Low Charge Heat Pump Water Heater Using Propane

Oak Ridge National Laboratory
PI: Bo Shen
Presenter: Mingkan Zhang
865-574-5745, shenb@ornl.gov
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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
- Develop and calibrate propane HPWH system design tool
- Motivate supply chain to develop propane enabling technologies, i.e., propane specific compressor@60HZ, optimized microchannel condensers
- Laboratory verification and accelerated life tests on a 220V, HPWH prototype reaching 3.3 UEF with propane < 150 g

Propane (R290), natural refrigerant

Team and Partners

Rheem Manufacturing Company

Stats

Start date: 04/01/2022

Planned end date: 09/30/2023

Budget: DOE total-$300K; Rheem cost-share-$300K

Key Milestones

1. Experimentally study performance of compact condensers, i.e., microchannel and submerged condensers, 04/30/2022
2. Develop compact condenser coil sizing and propane HPWH system design tool, 06/30/2022
3. Initial lab tests verify a UEF > 3.0 using propane charge near 200 grams, 09/30/2022
4. Experimental results prove measured UEF > 3.3, system charge < 150 grams, 06/30/2023

Problems addressed

- The HPWH industry is phasing out R-134a (GWP of 1430).
- Propane has an ultra-low GWP < 3.3, and is less expensive, more environment-friendly than HFO alternatives (R-1234yf, ze). But extremely flammable and subject to charge limit, i.e., < 150 g for indoor use.
- European market prefers propane than F-gas refrigerants. Propane HPWHs have better marketing potential internationally. However, no propane heat pump water heaters on the U.S. market.
- Component technologies are not fully ready for propane, i.e., propane specific compressor@60HZ, and compact heat exchangers with reduced charge.

Alignment and Impact

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

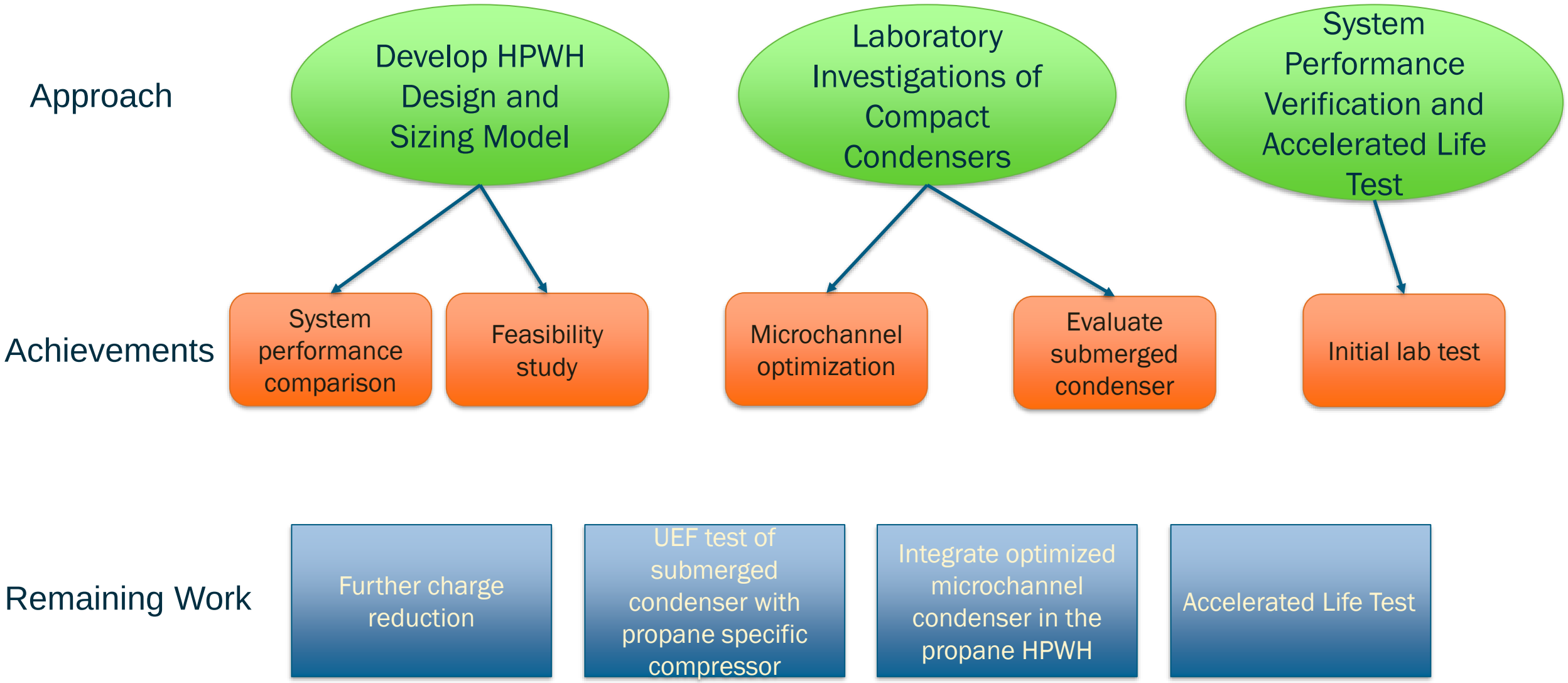
100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

- Green House Emissions Reductions: Replace high GWP refrigerants in Rheem's residential HPWH product families.
- Energy Justice: Very low-cost (150 grams propane costs less than 10¢) propane leads to heat pump water heaters with low prices.
- Develop and calibrate high-fidelity, public-domain HPWH and heat exchanger modelling and design tool for propane, to accelerate product development.

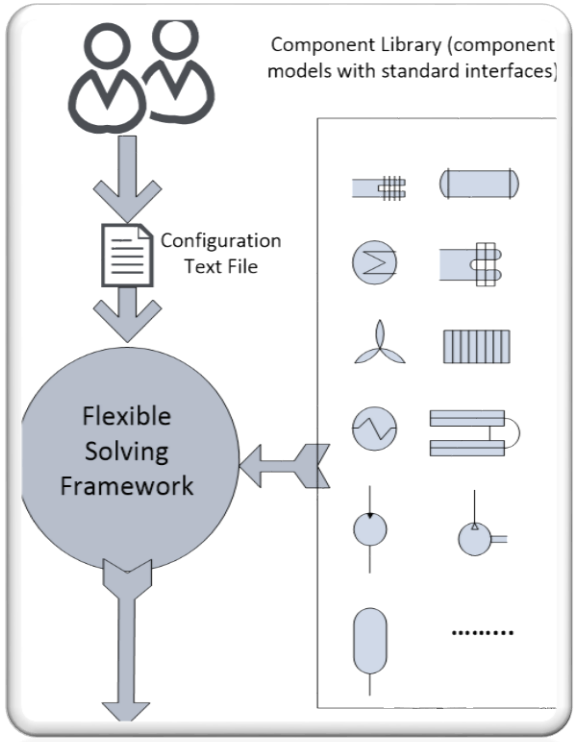
Layout of Research Path

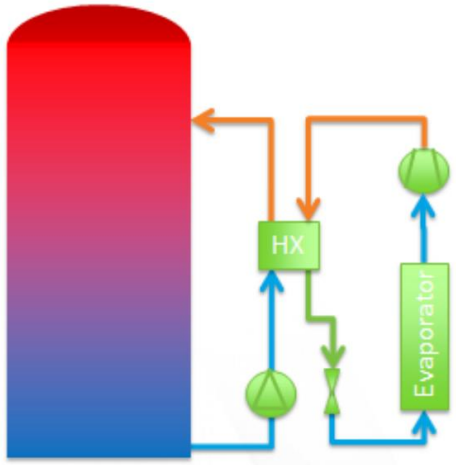


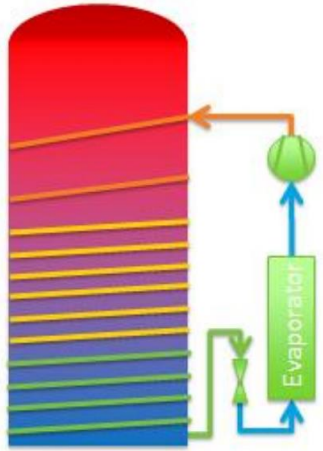
Approach – Upgrade DOE/ORNL Heat Pump Design Model

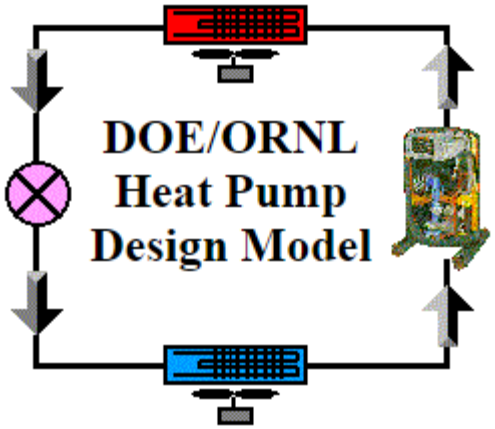
Component models have standard interfaces to the solving framework, and generic connections to each other.

Component-Based









https://hpdmflex.ornl.gov

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

Approach – Laboratory Investigations of Compact Condensers

- Investigate microchannel condenser for charge reduction: Refrigerant charge (inner volume) in a tube relative to its surface area is ($\pi*d^2/4*$Tube Length/$\pi*d*$Tube Length) = d/4.

- Evaluate finned, double-wall submerged condenser and study impact of water side scaling via an extended period of life test.

Approach – System Performance Verification and Accelerated Life Test

- Drop-in performance tests using R-134a compressor, control and a compact condenser, achieving near 3.0 UEF and 200 grams of propane
- Fabricate a propane specific HPWH, with optimized compressor, condenser and evaporator, reaching a UEF of 3.3 with a charge < 150 grams
- Accelerated life test to demonstrate a market ready product

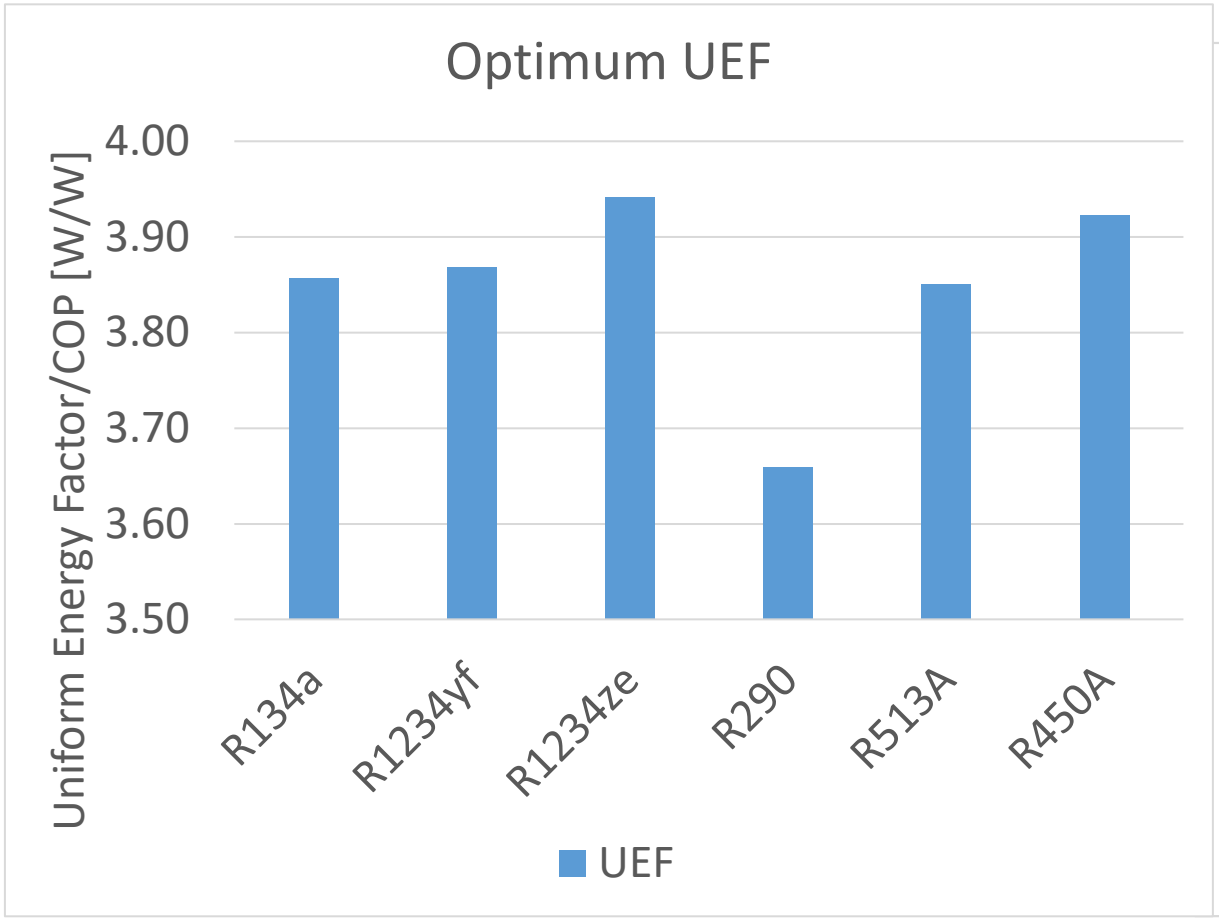
Progress: Propane HPWH system model with other alternatives

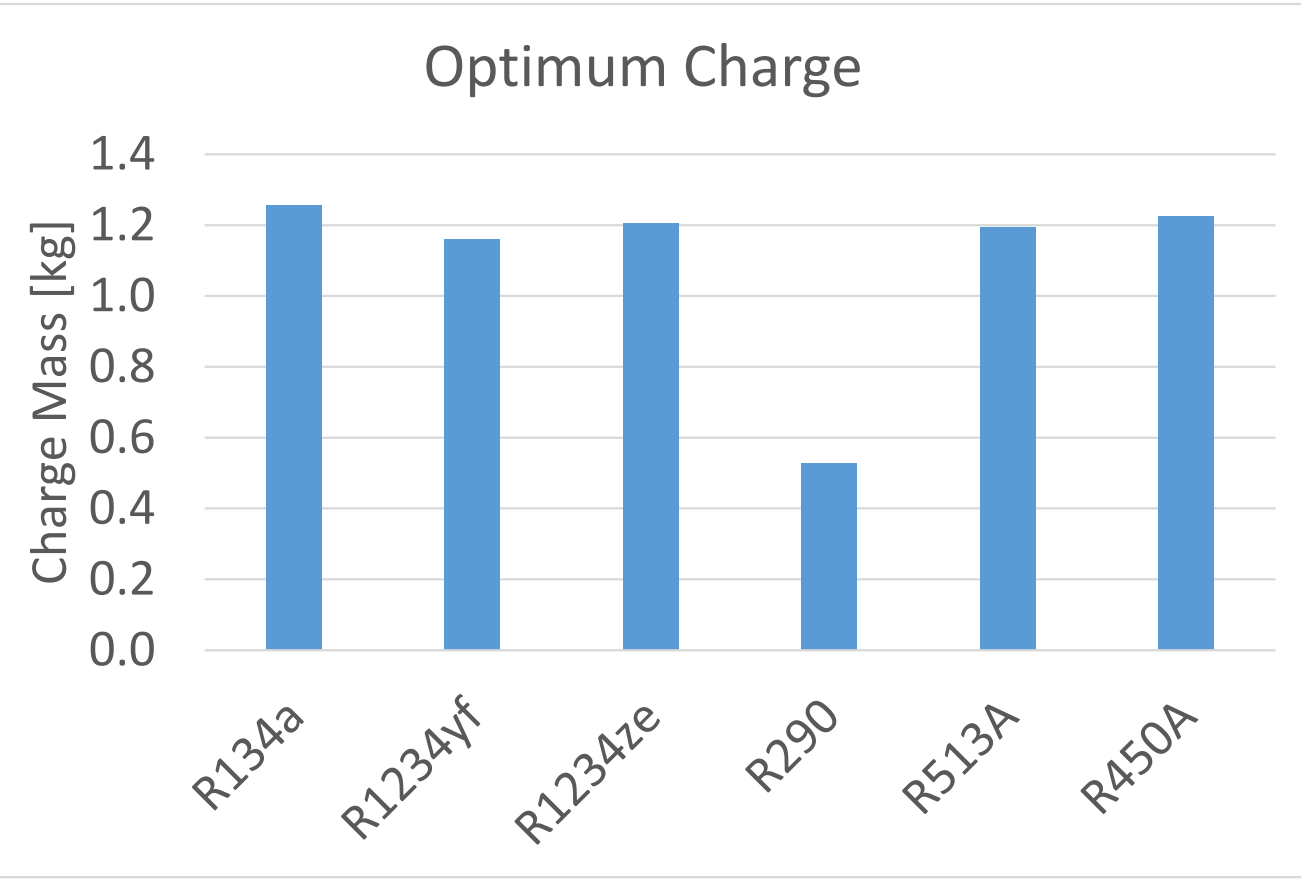
Refrigerant	GWP	Safety Class	Glide/pressure in Condenser @54.4°C [K]/[kPa]	Glide/pressure in Evaporator @ 4.4°C [K] /[kPa]	Critical Temperature/Mole weight [C]/[g/mol]	Volumetric Vaporization Heat@54.4°C [kJ/m^3]	Volumetric Vaporization Heat@ 4.4°C [kJ/m^3]
R-134a (baseline)	1430	A1	0/1469	0/342	101.06/102.03	10959.4	3276.0
R-290	3	A3	0/1883	0/541	97.0/40.06	11800.3	4335.3
R-1234yf	4	A2L	0/1444	0/366	95.0/114.04	10024.4	3263.7
R-1234ze	6	A2L	0/1114	0/254	153.7/114.04	8522.1	2473.2
R-450A[a]	547	A1	0.60/1284	0.64/297	104.4/108.67	9700.5	2861.0
R-513A[b]	573	A1	0.01/1530	0.01/377	96.5/108.43	10832.0	3442.8

[a] R-450A has mass-based compositions of R-1234ze (0.58)/ R-134a (0.42).
[b] R-513A has mass-based compositions of R-1234yf (0.56)/ R-134a (0.44).

Propane has higher working pressure and volumetric capacity (smaller compressor)

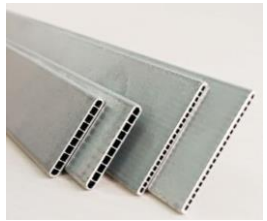
Progress: Feasibility Study by Simulation



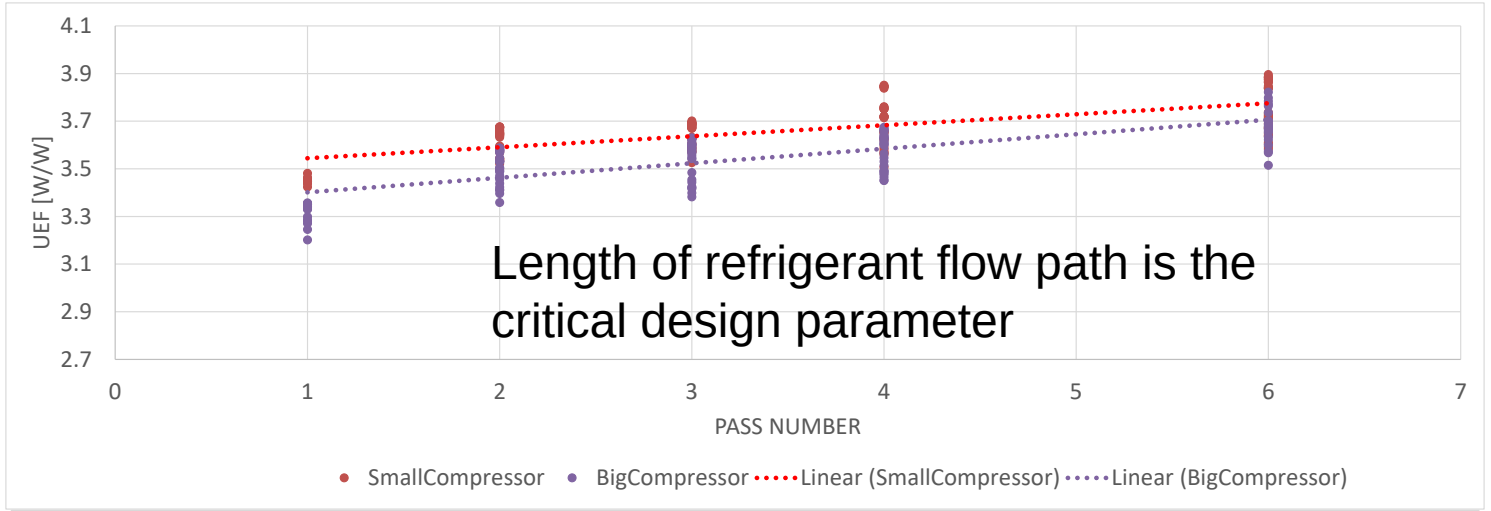


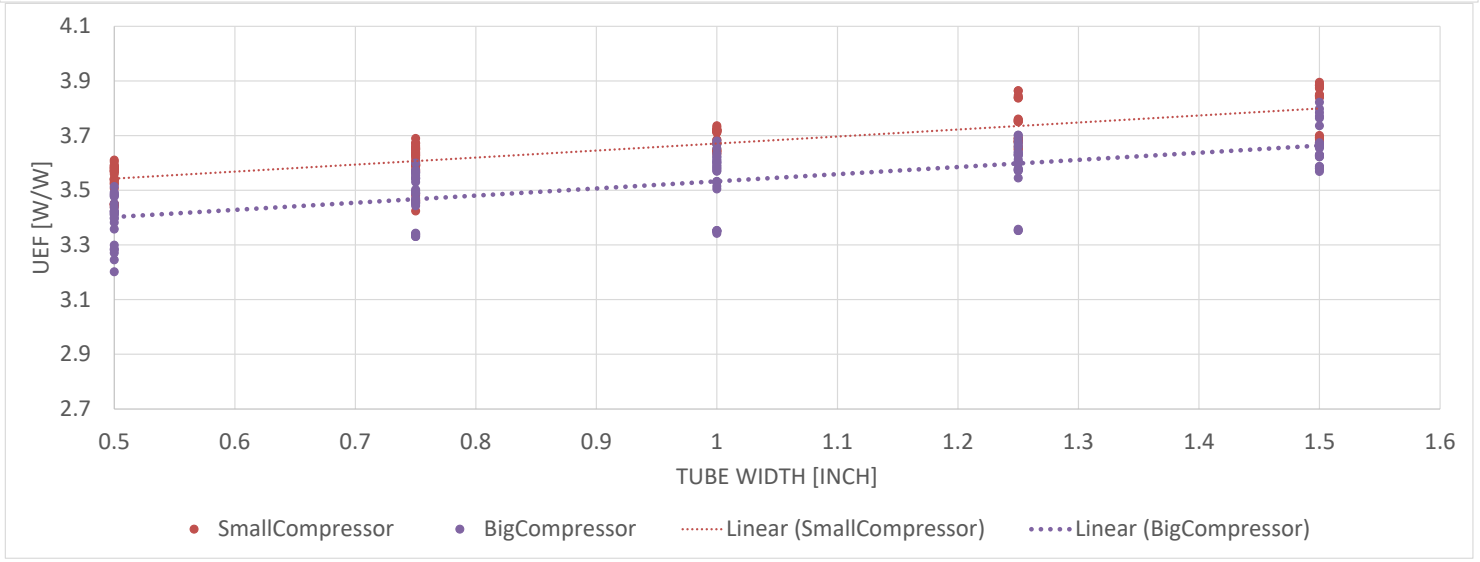
Propane HPWH can reach similar 24-hr heating efficiency (95%), and the required 50% charge of R-134a because of propane's small molecular weight.

Design Optimization to Improve Microchannel Condenser Design



Working with Supplier to optimize microchannel geometry, balance between pressure drop and heat transfer @ target compressor size

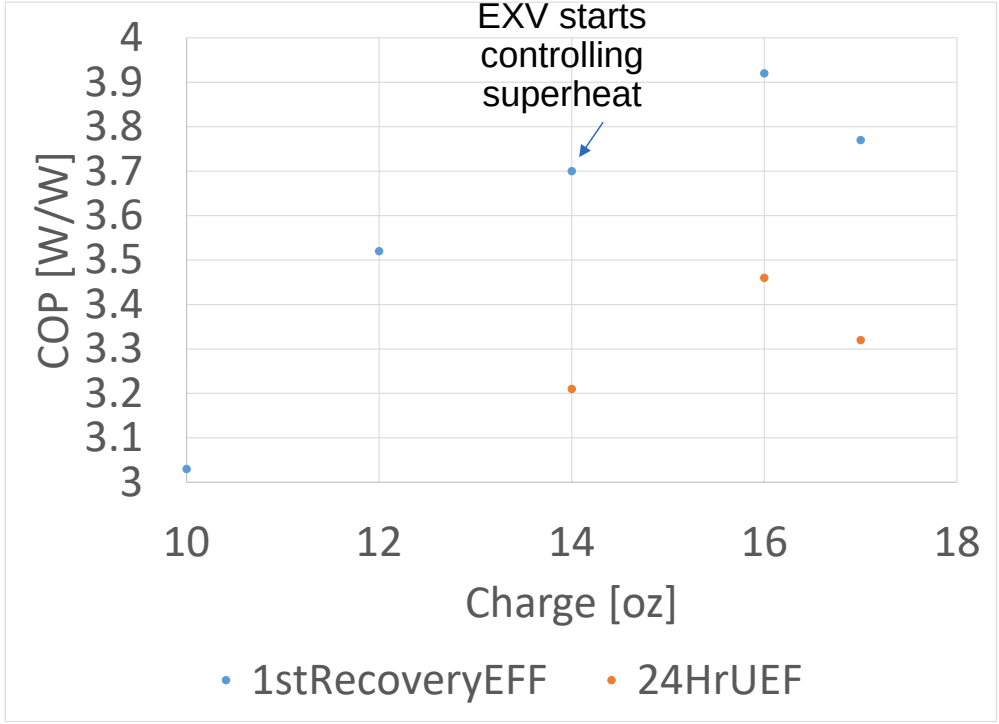




Extensive parametric study to identify optimized geometry

Progress: Apply finned double-wall submerged condenser

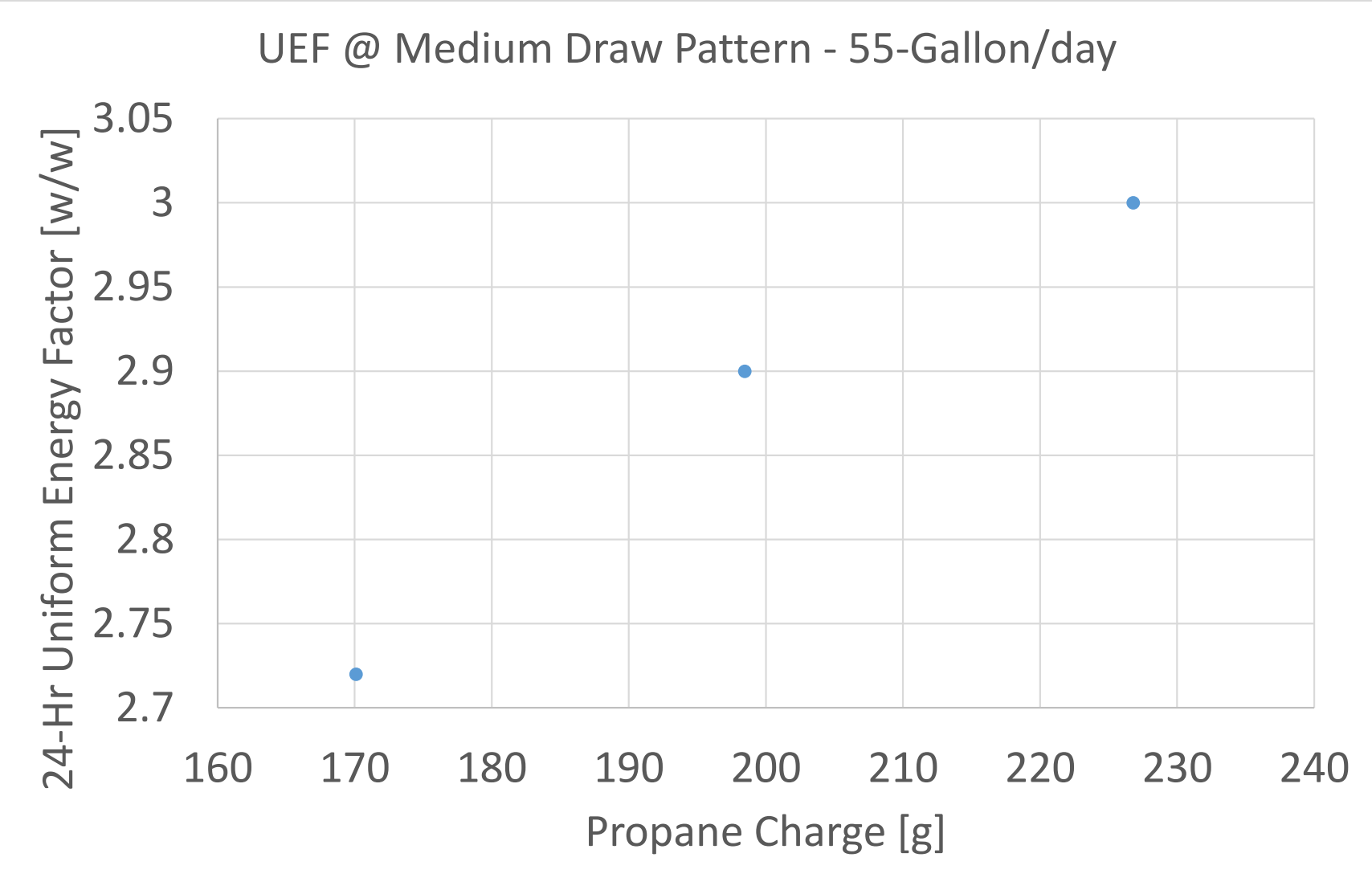
Optimized UEF



- Achieved 3.45 UEF@16 oz R-134a versus 3.56 UEF@24 oz using D-shape wrapped-tank condenser

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

Progress: Initial lab tests verify a UEF near 3.0 using propane charge of 200 grams



- Laboratory investigations @ uniform energy factor test condition
- 50-gallon tank
- 24-Hr medium draw pattern
- Entering water@58˚F,
- Temperature set@120˚F
- Finned double-wall submerged condenser

- Confirmed control (electronic expansion valve) directly workable for propane systems

Remaining Project Work

Further charge reduction, i.e., microchannel evaporator or 5 mm tube fin-and-tube evaporator

Conduct UEF test of submerged condenser with propane specific compressor

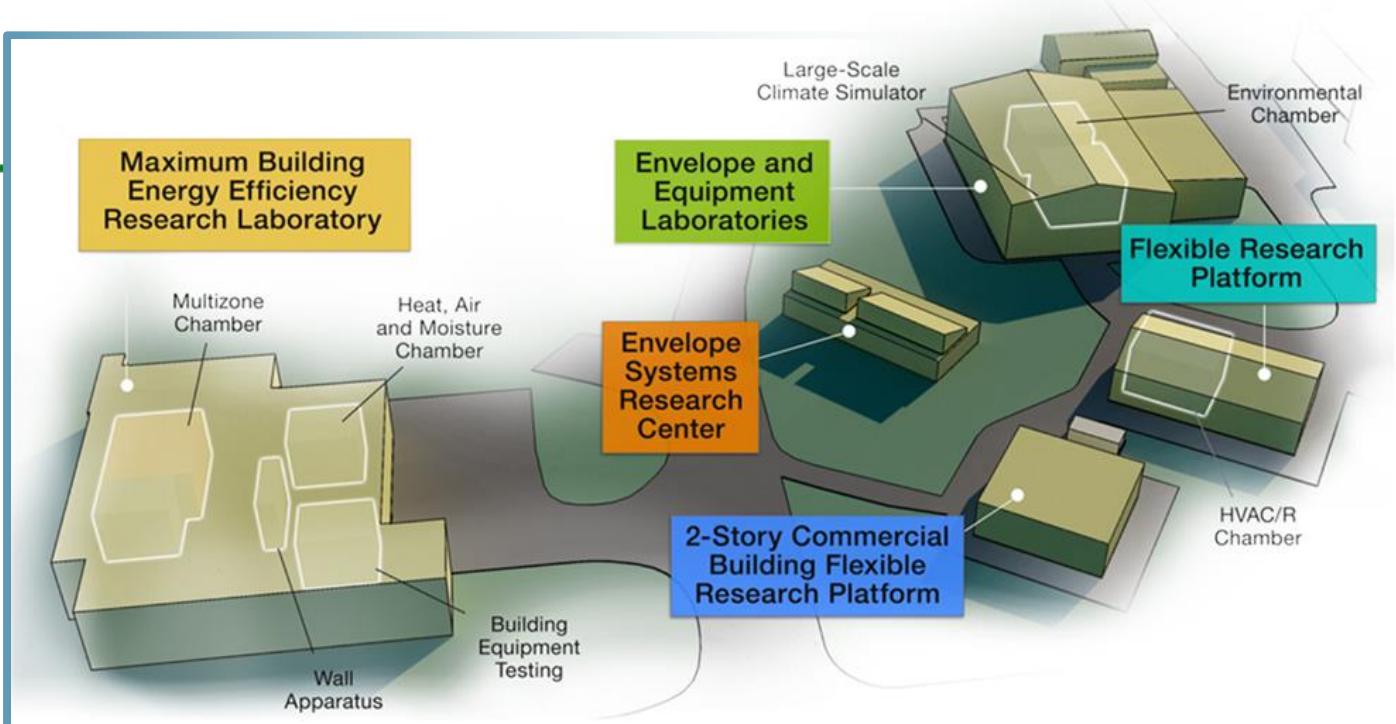
Integrate optimized microchannel condenser in the propane HPWH and measure the performance

Accelerated Life Test

Publication:
"A Numerical Modelling Study on Submerged Condensers for Heat Pump Water Heaters Using Low-GWP Refrigerants", Mingkan Zhang, Bo Shen, International Refrigeration Conference at Purdue, 2022.

Thank you

Oak Ridge National Laboratory
Bo Shen, Research Staff
(865)-574-5745; shenb@ornl.gov



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

Project Schedule

	Task		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Year 1	1	Development of submerged condenser coil sizing and propane HPWH system design tool								
	2	Develop double-wall submerged condenser using microtubes, and size evaporator(s)								
	Milestone 1	Report optimized design, heat exchanger configurations, and manufacturing method								
	3	Identification of anti-scaling coating material								
	4	Fabrication of HPWHs using submerged coils with regular tubes and microtubes								
	5	First Round of Laboratory Investigations								
	Milestone 2	Initial lab tests verify a UEF > 3.0 using propane charge < 200 grams					Go/No-Go			
Year 2	6	Improvement and Modification towards the final project goals								
	Milestone 3	experimental results prove measured UEF > 3.3, system charge < 150 grams						Go/No-		
	7	Accelerated Life Tests								
	8	Develop a Commercialization Plan and Manufacturing guidelines								
	9	Final Reporting								
	Milestone 4	Submit project final report summarizing all the laboratory investigations, manufacturing guidelines.								

Project Budget

Project Budget: $300K (DOE)
Variances: NONE
Cost to Date: $300K
Additional Funding: NONE

Budget History					
FY 2022		FY 2023		FY 2024	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
50K	50K	$150K	$150K	$100K	$100K

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 motivated its suppliers to improve microchannel condenser design and make propane specific compressor @ 60HZ.
- 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.

REFERENCE SLIDES