Evaluation of a Micro-Cascade System for Supermarket Refrigeration using Low GWP Refrigerants

Refrigeration Equipment

Fresh Food

Frozen Food

ORNL
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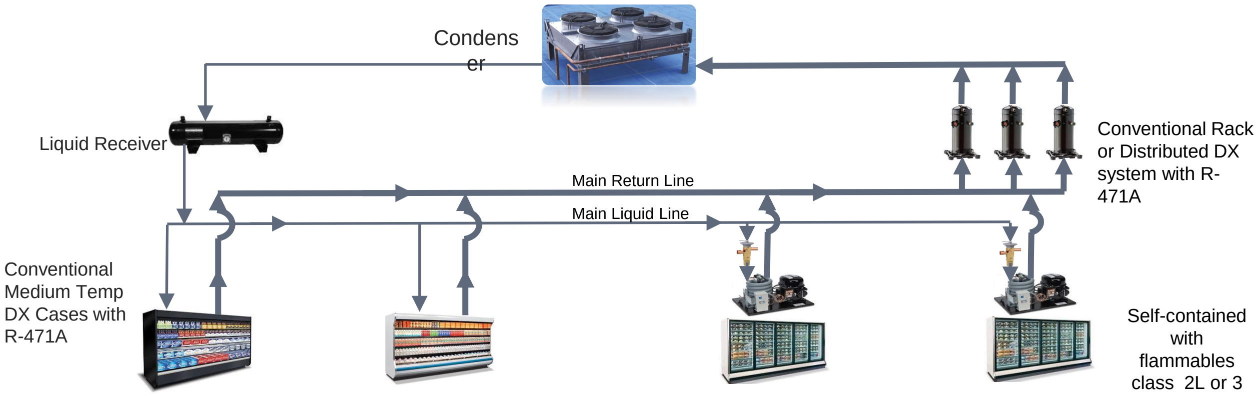
Project Summary

Objective and outcome

Objective: Enable highly efficient distributed/Micro-Cascade systems for supermarket refrigeration using refrigerants with GWP<150.

Outcome: Reduce energy consumption by up to 15%, and direct CO2 emissions by up to 99%.



Team and Partners

PI: Samuel F. Yana Motta, ORNL

ORNL Researchers: Vishal, Junjie Luo, Bo Shen

Partners: CRADA with Honeywell

Collaborators: Emerson, Hussmann

Stats

Performance Period: FY23-FY24

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

Milestone 1: Lab performance – Q4 FY23

Milestone 2: Detailed LCCP analysis – Q4 2023

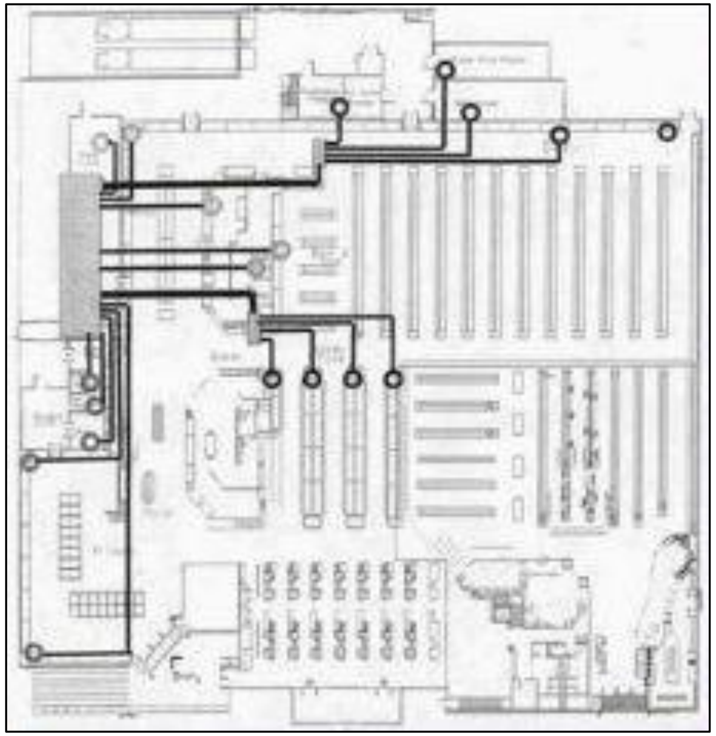
Milestone 3: Field Trials – Q4 2024

Problem: High Environmental Impact of Current Supermarket

The Problem

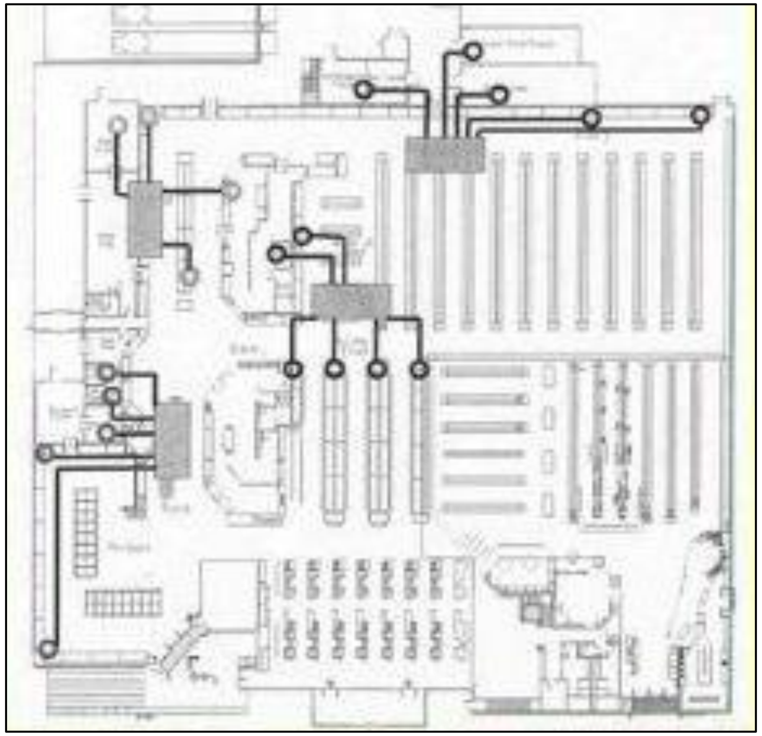
- Current centralized refrigeration system carry ~3500 pounds of high GWP refrigerant R-404A (GWP of 3,922), have a high leakage rate (~25% per year).
- There is a clear need to reduce the environmental impact by using low GWP refrigerants while maintaining or improving energy efficiency
- There are over 38,000 stores in the US which have a significant level of GHG emissions:
  - 43.8 million Tons CO2 eq /year (**69.7%**) of direct emissions
  - 19.08 million Tons CO2 eq/year (**30.3%**) of indirect emissions

Central DX



One central system distributes the refrigerant across the whole store

Distributed DX



Several smaller systems reduce the charge (60%) and the leak rates (below 10%).

Alignment and Impact

Major Goals:

- Reduce supermarkets direct GHG emissions enabling low-GWP (<150) refrigerants
  - Distributed/Micro-Cascade systems have low leak rates (<5% per year) and employ refrigerants with GWP<150.
  - Use a class 1 refrigerant for most of the store reduce the burden of using flammable refrigerants (removing barriers)
- Reduce supermarkets energy consumption by up to 15% compared to current systems
  - Use new class 1 refrigerant (R-471A) in the MT cases and in the high stage of cascade system: Because of its high critical temperature, It has high efficiency at a wide range of ambient conditions.
  - The low stage uses a 2L refrigerant in a compact/fully-optimized operating at almost constant conditions.

Contribution to EERE goals:

- **Reduce GHG emissions** from supermarket segment by ~**74%** (46.4 million Tons CO_2 eq/year). Higher than EERE's target of 50% to 52% established for 2030.
- **Energy savings:** up to **15% reduction of energy consumption** compared to current systems (6.75 TWh/year for the US supermarket segment). energy saving help the decarbonization.
- The **use of highly-efficient/smaller-footprint systems** (distributed) can indirectly help faster deployment and to **better reach disadvantaged communities**

Greenhouse gas emissions reductions

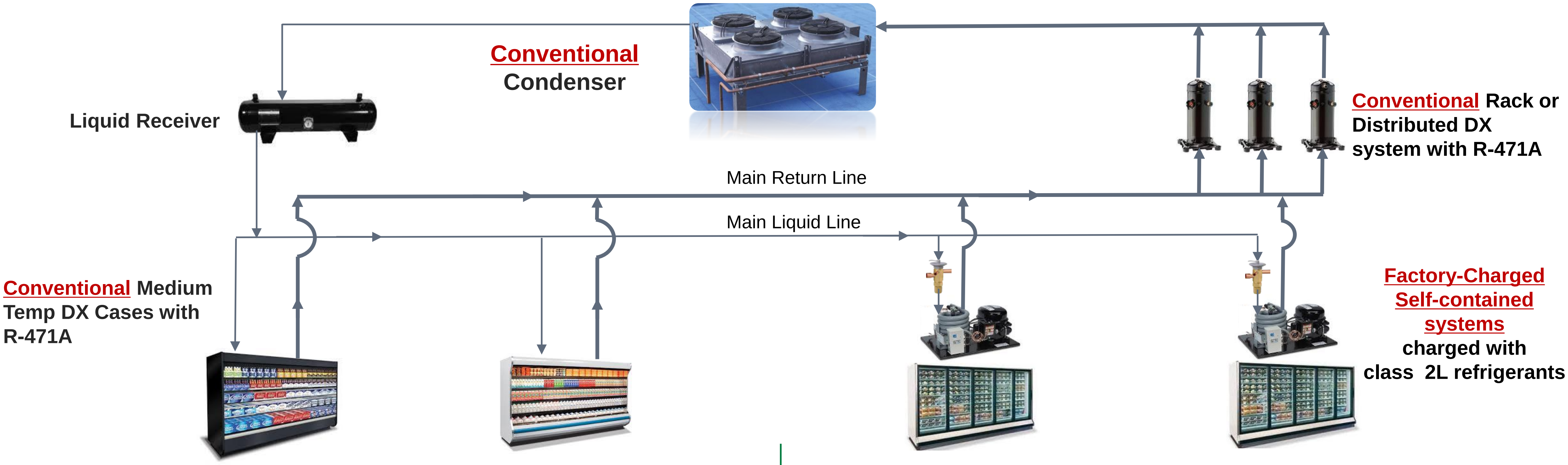
50-52% reduction by 2030 vs. 2005 levels

Power system decarbonization

100% carbon pollution-free electricity by 2035

Approach

Approach: Relevant Characteristics of the Micro-Cascade system



Fresh food is usually 60% to 70% of the Supermarket
Use R-471A (class A1) with GWP<150

- Distributed system reduces the charge and leaks and allows a superior energy efficiency operating of compressors.
- The use of class 1 refrigerant in most of the store reduces significantly the use of costly safety mitigation.

Frozen food is usually 30% to 40% of Supermarket
Use R-455A class A2L with GWP<150

- Self-contained/Low-charge systems reject heat to medium temp circuit using common tube-in-tube or plate heat exchangers
- Systems operate at a fixed condition year-round (almost constant evaporation and condensing temperature), producing high efficiency.

Uses conventional components - Properly sized and arranged

Approach: Modeling, Lab testing, Field Evaluations

- **Modeling**
  - **Modeling of test system to** Verify energy savings of up to 15%
  - **Modeling of a typical store to obtain a life cycle climate analysis.** Verify reduction of overall CO_2 emissions by 60%.
- **Proof of concept by detailed laboratory testing**
  - **Validate the energy efficiency predictions of the modeling through detailed experimental measurements.** Simulated energy efficiency must match experiments within experimental uncertainty (±3%). Update expected CO_2 emissions reduction.
- **Field evaluations in at least two stores.**
  - 1-year data collected to demonstrate at least a 15% energy savings and 60% reduction in overall CO_2 emissions compared the baseline refrigeration system.

Will use a calibrated version of HPDM to simulate current and new configuration of supermarket system.

The LCCP will employ the Bin method to simulate the weather in at least 3 US cities

A scale prototype of a supermarket will be designed, constructed and tested at a wide range of ambient temps.

Data will be used to further calibrate HPDM and validate the LCCP (proof of concept)

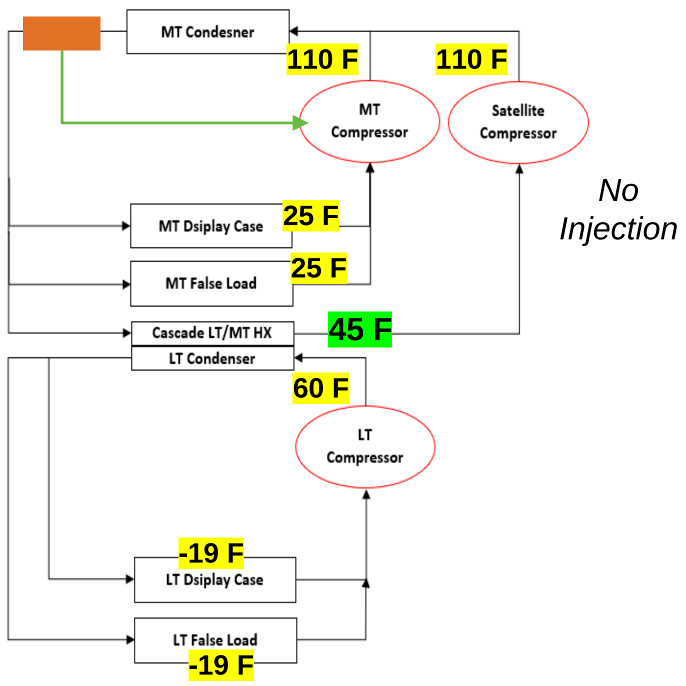
Two supermarket stores will be fully equipped to obtain energy data for a full season (1 year).

Progress

Preliminary Modeling of the test system

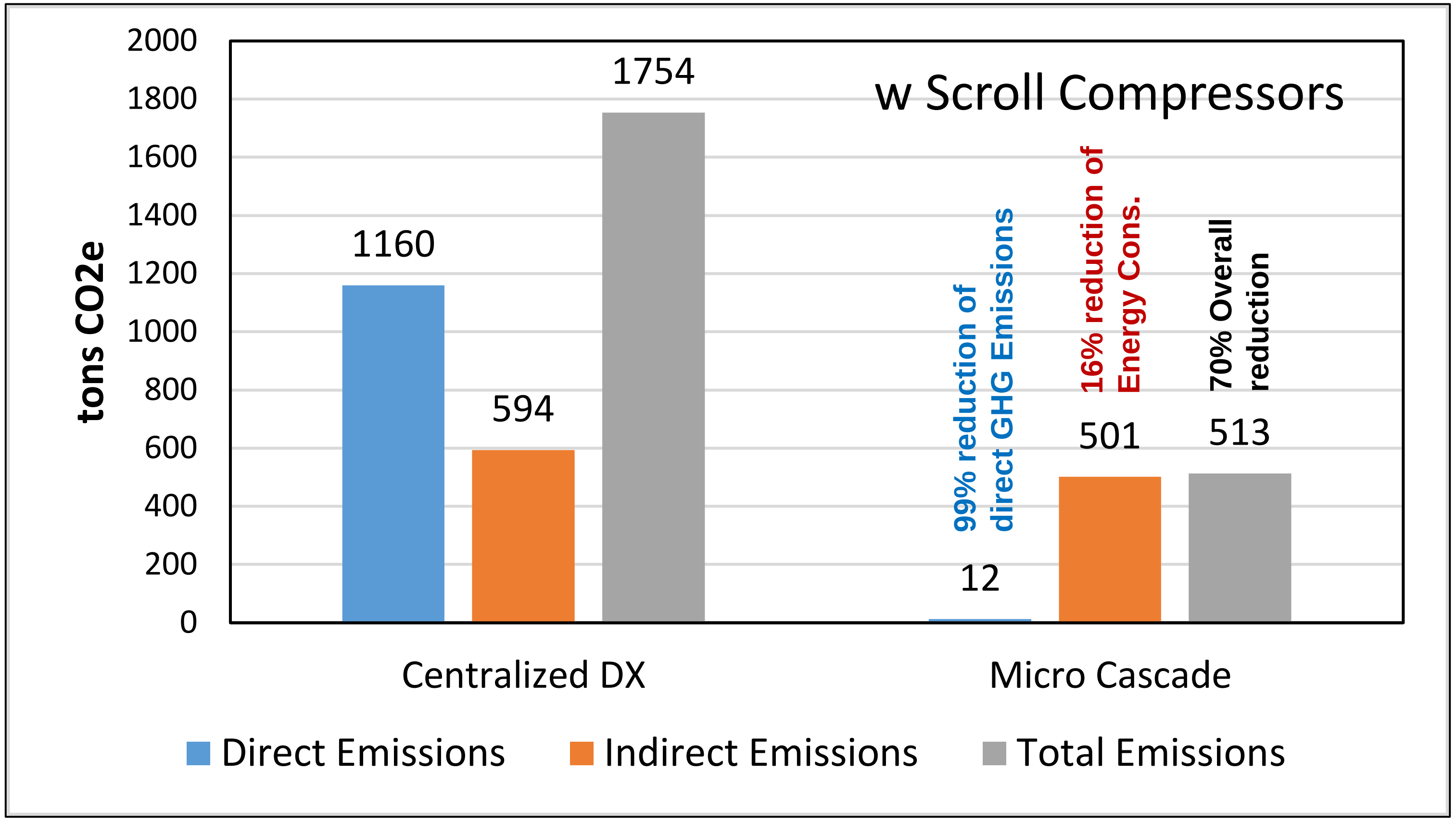
PARAMETERS	LT	MT	Satellite Compressor (with no injection)
	R455A	**R471A**	**R471A**
Compressor Speed (Hz)	60	60	45-60
Evaporation Temperature (F)	-19	25	**45**
Condenser Temperature (F)	60	110	110
Compressor Capacity (kBTU/hr)	28	40	40
Compressor Isentropic Efficiency	61%	68%	65%
Display Case Capacity (kBTU/hr)	4	11	-
False Load Capacity (kBTU/hr)	24	29	-
Refrigeration Load (kBTU/hr)	28	40	-
THR (kBTU/hr)	40	55	50
Evaporator Pressure (psia)	28.5	23.3	**35.5**
Condenser Pressure (psia)	135.7	108.1	108.1
Liquid Temp @ Condenser Out (F)	60	64	64
System COP	1.97		
System COP relative to Central DX R404A	**118%**		

DESIGN LOAD
LT = 28 kBTU/hr (40% of Total)
MT = 40 kBTU/hr (60% of Total)



- *Mid-point analysis. Assumed similar compressor efficiencies for R-404A (61% LT; 68% MT)*
- *Evaporator Superheat of 9F & Suction Line Temperature Rise of 20F*
- Use same compressor (ZBXX for R471A) for satellite compression

LCCP analysis of an actual store located in Atlanta Ga



- 15-year LCCP analysis of a 350000 sqft store located in Atlanta GA using the bin methodology. Configuration extracted from Greenchill Study (2005): 70% fresh food, 30% frozen food.
- 25% annual leak rates for Central Dx.5% annual leak rate for distributed Micro-Cascade System.
- Used standard display cases described in the report and efficiencies of current scroll compressors.

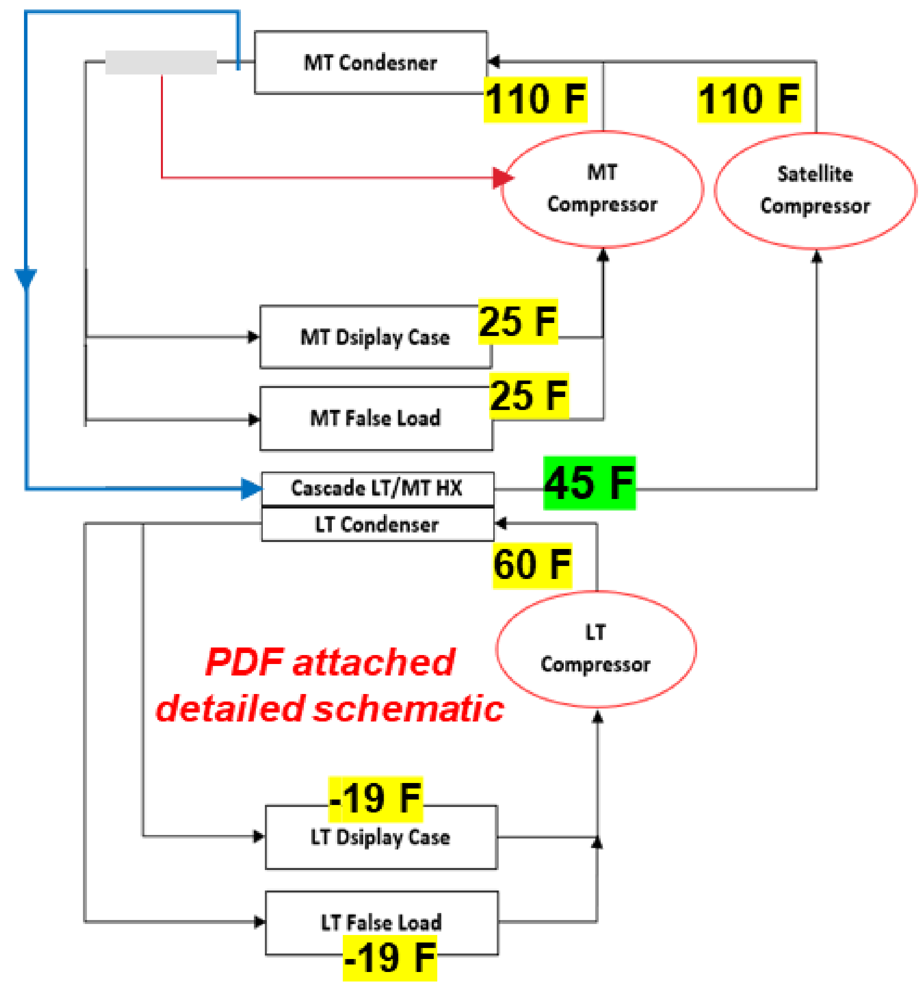
Overall GHG emissions are reduced by 70% compared to the central DX

Laboratory testing: Test setup and Operating Conditions

Testing Plan

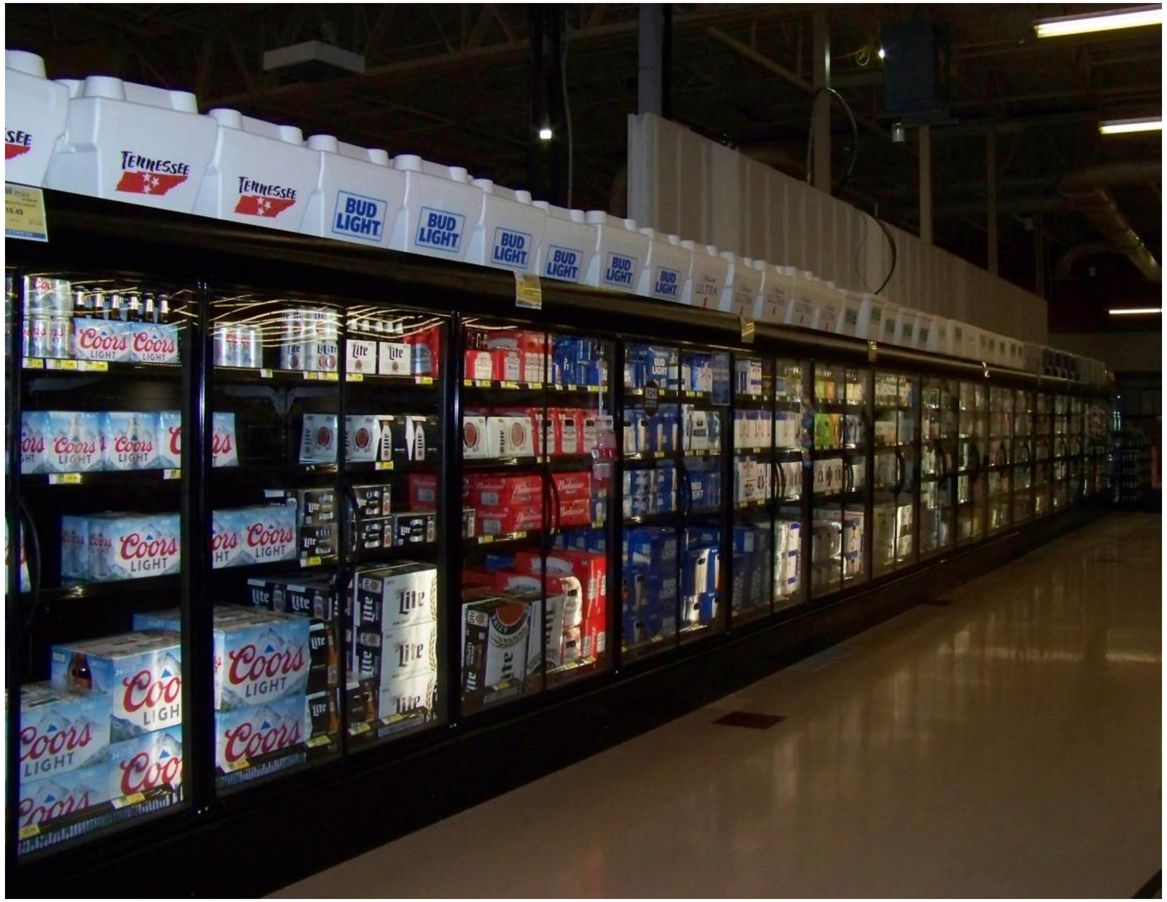
- **Design Load:**
  - LT = 28 kBTU/hr (40% of Total)
  - MT = 40 kBTU/hr (60% of Total)
- **Equipment:**
  - Two Hussmann display cases: 1 open for fresh food, one glass door for frozen goods
  - A rack equipped with Scroll Emerson Copeland compressors.
- **Steady operating conditions:**
  - Outdoor Temperatures: 55F, 75F, 95F, 110F
  - Indoors maintained at 70F and 60% RH
- **Goodness of data:**
  - Stable pressures and temperatures for at least 20 min before acquiring data
  - Projected uncertainties must be within ±5%

Test Setup - High Level Schematic



Field trials: First store trial using R471A

Floor space equipment – Display cases



Condensing Units

- Condensing units equipped with scroll compressors originally designed for R-134a
- Testing started at the beginning of 2023 and are operating adequately
- Main operating parameters will be acquired.
- Goodness of compressor operation will be validated with compressor manufacturer,

Future Work

- **Verification of system performance through experimental testing**
  - Obtain and install system prototypes, Complete by Q3 of FY2023
  - Complete testing of lab prototype, Complete by Q4 2023
  - Update LCCP analysis based on lab data. Complete by Q4 2023
- **Field trials**
  - Analyze 6-month data coming from first store. Complete by Q4 of FY 2023
  - Start second store by Q1 of FY 2023.
  - Complete field trials by Q4 of FY 2024
- **Conclude project with final report by Q4 of FY 2024**
  - Two journal articles (modeling and lab testing), and
  - A magazine publication expected from this project. (field trials – help the commercialization)

Very active engagement with well known Supermarket chain can help the commercialization of this technology

Thank you

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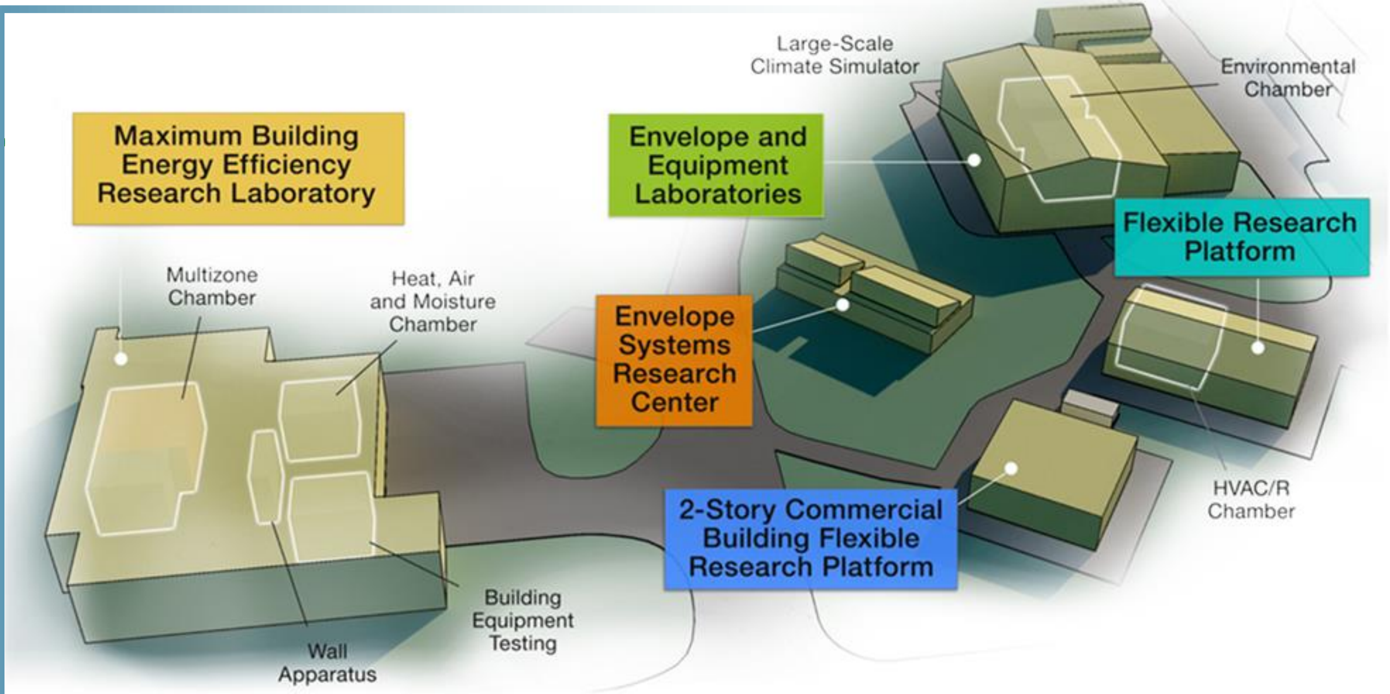

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Scientific and Economic Results

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

Control Plan

	PY1				PY2			
Tasks Months →	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24
1 - Modeling and simulation of system								
Task 1.1: Identify characteristics of the system								
Task 1.2: Develop a thermodynamic model								
Task 1.3: Develop lumped parameter model								
Task 1.4: Simulate system and LCCP								
Task 1.5: Develop optimized system design								
2 - Performance testing at steady state conditions								
Task 2.1: Fabricate laboratory-scale system								
Task 2.2: Develop test plan								
Task 2.3: Evaluate steady-state performance								
3 - Field evaluation to verify performance								
Task 3.1: Identify test site								
Task 3.2: Fabricate and install refrigeration system								
Task 3.3: Evaluate refrigeration system performance								
4 - Publications in scientific journals and magazines								
Task 4.1: Produce publications and final report								

The CRADA contract is going through final approvals at the DOE

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