration of the Magnetocaloric Heat Pump in a Single Family House in Denmark

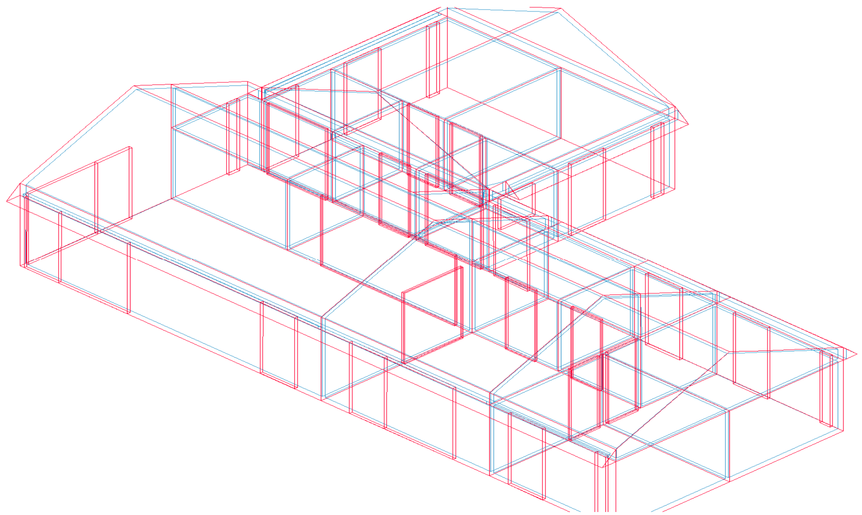


Integration in a single hydronic loop with ground source and under-floor heating

Case Study Building

- Danish single-story house: 150 m²
- Low-energy design "class 2020" : 16 kWh/m².year
- Hydronic radiant under-floor heating system
- Horizontal or vertical ground source heat exchanger
- water-brine: 20 volume% ethylene glycol





Magnetocaloric Heat Pump Modeling

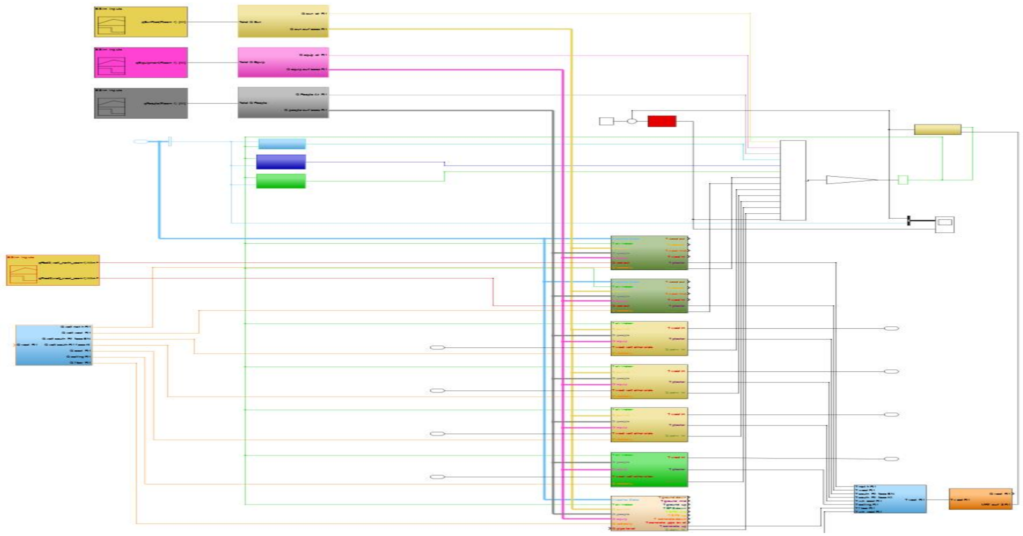
- 5-dimensional lookup table implemented in MATLAB with 1600 points
- Valves average power consumption measured on prototype
- Motor efficiency kept constant
- Pump work modeled with a polynomial from manufacturer's data

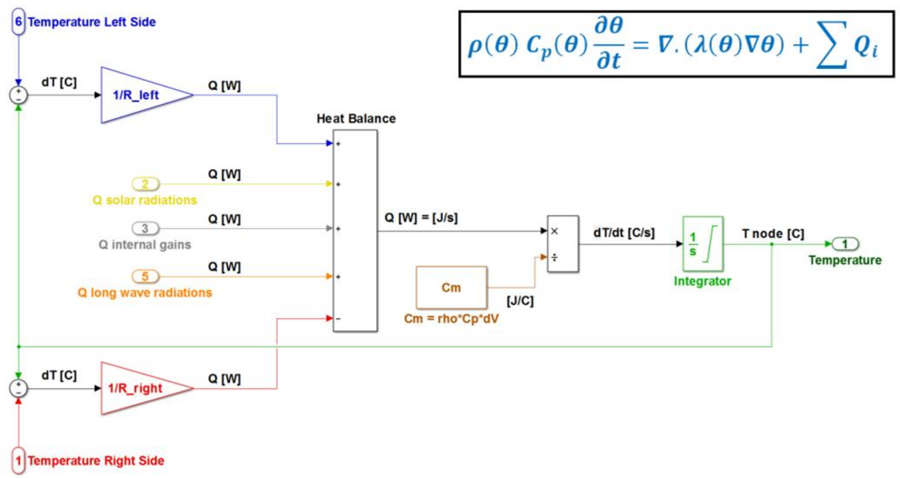
$$\frac{\partial}{\partial x}\left(k_{\text{disp}}A_c\frac{\partial T_f}{\partial x}\right) - \dot{m}_f c_f\frac{\partial T_f}{\partial x} - \frac{Nuk_f}{d_h}a_s A_c\left(T_f - T_s\right) + \left|\frac{\partial P}{\partial x}\frac{\dot{m}_f}{\rho_f}\right| = A_c\varepsilon\rho_f c_f\frac{\partial T_f}{\partial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

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

Building Modeling

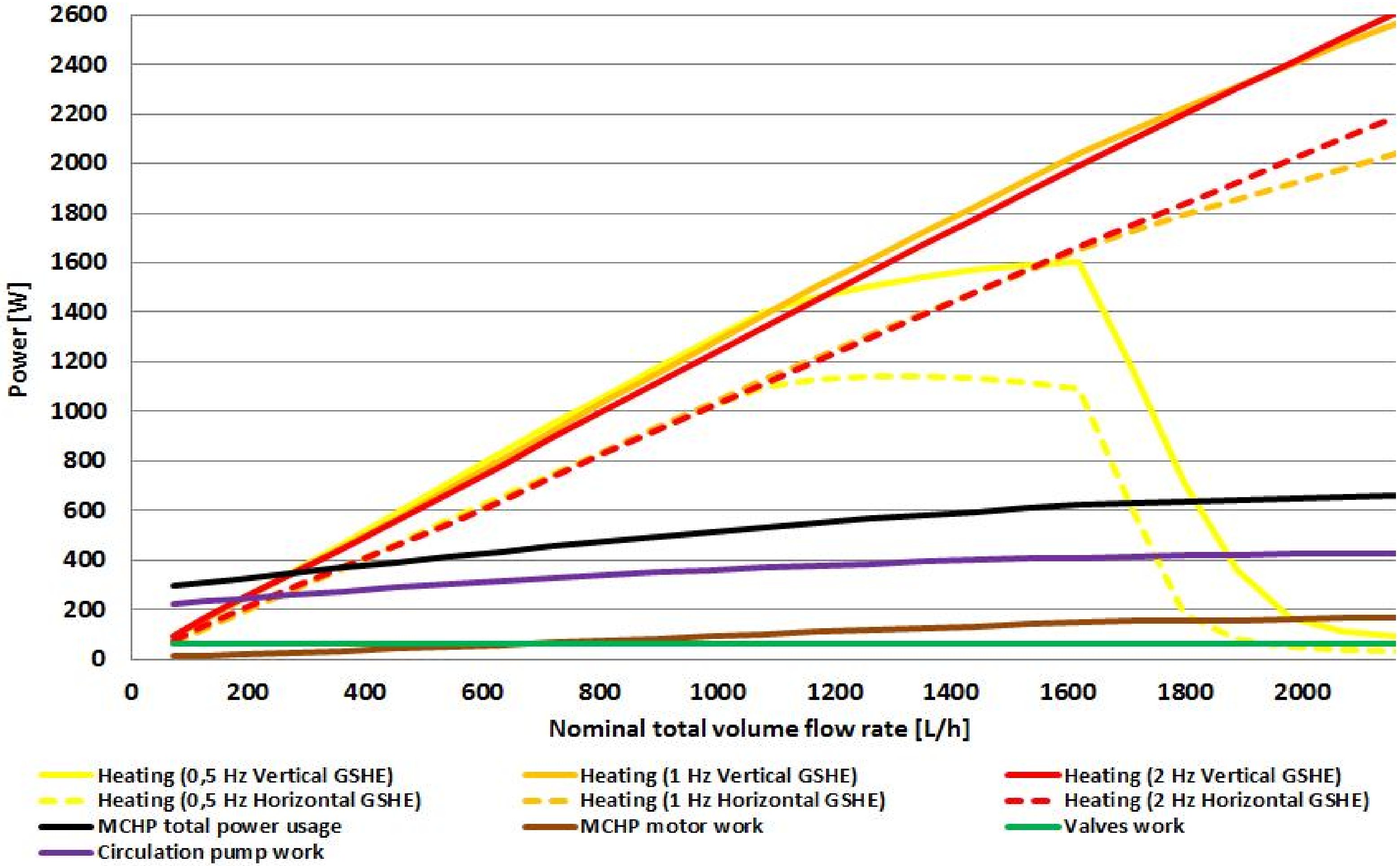
- Multi-zone model of the house in Simulink
- Explicit FVM for heat transfer in construction elements
- Similar to HAM-tool
- Nested MATLAB functions for hydronic elements with ε-NTU model combined with plug flow model





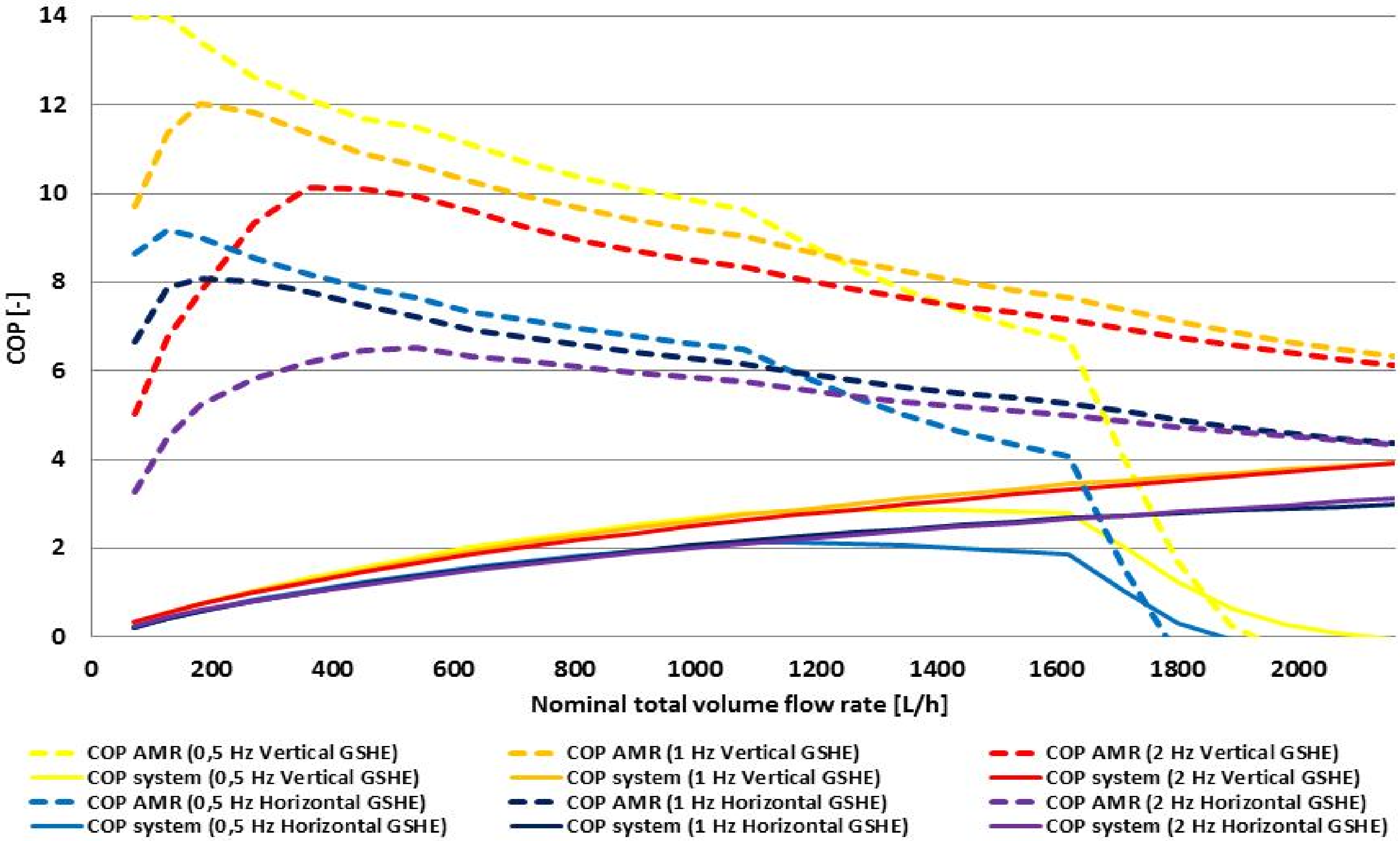
$$\rho(\theta)\, C_p(\theta)\frac{\partial \theta}{\partial t} = \nabla.(\lambda(\theta)\nabla\theta) + \sum Q_i$$

Results



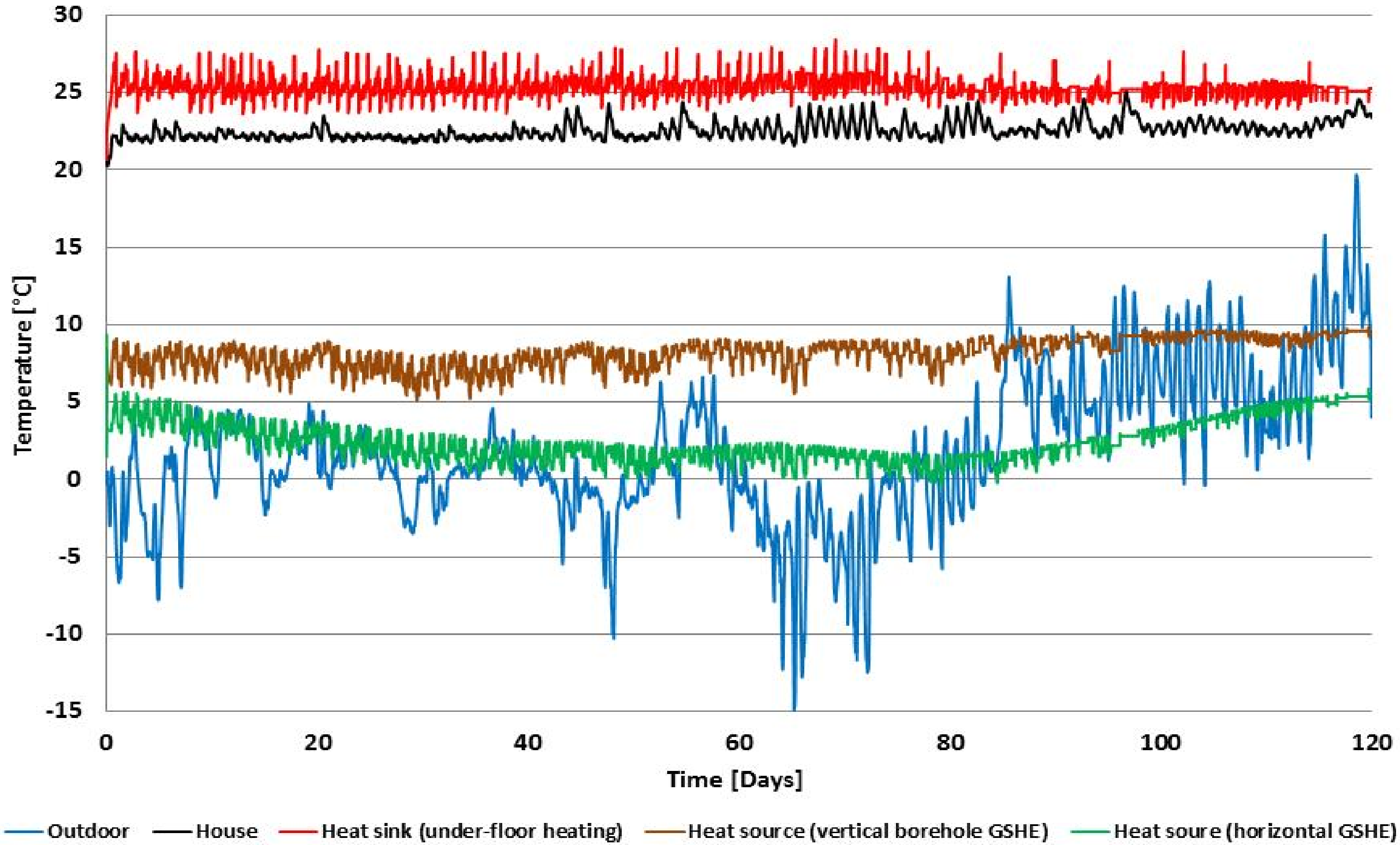
Heating power production and usage of the magnetocaloric heat pump

Results



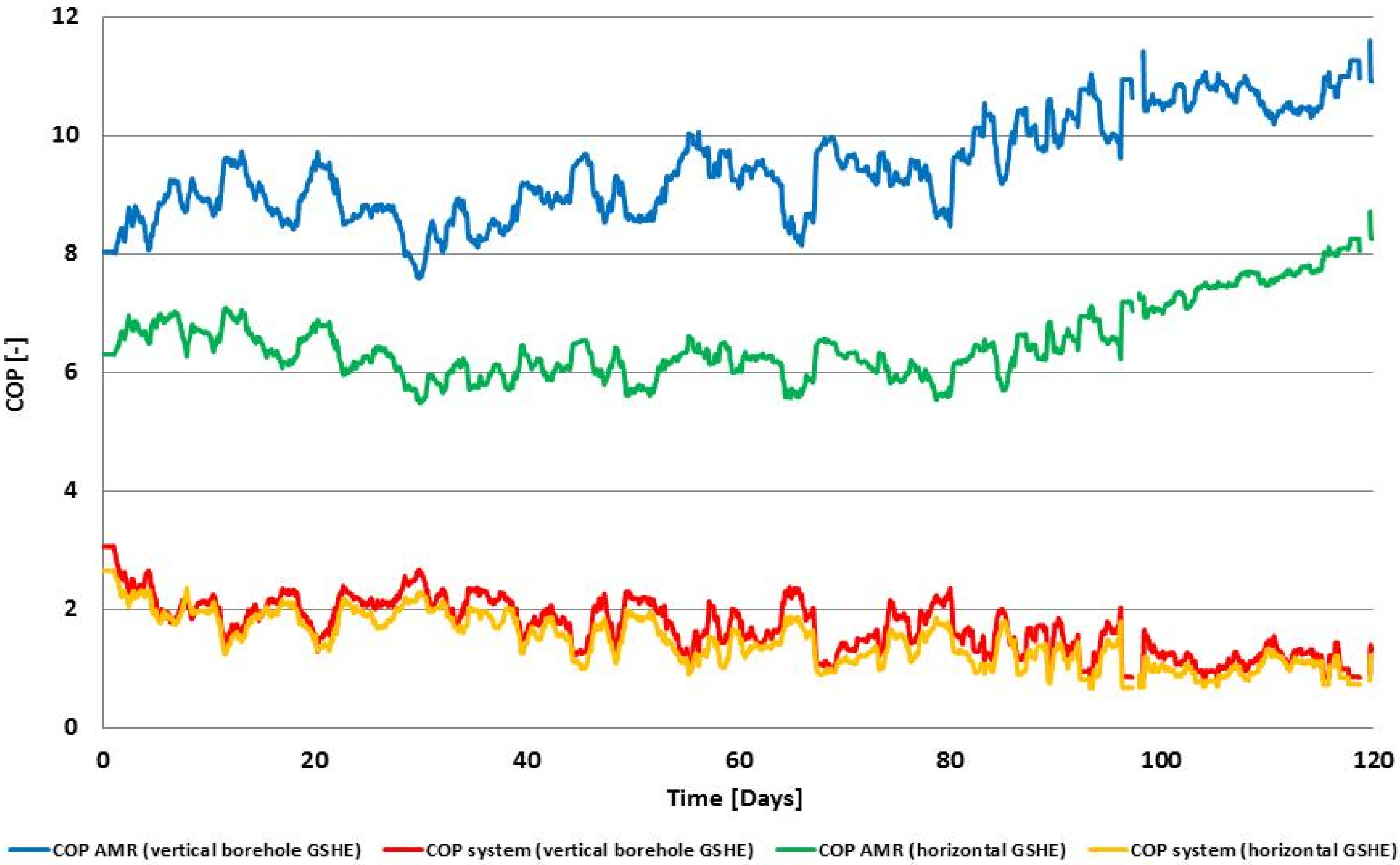
Heat pump COP and total system COP

Results



Four-month test of heating up a house

Results



Daily average COPs during the four-month heating test

Conclusion

- It works !!! (at least in the numerical simulation)
- Can deliver up to 2600 W of heating power with average seasonal system COP of 3.93
- Use of a vertical borehole as a heat source allows better performance
- However, often operates at part-load capacity which decrease total system's COP (1.84)
- Demand side management strategies such as indoor temperature set point modulation for building energy flexibility, could be an interesting solution to improve the heat pump operation

Thank you for your attention !
Any questions ?

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