IEA Annex 54 Update –
Low GWP Refrigerants in Residential AC

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Yunho Hwang, Lei Gao

Center for Environmental Energy Engineering
Department of Mechanical Engineering
University of Maryland
College Park, MD 20742-3035

Energy Efficiency and Heat Pumps Consortium

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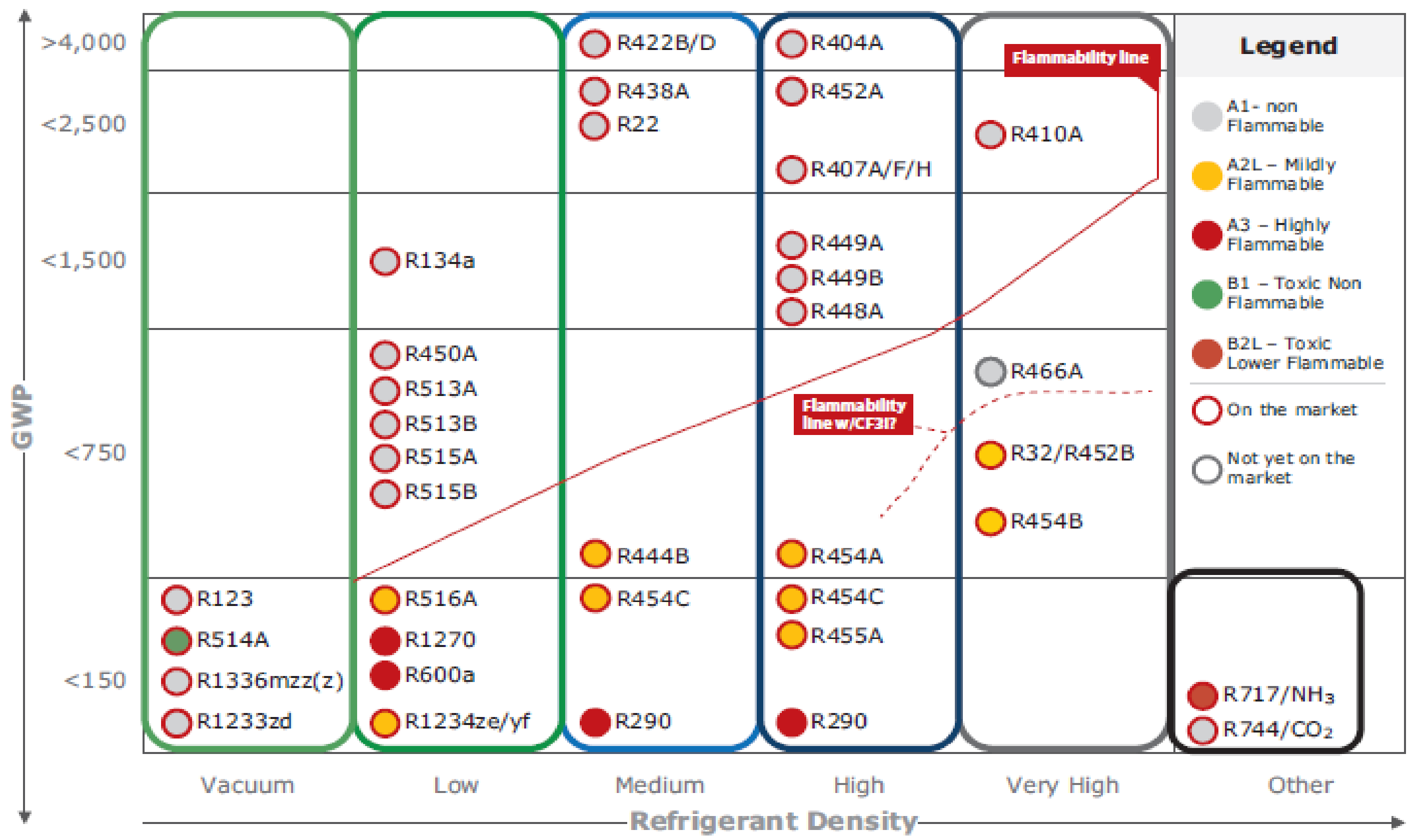
Country Report: US

- Ensure Safe Use of Flammable Refrigerant
- Recent Development of Alternative Refrigerant
- Standard and Policy for HP System
- R-516A for Heat Pump Systems
- Unitary AC System
- Energetics/ORNL HP Research Project
- Saturation HP System Analysis
- Refrigerant HX Shape Topology Optimization
- LCCP review for AC system

- **Task1: Review of State of the Art Technologies**

Recent Development of Alternative Refrigerant

- **R466A, R32, R452B / R454B and R290 remain the top replacements of R410A for now, considering balances among the GWP, performances and property similarities.**



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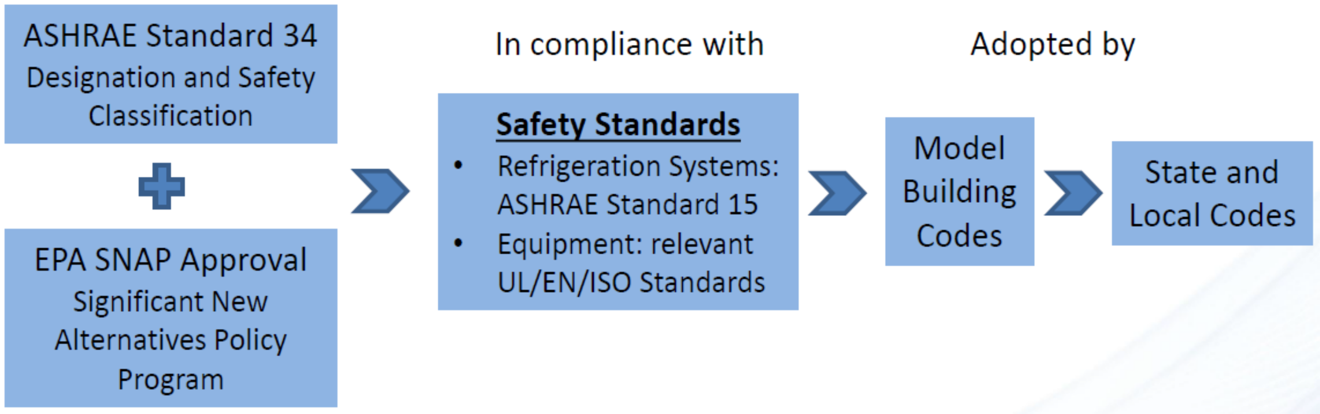
Launched High-Priority Low-GWP Projects in the USA

Projects	Funding Organization	Project Description	Status
AHRTI-9007-01: Benchmarking Risk by Whole Room Scale Leaks and Ignitions Testing of A2L Refrigerants	AHRI	A2L refrigerants leak and ignition testing under whole room scale conditions was conducted to develop data and insight into the risks associated with the use of A2L refrigerants versus A1 refrigerants while considering ambient conditions (temperature and humidity) and refrigerant lubricants.	Completed
AHRTI-9007-02: Benchmarking Risk by Whole Room Scale Leaks and Ignitions Testing of A3 Refrigerant	CARB	This project is to conduct A3 refrigerant leaks and ignitions testing under whole room scale conditions, understand the risk associated with the use of A3 refrigerants, and provide test data to support future revisions of relevant safety standards associated with using A3 refrigerants.	Completed
AHRTI-9008: Investigation of Hot Surface Ignition Temperature for A2L Refrigerants	AHRI	The objective of this work is to develop a test methodology to assist in the evaluation of the propensity of A2L refrigerants (R32, R1234ze, and R452B) to ignite on hot surfaces, and to carry out testing per the new test methodology.	Completed
AHRTI-9009: Leak Detection of A2L Refrigerants in HVACR Equipment	AHRI	A thorough review of sensor technologies was conducted to evaluate available technologies that can be used to meet safety standards requirements of detecting A2L refrigerants and easily integrated into air-conditioning and refrigeration equipment. Infrared (IR) and Metal Oxide Semiconductor (MOS) sensors were found to be the most promising sensor technologies.	Completed
AHRTI-9014: Assess Refrigerant Detector Characteristics for Use in HVACR Equipment	AHRI	The objective of the project is to assess refrigerant sensor and refrigerant detector performance requirements for class 2L, 2, 3 flammable refrigerants for use with indoor HVACR equipment, whether in an occupied space or a machinery room.	Completed
AHRTI-9015: Assessment of Refrigerant Leakage Mitigation Effectiveness for Air-Conditioning and Refrigeration Equipment	AHRI	The objective of this project is to demonstrate the efficacy of refrigerant leakage mitigation strategies contained within residential split-systems, packaged air-conditioning equipment and commercial refrigeration products.	Completed
ASHRAE-1806: Flammable Refrigerants Post-Ignition Risk Assessment	ASHRAE	The objective of this project is to understand the Severity of events where flammable refrigerants are ignited under different scenarios for various HVAC&R products.	Ongoing
ASHRAE-1807: Guidelines for flammable refrigerant handling, transporting, storing and equipment servicing and installation	ASHRAE	This project accessed flammable refrigerant safety guidelines and/or requirements that exist domestically and internationally. The assessment will be used to propose requirements/guidelines for the safe handling, storing and transporting of flammable refrigerants	Completed
ASHRAE-1808: Servicing and Installing Equipment Using Flammable Refrigerants: Assessment of Field-made Mechanical Joints	ASHRAE	This project tested the leak-tightness of various types of field-made joints used to connect refrigerant piping and system components in HVAC&R equipment. The results of this project provided necessary data to suggest whether or not common types of joints, other than brazed or soldered joints, should be permissible for use in equipment containing flammable refrigerants.	Completed
ASHRAE-1855: Determination of the Impact of Combustion byproducts on the Safe Use of Flammable Fluorinated Refrigerants	ASHRAE	The overall objective of the project is to understand the HF and COF2 exposure risk if ignitions of flammable halogenated refrigerants occur and how to clean up following a variety of ignition events, as well as to identify knowledge gaps.	Ongoing
ORNL: Determination of setting charge limits for various types of equipment employing flammable refrigerants	DOE	The primary objective of the project is to examine the currently imposed limits for flammable refrigerant alternatives (A2L, A2, and A3) and identify reasonable adjustments to these limits as appropriate.	Completed
ORNL: Experimental Evaluation of Refrigerant Leak Characteristics for Different HVAC&R Equipment Types	DOE	The objective of the project was to quantify actual leak rates and duration for various pieces of equipment by conducting refrigerant leak tests under operating conditions representative of actual applications.	Completed
NIST: Modeling Tools for Flammability Ranking of Low-GWP Refrigerant Blends	DOE	The project is to develop modeling tools that can predict the burning velocity of arbitrary mixtures of R32, R125, R134a, R152a, 1234yf, and 1234ze(E), so that flammability of a blend can be minimized, while simultaneously maximizing performance related to other parameters.	ongoing

Standard and Policy for Low GWP Refrigerants

- **Refrigerants**
  - **ASHRAE Standard 34: refrigerant classification**
  - **EPA SNAP: identify acceptable substitutes (environment aspect)**
- **System**
  - **ASHRAE 15: refrigerant system safety (subcommittee 15.2 for flammable refrigerants)**
  - **UL → IEC: safety of household appliances**
- **Building & Local Codes**

Code Adoption Process



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Energetics/ORNL HP Research Project

- **Summary of alternative refrigerants that meet GWP, COP, and volumetric capacity requirements**

Traditional Refrigerant	Application	Short-Term Alternatives	Long-Term Alternatives	Meets or Exceeds Baseline COP (99.9%+)	Acceptable Volumetric Capacity (>= 90% of Baseline)
R-123	Chillers	R-1224yd(Z)	R-1233zd(E)	N/A	R-1233zd(E), R-1224yd(Z)
R-245fa	Heat Pumps			R-1233zd(E), R-1234ze(Z)	R-1234ze(Z)
R-134a	Chillers, W2W, A2W	R-1234ze(E), R-1234y, R-513A, R-456A, R-450A	R-516A, R-515B, R-444A	R-1234ze(E), R-450A, R-515B	R-1234yf, R-444A, R-456A, R-513A, R-516A
	Mobile Air Conditioning			N/A	
	Heat Pumps				
R-404A	Heat Pumps	R-448A, R449A, R449C, R-452A, R454C	R-454A, R-454C, R-455A, R-457A, R-457B, R-465A	R-448A, R-449A, R-449C, R-452A, R-454C, R-455A, R-457A, R-457B (mid- and high-temp only)	All Alternatives
R-410A	Heat Pumps	R-32	R-452B, R-454B, R-466A	R-32, R-452B, R-454A, R-454B, R-454C, R-466A (air-to-air and water-to-air only), R-468C	R-32, R-452B, R-454B, R-463A, R-466A, R-468C (air-to-air and water-to-air only)
	Air Conditioning	R-32, R-463A	R-452B, R-454B, R-466A, R-468C	R-32, R-452B, R-454A, R-454B, R-454C, R-466A (excluding water-to-air), R-468C	R-32, R-452B, R-454B, R-463A, R-466A, R-468C

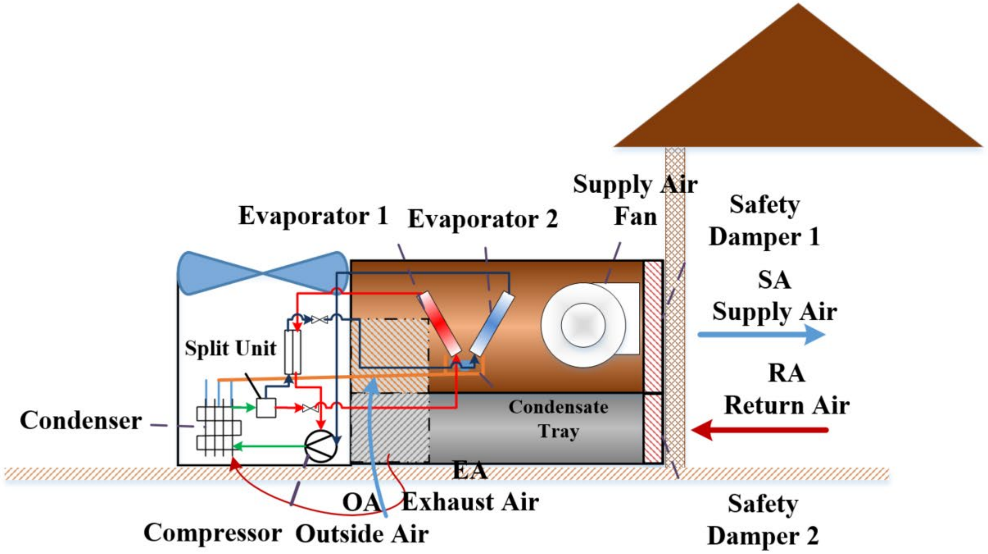
[1] Short-term alternative refrigerants are defined as those which are currently available and are being offered by at least one commercial provider.
[2] Long-term alternative refrigerants are defined as those which are listed in ASHRAE 34 and have the potential to replace the baseline refrigerant with similar performance but have not yet been commercialized.

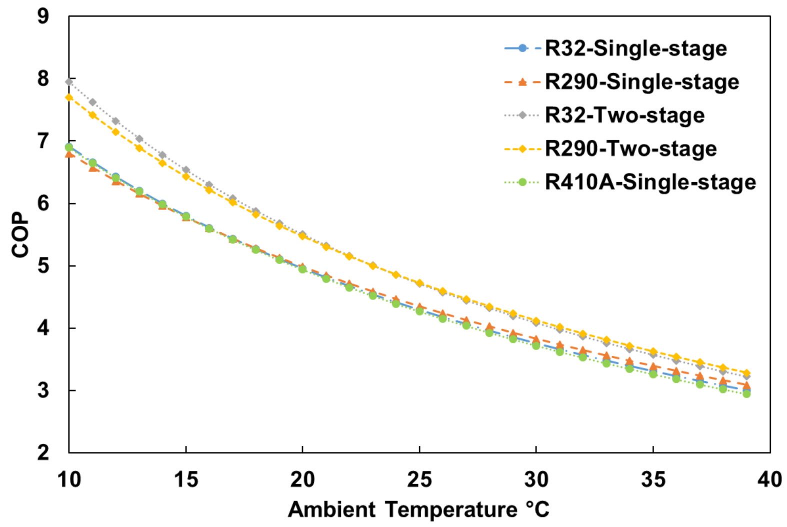
- **Task2: Case Studies and Design Guidelines**

Unitary System Design

- **Propose a novel design, enabling safe flammable refrigerant usage while ensuring performance advantages over R410A**

System Schematic



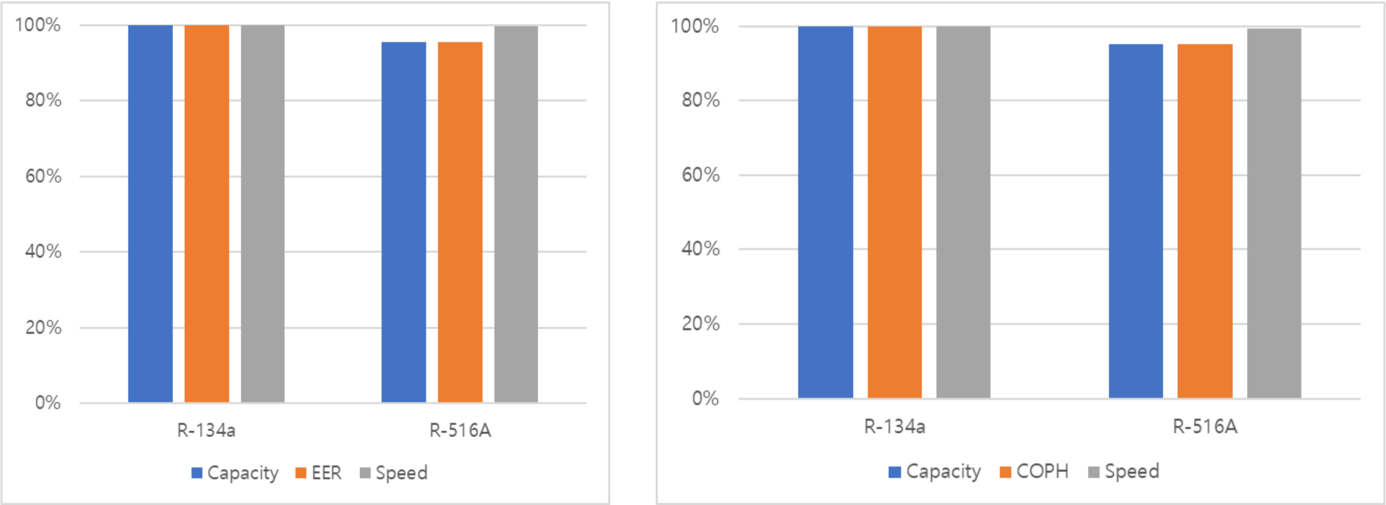


COP Comparison vs. Ambient Temperature (Top); Performance Comparison in Different Climates (Bottom)

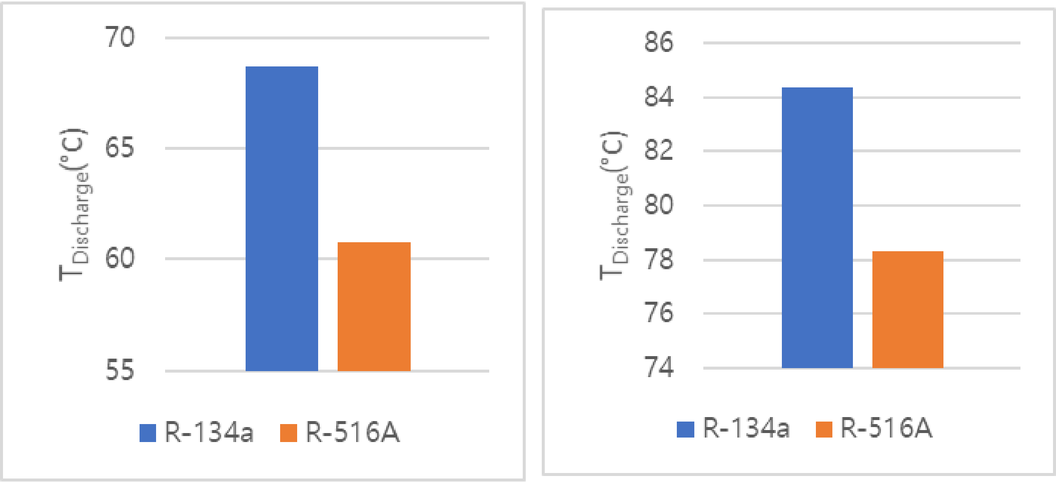
City	Refrigerant	Single stage cycle without economizer	Single stage cycle with economizer	Two-stage cycle with economizer	Changes (UP%)	Energy savings (%)
Baltimore	R290	4.84	5.79	6.31	31	23
	R32	4.80	5.72	6.31		
Miami	R290	4.09	4.11	4.45	7	8
	R32	4.02	4.04	4.42		
Houston	R290	4.25	4.66	5.05	20	16
	R32	4.19	4.59	5.03		
Chicago	R290	5.14	6.78	7.41	45	31
	R32	5.12	6.71	7.42		

R-516A for Heat Pump Systems

- **Performance evaluation**



Cooling & heating modes compressor performance



Cooling and heating mode discharge temperatures

- R-516A showed comparable performance to R-134a both in cooling and heating mode while providing a 90% reduction in direct emission.
- The heating performance of R-516A was closer to R-134a than in cooling mode.
- Similar stability, compatibility, and oil miscibility of R-516A to R-134a

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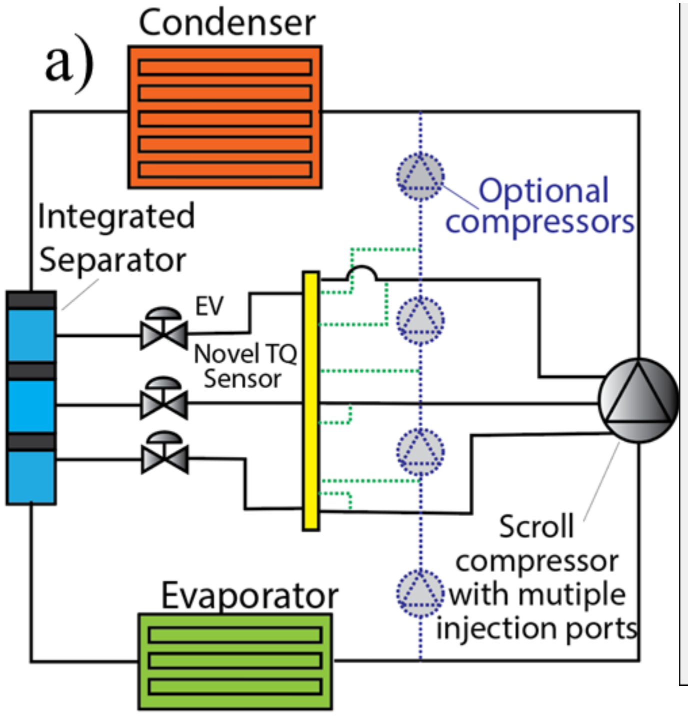
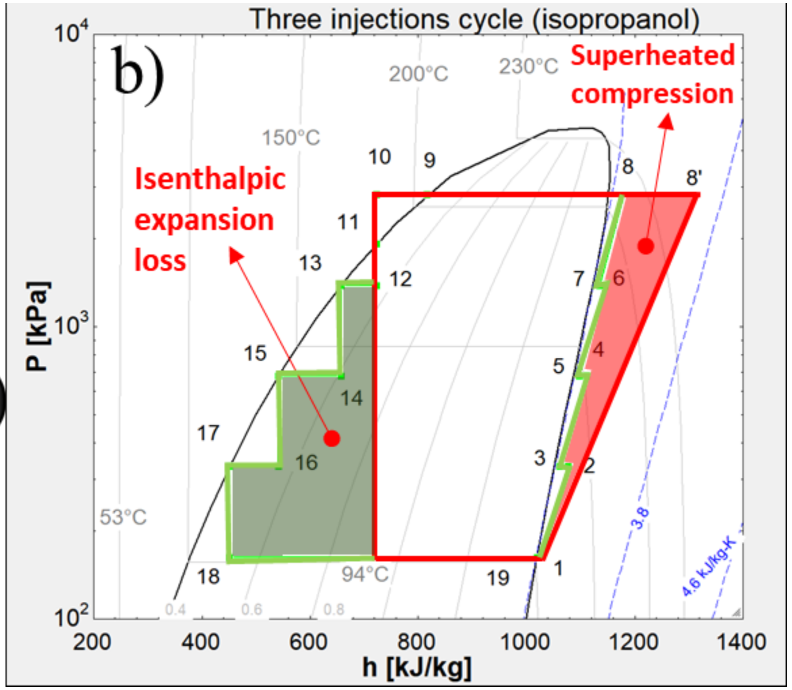
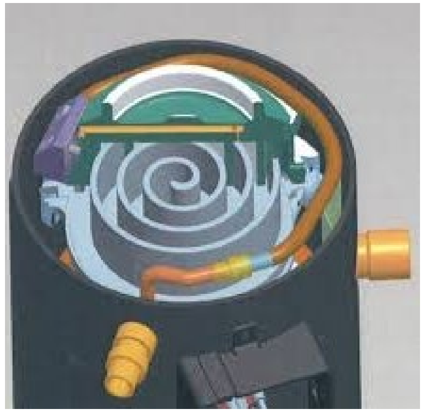
Saturation Heat Pump System

- **Develop a saturation high-temperature heat pump (SHTHP) system to provide a heat sink temperature of 200°C while achieving as high as 67% of Carnot efficiency by adopting a novel multi-stage injection saturation and low-GWP refrigerant (GWP<150).**





Schematic diagram of the proposed saturation heat pumps



Multi-injection Compressors

Novel Cast Aluminum Cerium Heat Exchanger

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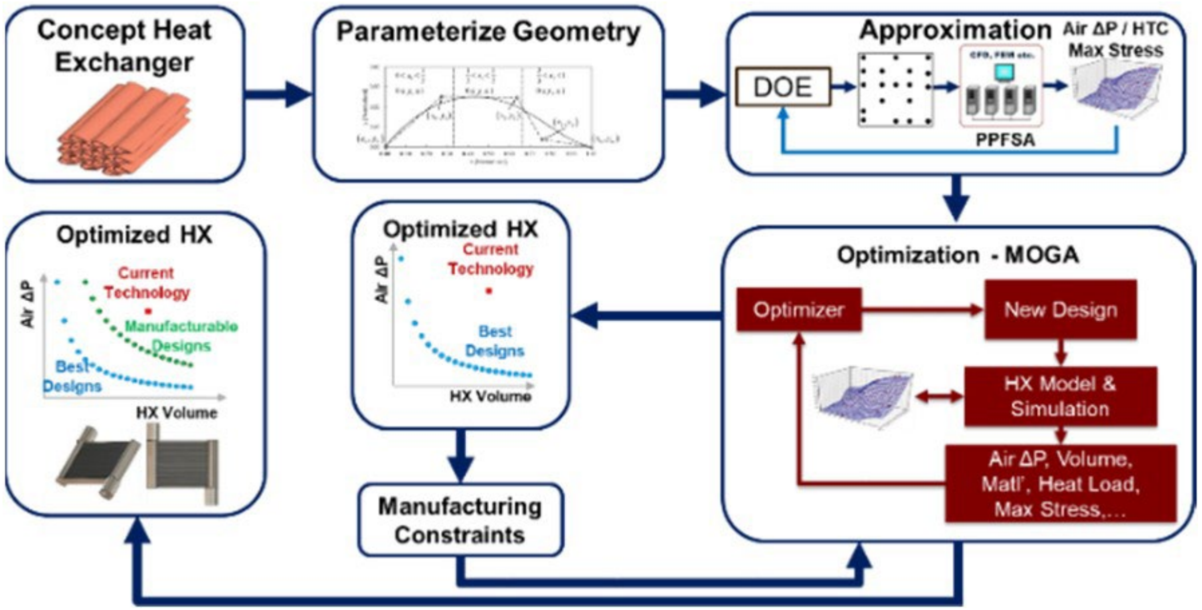
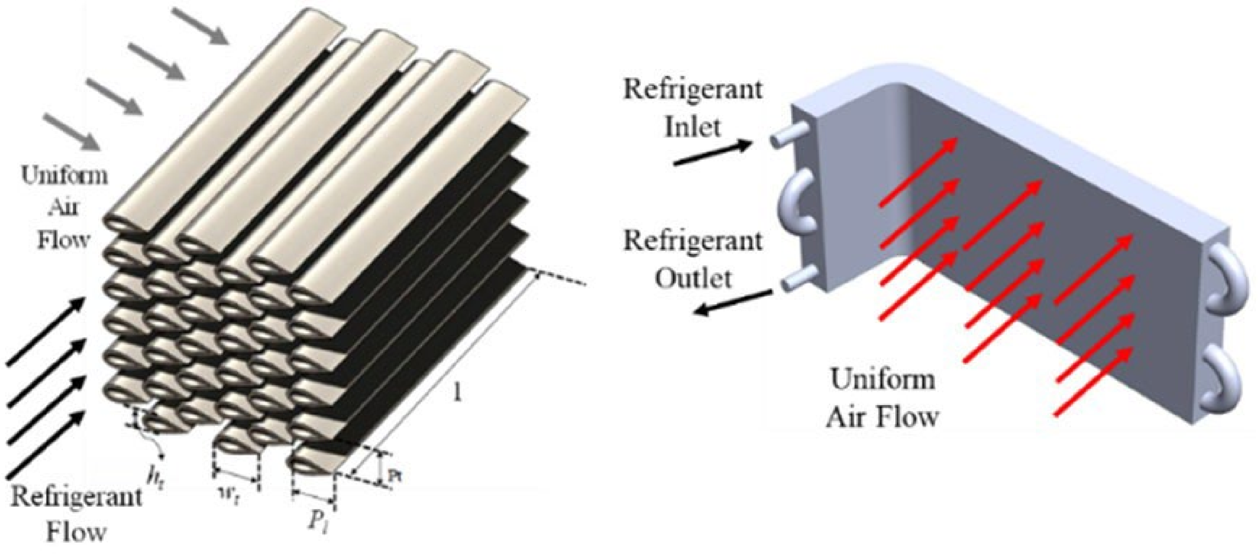
Air to Refrigerant HX Shape Topology Optimization



Numerical optimization framework



L: Generic HX with shape-optimized tubes;
R: Generic multi-pass tube-fin condenser

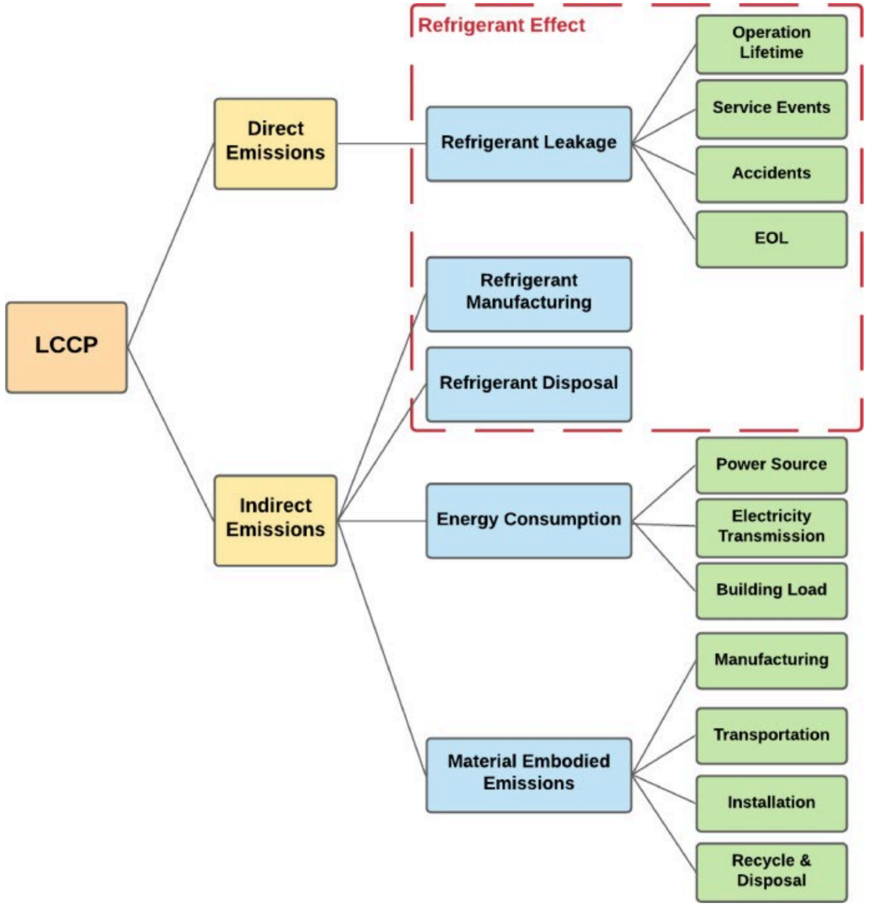
Air to Refrigerant HX Shape Topology Optimization

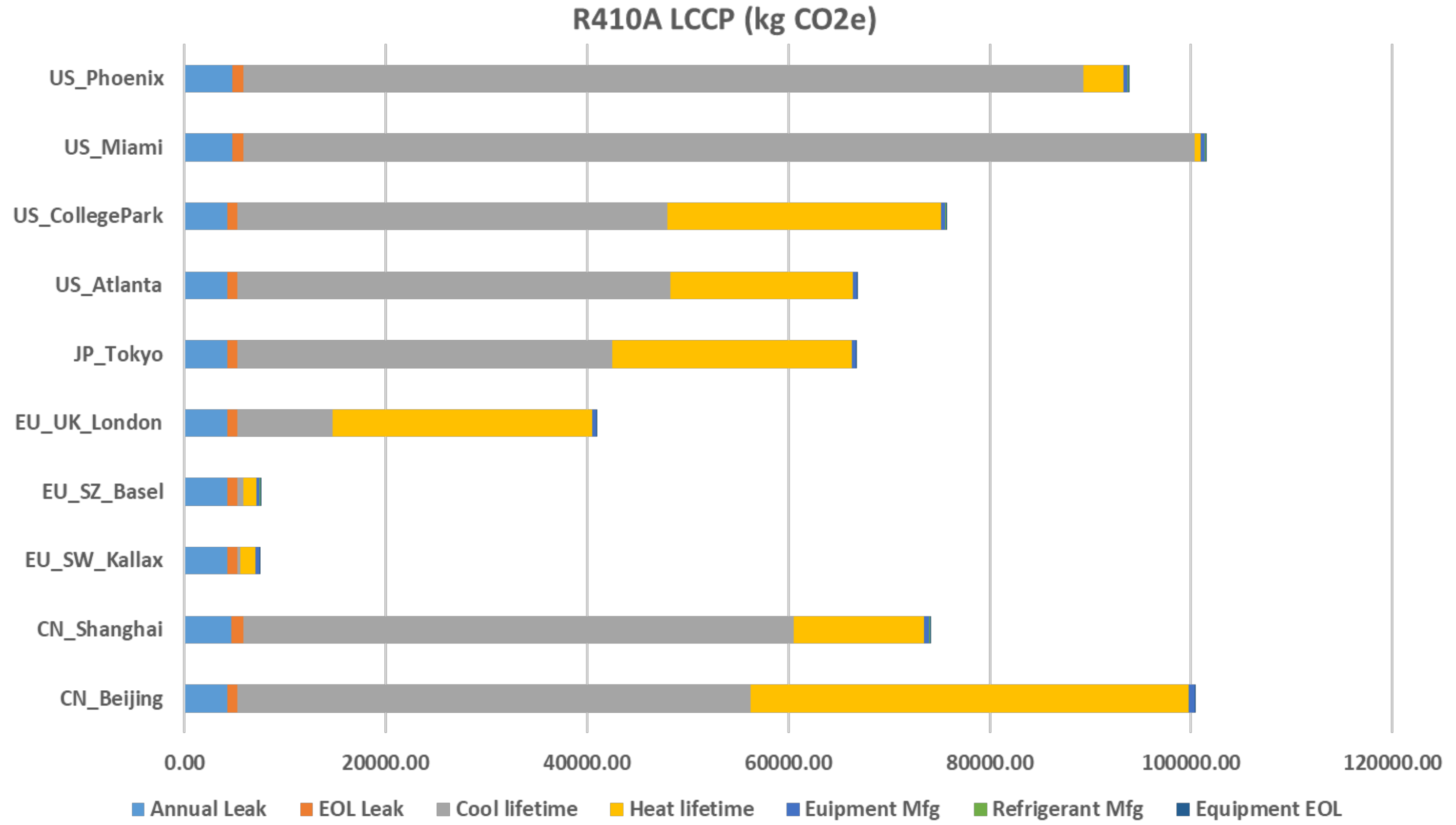
- **Summary of completed HX optimization studies**

Reference	Optimization Study	Application	Tube Shape	Air ΔP	Core Envelope Volume	Face Area	Core Internal Volume
Tancabel et al.	R410A Condenser (A)	Nom. 5.28 kW A/C system	NTHX1	43%↓	47%↓	31%↓	31%↓
	R410A Condenser (B)	Nom. 5.28 kW A/C system	Variable	46%↓	90%↓	27%↓	83%↓
Tancabel et al.	R410A Condenser (C)	Nom. 5.28 kW A/C system	NTHX1	62%↓	53%↓	34%↓	43%↓
Internal Study (A)	R410A Evaporator	Nom. 5.28 kW A/C system	NTHX1	82%↓	68%↓	16%↓	70%↓
Internal Study (B)	R410A Indoor Unit HX (A)	Dual-mode heat pump	NTHX1	62%↓	N/A	40%↓	N/A
	R410A Indoor Unit HX (B)	Dual-mode heat pump	Variable	77%↓	N/A	37%↓	N/A
Tancabel et al.	R32 Condenser	Nom. 5.28 kW A/C system	NTHX1	47%↓	57%↓	50%↓	44%↓
	R454B Condenser	Nom. 5.28 kW A/C system	NTHX1	63%↓	47%↓	34%↓	41%↓
Tancabel et al.	R290 Condenser	Nom. 2.4 kW A/C system	NTHX1	43%↓	69%↓	14%↓	49%↓
Tancabel et al.	sCO2 Gas Cooler (A)	FTHX Baseline	Variable	N/A	74%↓	7%↓	74%↓
	sCO2 Gas Cooler (B)	MCHX Baseline	Variable	79%↓	85%↓	133%↑	73%↓

- **Task3: Review of Design Optimization and Advancement Impacts on LCCP Reduction**

LCCP review for AC system





LCCP for Basel and Kallax are very small. The reason is that the power factors of Sweden and Switzerland are very small. Only for the two regions the annual leakage is the major factor of the LCCP. For all other regions, the annual energy consumption is the main factor for the LCCP.

Highlight for LCCP Review

- **Conclusions:**
  - Major Factors: Annual energy consumption and refrigerant leakage are primary contributors to LCCP. In high-GEF countries, system efficiency is crucial, while in low-GEF countries, leakage plays a significant role.
  - Weather Data Discrepancies: The Urban Heat Island (UHI) effect can cause notable differences in LCCP calculations. Accurate local weather data is essential for reliable assessments.
  - Low-GWP Refrigerants: While effective in reducing emissions, their performance varies by region. R-290 shows the most promise in reducing LCCP, particularly in low-GEF countries.
- **Future Work:**
  - Additional Refrigerants: Expanding evaluations to include new refrigerants like R-466A.
  - More Regions: Increasing the number of regional comparisons to provide a comprehensive global perspective.
  - Cost Relationship: Studying the relationship between LCCP and cost to optimize performance based on economic considerations.

Task 4: Outlook for 2030

- **Research Directions:**
  - Comprehensive Evaluations: Focus on R-466A and other potential A1 refrigerants. These refrigerants offer the potential for high performance with low environmental impact but require thorough evaluation.
  - Safety Research: In-depth studies on A2L and A3 refrigerants are necessary to address safety challenges and ensure their safe adoption in various applications.
  - Beyond Low-GWP Refrigerants: Exploration of zero or near-zero GWP refrigerants and innovative system designs to achieve the ultimate goal of minimal environmental impact.
- **Regulatory Trends:**
  - Increased Adoption: Efforts in the US, Europe, and China continue to promote the use of low-GWP refrigerants. Regulatory bodies are updating standards and policies to support this transition.
  - Standards and Policies: Ongoing updates to safety standards, such as ASHRAE 15 and UL 60335-2-40, are critical for facilitating the safe and effective use of low-GWP refrigerants.
- **Technological Advancements:**
  - Innovative Systems: Development of new system configurations and refrigerant blends will drive future advancements. These innovations aim to enhance efficiency and reduce environmental impact.
  - Optimization Techniques: Advanced methodologies for optimizing component performance and system efficiency are essential for achieving sustainability goals.