Performance Evaluation of Packaged Rooftop Unit at High Ambient Temperature Environments

2017 Building Technologies Office Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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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. Letter report documenting the experimental evaluation plan and the selection of the candidate refrigerants. Completed 1 month after project start.; 06/30/2016
2. Test results and report document findings on testing of 4 alternative refrigerants in R-22 RTU; 08/31/2016
3. ORNL-Published Report documenting the research work and results. Completed 9 months after project start.; 09/30/2016

Budget:

Total Project $ to Date:

- DOE: $1685k
- Cost Share: $0

Total Project $:

- DOE: $1685k
- Cost Share: $0
- → Units donated, refrigerants supplied, refrigerant manufacturers provided support (MSDS, properties, etc.)

Key Partners:

Panel of International Experts: Dr. Pat Phelan, Dr. Dr. Suely Machado Carvalho	
Dr. Radhey Agarwal, Dr. Jitendra M. Bhambure (India)	Dr. Fotouh Al-Raqom (Kuwait)
Dr. Karim Amrane (USA)	Dr. Enio Bandarra (Brazil)
Mr. Ayman El-Talouny (UNEP)	Dr. Tingxun Li (China)
Dr. Samuel Yana Motta (Peru)	Mr. Maher Mousa
Mr. Ole Nielsen (UNIDO)	Mr. Tetsuji Okada (Japan)
Dr. Alaa Olama (Egypt)	Dr. Alessandro Giuliano Peru (Italy)
Arkema	Chemours
Honeywell	Petra
SKM	

Project Outcome:

Evaluate acceptable low-GWP refrigerants for rooftop units (RTU) designed and fabricated in Middle East to operate in high ambient temperature environments.

Purpose and Objectives

Problem Statement: This project directly supports the BTO's MYPP HVAC/WH/Appliances Strategies, Current and Planned Activities, and Key Targets "Strategy 1: Near-Term Technology Improvement." It provides the industry with a unique opportunity to access unbiased science-based systematic evaluation of alternative refrigerants for considerations as replacement to R-22 and R-410A equipment in a range of operating conditions up-to extreme hot conditions experienced in the Middle East and India – two of the most expanding AC markets.

Target Market and Audience: The target market for this RTU is the U.S. Building sector and can potentially reach to international impact with a national energy market of 0.72 Quad. The target audience: HVAC&R/Appliances industry, AHRI/ASHRAE, and Codes and Standard Committees.

Impact of Project: This project provided the HVAC community with an unbiased, science-based investigation into the performance of different suggested drop-in alternative refrigerants for R-22 and R-410A units for packaged RTU. A public report was published (ORNL Technical Report) as well as several technical papers, conference seminars, and workshop presentations to disseminate the information to the community.

Purpose and Objectives

Problem Statement:

- Provide the industry with a unique opportunity to access unbiased science-based systematic evaluation of alternative refrigerants for R-22 and R-410A equipment in a range of operating conditions up-to extreme hot conditions experienced in the Middle East and India – 2 of the most expanding AC markets
- Support the BTO's MYPP HVAC/WH/Appliances Strategies, Current and Planned Activities, and Key Targets "Strategy 1: Near-Term Technology Improvement"

Target Market and Audience:

- The target market for this RTU in the U.S. Building sector with a national energy market of 0.72 Quad; It has a strong global impact
- The target audience are: HVAC&R/Appliances industry

Impact of Project: This project provided the HVAC community with an unbiased, science-based investigation into the performance of different suggested drop-in alternative refrigerants for R-22 and R-410A units for packaged RTU. A public report was published (ORNL Technical Report) as well as several technical papers, conference seminars, and workshop presentations to disseminate the information to the community. This information directly supported the consensus reached at the **Kigali** Meeting Of the Parties and the **approved amendments to the Montreal Protocol**.

Approach

This project supports the “Near-Term Technology Improvement” of the HVAC/WH/Appliances Strategies. It systematically evaluated the drop-in performance of alternative refrigerants supporting the industry needs for refrigerant solutions beyond typical HFC refrigerants.

Key Issues: Alternative refrigerants are mildly flammable (A2L), thermodynamic properties are not 100% match (need to replace the TXV with an EXV), volumetric capacity mismatch (loss or gain in capacity), refrigerant glide in multi-component refrigerants.

Distinctive Characteristics: This project involved a panel of international experts to review the research approach, refrigerant selection, and results. This Panel provided much needed guidance to ensure worldwide acceptance of results and facilitated the dissemination of the information among the Montreal Protocol Open Ended Working Group (OEWG) delegates, which resulted in significant support to the U.S. proposed amendment to the Montreal Protocol and eventual approval in Kigali.

Progress and Accomplishments

Accomplishments:

- Organized and held a workshop at the OEWG in Vienna (July 2016)
- Published final technical report (September 2016)
- Supported the Kigali amendments to the Montreal Protocol (October 2016)
- Co-organized and presented a Seminar at AHR EXPO (January 2017)
- Keynote Presentation at the 2nd International Conference on Energy and Indoor Environment for Hot Climates (February 2017)

Market Impact:

- The technical report is widely disseminated and recognized by the HVAC&R community
- Montreal Protocol Amendments have been approved in Kigali Rwanda (October 2016)

Awards/Recognition: Invited Keynote presentation, ASHRAE Distinguished Service Award

Lessons Learned: Working with flammable refrigerants required additional level of HVAC technician safety training and facility upgrades

R-22 Alternative Refrigerants

Refrigerant	Manufacturer	ASHRAE Safety Class	GWP	
			AR4	AR5
R-22[a]	-	A1	1,810	1,760
ARM-20b[b]	Arkema	A2L	251	251
ARM-20a[b] (R-457A)	Arkema	A2L	137	139
L-20a (R-444B)[b]	Honeywell	A2L	295	295
DR-7 (R-454A)[b]	Chemours	A2L	239	238

[a] Sources: IPCC AR4, 2007; IPCC AR5, 2013

[b] GWP values for refrigerant blends not included in IPCC reports are calculated as a weighted average using manufacturer-supplied compositions

R-410A Alternative Refrigerants

Refrigerant	Manufacturer	ASHRAE Safety Class	GWP	
			AR4	AR5
R-410A[a]	-	A1	2088	1924
L41-Z (R-447B)[b]	Honeywell	A2L	740	715
DR-55[b]	Chemours	A2L	698	676
ARM-71a[b]	Arkema	A2L	460	461
R-32[a]	Daikin	A2L	675	677

[a] Sources: IPCC AR4, 2007; IPCC AR5, 2013

[b] GWP values for refrigerant blends not included in IPCC reports are calculated as a weighted average using manufacturer-supplied compositions

Test Conditions

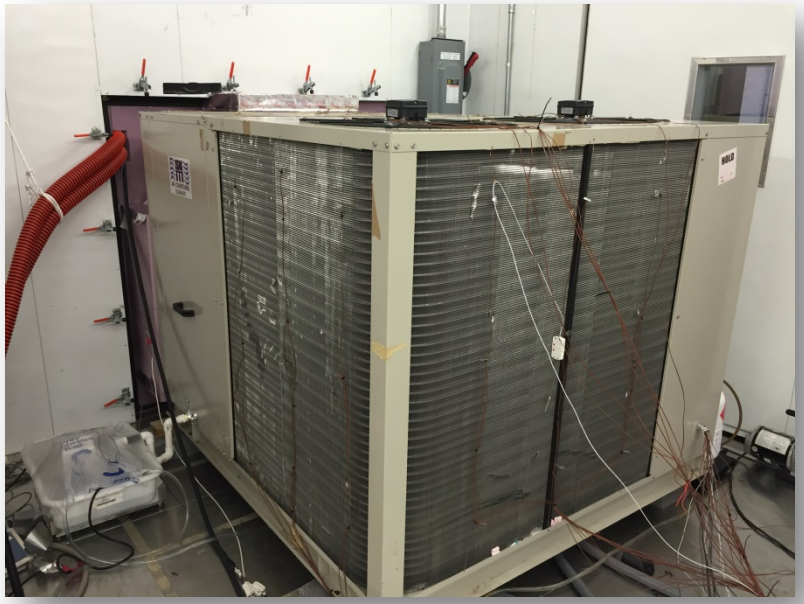
Test condition	Outdoor	Indoor		
	Dry-bulb temp.	Dry-bulb temp.	Wet-bulb temp.	Relative humidity
	°F	°F	°F	%
AHRI	95	80	67	50.9
T3	114.8	84.2	66.2	39.0
Hot	125.6	84.2	66.2	39.0
Extreme	131	84.2	66.2	39.0

RTUs

- R-22 Unit
  - SKM PACL-51095Y
  - 380/415V, 3 Ph, 50 Hz
  - Capacity* = 92.8 kBtu/h (27.2 kW)
  - EER = N/A
- R-410A Unit
  - Petra PPH4 115
  - 460V, 3 Ph, 60 Hz
  - Capacity* = 132 kBtu/h (~ 38.68 kW)
  - EER* = 10.66 (COP ~ 3.12)

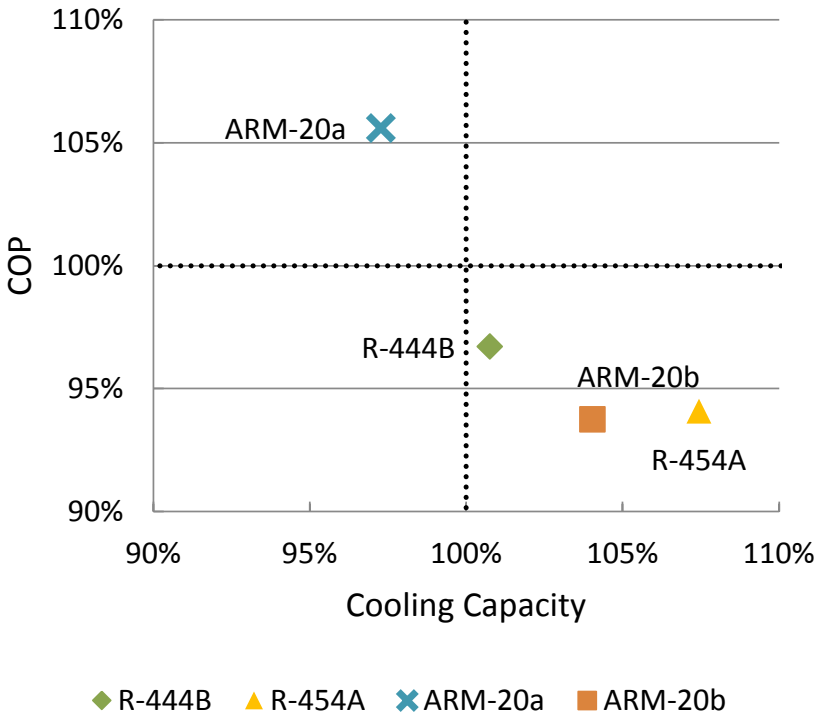
*Gross capacity at ISO 5151 T1 (Indoor DBT 27°C, WBT 19°C)

Experiment Setup (RTU)

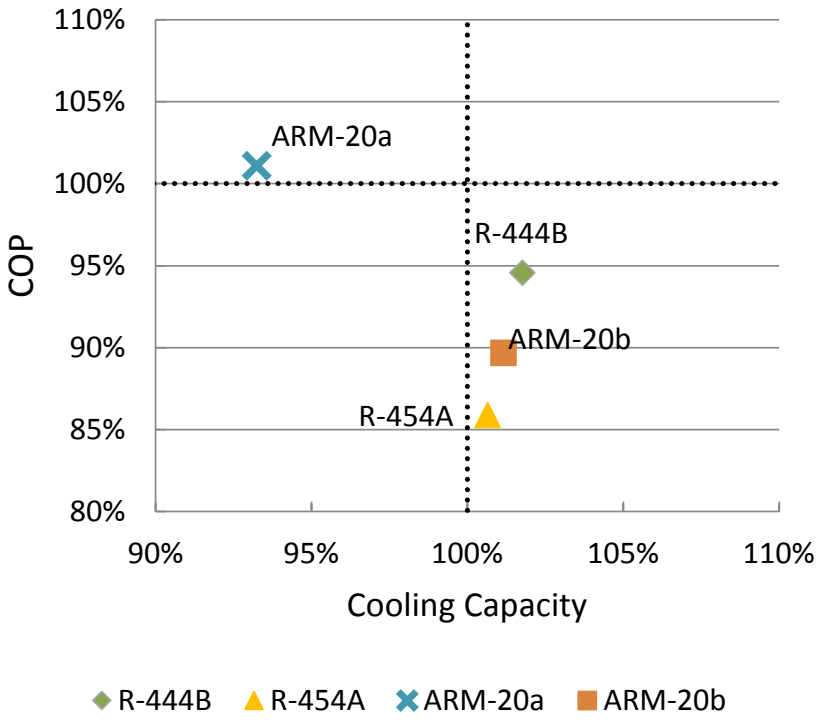


Performance Relative to R-22

AHRI Rating Conditions (R-22 RTU) – 95°F Ambient



Hot Conditions (R-22 RTU) – 125°F Ambient



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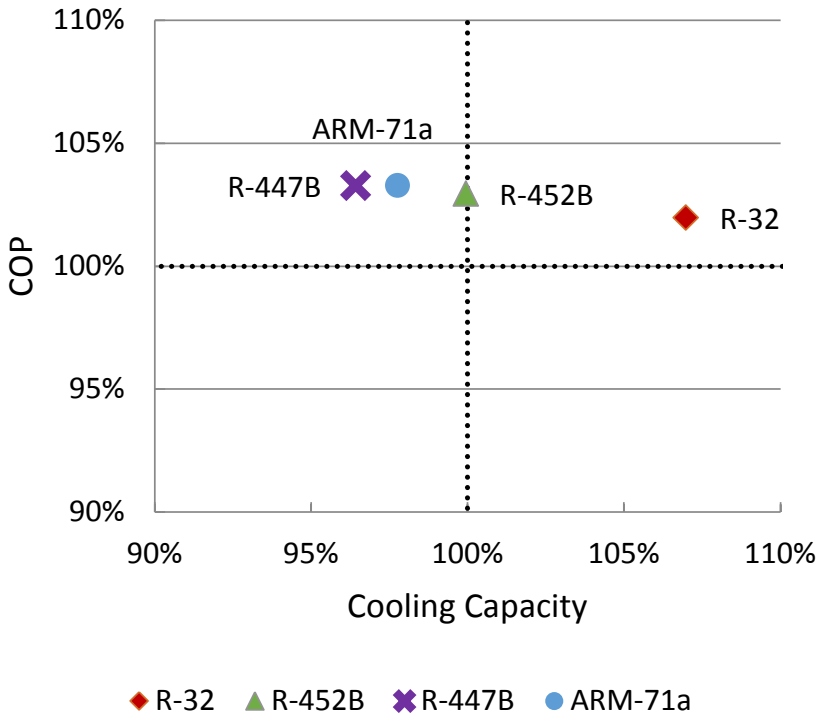
R-22 Conclusions (RTU)

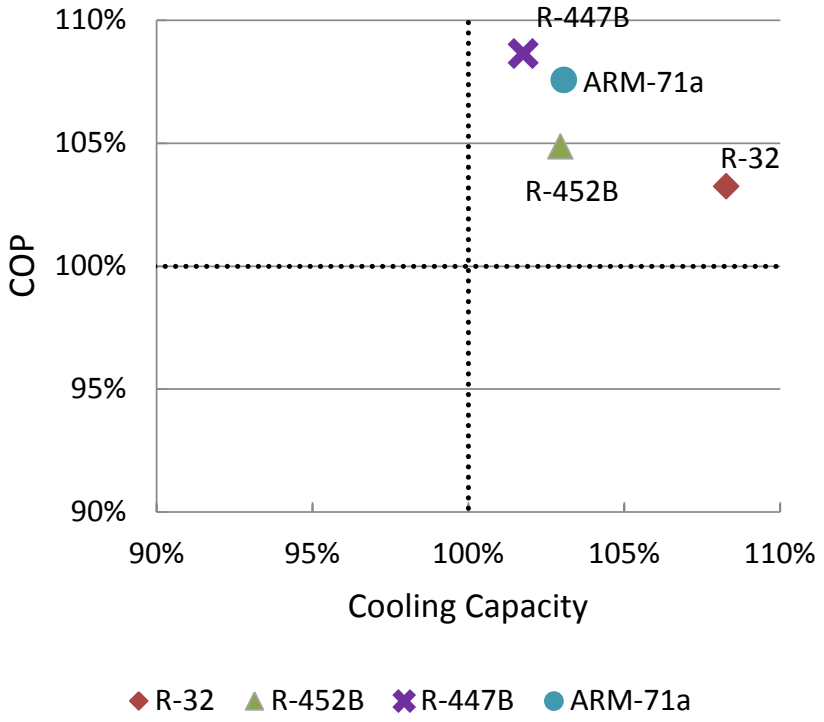
- At 95°F, ARM-20a had higher COP but lower capacity, the other three refrigerants showed almost equal or higher cooling capacity, but lower COPs
- Higher the ambient temperature, lower the relative COP
- Lower compressor discharge temperature

Performance Relative to R-410A

AHRI Rating Conditions (RTU) – 95°F Ambient



Hot Conditions (RTU) – 125°F Ambient



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R-410 Conclusions (RTU)

- At 95°F, all four low GWP refrigerants had higher COPs; DR-55 and R-32 had equal or higher capacities
- Higher the ambient temperature, higher the relative COPs and capacities; but R-32's COP degraded at 131°F ambient
- Higher compressor discharge temperature for all alternatives and is most significant for R-32

Project Integration and Collaboration

Integration:

- Panel of International Experts
- Organizing workshops and seminars
- Presenting at conferences and professional societies

Partners, Subcontractors, and Collaborators:

- Refrigerant manufacturers provided sample refrigerant, refrigerant properties data, and guidance: Arkema, Chemours, Honeywell
- Middle East Packaged AC unit manufacturers provided samples designed for operation in hot climates: Petra, S.K.M.
- Navigant Consulting provided support in data analysis and reporting

Communications:

- Workshop at the Montreal Protocol OEWG – Vienna, July 2016
- Seminar at AHR EXPO – Las Vegas, January 2017
- Keynote, 2nd International Conference on Energy and Indoor Environment for Hot Climates – Doha, Qatar, February 2017

Next Steps and Future Plans

- Optimize the design of RTU for most relevant refrigerant
- Develop optimized window AC unit based on alternative flammable refrigerants

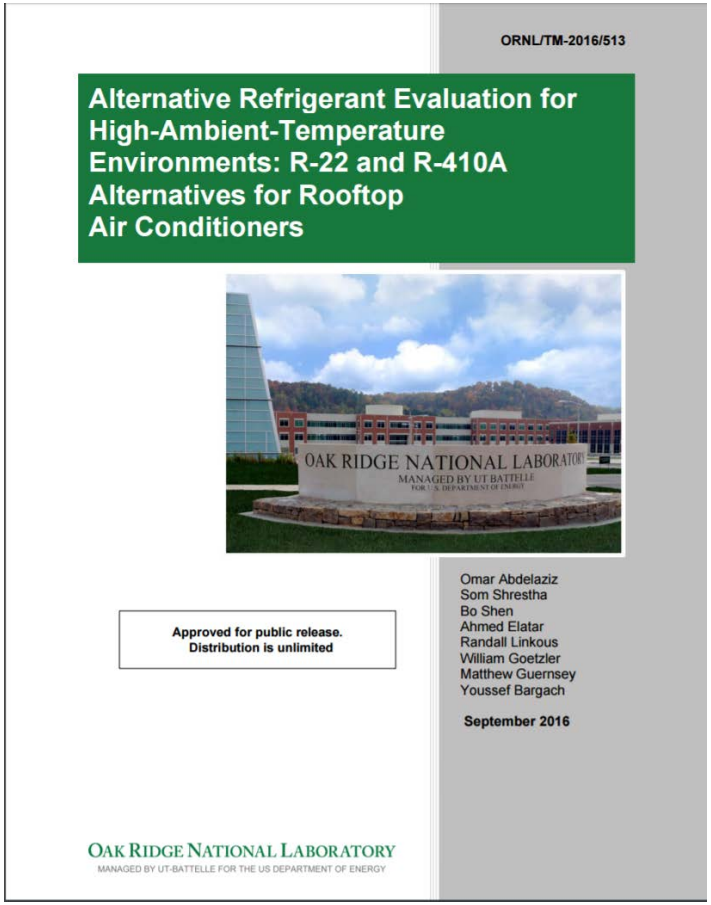
Potential follow-on activities:

- Work with OEM and suppliers to improve system performance with alternative refrigerants (e.g. solving compressor problems with R-32)
- Analyze flammable refrigerant risks and develop proper mitigation strategies

REFERENCE SLIDES

Full Report Available

- ORNL Technical Report 2016/513 available at: http://info.ornl.gov/sites/publications/Files/Pub69980.pdf



Project Budget

Project Budget: This project started in FY16. It is a follow-on project to the project "Performance Evaluation of Alternative Refrigerants in Mini-Split AC units for High Ambient Temperature Environments." The starting budget was $458.5 of FY15 money and $938.4k in FY16. Additional activities in FY17 include finalizing information dissemination (conference attendance and publications) and developing a CRADA on the development of window AC unit using alternative refrigerants.
Variances: NA
Cost to Date: 85% 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
$1396.9k	$0	$288.5k	$0	$0	$0

Project Plan and Schedule

2016

- Early February to Mid-March: Procure RTUs
- Mid-March to Mid-April: Install and Instrument RTUs
- Mid-April to Mid-July: Evaluate Baseline and Alternative Refrigerants
- Mid-July: Meeting on Margins of Open-Ended Working Group in Vienna to Discuss Results and Conclusions (July 18-21)
- Mid-August: Review Final Report
- Early September: Publish Final Report

2017

- Presentation at AHR EXPO: Las Vegas, January 31
- Keynote at ASHRAE Second International Conference on Energy and Indoor Environment for Hot Climates, Doha, Qatar, February 27