Decarbonizing Steam Generation with High Temperature Heat Pumps

Refrigerant Selection and Flowsheet Evaluation

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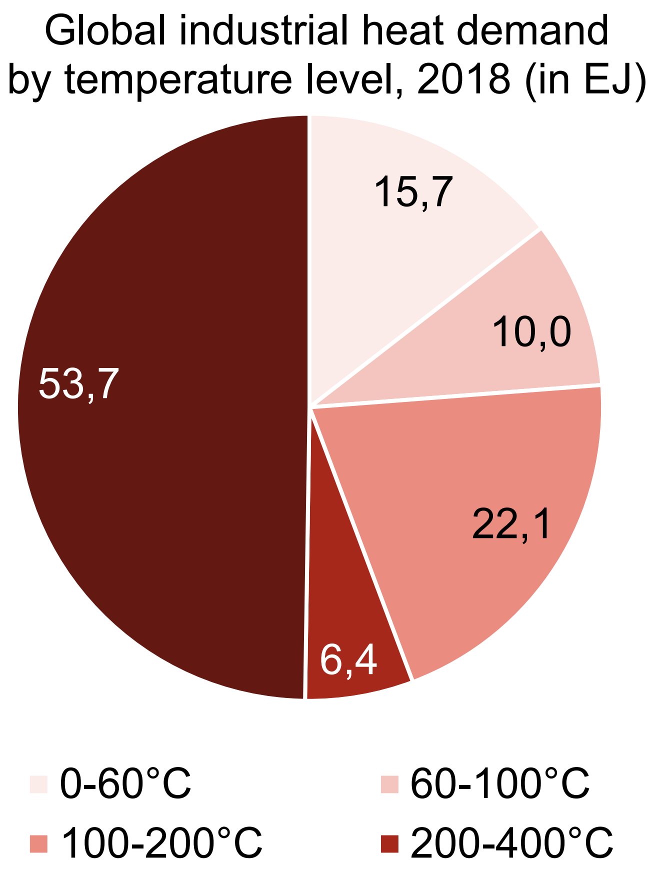
Emission saving potential of industrial heat pumps

- Short- and medium-term substitution of applications with natural gas
  - Heat pumps enable electrification and utilization of renewable energies
- Higher temperature levels in industrial applications require adjustments to the refrigerant cycle
  - Refrigerant (e.g. ammonia)
  - Flowsheet
- High demand for steam in industrial applications
  - Relatively new topic compared to A/C units and residential heat pumps
  - Little literature so far
  - Challenge: sensitive and latent sink

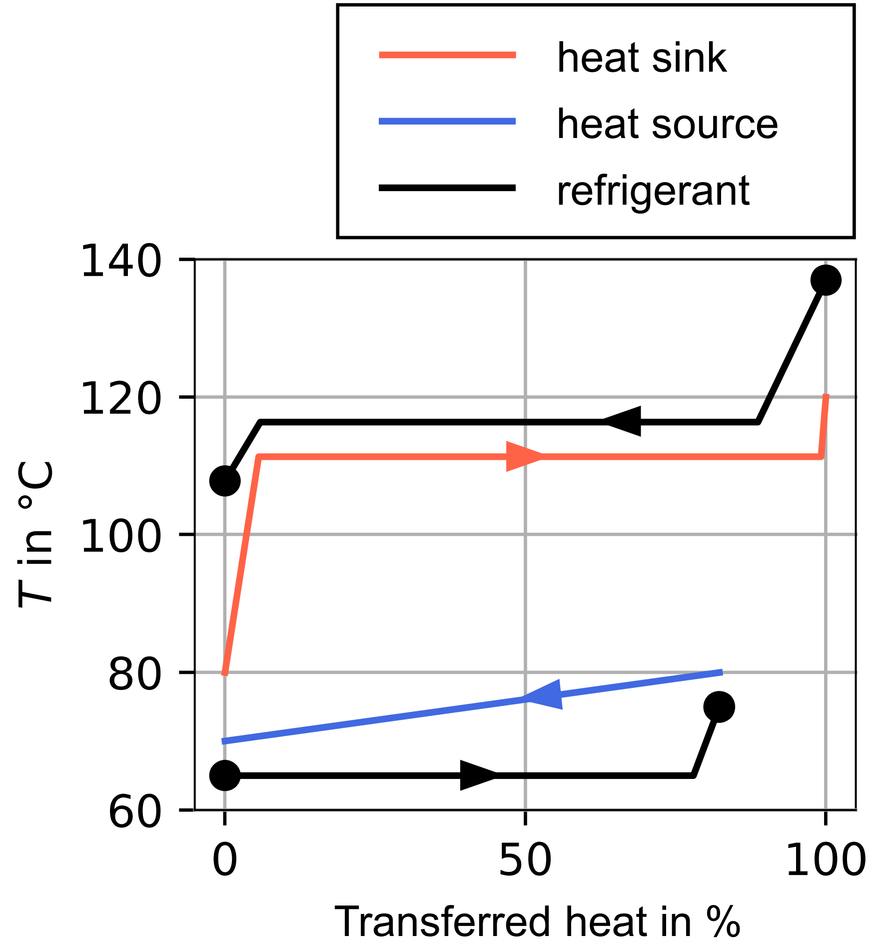


Source: https://www.iea.org/data-and-statistics/charts/industrial-heat-demand-by-temperature-range-2018

Steam generation with high temperature heat pumps

- Generation of steam at 1.5 bar
  - Inlet in condenser at 80 °C
  - Evaporation temperature of water approx. 111 °C
  - Outlet of condenser 120 °C

- Heat source transfers sensible heat



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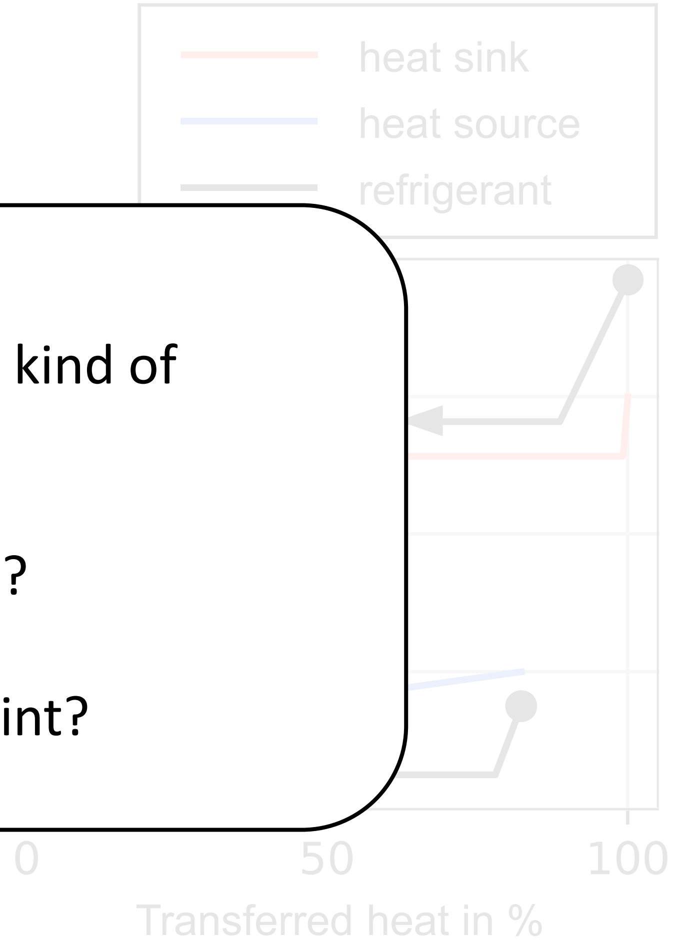


Focus of the present case study

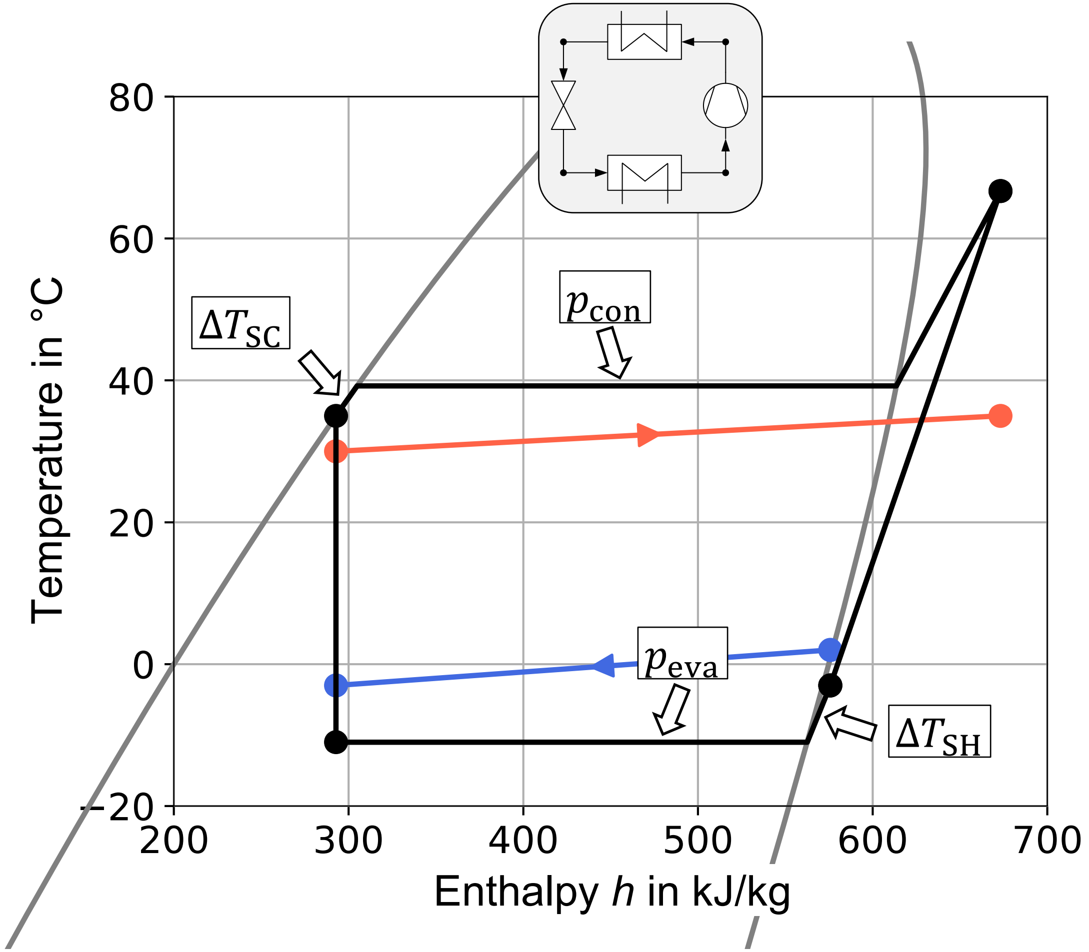
1. Which refrigerants have high potential for this kind of application?
2. Which flowsheets shows highest performance?
3. Are the results influenced by the operating point?

Cycle calculation

- Based on optimization
  - Specific calculation
  - Constraints for thermodynamic feasible operation

$$\text{Target function: } \max(COP)$$

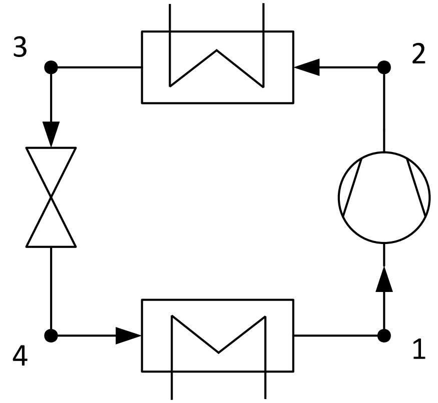
- Optimization of process parameters
  - Evaporation pressure p_{eva}
  - Condensation pressure p_{con}
  - Superheating at compressor inlet ΔT_{SH}
  - Subcooling at condenser outlet ΔT_{SC}



Overview of investigated flowsheets

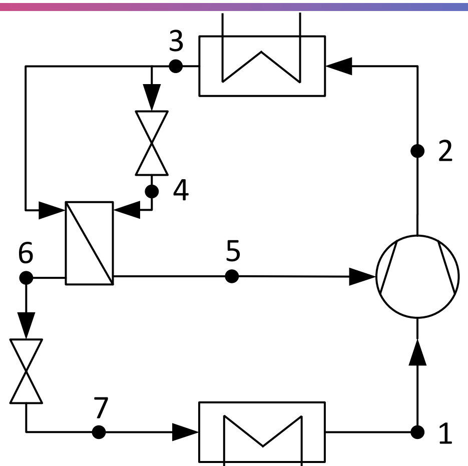
Simple cycle *(simple)*

- Reference



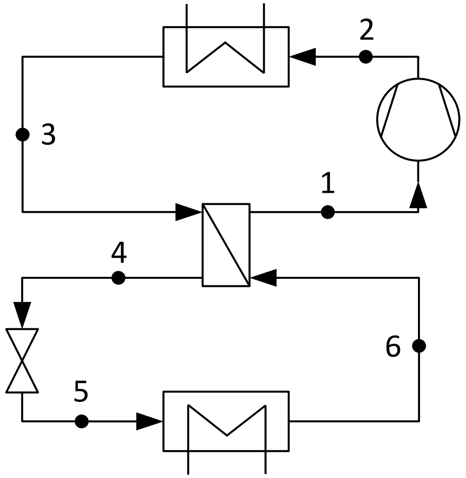
Vapor injection *(vi)*

- Increase in heating capacity



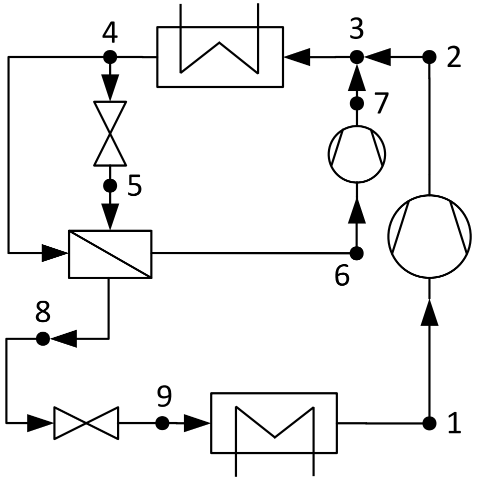
Ihx cycle *(ihx)*

- Shift of superheating from evaporator to ihx



Parallel compression *(pc)*

- Two compressors



Overview of investigated flowsheets

<u>Simple cycle</u> *(simple)*

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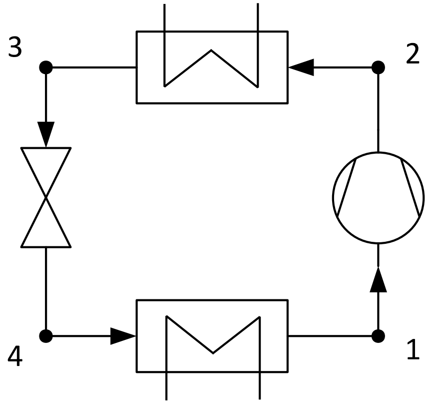

<u>Vapor injection</u> *(vi)*

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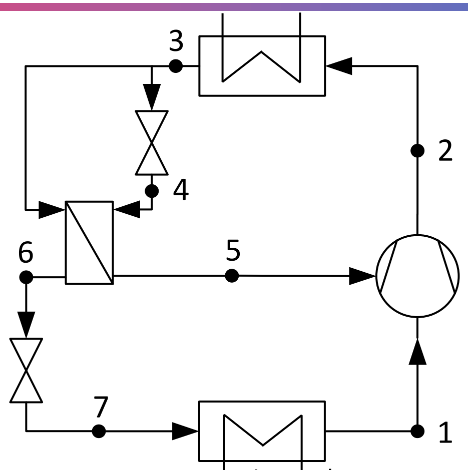
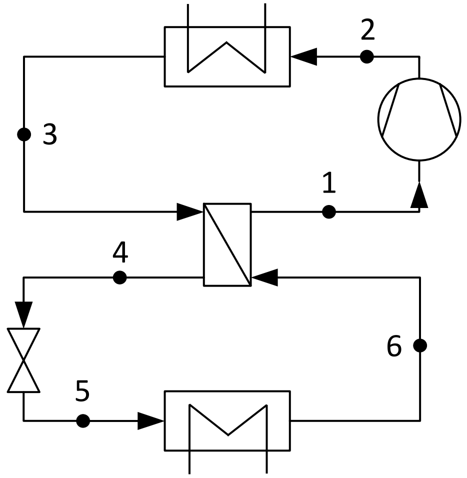


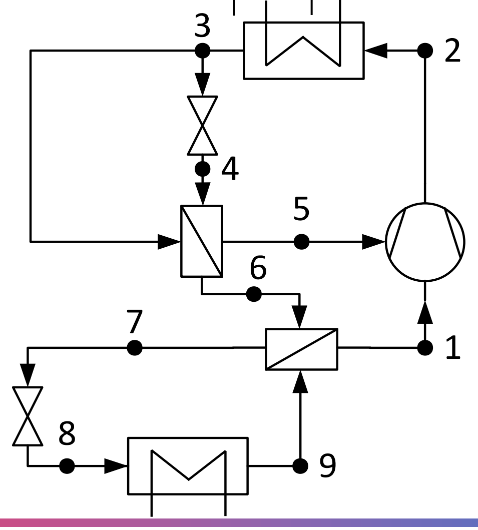
<u>Ihx cycle</u> *(ihx)*

- Shift of superheating from evaporator to ihx



<u>Vapor injection with ihx</u> *(vi-ihx)*

- Combination of vi and ihx flowsheet



Overview of investigated flowsheets

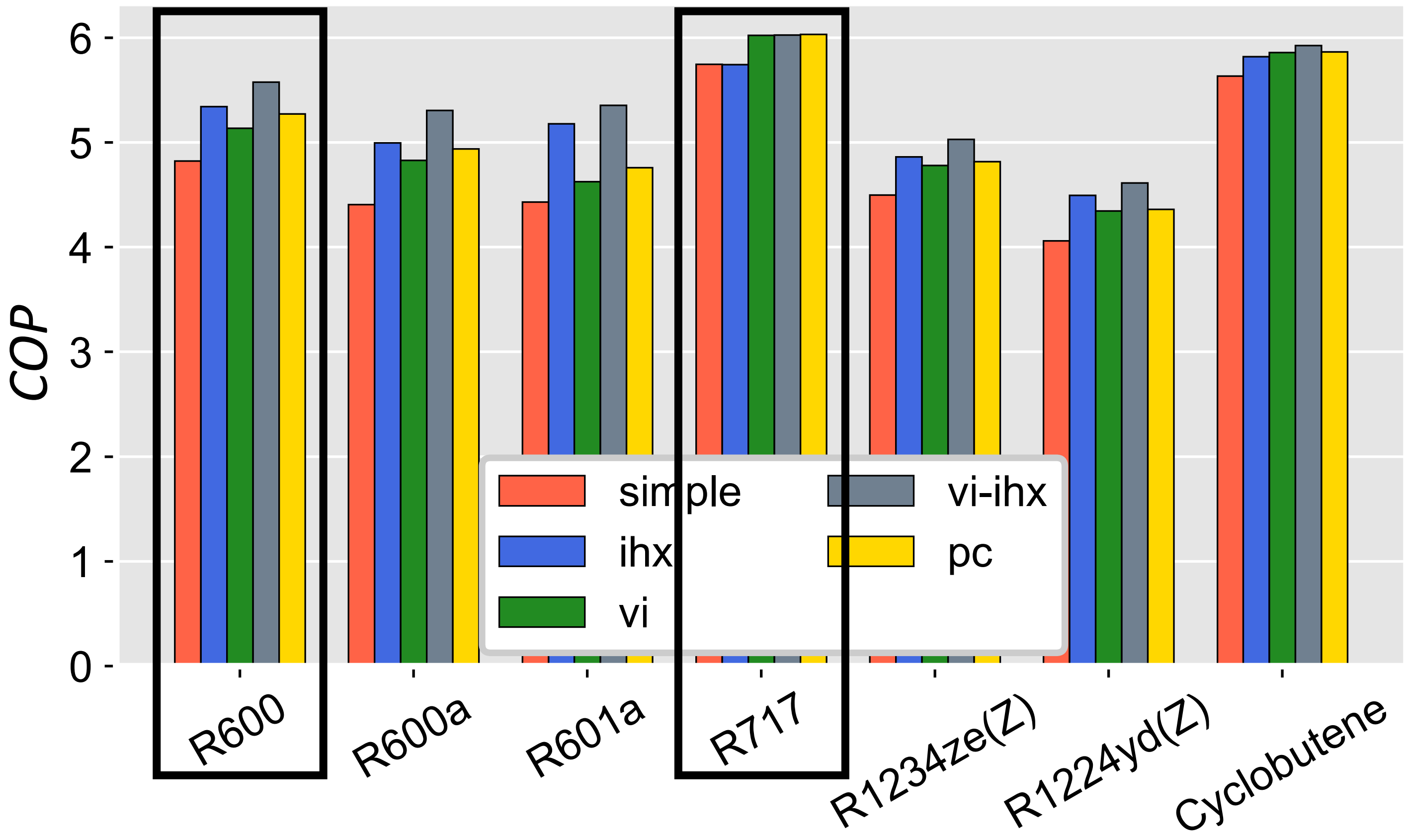
Case study

- Heat Sink
  - 80 °C to 120 °C
  - Evaporation of water: 111 °C @ 1.5 bar
- Heat Source
  - 10 K temperature difference
  - Inlet varying from 40 to 80 °C

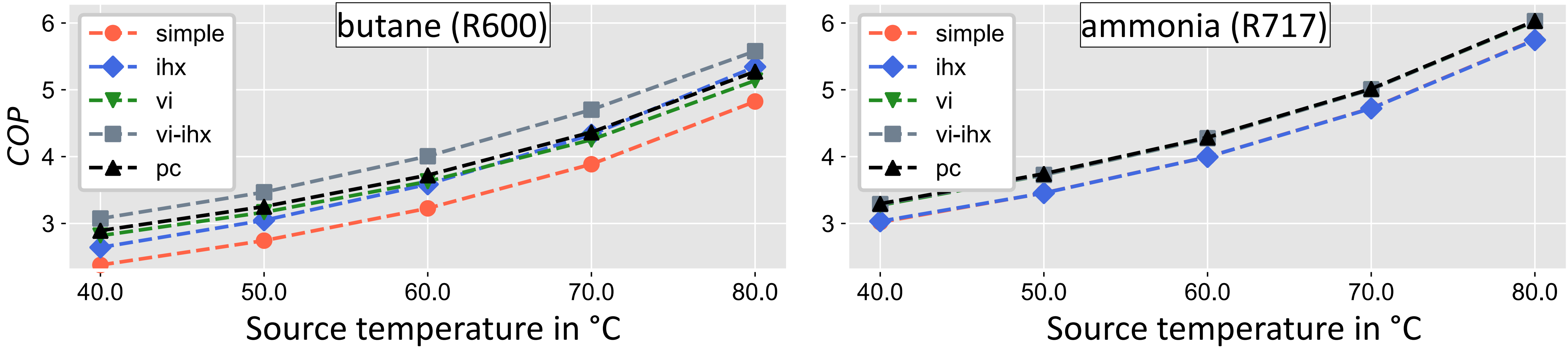
- Refrigerants
  - 15 fluids selected based on properties (further details in paper)
  - Presentation includes 7 representative fluids

Results – Source temperature 80 °C

- Performance depend on refrigerant and flowsheet
- Ammonia and cyclobutene show highest efficiency
- HFO show relatively low efficiencies
- Vi-ihx cycle leads to highest performance

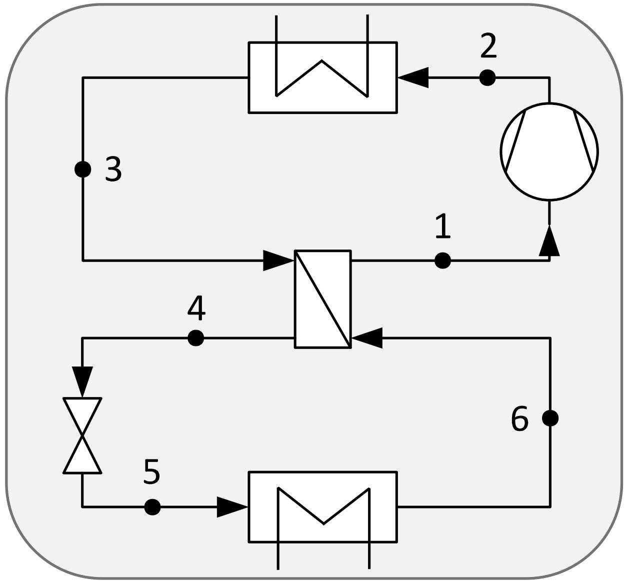


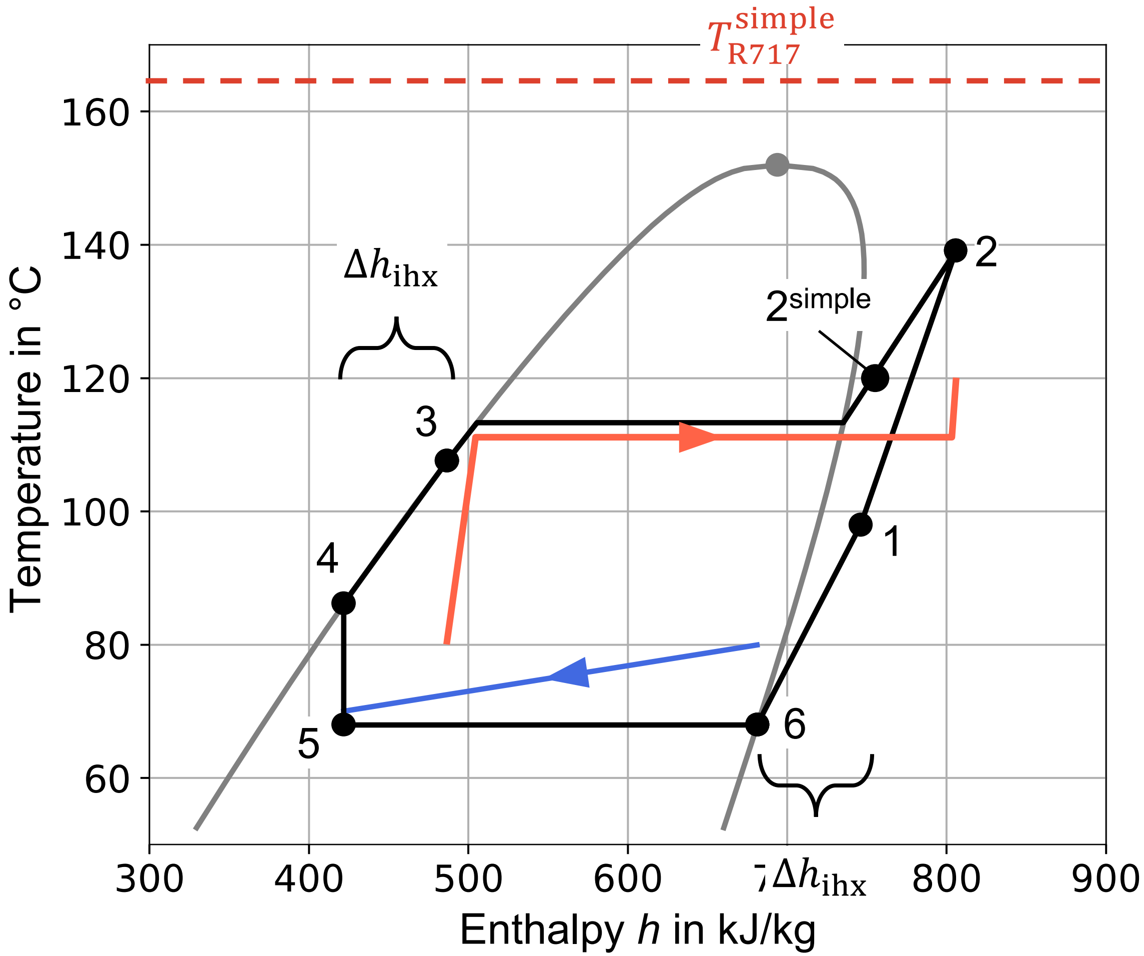
Results – Variation of source temperature



- Results similar for difference operating conditions
- For ammonia: ihx, vi and vi-ihx cycle show similar efficiencies
- Differences between refrigerant-flowsheet interaction due to higher compressor discharge temperatures

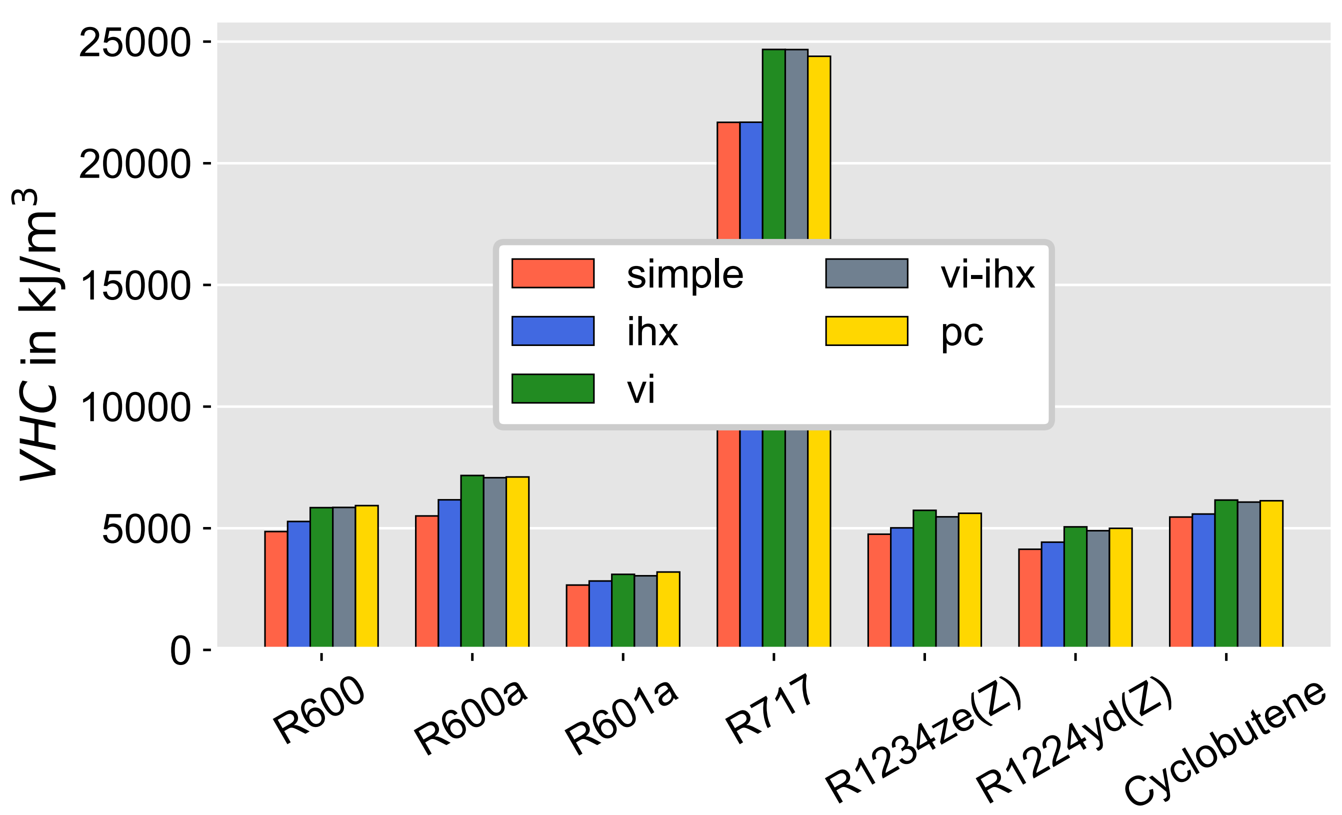
Influence of compressor discharge temperature





Results – Influence on volumetric heat capacity (VHC)

- VHC increases by up to 30 % when using vapor injection
- Vi, vi-ihx and pc show similar improvements of VHC
- Ammonia shows highest VHC due to very high operating pressures



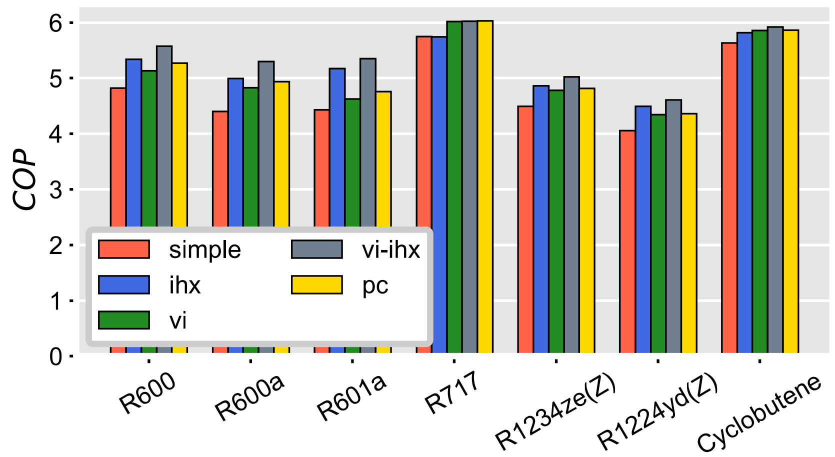
Conclusion

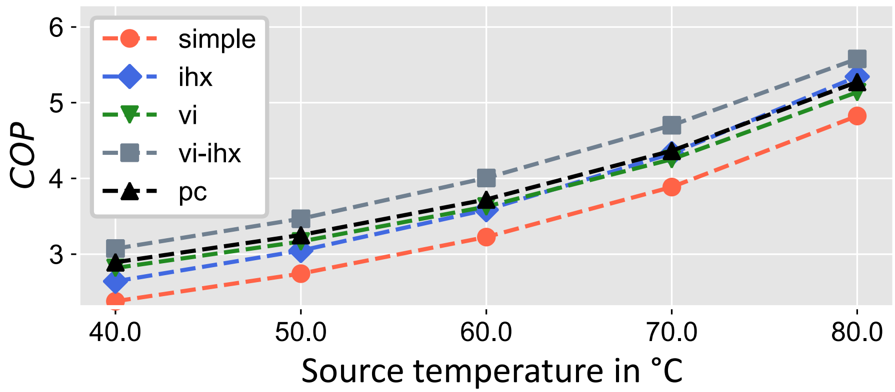
Summary

- Ammonia (R717) shows highest efficiencies
- Vi-ihx cycle leads to best performance for all refrigerants
- For most flowsheets, performance depend on the refrigerant

Future work

- Include further flowsheets
- Investigation of (a)zeotropic mixtures
- Combined optimization of heat pump and additional compressor





Maximum temperature