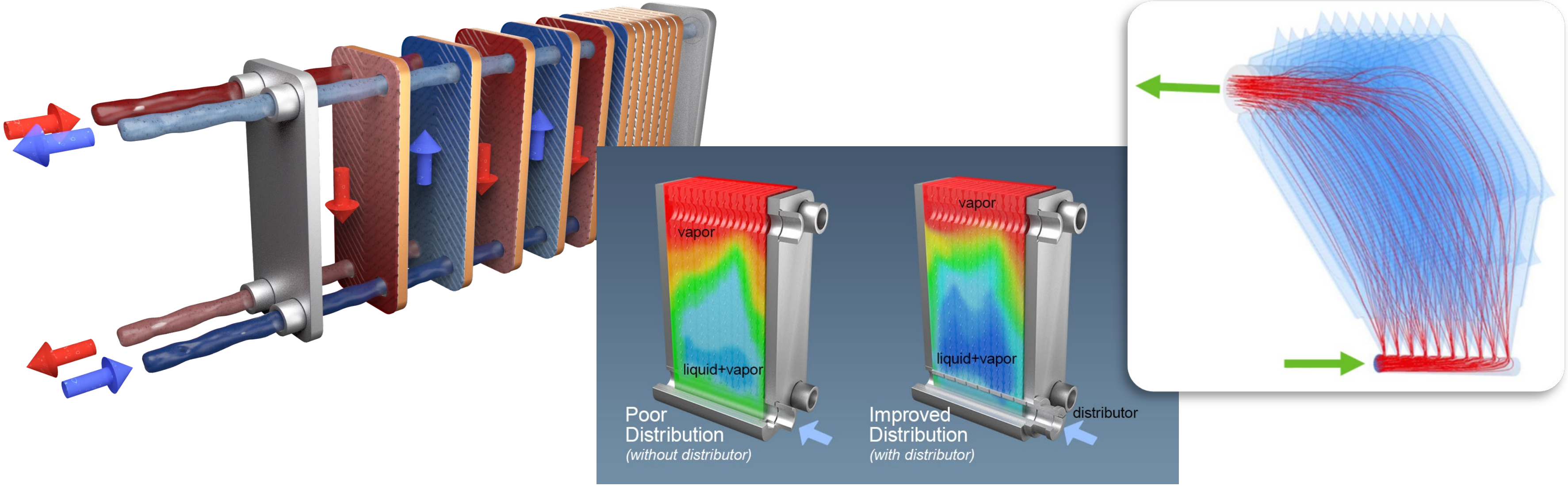
2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Heat Exchanger Solutions for Low-GWP Refrigerants

Heat exchanger solutions for low-GWP refrigerants



Oak Ridge National Laboratory
Cheng-Min Yang (R&D Associate Staff)
865-341-0340, yangc1@ornl.gov
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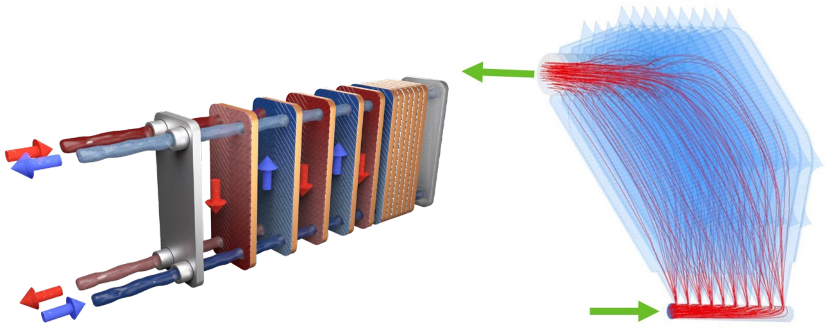
Project Summary

OBJECTIVE, OUTCOME, & IMPACT

The objective is to develop heat exchanger technology for low-GWP refrigerants to enhance performance and reduce refrigerant charge of compact heat exchangers. Extensive experimental data and models to evaluate performance of the heat exchanger using emerging refrigerants will be developed with a focus on charge minimization, refrigerant distribution, and capacity improvement.



TEAM & PARTNERS

Oak Ridge National Laboratory:

Cheng-Min Yang, Muneeshwaran Murugan, Kashif Nawaz, Mingkan Zhang, Aaron Thornton, Troy Seay, Vishaldeep Sharma, Praveen Cheekatamarla

Partners:

Honeywell, Chemours, Technische Universität Berlin

STATS

Performance Period: May 2022–September 2025

DOE Budget: $650k/year (FY23)/ $500k/year (FY24)

Milestone 1: Development of test facility for evaluating compact heat exchangers (Q3 FY23)

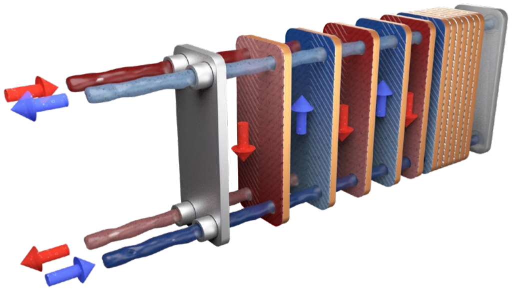
Milestone 2: Review of refrigerant flow distribution in compact heat exchangers (Q1 FY24)

Milestone 3: Evaluation of various low-GWP refrigerants in the selected heat exchanger (Q2 FY24)

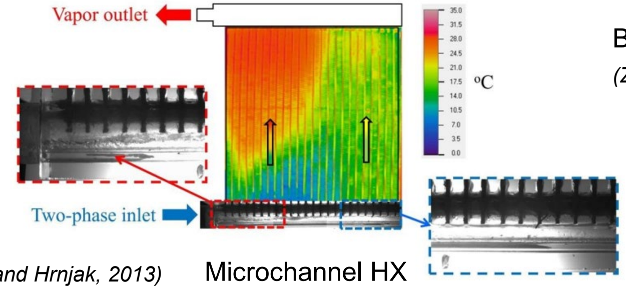
Problem

- Development of a novel heat exchanger for low-GWP refrigerants is vital to improve system efficiency and reduce refrigerant charge
- In the last few decades, research on heat exchangers has focused on investigating the evaporation and condensation behavior of high-GWP refrigerants (e.g., R-134a, R-404A, and R-22) under different operating conditions
- Refrigerant mixtures are attractive alternatives because their composition can be tailored to comply with environmental regulations while preserving favorable thermophysical properties. However, new low-GWP zeotropic mixture refrigerants have temperature glides, which may cause refrigerant flow maldistribution and degradation of overall heat transfer performance

Brazed plate heat exchanger



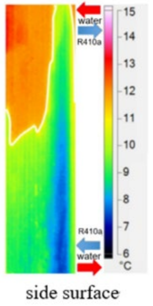
Refrigerant flow maldistribution in heat exchangers



(Tuo and Hrnjak, 2013) Microchannel HX

Brazed plate HX

(Zhang et al., 2021)



Alignment and Impact

- Support the nation’s ambitious climate mitigation goals by reducing GHG emissions 50%–52% by 2030 vs. 2005 levels
  - ✓ Implementing low-GWP refrigerants (<150) in heat exchangers would lead to >90% reduction in direct GHG emissions. This project aims to reduce refrigerant charge by 10%, which will diminish hazards of flammable refrigerants
- Support DOE BTO’s goal to reduce onsite use intensity in buildings 30% by 2035 and 45% by 2050, compared with 2005 levels
  - ✓ Increasing heat exchanger capacity by at least 10% would lead to significant annual energy savings.
- Support DOE BTO to decarbonize the US building stock in line with economywide net-zero emissions by 2050

Greenhouse gas emissions reductions

50–52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Increase building energy efficiency

Accelerate onsite emissions reductions

Approach

- Extensive experimental database for heat exchanger performance using ultralow-GWP refrigerants at various operating conditions
- Models to predict heat exchanger performance and evaluate the potential of charge reduction for emerging refrigerants
- Investigation and quantification of refrigerant flow distribution in the heat exchanger

Refrigerant	Composition (blends)[1]	Regulatory GWP[2]	ASHRAE Class[1]
R-1233zd(E)	Pure fluid	4	A1
R-1336mzz(Z)	Pure fluid	2	A1
R-1336mzz(E)	Pure fluid	26	A1
R-457A	R-32, R-1234yf, R-152a (18%, 70%, 12%)	137	A2L
R-516A	R-1234yf, R-134a, R-152a (77.5%, 8.5%, 14.0%)	140	A2L
R-454C	R-32, R-1234yf (21.5%, 78.5%)	146	A2L
R-455A	R-32, R-1234yf, R-744 (21.5%, 75.5%, 3%)	146	A2L

[1]ANSI/ASHRAE Standard 34-2022; [2]EPA, https://www.epa.gov/climate-hfcs-reduction/technology-transitions-gwp-reference-table

Approach

Phase I:
Facility development

- Review state-of-the-art test facility in literature
- Develop detailed test plan and design test apparatus
- Build infrastructure for measuring performance of compact heat exchangers
- Validate the test facility
- Characterize geometric details of heat exchangers

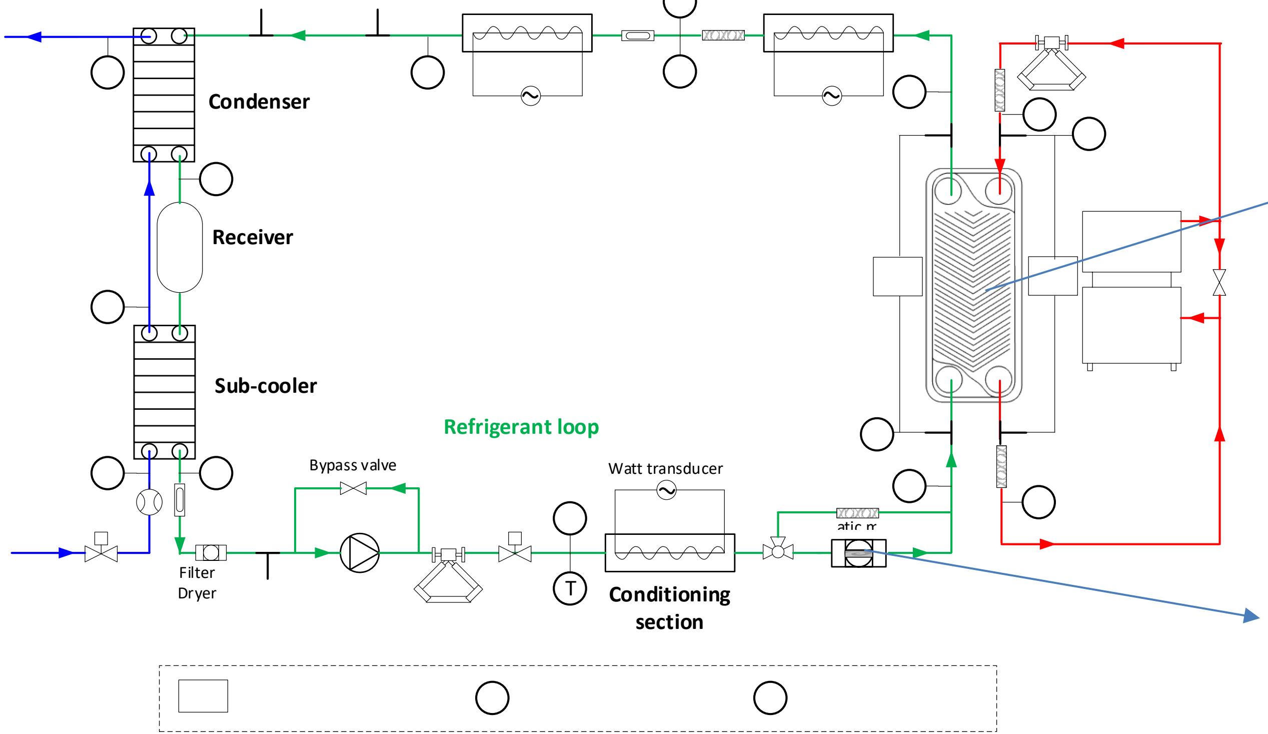
Phase II:
Evaluation of low-GWP refrigerants

- Evaluate thermal-hydraulic of liquid-to-refrigerant heat exchangers for various low-GWP refrigerants
- Compare the results with existing correlations
- Develop a model to predict performance of new refrigerants
- Conduct parametric studies

Phase III :
Improvement of flow distribution in heat exchangers

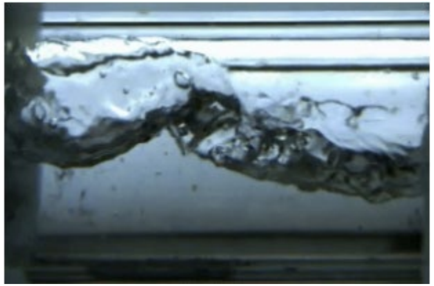
- Simulate flow distribution in heat exchangers through CFD
- Design new manifold or distributor to reduce flow maldistribution in heat exchangers
- Experimentally investigate and quantify refrigerant flow distribution in compact heat exchangers

Approach Development of Liquid-to-Refrigerant HX Test Apparatus



P&ID of the heat exchanger apparatus

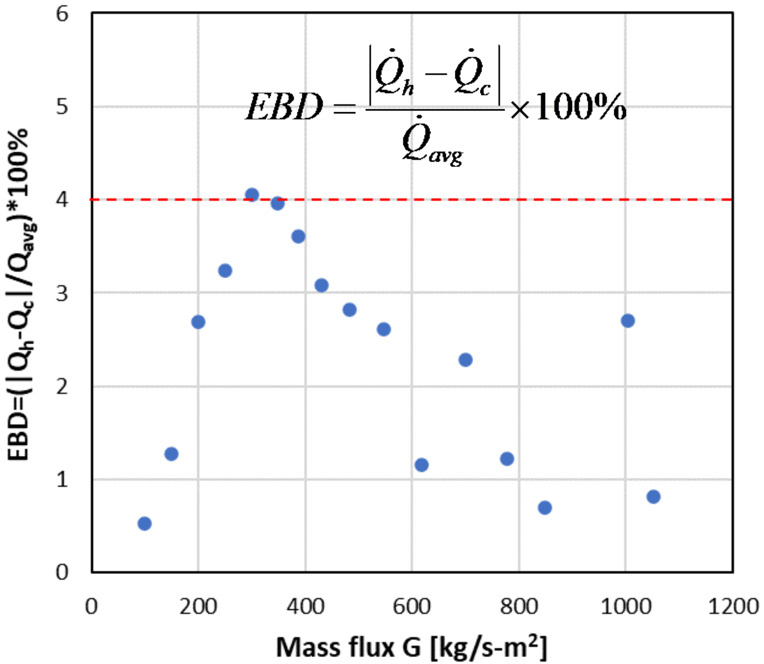
Brazed plate HX (evaporator)



Two-phase flow pattern (R-454C)

Approach Development of Liquid-to-Refrigerant HX Test Apparatus

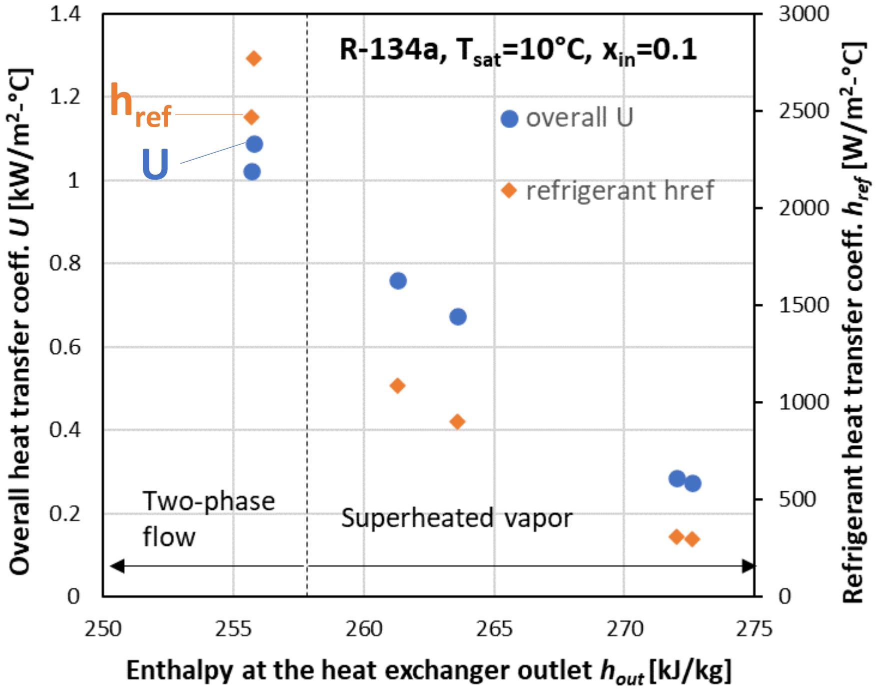
Liquid-to-refrigerant heat exchanger test rig



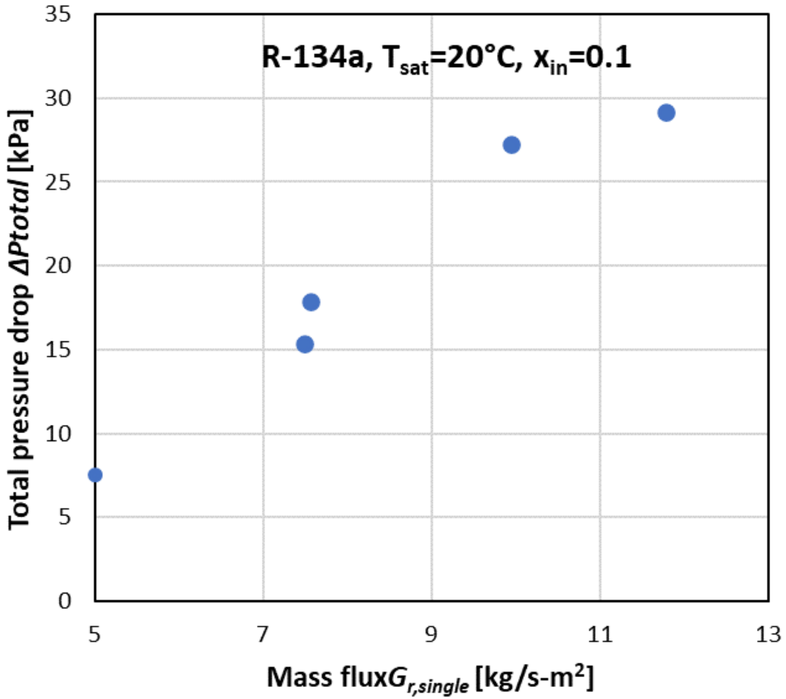
Single-phase water-to-water experiments

Progress Flow Boiling Experiments of Plate HX with R-134a

Subcooled liquid and superheated vapor at the inlet and outlet to check energy balance (1.78%)



Effect of outlet enthalpy on heat transfer coefficient

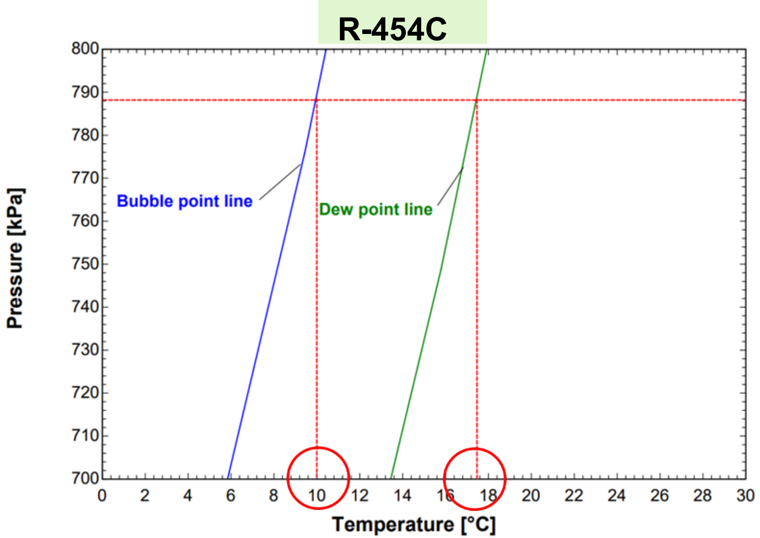


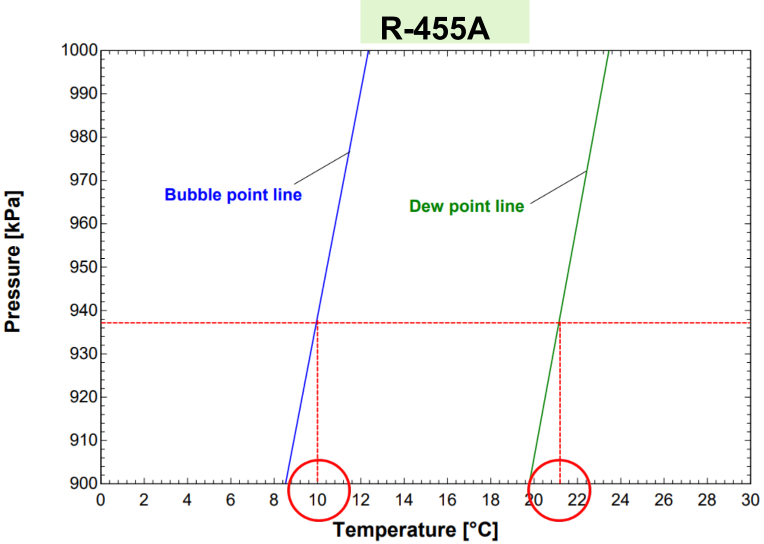
Effect of mass flux on pressure drop

Progress Low-GWP Mixture Refrigerants: R-454C and R-455A

R-454C (GWP = 148) and R-455A (GWP = 148) are intended replace R-410A (GWP = 2,088) and R-404A (GWP = 3,943)

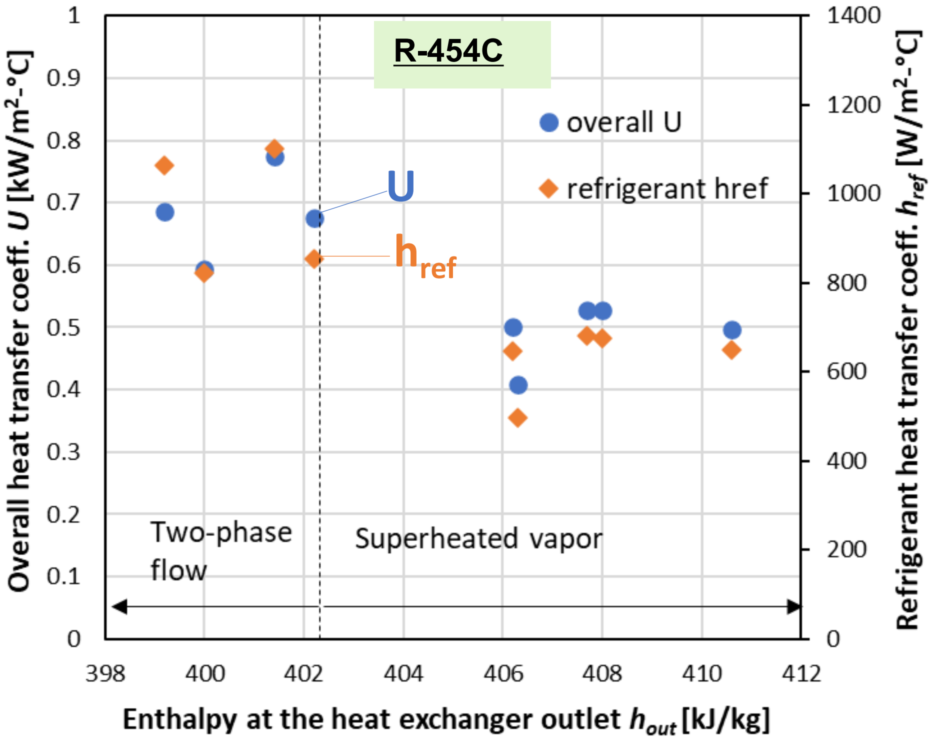
Refrigerant	Composition	Temperature glide
R-454C	21.5% R32 78.5% R1234yf	7.4°C
R-455A	21.5% R-32, 75.5% R-1234yf, 3% CO_2	11.2°C

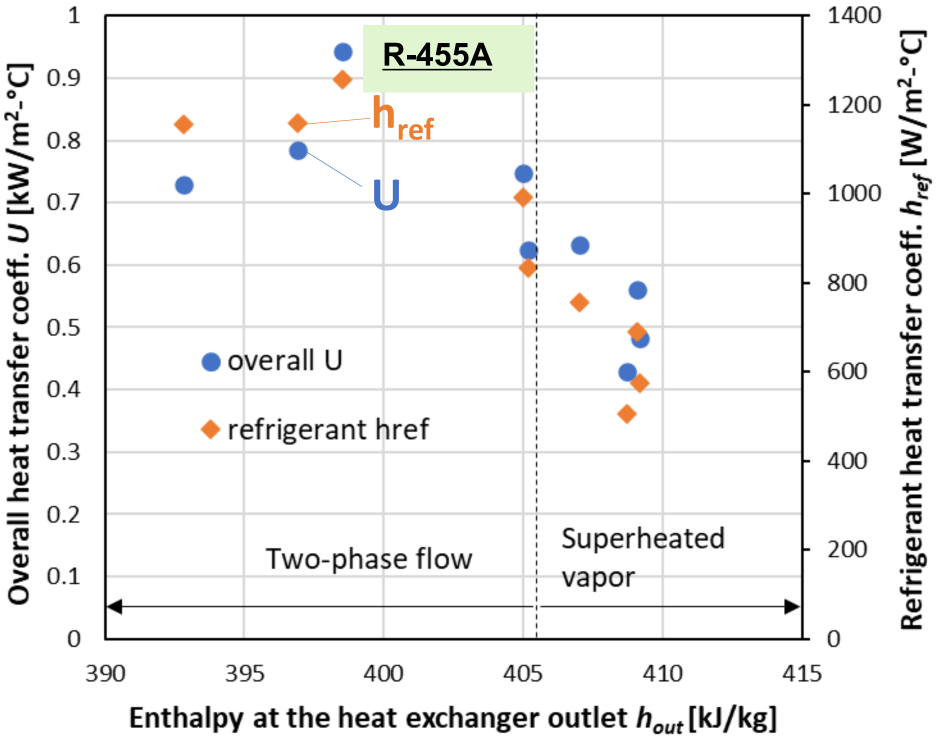




Pressure-temperature curves of R-454C and R-455A

Progress Heat Transfer Performance of HX: R-454C and R-455A





Effect of outlet enthalpy on heat transfer coefficient

Progress Analysis of Refrigerant Flow Maldistribution in Plate HXs

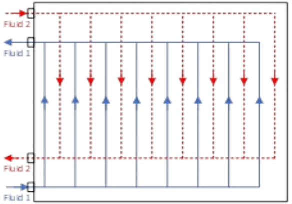
Geometrical

- Port diameter
- Flow configuration (U and Z type)
- Pass (single and multiple
- Chevron angle
- Number of channels

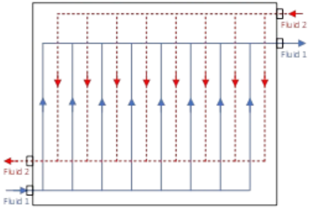
Operational

- Flow rate
- Operating temperature (affects viscosity and density)
- Working fluid
- Isothermal and non-isothermal conditions

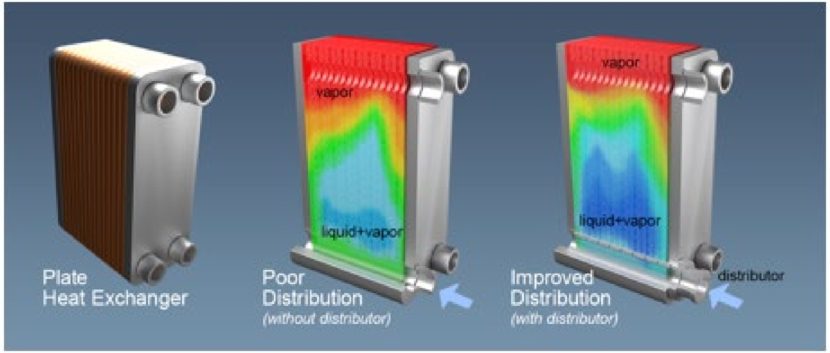
U-type HX



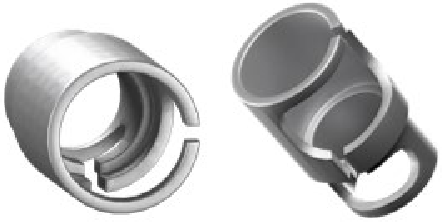
Z-type HX



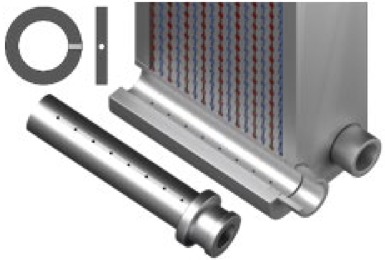
Flow maldistribution in plate heat exchangers



Innovative distributors in the heat exchanger

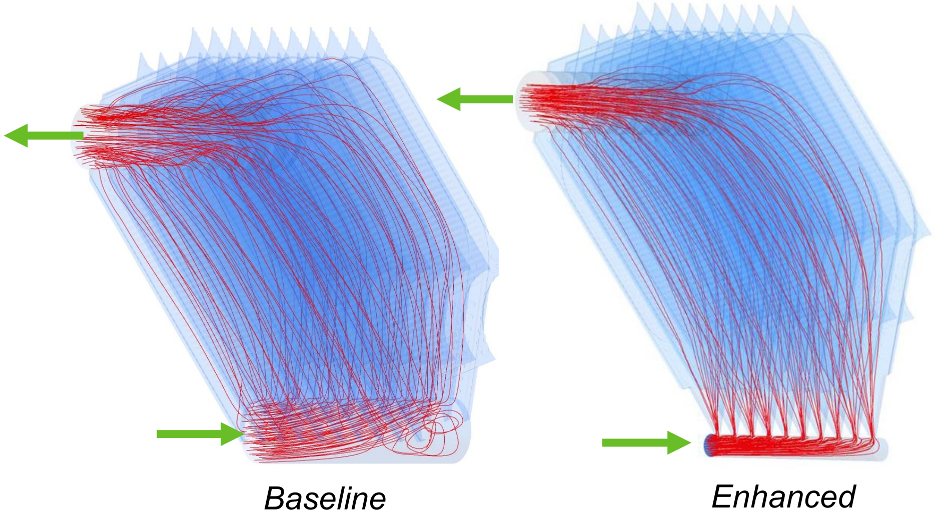


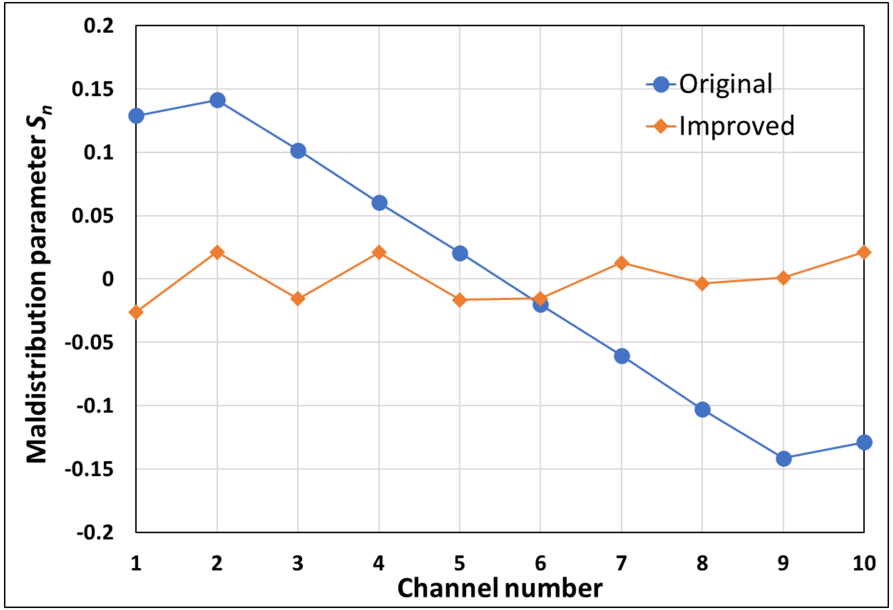
Equalancer (Alfa Laval)



Distribution rings and Q-pipe (SWEP)

Progress Flow Distribution in Heat Exchangers through CFD Simulation





CFD simulation of flow distribution in the plate heat exchanger with novel manifold design

Maldistribution parameters of R-454C between the baseline and improved design in plate heat exchanger

Future Work

- Investigate and quantify refrigerant flow distribution in selected heat exchanger
- Evaluate potential of charge reduction for various low-GWP refrigerants
- Test more low-GWP refrigerants in liquid-to-refrigerant heat exchangers
- Develop a correlation to predict performance of low GWP-refrigerant for selected heat exchanger

Thank you

Oak Ridge National Laboratory

Cheng-Min Yang, R&D Associate Staff
(865) 341-0340 / yangc1@ornl.gov

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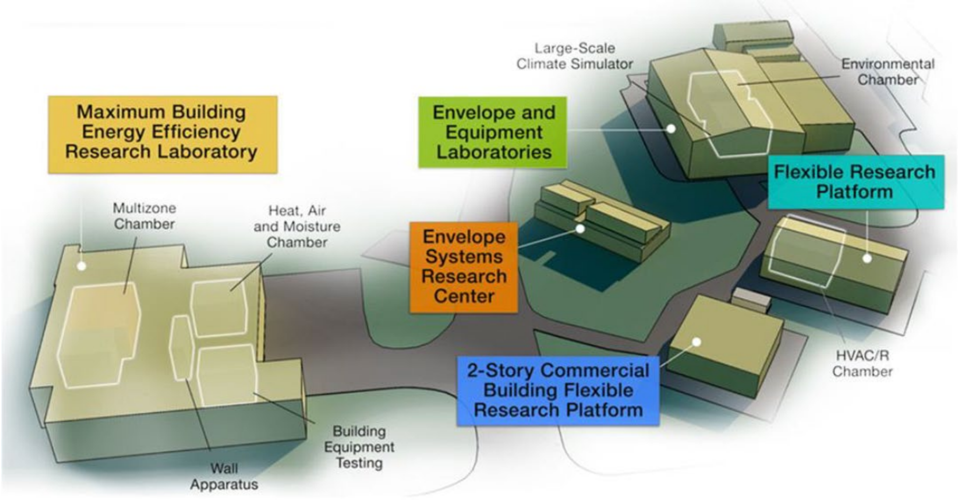

The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is composed of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	$650k				$500k							
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Design liquid-to-refrigerant HX test setup												
Q2 Milestone: Validate the test facility using R134a												
Q4 Milestone: Modeling strategy for compact HXs												
Q1 Milestone: Review refrigerant flow in heat exchangers												
Q2 Milestone: Test various low GWP refrigerants												
Current/Future Work												
Q4 Milestone: Study refrigerant flow distribution												
Q2 Milestone: Investigate two-phase flow pattern												
Q3 Milestone: CFD simulation of two-phase flow												

Team

Oak Ridge National Laboratory

Cheng-Min Yang
R&D Staff

Muneeshwaran Murugan
R&D Staff

Mingkan Zhang
R&D Staff

Vishaldeep Sharma
R&D Staff

Kashif Nawaz
Section Head of Building Technology Research

Troy Seay
Technical Staff

Aaron Thornton
Technical Staff

Praveen Cheekatamarla
Sr. R&D Staff

Technische Universität Berlin

Stefan Elbel
Professor