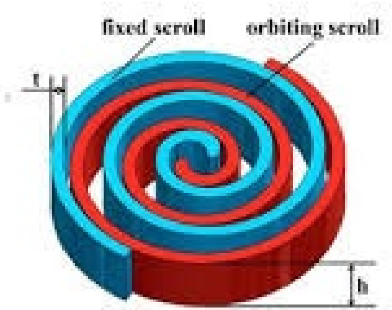
2024 PROJECT PEER REVIEW

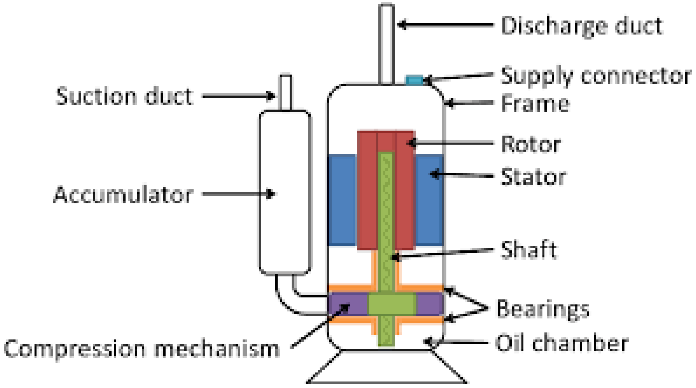
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Compressor Technologies for Low and Ultra-Low GWP Refrigerants

Compressor Technologies for Low and Ultra-Low GWP Refrigerants





Oak Ridge National Laboratory
Samuel F. Yana Motta, Distinguished R&D Staff
yanamottasf@ornl.gov, (716) 4183945
WBS: 03.02.02.79

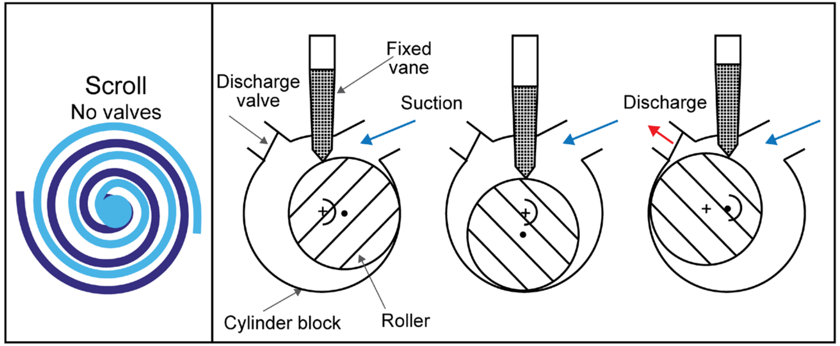
Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

Objective: Enable development of compressors for low-GWP refrigerants in residential and light commercial A/C heat pumps

Outcome: Redesigned compressors that achieve optimal performance with low-GWP refrigerants

Impact: Reduce direct CO_2 emissions by 96.4% (32,500,000 tons of CO_2); potential energy savings of up to 5.6% (37,934 TWh/year, equivalent to 16,000,000 tons of CO_2)



Scroll | Rotary

TEAM AND PARTNERS

ORNL: Samuel F. Yana Motta (PI), Junjie Luo

CRADA partner: Copeland

Collaborators: Purdue University team (Steven Liang, Yash Shantilal Parmar, Haotian Liu, Riley Barta, Eckhard Groll)

STATS

Performance Period: FY24/FY25

DOE Budget: $500k, Cost Share: $300k

Milestone 1: Testing of scroll and rotary compressors

Milestone 2: Optimization of scroll and rotary compressors

Milestone 3: System level evaluations

Problem

- The **refrigeration, air-conditioning, and heat pump market** must reduce GHG emissions by 70% to comply with US (EPA) and global (Kigali) regulations
  - Direct CO_2 emissions from refrigerants amount to 32.5 million tons of CO_2 per year
  - Annual energy consumption is 682,827 TWh, leading to indirect emissions of 289 million tons of CO_2
- Highly **efficient systems** using **low-GWP refrigerants** are needed to reduce emissions
- Compressors greatly influence system energy efficiency as heart of the system; current R-410A scroll compressors have isentropic efficiency as high as 74%
- Compressors for new refrigerants (e.g., R-454C, propane) should be optimized to match or improve efficiency of current technologies (e.g., scroll, rotary)

This project aims to enable development of highly efficient compressors

[1] https://www.statista.com/statistics/1228433/data-centers-worldwide-by-country
[2] de Bock, P., V. Lecoustre, C. Noyes, T. Bress, R. Radhakrishnan, and J. Gallagher. 2021. “Cooling Compute Systems Efficiently, Anytime, Anywhere.” *Energy Efficiency Computing Workshop*, December 21, 2021. [Online] Available at https://www.arpa-e.energy.gov/sites/default/files/4.%20Vision%20Pitch%20-%20deBock.pdf

Alignment with Nation's Goals and Impact

Alignment

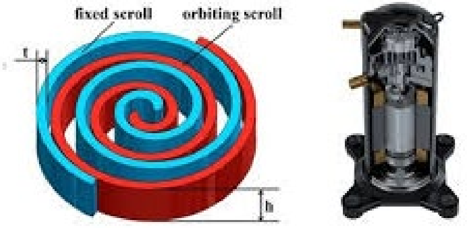
- **GHG emission reduction**
  - ➢ Use of low and ultra-low GWP refrigerants reduces direct emissions
  - ➢ Highly efficient compressors increase system efficiency, reducing indirect emissions
- **Power system decarbonization**
  - ➢ Heat pump electrification reduces reliance on fossil fuels for heating and cooling needs
  - ➢ Integration of heat pumps with smart grids supports grid stability when using renewable energy sources
- **Energy justice**
  - ➢ Efficient compressors with costs similar to that of current ones makes equipment available for everyone
  - ➢ Transition from electric heating to efficient heat pumps can reduce energy bills for low-income individuals

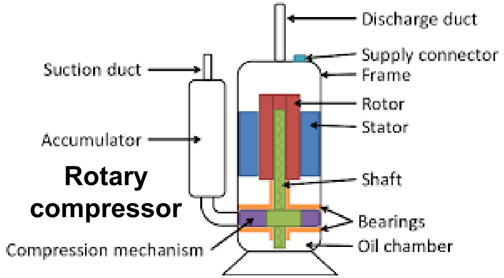
Impact

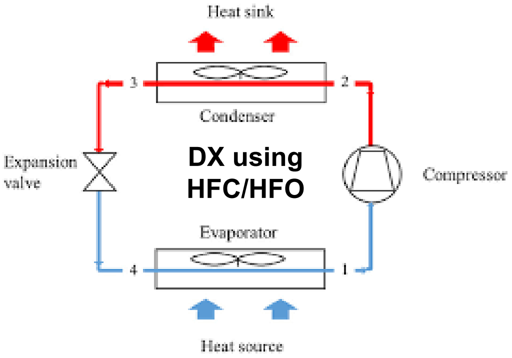
- **Direct emissions:** reduced by up to 96.4% (32,500,000 tons of CO_2)
- **Indirect emissions:** reduced by up to 5.6% owing to energy savings (16,000,000 tons of CO_2)
- **Deliverables:** (1) Precompetitive research shows potential to optimize compressors beyond what is available today; (2) partnership with compressor manufacturers to enable commercialization of highly efficient compressors

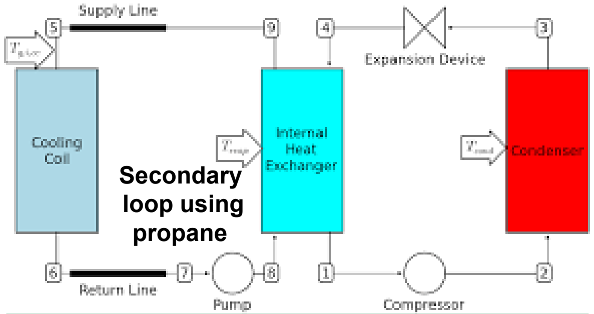
Approach Why improve components?

Scroll compressor

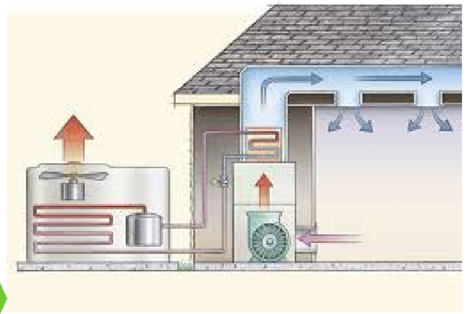








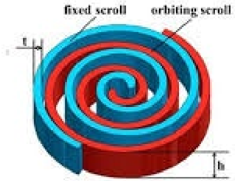
Houses

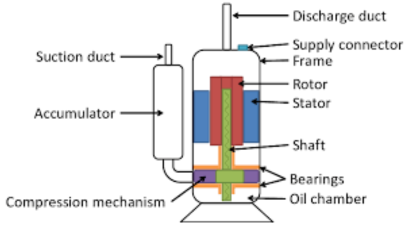


Component	System	Building

Approach Technical Methodology

- **Critical literature review**
  - ➢ Identify top two compressor technologies for residential A/C applications
  - ➢ Ensure they are not just exploratory but rather established technologies that can be further developed
- **Compressor modeling and optimization**
  - ➢ Modeling/optimization of top two compressor technologies identified in literature review: scroll and rotary
  - ➢ Collaborate with industry to ensure feasibility of designs
- **Performance validation**
  - ➢ Validate compressor performance with experimental testing
  - ➢ Evaluate top compressor/refrigerant technologies using simulation of residential AC 3-ton systems

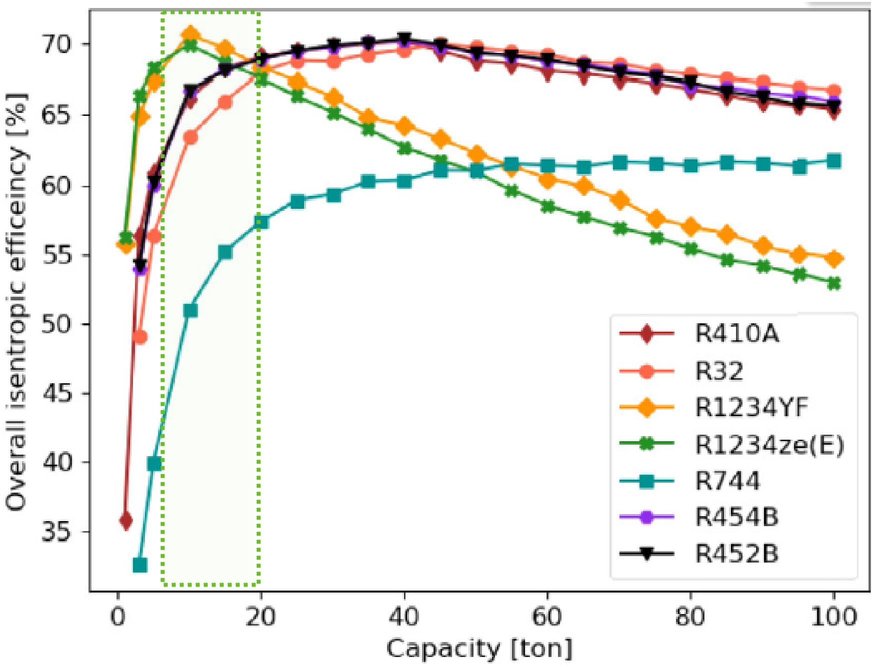


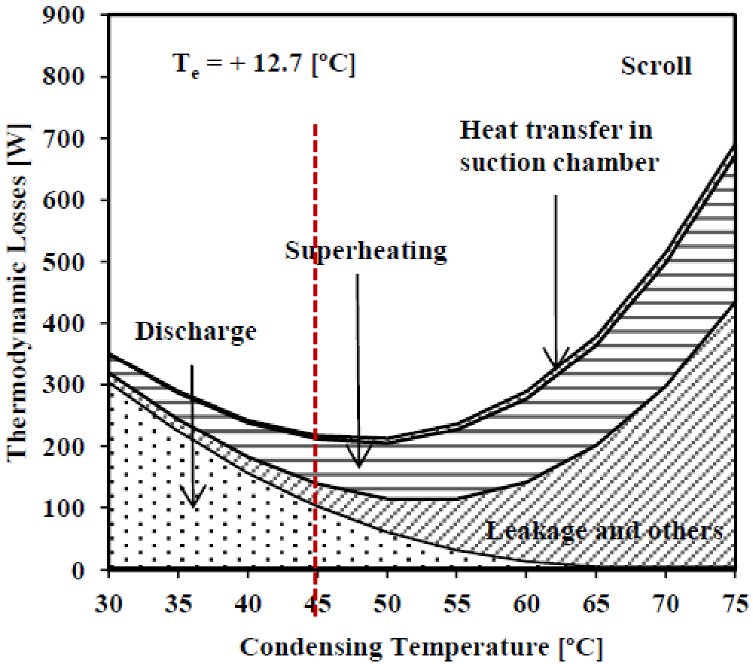
Approach Risks and Implementation Strategies

- **Barriers, technical challenges, risks**
  - Achieving equivalent or better performance compared with existing compressors
- **Mitigation strategies for risks**
  - Iterate designs to achieve modeled results using experimental testing
- **Demonstration strategy**
  - Install compressors in residential heat pumps and conduct performance tests
- **Commercialization strategy**
  - Work with manufacturers to implement new compressor designs for low-GWP refrigerants

Progress Literature Review on Scroll Compressors



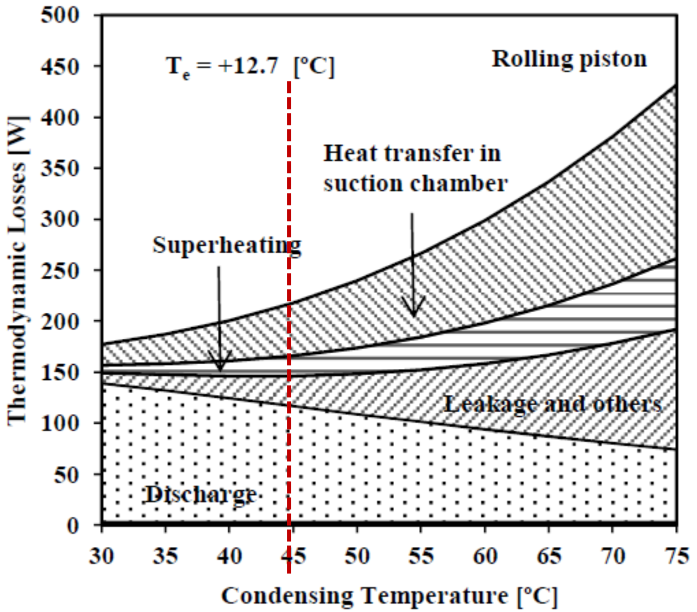
Low-pressure refrigerants such as R-1234yf and R-1234ze(E) show higher efficiencies for lower capacity range (7–20 tons)



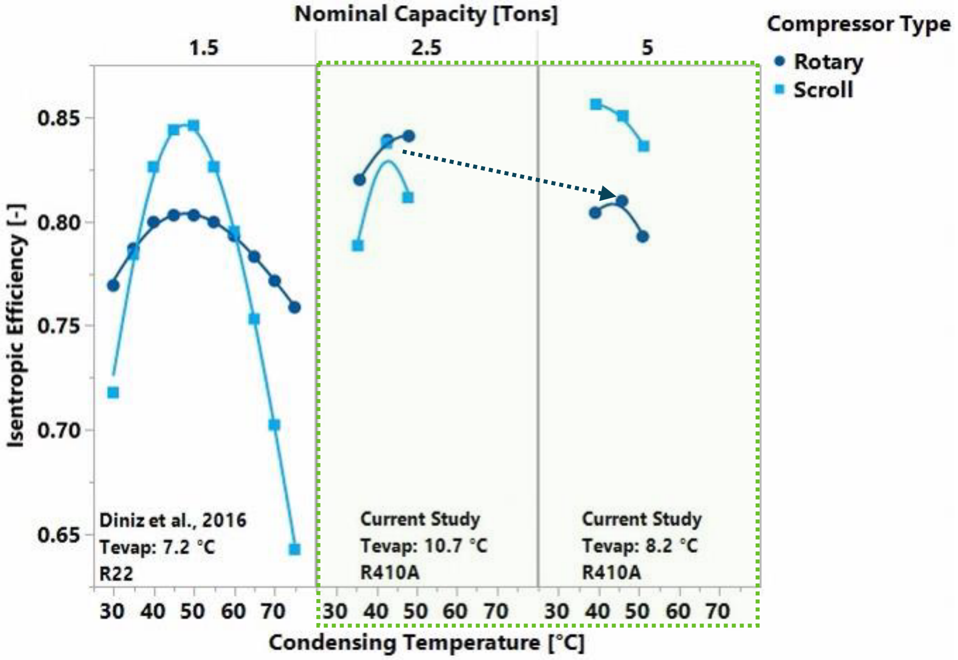
Main losses at 45°C: superheating in suction passages, internal leaks, and discharge passages

Minimizing internal losses is essential for achieving higher efficiency

Progress Literature Review on Rotary Compressors



Main losses at 45°C: Heat transfer in suction and discharge passages, leakage, and superheating

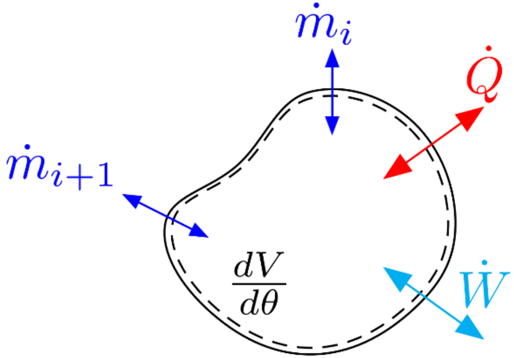


R-410A evaluations show lower efficiency for higher capacities when compared with scroll compressors

Widespread use in small systems (<2.5 ton)—should be explored for larger capacities (3–5 ton); failures owing to lubrication issues in 1980s limited their application

Progress Modeling of Compressors

Model



Use PDSim framework to model compressors with following main assumptions:

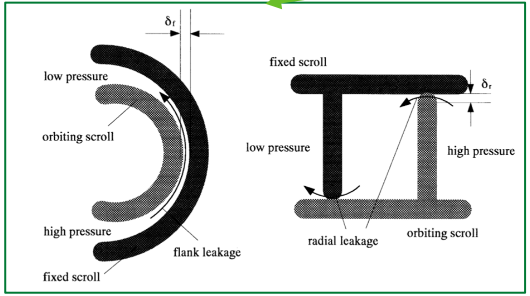
- Uses static and dynamic control volumes to represent each compressor part
- Apply mass and energy conservation laws
- Gravitational effects are considered negligible
- Thermal interactions evaluated through heat transfer
- Uses NIST Refprop 10 for properties

Compressor characterization

V_{ratio} = **Vol**_suct_ch / **Vol**_disch_ch

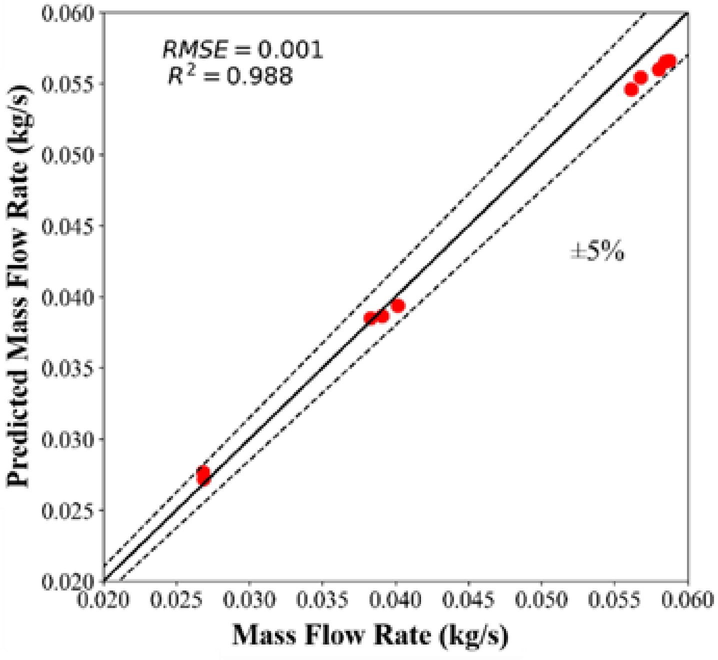
- Calculated using Bell (2014)
- Typically, between 1.5 and 3.5
- High values can affect manufacturing cost

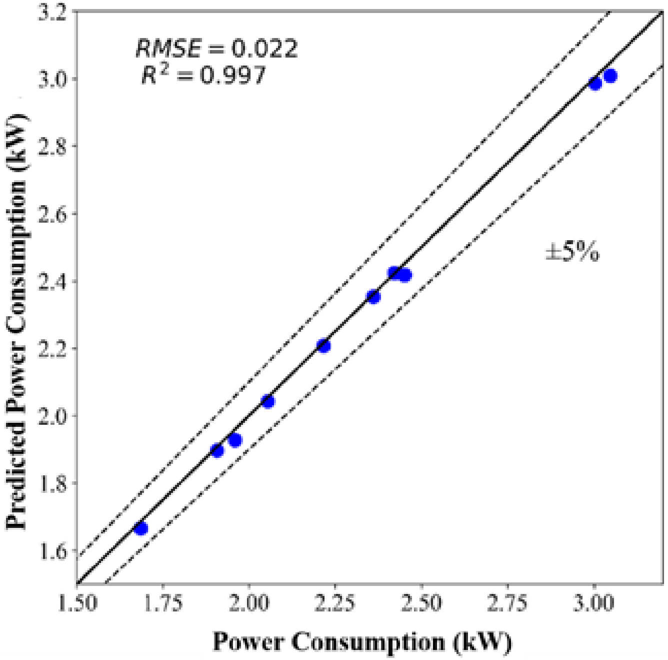
Input	Value	Unit
Displacement	29.35 x 10^{-6}	m^3
Volume Ratio (V_{ratio})	2.77	-
Thickness of scroll wrap	0.0028	m
Orbiting radius of the orbiting scroll (r_o)	0.00345	m
delta flank (δ_f)	20 x 10^{-6}	m
delta radial (δ_r)	1 x 10^{-6}	m
delta suction offset	0.2	m^2
Phi_ie_offset (φ_{ie})	0	m
Lower bearing "D"	0.019	m
Lower bearing "L"	0.03 m	m
Lower bearing "c"	22 x 10^{-6}	m
Bearing thrust ID	0.05	m
Orbiting scroll mass	1.54	lbm



Delta flank   Delta radial

Progress Calibration of Scroll Compressor



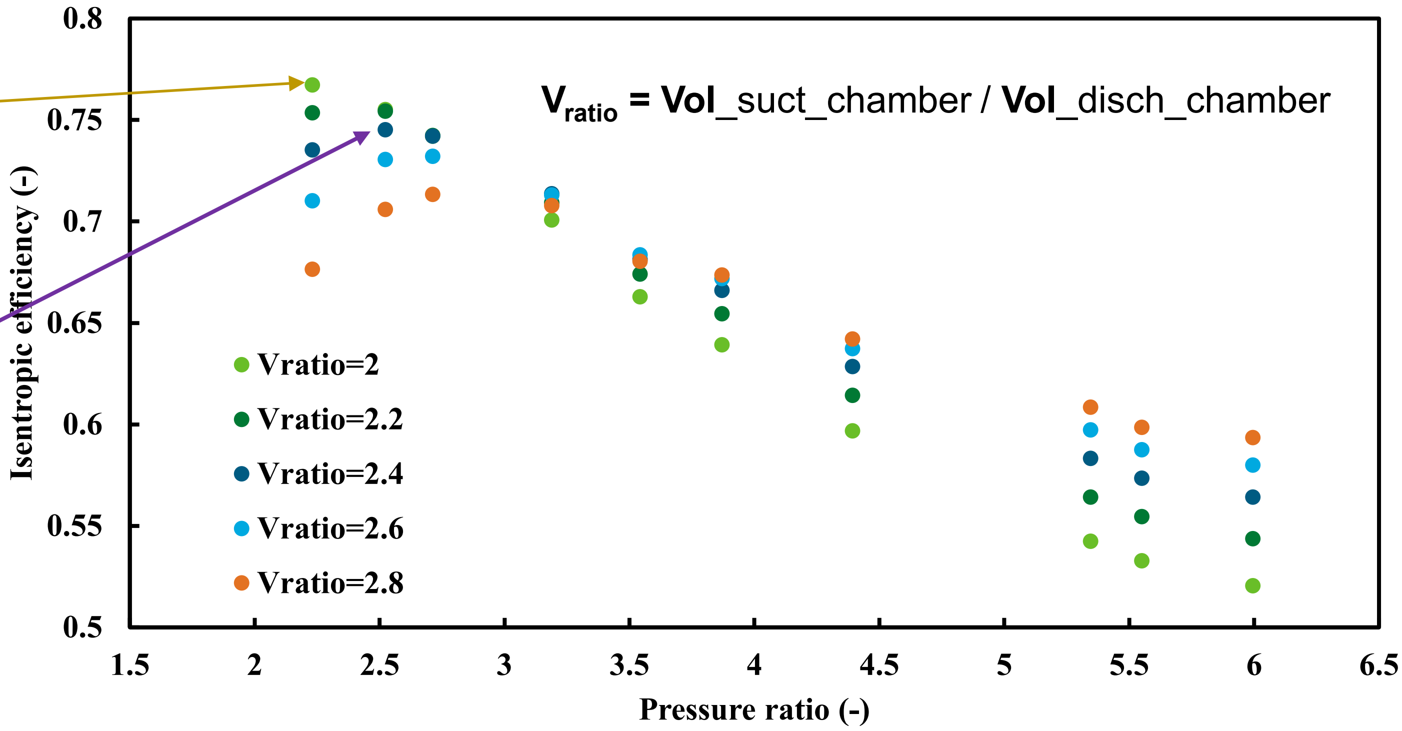


Scroll compressor model was calibrated using data for R-410A; predictions of main parameters match experimental data within experimental error (±5%)

Progress Scroll Compressor Designs for R-454C

Highest isentropic efficiency (77%) obtained for VR of 2

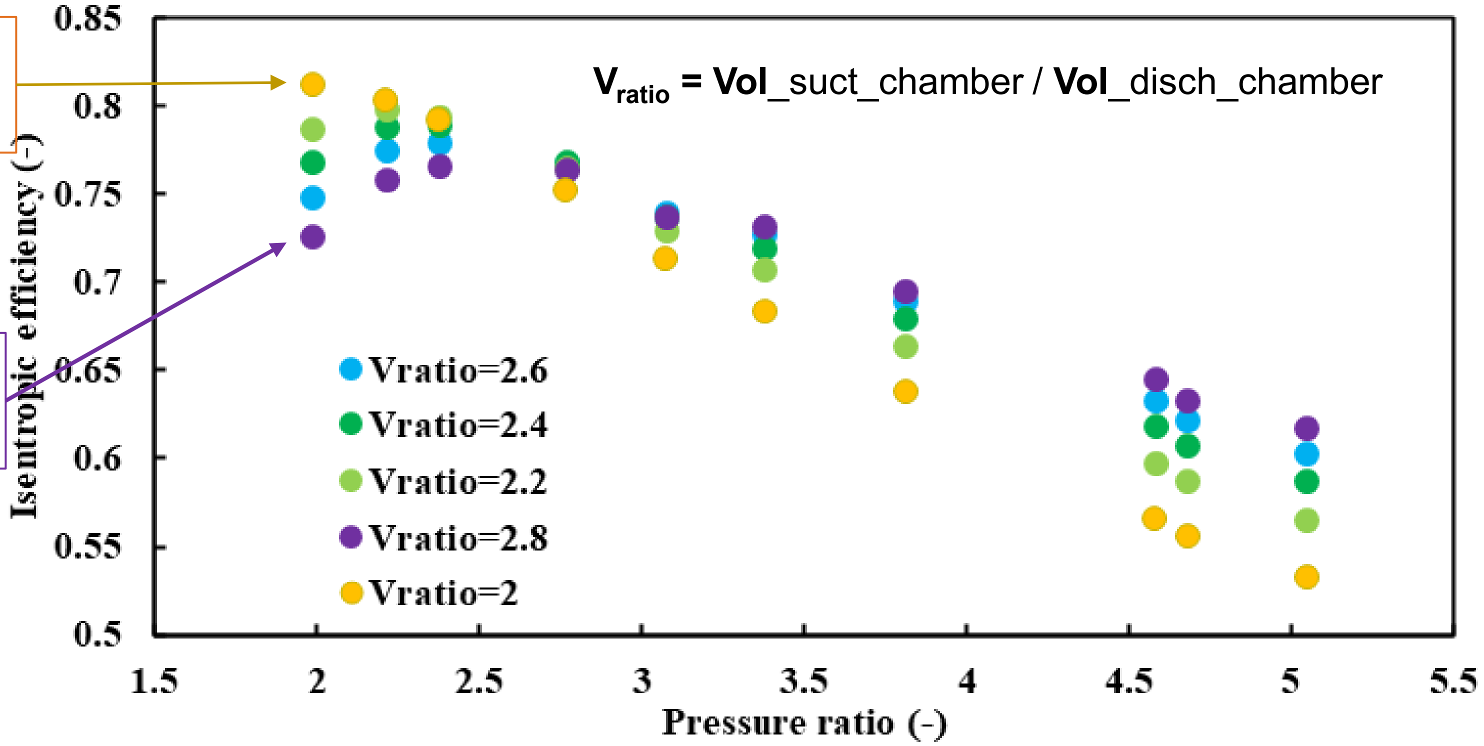
A balanced performance with the highest efficiency of 74.5% was obtained for a VR of 2.4



Progress Scroll Compressor Designs for R-290

Highest isentropic efficiency obtained for VR of 2

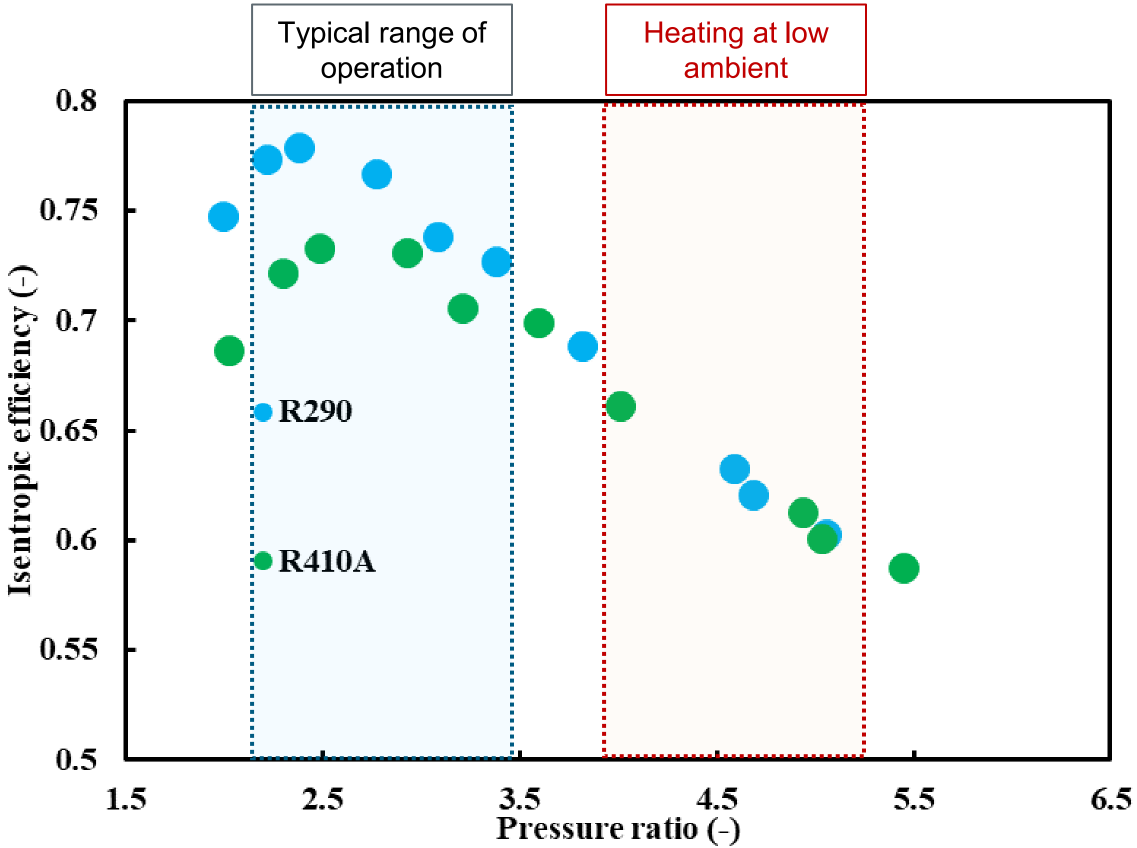
Most balanced performance obtained for VR of 2.8



Progress Balanced Scroll Compressor for R-290

A scroll compressor with a volume ratio of 2.6 can provide efficiencies as high as **78%**

R-410A scroll compressor with volume ratio of 2.77 provides up to **74%** isentropic efficiency



Future Work

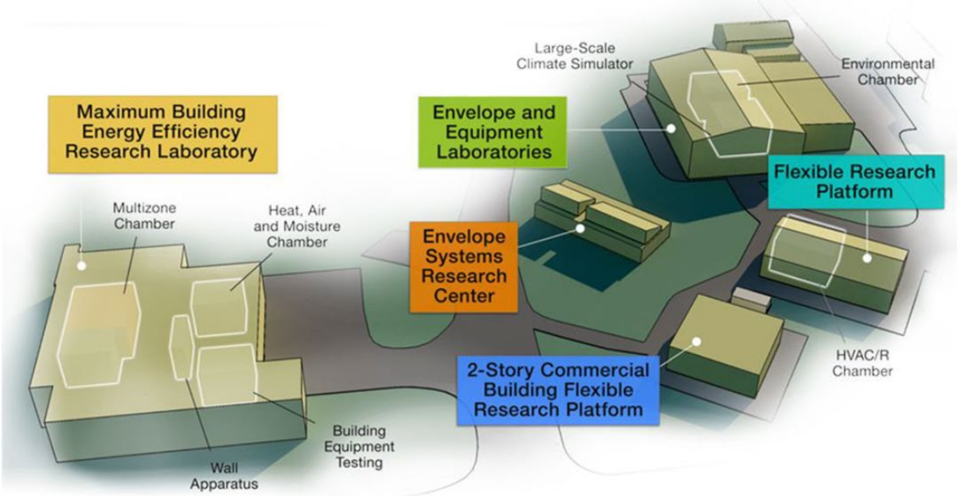
- **Completion of current project tasks**
  - Continue experimental testing of scroll and rotary compressor using HFC/HFO refrigerants and propane
  - Conduct simulation and optimization of scroll compressors with industry (Copeland) and research (Purdue University) partners
  - Using simulation, evaluate effect of compressor optimization on system efficiency for two residential AC systems:
    - Direct expansion (DX) system using R-454C
    - Secondary loop system using propane
- **Explore system enhancements through simulation using calibrated models**
  - Improvements in system for direct expansion (DX) R-454C 3-ton RAC
  - Performance improvements of secondary loop R-290 3-ton RAC system

Thank you

Oak Ridge National Laboratory

Samuel F. Yana Motta, Distinguished R&D Staff
(716) 418-3945 / yanamottasf@ornl.gov

WBS 03.02.02.79



The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is comprised 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

	FY2024				FY2025				FY2026			
Planned budget	$500k				$500k							
Spent budget	$210k											
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Critical literature review												
System modeling to estimate targets												
Modeling of scroll and rotary compressor												
Initial optimization for propane and R-454C												
Current/Future Work												
Testing of scroll and rotary compressors												
Optimization of scroll and rotary compressors												
System level evaluations												

Team

Samuel F. Yana Motta

Distinguished R&D Staff

Junjie Luo

Technical Professional