BTO Peer Review:

MaxTech Heat Pump Water Heater Using Ultralow Global-Warming-Potential Refrigerants

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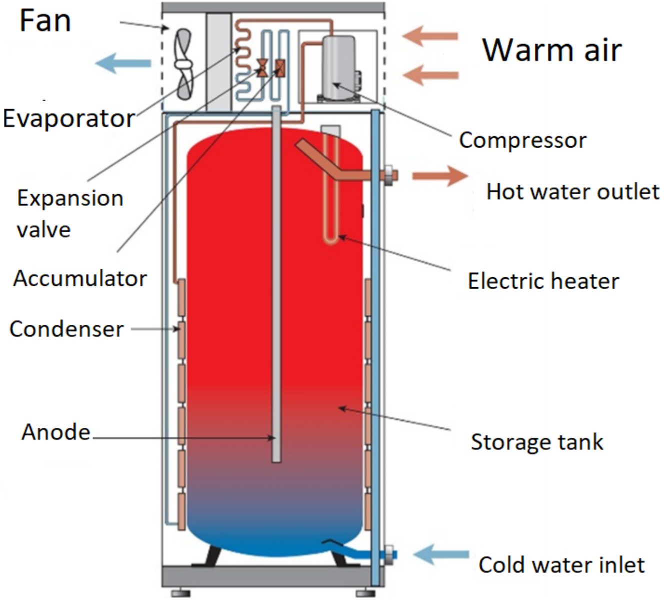

Oak Ridge National Laboratory
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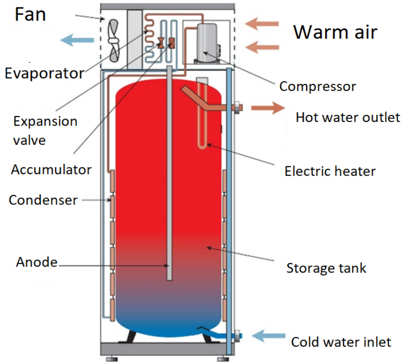
WBS 03.02.02.79.02

Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

Evaluate the potential of propane (R290) to replace R134a for a residential hybrid heat pump water heater (HPWH) as a drop-in replacement refrigerant.
Evaluate various charge-reduction approaches and analyze the impacts of various component and system modifications on total refrigerant charge.
Conduct a field evaluation of the optimized configuration.



TEAM AND PARTNERS

Oak Ridge National Laboratory: Kashif Nawaz, Bo Shen, Joe Rendall, Ahmed Elatar, Jian Sun
A.O. Smith: Steve Memory, Jiamin Yin, Tim Rooney

STATS

Performance Period: March 2023–September 2026

DOE Budget: $300K, Cost Share: $100K

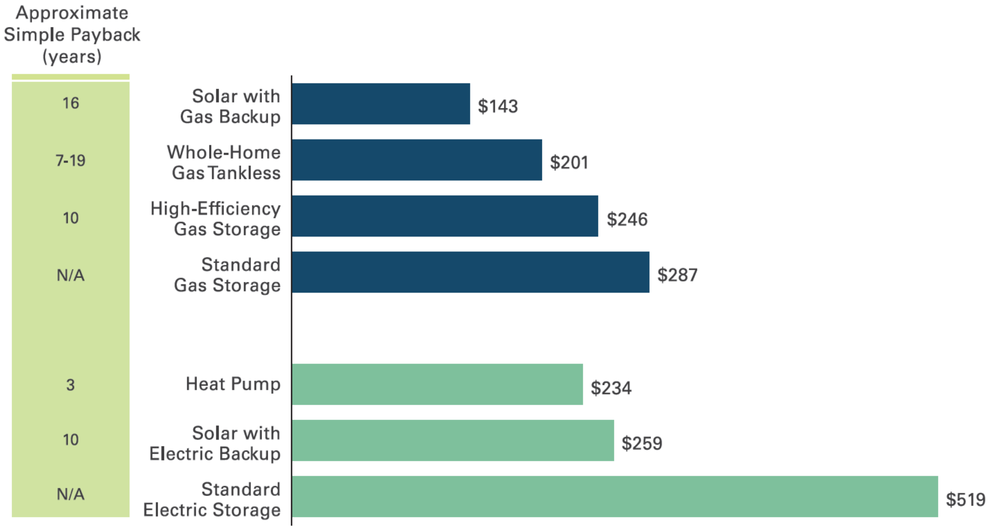
Milestone 1: Completion of thermodynamic analysis

Milestone 2: Drop-in replacement analysis (baseline)

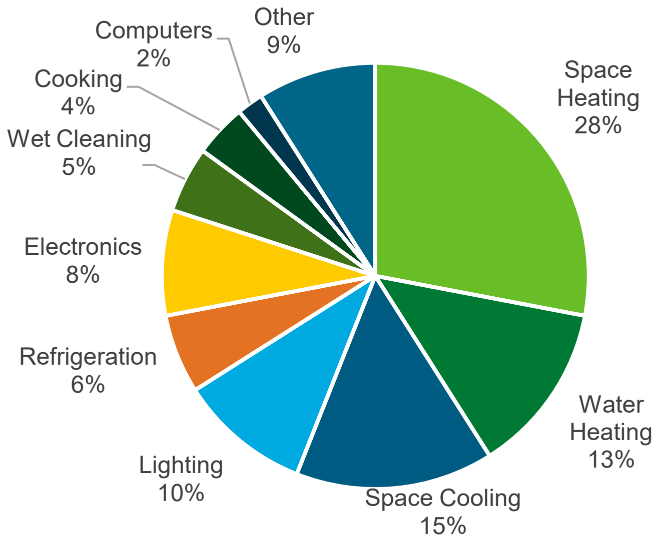
Milestone 3: Development of prototype for lab-scale performance evaluation

Problem

- Water heating accounts for about 10% of all residential- and commercial-site energy use in the United States
- Replacing gas-fired and electric-resistive water heaters with HPWHs is critical for decarbonizing the buildings sector



Annual energy consumption of various water-heating technologies

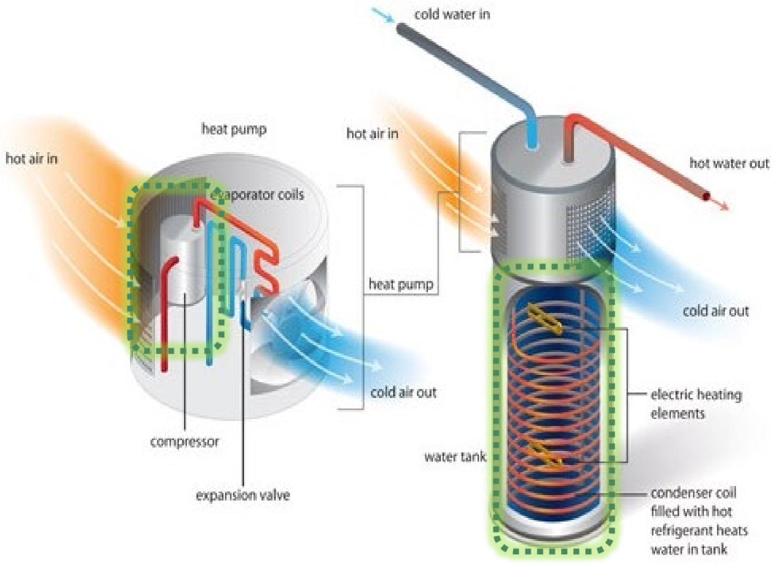


Residential end-use energy by different applications (US EIA, 2013)

Energy Star Water Heater Market Profile, D&R International, 2010

Problem

- HPWH technology has been validated and proven to be successful through lab and field experiments
- Although the technology is mature, there are obvious opportunities to further enhance the performance of the systems
- Hybrid configuration can help meet demand when heat pumps cannot provide sufficient heating
- Overall system performance depends on several factors, including the following:
    - Tank thermal stratification
    - Condenser design
    - Compressor
    - **Working fluid**

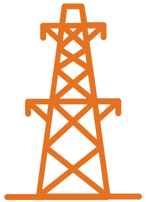


Operation of a HPWH

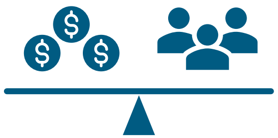
Alignment and Impact

- At least 250 TBtu energy savings in water-heating technology
- Emission reductions of more than 100 Mt CO_2 (direct and indirect)
- Enabling A2L and A3 refrigerants to be developed for deployment
  - Reduction in refrigerant charge
  - Reduced cost of the working fluid
  - Reduced required maintenance due to compact design
- Implications for additional processes
  - Residential air cooling/heating, refrigeration, process-water heating
- Opportunities to create more than 4,000 new jobs
- Paving the path for US manufacturers to expand to international markets

Greenhouse gas emissions reductions



Power system decarbonization

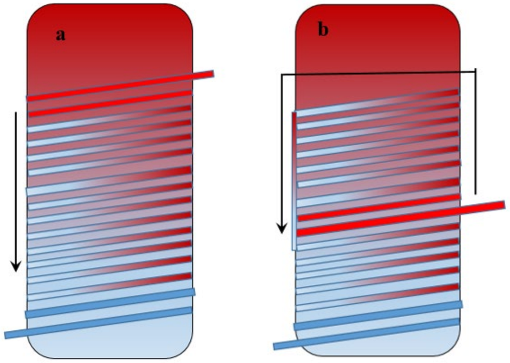


Energy justice

Approach

- Heat pump thermostat at the top: on at 115°F, off at 125°F
- Electric element at the top: on at 110°F, off at 125°F
- Two different condenser coil wrap patterns

Case number	Wrap pattern	Tank insulation effectiveness (%)
1	Parallel counterflow	90
2	Parallel counterflow	95
3	Counterflow	90
4	Counterflow	95



Condenser wrap configurations:
(a) counterflow, (b) parallel counterflow

Approach Performance Evaluation Criteria

FHR greater or equal to (gal)	FHR less than (gal)	Draw pattern for 24 h UEF
0	20	Point of use
20	55	Low usage
55	80	Medium usage
80	Max	High usage

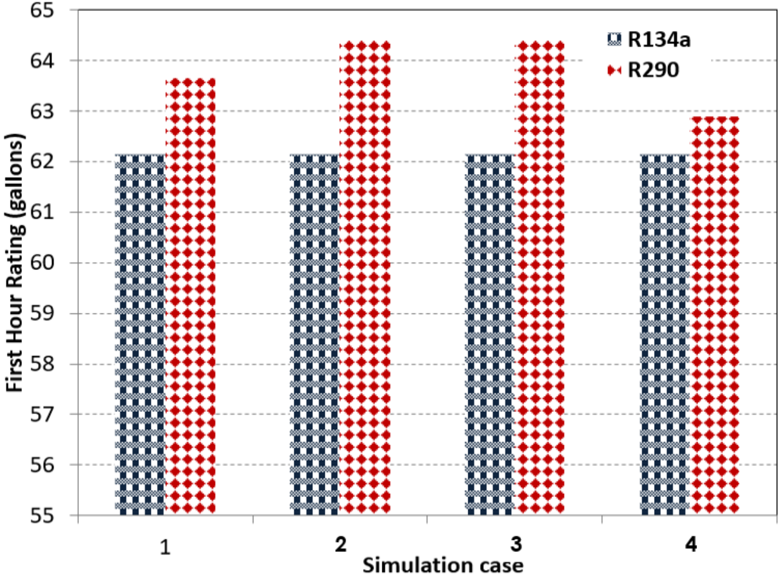
Medium-usage draw pattern

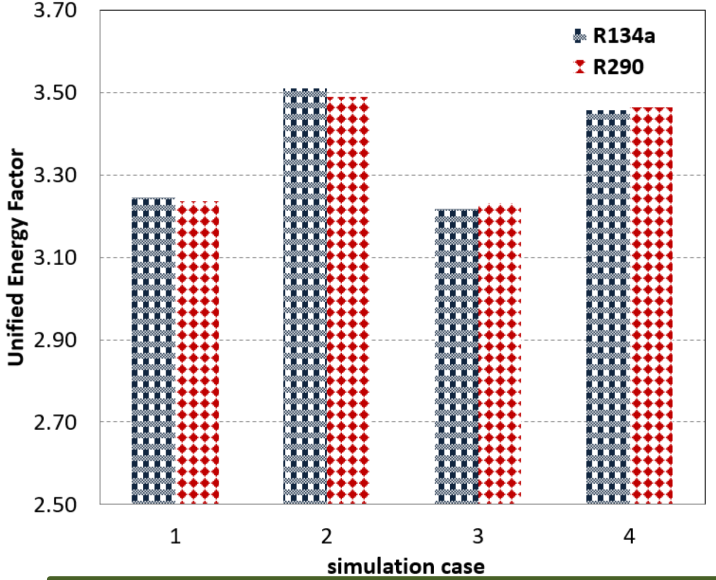
Draw number	Time during test (hh:mm)	Volume (gal/L)	Flow rate (GPM/LPM)
1	00:00	15.0 (56.8)	1.7 (6.5)
2	00:30	2.0 (7.6)	1 (3.8)
3	01:40	9.0 (34.1)	1.7 (6.5)
4	10:30	9.0 (34.1)	1.7 (6.5)
5	11:30	5.0 (18.9)	1.7 (6.5)
6	12:00	1.0 (3.8)	1 (3.8)
7	12:45	1.0 (3.8)	1 (3.8)
8	12:50	1.0 (3.8)	1 (3.8)
9	16:00	1.0 (3.8)	1 (3.8)
10	16:15	2.0 (7.6)	1 (3.8)
11	16:45	2.0 (7.6)	1.7 (6.5)
12	17:00	7.0 (26.5)	1.7 (6.5)

Total volume drawn per day: 55 gal (208 L)

FHR = first-hour rating
UEF = Uniform Energy Factor

Progress FHR and UEF



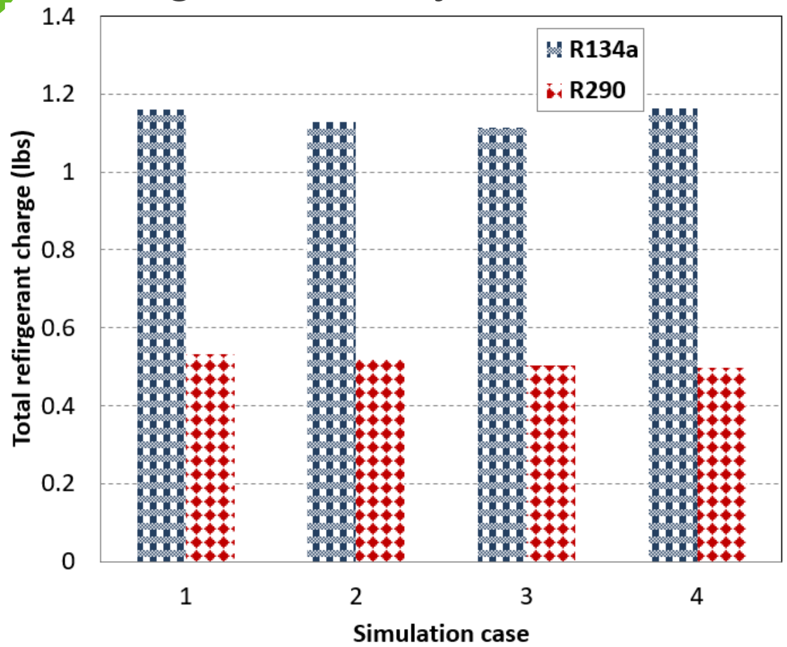


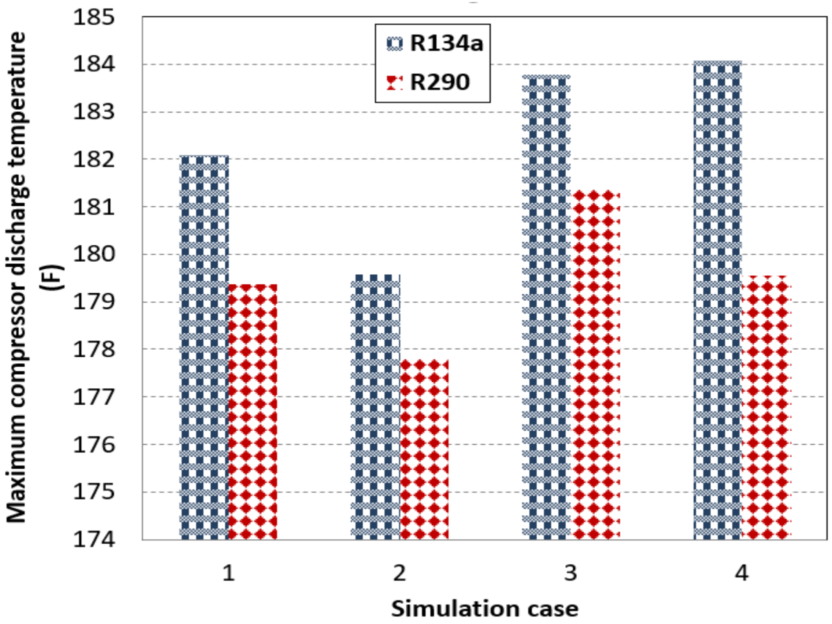
The FHR is a measure of the available hot-water capacity of the water heater (in gallons).

$$\mathbf{UEF} = \sum_{k=1}^{n} \frac{M_k c_p (T_s - T_i)}{W_i}$$

K. Nawaz, B. Shen, A. Elatar, V. Baxter, O. Abdelaziz, "R-290 and R-600a as Natural Refrigerants for Residential Heat Pump Water Heaters," *Applied Thermal Engineering*, 2017, 127, 870–883

Progress Compressor Discharge Temperature and Refrigerant Charge Inventory



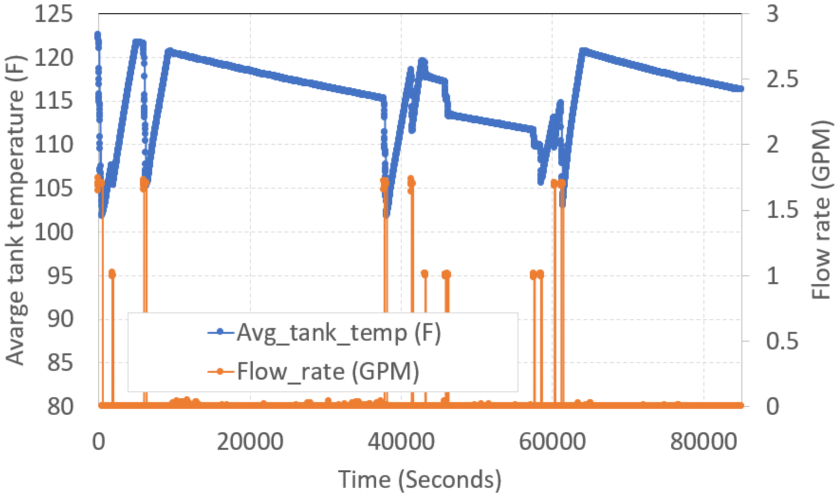


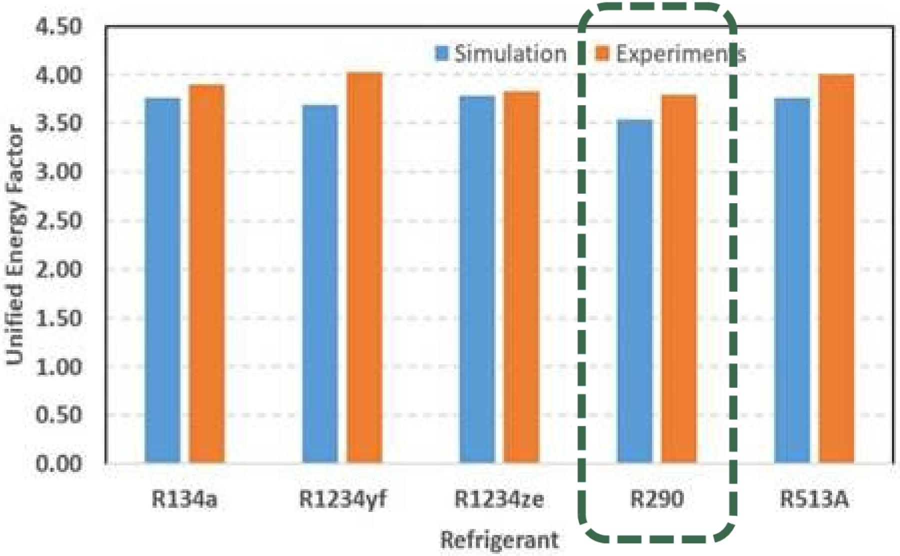
Direct refrigerant replacement leads to a major charge reduction, mainly because of thermophysical properties.

Lower compressor discharge is always advantageous for direct replacement.

K. Nawaz, B. Shen, A. Elatar, V. Baxter, O. Abdelaziz, "R-290 and R-600a as Natural Refrigerants for Residential Heat Pump Water Heaters," *Applied Thermal Engineering*, 2017, 127, 870–883

Progress Experiments and Validation of Model

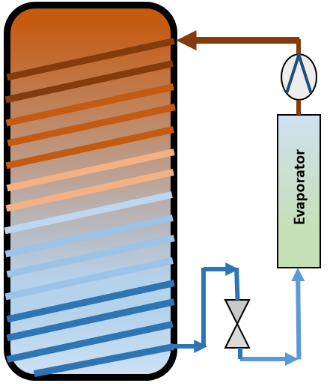




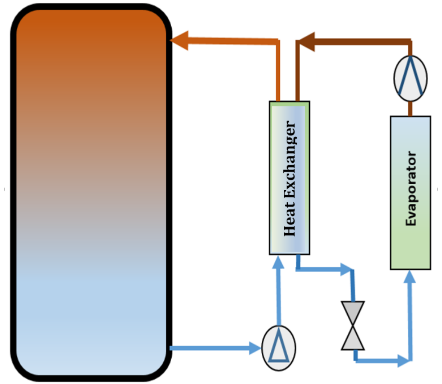
Average stored water temperature for propane is comparable with R134a.

Parameter	R134a	Propane (R290)
Optimum refrigerant charge	1.68 lb	0.85 lb
FHR	66 gal	64 gal
UEF	3.44	3.60

Progress Preliminary Developments for Charge Reduction

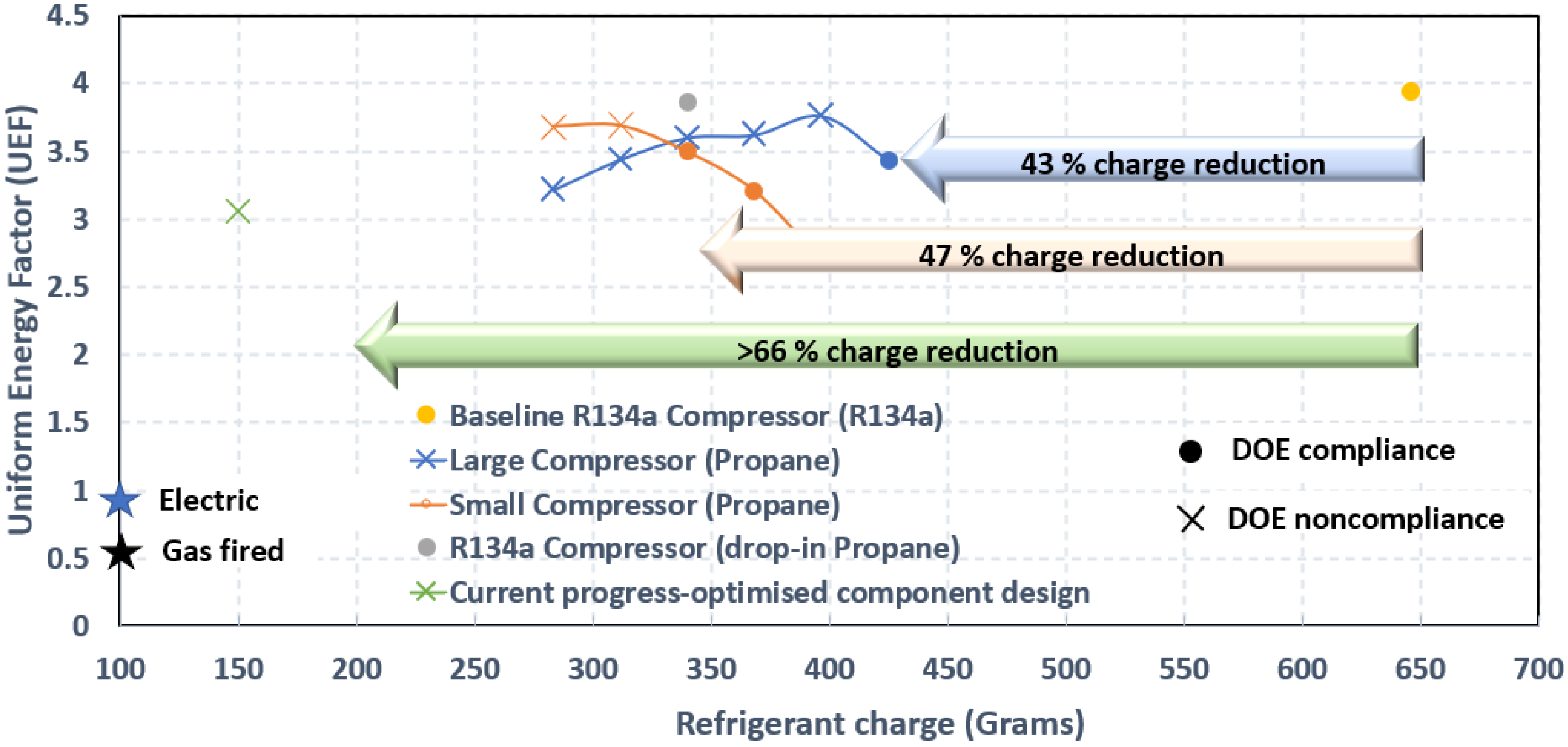


- Refrigerants with higher volumetric capacity
- Component modifications—design improvement of heat exchangers
- Deployment of improved compressor design
- System modifications—wrapped vs. split configurations



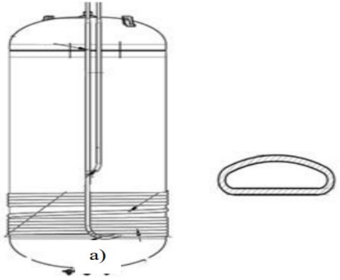
A refrigerant charge less than **150 g** is recommended for all indoor applications.

Progress Preliminary Developments for Charge Reduction

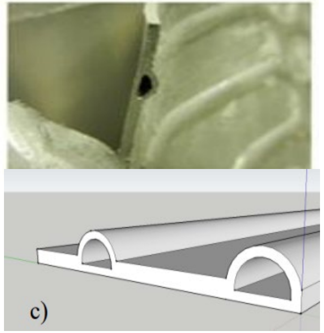


Progress Preliminary Developments for Charge Reduction

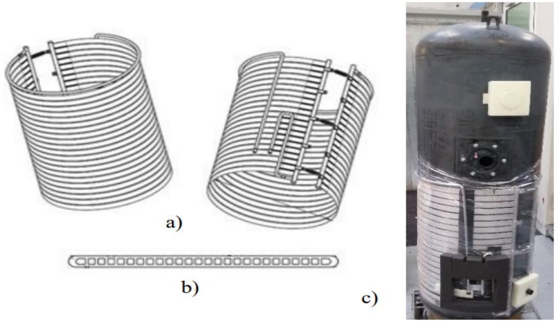
- 60% of the charge resides in the condenser for packaged HPWH



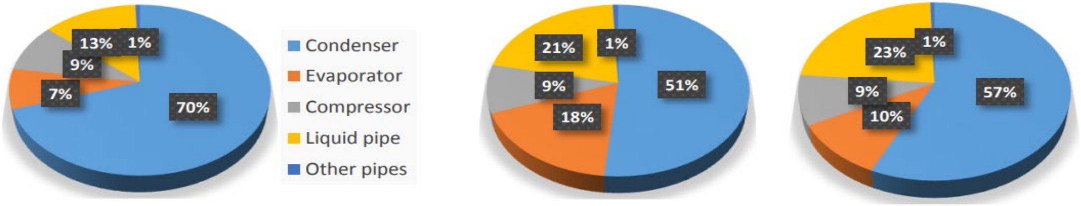
D-shaped tube based wrapped condenser



Roll-bond wrapped condenser



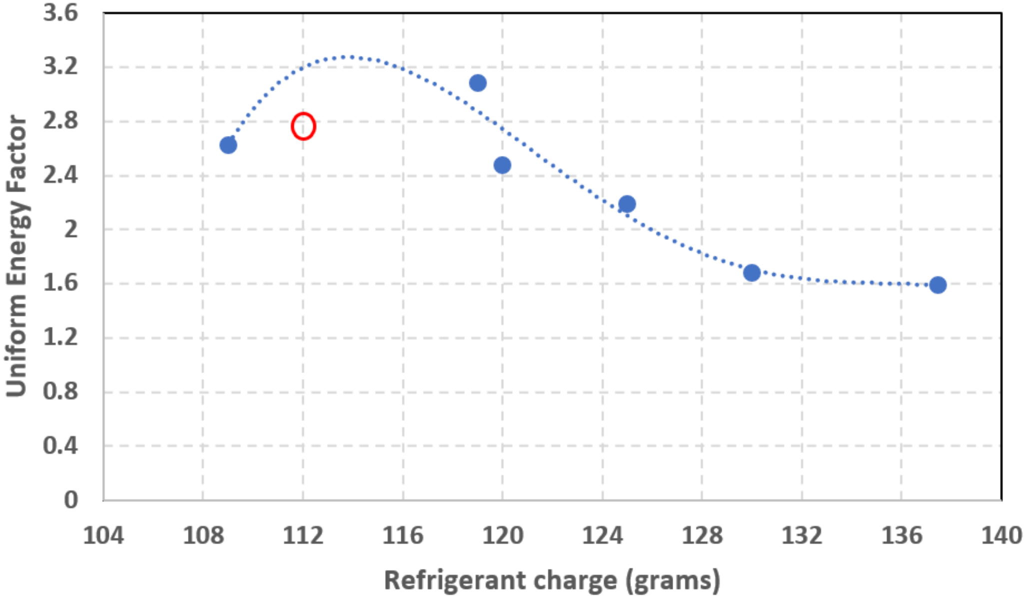
Microchannel wrapped condenser



a) D-tube b) Roll-bond c) Microchannel

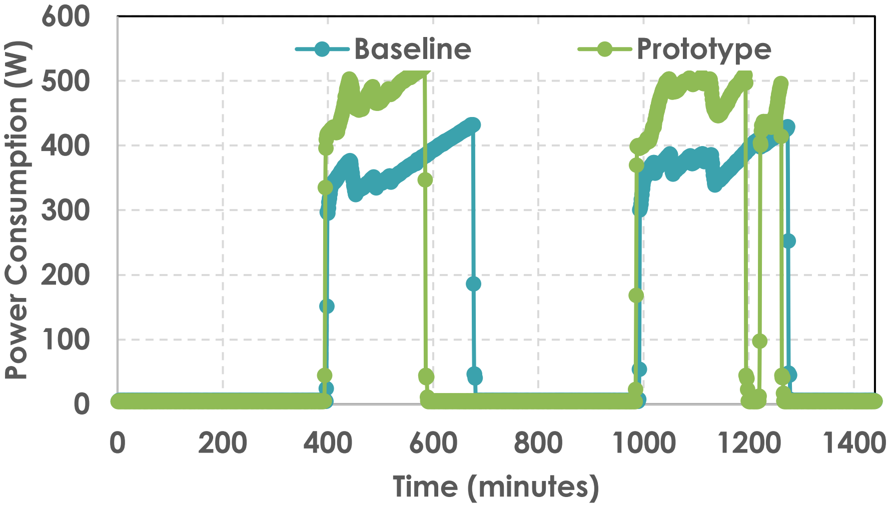
R. Ghoubali, P. Byrne, F. Bazantay, 2017, Refrigerant charge optimization for propane heat pump water heaters, International Journal of Refrigeration 76, DOI:10.1016/j.ijrefrig.2017.02.017

Progress Preliminary Developments for Charge Reduction



Progress Field Validation

Field study at Yarnell House: side-by-side comparison



Field evaluation has been in progress for over 3 months.

Conclusions and Future Developments

- R290 (propane) is a feasible working fluid for residential HPWHs
- Because of the higher volumetric capacity, direct drop-in replacement significantly reduces charge
- The total refrigerant charge in the system can be further reduced by appropriate component design modifications
- System-level modification is in progress with a focus on further charge reduction for comparable performance and cost

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Research Paper

R290 (propane) and R600a (isobutane) as natural refrigerants for residential heat pump water heaters ☆

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HIGHLIGHTS

- A HPDM model has been used to evaluate the performance of hydrocarbon as refrigerants for HPWH applications.
- The UEF and FHR have been used to evaluate the performance of R134a, R290 and R600a refrigerants.
- Different condenser wrap patterns and storage tank thermal insulation effectiveness have been consider.
- The impact of compressor discharge temperature, water stratification has been evaluated.
- The impact of saturation temperature change in condenser and total refrigerant charge has been evaluated.

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Hydrocarbons
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ABSTRACT

Growing awareness of the potential environmental impacts of various refrigerants has led to the phase-down of hydrofluorocarbon (HFC) refrigerants and to initiatives replacing HFCs with hydrocarbons or other environmentally friendlier fluids. This study evaluated the performance of R290 (propane) and R600a (isobutane) as substitutes for R134a (a HFC) for heat pump water heating (HPWH). A component-based model (calibrated against the experimental data) was used to predict the performance of the HPWH system. Key performance parameters such as unified energy factor, first hour rating, condenser discharge temperature, thermal stratification in the water tank, and total refrigerant charge were investigated. Analysis results suggest that both alternative refrigerants could provide comparable system performance to that of the baseline system containing R134a, with one caveat. As a drop-in alternative, R290 was found to be a better substitute for R134a, whereas R600a is expected to provide similar performance if the compressor size is increased to provide similar heating capacity. Significant reductions in system charge and lower condenser discharge temperatures were identified as additional benefits.

Thank you

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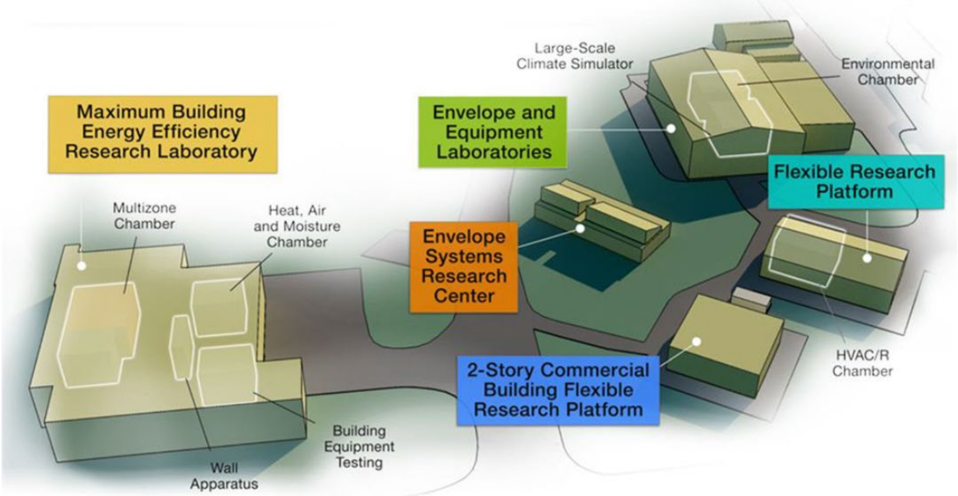

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Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

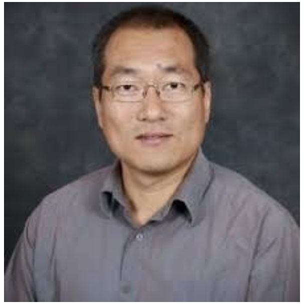
Reference Slides

Project Execution

	FY2023				FY2024				FY2025			
Planned budget	200,000				200,000				200,000			
Spent budget	220,000				180,000							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Market assessment												
Q2 Milestone: Simulation analysis												
Q3 Milestone: R134 based experiments												
Q4 Milestone: Prototype development R290												
Q1 Milestone: Drop-in-replacement study												
Current/Future Work												
Q3 Milestone: Charge minimization												
Q4 Milestone: Extended field evaluation												

Team

Kashif Nawaz
Project management
Experimentation



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Steve Memory
Prototype development

Ahmed Elatar
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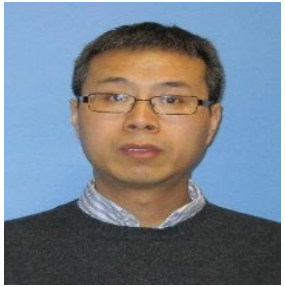

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