Karlsruher Institut für Technologie

Heat transformation and storage facility

Efficiency enhancement of transcritical CO_2 heat pump by coupling to adsorption unit and storage integration

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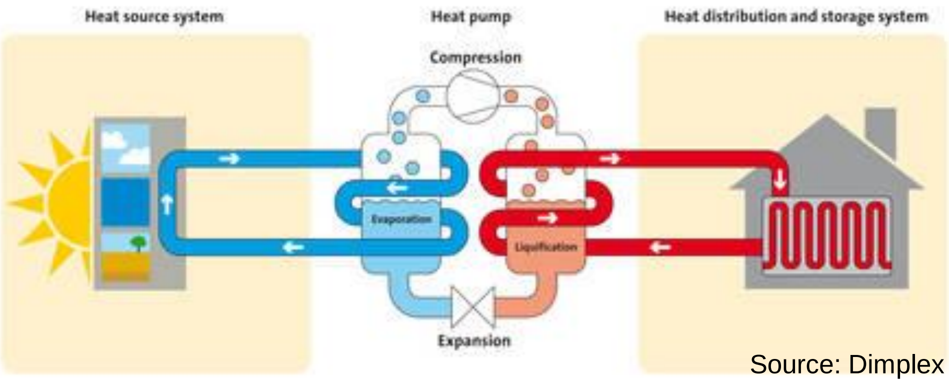
Motivation

- Challenges for building sector in energy transition:
  - Reduce greenhouse gas emissions through
    - Improved building shells (e.g. passive house concept)
    - Decarbonization of heating & cooling technologies

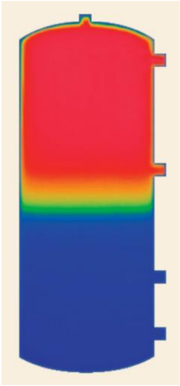
    => Compression heat pumps as
    key technology / component



Source: Dimplex

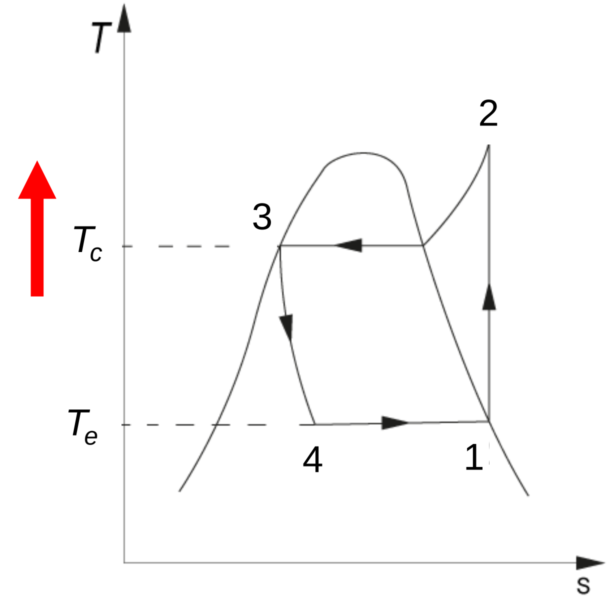
  - Provide flexibility to power sector:
    - Adapt power use to fluctuating renewable supply (PV, wind)
    - Feed power back to grid at times of low supply (cogeneration)

    => Thermal storage as key technology / component



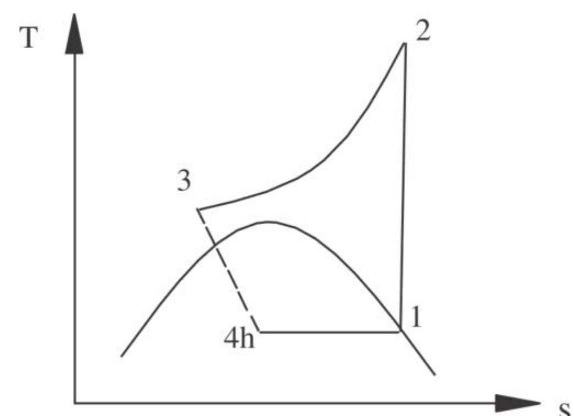
Motivation (II)

- Key Challenge for system integration of compression heat pumps with thermal storage:
  - By far most relevant thermal storage type is hot water storage (sensible)
  - Heat pump performance deteriorates when charging storage (above required heating temperature) due to increased temperature lift)



- Latent storage (PCM, nearly isothermal charging) would provide better fit to heat pump cycle => cost competetive?

- Our approach: Transcritical heat pump cycle (CO_2) coupled to stratified storage

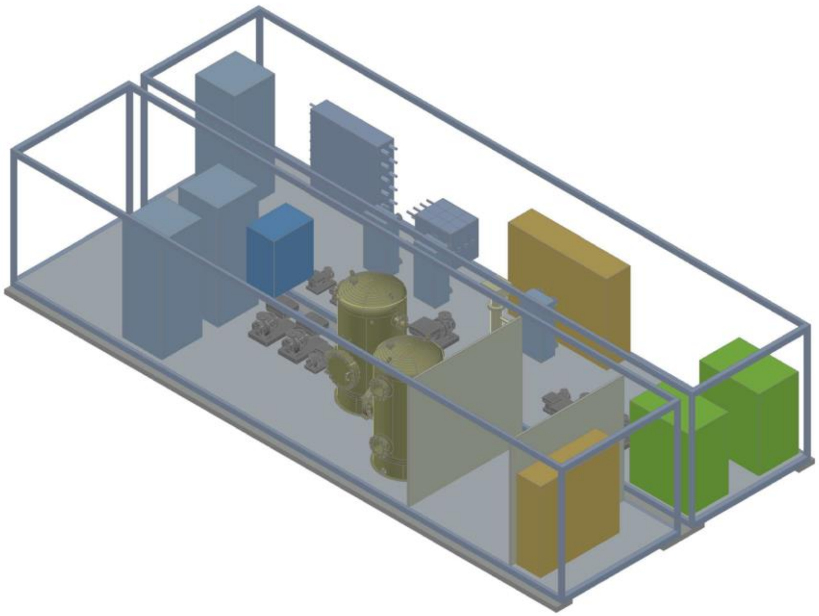


Source: Ma et al., Energy (2013).

Heat transformation and storage facility planned at KIT-INR

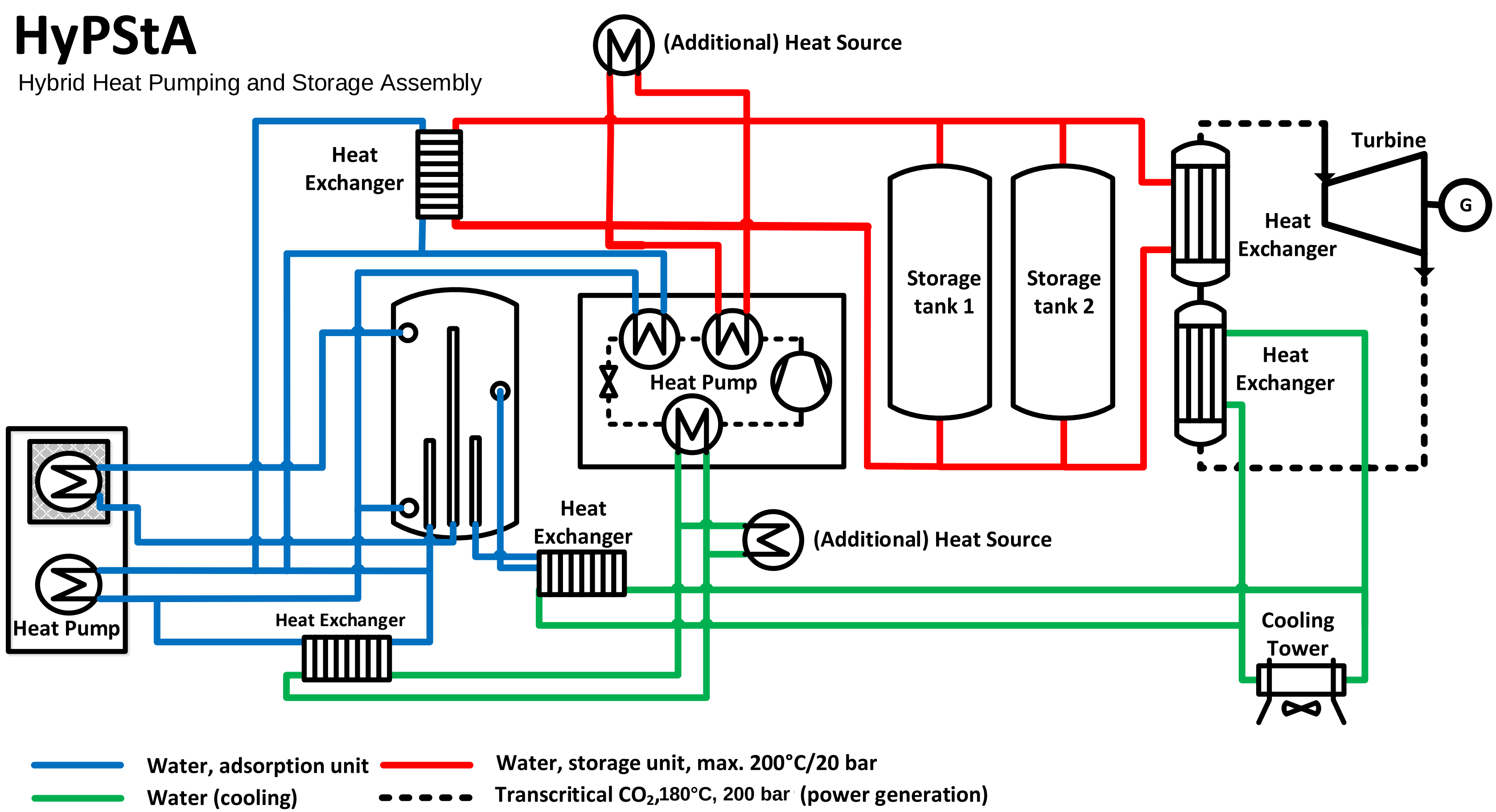
HyPStA: „Hybrid Heat Pumping and Storage Assembly“

- Technical scale assembly realized in two high cube containers
- Stratified hot water storage (2x 2.5 m³, 200°C, 20 bar) as central component
- Analysis of charging and discharging processes with transcritical CO_2 heat pump and CO_2 power loop
  - Coop with KIT Institute of Thermal Turbomachinery (ITS)
- A platform for scientific tasks as well as for applied research
- A hub for teaching and scientific exchange

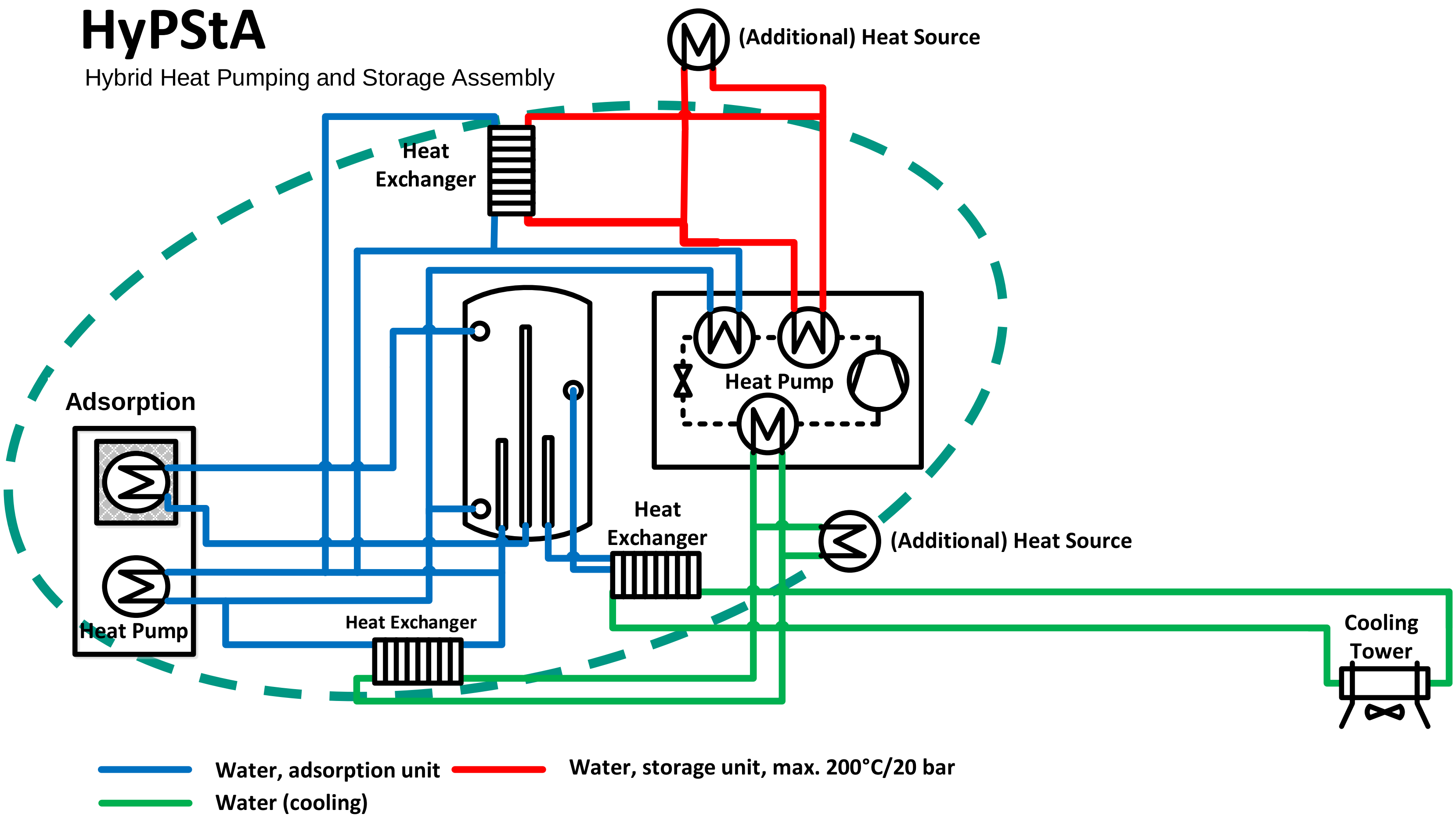


Basic circuit diagram

Simplified circuit diagram mostly without pumps, valves and instrumentation

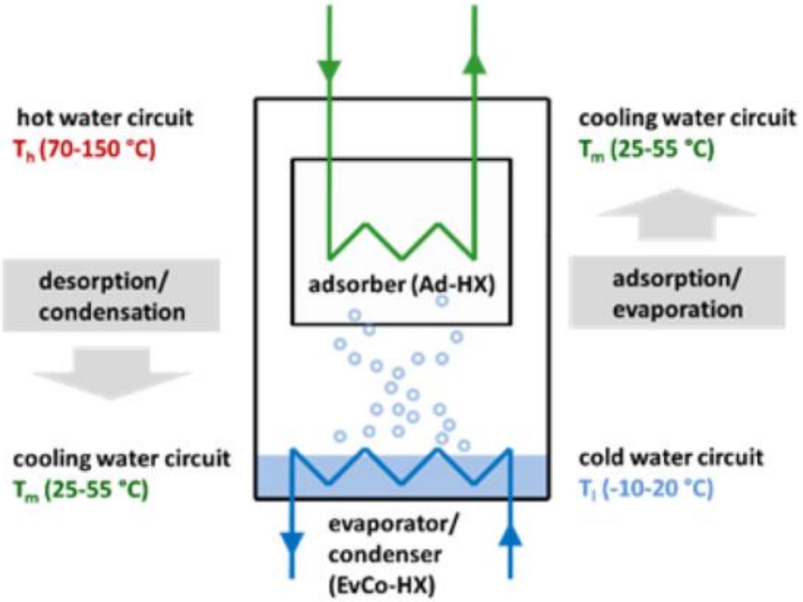


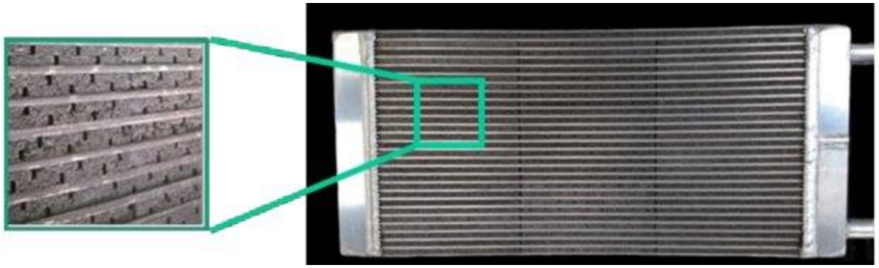
Hybrid Heat Pump: Transcritical CO_2 compression + auxiliary adsorption cycle



Motivation for adsorption heat pump integration

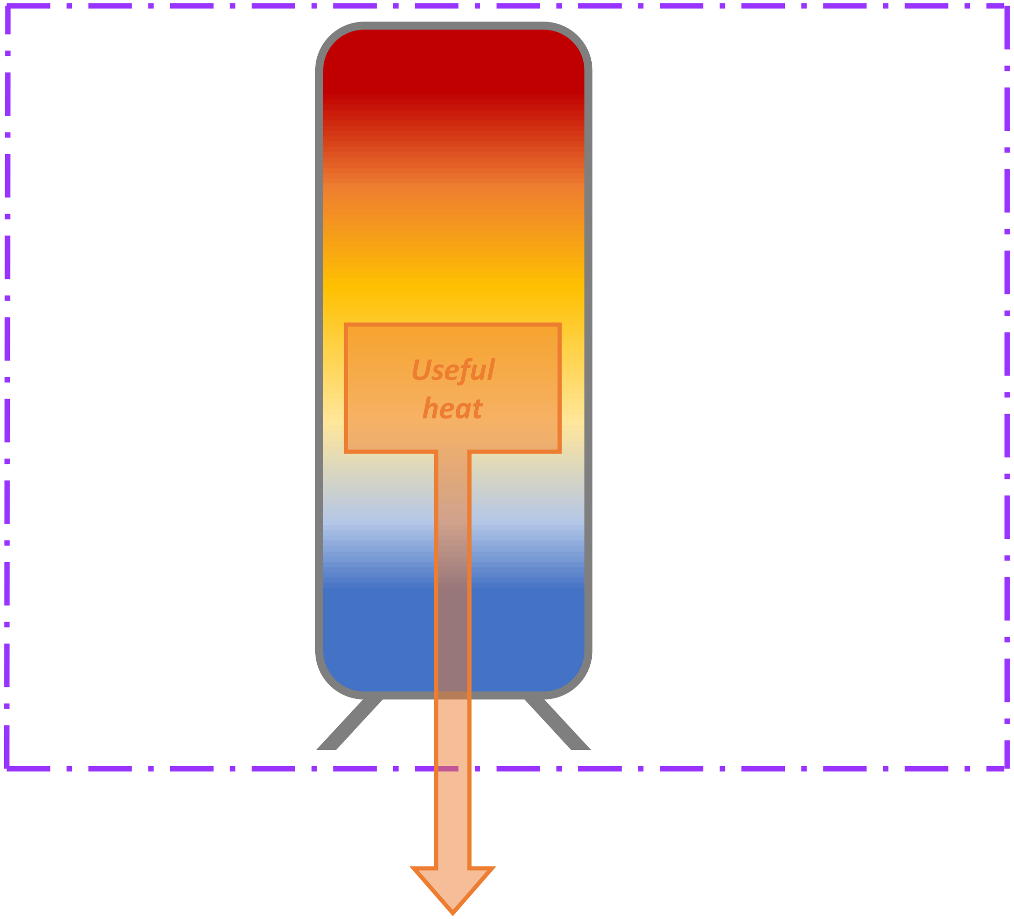
- Performance of CO_2 heat pump (COP) strongly dependent on gas cooler return temperature
- At typical operating points for heating renovated buildings, COP of CO_2 HP is not competitive to other heat pumps / working fluids
- Integration auf auxiliary adsorption HP cycle reduces gas cooler return temperature and increases efficiency





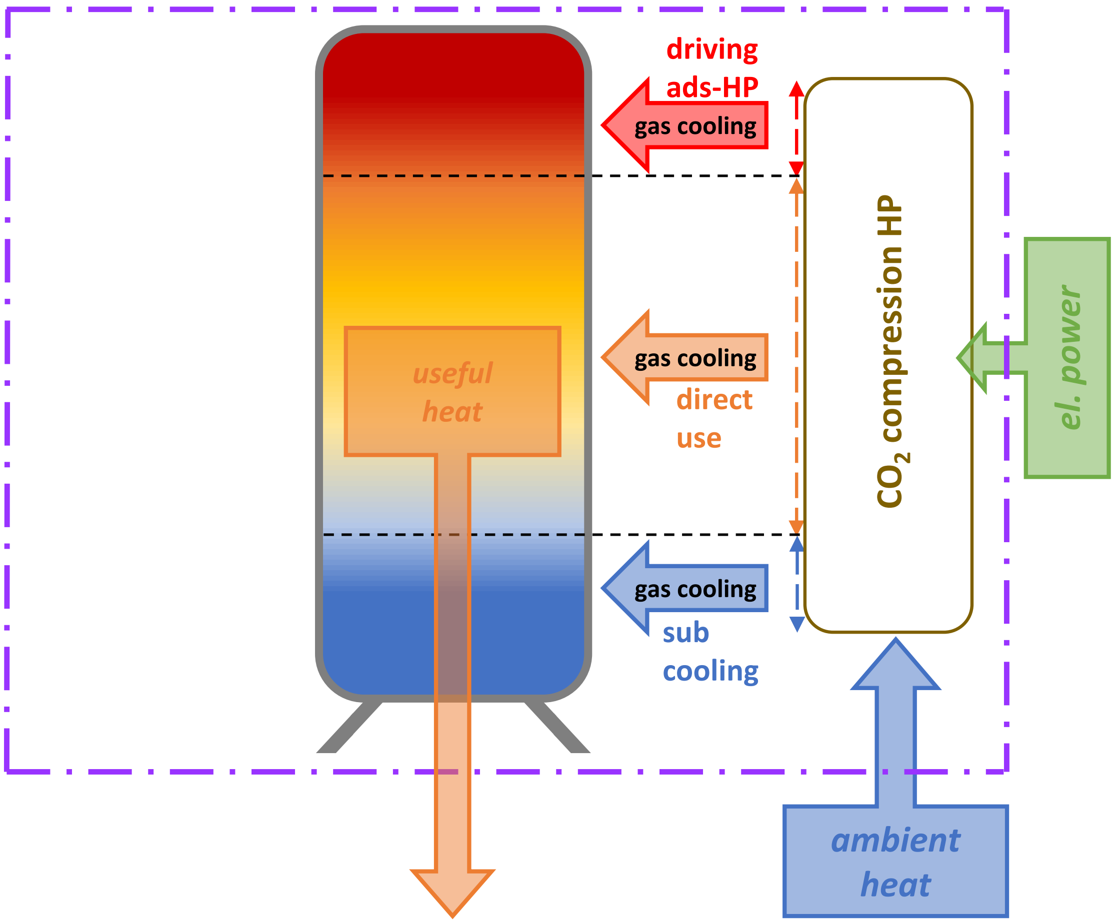
Source: Wittstadt et al., IEA Heat Pump Conf. 2017

Hybrid Heat Pump: Transcritical CO_2 compression + auxiliary adsorption cycle



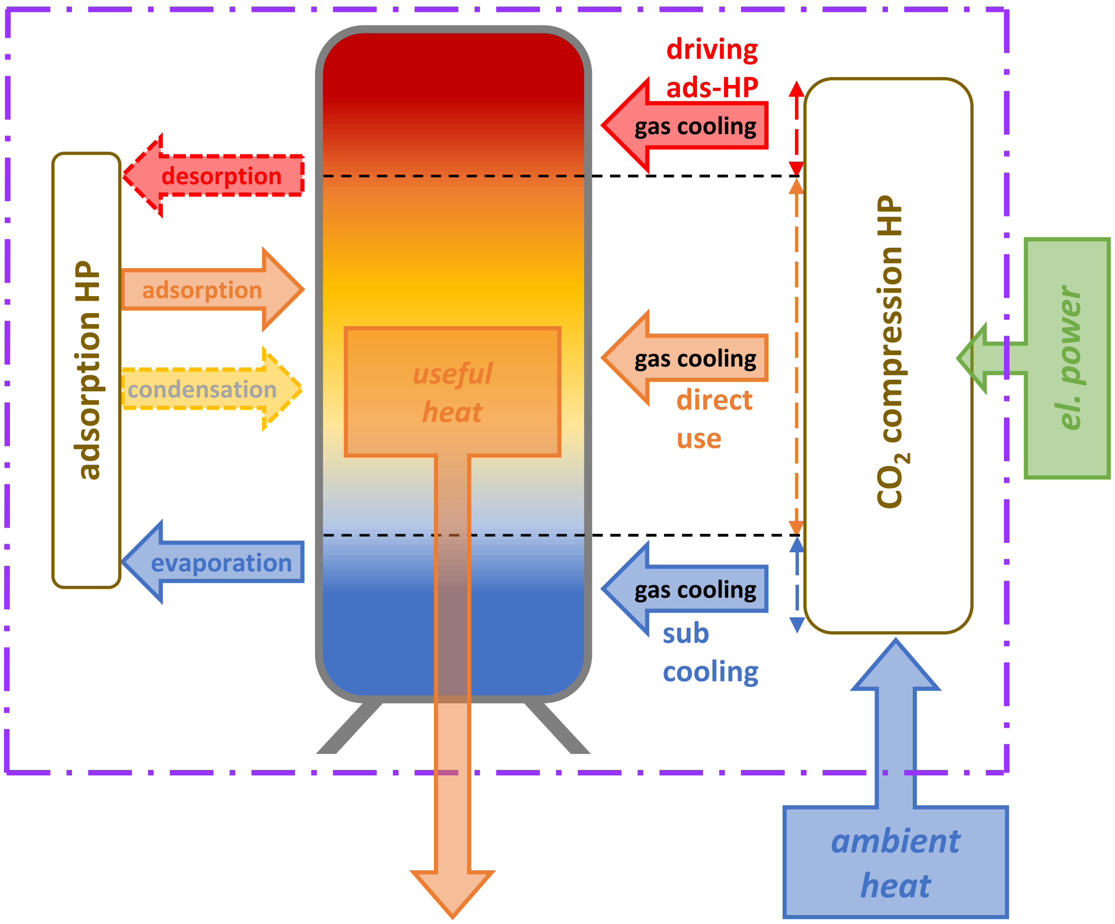
- Stratified storage
  - three zones
  - delivery of useful heat (middle zone)

Hybrid heat pump: Concept



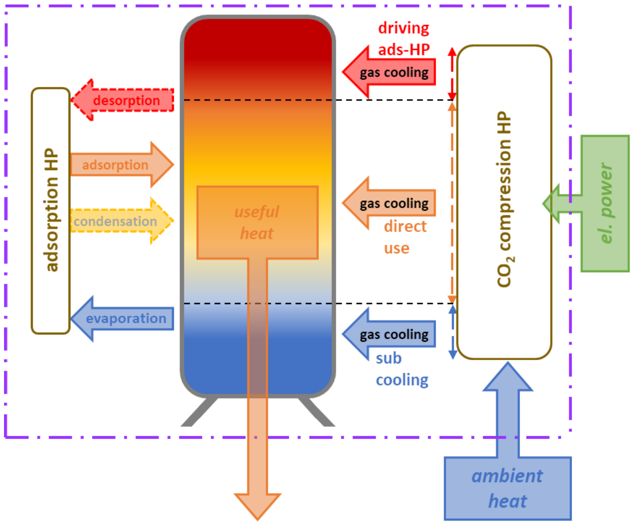
- Stratified storage
  - three zones
  - delivery of useful heat (middle zone)
- Compression HP
  - heat supply to storage (all zones)

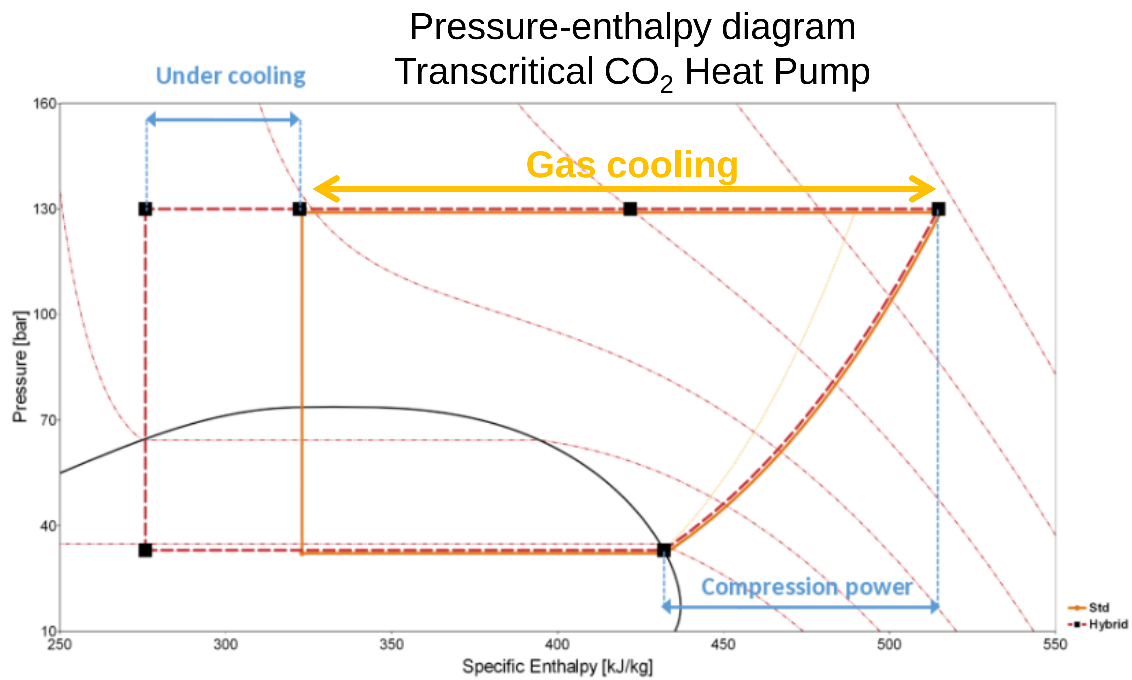
Hybrid heat pump: Concept



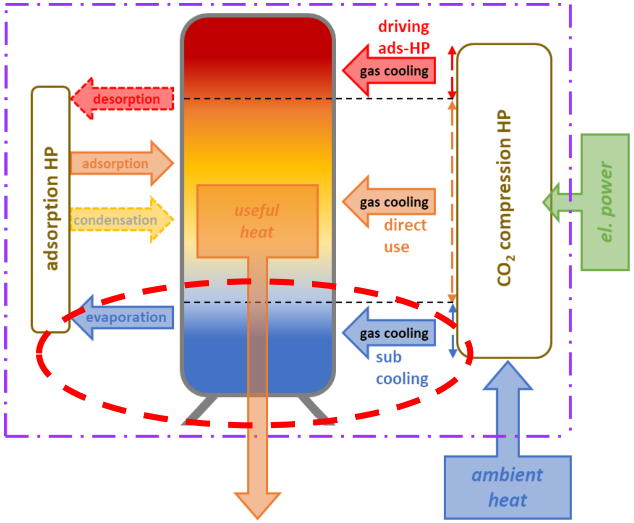
- Stratified storage
  - three zones
  - delivery of useful heat (middle zone)
- Compression HP
  - heat supply to storage (all zones)
- Adsorption HP
  - cool bottom zone of storage (evap.)
  - cool top zone of storage (desorp.)
  - heat middle zone (adsorp., cond.)

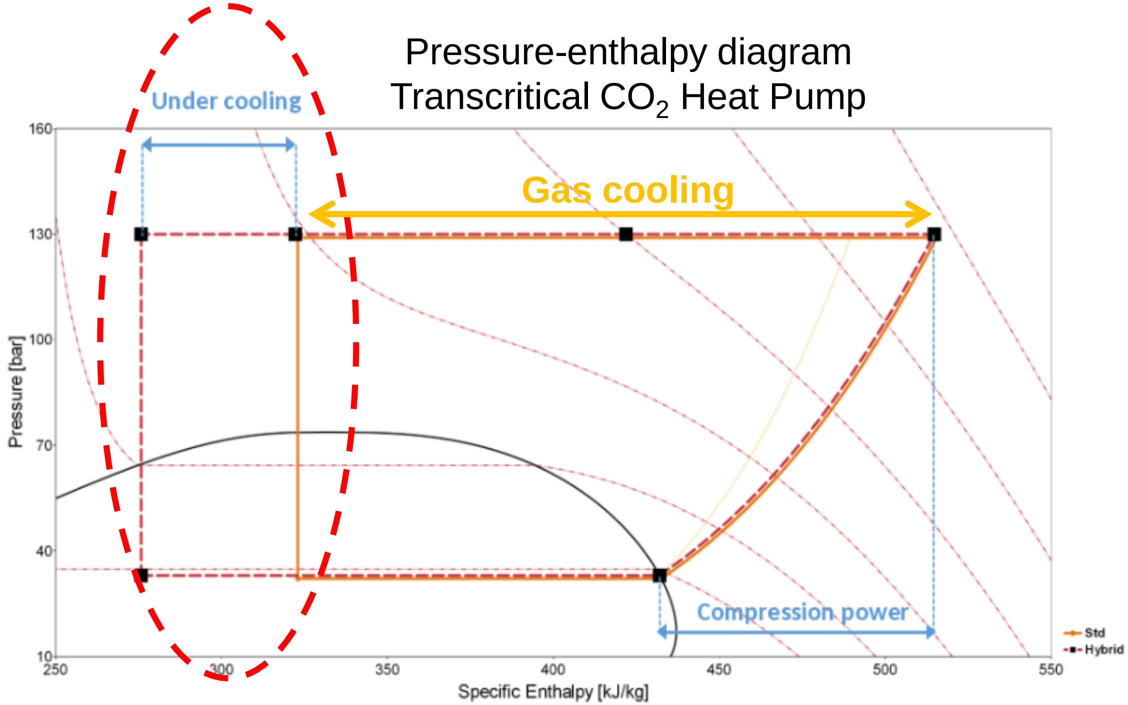
Hybrid heat pump: Cycle





Hybrid heat pump: Cycle





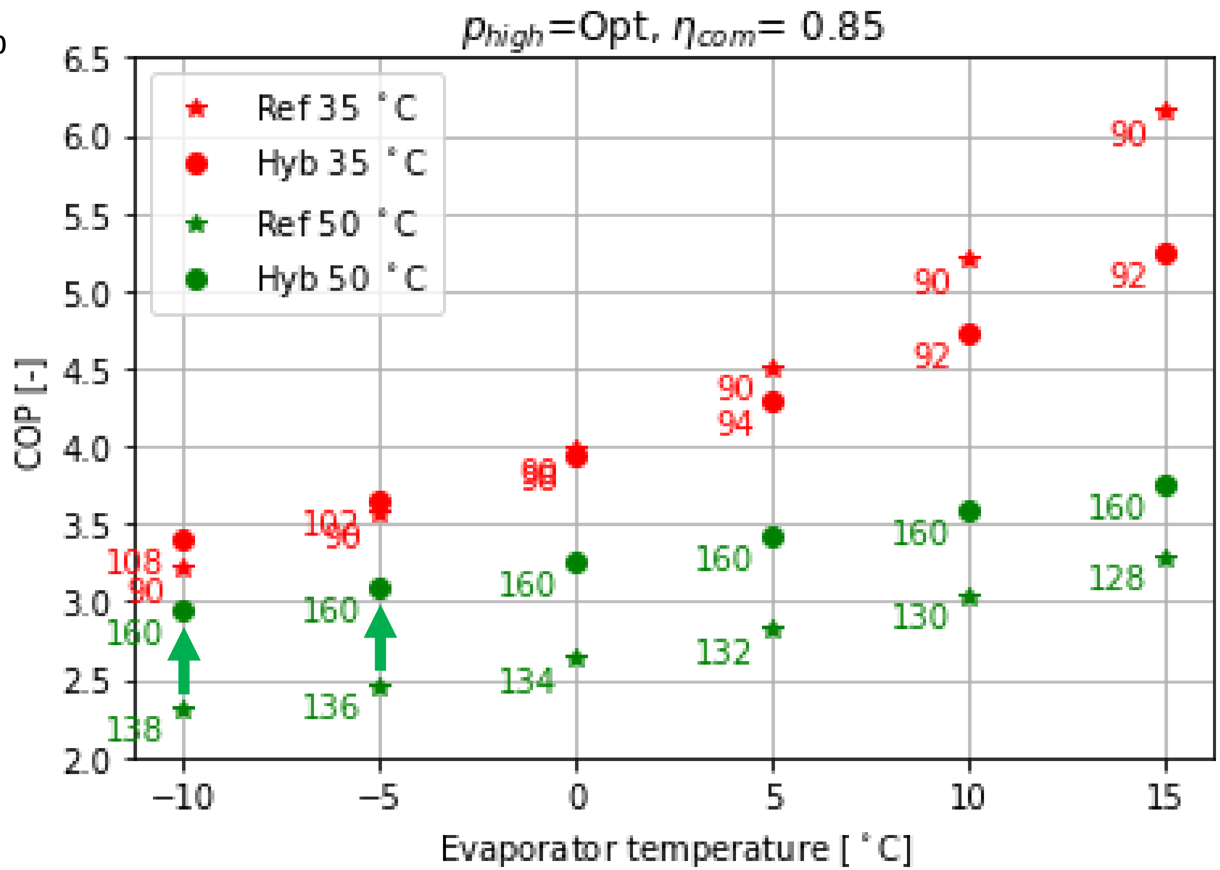
- Subcooling (below sink temperature, e.g. heating return temperature) => COP ↑

Hybrid heat pump: Initial cycle comparison results

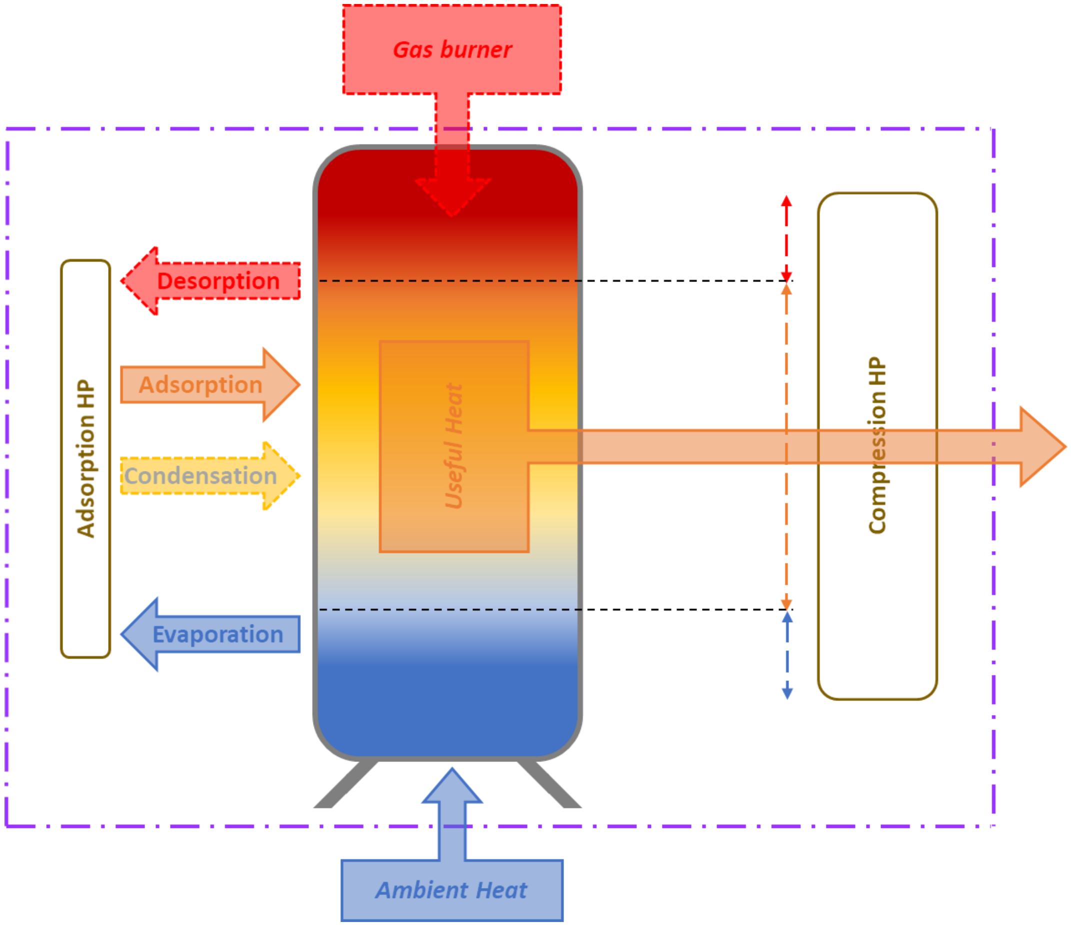
Comparison of pure CO_2 HP cycle (Ref) with hybrid (Hyb)

Assumptions :

- Compressor efficiency 85%
- Optimal high pressure chosen for each cycle in range [90,160] bar
- Adsorption cycle COP 0.5
- Temp range >80°C usable for desorption
- Two mimimum heat sink temperatures considered (heating return flow): 35°C, 50°C
- Result: Highest gain from hybrid cycle at worst operating conditions



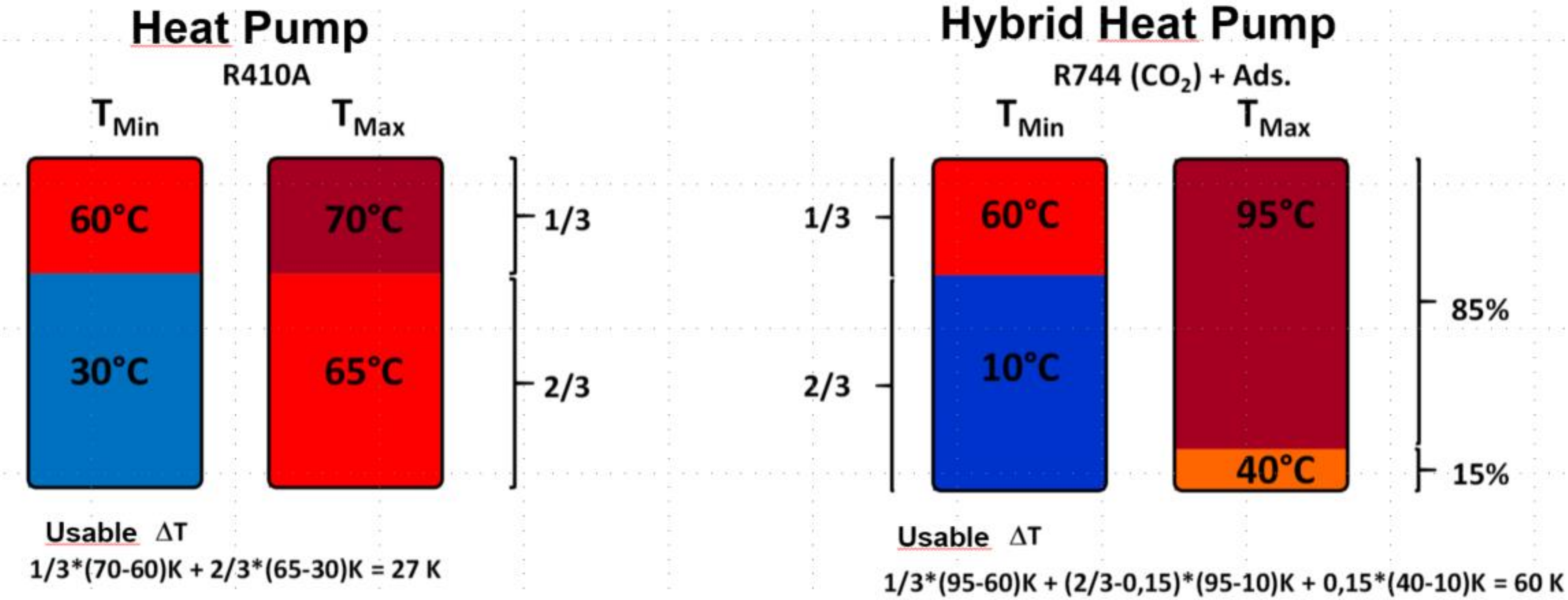
Hybrid heat pump: Gas heat pump mode



- Fallback operation mode in case of power scarcity
- Compression HP not in use
- Adsorption subsystem now works as gas driven heat pump
- ~20% more efficient than gas boiler

Hybrid Heat Pump: Advantage in storage integration

- Consider typical combi storage (domestic hot water & heating) for residential building
- Comparison of minimal and maximal state of charge of storage between conventional compression heat pump (subcritical cycle) and hybrid CO_2 heat pump
- Usable storage density can be increased by factor ~2



Thank you!

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