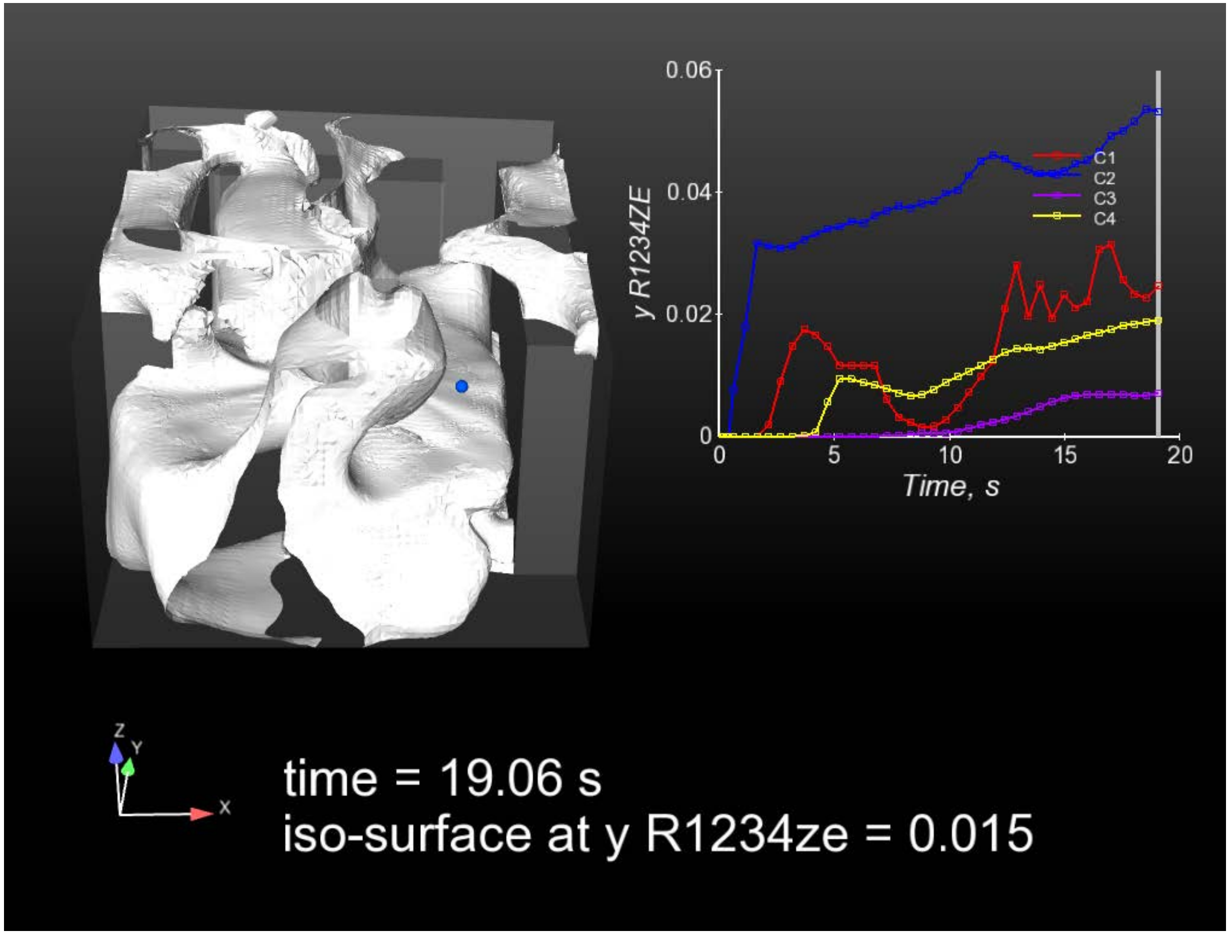
Probability Risk Assessment of Alternative Flammable Refrigerants

2017 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: 06/01/2016

Planned end date: 09/30/2017

Key Milestones (insert 2-3 key milestones and dates)

1. Hold a workshop with key stakeholders; 12/31/2016
2. Finalize CFD simulations as per the design of experiment; 06/30/2017
3. Submit a draft for the final report; 09/30/2017

Budget:

Total Project $ to Date:

- DOE: $1000k
- Cost Share: $0

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- DOE: $1000k
- Cost Share: $0

Key Partners:

AHRI	
Convergent Science	

Project Outcome:

Suggest appropriate flammable refrigerant charge limits and mitigation tactics to keep risk levels to the same risk levels in products widely used today.

Enable the widespread use of environmentally friendly higher efficiency refrigerants for different applications with potential of up to 10% reduction in energy consumption and up to 90+% reduction in global warming potential reduction.

Purpose and Objectives

Problem Statement:

- Provide the industry with a unique opportunity to systematically set flammable refrigerant charge limits based on unbiased science-based investigations
- Allow for safe use of flammable refrigerants and potentially enable widespread use of more efficient and environmentally friendly refrigerants
- Support BTO's MYPP HVAC/WH/Appliances Strategies, "Strategy 1: Near-Term Technology Improvement"

Target Market and Audience:

- HVAC&R applications in the U.S. Building sector with potential for international impact
- Audiences: HVAC&R/Appliances industry, AHRI/ASHRAE Codes and Standard Committees
- National energy market amounts to 7.81 Quad

Impact of Project:

- Inform the HVAC&R industry with appropriate flammable refrigerant charge limits and appropriate mitigation strategies to ensure safe use of efficient and environmentally friendly refrigerants
- Produce a white paper and a set of publications informing national and international standards and codes

Approach

Tactics:

- Literature review (academic, codes, and standards) to analyze key technology gap and missing information
- Workshop held with industry leaders and experts to understand the need for better flammable refrigerant charge limit settings
- Assemble information from old reports and OEM funded research (analyze and scrutinize)
- Perform CFD simulations for relevant cases to verify and validate CFD simulation tools
- Develop new correlations

Key Issues:

- Multiple variables and infinite configurations
- CFD tools might not be readily useable for our research

Distinctive Characteristics

Need for Unbiased Science-Based Recommendation:

Industry advocacy

Refrigerant manufacturer A

Refrigerant manufacturer B

Consumer advocacy

International issues:

- Other countries have already started efforts to set refrigerant charge limits and flammable refrigerant safe use guidelines
- No clear refrigerant choice yet

Progress and Accomplishments

Accomplishments:

- Held an industry workshop at the ASHRAE headquarters in Atlanta, Ga
- Finalized a critical literature review on charge limit setting and previous CFD simulations related to charge limits

Market Impact:

- Provide required support for ASHRAE Standard 15 and IECC 60335-2-40 in setting allowable flammable refrigerant charge limits → key for model building code and initial deployment starting in 2021
- Examine mitigation strategies that reduce the risks associated with the use of flammable refrigerants → potential improved performance

Lessons Learned:

- Industry needs more assurance that flammable refrigerant risks can be mitigated
- Commercial CFD solvers require additional user defined functions and additional code development
- Refrigerant leakage may result in liquid pooling on the floor – more challenging simulations

Progress

- Conducted preliminary literature review
- Conducted preliminary review of IEC60335-40 and WG9 proposals
- Conducted Workshop at ASHRAE HQ (*thanks to ASHRAE for hosting the workshop*) and disseminated workshop report to all attendees
- Continued the literature review
  - Identified additional literature sources
  - Foreign society HVAC&R resources
- Initiated the CFD simulations
  - Achieved higher accuracy than FLACS
  - Initiated new case studies
- Submitted critical literature review report

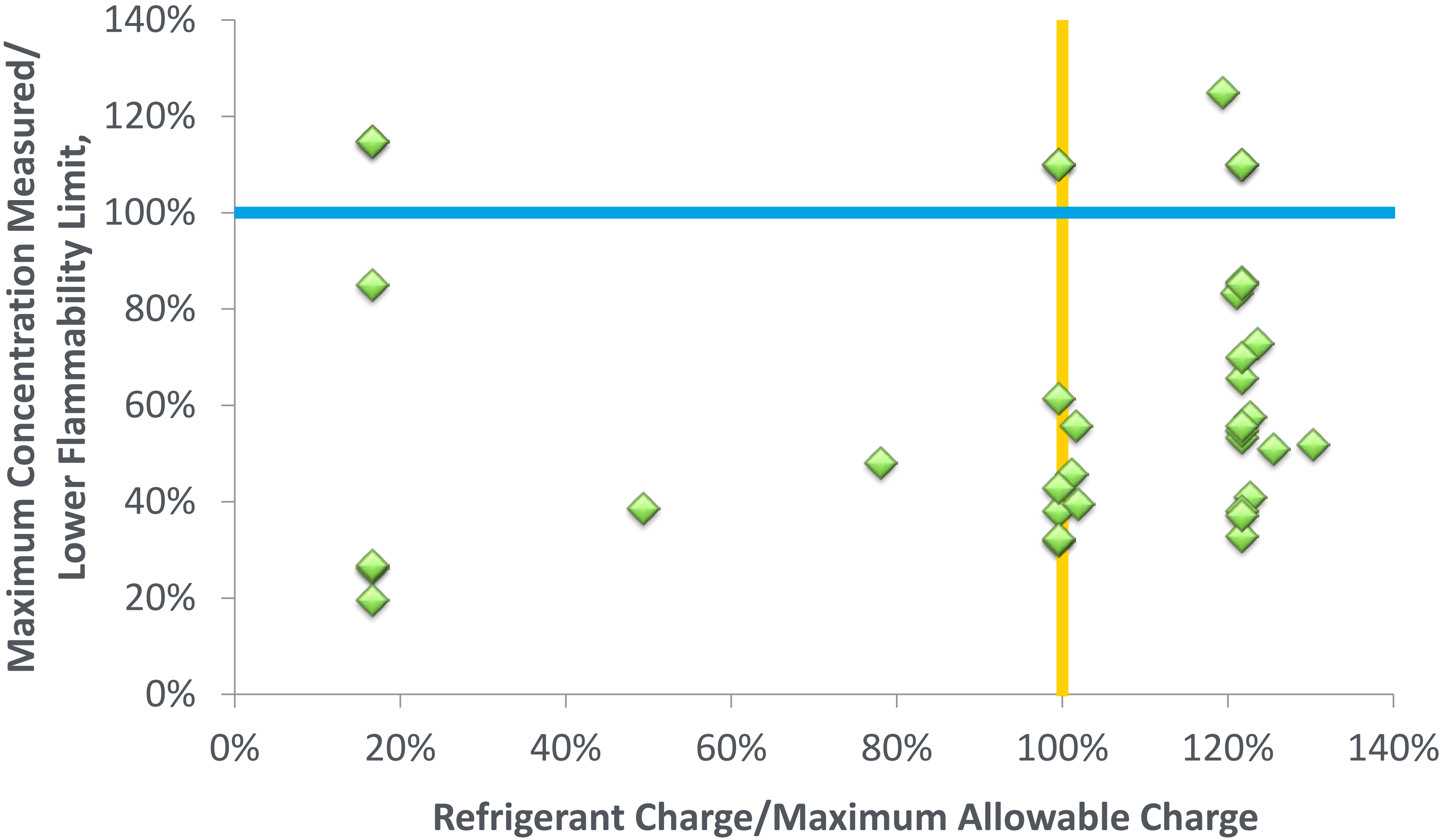
Literature Review Summary

- The literature we have compiled so far (31 publications) on flammable refrigerant leak studies is divided into the following broad categories:
  - Probability risk assessment: 4 journal publications, 6 major reports
  - Experimental/numerical/analytical studies of leak scenarios for various applications: 13 journal publications
  - General studies on flammability characteristics, ignition and standards: 7 journal publications and 1 report
- The above encompass the following residential and commercial applications:
  - Residential: Heat pump, refrigeration, room air conditioning
  - Commercial: Roof-top unit, refrigeration, machinery room chiller

Literature Review Summary

- Additional resources
  - JSRAE: Research committee for the risk assessment of mildly flammable refrigerants http://www.jsrae.or.jp/jsrae/committee/binensei/risk_eng.html
  - Nedo supported projects: http://www.nedo.go.jp/events/report/ZZEV_100009.html
  - Australian AIRAH : http://www.airah.org.au/Content_Files/TechnicalPublications/Flammable-Refrigerant-Safety-Guide-2013.pdf
  - UK FETA: http://www.feta.co.uk/uploaded_images/files/BRA%20Guide%20to%20Flammable%20Refrigerants%20-%20Issue%201%20-%20Oct%2012.pdf
  - Germany: https://www.giz.de/expertise/downloads/giz2010-en-guidelines-safe-use-of-hydrocarbon.pdf

Experimental Studies Summary



CFD Simulations

- Validations using data from the walk-in cooler experimental results from AHRI Report 8009
  - Better accuracy than other tools
- Strong technical support from Convergent Science Inc.; provided 500 CONVERGE pooled licenses
- Simulations for a 120 ft^2 room with m_{max} using R-32 as the refrigerant
- Simulations for a large single story building (ORNL FRP-1) served by RTU
- Requested quotes for experimental validation using scaled-down version of the room space

Parametric CFD Analysis for R-32

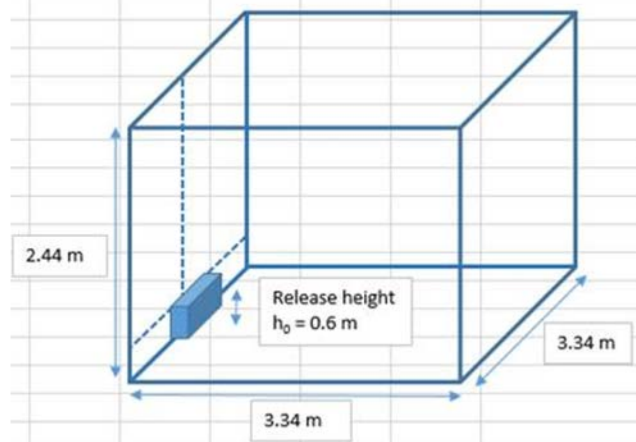
- 11.16 m^2 (120 ft^2) room
- Leak upwards with 45° angle and horizontal
- Leak source diameter: 6.35 mm (1/4")
- Mesh size: 10 mm cell – no adaption
- Cases:
  - a) Refrigerant charge = 1.145 kg with Cd = 0.39 (m_{max})
  - b) Refrigerant charge = 1.145 kg with Cd = 0.026 (m_{max})
  - c) 5 g/s air leakage into room

  NOTE: Cd → discharge coefficient

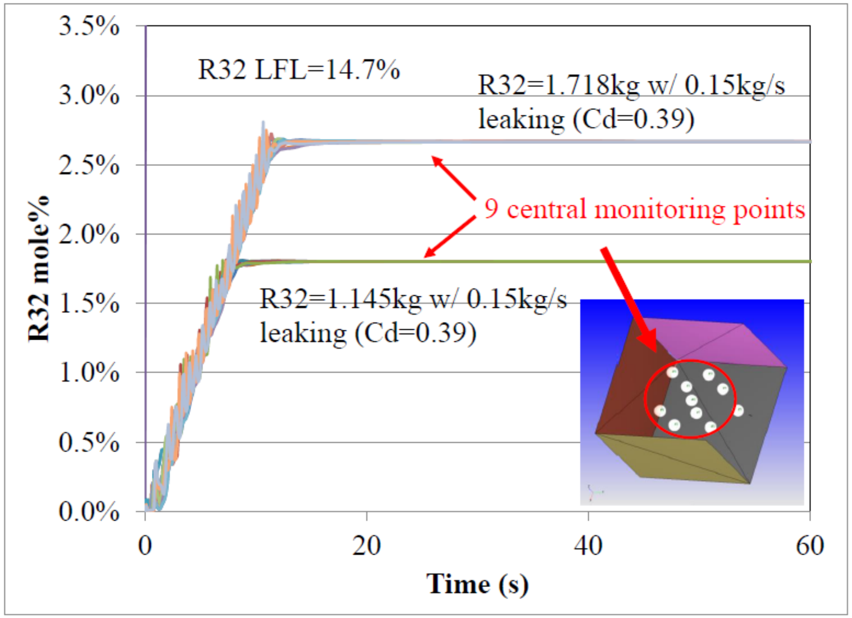
Enter floor area and release height to determine max charge based on GG.2 for R-32

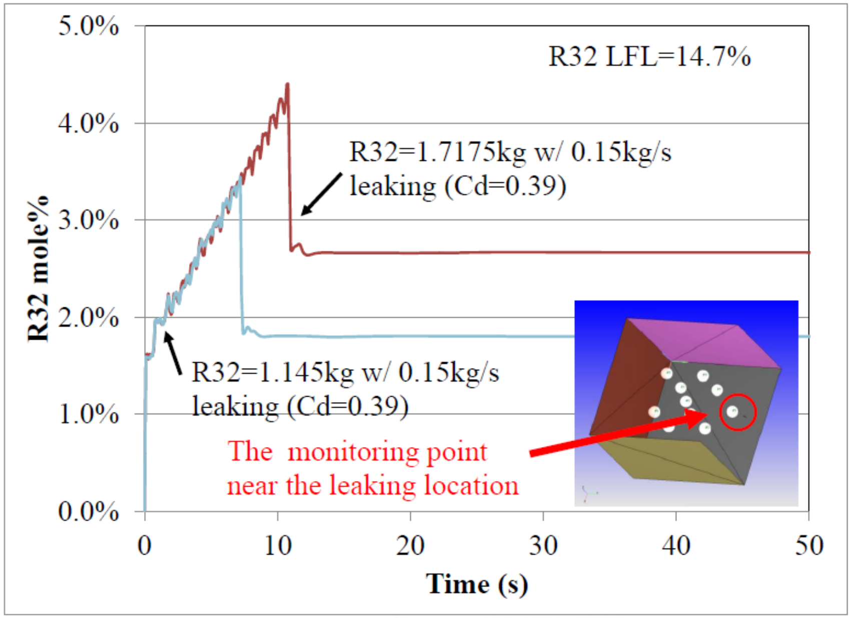
Floor area [ft^2]	Floor area [m^2]	Release height [m]	m_{max} [kg]		Floor length/width [ft]	Floor length/width [m]
120	11.14836	0.6	1.144511		10.95445115	3.338916711

$$m_{max} = 2.5 \times (LFL)^{\left(\frac{5}{4}\right)} \times h_0 \times (A)^{\left(\frac{1}{2}\right)}$$



Impact of Refrigerant Charge on Concentration Distribution





Average R32 concentration over nine central monitoring points

Average R32 concentration at monitoring point closest to leak source

NOTE – with ideal gas assumption, mole% and vol% are equivalent

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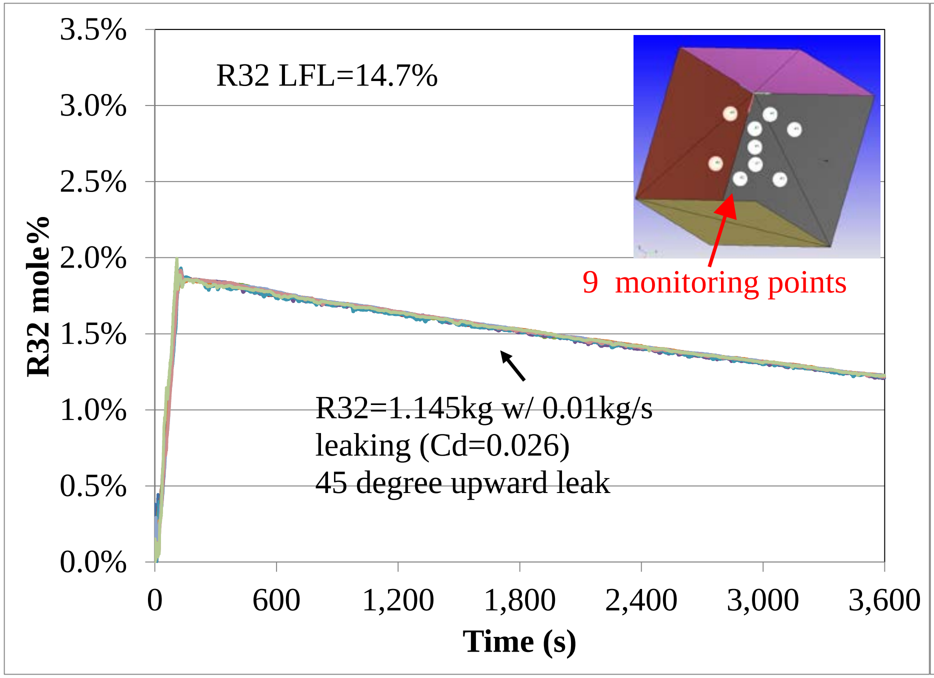
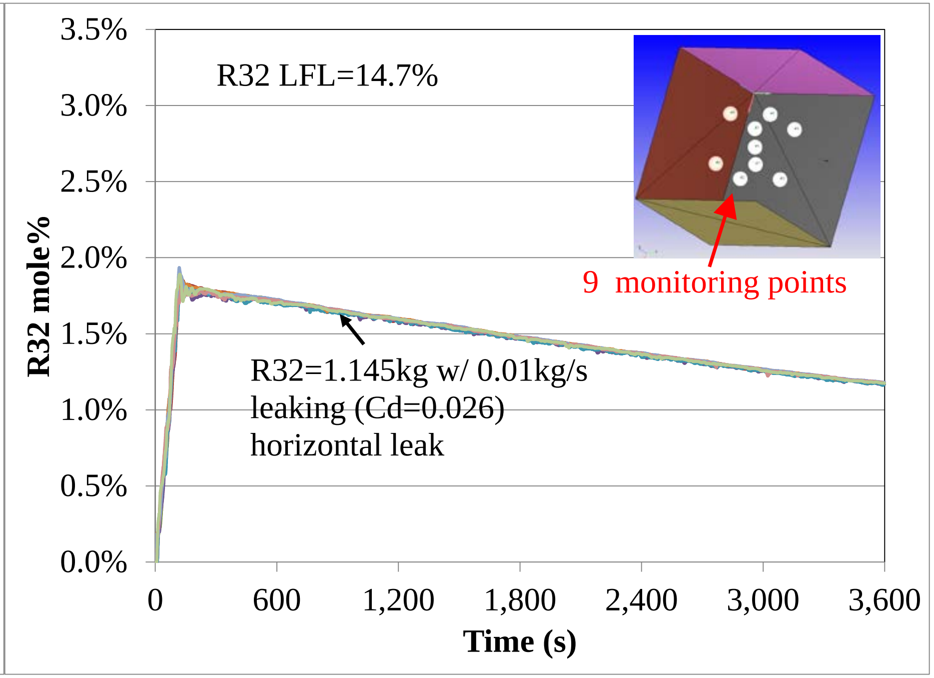
Impact of Leak Source Direction





NOTE – with ideal gas assumption, mole% and vol% are equivalent

Project Integration and Collaboration

Project Integration:
- Strong participation within the AHRTI FRS
- Participation in conference presentations and academic publications
- Organize industry workshops
- Hold meetings with key industry partners and sign NDAs to streamline information sharing

Partners, Subcontractors, and Collaborators:
- Convergent Science: provide CFD modeling platform and support
- AHRTI FRS: provide technical guidance
- Daikin, UTC/UTRC: provide historic knowledge and supporting material for current flammable refrigerant charge limits

Communications:
- Industry workshop, October 2016, Atlanta, Ga
- AHRTI FRS in person meeting, December 6th, Arlington, VA
- Seminar 64, ASHRAE winter meeting, Las Vegas, NV, 2/1/2017

Next Steps and Future Plans

- CFD simulations for ORNL FRP-1 Building with RTU:
  - Refrigerant: R32
  - Charge =14.4 kg
  - Simulation time= 42 seconds
  - Leak diameter= 3/8" (catastrophic leak)
  - Cd=0.8 (NOTE: Cd → discharge coefficient)
  - Pin = Pat + 75 Pa, Pout = Pat Pa
- Experimental validation for the CFD studies.
  - Contacted Dr. Ali Rangwala, Department of Fire Protection Engineering, Worcester Polytechnic Institute, Worcester, MA
  - Will perform analysis in a scaled down ISO room using R-32 (no-combustion)
  - Designed a test matrix to change refrigerant charge, leak source location, leak direction, mitigation strategy, and different indoor blocks

REFERENCE SLIDES

Project Budget

Project Budget: Started the project in July 2016 with an expected end date of September 30th 2017.
Variances: NA.
Cost to Date: 20% of the project budget has been expended to date.
Additional Funding: NA.

Budget History					
FY 2016 (past)		FY 2017 (current)		FY 2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1000k	$0	$1000k	$0	$0	$0

Project Plan and Schedule

Project Schedule												
Project Start: 7/2016		Completed Work										
Projected End: 9/2017		Active Task (in progress work)										
	◆	Milestone/Deliverable (Originally Planned)										
	◆	2										
	FY2016				FY2017							
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
Hold a workshop with key stakeholders					◆							
Current/Future Work												
Submit critical literature review on charge limit setting and previous CFD simulation related to charge limit						◆						
Finalize CFD simulations as per the design of experiment							◆					
Submit a draft for the final report								◆				

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