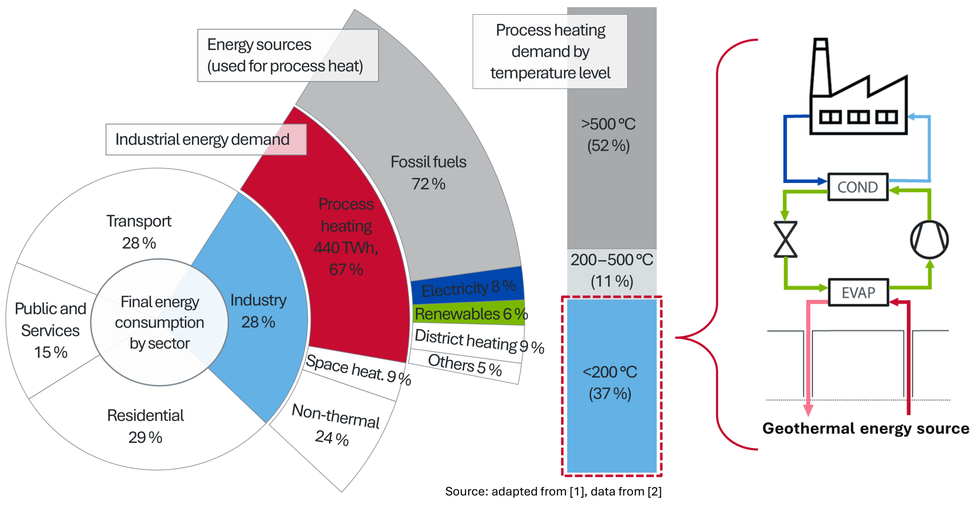
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Heat Pumps for Geothermal Heat and Steam Supply

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MOTIVATION

- Electrification of heat demand below 200 °C is possible with a low-grade heat source in combination with a high-temperature heat pump (HTHP)



Source: adapted from [1], data from [2]

Research Objective:
Thermodynamic comparison of a single-stage and two-stage cascaded HTHP for industrial heat and steam supply, using medium-depth geothermal sources

METHOD

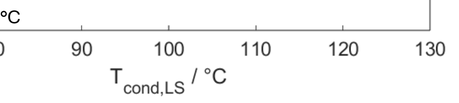
Simulative analysis comparing a **single-stage HTHP** vs. a **two-stage cascade HTHP** configuration

Geothermal heat source

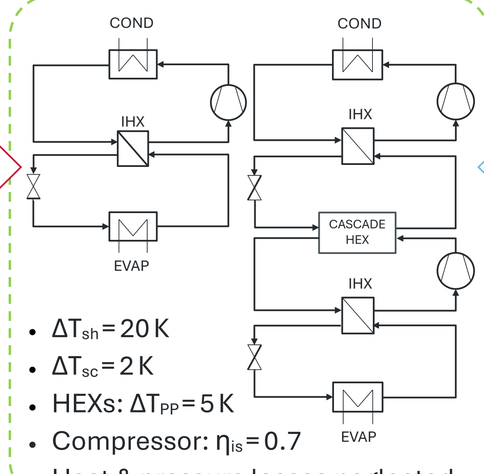
South German Molasse Basin

Case 1:
T = 45 °C
ṁ = 100 kg/s

Case 2:
T = 65 °C
ṁ = 115 kg/s



Source: [3,4]



- $\Delta T_{sh} = 20$ K
- $\Delta T_{sc} = 2$ K
- HEXs: $\Delta T_{PP} = 5$ K
- Compressor: $\eta_{is} = 0.7$
- Heat & pressure losses neglected

Industrial heat sink

Base Case — Paper drying:

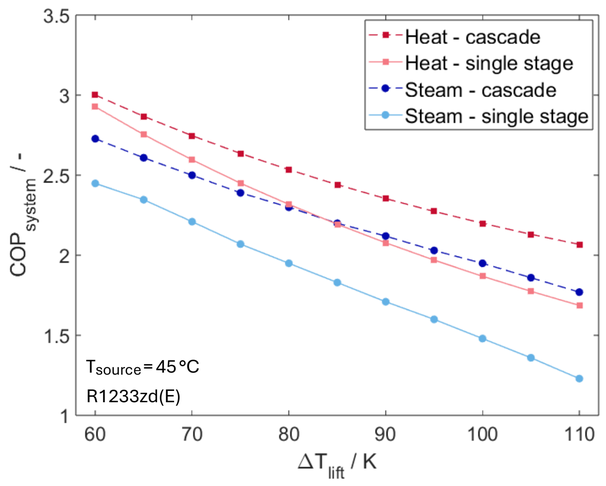
T = 145 °C
p_{heat} = 5 bar; p_{steam} = 4 bar
ṁ = 14 t/h

Sector	Process	80	120	160	200	[°C]
Pulp and Paper	Drying					90 - 240
	Boiling					110 - 180
	Bleaching					40 - 150

Source: adapted from [5]

Verification of thermodynamic cycle model using experimental data from a single-stage laboratory HTHP

SIMULATIVE ANALYSIS OF GEOTHERMAL HEAT AND STEAM SUPPLY

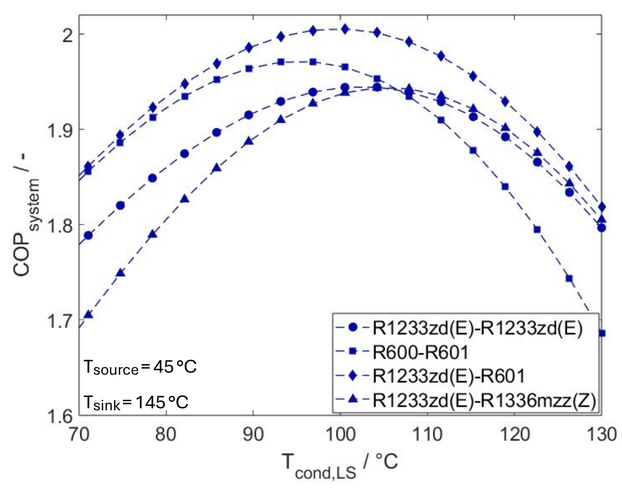


Comparison of heat and steam generation for both HTHP configurations:

- Two-stage cascade HTHP leads to higher system COPs for both heat and steam generation using the same refrigerant
- Difference in COP increases for larger temperature lifts

Comparison of the optimal LTS-condensation temperature for base case scenario:

- LTS-condensation temperature significantly influences system COP
- Optimum LTS-condensation temperature for steam supply is higher due to two-phase heat transfer and higher HTS-condensation temperature



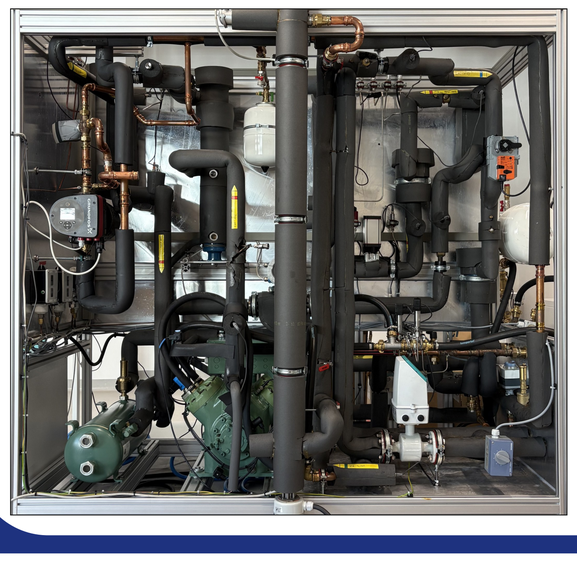
Comparison of refrigerant combinations for saturated steam generation (base case scenario)

- Optimum LTS-condensation temperature depends on the refrigerants used
- Maximum theoretical COP of 2 can be achieved with the refrigerant combination R1233zd(E)-R601

LABORATORY HTHP — EXPERIMENTAL INVESTIGATION

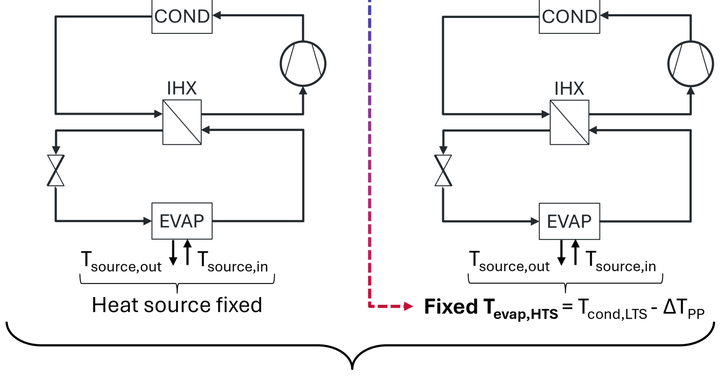
High-temperature heat pump test rig:

- Single-stage vapor compression heat pump
- Refrigerant: R1233zd(E)
- Reciprocating piston compressor
- IHX with adjustable suction gas superheating
- Maximum thermal capacity: 40 kW
- Supply temperatures up to 140 °C



Experimental procedure:

Separate **low-temperature stage (LTS)** and **high-temperature stage (HTS)** measurements



System Performance Evaluation

- LTS and HTS measurement theoretically coupled via $\Delta T_{PP} = 5$ K
- Assuming perfect heat transfer at the cascade HEX ($\dot{Q}_{evap,HTS} = \dot{Q}_{cond,LTS}$) and const. COP_{LTS} at fixed ΔT_{lift}

$$COP_{system} = \frac{\dot{Q}_{cond,HTS}}{P_{el,HTS} + P_{el,LTS,corrected}}$$

SUMMARY AND OUTLOOK

Summary:

HTHPs using medium-depth geothermal energy offer potential for decarbonization of process heat and steam supply:

- Cascaded HTHP achieves higher system COPs, particularly at temperature lifts > 60 K
- LTS-condensation temperature strongly affects system performance
- Refrigerants were selected based on high-temperature suitability and low GWP
- Refrigerant selection influences COP and optimal LTS-condensation temperature → potential for optimization

Outlook:

- Implementation of Component models including non-ideal heat transfer effects for thermodynamic and techno-economic analysis
- Modification of the test rig for experimental steam generation
- Model validation using experimental data from the laboratory HTHP

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