Heat Pump Water Heater with Wrapped-tank Microchannel Condenser and Submerged Condenser

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Project Summary

Objective and outcome

- Develop compact condensers to reduce charge and achieve similar heat transfer effectiveness of wrapped-tank D-shape coils
- Development of microchannel and submerged condenser coil sizing and HPWH system design tool
- Conduct an extended period of life test to assess the impact of water side mineral scaling

One submerged condenser prototype

Team and Partners

Partner: Rheem Manufacturing Company

Stats

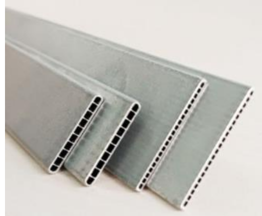
Performance Period: Start date: 10/01/2019 -- End date: 09/30/2022
DOE budget: $170k total, Cost Share: $100k
Milestone 1: Test HPWH Prototype with wrapped-tank microchannel condenser to meet baseline UEF, 09/30/2020
Milestone 2: Fabricate and test prototypes with capillary tube submerged condenser to achieve 50% charge reduction, 03/30/2021
Milestone 3: Fabricate and evaluate prototype of finned submerged condenser 07/30/2021
Milestone 4: Finned submerged condenser life test on HPWH 04/30/2022

Background (HPWHs using Innovative Condensers Design)

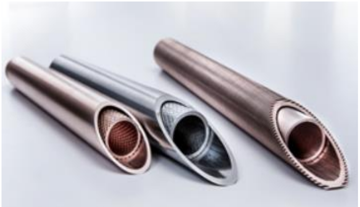
Conventional

D-shape tube, wrapped tank coil

Proposed designs



Microchannel, wrapped tank coil



Double-wall, submerged condenser (internal)

only zero-emission water heaters can be sold or installed in the Bay Area in 2027.

https://www.cbsnews.com/sanfrancisco/news/natural-gas-furnace-water-heater-phase-out-ban-bay-area-air-district/

Problems

The HPWH industry is phasing out R-134a (GWP of 1430), to use R-1234yf, R-1234ze, R-516A, or propane with GWP < 150

These low GWP alternatives in A2L, or even A3, mildly or extremely flammable. Expensive and subject to charge limit, i.e., < 150 g propane.

High efficiency and 120V HPWHs (> 4 lbs. R-134a) need larger heat exchangers and refrigerant charge; majority of charge resides in condenser.

Conventional D-shape tubes have large inner volume but < 40% contacting surface area, causing up to 10% heat loss to the surrounding air.

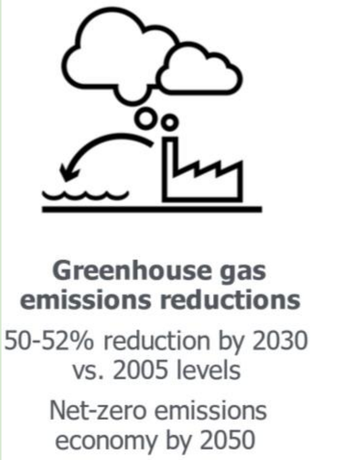
Submerged condensers have no heat loss but are subject to water-side scaling.

Small diameter tubes lead to high refrigerant side pressure drop.

Lack of heat exchanger and system design tool for HPWHs with stratified water tank and new refrigerants.

Must develop compact condensers to prepare refrigerant transition in HPWHs.

Alignment and Impact



-Enable flammable low GWP refrigerants below charge limits

-Achieve UEF > 3.3 versus Energy Star UEF of 2.2.

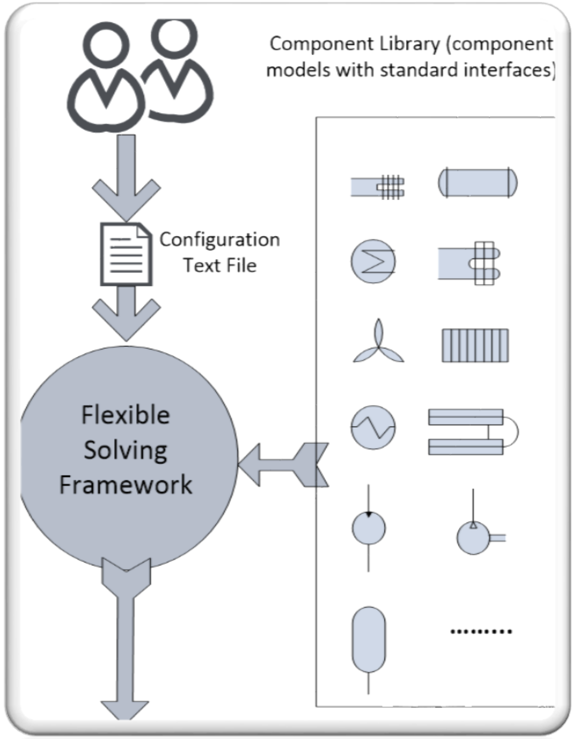
Support the effort for providing HPWH with high performance to replace gas water heaters

Enforce HPWH market penetration by reducing the manufacturing cost (reduced refrigerant cost)

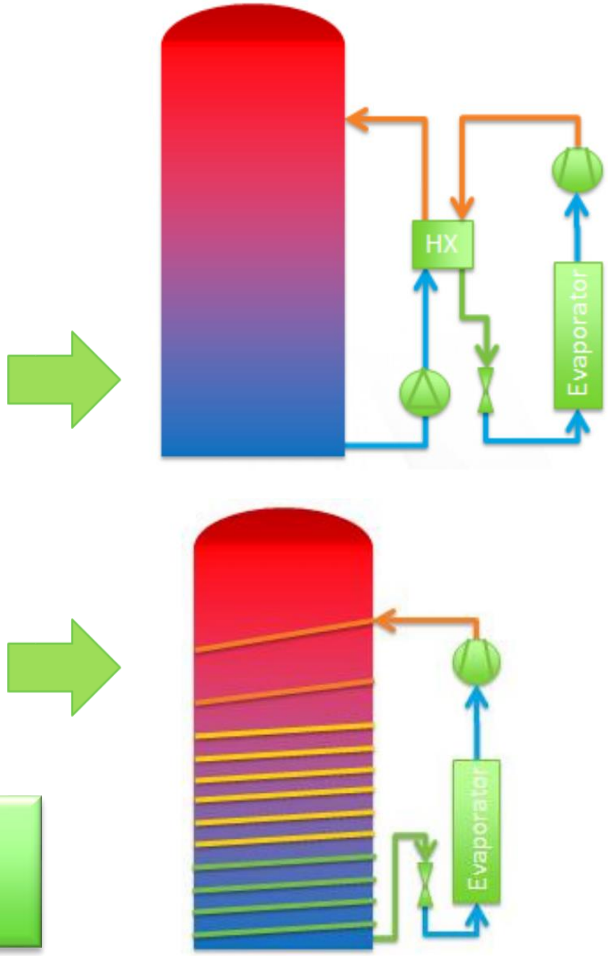
Approach – Upgrade DOE/ORNL Heat Pump Design Model

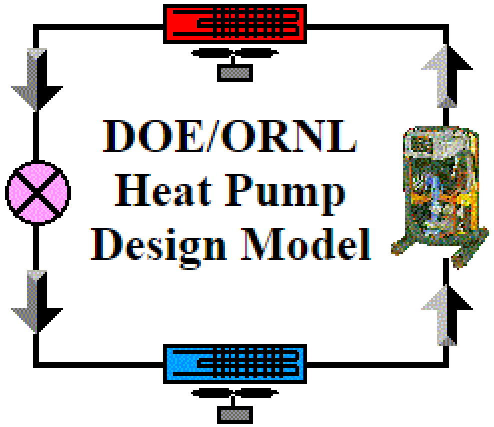
Component-Based

Component models have standard interfaces to the solving framework, and generic connections to each other.



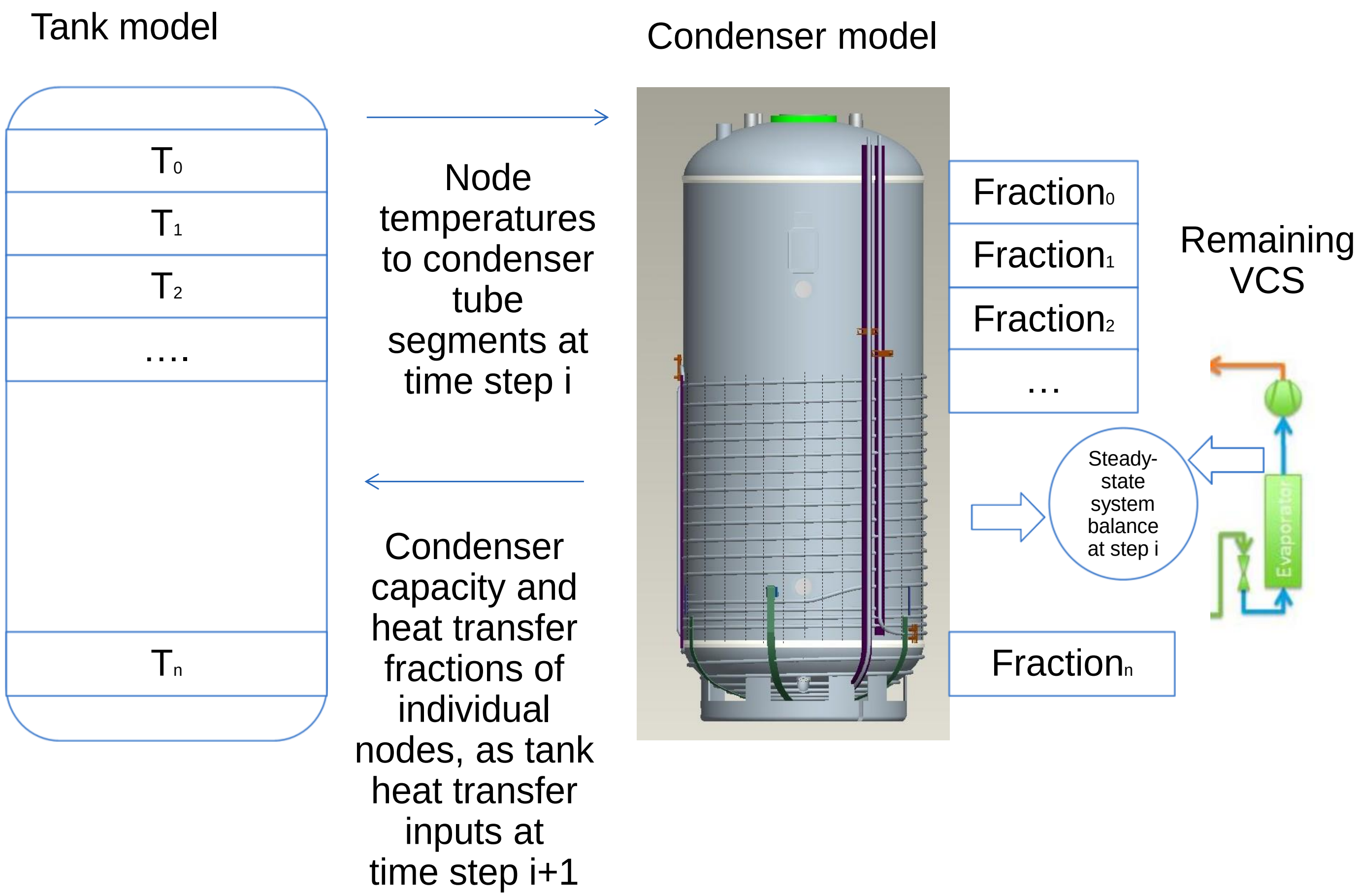
Automatically connect components into required system configuration by user input file.

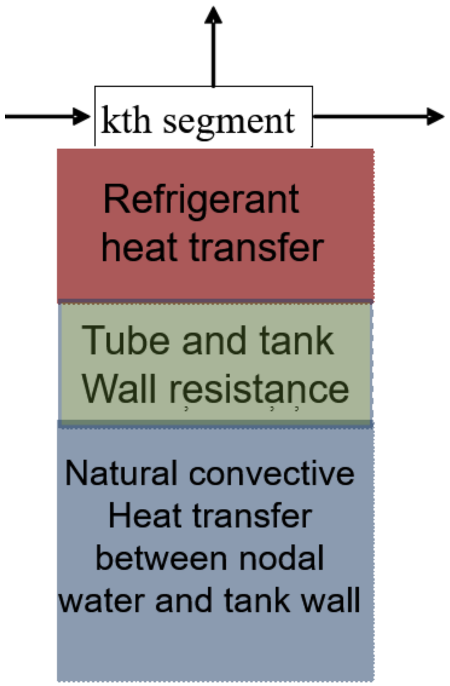




https://hpdmflex.ornl.gov

Segment-to-Segment Tank Coil Model





24-hr Uniform Energy Factor (UEF) and 1st Hour Rating, Simulated within 5 Minutes

Coupled a segment-to-segment coil model to stratified tank model

- **Pattern of wrapped-tank coil affects stratification**
- **Water stratification is a boundary condition to the segment-to-segment coil model**

Approach – Laboratory Investigations of Multiple Condenser Types

HPWHs have high capital cost that hurt its market penetration

Current HPWHs use charge amount higher than the allowed flammable refrigerant amount

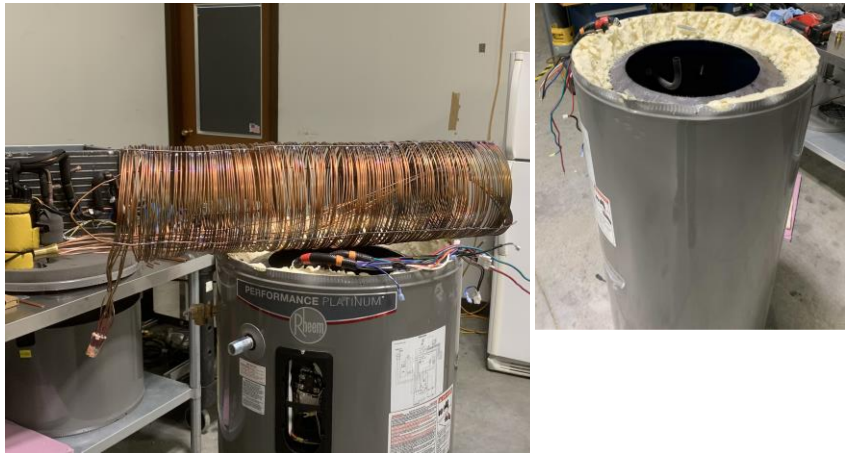
Micro-diameter tubes, i.e. microchannel heat exchangers or capillary tubes, can effectively reduce the refrigerant charge while maintaining adequate heat transfer effectiveness.

Investigate microchannel (wrapped tank) and submerged condensers in HPWH

Prototypes experimental evaluation and study the impact of waterside scaling via an extended period of life test.

*Baseline unit is a Rheem 50-gallon HPWH having UEF of 3.55@24OZ; use the same tank, evaporator, fan, electronic expansion valve, and control.

Progress: Development of Submerged Capillary Tube Condenser



1st version

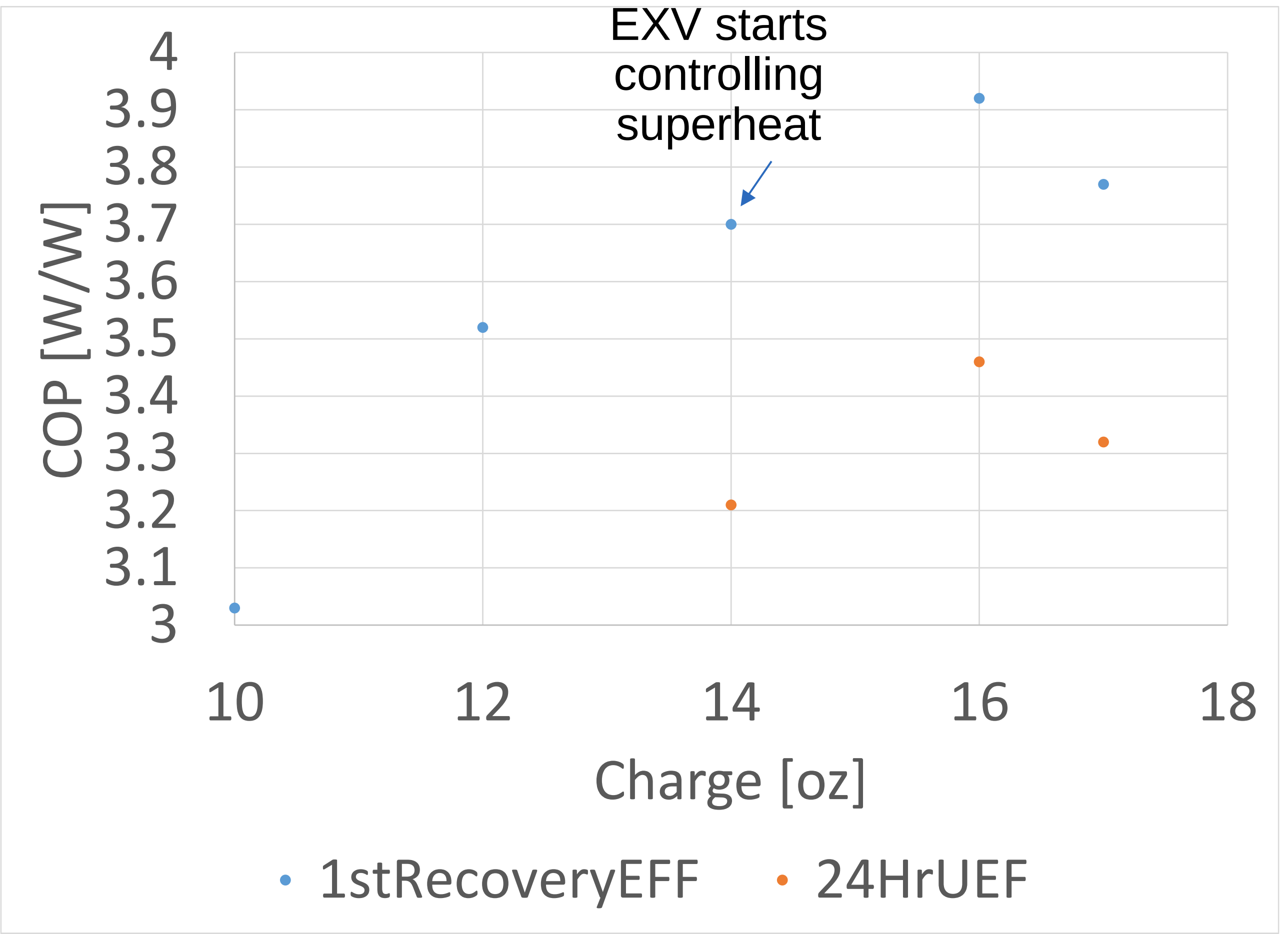
3rd version

Four prototypes to find optimized parameters.

	Baseline D-shape tube	1st-micro-tube bundle	2nd -micro-tube bundle	3rd-micro-tube bundle	4th -micro-tube bundle
Tube outside diameter	10.6 mm	3 mm	3 mm	3 mm	3 mm
Total Tube length [ft]	118	400	250	136	180
#Circuits	1	8	12	12	16
Tube surface area at water side [ft^2]	4.1	12.4	7.7	4.2	5.6
UEF [W/W]	3.55	2.8	3.0	3.20	3.26
Charge [oz]	22	22	22	14	18
Coil Pressure Drop [psiD]	20	80	40	30	20

Achieved 40% charge reduction with 10% lower UEF than baseline

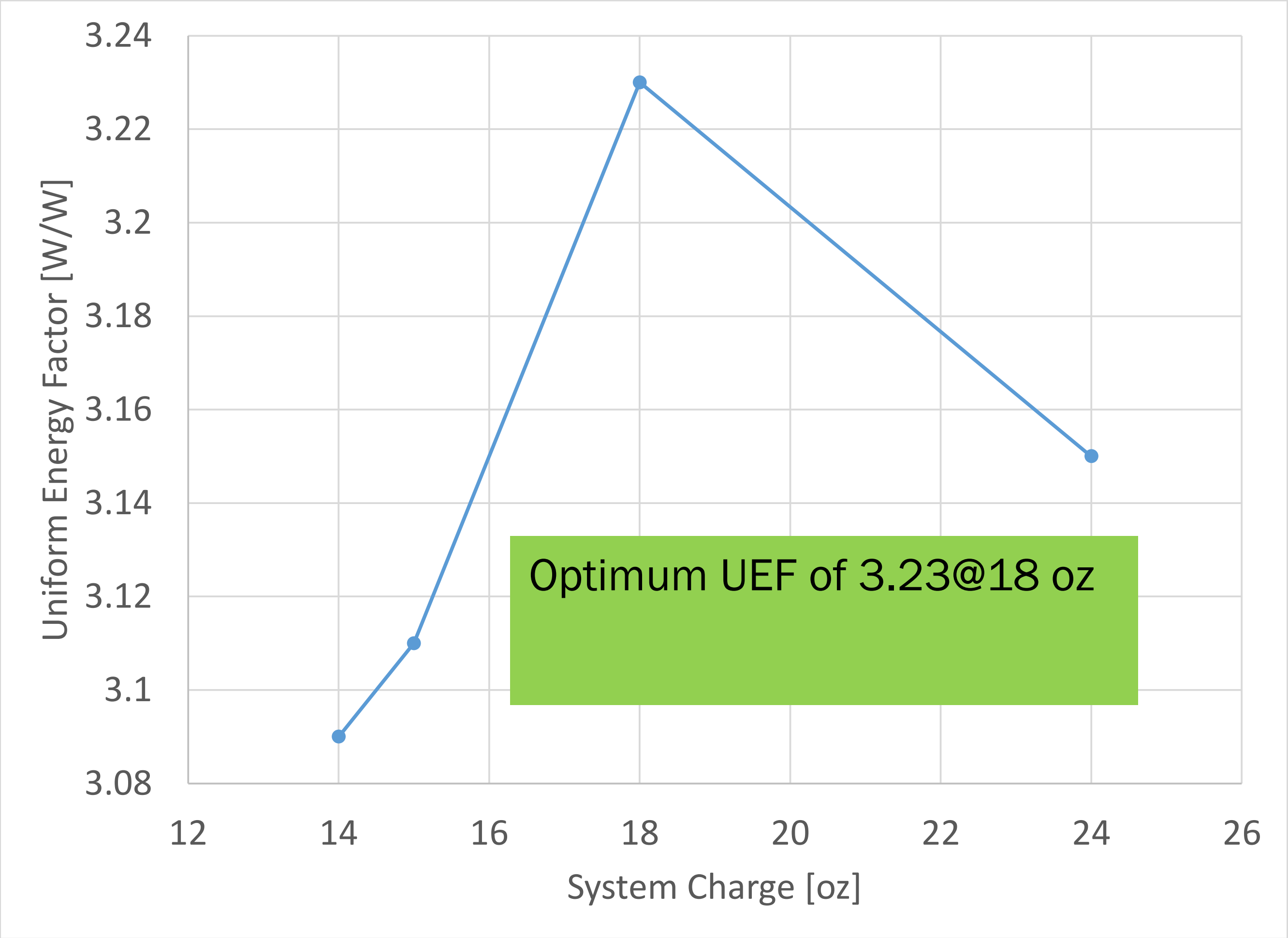
Progress: Evaluate finned double-wall submerged condenser

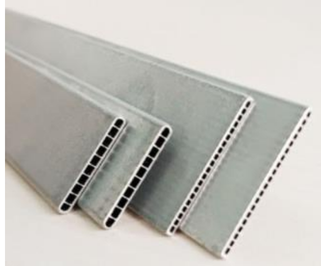


- Achieved 3.45 UEF@16 oz versus 3.55 UEF@24 oz –wrapped tank coil, using the same evaporator, fan and blower.

Performed 8-month life test (55-gallon UEF test, TN city water every day), no apparent performance degradation due to water scaling

Progress: Evaluate One Microchannel Condenser





- Due to the inlet and outlet headers, difficult to eliminate contact resistance
- Refrigerant flow merges and separates in multiple intermediate passes, causing two-phase refrigerant flow mal-distribution at downstream passes.

Project Completed; Outcomes continue in a new project

Project Completion 2022

New Partnership with Rheem (CRADA 2022)

low charge heat pump water heater using propane (WBS#03.02.02.43, Lab Call CRADA)

Field Demonstration

2023/2024

Take-aways

All three compact condensers required 40% less optimum charge, however, the UEF degraded by 10%.

The finned submerged condenser led to best performance at reduced charge.

Able to achieve UEF of 3.4 @ 16 oz of R-134a.

Need to improve the microchannel wrapped-tank condenser configuration by optimizing number of passes, port dimensions, number of tubes, eliminating heaters, etc., and minimizing contact resistance via developing new assembly process.

Thank you

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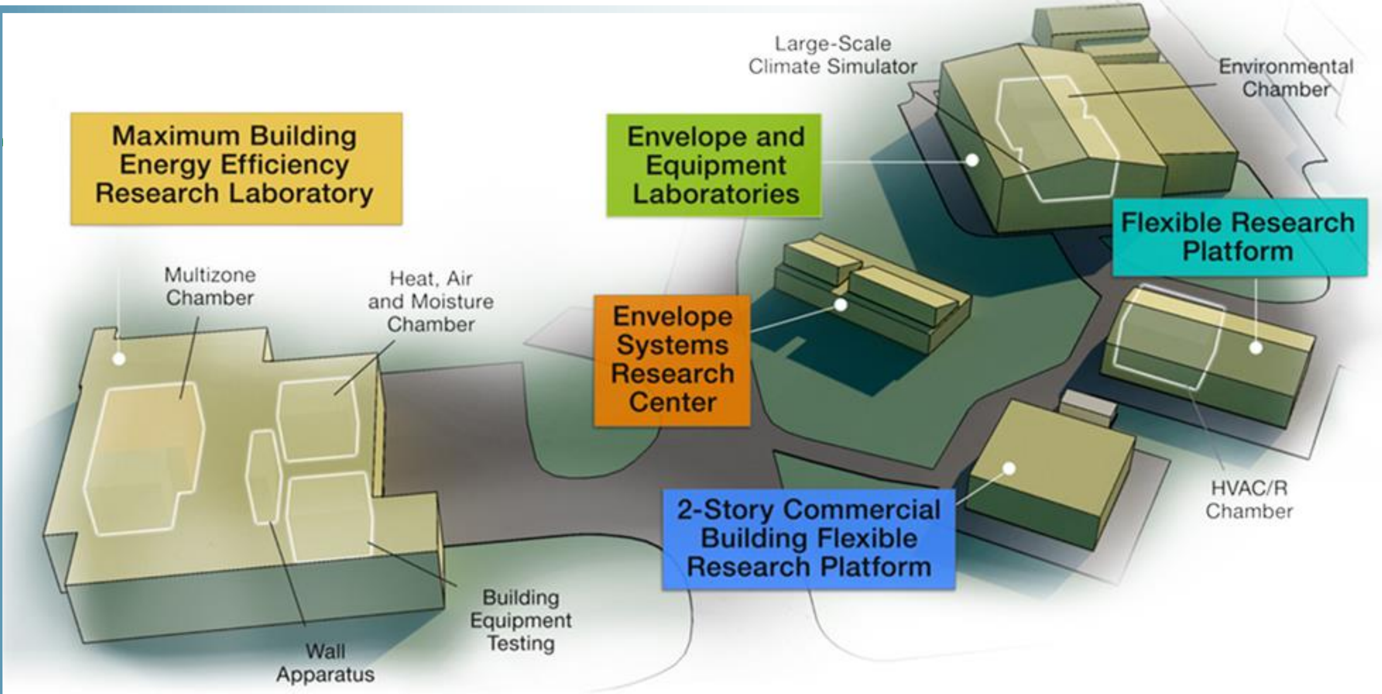

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free 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: $170K (DOE)
Variances: NONE
Cost to Date: $170K
Additional Funding: NONE

Budget History					
FY 2020		FY 2021		FY 2022	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
70K	70K	$50K	$50K	$50K	$50K

Barriers and Technical Challenges

Barriers and Challenges	Mitigation Strategies
Condensers' Fabrication and Cost	Establish a production path to produce cost-effective compact heat exchangers.
Low performance than UEF = 2.2	Improve condenser heat transfer rate Improve evaporator coil heat transfer rate
Scale formation on submerged condenser outer wall	Condenser outer wall treatment to prevent scales
Higher pressure losses in the tested condensers	Identification and reduction of pressure losses in the entire system

Stakeholder Engagement

Industry Partner – Rheem Manufacturing Company

Supported Rheem team to use DOE/ORNL Heat Pump Design Model to optimize heat exchanger design and accelerate HPWH system development

Rheem selected and procured submerged and microchannel condensers through its supply chain

Rheem team developed coating material to mitigate water side scaling and manufacturing procedure to integrate the compact condensers.

Rheem fabricated system prototypes embedded with numerous condenser technologies for ORNL's system level experiments.

Weekly meetings with Rheem engineers to monitor the progress.