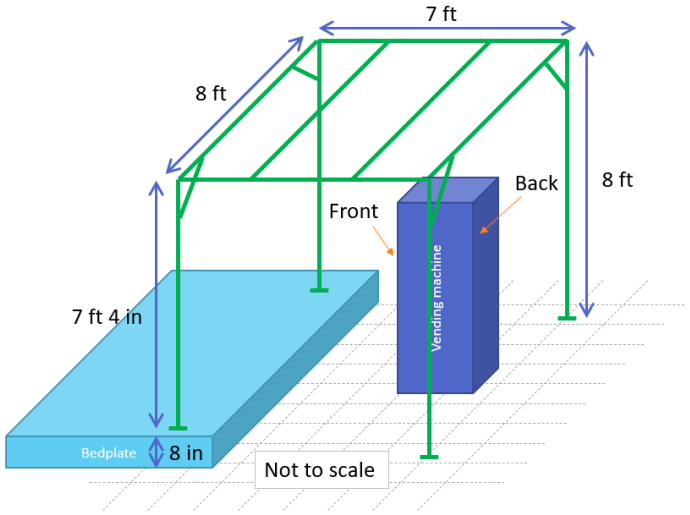
High efficiency flammable refrigerant leak event risk mitigation



Oak Ridge National Laboratory
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Project Summary

Timeline:

Start date: 10/01/2019

Planned end date: 09/30/2021

Key Milestones

1. Complete the experimental campaign and suggest modifications if needed, 03/31/2021
2. Complete the evaluation of the final improved leak mitigation solutions to determine their effectiveness in reducing refrigerant concentration to below LFL 5 min after release, 03/31/2021

Budget:

Total Project $ to Date:

- DOE: $400,000
- Cost Share: $240,000

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Key Partners:

Foundation of the National Automatic Merchandising Association (NAMA Foundation)

Project Outcome:

To support the refrigerated vending machine (RVM) industry in transitioning to the low-GWP R-290 refrigerant by:

1. Identifying viable flammability risk mitigation techniques and verifying their effectiveness in the laboratory
2. Providing NAMA with experimental data to support their efforts to reassess usage restrictions on RVMs using R-290

The work will support the RVM transition from high-GWP refrigerant ($GWP_{R\text{-}134a}$ = 1430) to low-GWP refrigerant ($GWP_{R\text{-}290}$ = 3).

Team

- ORNL R&D staff:

Viral Patel

R&D Staff - project coordination and planning, performing experiments, data analysis, report preparation, communication with project team and partners

Tugba Turnaoglu

Postdoctoral Research Associate – performing experimental work, data analysis, report preparation

Ahmad Abu-Heiba

R&D Staff – performing experimental work, data analysis, communication with project team and partners

Anthony Gehl

Technical Senior Staff – experimental setup, hardware and software for data acquisition

- ORNL facilities and operations staff, craft personnel
- NAMA members
  - Represents manufacturers and distributors of automatic vending machines in North America

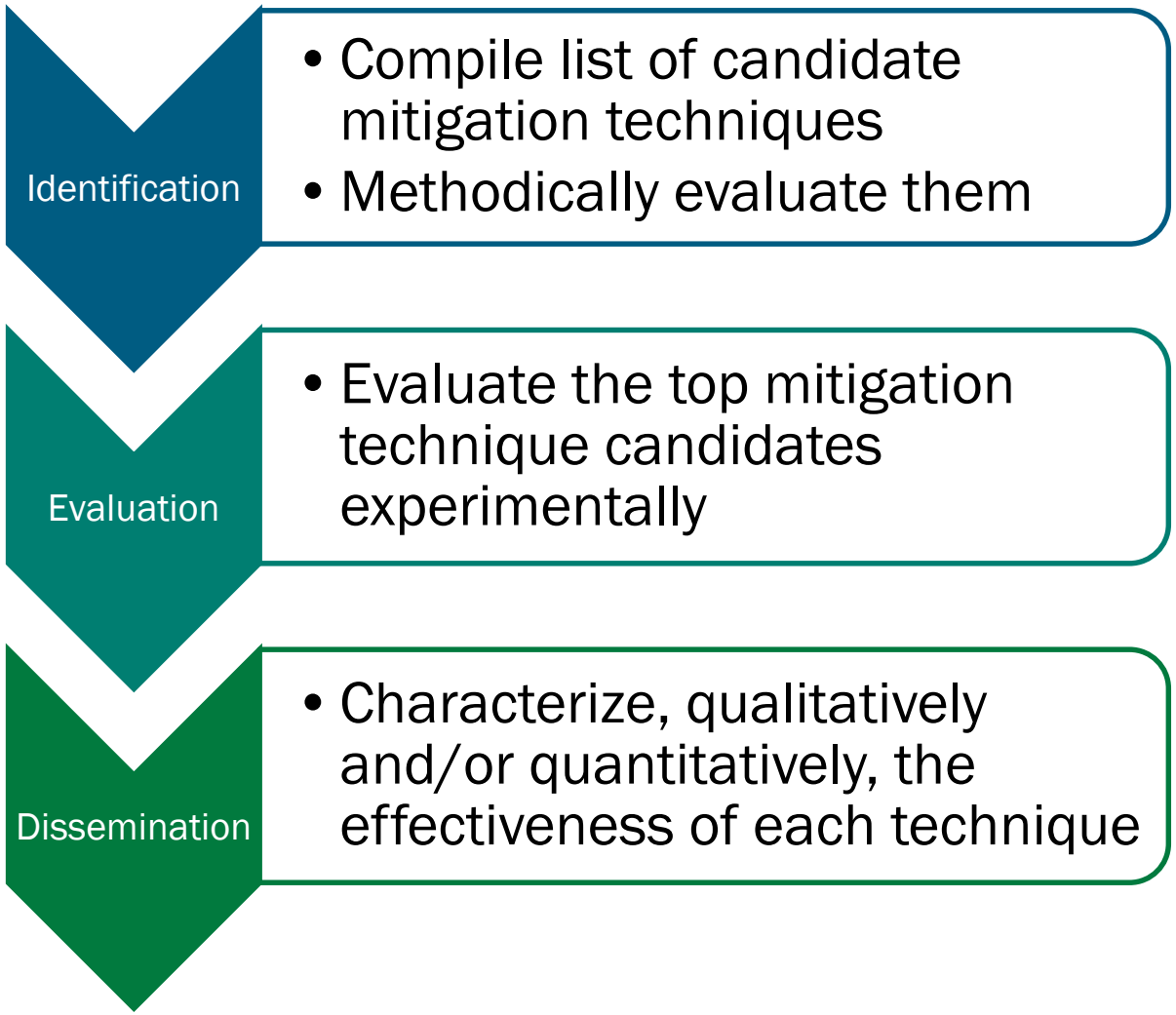
Challenge

- Most current RVMs in US use R-134a (A1 refrigerant[1]) which is deemed unacceptable in new equipment as of January 1, 2019, by the (EPA SNAP Rule, Substitutes in Vending Machines) and banned by California Air Resources Board (CARB) regulations
- For technical and economic reasons, the RVM industry has selected R-290 (A3 refrigerant[1]) as the alternative to R-134a.
- Safety standards have dictated that only A1 refrigerants allowed in RVMs in common areas of commercial buildings (represent 75% of all applications for RVMs). ASHRAE 15 formed a working group to assist with information on possibly allowing A3 refrigerants in those locations:
  - ASHRAE 15 and UL have updated their standards with input from NAMA to allow up to 114 g of an A3 refrigerant in previously restricted area; current machines using an A3 refrigerant are thus in compliance with ASHRAE and UL
- The RVM industry, through NAMA, needs assistance in identifying ways to reduce the risk of leaks which may have safety implications, assist the industry in finding ways to build these machines and remain competitive and in compliance with DOE energy efficiency rules and to address the mitigation that will be necessary when quantities of A3 refrigerants above 114 g are used (e.g., in larger systems).

[1]*ASHRAE Standard 15-2019: Safety Standard for Refrigeration Systems*

Approach

- **Develop a mitigation technique that can reduce the risk of flammability.**
  - Criteria for successful mitigation was set forth by NAMA: bring the local concentration around the machine below LFL within 5 minutes of full-bore leak under any operating condition
- **Verify the effectiveness of the developed technique experimentally under different working conditions:**
  - Machine state: ON or OFF
  - Release location: high or low side
  - Release rate: fast or slow



Impact

Safety standards	• The project generates information critical for safety standards bodies to decide on allowable placement of RVMs in commercial buildings
OEMs	• Develop and verify mitigation techniques, that do not negatively impact energy efficiency levels, and provide OEMs with information they need for safety standards development
Program	• Increase penetration of the low-GWP R290 while maintaining current energy efficiency levels

Progress

In FY20:

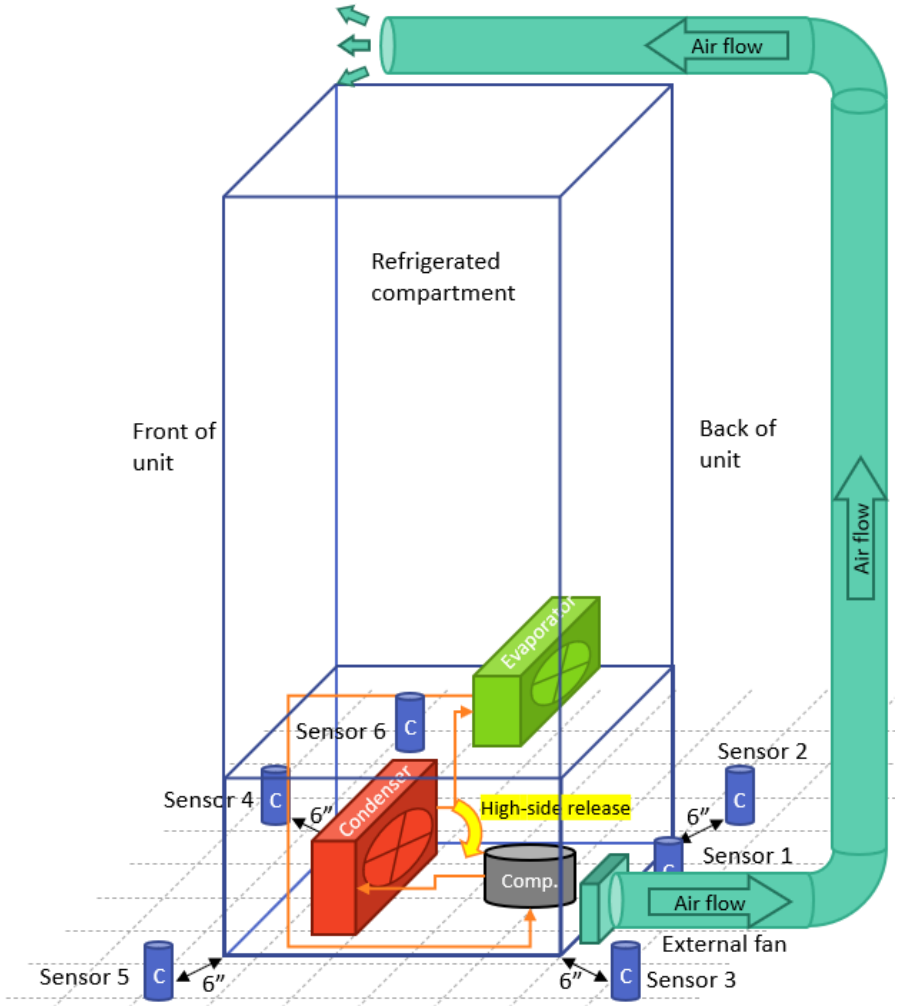
- A survey was sent out to manufacturers to compile data on most common types of RVMs and most common arrangements
  - Four machines were selected for this work that covered most variations
- Results of related work in the literature on flammable refrigerant risk mitigation were reviewed
- NAMA members were asked to rank several solutions for flammable refrigerant leak mitigation
  - The two highest ranking solutions were selected for investigation
- A test matrix was developed for testing of the four different RVM samples
- A lab setup was built to conduct tests

Progress

- Tests involved release of R-290 and study of effectiveness of mitigation techniques for four RVMs:

Stack vendor unit 1	Reach-in bottle cooler	Glass-front vendor	Stack vendor unit 2

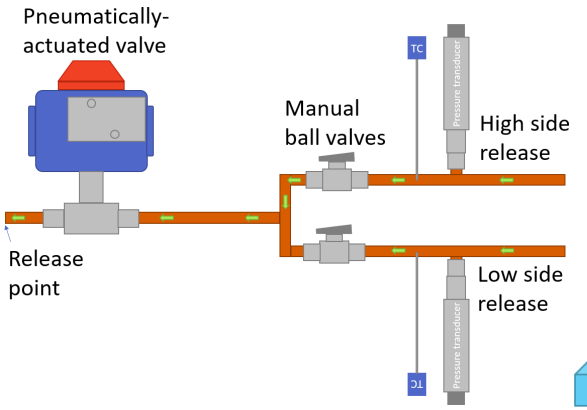
- Parameters varied:
  - Mitigation method (Additional fans, CO_2)
  - R-290 charge (114 g, 150 g)
  - Equipment operation (on, off)
  - Leak location (high-side, low-side)
  - Leak rate (fast, slow)
  - Other (door opening, machine fill level)
- Measurements:
  - R-290 concentration
  - Pressure, temperature, power consumption

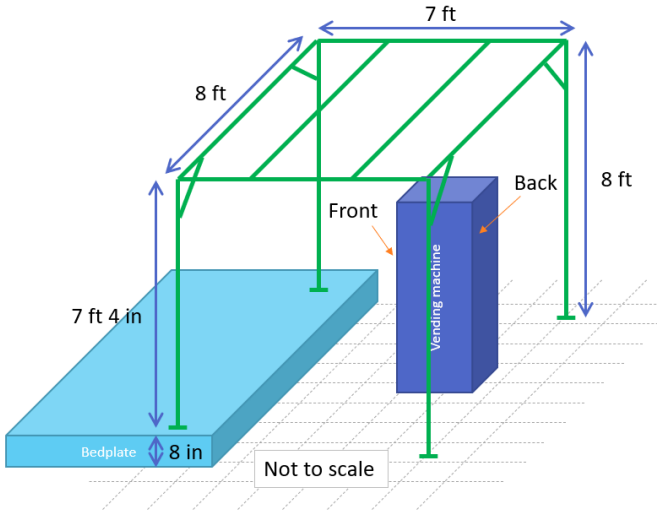


Note: schematic is only a representation; locations of components and sensors depended on specific unit

Progress

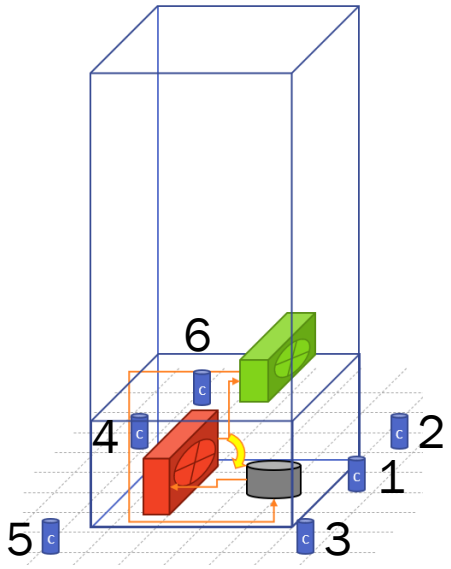
- Refrigerant release tests performed inside 7 ft x 8 ft x 8 ft enclosure to simulate the installation of RVMs in small break room
- Enclosure structure entirely covered with heavy-weight, flame- and heat-resistant fiberglass cloth
- Test enclosure located inside engine test cell with adjacent control room
- All sensors and controls including electronic refrigerant release valve wired to data acquisition computer in control room
- Tests initiated, and all measurements monitored safely by researchers in control room

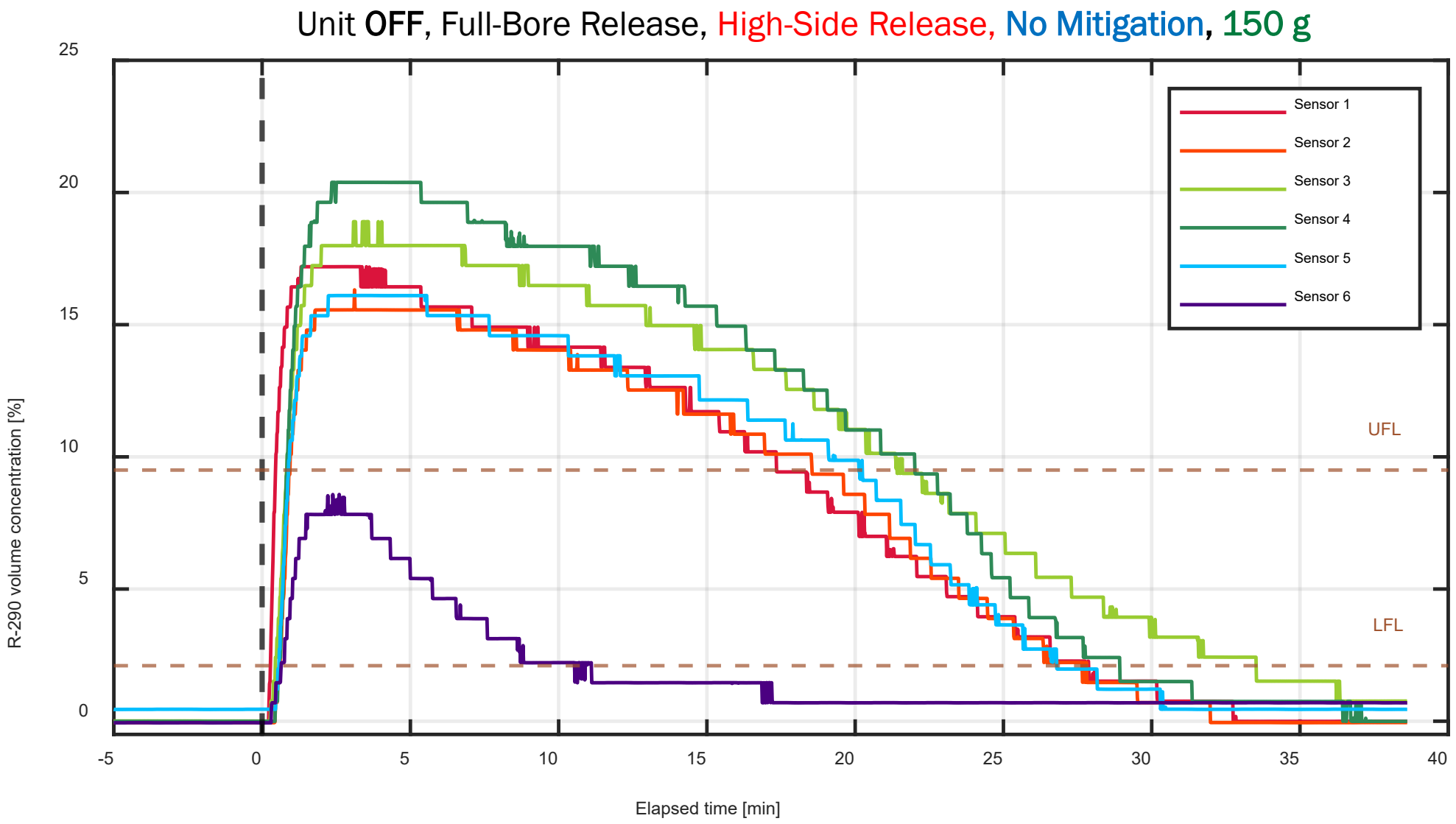




Progress

- Example results are shown for one unit under test
- LFL and UFL are lower and upper flammability limits for R-290

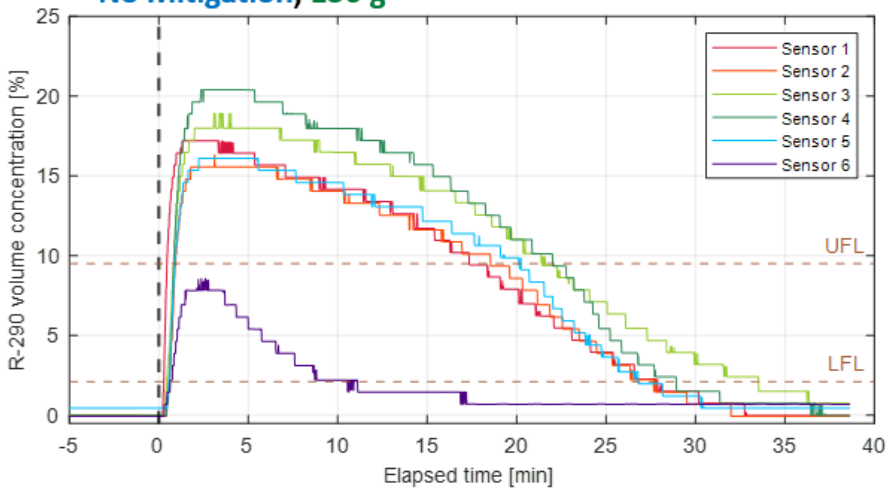




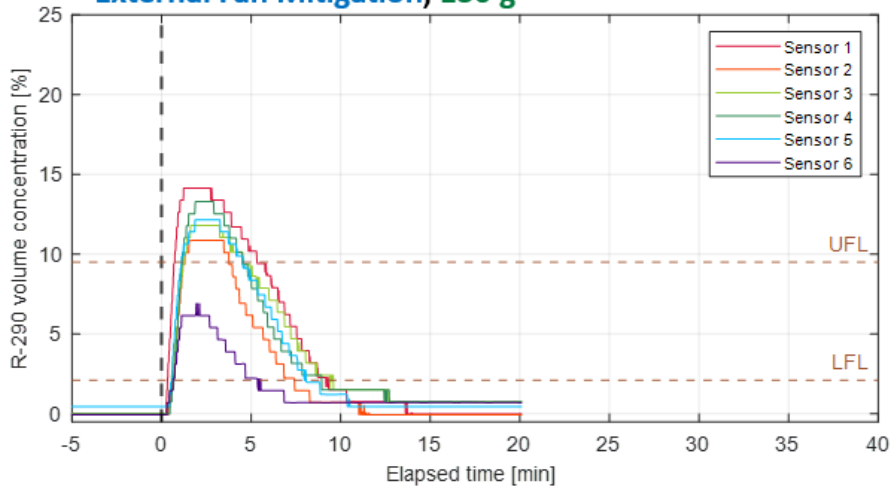
Progress

- Example results are shown for one unit under test
- 59 experiments completed in total for all machines

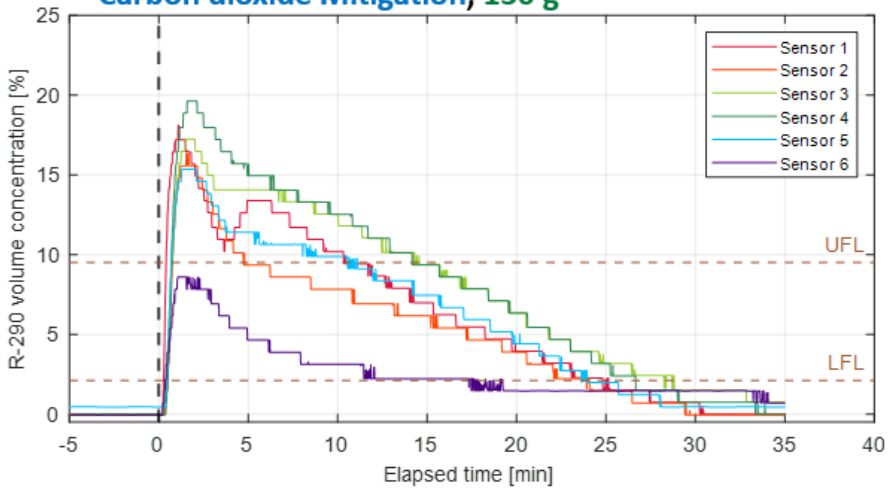
Unit **OFF**, Full-Bore Release, High-Side Release,
No Mitigation, **150 g**



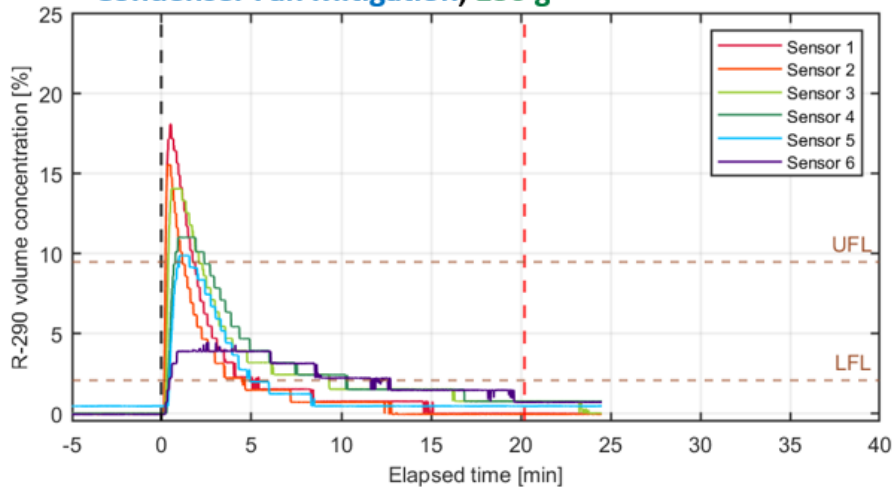
Unit **OFF**, Full-Bore Release, High-Side Release,
External Fan Mitigation, **150 g**



Unit **OFF**, Full-Bore Release, High-Side Release,
Carbon dioxide Mitigation, **150 g**



Unit **ON**, Full-Bore Release, High-Side Release,
Condenser Fan Mitigation, **150 g**



Stakeholder Engagement

- The project is a late-stage cooperative R&D agreement (CRADA) between ORNL and NAMA
- Relevant safety standards bodies (ASHRAE, UL) will be engaged through NAMA
- Diverse set of OEMs that are part of NAMA have been engaged in every step to discuss approach and results and have provided guidance on relevant test parameters and test matrix
  - Represents most of the manufacturers and distributors of automatic vending machines in North America.

Remaining Project Work

- Milestones met this FY:
  - Complete the experimental campaign and suggest modifications if needed
  - Complete the evaluation of the final improved leak mitigation solutions to determine their effectiveness in reducing refrigerant concentration to below LFL 5 min after release
- In progress:
  - Prepare report of experimental data
- Further potential work to be done in FY22 (CRADA extension request in progress):
  - Low-cost reliable flammable refrigerant sensors
  - Reduction in energy consumption of RVMs through component and charge optimization

Thank you

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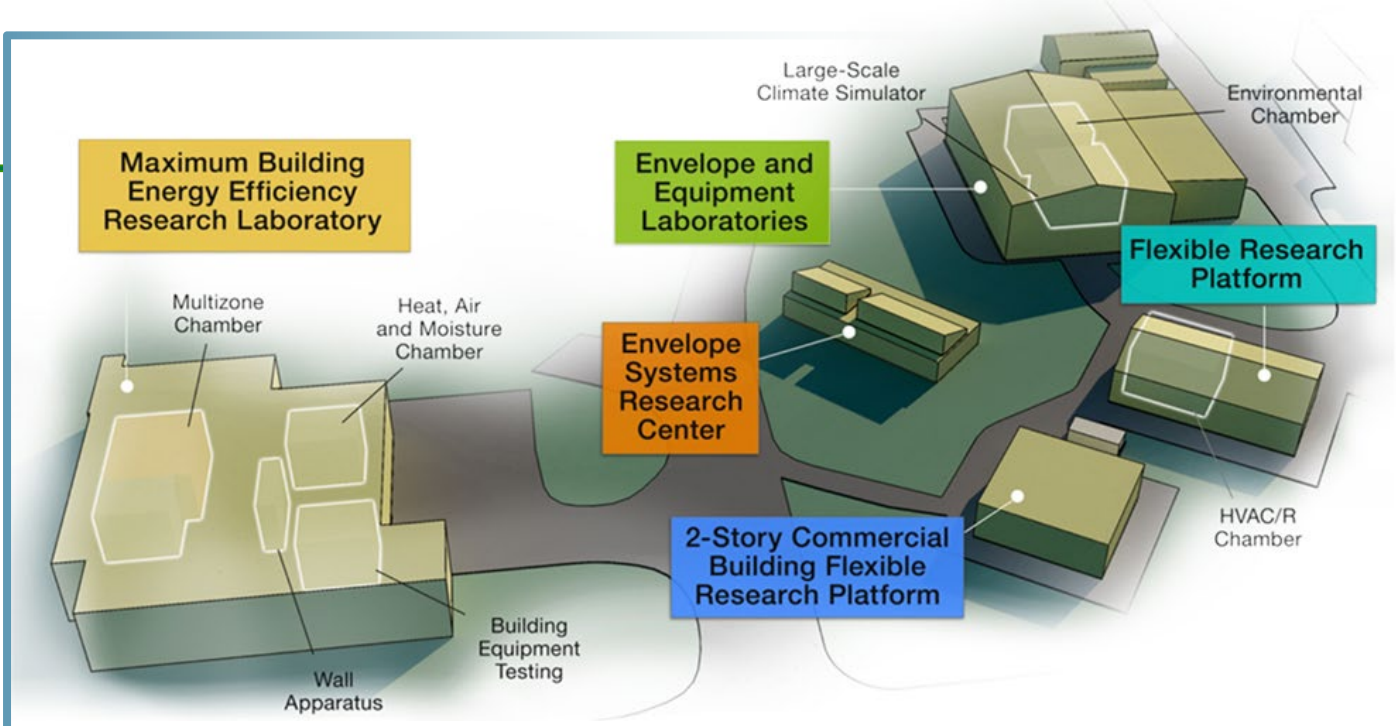

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

238 publications in FY20
125 industry partners
27 university partners
10 R&D 100 awards
42 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Budget

Project Budget: DOE: $400,000, Cost Share: $240,000
Variances: None
Cost to Date: $370,211
Additional Funding: None

Budget History					
10/01/2019 – FY 2020 (past)		FY 2021 (current)		FY 2022 – (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$200,000	$120,000	$200,000	$120,000		

Project Plan and Schedule

Project Start: 10/01/2019	Completed Work
Projected End: 09/30/2021	Active Task (in progress work)
	Regular Milestone/Deliverable
	Go/No-Go Milestone/Deliverable

Task	FY2020 Q1 (Oct-Dec)	FY2020 Q2 (Jan-Mar)	FY2020 Q3 (Apr-Jun)	FY2020 Q4 (Jul-Sep)	FY2021 Q1 (Oct-Dec)	FY2021 Q2 (Jan-Mar)	FY2021 Q3 (Apr-Jun)	FY2021 Q4 (Jul-Sep)
Past Work								
Complete the review of refrigerated vending machines and UL541 requirements	◆							
Report the Task 2 review results and make multiple suggestions for risk mitigation		◆						
Complete the lab setup for evaluation, and submit the summary overview of the past research to identify the safety measures to prevent refrigerant built-up			◆					
Complete the screening studies and proposed the two highest potential solutions				◆				
Report the two highest potential solutions after incorporating Participant's input				◆				
Complete the integration of the top two solutions to RVM and initiate the evaluation					◆			
Complete the experimental campaign and suggest modifications if needed.						◆		
Complete the evaluation of the final improved leak mitigation solutions to determine their effectiveness in reducing refrigerant concentration to below LFL 5 min after release							◆	
Current/Future Work								
Submit the final report								◆