2024 PROJECT PEER REVIEW
U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review: Low–Global Warming Potential Refrigerant Leak-Sensing Methods for Commercial Refrigeration

Low–Global Warming Potential Refrigerant Leak-Sensing Methods for Commercial Refrigeration

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WBS 3.2.2.81.2101

Project Summary

OBJECTIVE, OUTCOME, & IMPACT

- Enable successful adoption of low and ultralow-GWP refrigerants in commercial refrigeration
- A2L and A3 sensor, standards and equipment design are parallelly evolving
- Holistic approach to realize flammable refrigeration system complying with existing standards and beyond
- Smart control, leak detection/isolation - multiple refrigeration system architectures
- CO_2,eq impact – 44 MMT/year

TEAM & PARTNERS

- ORNL
- Collaborators – Nevadanano, Emerson, Figaro, Senseair, Kolpak, HEB, Food City

STATS

Performance Period: 10/1/2022 – 9/30/2025

DOE Budget: $1400k, Cost Share: $200k

Milestone 1: Comprehensive experimental setup

Milestone 2: Evaluation of A2L refrigerant sensors

Problem

- **Direct emissions from supermarkets and large food retail stores**
  - Direct expansion refrigeration systems is most common system (90% of current refrigeration system)
  - refrigerant charge ranges from 1000 lb – 3500 lb
  - annual refrigerant leaks of 25%, 70% of total emissions
  - Common working fluid: R-404A (**GWP 3922**)
- **Solution and Impact**
  - Low-GWP (<150) and ultra low-GWP options such as hydrocarbons, R454C and R455A are flammable (A3 and A2L class)
  - Due to flammability concerns, robust safety solutions are necessary
  - Reliable sensor integrated with control system are required to mitigate risks
  - Sensors should have accuracy, sensitivity, fractionation, selectivity

	Lower Toxicity	Higher Toxicity
Higher Flammability	**A3**	**B3**
Flammable	**A2**	**B2**
Lower Flammability	**A2L**	**B2L**
No Flame Propagation	**A1**	**B1**

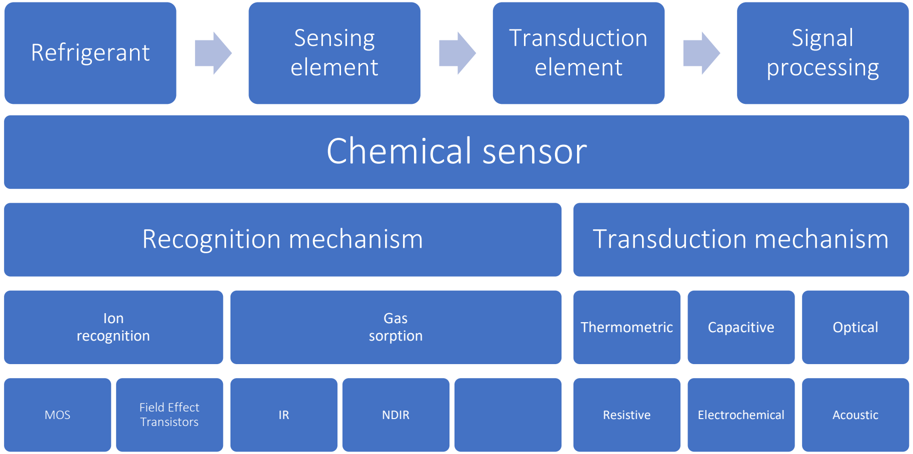
Accelerate building electrification
Reduce onsite fossil-based CO_2 emissions in buildings – 25% by 2035 and 75% by 2050, compared to 2005

Greenhouse gas emissions reductions
50-52% reduction by 2030 vs. 2005 levels
Net-zero emissions economy by 2050

Most important sensor requirements for flammable sensors in HVAC&R Industry

- Capable of operating safely with any flammable refrigerant without becoming an ignition source
- Very high reliability during the lifetime (10+ years)
- Ready to operate with smart control and fault detection and diagnostics systems employed in these applications
- Wireless capabilities (Internet of Things connectivity) to simplify deployment in typical supermarket stores
- Capable of measuring refrigerant concentration with sufficient accuracy for WCF and WCFF, and adequate response time per safety standards (UL 60335-2-89, 2-40)

Sensing mechanisms for detecting refrigerants



- Sensing capabilities are constrained by the physical properties of the sensing mechanism
- Multi-objective testing can determine the most appropriate sensor for a specific application

Table 1: Test matrix for selecting an appropriate sensor solution.

Attribute	Range	Test method
Concentration / accuracy	• 5% – 25% LFL; ±3%	Signal response vs concentration
Time constant / response time	• 1% – 25% LFL	Signal response time after leak initiation
Sensitivity and selectivity	• Humidity (10%-90%) • Temperature (-30F to +275F) • CO_2 (0.05% to 1%) • Other refrigerants (134a, 404A, 407A) • (NO_X – ppmv; CO – ppmv) • Impact of fractionation, oil, cleaning agents, engine exhaust	Presence of humidity, temperature, CO_2, other refrigerants, poison species: co-injection
Repeatability	• Signal variance between sensors	Simultaneous evaluation
Reliability	• Continuous exposure time • Oversaturation (pure refrigerant exposure) • On/off cycling • Powered sensor • Signal drift vs. time	Exposure to different test conditions
Location	• Floor vs. Ceiling	Impact of density
Robustness (vibration/shock)	–	Vibration sensitivity, shock sensitivity
Flexibility	• Multiple A2L blends	Cross compatibility feasibility

Literature Review

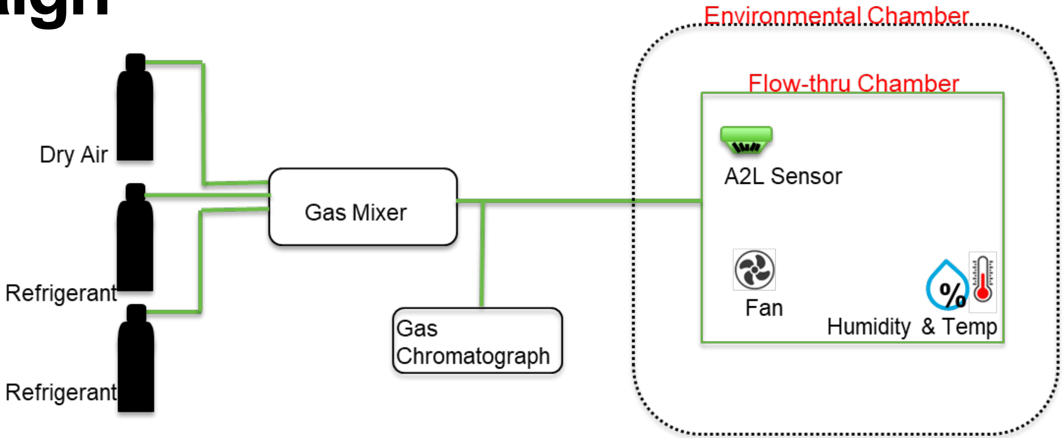
- UL 60335-2-89, 2-40 and ASHRAE 34 Standards
- AHRTI Study
  - Test method development and evaluation of 6 sensors
    - 4 sensing principles using R32
    - Response time evaluation
    - Test method for robustness and reliability evaluation
      - Fluid Resistance and Poisoning test
      - Temperature (-20°C and 55°C, **30-70%**RH)
      - Humidity (40°C, 20%RH)
      - Air velocity
      - Altitude
      - Sensor Orientation

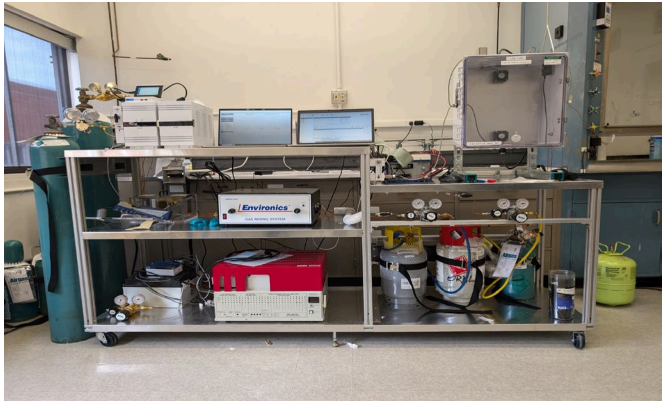
Letter Code	Sensor type	% of requirements passed	Average time delay (sec)	Average time constant (sec)
A	MMM	100%	4.5	0.25
B	NDIR	96%	1.6	15.8
C	TC	86%	0.0	0.1
D	NDIR	79%	0.1	13.7
E	MOS	75%		
F	MOS	64%		

- Principles selected: NDIR, Speed of sound, IR, Spectrometry, MOS, Thermal Conductivity

Experimental Campaign

- Composition Sensitivity
  - Nominal composition
  - WCF
  - WCFF
- Humidity Impact
- Pollutants
  - CO
  - NO_2
- Contaminants
  - Common household cleaning agents
- Temperature
- CO_2
- Misc. contaminants



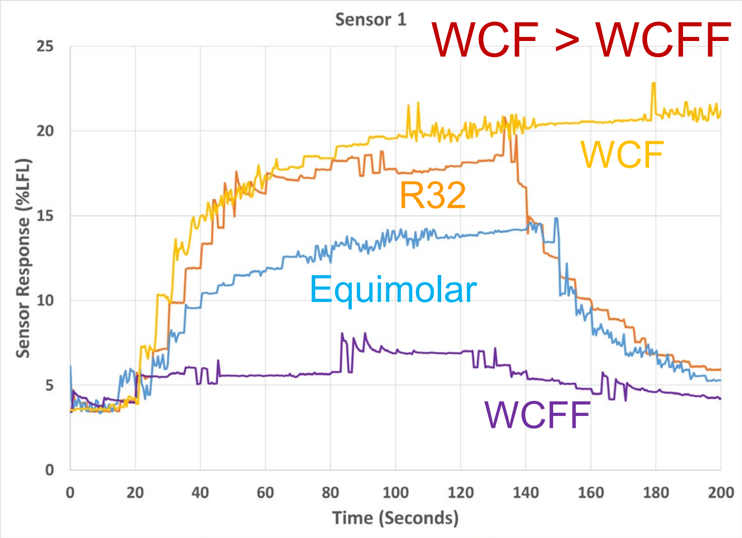


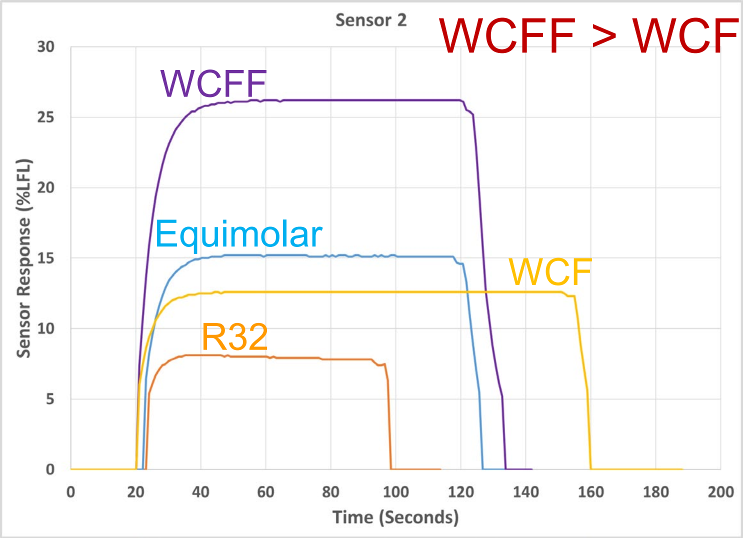
Composition Sensitivity

Application	Refrigerant	Nominal	WCF	WCFF
Refrigeration	R454C	x	x	x
Refrigeration	R454A	x	x	x
Refrigeration	R455A	x	x	x
Refrigeration	R457A	x	x	x
Air-conditioning	R454B	x	x	x

	R454C	R454A	R455A	R457A	R454B
Nominal	R-32/1234yf (21.5/78.5)	R-32/1234yf (35.0/65.0)	R-744/32/1234yf (3.0/21.5/75.5)	R-32/1234yf/152a (18.0/70.0/12.0)	R-32/1234yf (68.9/31.1)
WCF	R-32/1234yf (19.5/80.5)	R-32/1234yf (33.0/67.0)	R-744/32/1234yf (2.0/20.5/77.5)	R-32/1234yf/152a (18.0/70.0/12.0)	R-32/1234yf (67.9/32.1)
WCFF	R-32/1234yf (0/100)	R-32/1234yf (0/100)	R-744/32/1234yf (0/0.15/99.85)	R-32/1234yf/152a (18.0/70.0/12.0)	R-32/1234yf (1.69/98.3)

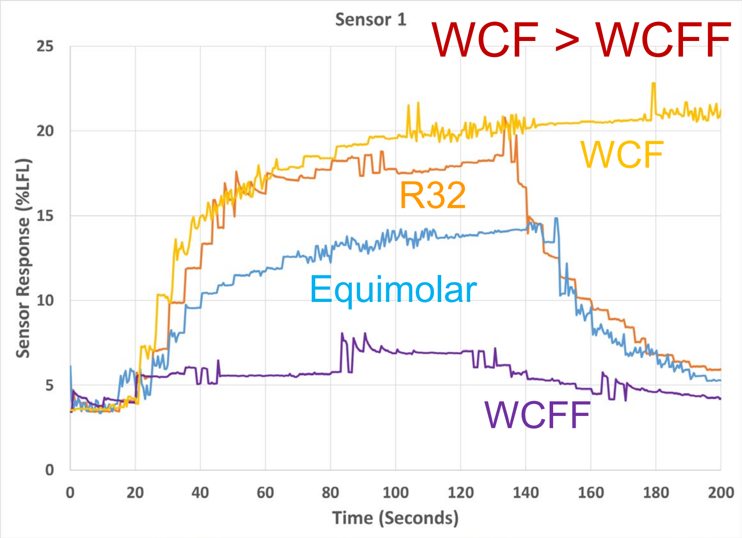
Results: R32 - R1234yf blends

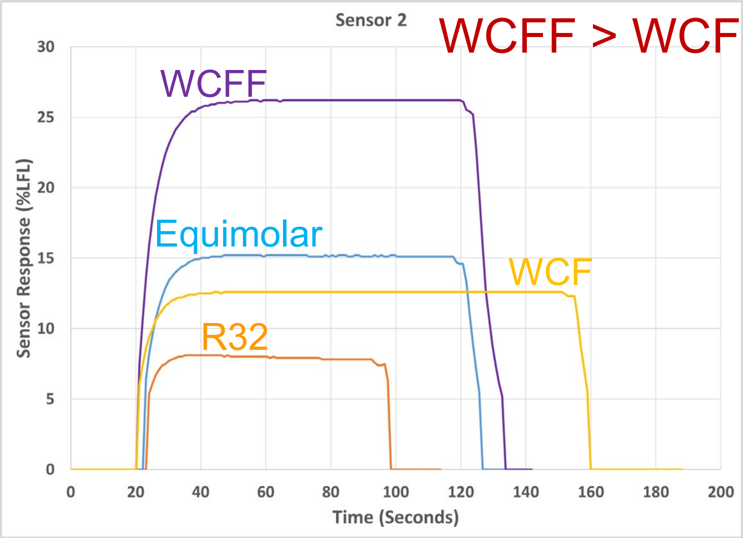




- Sensor response towards composition
  - 1.6 vol % (20% LFL R454B) refrigerant in air at room temperature
  - Cases studied
    - R454B WCFF– R32/R1234yf (3.7%/96.3% vol: 1.7%/98.3% mass)
    - Equimolar blend- R32/R1234yf (50%/50% vol: 31.3/68.7% mass)
    - R454B WCF – R32/R1234yf (83%/17% vol: 67.9%/32.1% mass)
    - Pure R32

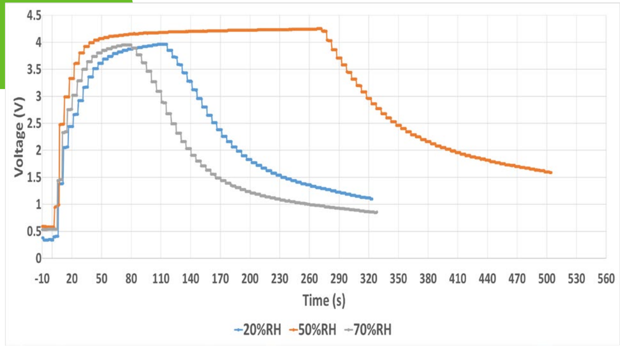
Results: R32 - R1234yf blends



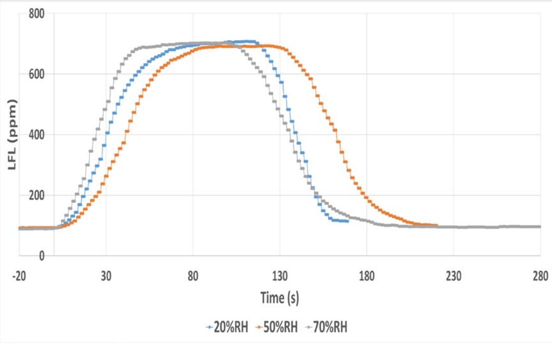


- Sensor response varied by type
  - More responsive to WCFF, enhancing safety margin
  - Quick response to WCF, negative response to WCFF
- Response time behavior of some sensors varied with blend composition

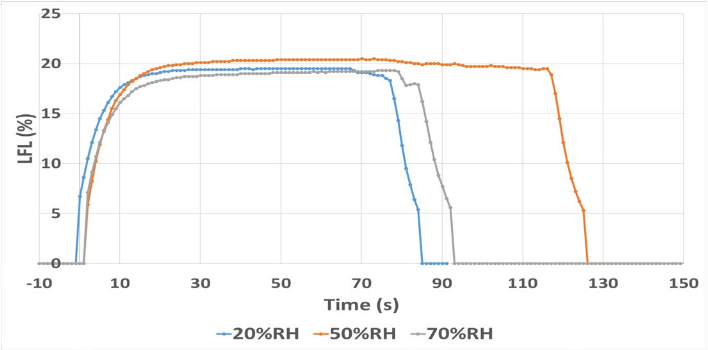
Humidity Impact



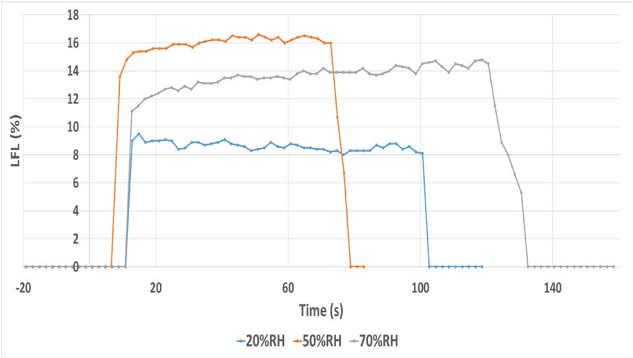
Sensor 1



Sensor 2



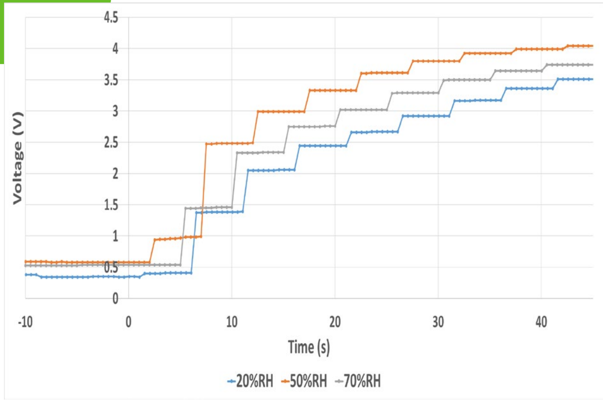
Sensor 3



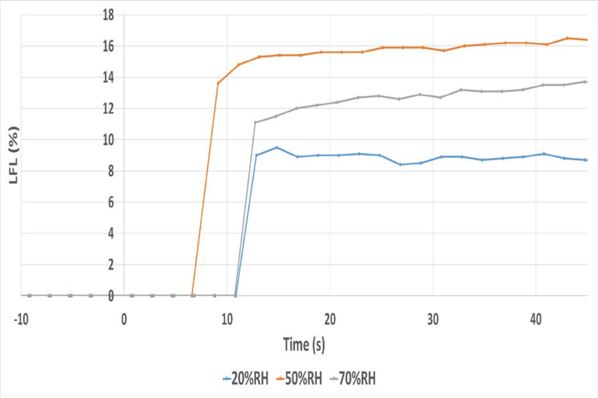
Sensor 4

- Measured with R454C
- 5 working principles
- 20% RH to 70% RH at ~ 24°C (T_{dew}: -0.4°C to +18.4°C)
- All sensors showed signal strength variance

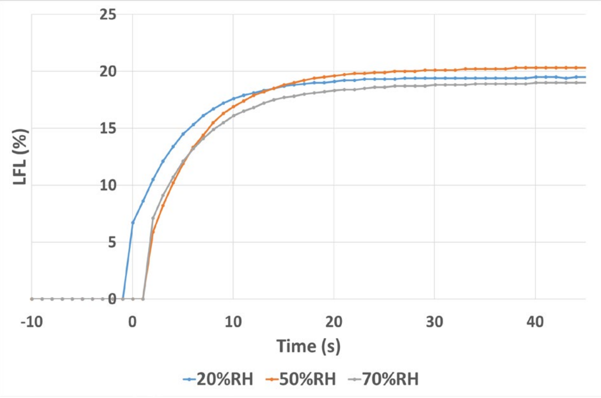
Humidity Impact (continued)



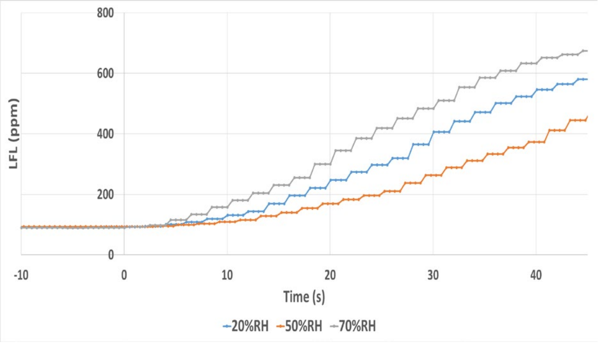
Sensor 1



Sensor 2



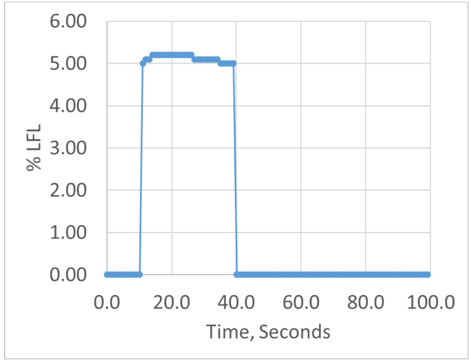
Sensor 3

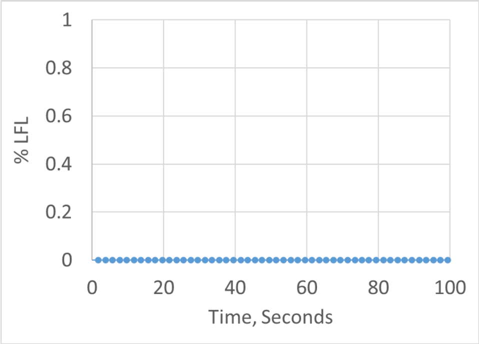


Sensor 4

CO and NO_2 sensitivity

Sensor	CO (25 ppmv)	NO_2 (20 ppmv)
1		
2	●	
3	●	
4	●	●
5		
6	●	●

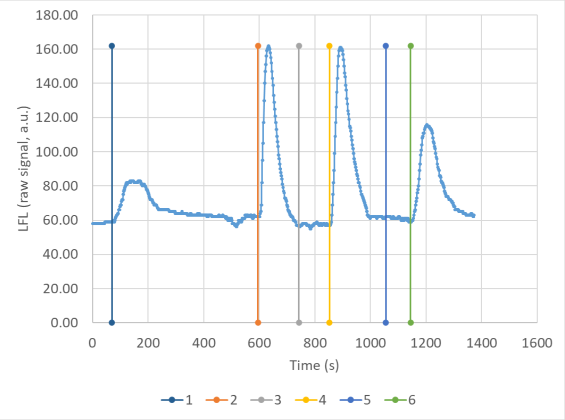


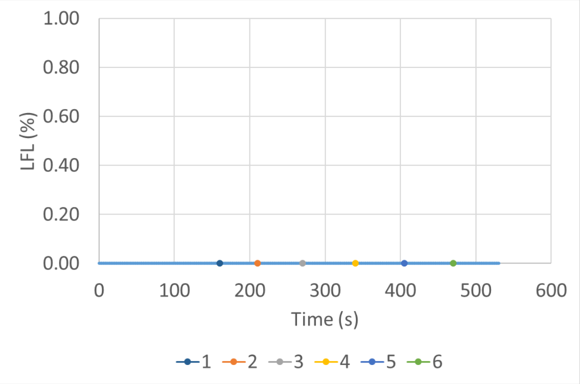


Cleaning agents

Cleaning agent	Description
1	Rust and lime removing agent (glycol, acetate, ketone)
2	Deodorizing spray (IPA, NPPEE)
3	Floor cleaning liquid (PEG, Ether)
4	Lysol (ethanol, benzyl compound)
5	Clorox (NaOCl)
6	Floor polish (Ketone, acetate, alcohol)

Sensor Type	1	2	3	4	5	6
1						
2	●	●		●		●
3						
4			●			●
5						
6	●		●			





Real World Implications

- Sensor location is critical
- Leak dispersion dynamics in real world installations need to be considered
- Sensitivity towards humidity was noticed
- Extreme temperatures and humidity
- Contaminants

Conclusions

- Sensor’s sensitivity towards numerous operational and installation scenarios can present a challenge
  - Signal strength variance
  - Response time
  - False positive
- Need to be considerate towards sensor location
- Standard needs to be expanded for other scenarios not yet implemented (e.g. higher humidity, WCFF, contaminants)
- Recommendations
  - Sensor accuracy analysis should be added to routine refrigeration system maintenance schedules
  - Application specific bump kit
  - Sensor Location identification
- We will analyze the entire data set in identifying hybrid sensor combination suitable for addressing all hypothetical real-world scenarios

Next Steps

- Sensor performance evaluation at colder conditions (-20 ºF/ 90% RH)
- Lubricants impact
- Cross contamination with HFC
- Unique scenarios: Citrus juices, lead acid battery vapors, CO2
- A3 sensor evaluation
- Literature review
- Developing test setup
- Detailed analysis of sensor location and leak dispersion dependency
    - Multiphysics modeling of different HVACR equipment
    - Experimental study of WIF
- Field study
- Journal publications to disseminate the data

Thank you

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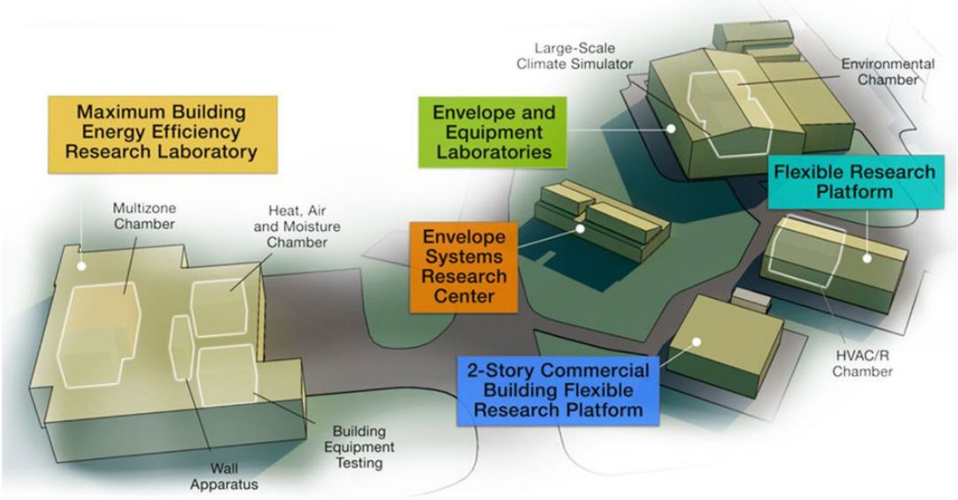

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Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	600				600				200			
Spent budget												
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Commercial sensor screening												
Q2 Milestone: Lab setup complete												
Q3 Milestone: A2L sensor performance evaluation complete												
Q4 Milestone: Data analysis and gap identification												
Current/Future Work												
Q5 Milestone: A3 sensor performance evaluation complete												
Q6 Milestone: Data analysis and gap identification												
Q7 Milestone: Modeling and HVAC&R system evaluation												
Q4 Milestone: Final Report												

Team

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