2024 PROJECT PEER REVIEW

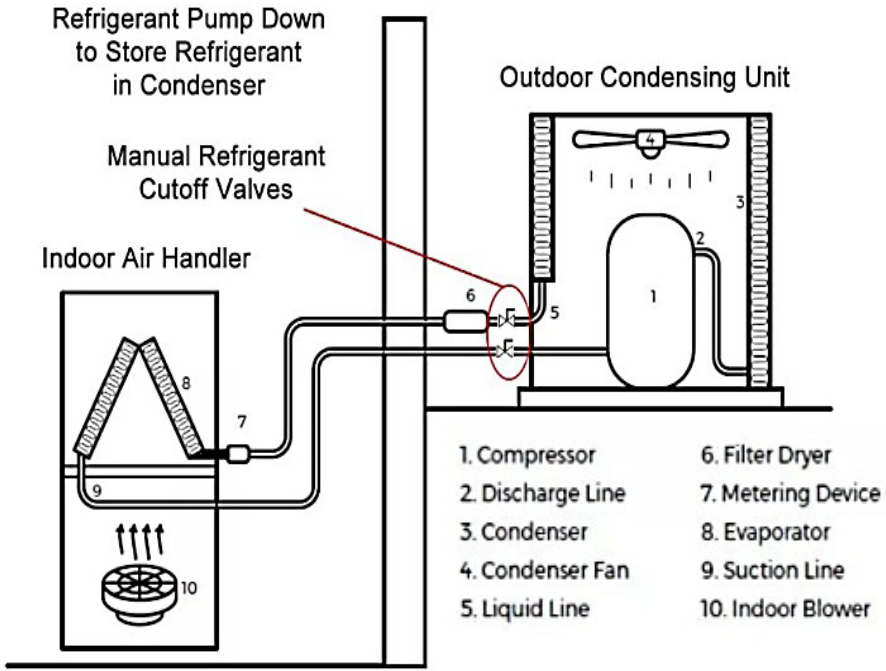
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

Compressor is a Sensor

Compressor is a Sensor CRADA Copeland

Emerson CoreSense™ Diagnostic, Communications, and Protection Technology



Pump-down commissioning

Oak Ridge National Laboratory
PI: Bo Shen, Senior R&D Staff;
Presenter: Zhenning Li, Associate R&D Staff
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WBS # 03.02.06.83, Lab call CRADA

Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

- Develop accurate charge fault detection and diagnosis technology embedded in existing compressor sensor board
- New technology automatically identifies refrigerant charge faults during regular heat pump commissioning operation and makes refrigerant charge value available at technician's fingertips
- New technology featured fast response, high accuracy, and universal applicability for various residential and commercial systems

Residential heat pump for charge prediction validation

Commercial roof-top unit for charge prediction validation

TEAM AND PARTNERS

ORNL Team: Bo Shen, Zhenning Li

CRADA Partner: Drew Welch (The Helix Innovation Center in Copeland)

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STATS

Performance Period: 10/01/2021-09/30/2025

Total DOE budget: $500k, Total Cost Share: $500k

Milestone 1: Dynamic modeling report

Milestone 2: Develop charge prediction algorithm

Milestone 3 (Go/No-go): Laboratory verification on residential system to capture system charge within ±10% accuracy

Milestone 4 (Go/No-go): Laboratory verification on commercial system to capture system charge within ±10% accuracy

Milestone 5: Field installation and instrumentation

Milestone 6: Final reporting

Problem

- Charge faults (overcharge or leakage) have significant impacts on HP performance
- Evacuating and weighing the refrigerant is time-consuming and cost-ineffective
- Subcooling and superheat degrees at steady-state operation are commonly used as prediction indices for charge fault
  - However, steady-state operation requires long data acquisition time owing to ambient temperature and building load variations
- ML-based charge prediction method requires large amount of experimental data for training; ML model is system-dependent
- Existing charge prediction method based on steady-state operation of vapor compression system cannot predict inactive charge in refrigerant buffers (i.e., accumulator and receiver)

Alignment and Impact

- **Increase building energy efficiency and reduce GHG emissions**
  - Accurate charge prediction method improves system reliability and energy efficiency, reduces indirect GHG emission
  - Reliable charge FDD method mitigates refrigerant leakage, mitigates danger of flammable refrigerants, and reduces direct GHG emission

Greenhouse gas emissions reductions

- **Prioritize equity, affordability, resilience**
  - Seamless integration into existing compressor sensors and commissioning operations to accommodate current manufacturing and installation processes

Prioritize affordability

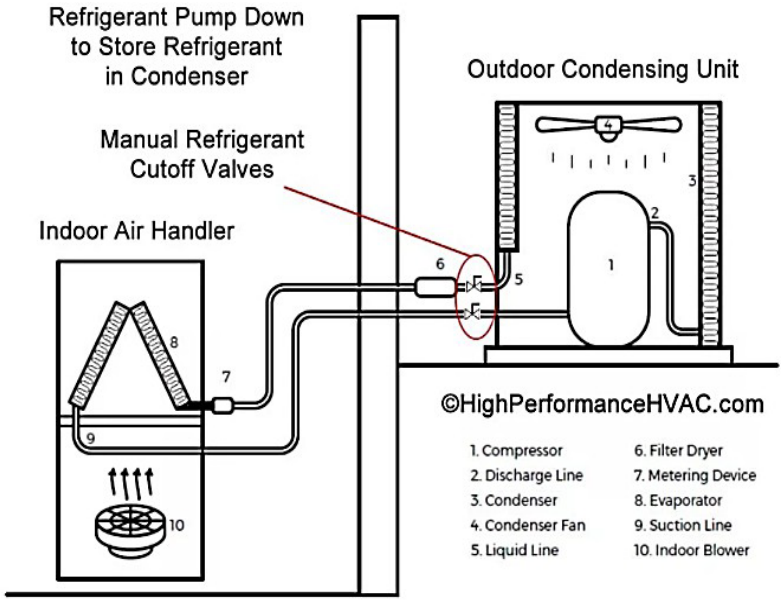
- **Pump-down based charge FDD technology features fast response, high accuracy, and universal applicability for various residential and commercial systems**

Approach

- Develop an accurate universal charge fault detection method that requires small amount of experiment data with high prediction accuracy
- Take advantage of existing sensors and control of compressor and identify charge fault during regular heat pump commissioning operations
- Predict the charge in refrigerant buffers (i.e., accumulator and receiver)
- Does not require indoor heat exchanger geometry, length of pipelines, and internal volume of accumulator and receiver

Approach (Cont'd)

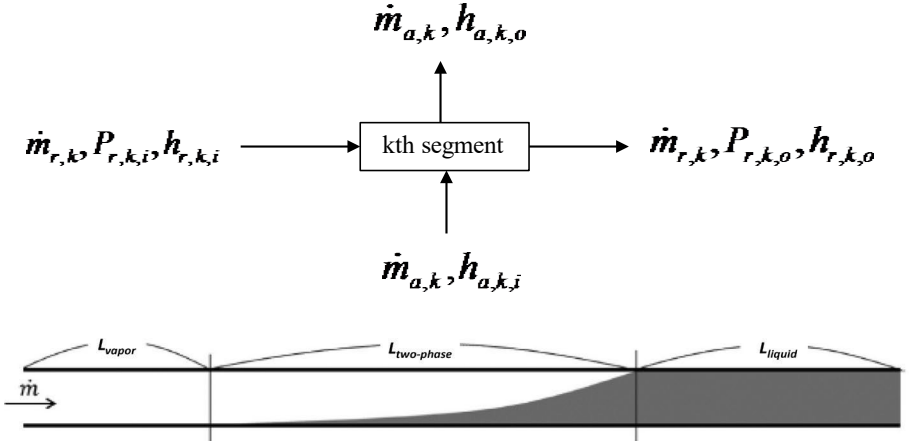
- A novel charge prediction method based on pump-down operation
- Total charge consists of four parts
  - **Part 1:** condenser charge during static state operation
  - **Part 2:** Charge migrated from low-pressure side to high-pressure side via compressor
  - **Part 3:** Charge leaked from high-pressure side to low-pressure side via four-way valve
  - **Part 4:** Remaining charge in low-pressure side after pump-down (negligible)



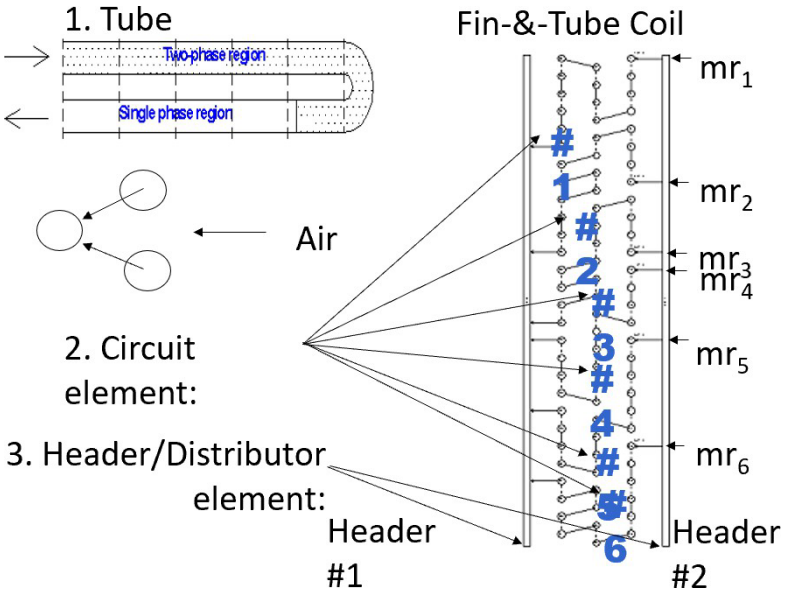
Pump-down (a typical commissioning operation performance by HVAC technicians)

Progress Predict Condenser Charge

- DOE/ORNL heat pump design model (Shen and Rice [2016]) is used to predict condenser charge
- Heat exchanger model uses segment-to-segment modeling approach to predict local heat transfer and pressure drop



Refrigerant distribution in high-pressure side flow path



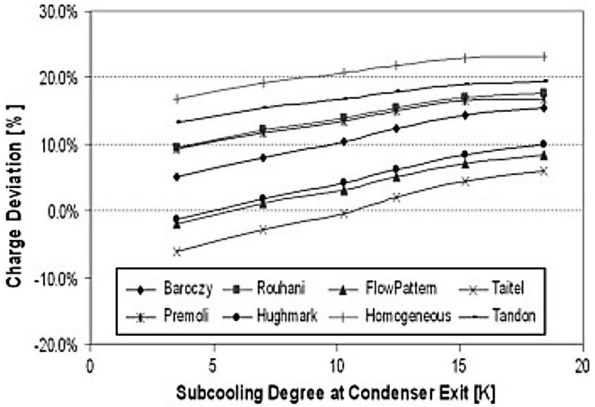
[1] https://hpdmflex.ornl.gov

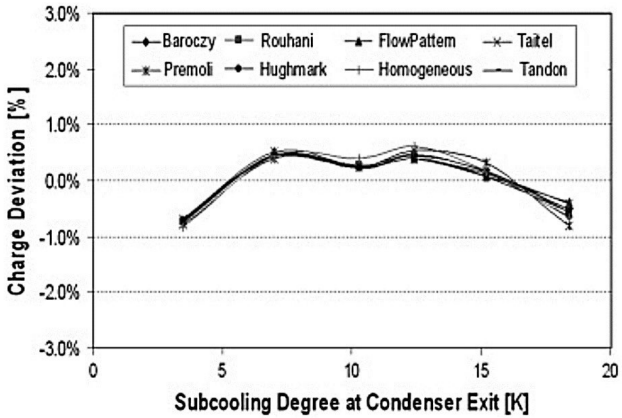
Progress Predict Condenser Charge (cont'd)

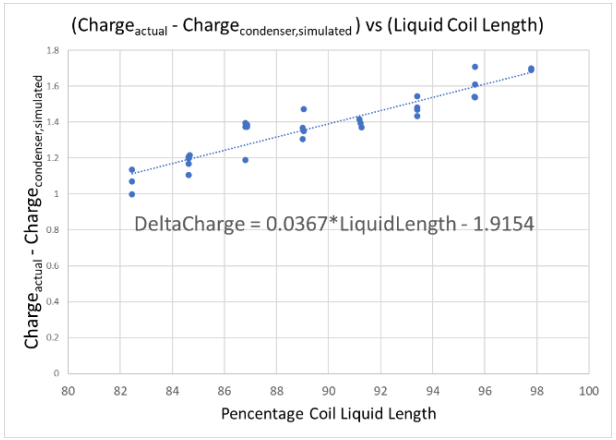
- Use heat exchanger model to predict subcooled liquid length and condenser charge
- Fine tuning the charge prediction based on previous research [1]
- The tuned charge prediction equation can be obtained by fitting OEM performance data

$$M_{corrected,LiqL} = M_{simulated} + \Delta M_{liqL}$$

$$\Delta M_{liqL} = C + k_{liqL} \times L_{liq}$$



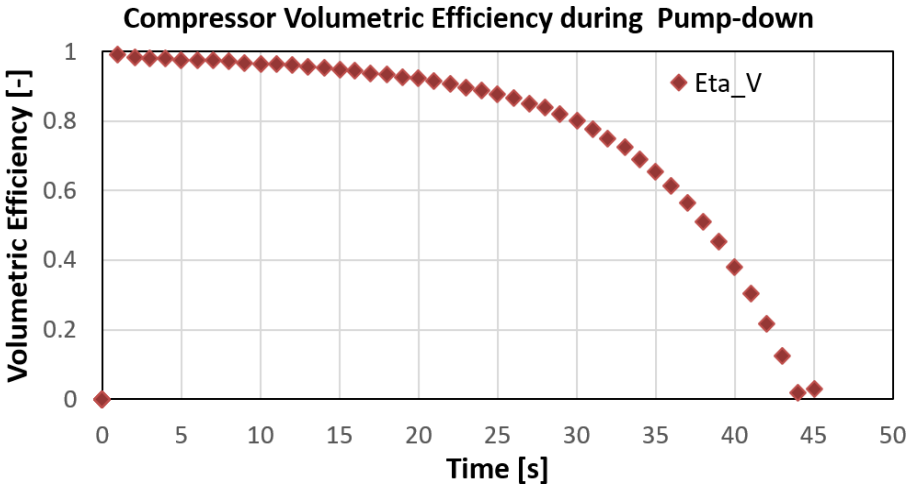




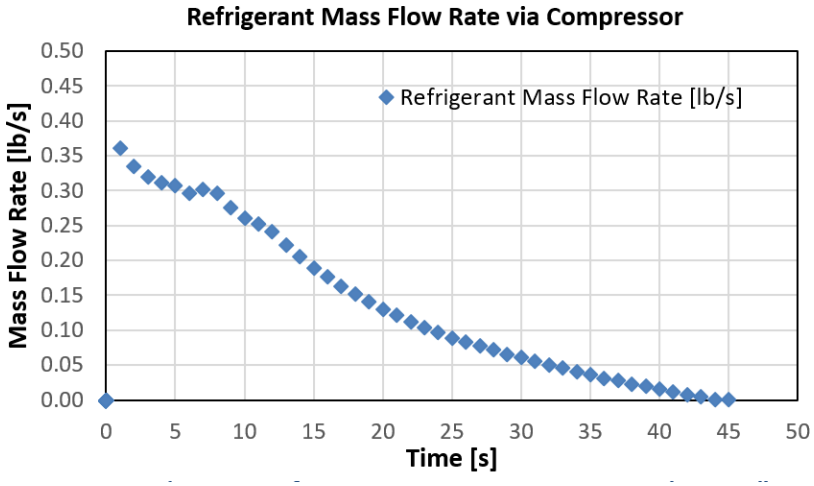
[1] Shen, B., Braun, J. E., & Groll, E. A. (2009). Improved methodologies for simulating unitary air conditioners at off-design conditions. Int. Journal of Ref., 32(7), 1837-1849.

Progress Predict Migrated Charge via Compressor

- Compressor map was used to predict volumetric efficiency degradation and refrigerant mass flow rate during pump-down process
- Accumulated refrigerant mass flow rate during pump-down is the migrated charge via compressor



Compressor volumetric efficiency during pump-down @71°F, 7 lbm charge

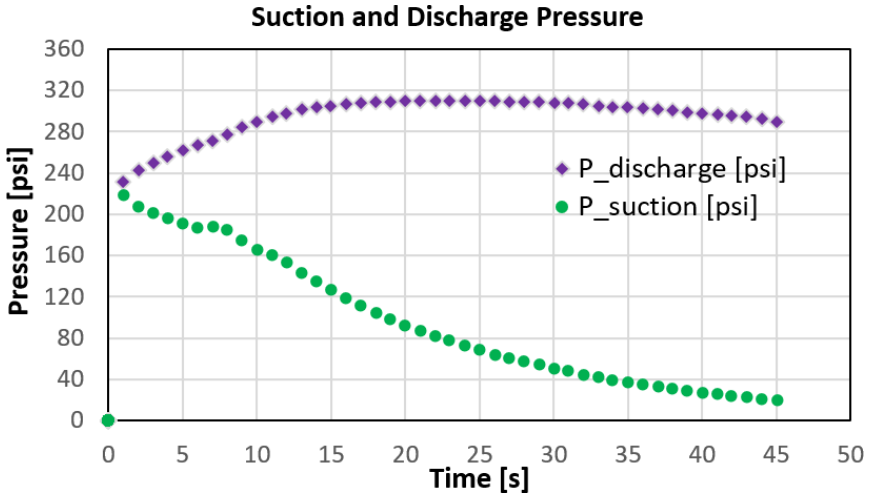


Refrigerant mass flow rate via compressor, @71°F, 7 lbm charge

Progress Predict Migrated Charge via Four-Way Valve

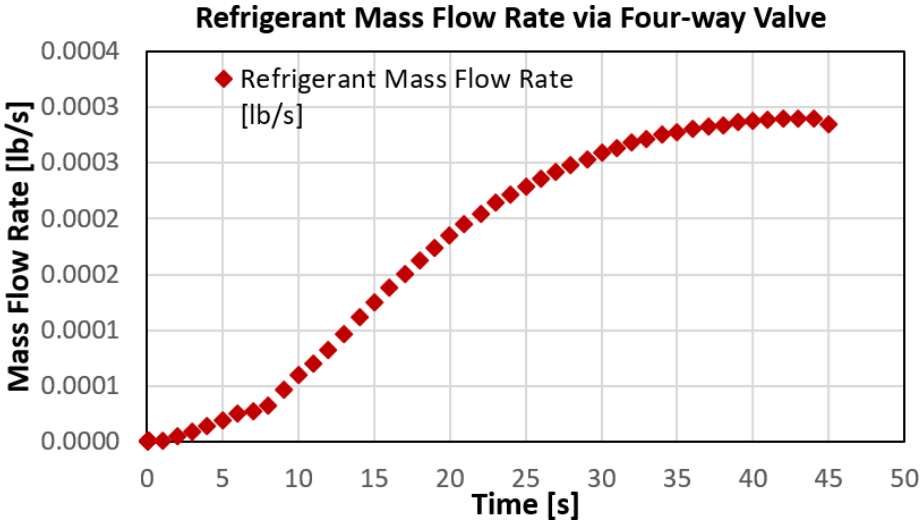
- Calculated reversed refrigerant flow via four-way valve owing to valve leakage
- Refrigerant flow in four-way valve is driven by pressure difference between discharge and suction points

$$VFR_{4WayValve} = Cv_{fourWayValve} \times (P_{discharge} - P_{suction})^2$$



Suction and discharge pressure during pump-down

$$Mr_{4-wayValve} = \rho_{discharge} * VFR_{4-WayValve}$$



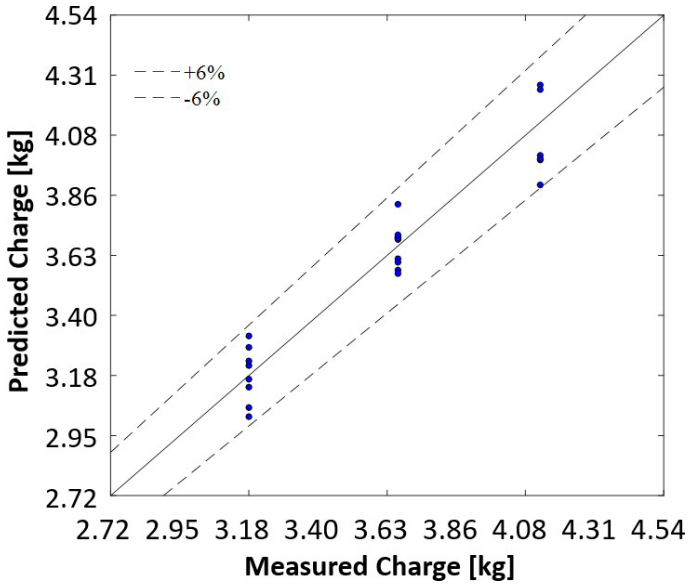
Refrigerant mass flow rate via four-way valve

Progress Validation on a Residential Heat Pump

- R-410A 3-ton split heat pump was used for experiment validation
- Outdoor unit placed on scale to measure charge migration
- Pump-downs were conducted at 3 charge levels and 4 ambient conditions
- The charge prediction deviation is within 6%

Outdoor unit using microchannel heat exchangers

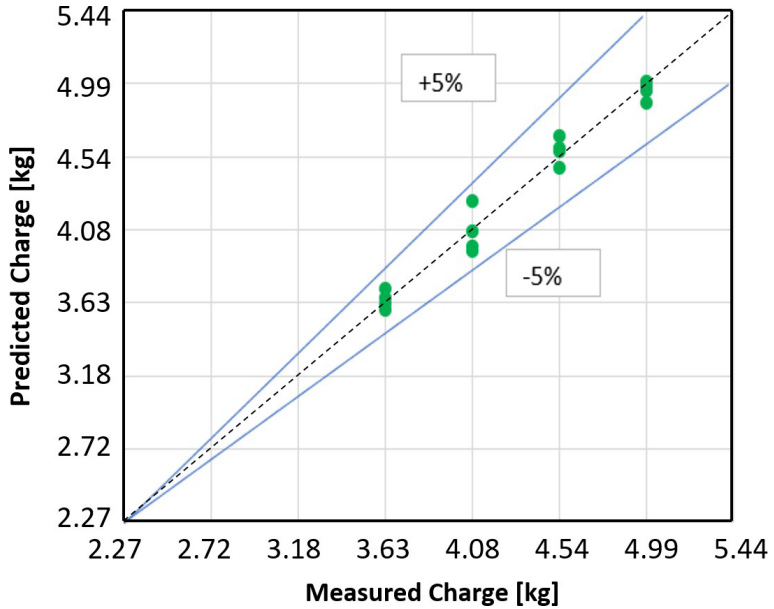
Indoor air handler of tested heat pump



Progress Validation on a Commercial System

- R-410A 4-ton roof-top packaged system was used for experiment validation
- Pump-downs were conducted at 4 charge levels and 4 ambient conditions
- The charge prediction deviation is within 5%

4-ton package roof-top heat pump system



Future Work and Publication

- Future work
  - Field installation and validation for the charge prediction method
- Outcomes

1 Li, Zhenning, Welch, Drew, Shen, Bo, Gluesenkamp, Kyle, Butler, Brian, and Morgan, Stuart. 2022. “A Universal Refrigerant Charge Fault Detection and Diagnostics Method Based on Pump Down Operation.” International Refrigeration and Air Conditioning Conference. Paper 2433.

2 Li, Z., Shen, B., Welch, D., and Gluesenkamp, K. 2024. “A Pump-Down Based Refrigerant Charge Fault Detection and Diagnostics Method Validated on Residential and Commercial Heat Pumps.” Gustav Lorentzen Conference. University of Maryland, College Park.

Thank you

Oak Ridge National Laboratory

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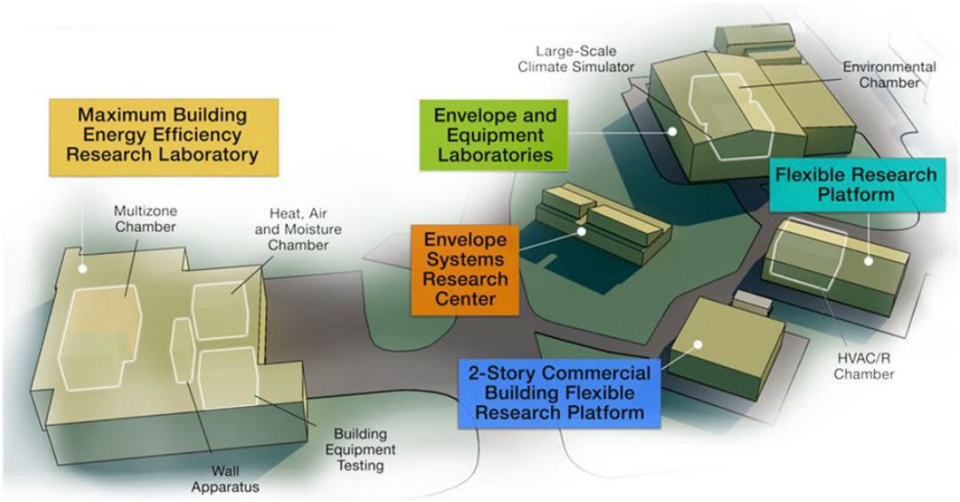

The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions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

Project Execution

	FY2022				FY2023				FY2025			
Planned budget	$150k				$150k				$200k			
Spent budget	$150k				$100k				0			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
FY22 Q1 Milestone: Charge fault detection market assessment												
FY22 Q2 Milestone: Development of dynamic model												
FY22 Q3 Milestone: Select sensors and instrumentation												
FY22 Q4 Milestone: Validation on residential system												
FY23 Q1 Milestone: Validation on commerical system												
Current/Future Work												
FY25 Q1 Milestone: Fabrication of a FDD controller												
FY25 Q2 Milestone: Field demonstration												
FY25 Q3 Milestone: Field installation and instrumentation												
FY25 Q4 Milestone: Reporting of automatic charge fault detection technology												

Team

OAK RIDGE National Laboratory

Dr. Bo Shen
PI

Development of new charge FDD approach and Team coordination

Dr. Zhenning Li

Pump-down simulation, Laboratory investigation, and Reporting

COPELAND

Drew Welch
Senior Lead HVAC Systems Engineer

Led development of Emerson compressor technology