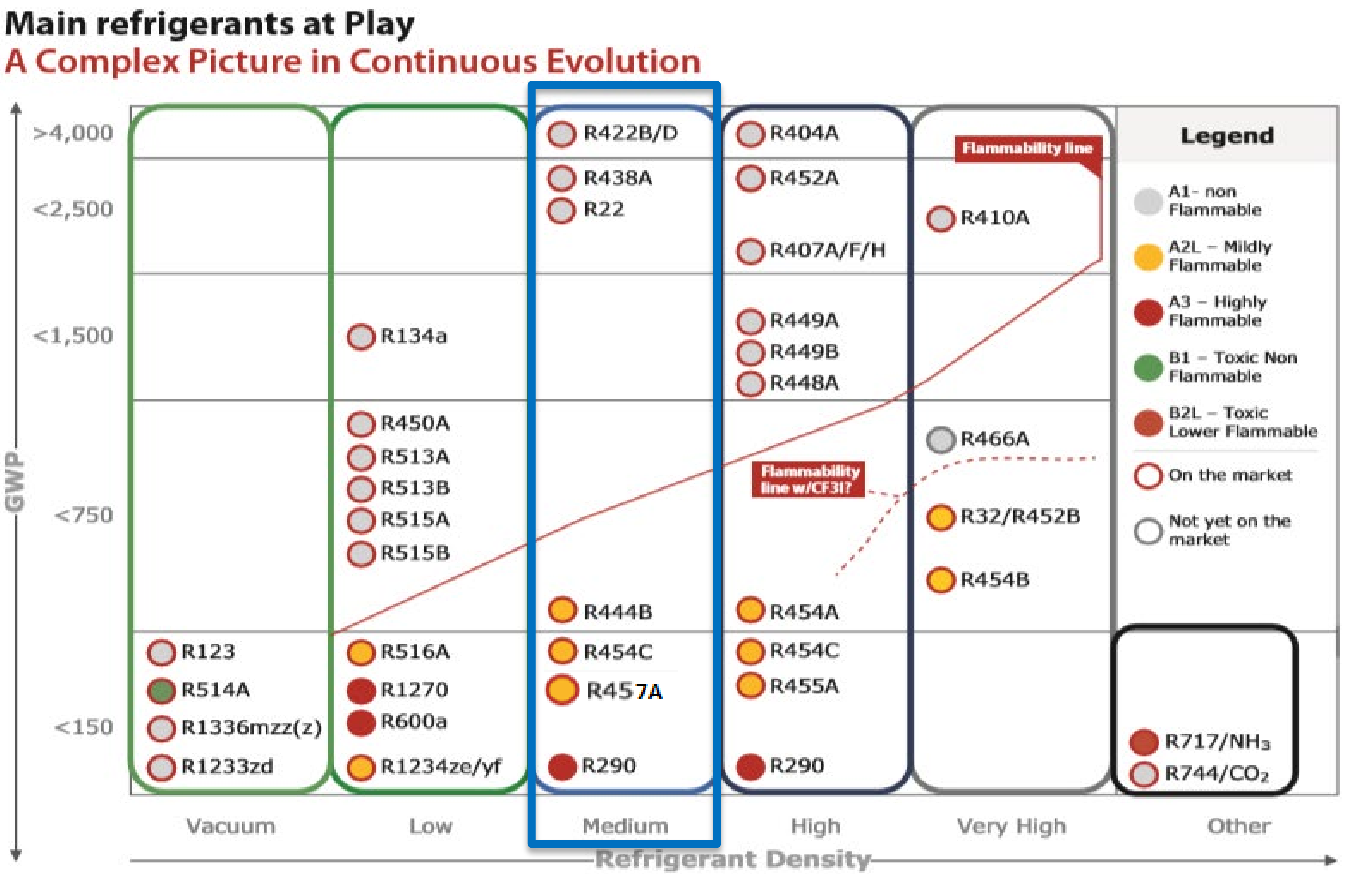
Direct Expansion Heat Pump for GWP <150



GWP versus Density (pressure) of the main refrigerant groups

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Reference: https://www.danfoss.com/media/7174/low-gwp-whitepaper.pdf

Project Summary

Timeline:

Start date: 10/01/2020

Planned end date: 09/30/2022

Key Milestones

1. Perform life cycle climate performance analysis, select candidate refrigerants, 12/30/2020
2. Model-based design optimization to achieve the performance goals (16.0 SEER/9.5 HSPF), 3/30/2021
3. Develop multi-stage compressor and flow control devices, 6/30/2021
4. Construct laboratory prototype to be ready for field tests, 9/30/2021

Budget:

Total Project $ to Date:

- DOE: $300k
- Cost Share: $300k

Total Project $:

- DOE: $600k
- Cost Share: $600k

Key Partners:

Emerson Commercial and Residential Solutions (the Helix center) - CRADA partner

EMERSON

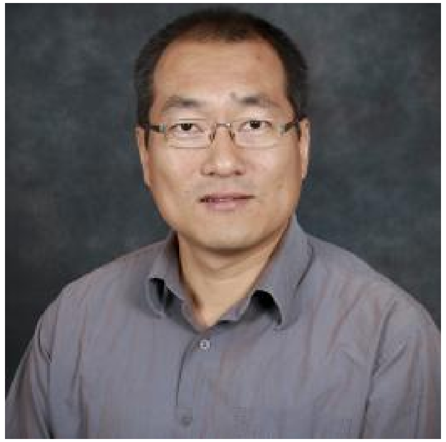
Super Radiator Coils – Supplier

SUPER RADIATOR COILS

Project Outcome:

- Develop low cost, direct expansion heat pump using long term refrigerants with GWP < 150 and suit mainstream building and equipment structure.
- Optimize both cooling and heating performances.
- Achieve seasonal cooling performance of SEER (season energy efficiency ratio) > 16.0.
- Achieve seasonal heating performance of HSPF (heating seasonal performance factor)> 9.5.

Team



Dr. Bo Shen (PI)
- System design
- Team Coordination

Dr. Zhenning Li
- Heat exchanger optimization
- Laboratory investigation

Drew Welch
Senior Lead HVAC Systems Engineer
- Leading development of multi-stage compressor, valves and accessories for <150 GWP refrigerant(s)

Dr. Jian Yu
Vice President of R&D at Super Radiator Coils
- Design and fabricate 5-mm multi-row coils

Challenge

- The requirements to reduce environmental impacts of heat pump systems: refrigerants with GWPs > 750 will be banned after 2023. In long-term, the industry will pursue refrigerants with GWP < 150
- Most low-GWP mixtures are flammable, new heat pump designs must reduce refrigerant charge and avoid explosion risk
- Low-GWP mixtures have high temperature glide. Switching from cooling mode to heating mode makes the counter-flow HX as parallel-flow, thus, induces performance degradation
- New heat exchanger designs and new flow control devices (i.e., valves) are needed to guarantee desirable performance of heat pump under cooling and heating modes
- The new low-GWP heat pumps must accommodate the current manufacturing and installation processes, and fit into current house structure
- A new design method for heat pump with low-GWP refrigerants is needed to make products cost effective and easily accepted by the end users

Approach – Model-based Design Optimization

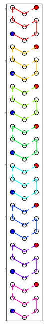
- **Innovative flow control to maintain counter flow HX configuration in both modes.**
- Optimize HX design in counter flow.

$$\text{Maximize}: \ EER$$
$$\text{Minimize}: \ HXs\ Cost$$
$$\text{Subject to}:$$
$$Heat\ exchanger\ tube\ diameter = 5\ mm$$
$$1 \le N_{circuits,evaporator} \le Ntubes\ per\ bank\ of\ evaporator$$
$$1 \le N_{circuits,condenser} \le Ntubes\ per\ bank\ of\ condenser$$
$$\Delta T_{\text{superheat, evaporator outlet}} = 10 - \frac{\Delta T_{glide}}{2}\ [R]$$
$$2\ [R] \le \Delta T_{\text{subcooling, condenser outlet}} \le 15\ [R]$$
$$Q_{evaporator} = 16.1\ kW$$
$$|\ SHR_{evaporator} - SHR_{baseline,evaporator}\ | \le 1\%$$
$$Height_{evaporator} = Height_{baseline}$$
$$Length_{evaporator} = Length_{baseline}$$
$$Height_{condenser} = Height_{baseline}$$
$$Length_{condenser} = Length_{baseline}$$

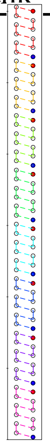
Design Space

HX	Design Variable	Unit	Baseline	Range	Variable Type
Condenser	Vertical Spacing Ratio (Pt/OD)	-	2.67	1.5-3	Continuous
	Number of Tube Banks	-	2	2-6	Discrete
	Number of Tubes Per Bank	-	48	48-144	Discrete
	Number of Circuits	-	8	1 - NTubes Per Bank	Discrete
Evaporator	Vertical Spacing Ratio (Pt/OD)	-	2.67	1.5-3	Continuous
	Number of Tube Banks	-	3	3-9	Discrete
	Number of Tubes Per Bank	-	24	24-72	Discrete
	Number of Circuits	-	8	1-NTubes Per Bank	Discrete

Fluid	GWP	Safety Class	T_{Glide} in Condenser [K]	T_{Glide} in Evaporator [K]	Critical T [C]
R-444B	295	A2L	7.6	8.9	92.11
R-454A	238	A2L	5.4	6.2	78.94
R-454C	146	A2L	6.0	6.0	82.4
R-457A	139	A2L	6.1	6.9	90.15
ARM-20B	251	A2L	5.3	6.0	88.74



Φ9.52 mm Baseline
Indoor HX
Cross flow
8 Circuits
72 Tubes
3 Bank
24 Tubes per Bank



Φ9.52 mm Baseline
Outdoor HX
Cross flow
8 Circuits
96 Tubes
2 Bank
48 Tubes per Bank

Approach – Life Cycle Climate Performance Analysis

- **A holistic CO_2 emission evaluation of the HVAC systems' life cycle[1] :**
  - The translation of direct refrigerant green house gas (GHG) emissions
  - The indirect fuel GHG emissions
  - The embodied equipment emissions
- **Institute of International Refrigeration (IIR) developed the Life Cycle Climate Performance (LCCP) evaluation[2]**
- ***LCCP=Direct emissions+Indirect emissions*[3]**
  - Direct: the emissions of the refrigerant itself during the usage phase and End of Life (EOL) phase;
  - Indirect: include emissions from energy consumption , manufacturing of materials, manufacturing of refrigerants and disposal of unit

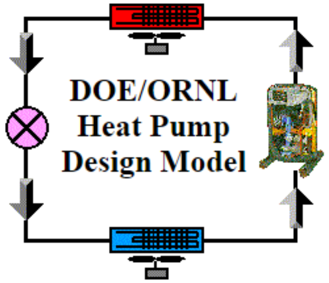
[1] Song K, Jang Y, Park M, Lee H-S, AhnJ. Energy efficiency of end-user groups for personalized HVAC control in multi-zone buildings. Energy 2020:118116.
[2] Andersen SO, Wolf J, Hwang Y, Ling J. Life-Cycle Climate Performance Metrics and Room AC Carbon Footprint. ASHRAE Journal 2018;25.
[3] Troch, S., Lee, H., Hwang, Y., & Radermacher, R. (2016). Harmonization of Life Cycle Climate Performance (LCCP) Methodology.

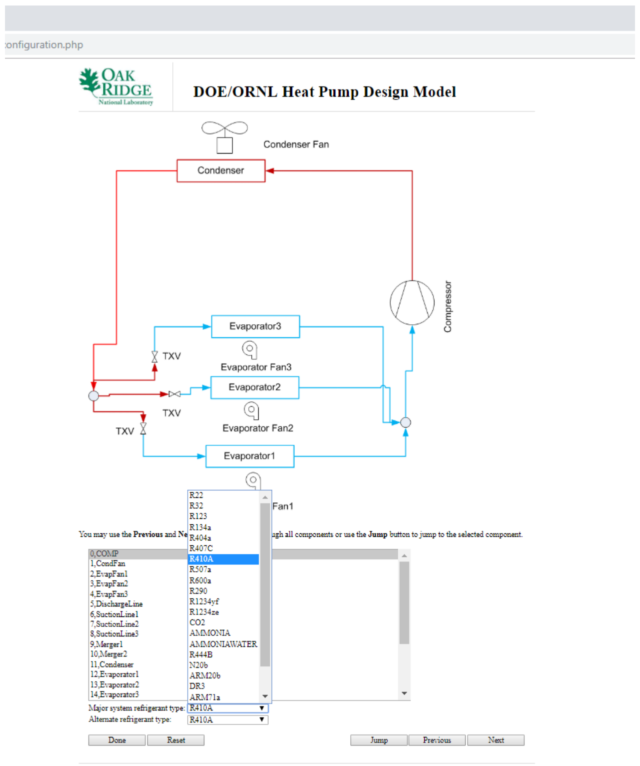
Impact

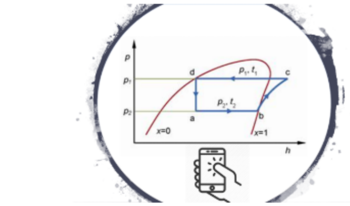
- **Deliver component technologies (new heat exchanger designs, flow control devices and compressors) and system configuration to support transition to refrigerant with high glide and GWP < 150**
- **Deliver heat pump designs with improved performance and significant charge reduction and CO_2 emission reduction**
  - high end efficiency levels in cooling modes, i.e., SEER > 16.0 (versus 14.0 Energy Star)
  - high end efficiency levels in heating modes and HSPF > 9.5 (versus 8.2 Energy Star)
- **Establish a production and installation path to produce cost-effective low-GWP heat pumps which will be easily accepted by end users**

Progress –Public-domain heat pump /coil design and optimization tools capable of HFC, HFO, natural refrigerants, etc.

The DOE/ORNL Heat Pump Design Model was upgraded to simulate all low GWP refrigerant mixtures







OAK RIDGE National Laboratory

DOE/ORNL Fingertip Fluid Properties (fProp)

Welcome to the Fingertip Fluid Properties (fProp) on the web

This website provides free fluid properties, easily accessible using your iPhone or other mobile devices, i.e. fingertips, with an INTERNET connection. It includes properties of psychrometric (air), coolant (water and glycols), refrigerants, and capacity calculation functions. It aims to support technicians and engineers to have a quick check of refrigerant, coolant and air properties when they work in the field. for example, installing a HVAC equipment. The main driver is to accelerate transition from conventional refrigerants having high global warming potential (GWP) to new low GWP refrigerants, to support professionals using these new refrigerants in the field.

The user can specify the inputs of each property calculation module. An example case is provided for each individual module.

The wizard will guide you through the use of the property modules. The wizard includes numerous property modules in multiple categories. You are more than welcome to work with us and create other new modules or categories for your interest. If you have suggestions or find any bugs related to this property calculation tool, please contact the author, Bo Shen, shenb@ornl.gov.

Below, you can either expand a category by clicking the triangle on the left, select an existing module and make your inputs (Customize Configuration).

Category / Configuration	Description
▾ Refrigerant Properties	
1.PtoDew	Calculate dew point temperature at given pressure
2.PtoBubble	Calculate bubble point temperature at given pressure
3.DewtoP	Calculate pressure at given dew point temperature
4.BubbletoP	Calculate pressure at given bubble point temperature
5.PTtoSuperheat	Calculate superheat degree at given pressure and temperature
6.PTtoSubcool	Calculate subcooling degree at given pressure and temperature
7.TSuptoP	Calculate pressure at given temperature and superheat degree
8.TSubtoP	Calculate pressure at given temperature and subcooling degree
9.PSuptoT	Calculate temperature at given pressure and superheat degree
10.PSubtoT	Calculate temperature at given pressure and subcooling degree
▸ Psychrometric Properties	
▸ Coolant Properties	
▸ Capacity calculation	

Customize Configuration | Upload Configuration

Web version 0.9b

This program was developed by the Oak Ridge National Laboratory , Building Technologies Research and Integration Center (BTRIC) under sponsorship of the Department of Energy (DOE) Program of Building Technologies.

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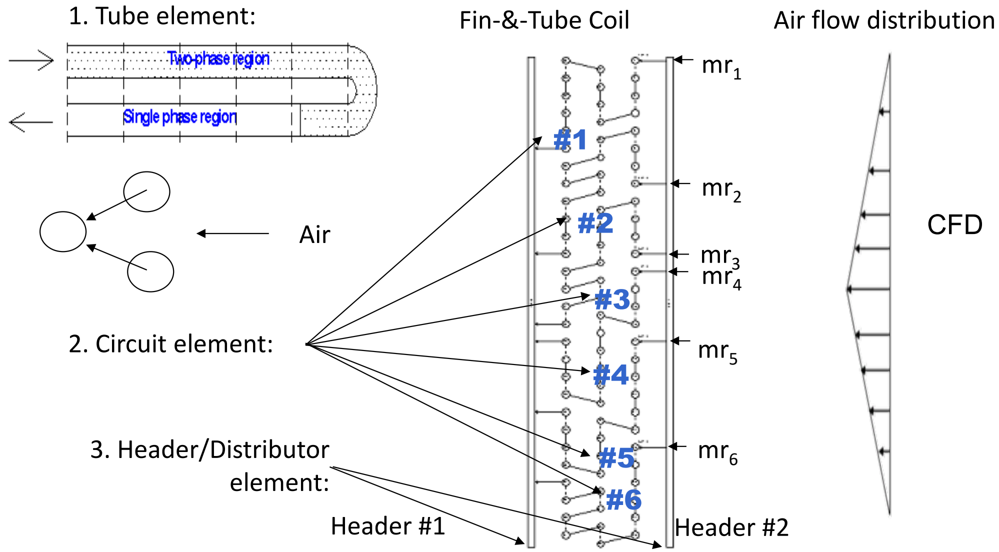


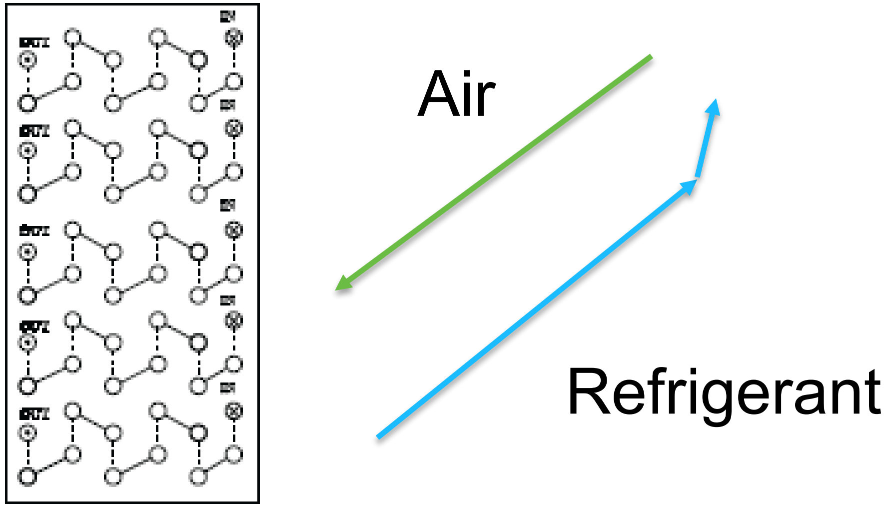
2-D air side distribution; Independent circuit refrigerant entering conditions; Arbitrary circuitry, provides more accurate real-world heat exchanger performance predictions

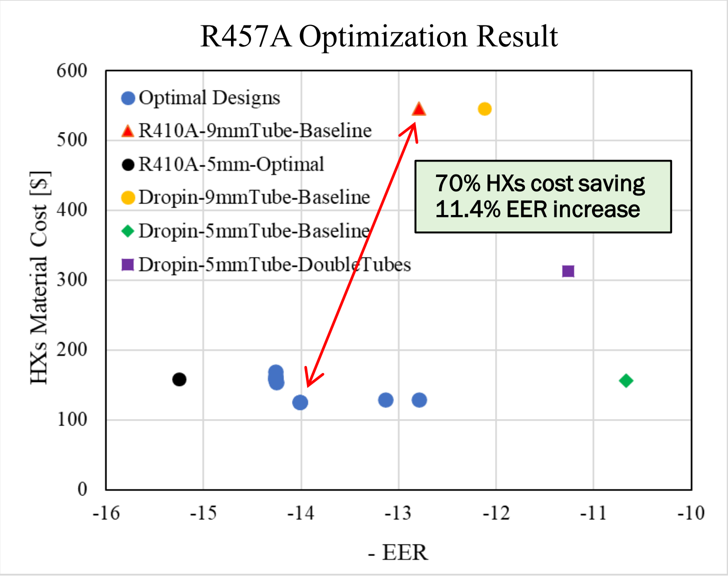
HPDM discretized coil modelling reveals temperature glide and variation of local properties, enable optimizing coil circuitry with arbitrary refrigerant mixture compositions.

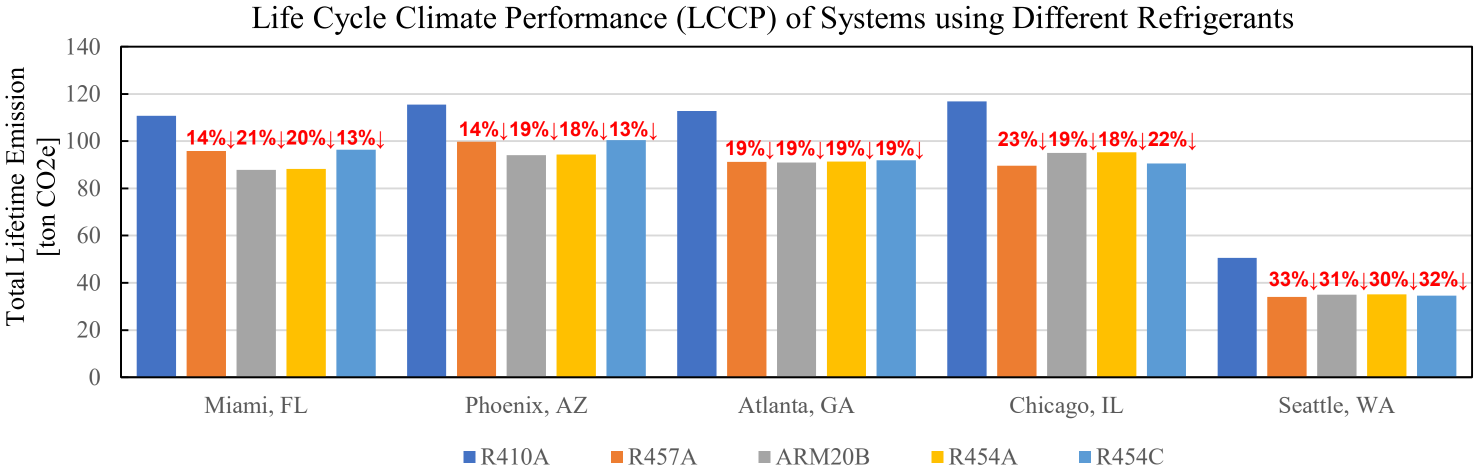
Google - “ORNL HPDM”

Progress – Design Optimization

Multi-row 5-mm tube coil in cross counter flow







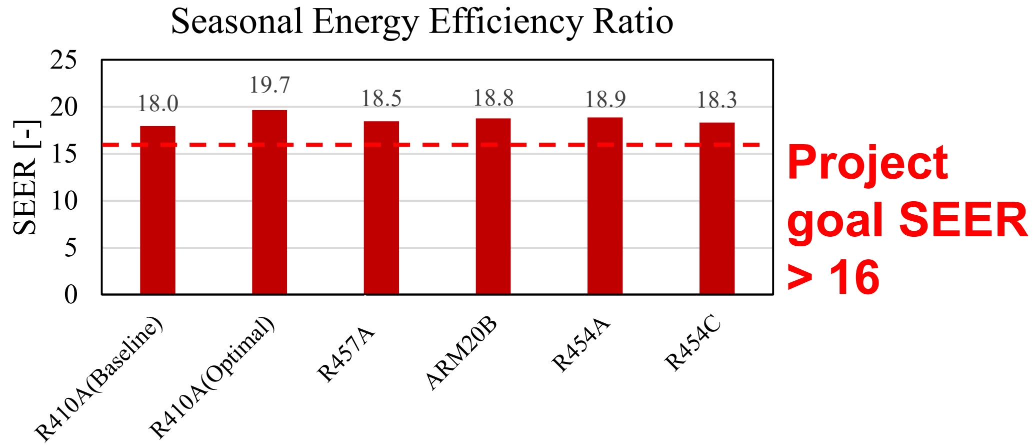
Keys:

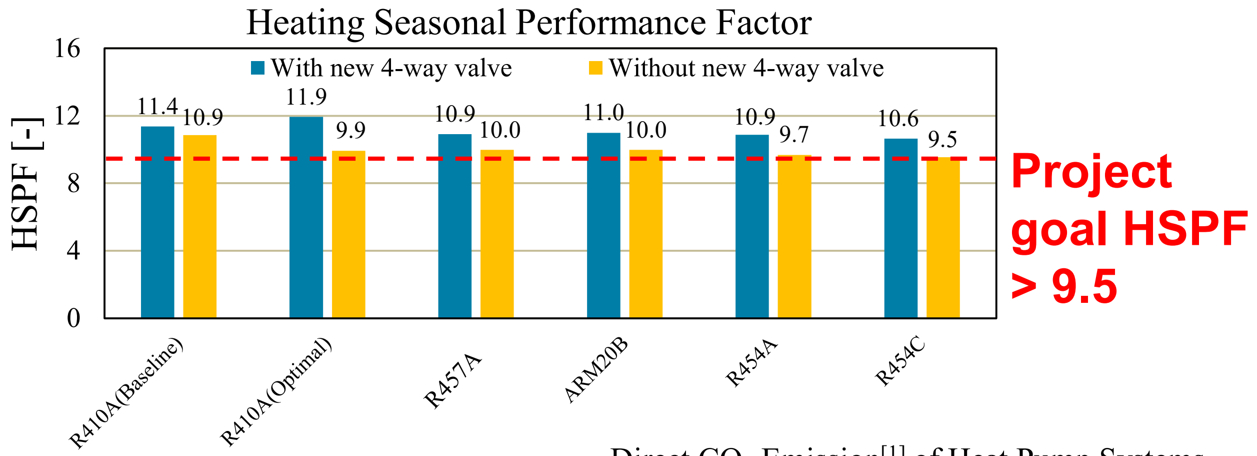
- Optimize multi-row coils, 5-mm tubes
- Flow control devices maintain optimum heat exchanger configurations in heating/cooling modes
- Develop multi-stage compressors for low GWP refrigerants

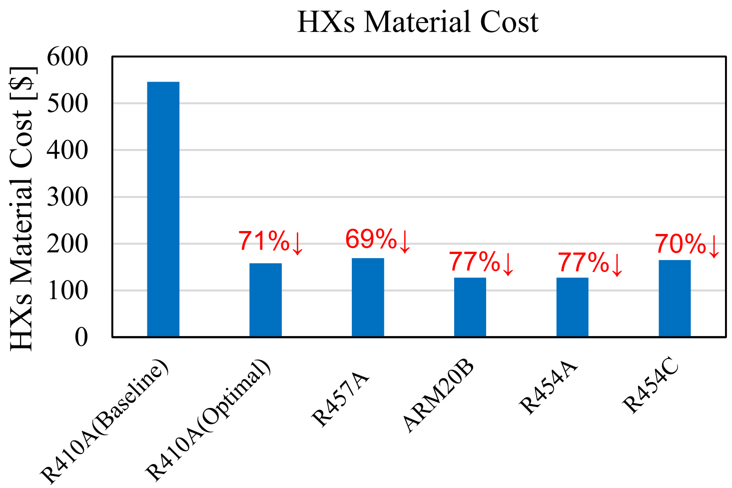
Optimized heat pump systems using low-GWP refrigerants can reduce total lifetime CO_2 emission by 13%-33% depending on the choice of refrigerant and climate zone

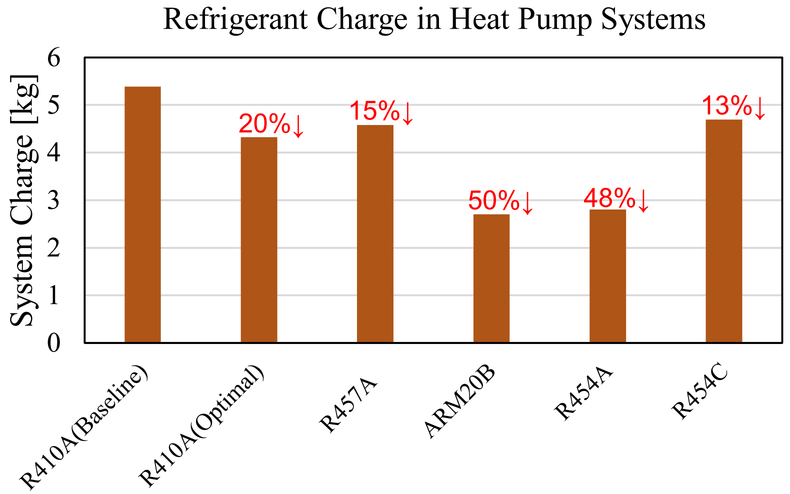
Progress – Performance of Optimal Low-GWP Heat Pump Systems

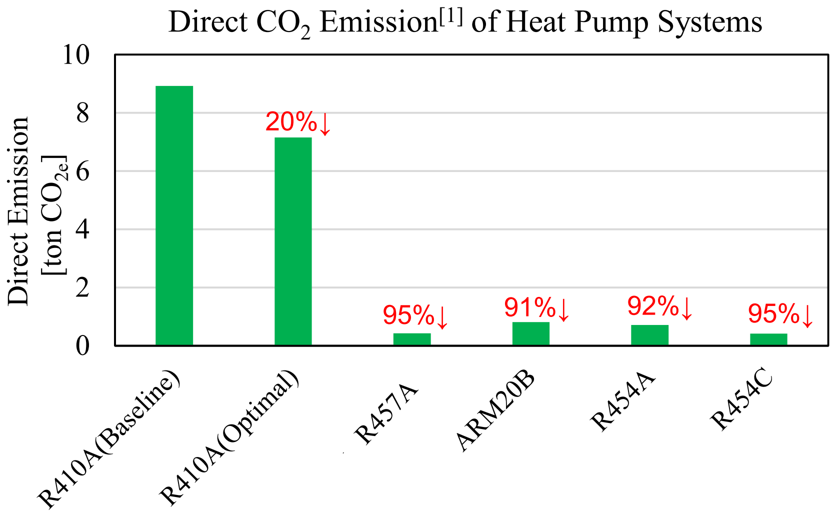
- Seasonal Energy Efficiency Ratio (SEER) is **18.3-18.9** (initial project goal: SEER > 16)
- Heating Seasonal Performance Factor (HSPF) is **10.6-11.0** (initial project goal: HSPF > 9.5)
- Heat exchangers material cost is reduced by **69% -77%** compared with R410A baseline heat pump
- Refrigerant charge is reduced by **13%-50%**, direct CO_2 emission[1] is reduced by **91%-95%**









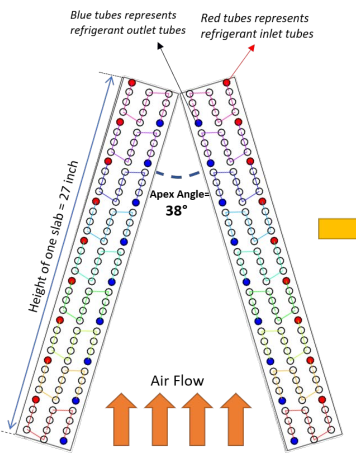


[1] Direct CO_2 Emission is the emission caused by refrigerant leakage during the heat pump usage phase and End of Life (EOL) phase.

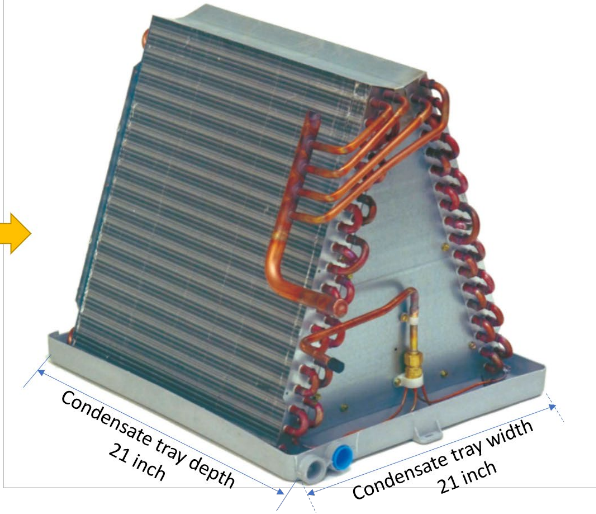
Progress – Prototyping

- Multi-stage compressor from Emerson (ETA: 9/10/2021)
- Flow control device from Emerson (ETA: 9/10/2021)
- Optimized 5-mm tube heat exchangers purchased and in the progress of fabrication by Super Radiator Coils (ETA: 9/15/2021)

5mm Tube Indoor Unit in Fabrication

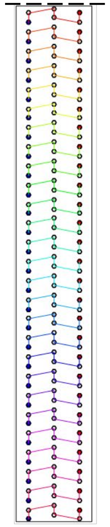


A-shape Indoor Heat Exchanger Circuitry Plot

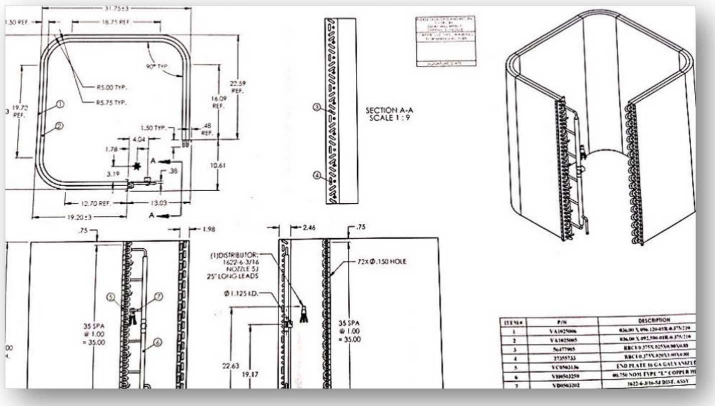


A-shape Indoor Heat Exchanger with Condensate Tray

5mm Tube Outdoor Unit in Fabrication



Outdoor HX Circuitry Plot



Outdoor Heat Exchanger CAD Plot

Outdoor unit with Casing

Stakeholder Engagement

Industry Partner 1 – Emerson Commercial and Residential Solutions

- Worked with Emerson to determine how to achieve optimal heat pump performance with their components
- Emerson will develop compressor optimized for the low-GWP refrigerants
- Emerson will invent flow control devices to maintain the heat exchangers' counter flow configuration under dual mode operations

Industry Partner 2 – Super Radiator Coils

- Established and signed NDA - 6/16/2021
- Worked with Super Radiator Coils to determine how to refine the heat exchanger design and verify their manufacturability
- Super Radiator Coils is fabricating and will deliver the optimized 5-mm tube, multi-row indoor and outdoor heat exchangers

Remaining Project Work

	Task	
Year 1	1	Perform life cycle energy and GHG emission analysis, select candidate refrigerant(s)
	2	Model-based design of system and component concepts, to achieve the performance goals (16.0 SEER/9.5 HSPF)
	3	Development of a 2 or 3-stage scroll compressor for the selected refrigerant and smart four-way valve (Emerson)
	4	Construct Prototype System
Year 2	5	Verify component technologies (compressor, smart four-way valve, bi-directional header/distributor, etc.)
	6	Verify the >90% efficiency performance goals via lab testing
	7	Prototype improvement and final performance verification (achieve 16.0 SEER/9.5 HSPF)
	8	Cost assessment and submit final report

Thank you

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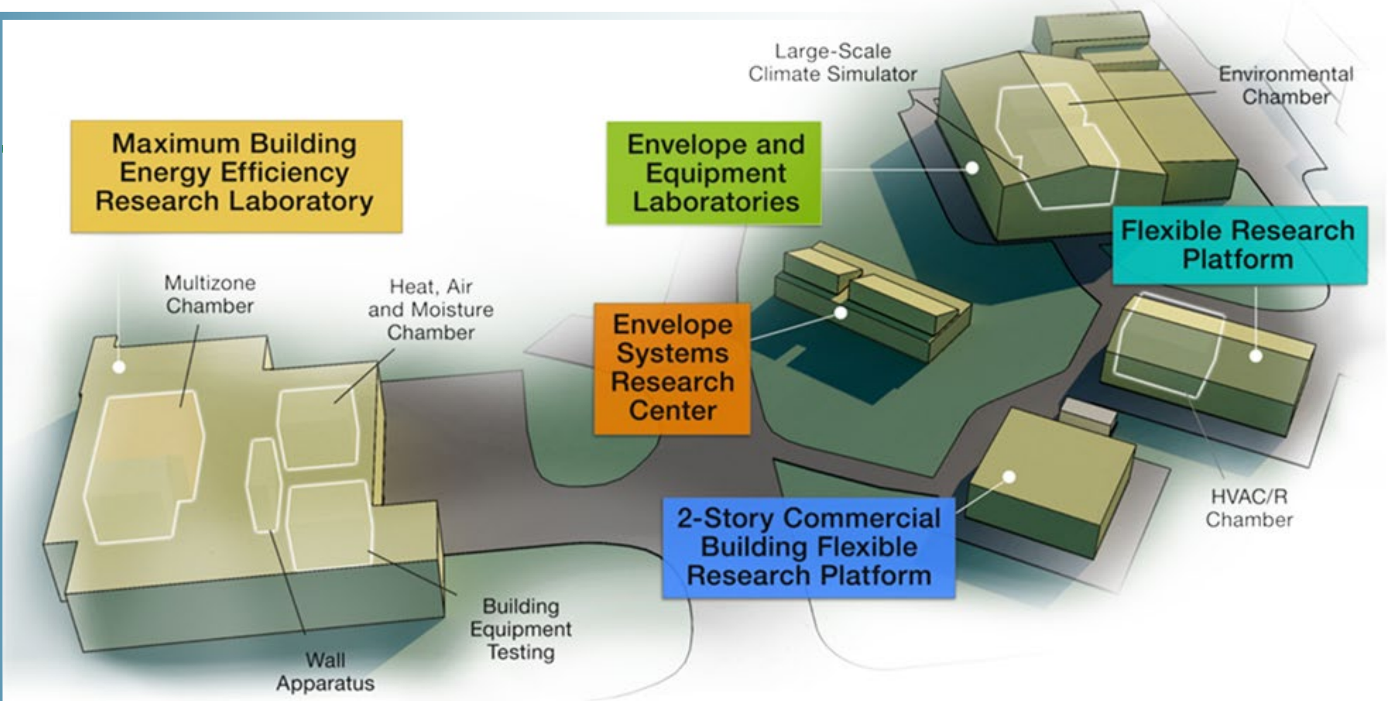

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free 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: $600K (DOE)
Variances: NONE
Cost to Date: $300K
Additional Funding: NONE

Budget History					
10– FY 2020 (past)		FY 2021 (current)		FY 2022 – 09/2022	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
0	0	$300K	$300K	$300K	$300K

Project Plan and Schedule

	Task		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Year 1	1	Perform life cycle energy and GHG emission analysis, select candidate refrigerant(s)								
	2	Model-based design of system and component concepts, to achieve the performance goals (16.0 SEER/9.5 HSPF)								
	3	Development of a 2 or 3-stage scroll compressor for the selected refrigerant and smart four-way valve (Emerson)								
	4	Construct Prototype System								
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	6	Verify the >90% efficiency performance goals via lab testing								
	7	Prototype improvement and final performance verification (achieve 16.0 SEER/9.5 HSPF)								
	8	Cost assessment and submit final report								

Go/No-Go Milestone

Go/No-Go miles