Cold Climate HPWH using Environment-Friendly Refrigerants

Phase I: Low GWP refrigerants evaluation for Rheem residential HPWHs

Phase II: Develop Cold Climate HPWH for Multi-family buildings

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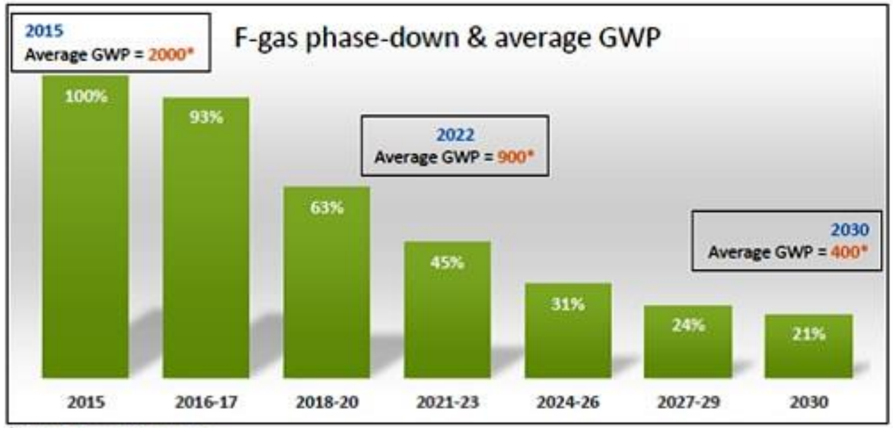
Project Summary

Objective and outcome

- Refrigerant transitions for residential and commercial HPWHs
- Upgraded DOE/ORNL Heat Pump Design Model (HPDM) as the product design and optimization tool to assist refrigerant transition in HPWHs
- Laboratory investigation of low GWP refrigerant options to replace R-134a in Rheem residential HPWH families including 220V and 110V products
- Development and laboratory verification on a commercial cold climate heat pump water heater

Team and Partners

Rheem Manufacturing Company (CRADA partner)



* Source: European Commission

Stats

Phase I (completed): 10/01/2020 to 09/30/2022 – residential; Budget: DOE-$80K, Rheem - $20K

Key Milestones

1. Investigate low GWP refrigerants in a 40-gallon, 220V Rheem residential HPWH, 09/30/2021
2. Investigate low GWP refrigerants in a 50-gallon, 110V, Rheem residential HPWH, 09/30/2022

Phase II (future work)-Cold Climate HPWH: 05/2023 to 06/2024 (separate project) –for final approval; Budget: DOE-$200K, Rheem - $200K

1. Phase II kicks off, 04/2023
2. Laboratory performance verification on light commercial HPWH, Heat water up >= 140˚F down to 5˚F having a COP > 2.0 and annual COP > 3.6, 05/2024

Problems

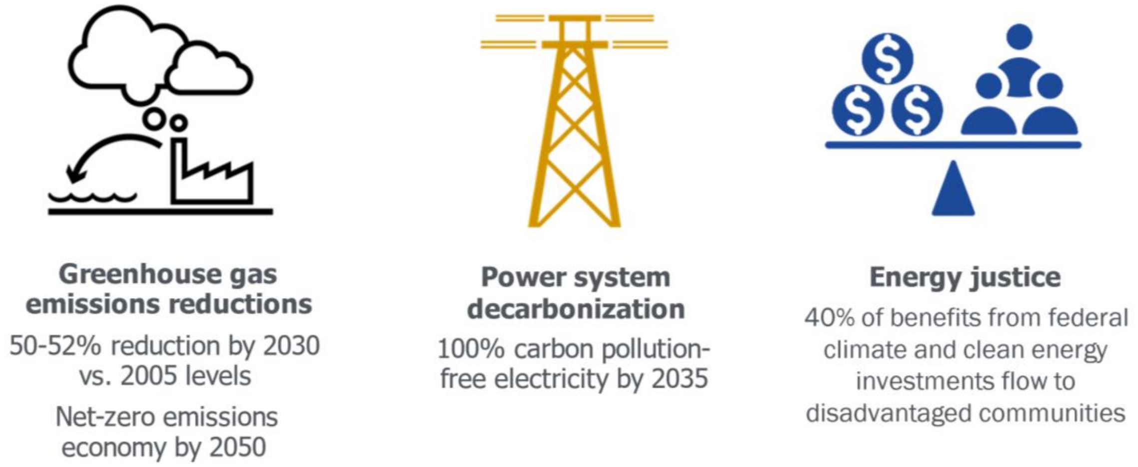
Phase I:

- The HPWH industry is phasing out high GWP refrigerants of R-134a (GWP of 1430) and R-410A (GWP of 1890)
- Uniform Energy Factors (UEF) and First Hour Ratings (FHR)of new low GWP refrigerants/blends in 220V/120V HPWHs are unknown yet.

Phase II:

- It is more challenging to develop a cold climate HPWH than heat pump, because higher water supply temperature > 110˚F than 95˚F air supply temperature
- High pressure ratio of CCHPWH at low ambient temperature causes drastic capacity degradation, low heating efficiency and high compressor discharge temperature.

Alignment and Impact

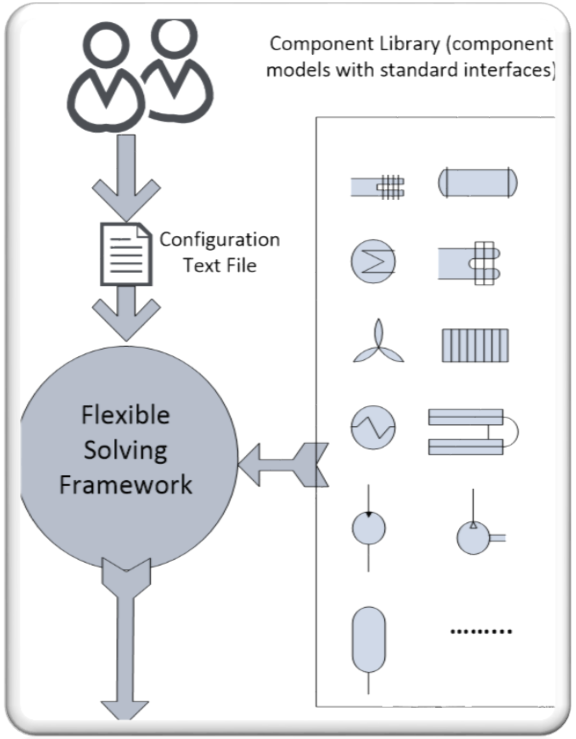


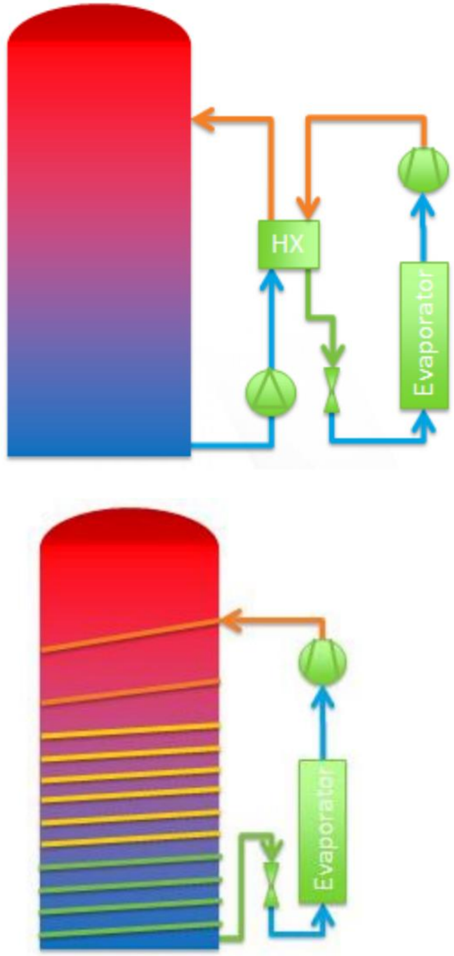
- Power System Decarbonization: Advance HPWH technologies to replace gas water heaters and reduce GHG emissions.
- Green House Emissions Reductions: Replace high GWP refrigerants in Rheem's residential and commercial HPWH product families
- Energy Justice: Develop commercial cold climate heat pump water heaters for multi-family buildings
- Develop and calibrate high-fidelity, public-domain HPWH and heat exchanger modelling and design tool for low GWP refrigerants in wrapped-tank and forced water flow configurations

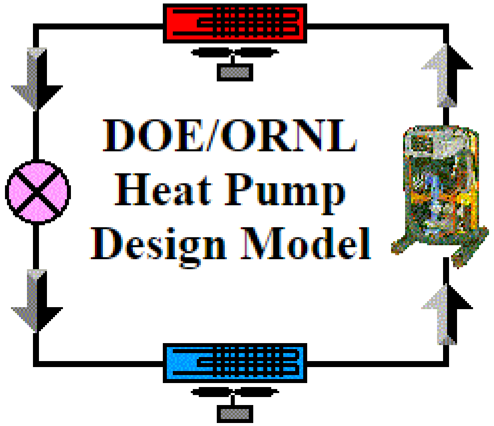
Approach – Upgrade DOE/ORNL Heat Pump Design Model

Component-Based

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



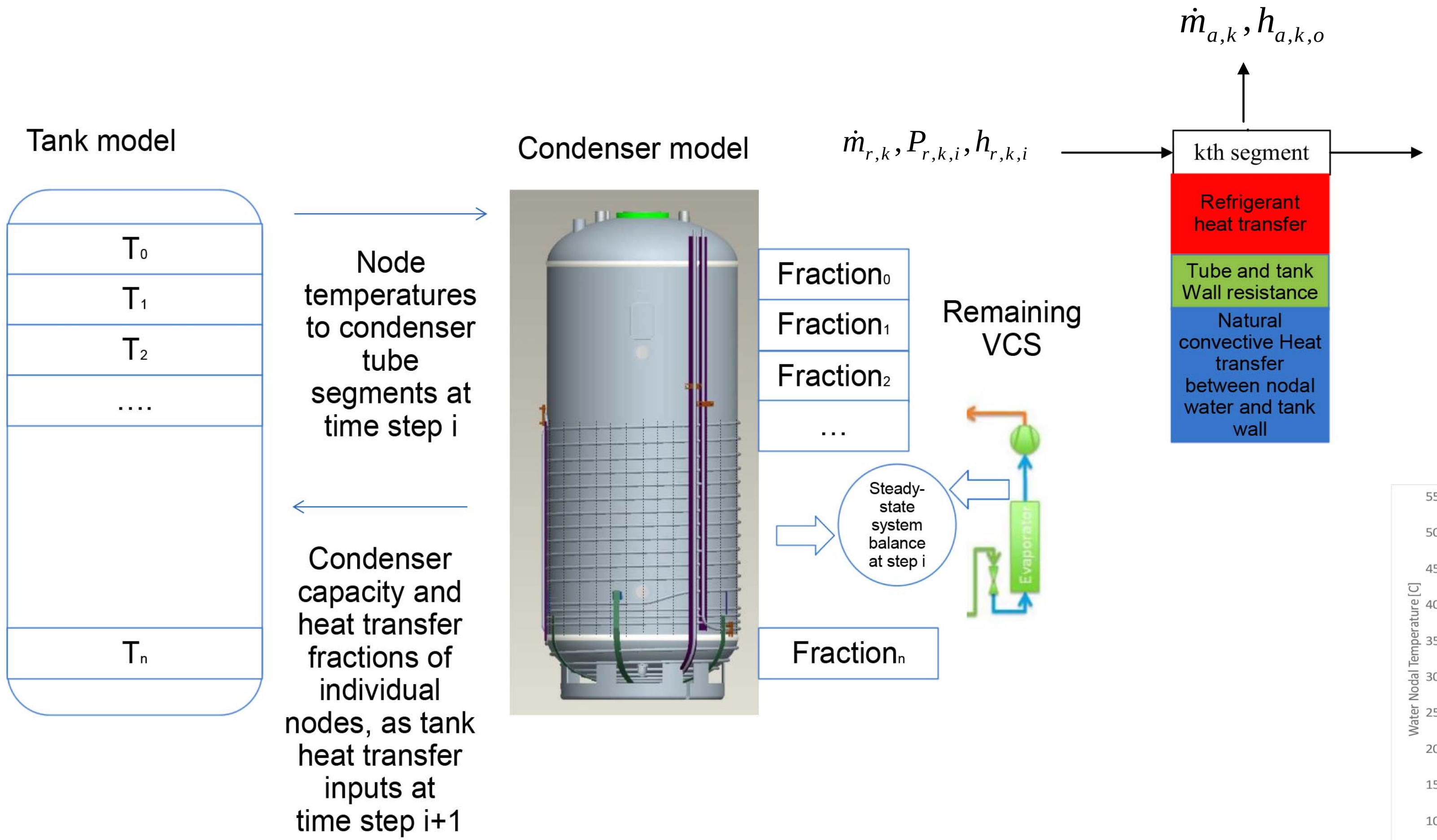




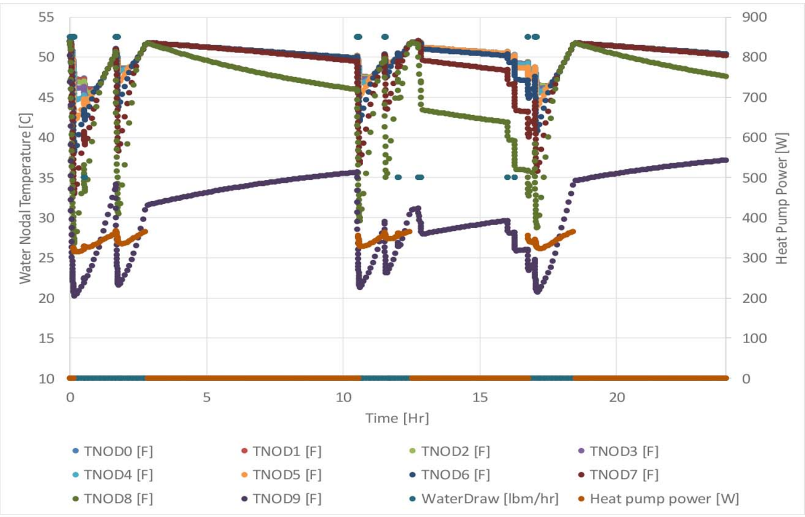
Automatically connect components into required system configuration by user input file.

https://Hpdmflex.ornl.gov

Progress: Segment-to-Segment Tank Coil Model



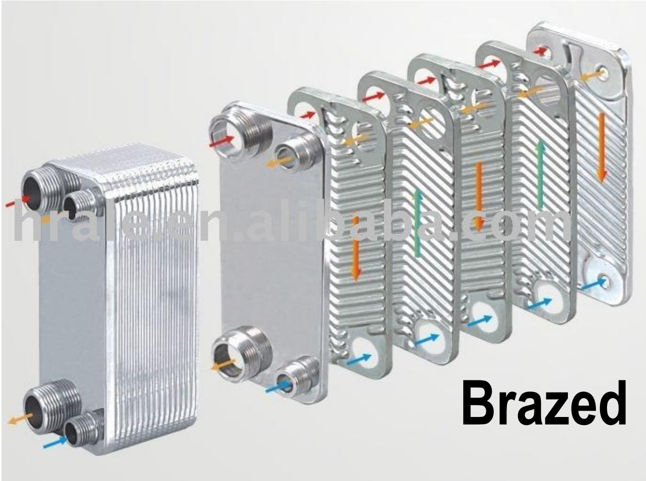
24-hr Uniform Energy Factor (UEF) and First-Hour Rating (FHR), Simulated within 5 Minutes



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

Progress: Segment-to-Segment Forced Flow Water-to-Refrigerant Heat Exchanger Model

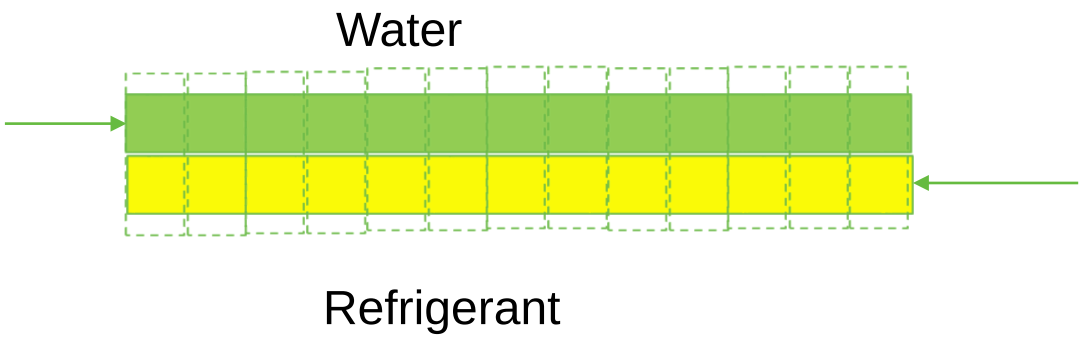


Brazed Plate HX

Tube-in-Tube HX

Canister shell-&-tube heat exchanger

Segmented control volumes



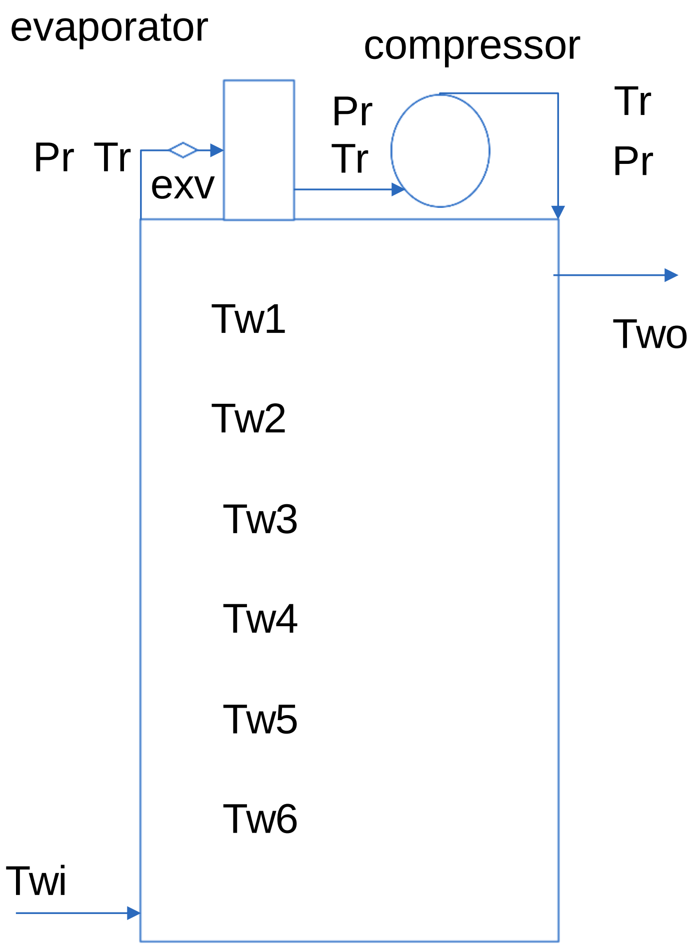
$$\dot{Q}_{max} = C_{min}(T_{h,i} - T_{c,i})$$

$$\varepsilon = 1 - \exp(-NTU)$$

Approach: Two Representative Rheem HPWHs (Phase I)

220V- 40-gallon HPWH

110V- 50-gallon HPWH

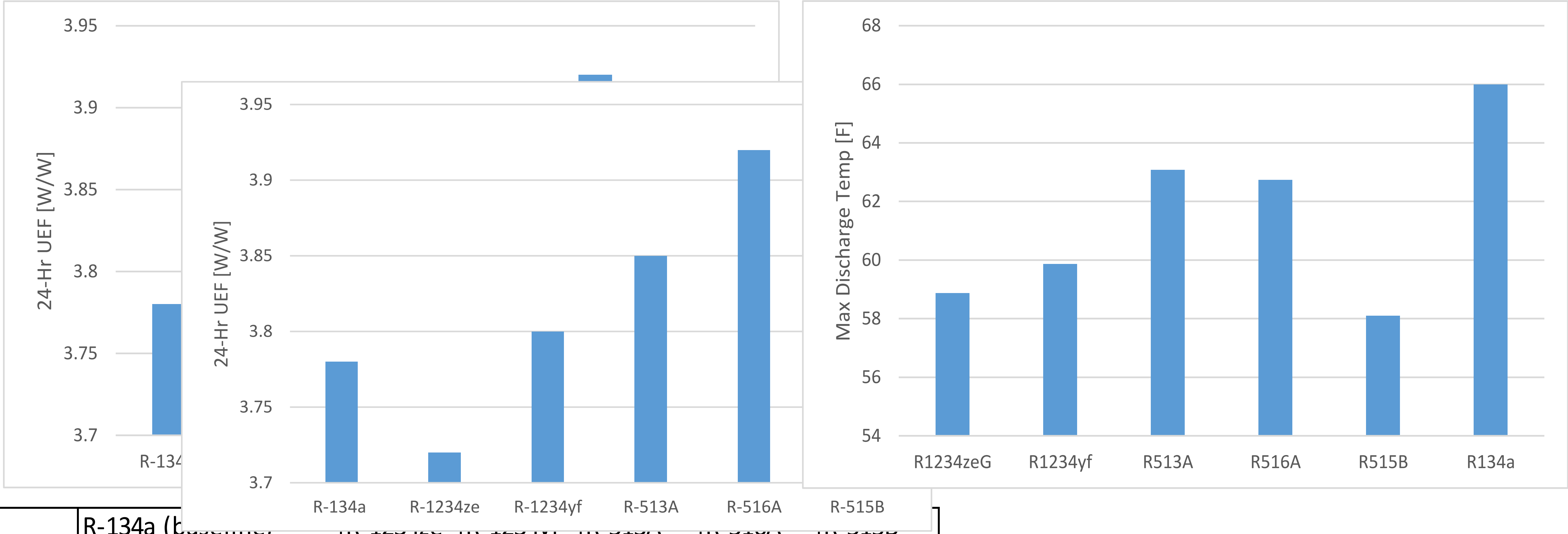


Progress: Rheem collected low GWP refrigerant candidates (Phase I)

Refrigerant	GWP	Safety Class	Glide/pressure in Condenser @54.4°C [K]/[kPa]	Glide/press in Evaporator @ 4.4°C [K] /[kPa]	Critical Temperature/Mole weight [C]/[g/mol]	Volume Vapor Heat@54.4°C [kJ/m³]	Volume Vapor Heat@ 4.4°C [kJ/m³]
R-134a (baseline)	1430	A1	0/1469	0/342	101.06/102.0	10959.4	3276.0
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-513A[a]	573	A1	0.01/1530	0.01/377	96.5/108.43	10832.0	3442.8
R-516A[b]	131	A2L	0.0/1478	0.0/369	97.17/102.6	10411.3	3332.5
R-515B[c]	293	A1	0.0/1107	0.0/252	108.7/117.48	8472.4	2457.9

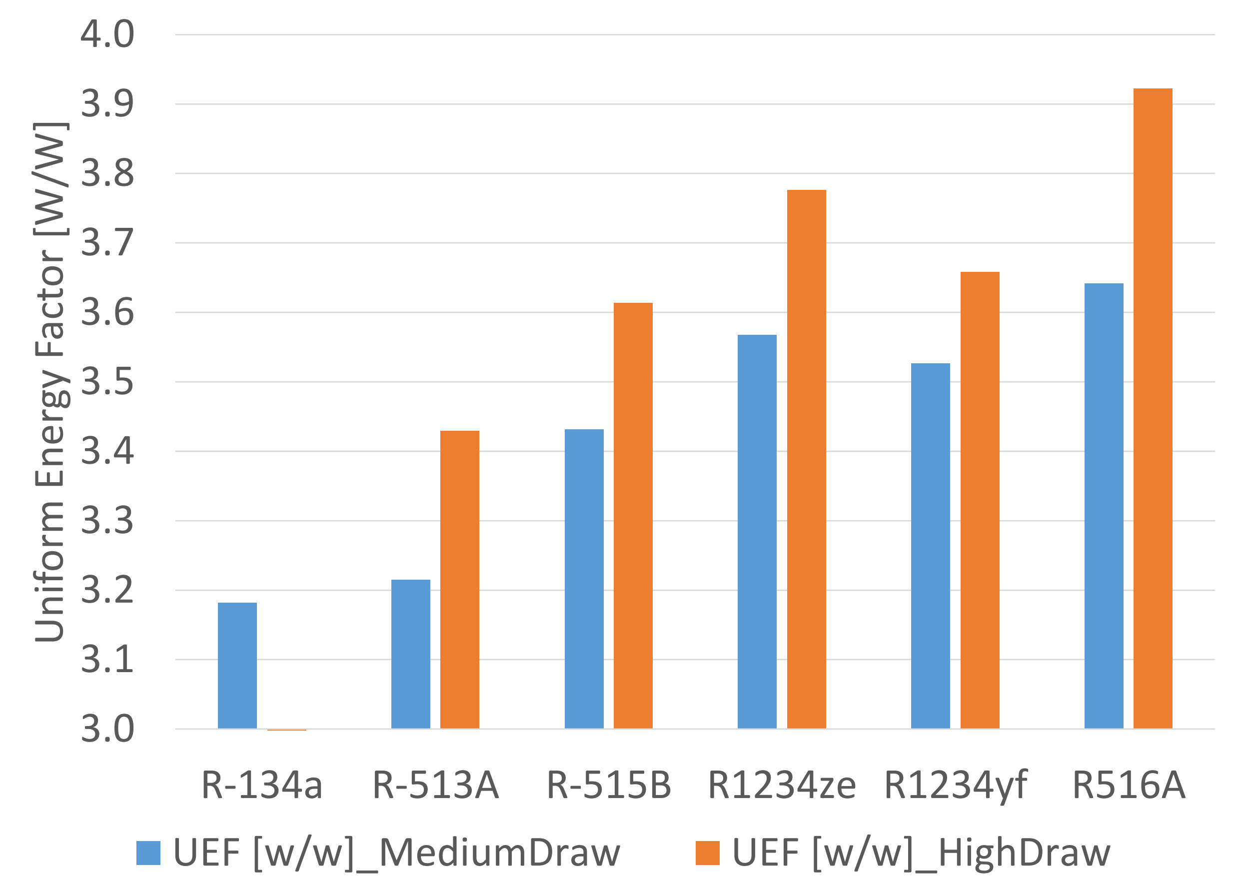
[a] R-513A has mass-based compositions of R-1234yf (0.56)/ R-134a (0.44).
[b] R-516A has mass-based R1234yf (0.775)/R152a (0.14)/ R134a(0.085).
[c] R-515B has mass-based R1234ze (0.911) and R227ea (0.089)

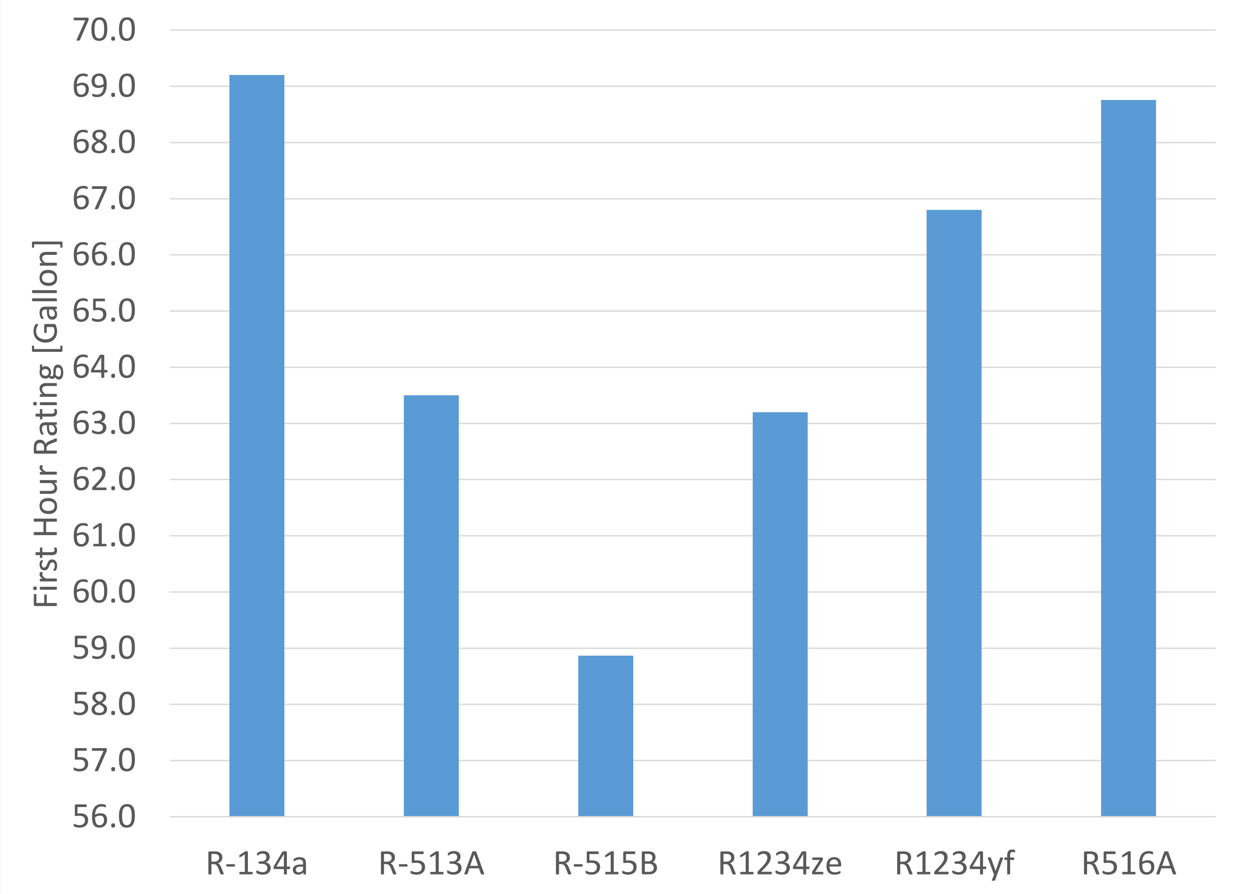
Progress: Experimental Results of 40-gallon, 220V HPWH



Refrigerant	R-134a (baseline)	R-1234ze	R-1234yf	R-513A	R-516A	R-515B
Charge [oz]	28	30	30	32	30	28
24-Hour UEF [W/W]	3.78 (nameplate: 3.75)	3.72	3.80	3.85	3.92	3.73

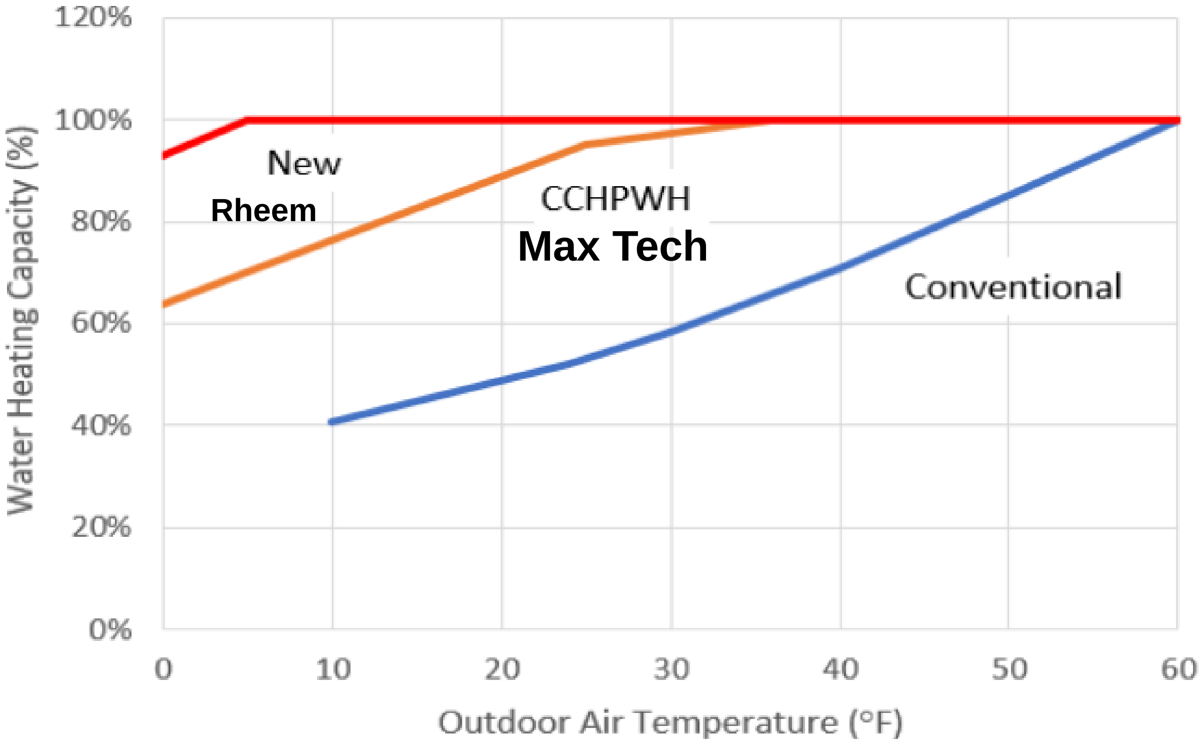
Progress: Experimental Results of 50-Gallon, 110V HPWH





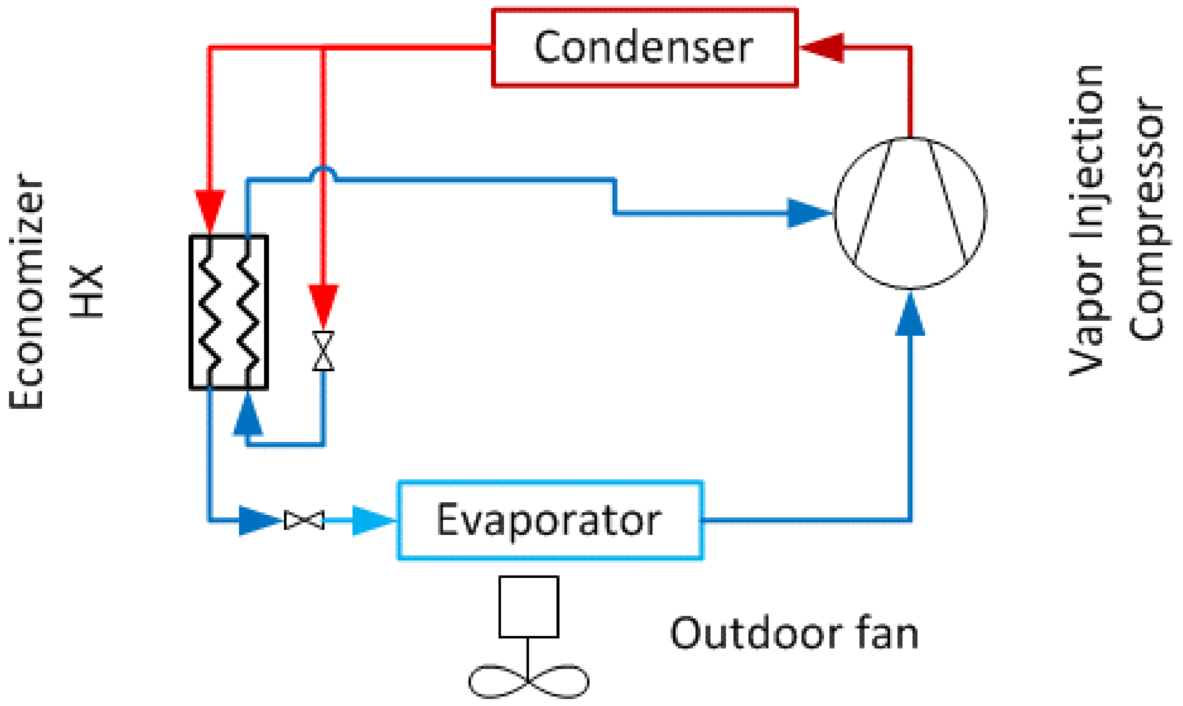
	R-134a	R-513A	R-515B	R1234ze	R1234yf	R516A
Optimized Charge [oz]	64	64	68	64	64	56
UEF [w/w]_MediumDraw	3.18	3.21	3.43	3.568	3.526	3.642
UEF [w/w]_HighDraw	N/A	3.43	3.61	3.776	3.658	3.922
FHR [gallon]	69.2	63.5	58.9	63.2	66.8	68.8

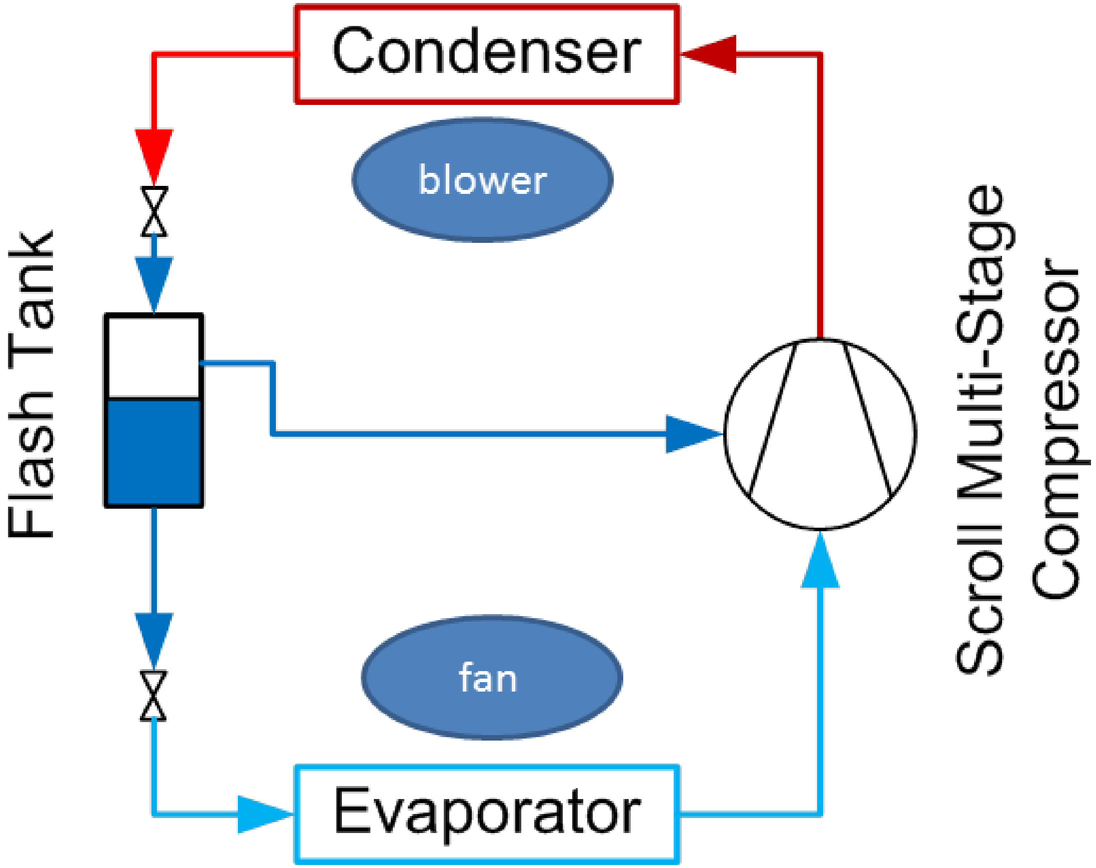
Future Work: Commercial CCHPWH Design Targets (Phase II)



	Low target	High target
DHW efficiency rating	UEF ≥ 2.20 (Energy Star v5.0 [3])	SCOP ≥ 3.6 (Tier 5 from NEEA Advanced Water Heater Specification v8.0 [4])
Hydronic space heating efficiency	CoP (Ambient air temperature- A7˚C/return water temperature- W35˚C) ≥ 4.5	CoP (A7/W65) ≥ 4.5
Cold climate heating capacity	No auxiliary electric heating down to 5 °F	No auxiliary electric heating down to −5 °F
Cold climate heating efficiency	CoP ≥ 1.7 at 5 °F outdoor temperature	CoP ≥ 2.0 at 5 °F outdoor temperature
Maximum leaving water temperature	140 °F	180 °F

Future Work: Variable-Speed Vapor Injection System Configurations





Model-based concept selection

Developed variable-speed vapor injection compressor model in HPDM library.

Publications

- Parametric studies of heat pump water heater using low GWP refrigerants, B Shen, K Nawaz, A Elatar - International Journal of Refrigeration, 2021
- Bo Shen, Kashif Nawaz, Van Baxter, Ahmed Elatar, Development and validation of quasi-steady-state heat pump water heater model having stratified water tank and wrapped-tank condenser, International Journal of Refrigeration, Volume 87, 2018, Pages 78-90, ISSN 0140-7007

Thank you

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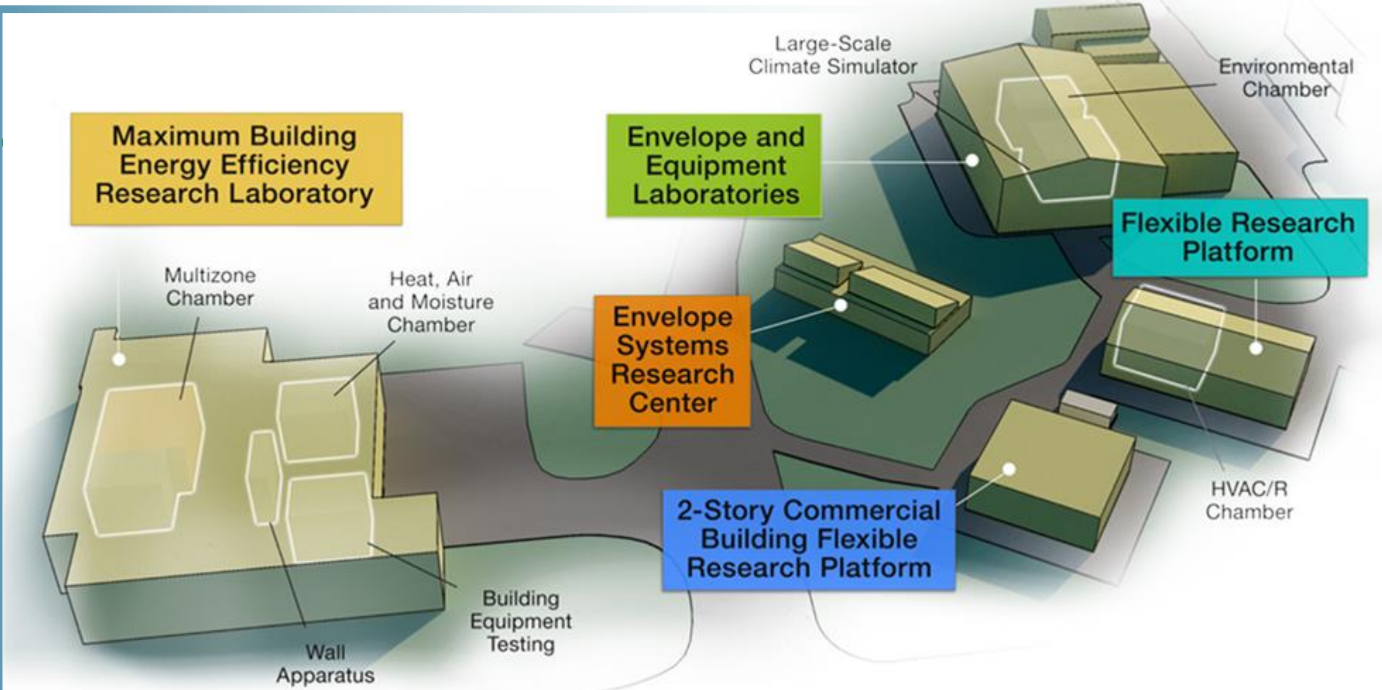

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 50,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free 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

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 fabricated system prototypes
- Rheem provided all the low GWP refrigerant samples
- Weekly meetings with Rheem engineers to monitor the progress.

Remaining Project Work

Phase I has completed and final report released

Phase II, development of commercial CCHPWH launched

Project Budget

Project Budget: $80K (DOE) (Phase I)
Variances: NONE
Cost to Date: $80K
Additional Funding: 200K (Phase II)

Budget History					
FY 2021		FY 2022		FY 2023	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
40K	10K	$40K	$10K	$200K	$200K

REFERENCE SLIDES