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Booster Heat Pump with Drop-in Zeotropic Mixtures Applied in 4&5th Generation District Heating System

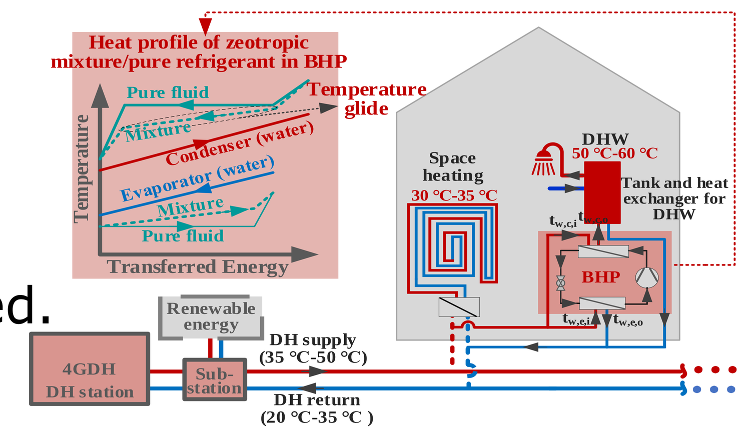
T. Zhu, E. Vieren, J. Liang, J. E. Thorsene, M. D. Paepe, S. Lecompte, B. Elmegaard

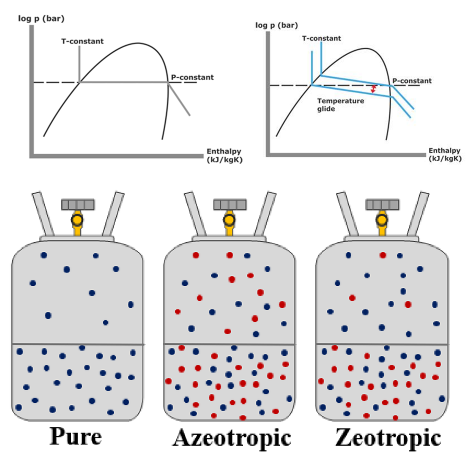
Heat Transfer and Thermodynamics, Department of Thermal and Fluid Engineering, UT

E-mail address: t.zhu@utwente.nl (Dr. T. Zhu)

Highlights:

1. Drop-in application of zeotropic mixtures in booster heat pumps are studied.
2. Coupling effects between district heating and heat pump parameters are analyzed.
3. Heating capacity and COP improvements with mixture refrigerants are demonstrated.
4. Temperature profile analysis identified the challenges for efficiency improvement.





Introduction

- Heat pumps face challenges in refrigerant selection, particularly due to EU Regulation No 517/2014, which phases down hydrofluorocarbons (HFCs) with high Global Warming Potential (GWP). This regulation increases the demand for sustainable alternative refrigerants in refrigeration, air conditioning, and heat pump systems.
- Using pure refrigerants can lead to excessive losses in thermodynamic cycles. Zeotropic mixtures—fluids with non-isothermal phase changes—can improve temperature profiles, reduce exergy destruction, and enhance the Coefficient of Performance (COP). They also allow for trade-offs between fluid properties like flammability and GWP, as well as operating conditions.
- Despite their potential, research on zeotropic mixtures as drop-in replacements for HFCs remains limited, with few experimental studies conducted on their practical application.

Question addressed

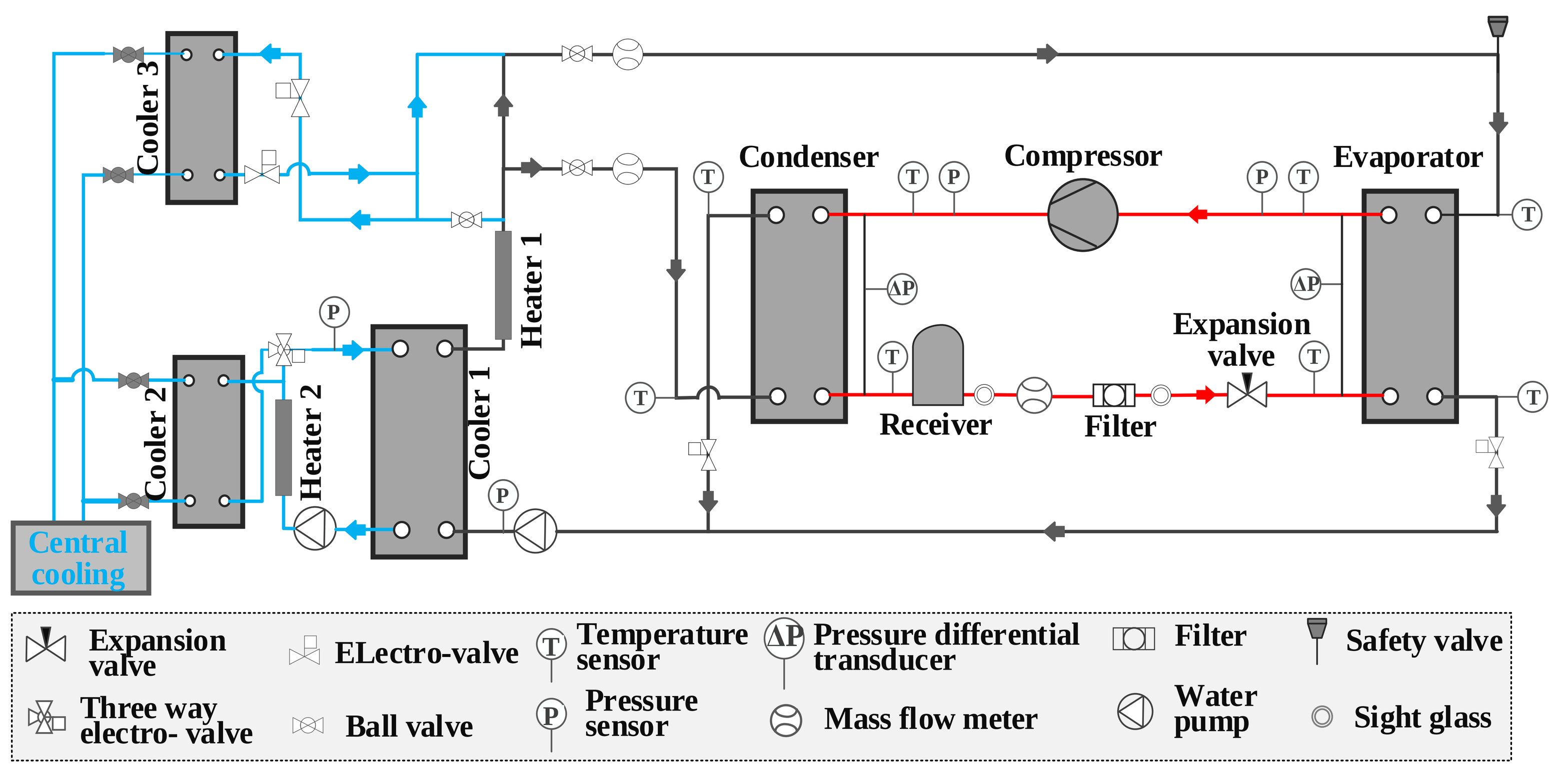
Address the gap by conducting an experimental validation-based feasibility analysis of R-1234yf/R-32 zeotropic refrigerant mixtures as a drop-in replacement for R-134a.

Answer: What is the thermal behavior and exergy performance of the studied zeotropic mixtures heat pump in district heating network application?

Methods

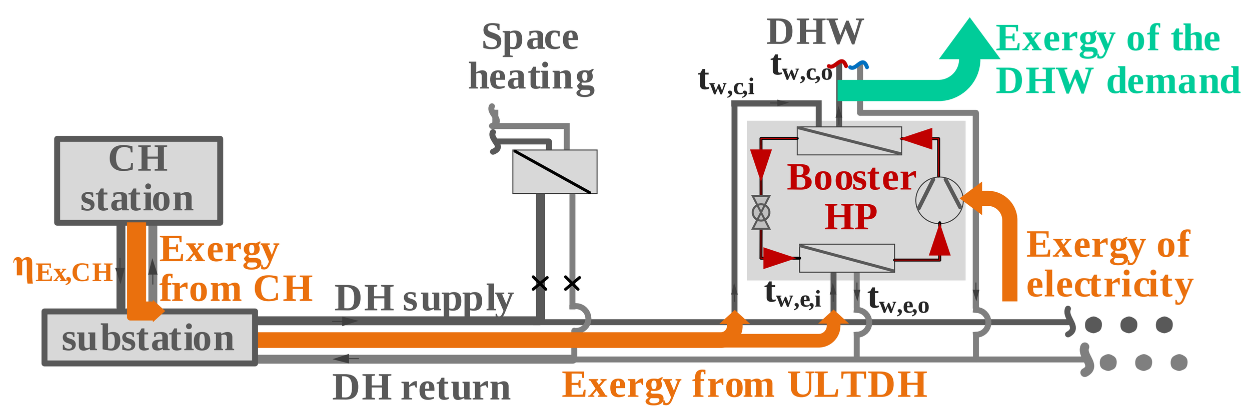
Experiments

Thermodynamic Analysis



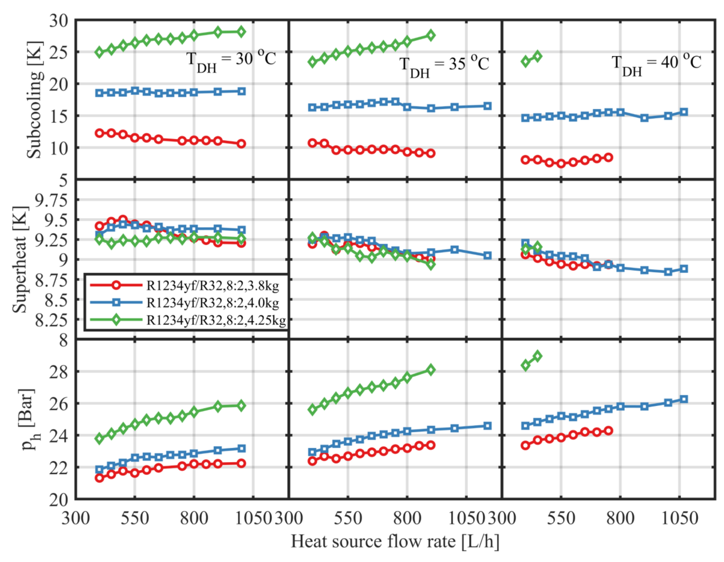
The experimental setup comprises four primary cycles: a BHP cycle, a water cycle simulating DHW preparation, a water cycle serving as a heat source for the evaporator, and a water cycle for temperature regulation in alignment with the DH supply.

A data acquisition system that encompasses two key measurements:
1) refrigerant cycle parameters such as temperature, refrigerant density, mass flow rate, and pressure, and 2) measurements from the water cycles, including temperature and mass flow rate.

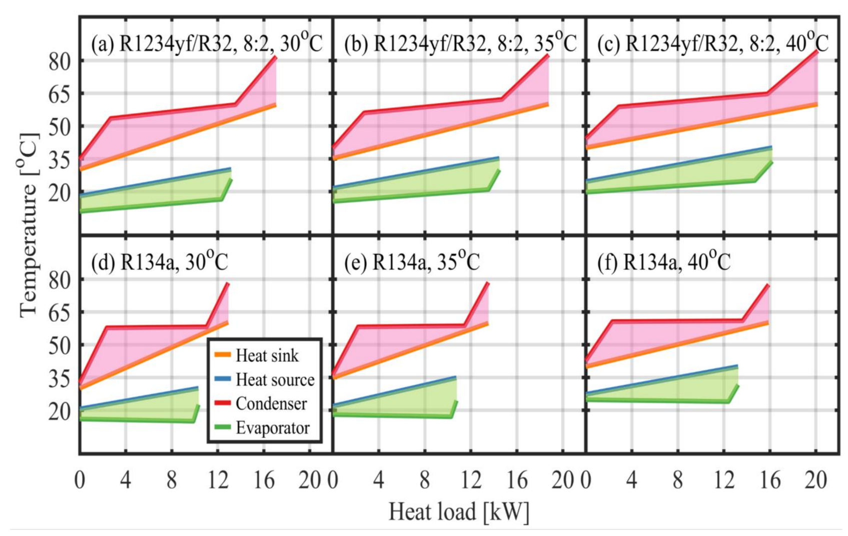


$$\eta_{Ex,DHW} = \frac{\dot{E}x_{DHW}}{\dot{E}x_{DH} + \dot{E}x_{BHP}} = \frac{\dot{m}_{sink}\left(\dot{e}x_{w,c,o} - \dot{e}x_{DH,ret}\right)}{\left(\dot{m}_{sink} + \dot{m}_{source}\right)\left(\dot{e}x_{DH,i} - \dot{e}x_{DH,ret}\right) + \dot{W}_{comp}}$$

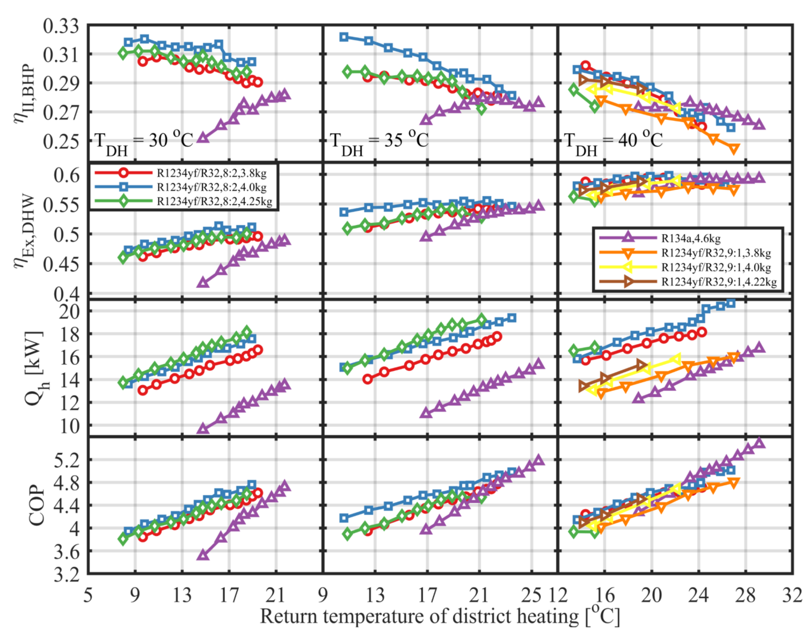
Results



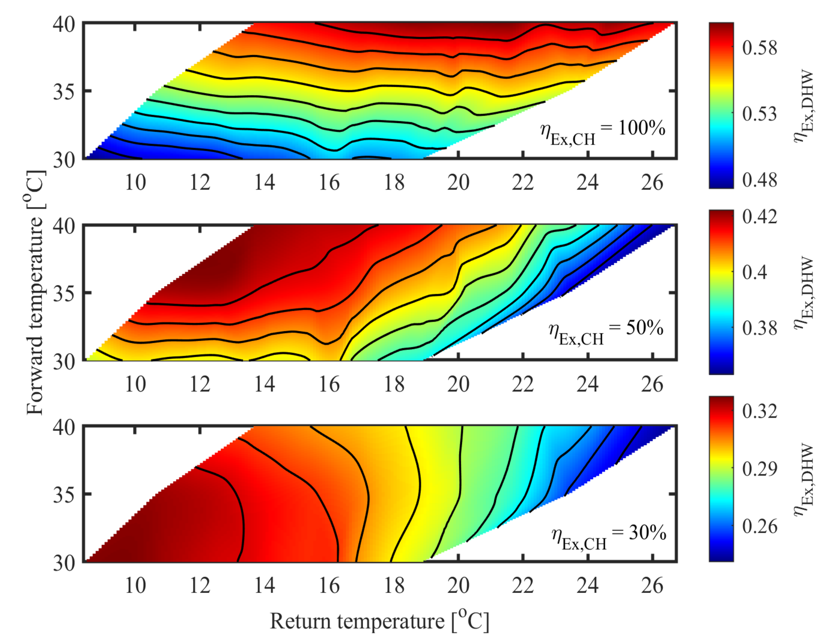
Subcooling, superheat, and discharge pressure of BHP with R-1234yf/R-32 (80%/20%) mixture operating at various district heating forward temperatures and heat source flow rates.



Comparative analysis of temperature profiles of condenser and evaporator between BHPs with R-1234yf/R-32 (80%/20%) configuration and R-134a at district heating forward temperatures of 30 °C, 35 °C, and 40 °C.



Second law efficiency, exergetic efficiency of DHW preparation system, BHP heating capacity, and COP as a function of district heating return temperature at different refrigerants.



Exergetic efficiencies of DHW preparation as a function of district heating forward and return temperatures based on the exergetic efficiency of 100%, 50%, and 30% for the central heating stations.

Conclusion

Component-Level Analysis:R-1234yf/R-32: Higher isentropic efficiency but lower volumetric efficiency for compressor; overall higher efficiency and comparable pressure drop in heat exchangers confirm operational feasibility.

A Device-Level Analysis: R-1234yf/R-32 (80%/20%): Higher COP at lower temperatures; Up to 58% heating capacity improvement over baseline.

System-Level Analysis: Exergetic efficiencies: 0.47, 0.55, 0.59 for 30°C, 35°C, 40°C. Lower central heating efficiency shifts optimal temperatures down.

Our study advances the understanding of booster heat pumps in ultra-low temperature district heating systems, emphasizing the significance of optimized design and operation to achieve enhanced performance and efficiency.

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