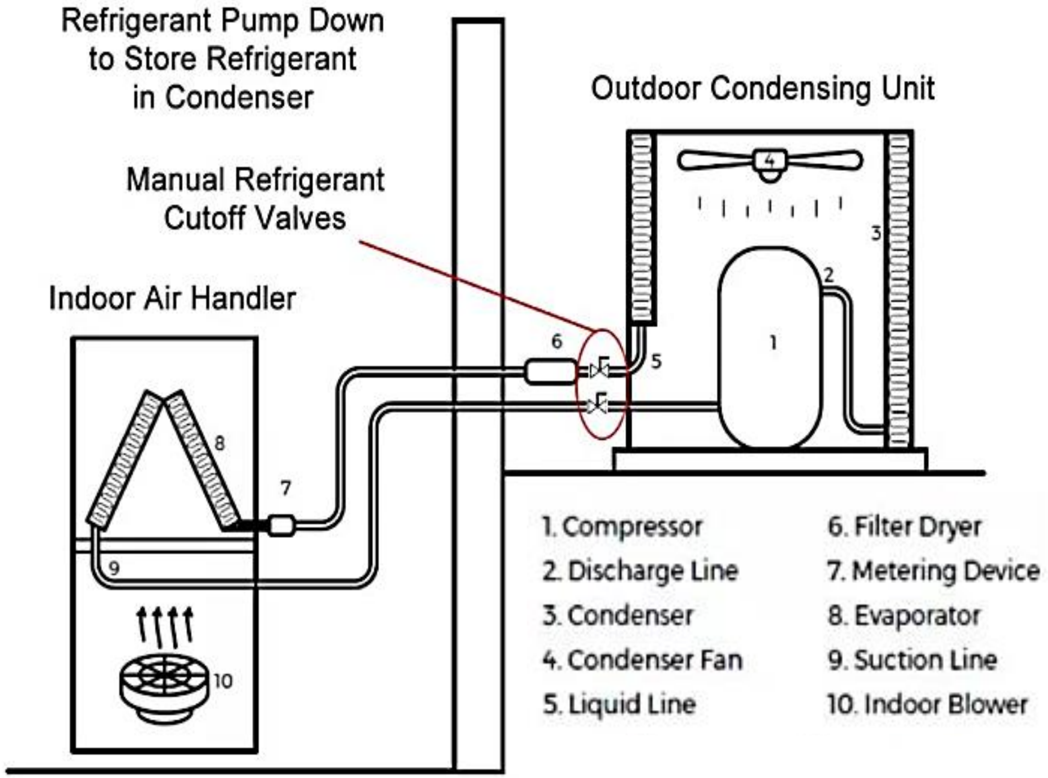
# Compressor is a Sensor (CRADA Emerson)

Emerson CoreSense™ Diagnostic, Communications & Protection Technology


**Pump-down Commissioning**


Oak Ridge National Laboratory
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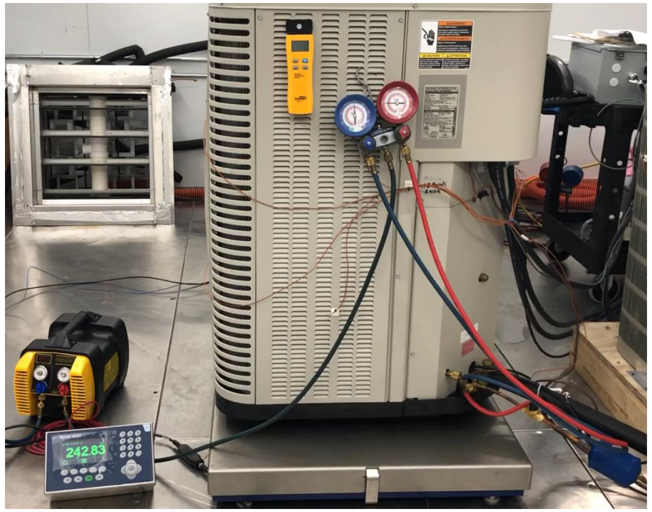
WBS # 03.02.06.83, Lab call CRADA

# Project Summary

## Objective and outcome

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



Outdoor unit of heat pump placed on a scale for charge migration measurement

## Team and Partners

Emerson Commercial and Residential Solutions (the Helix center) - CRADA

EMERSON.

## Stats

Performance Period: 10/01/2021-09/30/2023

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

Milestone 1: Dynamic modeling report

Milestone 2: Development of an algorithm to correlate the equipment delivered capacity with the system charge level

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

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

Milestone 5: Field installation and instrumentation

Milestone 6: Final reporting

# Problems

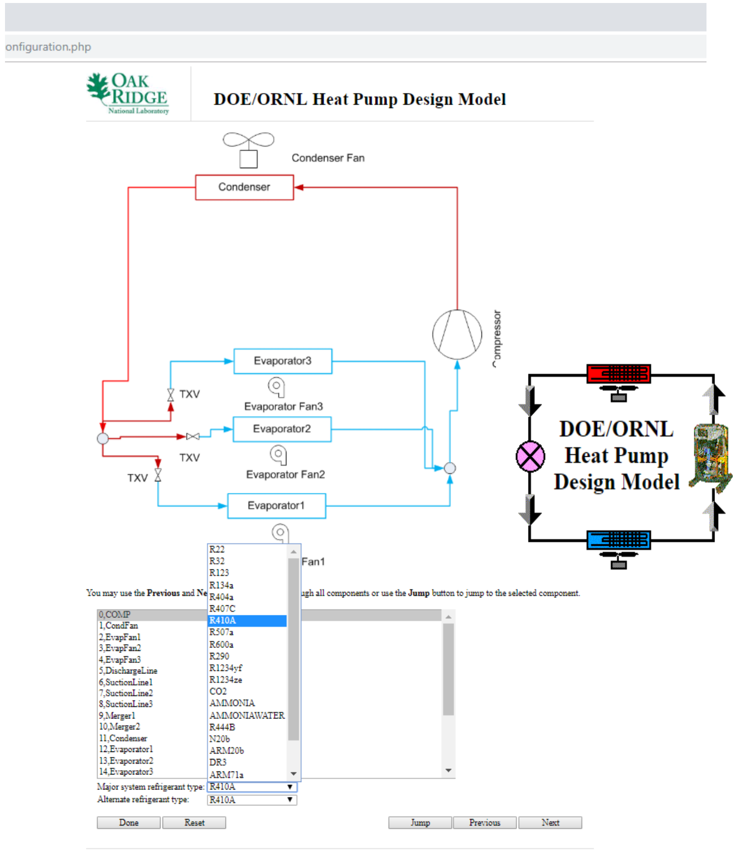
- Charge faults (overcharge or leakage) have a significant impact on heat pump performances
- Evacuating and weighing the refrigerant is time-consuming and cost ineffective
- Subcooling and superheat degrees at steady-state operation are commonly used as prediction indices for charge fault, however, steady-state operation requires long data acquisition time due to the variation of ambient temperature and building load
- Machine-learning based charge prediction method requires large amount of experimental data for training and 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

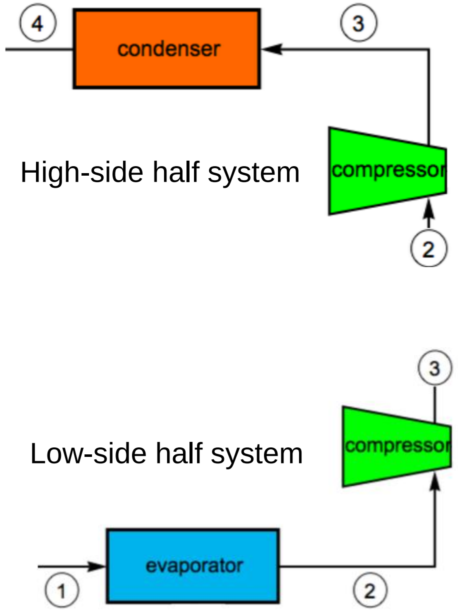
- **Increase building energy efficiency and reduce GHG emissions**
  - The accurate charge prediction method improves the reliability and energy efficiency of the system and reduces the indirect GHG emission
  - A reliable charge FDD method mitigates refrigerant leakage, mitigate the danger of flammable refrigerants and reduces the direct GHG emission
- **Prioritize equity, affordability and resilience**
  - It is seamlessly integrated into existing compressor sensors and commissioning operations, thus, accommodate the current manufacturing and installation processes
- **The pump-down based charge FDD technology features fast response, high accuracy, and universal applicability for various residential and commercial systems**

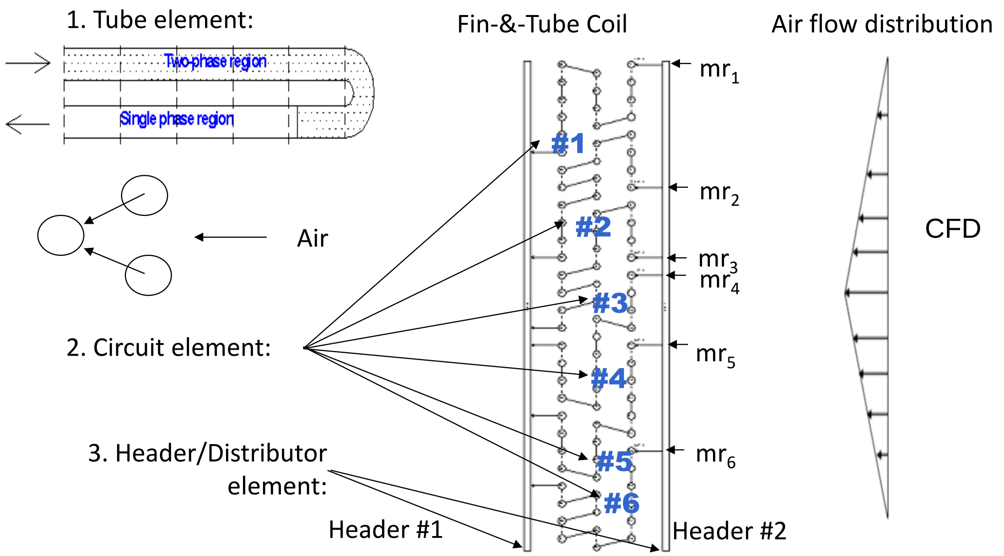
# Approach – Detailed Modeling of Charge Migration in Pump-down

- Performed quasi steady state simulation using DOE/ORNL Heat Pump Design Model[1]
- The system is dissembled into two half systems, and the algorithm iterates between high-side and low-side systems at each time step to calculate the charge moved at each second
- At start up, charge is assumed to be distributed proportionally per each component inner volume




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

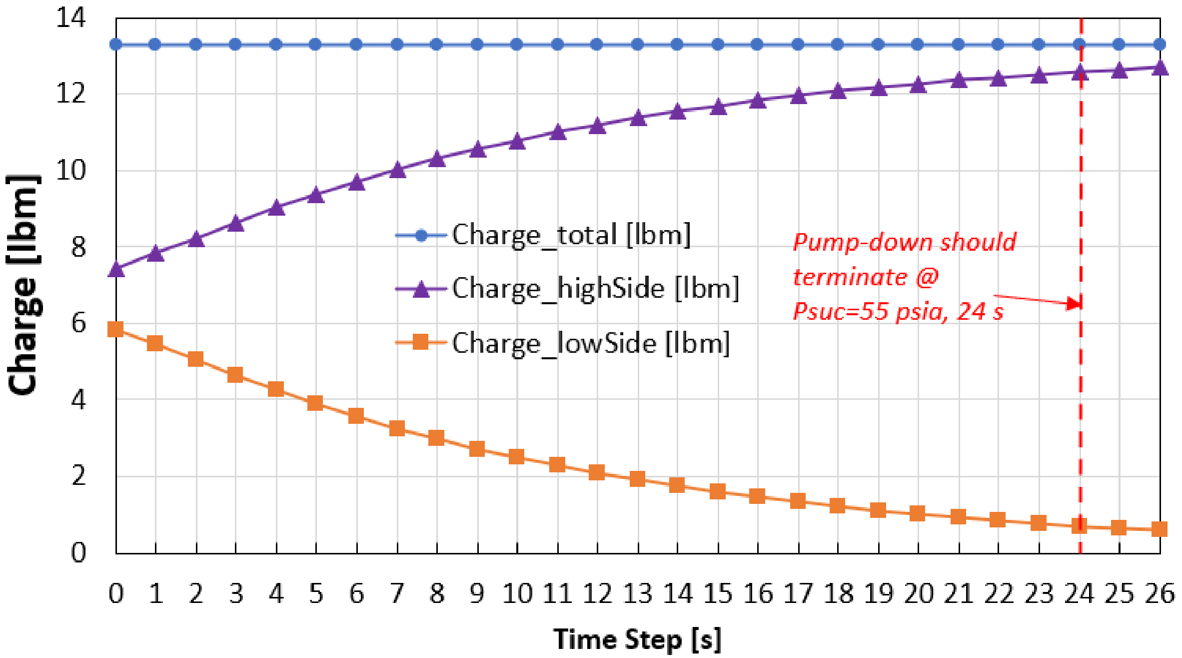


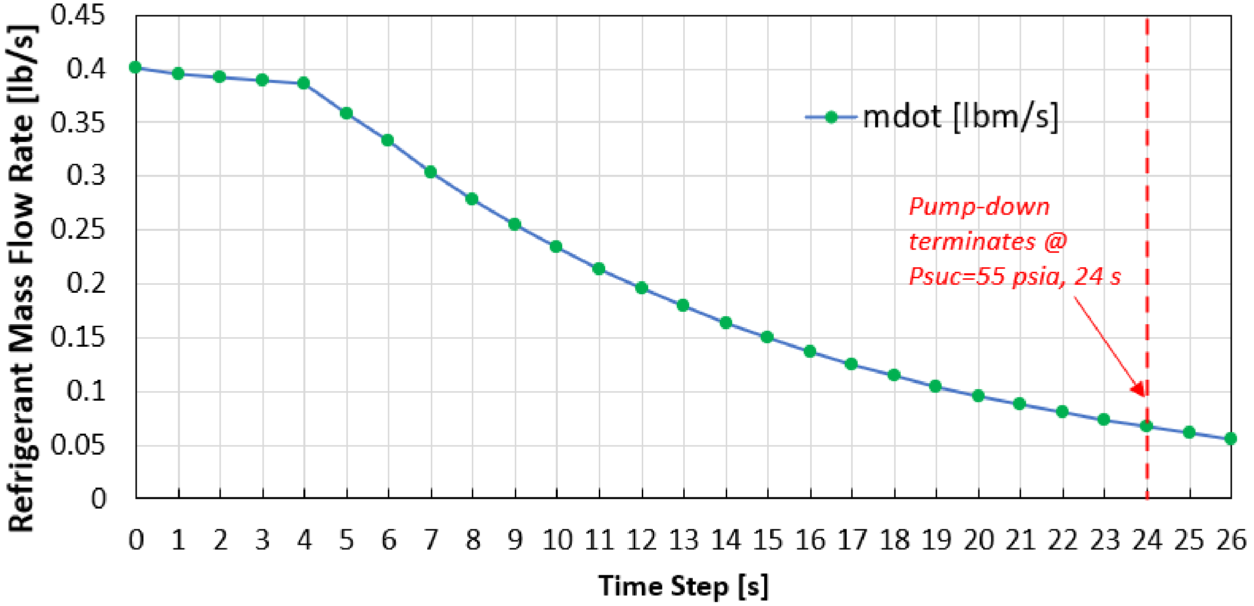

**2-D air side distribution; Independent circuit refrigerant entering conditions; Arbitrary circuitry, provides more accurate real-world heat exchanger performance predictions**

# Progress - Quasi Steady State Simulation Results

- Simulate a 5-ton heat pump system validated with experiments from partner
- Pump-down takes 24 seconds until compressor cut-off pressure 55 psia
- After 4 seconds, the entire low-pressure side is fully superheated
- At the end of pump-down, the remaining charge not moved via compressor is 5.2% of the total charge



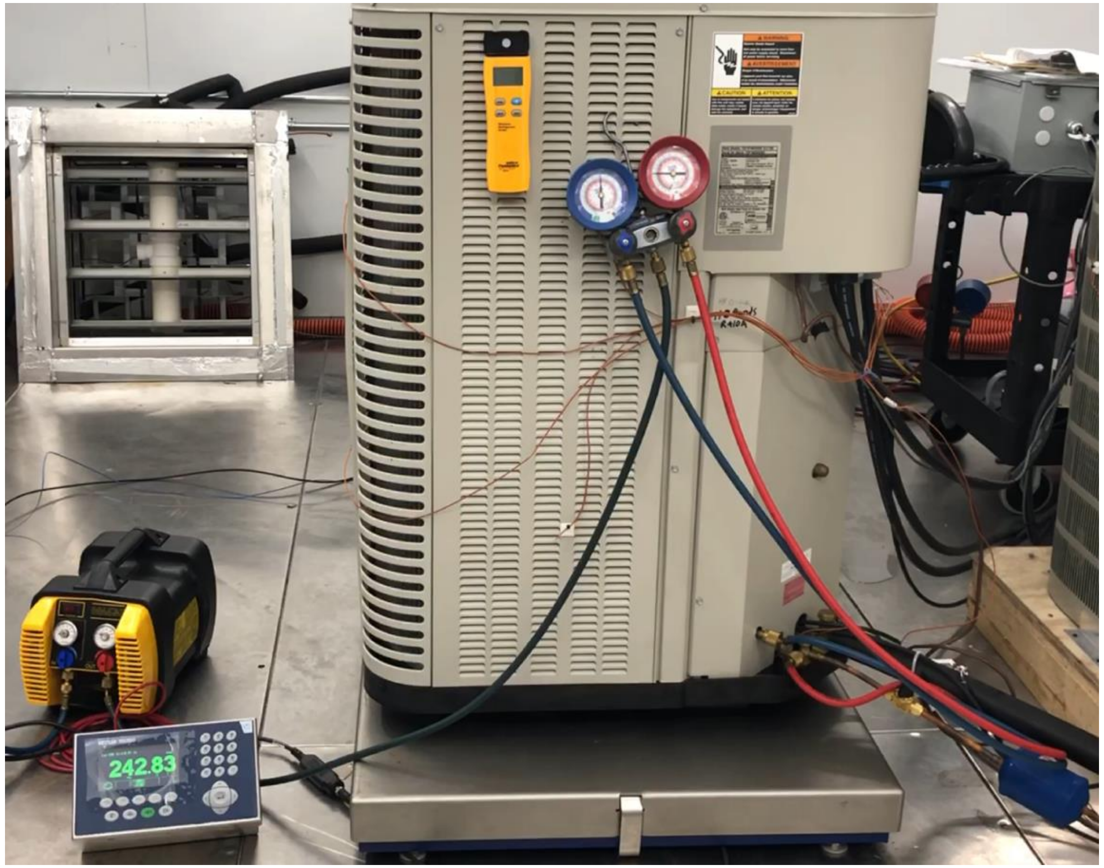

Transients of charge migration during pump-down



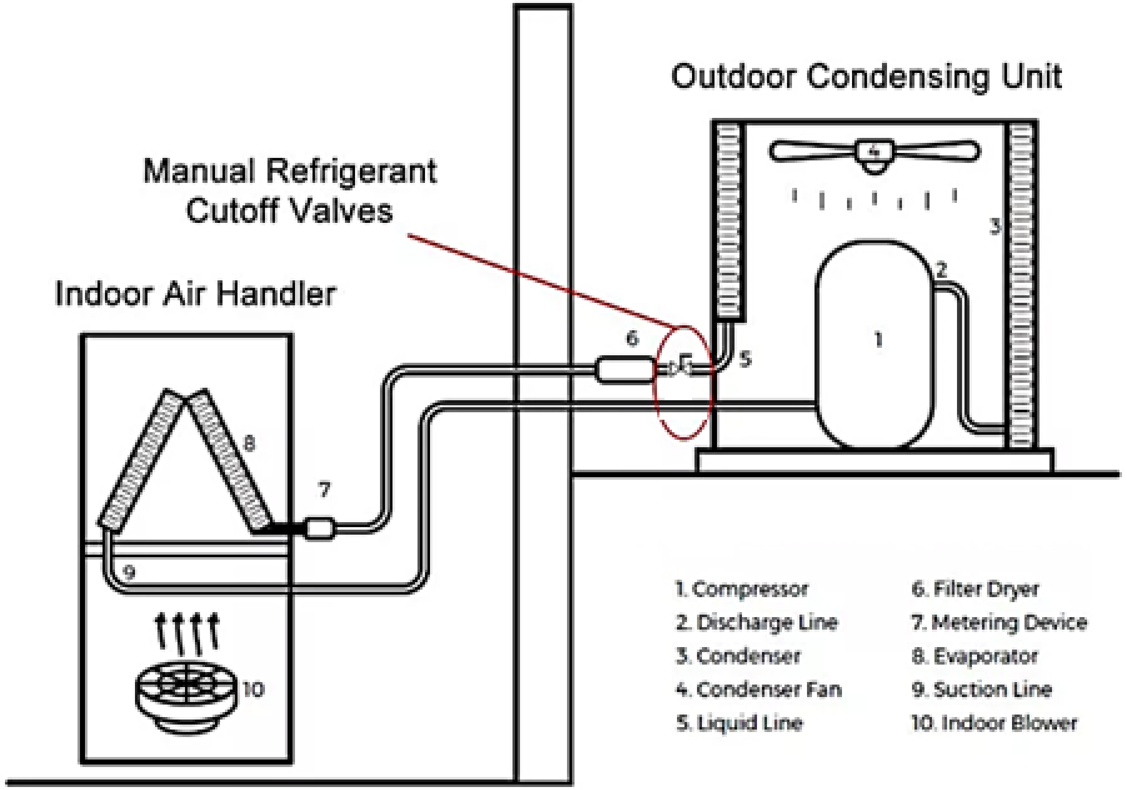

Transients of refrigerant mass flow rate during pump-down

# Progress –Charge Prediction Validation on a Residential Heat System

- A R410A residential 5-ton split heat pump was used for experiment validation
- Pump-down starts from system stand-by mode by closing the cut-off valve at liquid line and start the compressor and outdoor fan



Outdoor unit placed on scale to measure refrigerant migration



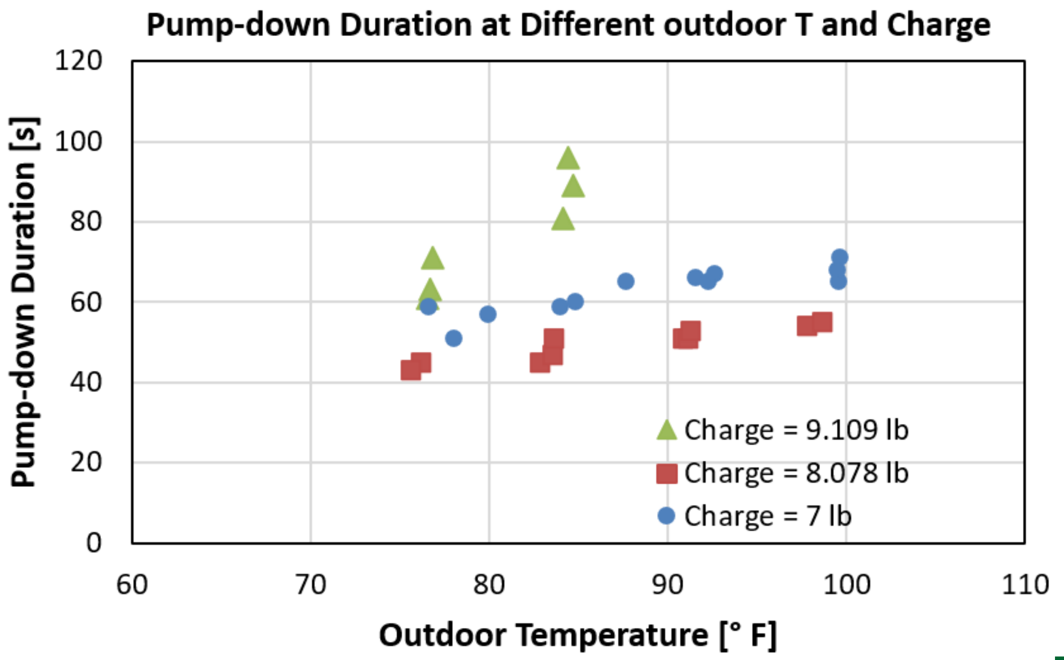
Schematic of the residential split system

# Progress –Test Matrix

- The pump-down operations were conducted at 3 different charge levels, i.e., 7 lbm, 8.078 lbm and 9.109 lbm and 4 different ambient conditions
- For each charge level, the pump-down were repeated three times for reproducibility test
- Pump-down is automatically terminated by low-pressure protection sensor when the suction pressure reaches 20 psi
- The more refrigerant is charged, the pump-down takes longer; the higher the outdoor temperature, the pump-down takes longer

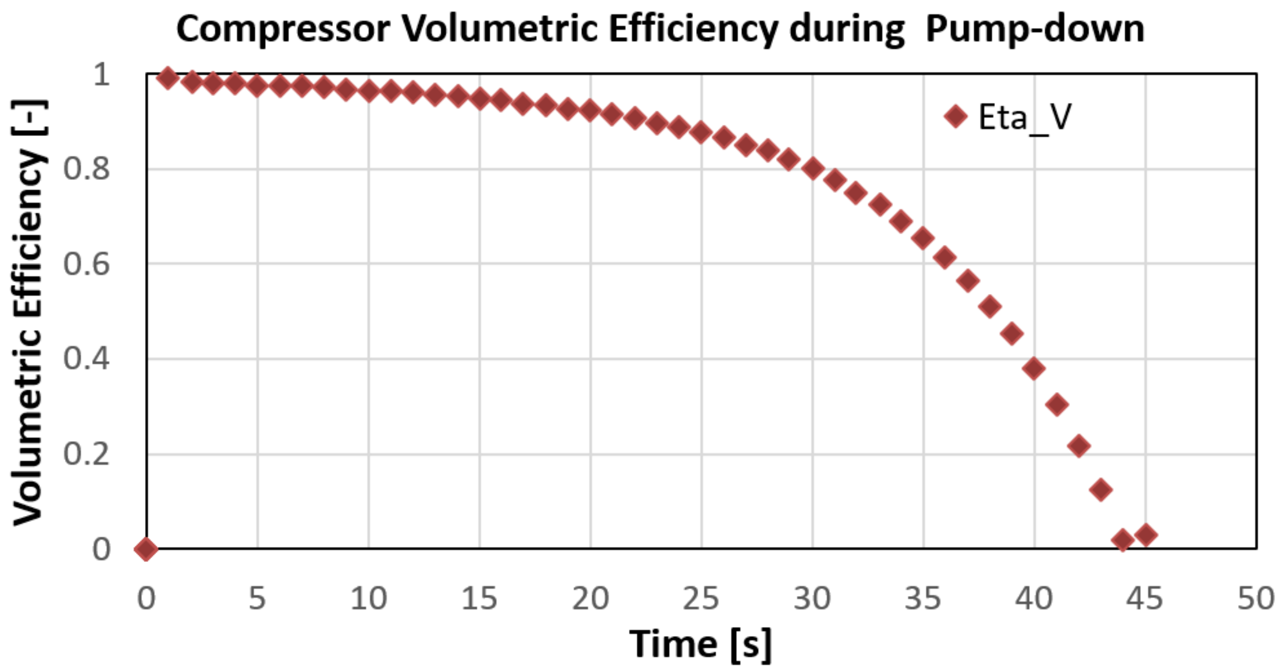
Pump-down test matrix

| Charge | 7 lb | 8.078 lb | 9.109 lb |
| --- | --- | --- | --- |
| Outdoor Temperature | 71 °F (Cooling) | 71 °F (Cooling) | 71 °F (Cooling) |
| | 79 °F (Cooling) | 79 °F (Cooling) | 79 °F (Cooling) |
| | 87 °F (Cooling) | 87 °F (Cooling) | NA |
| | 95 °F (Cooling) | 95 °F (Cooling) | NA |

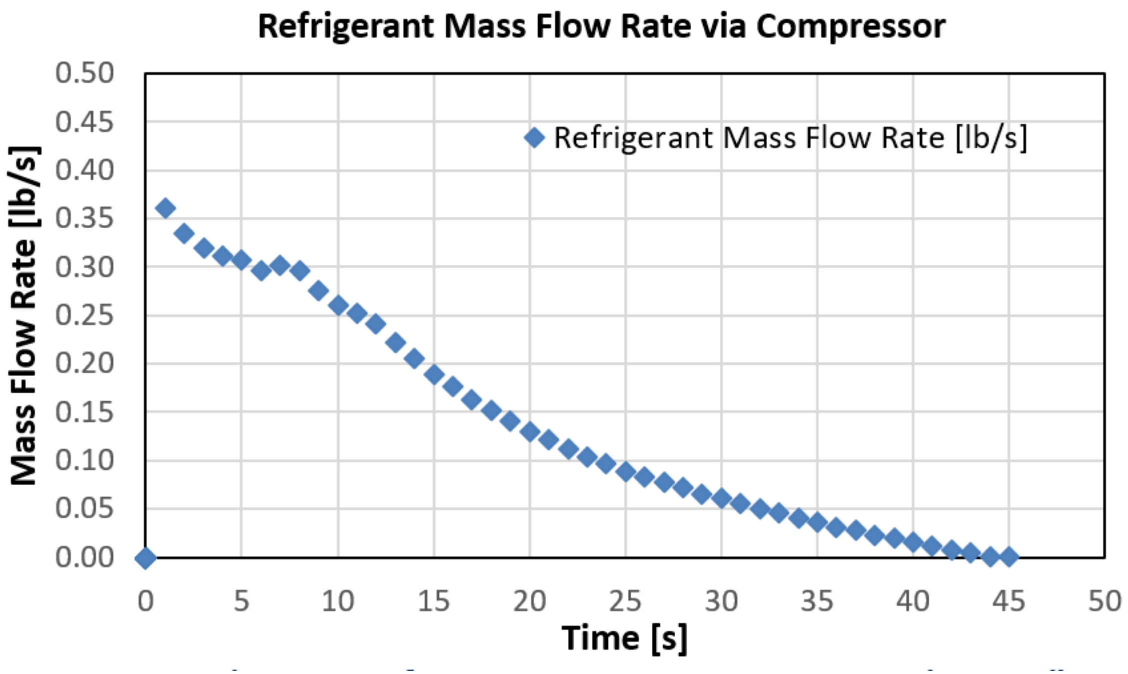


# Progress – Charge Prediction based on Pump-down Process (Method-1)

- Compressor map was used to predict the volumetric efficiency degradation and refrigerant mass flow rate during pump-down process




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



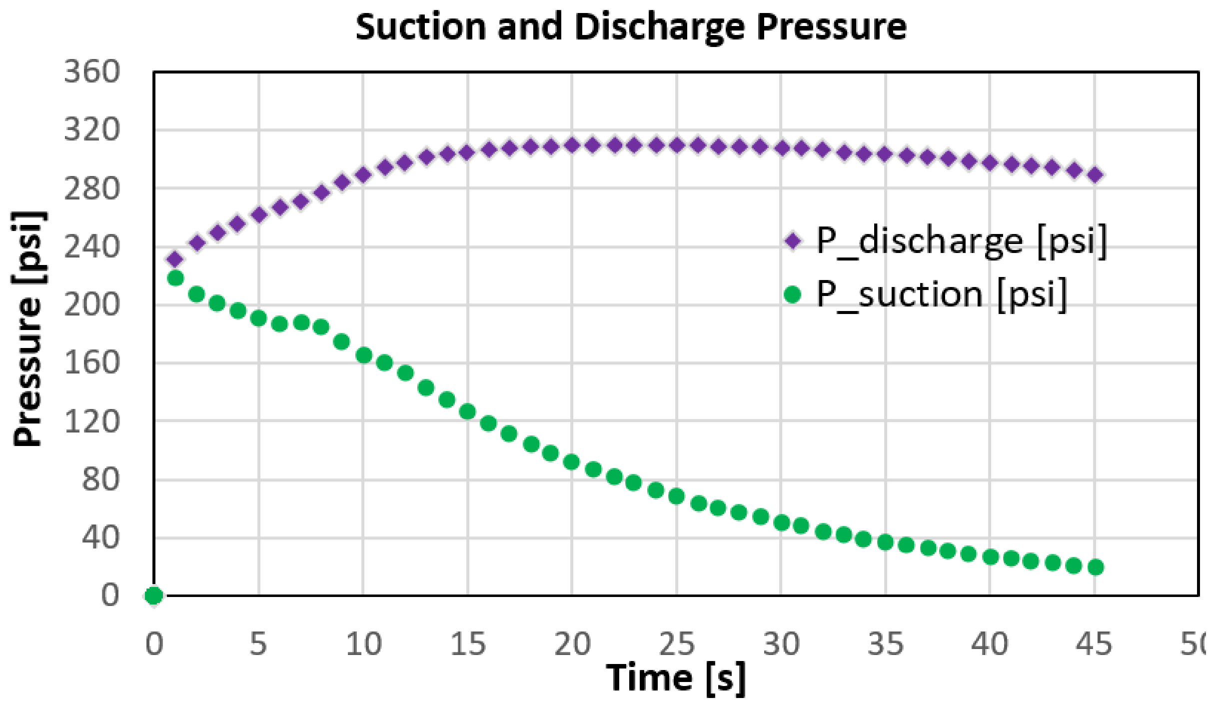

Refrigerant mass flow rate via compressor, @71F, 7 lbm charge

# Progress – Charge Prediction based on Pump-down Process (<u>Method-1</u>)

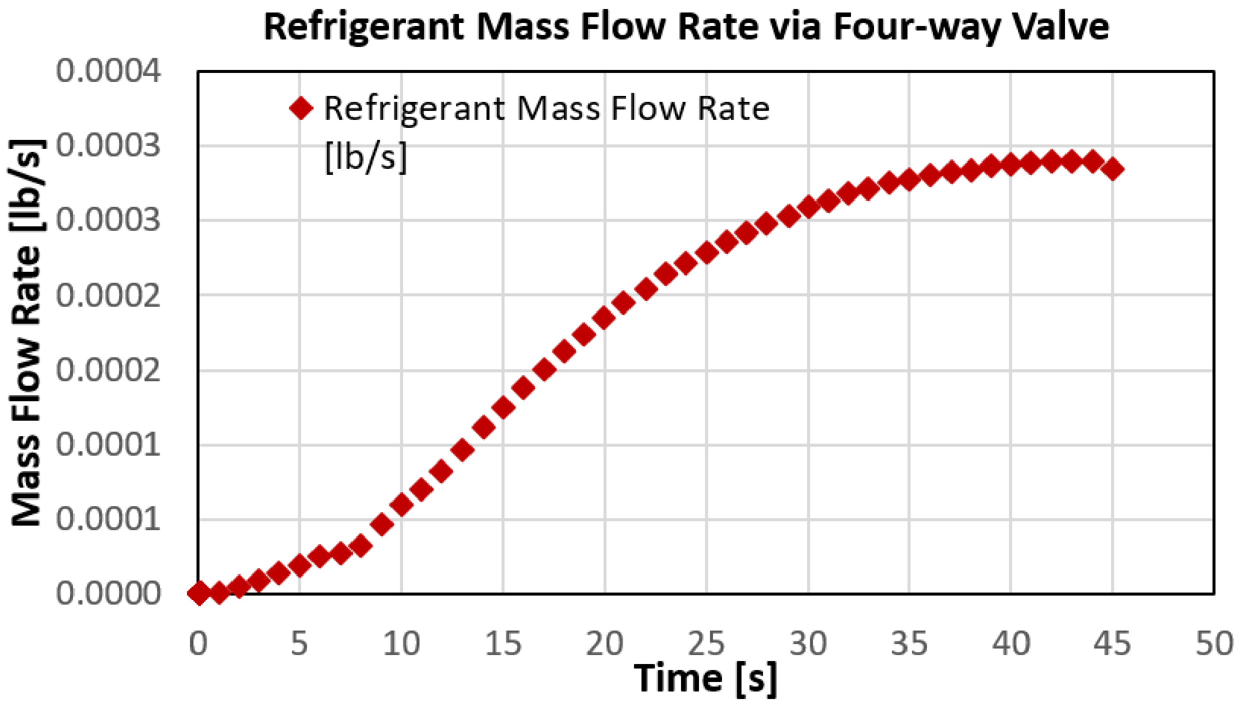
- Calculated the reversed refrigerant flow via 4-way valve due to valve leakage
- Refrigerant flow in 4-way valve is driven by the pressure difference between discharge and suction points

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

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



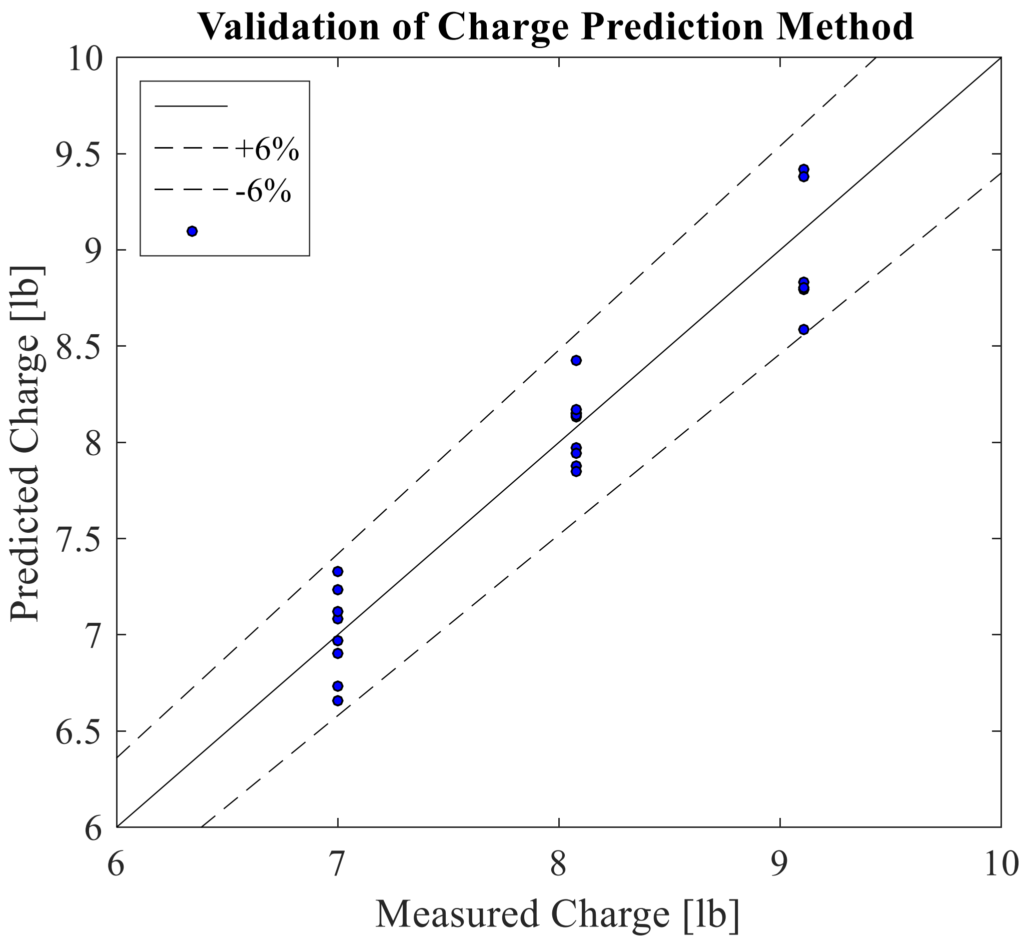

Suction and discharge pressure during pump-down




Refrigerant mass flow rate via four-way valve

# Progress – Charge Prediction based on Pump-down Process (Method-1)

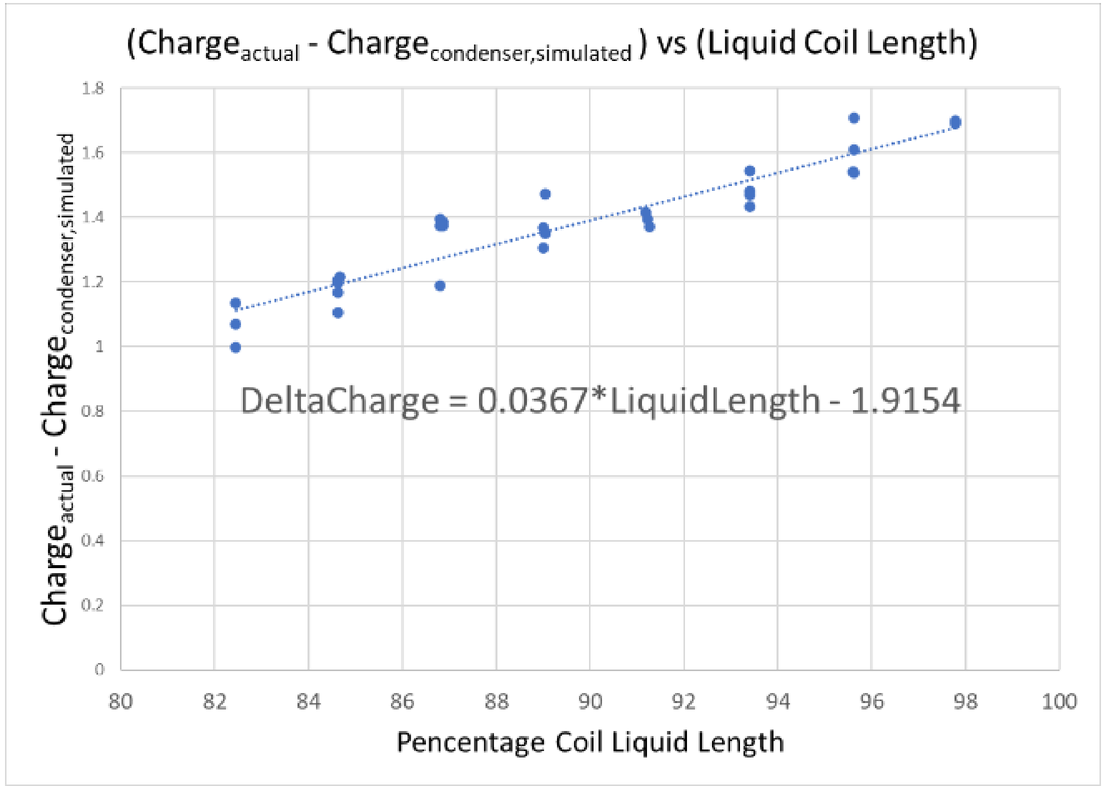
- The charge prediction is within 6% (project goal +/- 10% ) by considering the migrated charge via compressor and 4-way valve using the experiment data from pump-down process

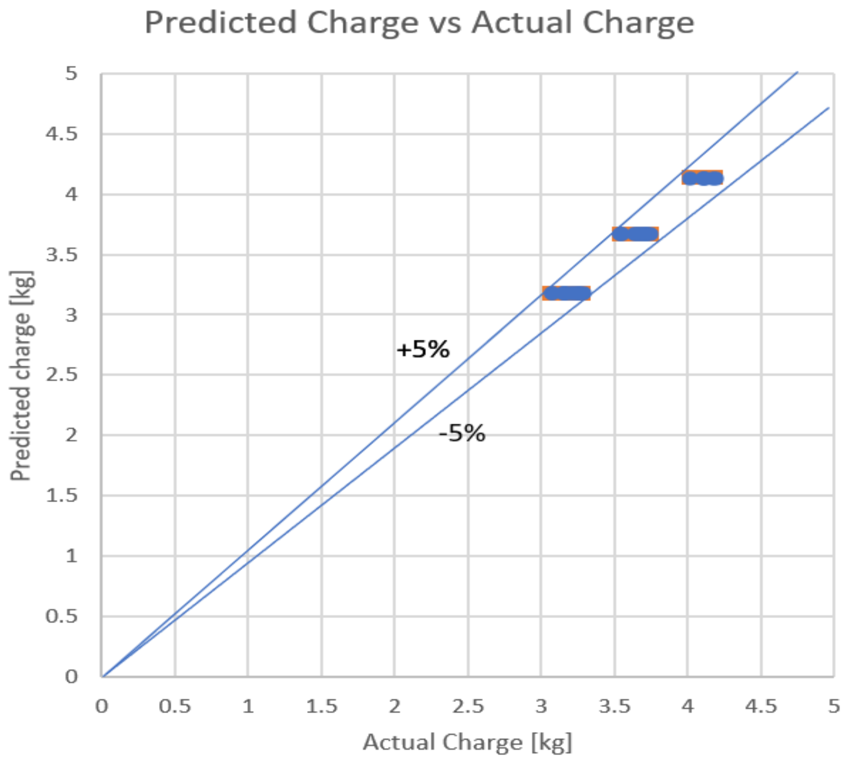



$$Charge = Charge_{ViaCompressor} - Charge_{via4WayValve} + StationaryCharge_{CondenserBeforePumpDown} + StationaryCharge_{EvaporatorAfterPumpDown}$$

# Progress –Charge Prediction based on the End of Pump-down (<u>Method-2</u>)

- At the end of pump down, the system reaches quasi steady state, and detailed HX model is used to predict the subcooled liquid length and the charge in condenser
- Previous research[1] of Purdue Univ. shows the errors between actual charge and simulated charge is a linear function of liquid length
- Once this equation is fitted using limited test data by OEM, it can be used to charge prediction




[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 and Future Work

- Laboratory verification on a commercial roof-top unit is in progress
- We will conduct field validation for the charge prediction method after the commercial system validation

Commercial Roof-top Unit Used for Charge Prediction Validation

**Outcome:** Li, Zhenning; Welch, Drew; Shen, Bo; Gluesenkamp, Kyle; Butler, Brian; and Morgan, Stuart, "A Universal Refrigerant Charge Fault Detection and Diagnostics Method Based on Pump Down Operation" (2022). International Refrigeration and Air Conditioning Conference. Paper 2433.

# Thank you

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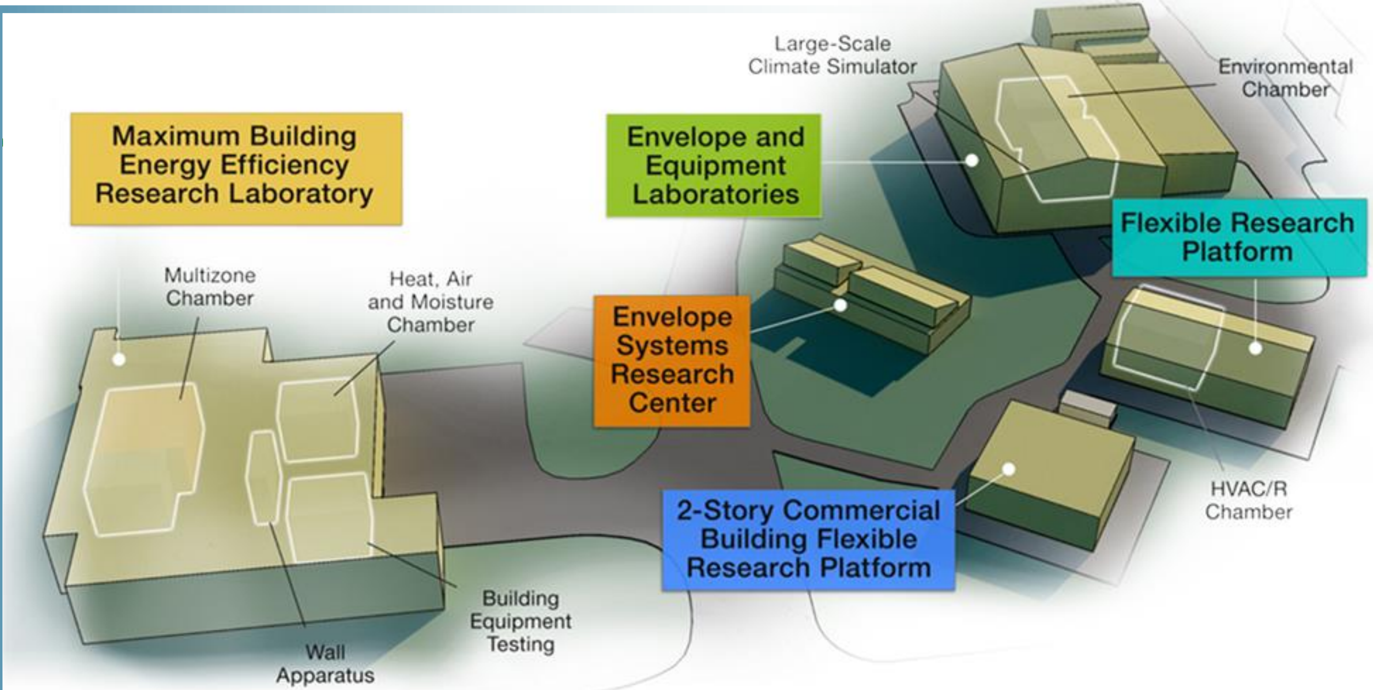


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236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
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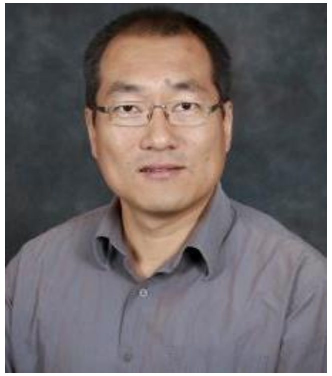
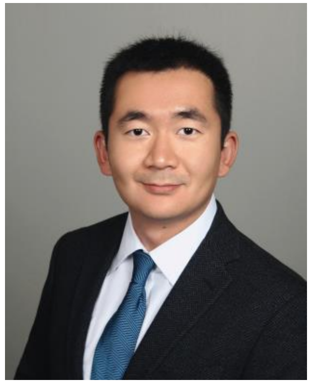
# REFERENCE SLIDES

# Project Execution

| | Task | | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 |
|---|---|---|---|---|---|---|---|---|---|---|
| FY21 | 1 | Charge Fault Detection Method Refinement and Market Assessment | | | | | | | | |
| | 2 | Development of Detailed Dynamic System Model to Represent Pump-Down Procedures | | | | | | | | |
| | Milestone 1 | Dynamic Modelling Report | | | | | | | | |
| | 3 | Selection of Sensors to Monitor Dynamic Process | | | | | | | | |
| | 4 | Experimental Validation of Automatic Charge Fault Detection on Residential Systems | | | | | | | | |
| | Milestone 2 | Laboratory Verification Report on Residential Systems | | | | | Go/No-Go | | | |
| FY22 | 5 | Experimental Validation of Automatic Charge Fault Detection on Light Commercial Systems | | | | | | | Go/No-Go | |
| | Milestone 3 | Laboratory Verification Report on Commercial Systems | | | | | | | | |
| | 6 | Fabrication of a FDD controller | | | | | | | | |
| | 7 | Field Demonstration with a Residential Split Unit | | | | | | | | |
| | Milestone 4 | Field installation and instrumentation | | | | | | | | |
| | 8 | Reporting of Automatic Charge Fault Detection Technology | | | | | | | | |
| | Milestone 5 | Final reporting | | | | | | | | |

# Team





Dr. Bo Shen (PI)
- Development of new charge FDD approach
- Team Coordination

Dr. Zhenning Li
- Pump-down simulation
- Laboratory investigation

Drew Welch
Senior Lead HVAC Systems Engineer
- Leading the development of Emerson compressor technology