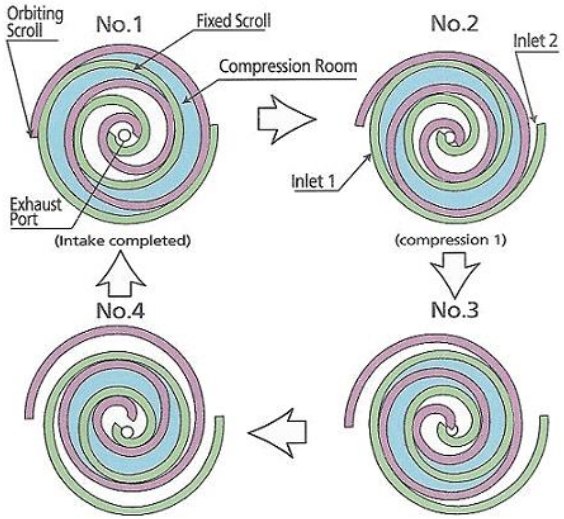
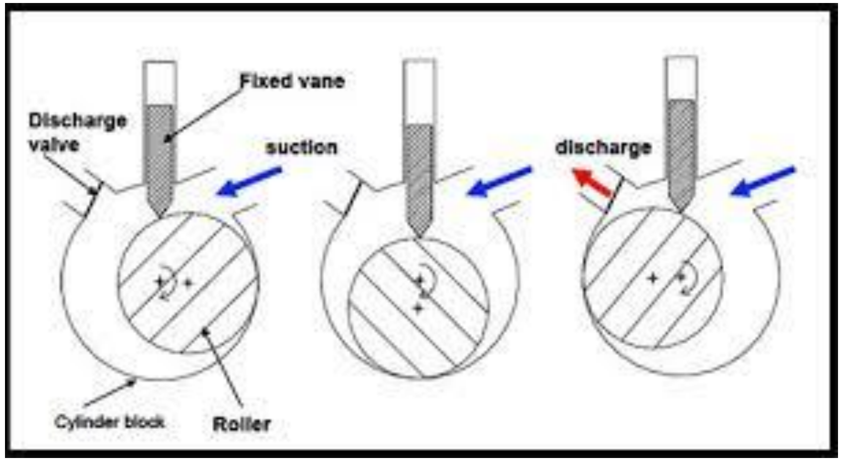
Compressor Technology Development for Refrigerants <150 Global Warming Potential





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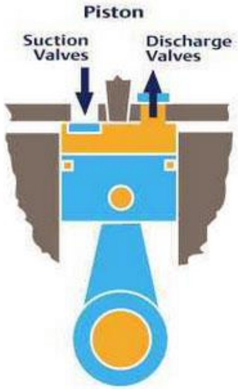
Project Summary

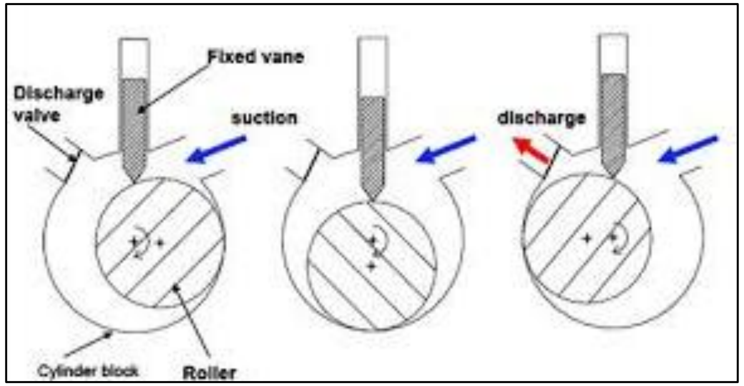
Objective: Enable the development of compressors for low GWP(<150) refrigerants used in Residential and light commercial A/C heat pumps.

Outcome: Reduce the direct CO_2 emissions by 96.4% (32,500,000 tons of CO_2). The potential energy savings can be up to 5.6% (37,934 TWh/year equivalent to 16,000,000 tons of CO2).



Reciprocating

Scroll



Rotary

Team and Partners

PI: Samuel F. Yana Motta, ORNL

ORNL Researchers: Junjie Luo, Bo Shen, Zhenning Li

Partners: Emerson, Purdue University

Stats

Performance Period: FY23 – FY24

DOE budget: $700k, Cost Share: NA

Milestone 1: Target for the Compressor Q3/2023

Milestone 2: Compressor Optimization Q2/2024

Milestone 3: System Performance Evaluation Q4/2024

Problem

- The **residential and light commercial A/C market** must reduce GHG emissions by 70% to comply with regulations coming from the EPA and the Kigali Agreement'
  - Direct CO2 emissions amount to 32.5 million tons of CO2 per year
  - Annual energy consumption is 682,827 TWh, leading to indirect emissions of 289 million tons of CO_2
  - Current interim solutions R-32 (GWP 675) and R-454B (GWP 466) are not enough to comply with the above regulations. Refrigerants with GWP at least lower than 150 are considered potential long-term solution

- Current compressors used in A/C heat pumps using new refrigerants such as R-454C, R-1234yf or R-1234ze cannot produce the minimum level of energy efficiency required by the DOE. Hence further developments in compressors (and heat exchangers) technologies are needed.

This project aims at enabling the development of compressors for the next generation A/C heat pumps.

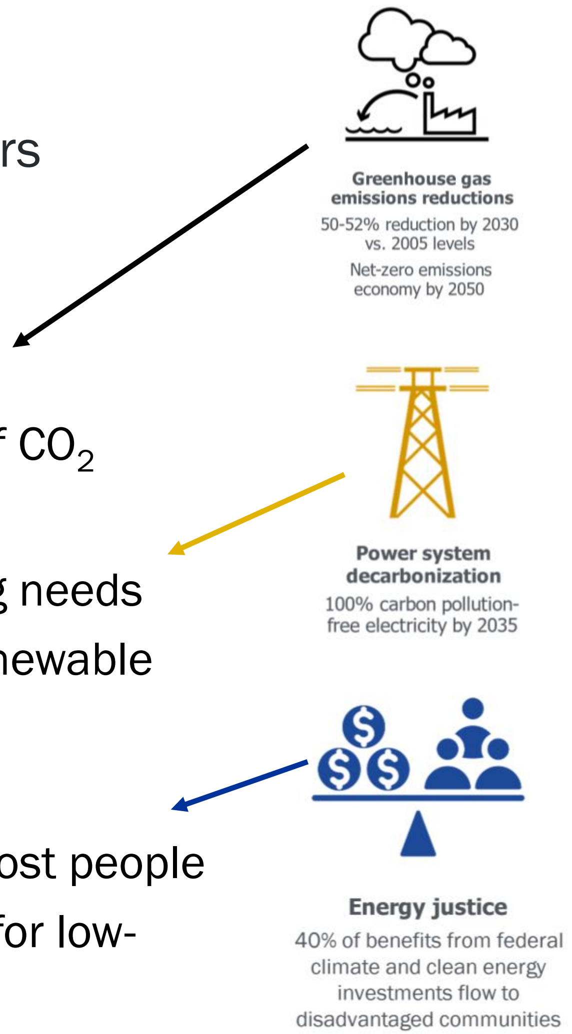
Alignment and Impact

Goals

- Enable development of compressors for low GWP (<150) refrigerants
- Enhance energy efficiency and affordability compared to R-410A compressors

Key Impacts

- Green house gas emission reduction
  - Direct emissions: up to 96.4% decrease, 32,500,000 tons of CO_2
  - Indirect emissions: up to 5.6% decrease from energy saving, 16,000,000 tons of CO_2
- 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
  - The implementation of this project will environmentally and financially benefit most people
  - Transition from electric heating to heat pumps significantly reduces energy bills for low-income individuals



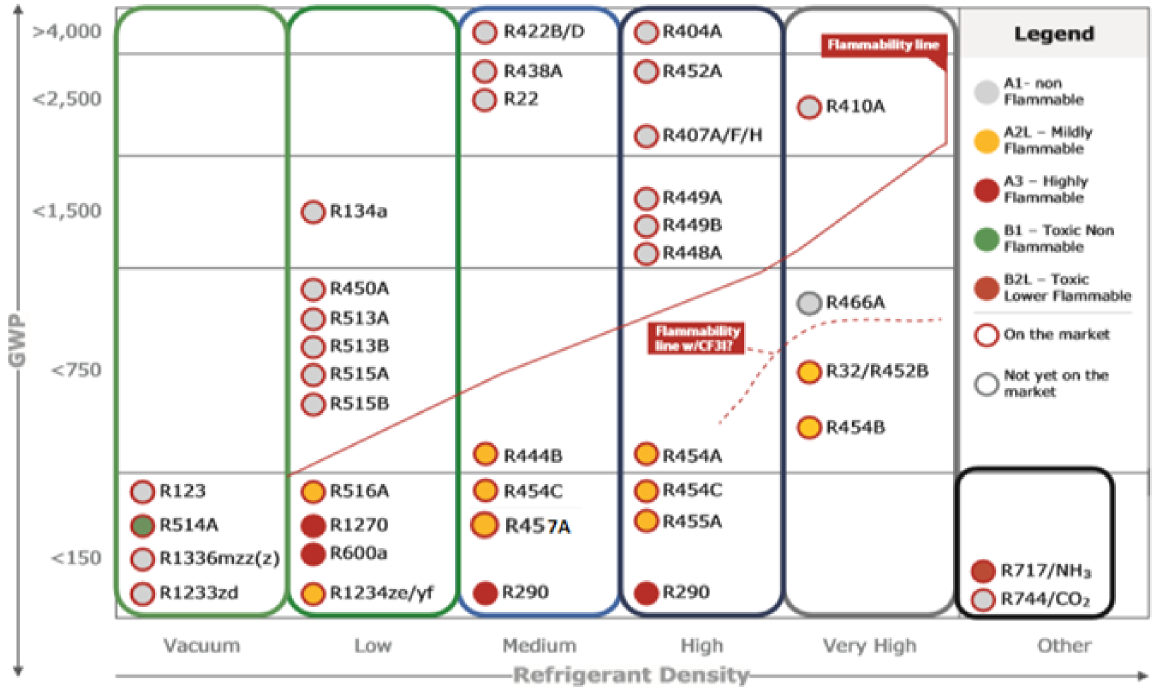
Approach: Background information

Current refrigerants: Dominance of R410A in AC/Heat Pump Products

- Early 2000s: Industry explored replacements for R22 due to ozone depletion concerns
- Innovation on compressor development helped increase 5% system efficiency with R-410A

New Environmental Requirements: Replacing R410A due to its high GWP (2088)

- Long-term replacements: Low GWP (<150) refrigerant
  - R-1234yf, R-1234ze, R-454C, R-455A
  - Technical challenges for low GWP refrigerants
    - Low operating pressure and density: Results in approximately 70% decrease in volumetric capacity.



Approach: Methodology

- **Critical Literature review (task 1)**
  - Extensive review of at least Scroll, Rotary, Linear and Centrifugal technologies.
  - Identify top two compressor technologies for residential A/C applications.
  - Identify and refine the list of refrigerants to be evaluated in this project.
- **Modeling of Compressor & heat exchangers (tasks 2 and 3)**
  - Optimization of 3-ton RAC to establish targets for compressor efficiency using low GWP refrigerants identified in literature review. Select two top refrigerants for further evaluations.
  - Modeling/optimization of the top two compressor technologies identified in literature review: Scroll + Other.
  - Select the top two compressor/refrigerant combinations.
- **Performance validation (tasks 4 and 5)**
  - Validate compressor performance using compressor calorimeter evaluations of selected technologies in phase 2.
  - Evaluate the top compressor/refrigerant technology using a 3-ton RAC system equipped with optimized heat exchangers

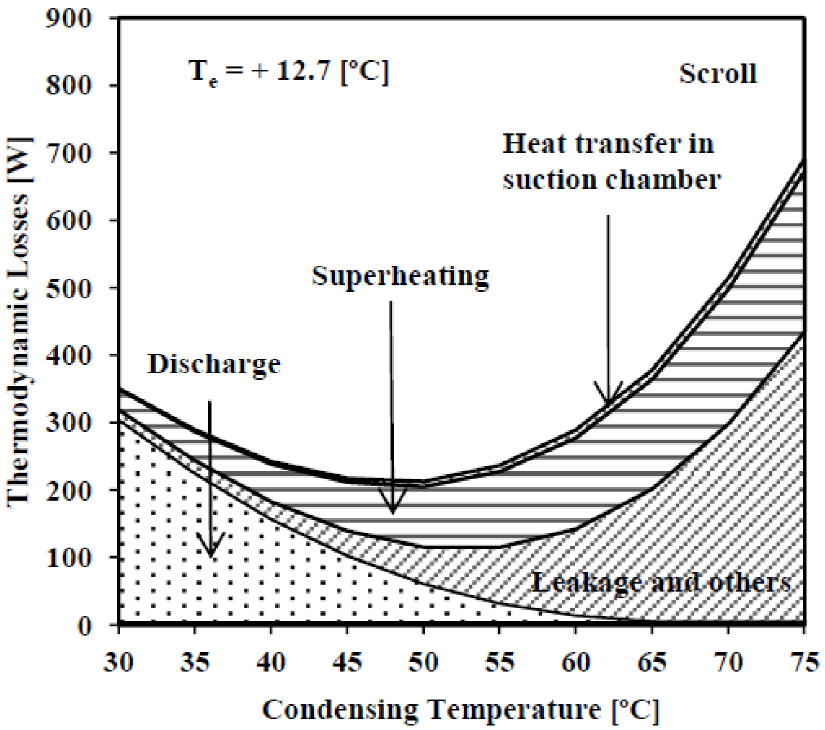
Will use a calibrated version of HPDM to simulate reversible HP system.

Will use "mechanistic" model that takes into account geometry and fluid properties

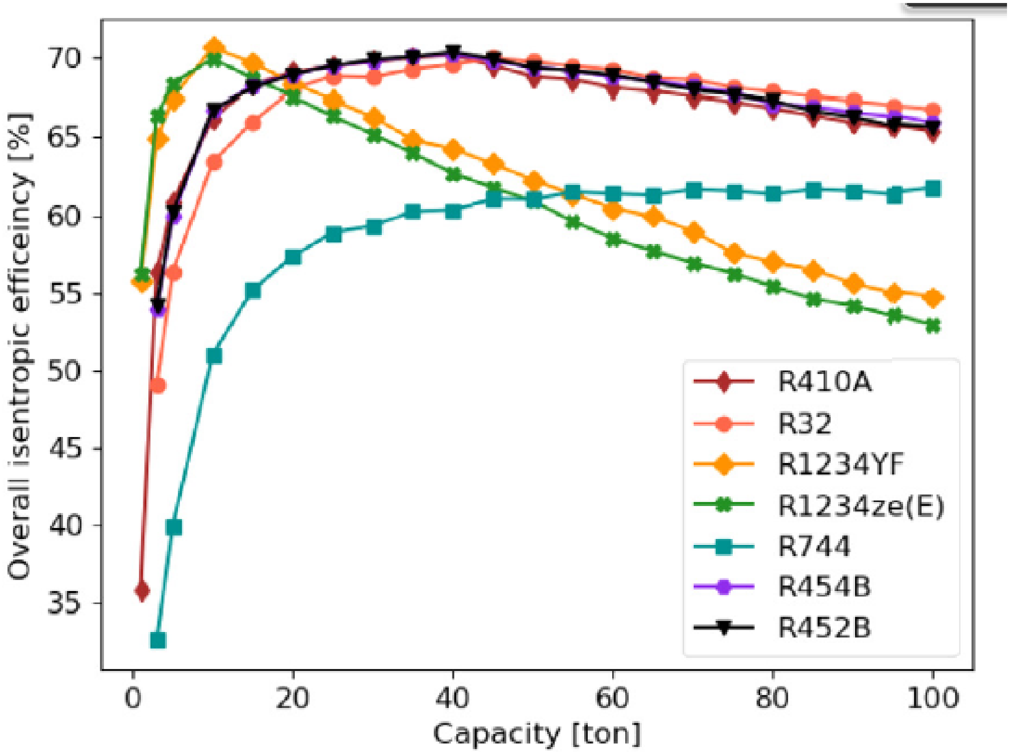
Will use compressor calorimeter to validate performance within experimental uncertainty (±5%)

Will use a fully optimized 3-ton residential A/C system equipped with optimized compressor

Critical Literature Review: Scroll Compressors



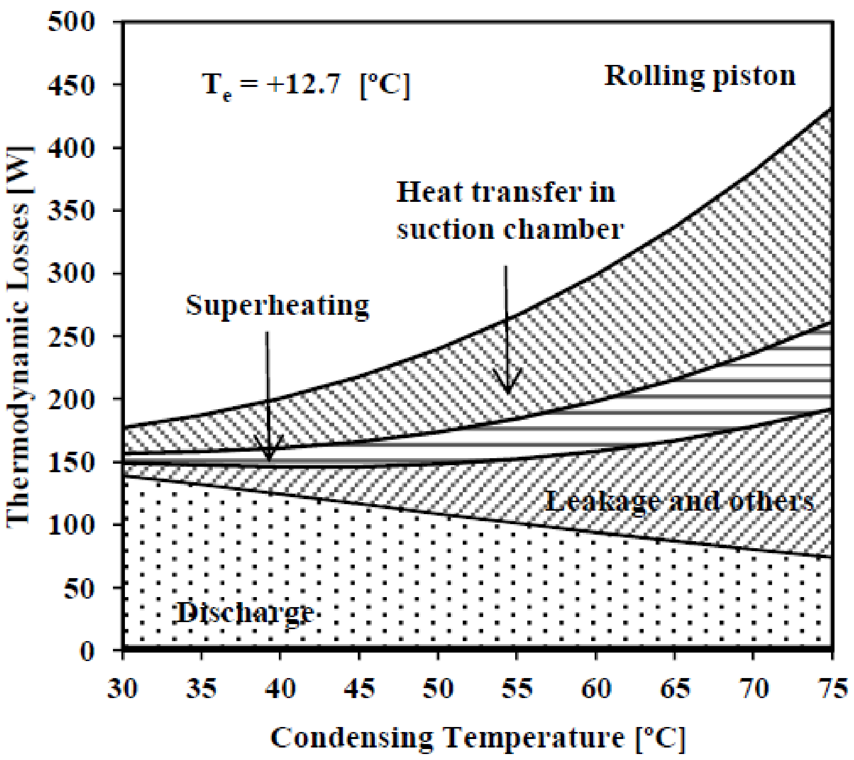
Losses in the 30-55°C range: compression heat (superheating), Internal leaks and discharge

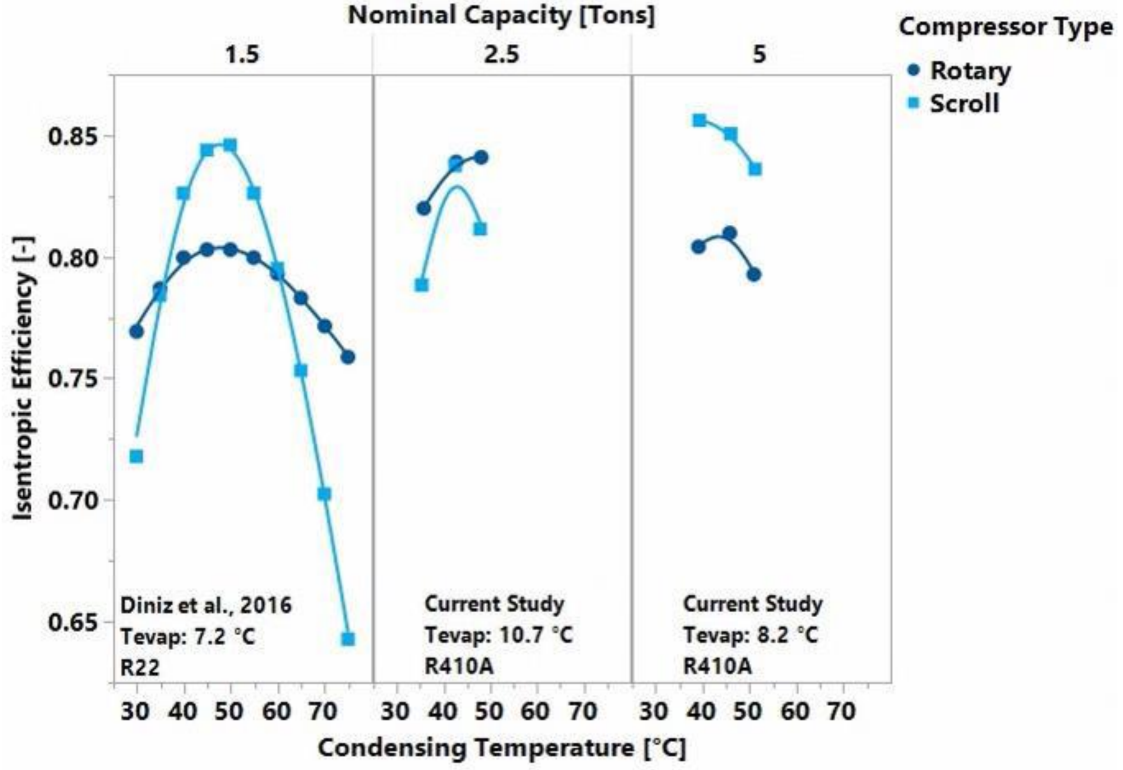


Higher volumetric & isentropic efficiencies achievable in lower capacity ranges for low-pressure refrigerants

Larger scrolls are required for low volumetric capacity refrigerants R-1234yf and R-1234ze(E)
Minimizing compression heat losses and internal leaks is essential for optimizing performance
Proper Electric motor selection and sizing are crucial for achieving higher efficiency

Critical Literature: Rotary Compressors





Losses in the 30-55°C range: Heat transfer in the suction and discharge passages, leakage and superheating.

For R-410A, higher efficiency for less than 2.5-ton capacities compared to scroll compressors

Widespread use in small A/C heat pump systems: No high-efficiency models for 2.5+ tons

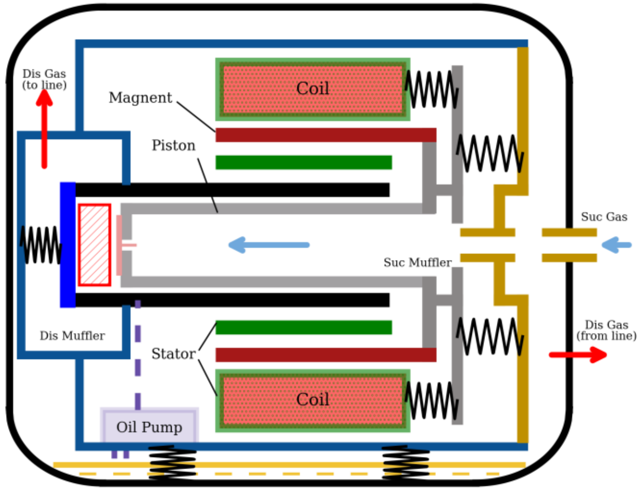
Historical setbacks in the 1980s: GE failures due to lubrication issues

Needs further studies for larger capacities (3-5 Ton)

Critical literature review: Other technologies

Linear compressors

- **Current use:** Small applications such as domestic refrigerators
- **Pros:** minimum moving parts, high efficiency in small capacities
- **Challenge for scaling up:** Efficiency drop, and cost increase due to larger piston
- Requires further study to evaluate loses for larger sizes (***scaling up***).



Centrifugal Compressors

- **Current applications:** Large capacity centrifugal chillers
- **Pros:** High efficiency with low pressure refrigerants (R-1233zd, R-1234ze)
- **Challenge for downsizing:** Bennet (2018): Studied prototypes using lower pressure refrigerants (R-1234ze, R-515A) for 5-ton systems
  - High rotating speeds (>100,000 rpm)
  - significant variation of efficiencies with load/speed
- Further research required to assess the feasibility of ***scaling down***

Both linear and centrifugal compressors face challenges to extend range of application

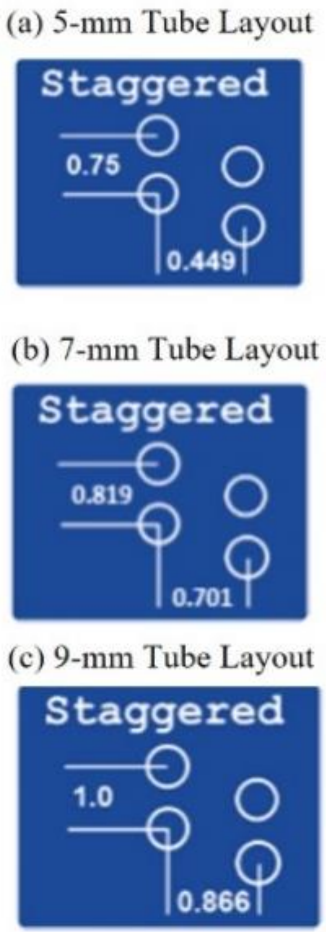
Critical Literature Review: Types of Models for compressors

Type	White box	Gray Box (Mechanistic)	Black box (performance)
Definition	• Physics-based • Fully distributed model (Partial differential equations)	• Construction oriented • Qualitative knowledge (rules) • Simplified relationships	• Extrapolation based on experimental data
Technique	• Computational Fluid Dynamics (CFD) simulation • FEA simulation	• Mechanistic Modeling • Lumped parameter model	• Compressor maps using curve-fitting • Semi-empirical based on isentropic and volumetric efficiency curves
Features	• Good description of geometry • Detailed physical process • Good accuracy after calibration	• Cover a wide range of compressors • 95% faster than “white Box” • Good accuracy after calibration	• Short development time • Little domain expertise required
Drawbacks	• Time consuming development (meshing and computation)	• In-depth knowledge on compressor physics required	• Not reliable for extrapolation out of experimental range
Application areas	• Optimizing individual components by investigating dynamic behavior	• Design based on variables: speed, capacity, heat transfer, internal leaks, fluid properties	• Performance prediction within the range of test data • System design

Mechanistic models seem appropriate for the objectives of this project

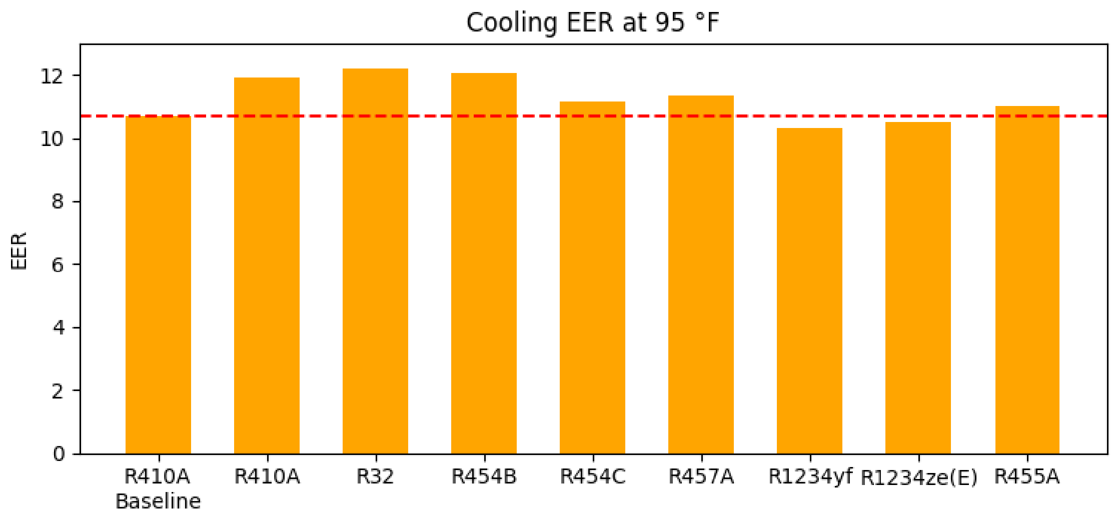
System Modeling: Model Calibration and Variable

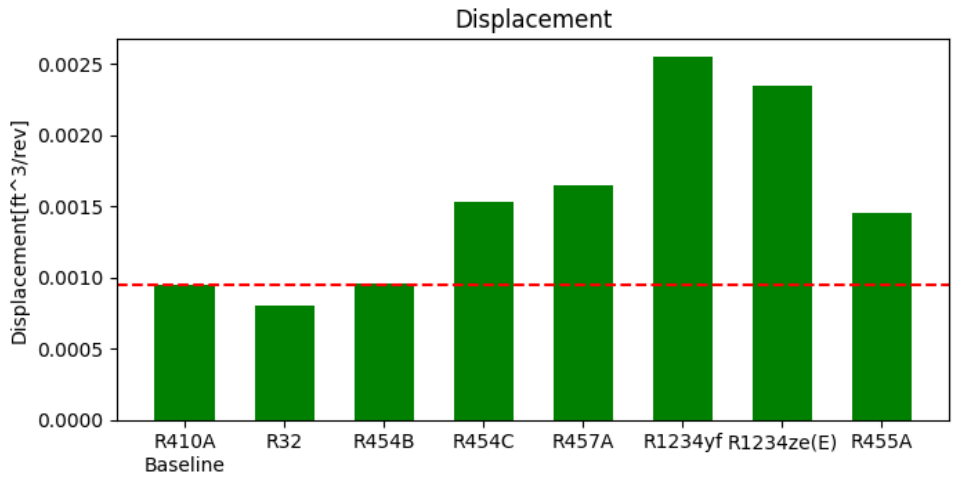
- **Model calibration:** Used experimental data obtained for a 3-ton RAC system with R-410A and R-32.
- **Simulations:** Conducted under A conditions of AHRI 210/240
  - R-410A, R-454C, R-1234yf, and R-1234ze(E) simulated
- **Constraints:**
  - Maintained overall heat exchanger volume (minimizes cost increase)
  - 36,000 BTU/h cooling capacity (adjusted compressor displacement)
  - Fixed efficiencies: 74% isentropic, 98% volumetric (R-410A benchmark)
  - Similar losses in connecting lines to R-410A (proper diameter selection)
- **Variables:** Heat exchanger configurations
  - Drop-in, 5-mm tube, 7-mm tube, 9-mm tube
- **Objective**
  - Maximize system efficiency
  - The results will be used to calculate the compressor efficiency that will allow to match the efficiency of the R-410A benchmark.



The results generated an article submitted to a journal

System Modeling: 5-mm Optimization Performance





- 5mm-tube heat exchangers achieved the most promising performance
- If the predicted efficiencies are used to back calculate compressor efficiencies:
  - R-457A: 67.9% (-6% compared to R-410A's compressor)
  - R-454C: ~69.8% (-4.2% compared to R-410A's compressor)
  - R-455A: 71.2% (-2.8% compared to R-410A's compressor)
  - R-1234ze(E): ~75.9% (+1.8% compared to R-410A's compressor)
  - R-1234yf: ~77.7% (+3.7% compared to R-410A's compressor)

Mixtures with GWP<150 look promising in these early estimates

Thorough experimental validation and validation of manufacturing is needed

Modeling of Compressors

- **Established collaboration with Purdue University to develop mechanistic models**
- **Models will be validated/calibrated using publicly available data and testing performed in this project with current refrigerants (R-410A, R-134a,..).**
- **Validated models will be used to find out the theoretical limits of compressor technologies with the new refrigerants.**
  - Optimize geometry for each refrigerant
  - Establish the maximum efficiency in the range of operation for A/C applications
- **The results will allow to narrow the compressor technologies to be further evaluated in this project.**

Future Work

- **Task 2: Establish target for compressor efficiency by system modeling by Q2 of FY2023**
- **Task 3: Modeling/Optimization of at least two compressor technologies. Complete by Q4 of FY2023**
  - Optimize a scroll compressor using established, complete by Q4 of FY2023
  - Optimize an alternative compressor technology, complete by Q4 of FY2023
- **Task 4: Verification of optimized compressor performance through experimental testing**
  - Work with compressor partner to obtain compressor prototypes, complete by Q1 of FY2024
  - Calorimeter testing of compressor prototype(s) at ORNL. Complete by Q2 of FY 2024
- **Task 5: Verification of optimized compressor performance through experimental system testing**
  - Build system prototype (3-ton A/C reversible HP). Complete by Q3 of FY2024
  - System prototype testing at ORNL. Complete by Q4 of FY2024

Thank you

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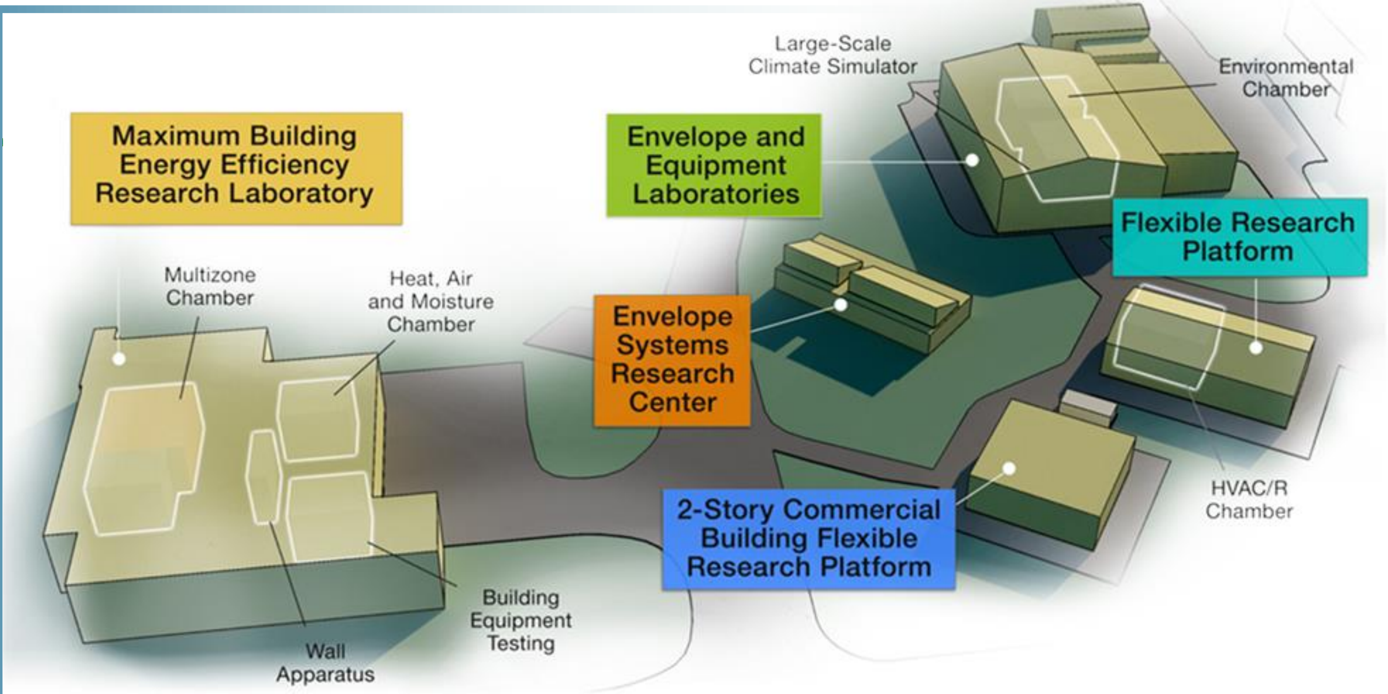

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Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

	FY2023				FY2024			
Planned budget								
Spent budget								
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work								
Q1 Milestone: Literature Review								
Q2 Milestone: System Modeling								
Current/Future Work								
Q3 Milestone: Compressor model development								
Q4 Milestone: Compressor optimization								
Q2 Milestone: Verification of optimized compressor performance through experimental testing								
Q4 Milestone: Verification of optimized compressor performance through experimental system testing								