OAK RIDGE National Laboratory

Propane as an Alternative Refrigerant for Heat Pump Water Heating Technology

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U.S. DEPARTMENT OF ENERGY

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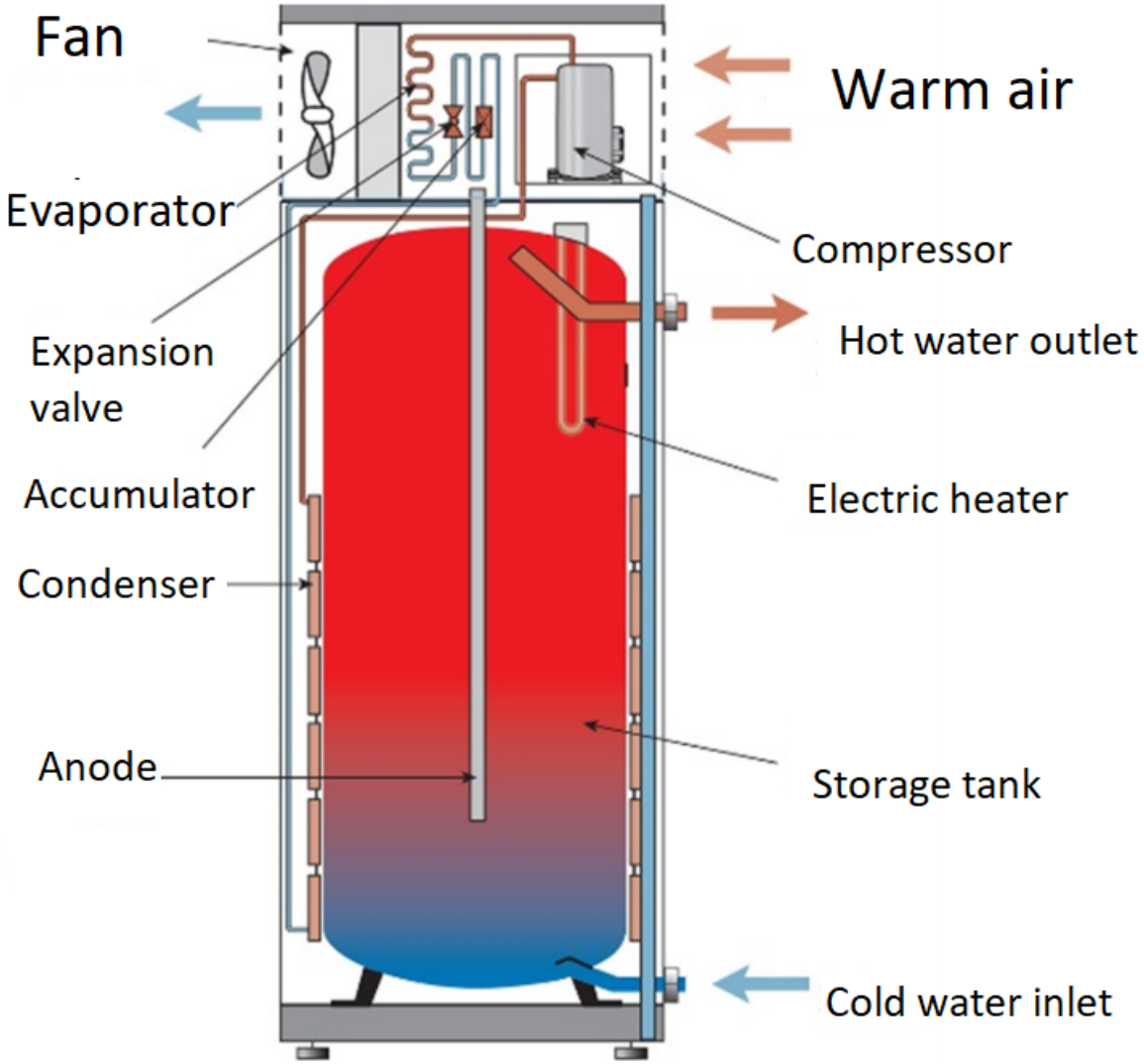
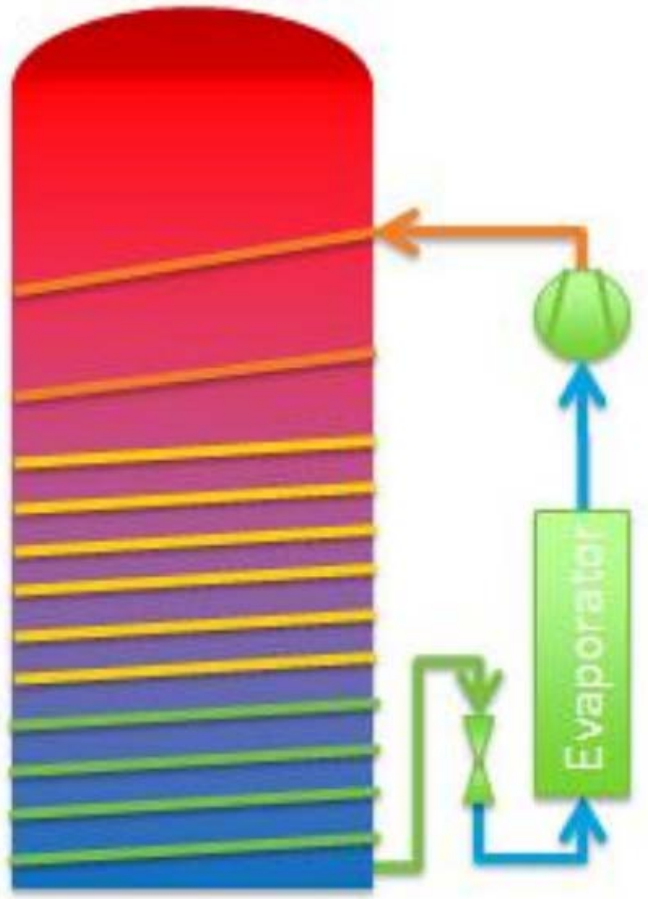
Background


Fan
Warm air
Evaporator
Compressor
Expansion valve
Hot water outlet
Accumulator
Electric heater
Condenser
Anode
Storage tank
Cold water inlet


Evaporator

Next Generation Refrigerants

Refrigerant group	Refrigerant example	ODP	GWP_{100}	Atmospheric lifetime (years)	Flammability
CFCs	R11, R12, R115	0.6–1	4750–14400	45–1700	Nonflammable
HCFCs	R22, R141b, R124	0.02–0.11	400–1800	1–20	Nonflammable
HFCs	R407C, R32, R134a	0	140–11700	1–300	Nonflammable or mildly flammable
HFOs	R1234fy, R1234ze, R1234yz	0	0–12	-	Mildly flammable
Natural refrigerants	R744, R717, HC (R290, R600, R600a)	0	0	Few days	HCs: Highly flammable R717: Flammable R744: Nonflammable

Goals

Identify appropriate substitute for R-134a as HFCs will phase out:

- **Evaluate the potential of Propane (R290) to replace R134a for a residential hybrid HPWH**
  - Low GWP, no direct environmental impact
  - No major modification of existing system is desired
  - Performance FHR and UEF should be comparable

Alternative Refrigerants

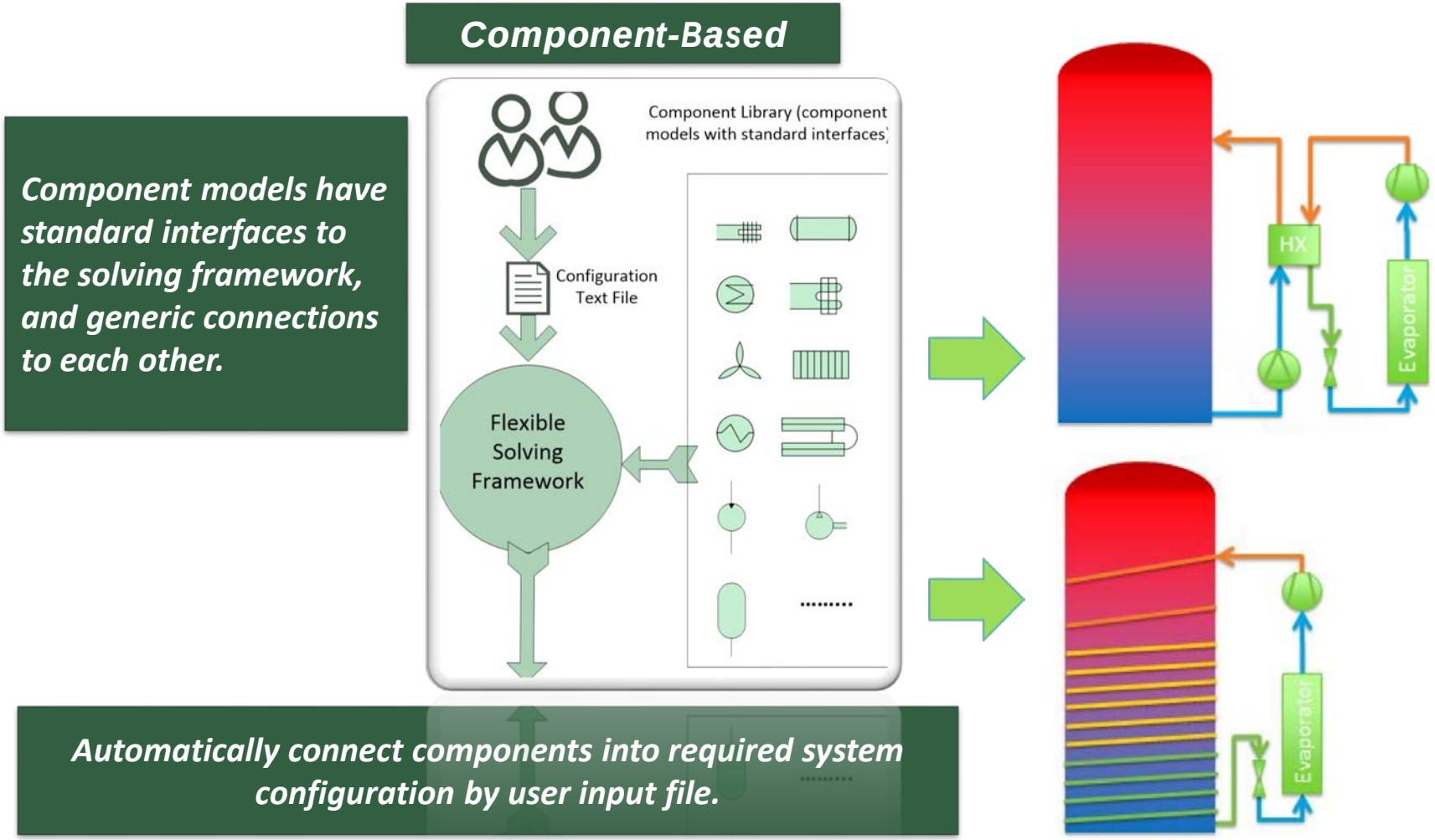
	R134a	R290
Formula	CH_2FCF_3	C_3H_8
CAS number	811-97-2	74-98-6
Molecular mass (g/mol)	102	44
Ozone depletion potential	0	0
Global warming potential, GWP_{100}	1300[a]	<3[a]
Safety classification[b]	A1	A3
Critical temperature (K)[c]	374.21	369.89
Critical pressure (MPa)[c]	4.06	4.25
Saturation pressure at 280.37 K (MPa)	0.3774	0.5879
Enthalpy of vaporization at 280.37 K (kJ/kg)	193.17	364.46
Vapor density at 280.37 K (kg/m^3)	18.66	12.75
Volumetric capacity at 280.37 K (kJ/m^3)	**3604.55**	**4646.87**
Saturation pressure at 341.48 K (MPa)	2.04	2.50

[a] IPCC 5th report, chapter 8 (Myhre et al., 2013)

[b] ANSI/ASHRAE standard 34-2013 (A, nontoxic; 1, nonflammable; 3, flammable)

[c] REFPROP 9.1 (Lemmon et al., 2013)

Model development- ORNL HPDM

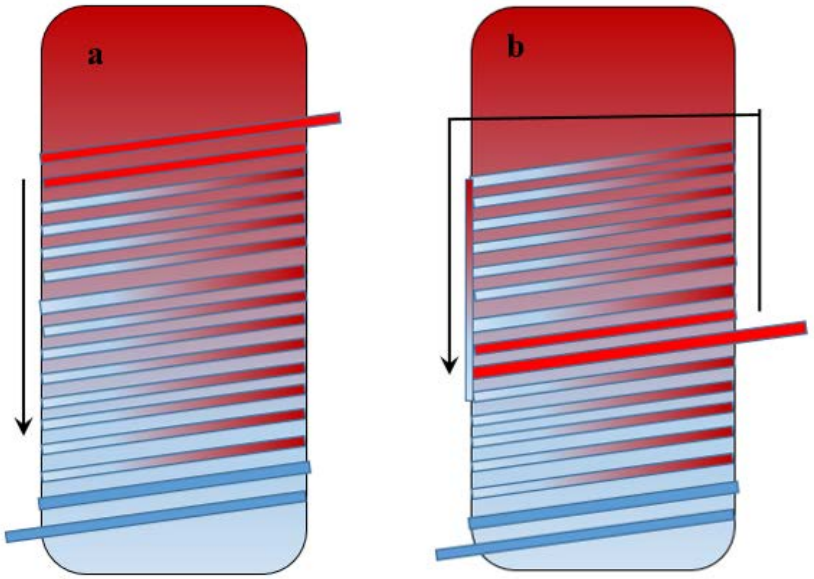


B. Shen, K. Nawaz, A. Elatar, V. Baxter, "Development and Validation of Quasi-Steady-State Heat Pump Water Heater Model Having Stratified Water Tank and Wrapped-Tank Condenser" International Journal of Refrigeration, 2018, 87,78-90.

Design Parameters

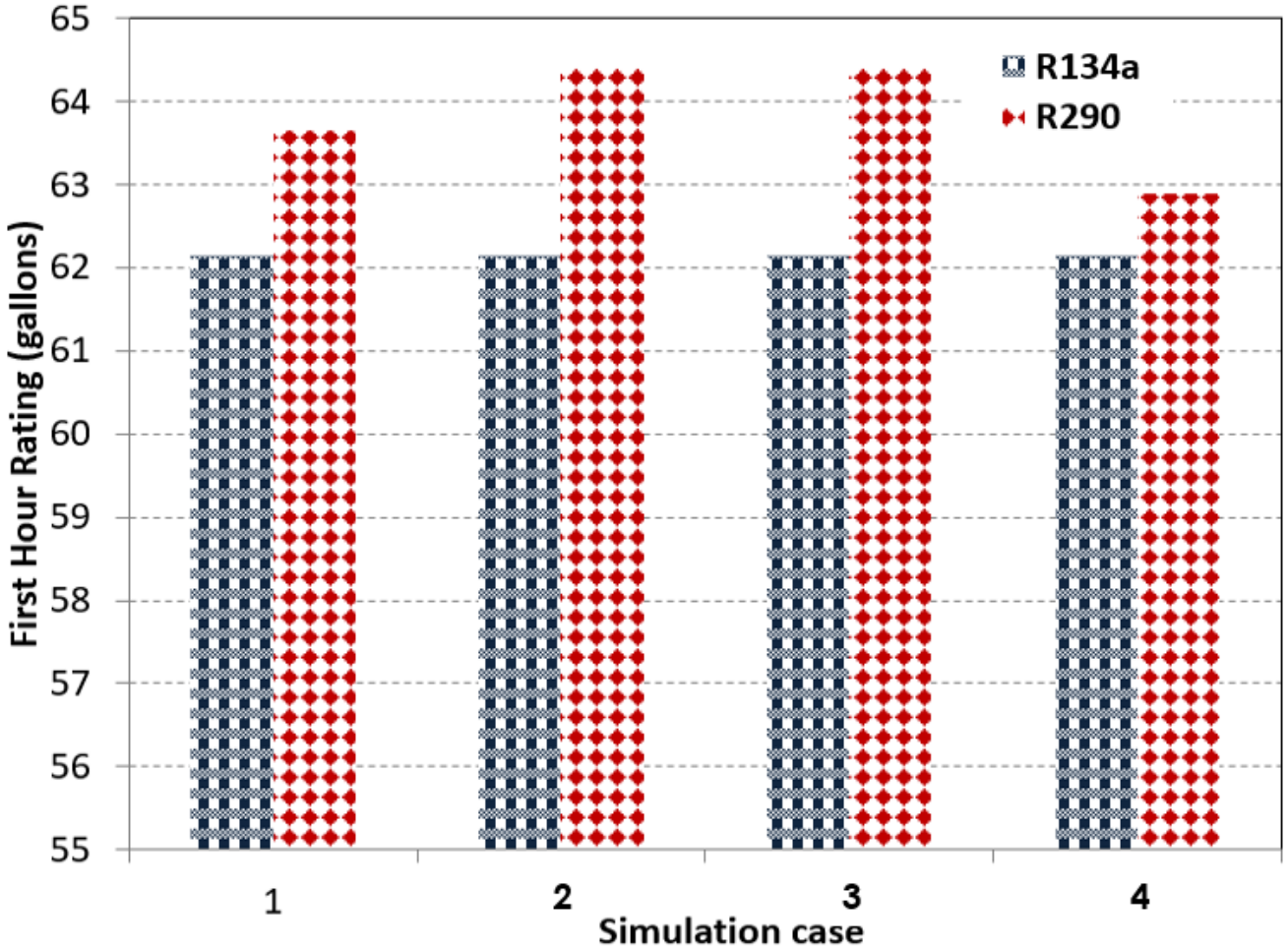
- Heat pump T-stat at the top: on at 115 °F, off at 125 °F.
- Electric element at the top: on at 110°F, off at 125 °F.
- Two different condenser coil wrap patterns

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

First Hour Rating (FHR)



The **First Hour Rating (FHR)** is a measure of the available hot water capacity of the water heater (in gallons).

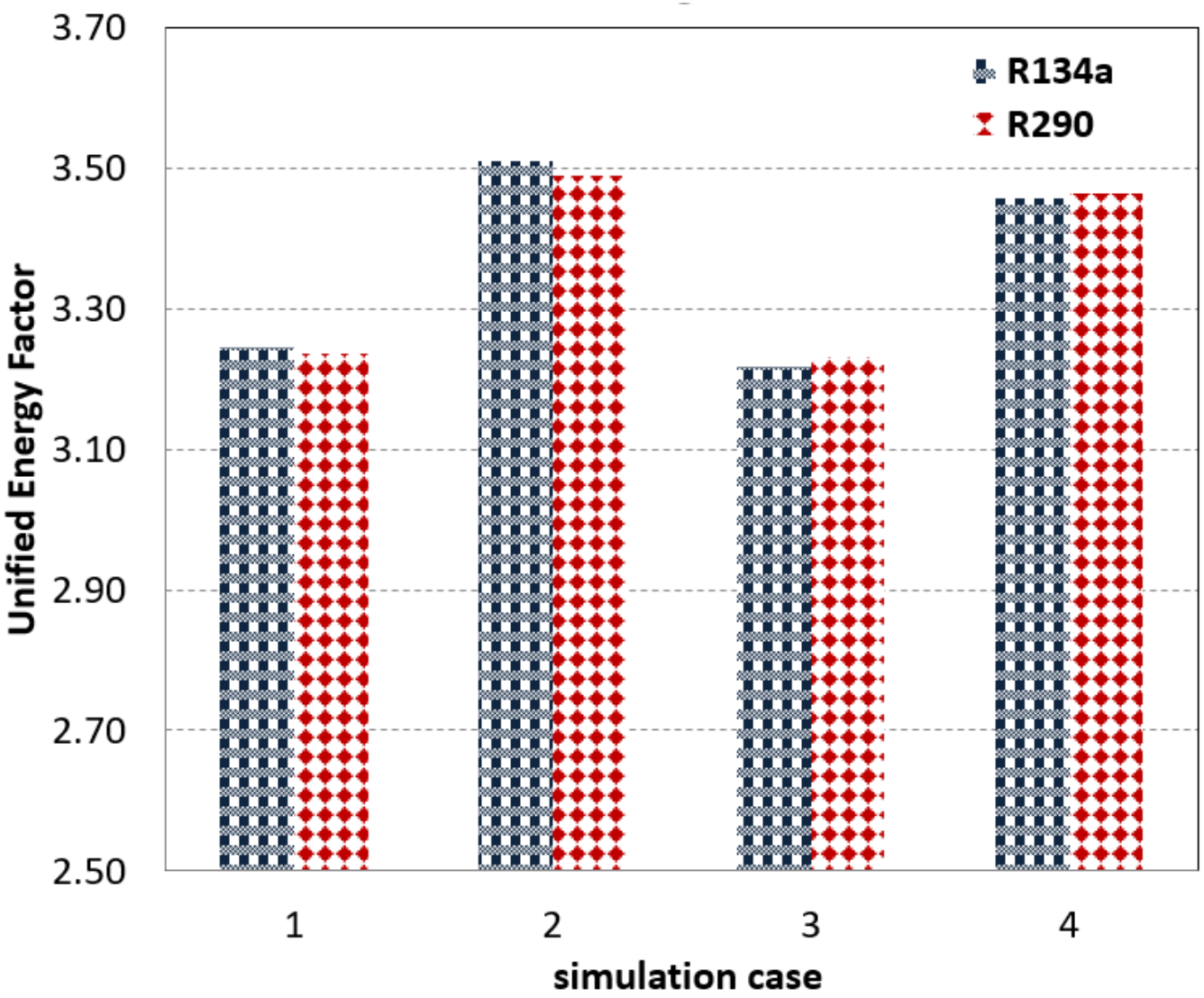
Performance Evaluation Criteria

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

Draw Number	Time During Test (hh:mm)	Volume (gals/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 gallons (208 L)			

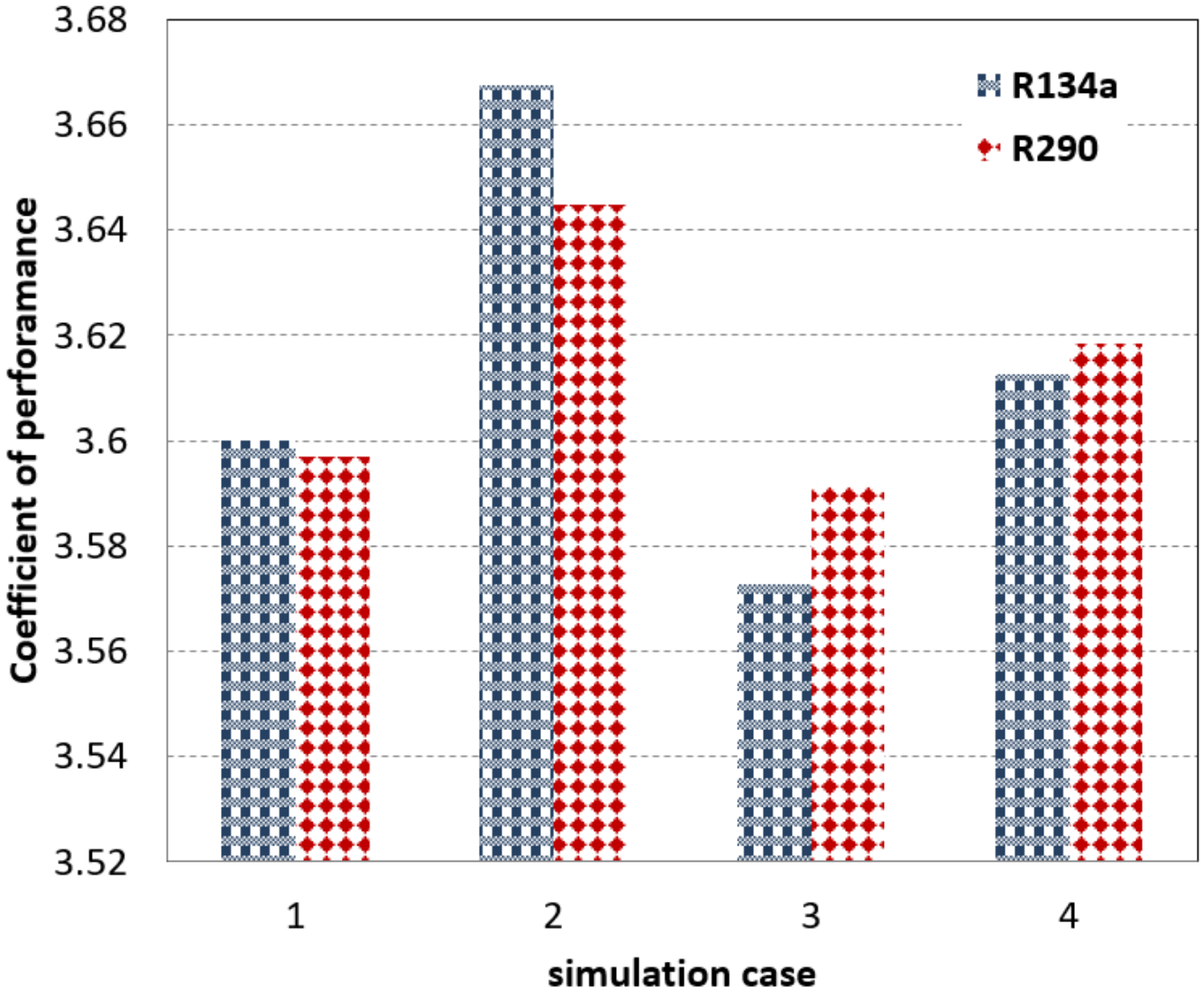
Medium usage draw pattern

Unified Energy Factor



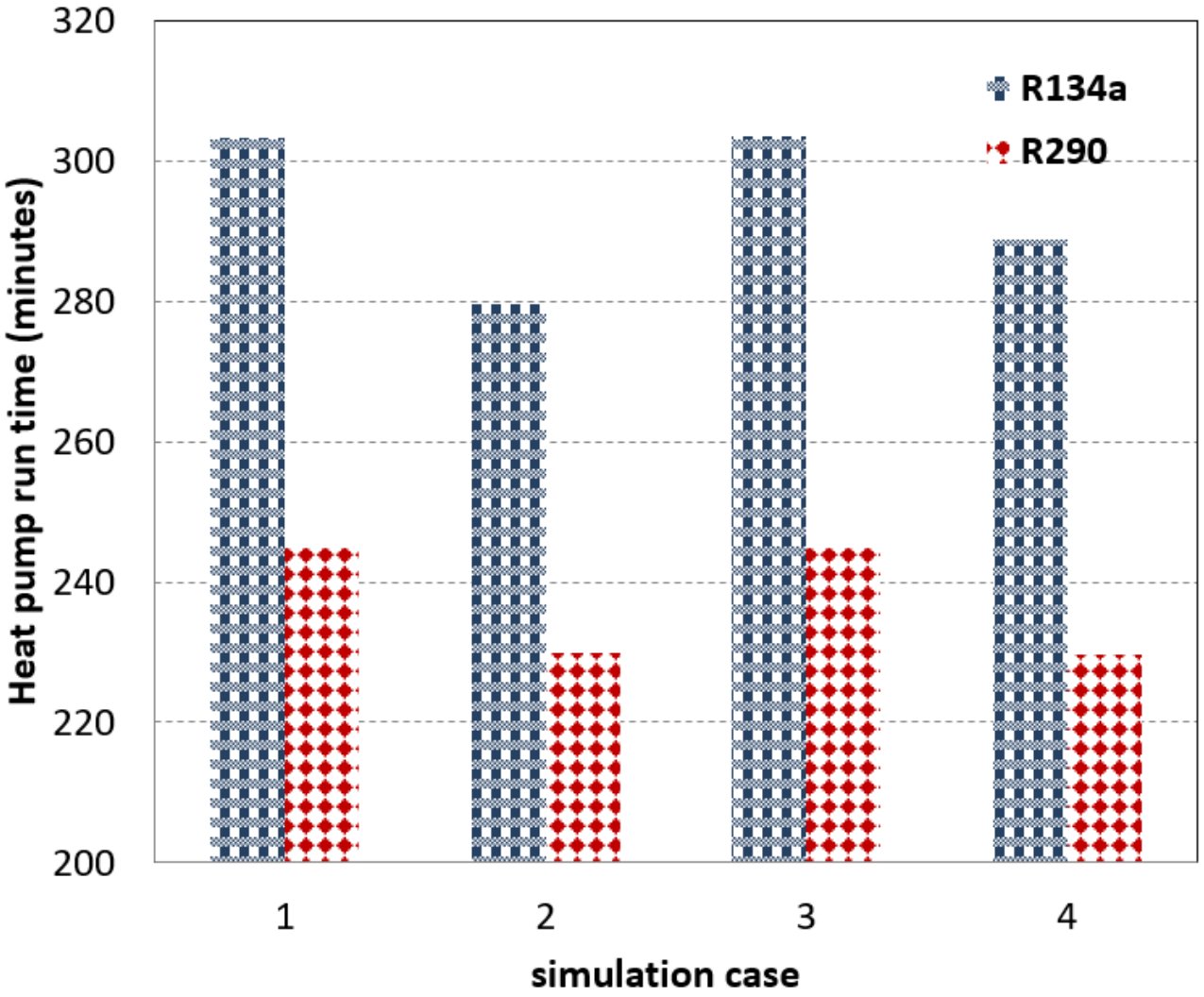
$$\text{Unified Energy Factor(UEF)} = \sum_{k=1}^{n} \frac{M_k c_p (T_s - T_i)}{W_i}$$

Coefficient of Performance

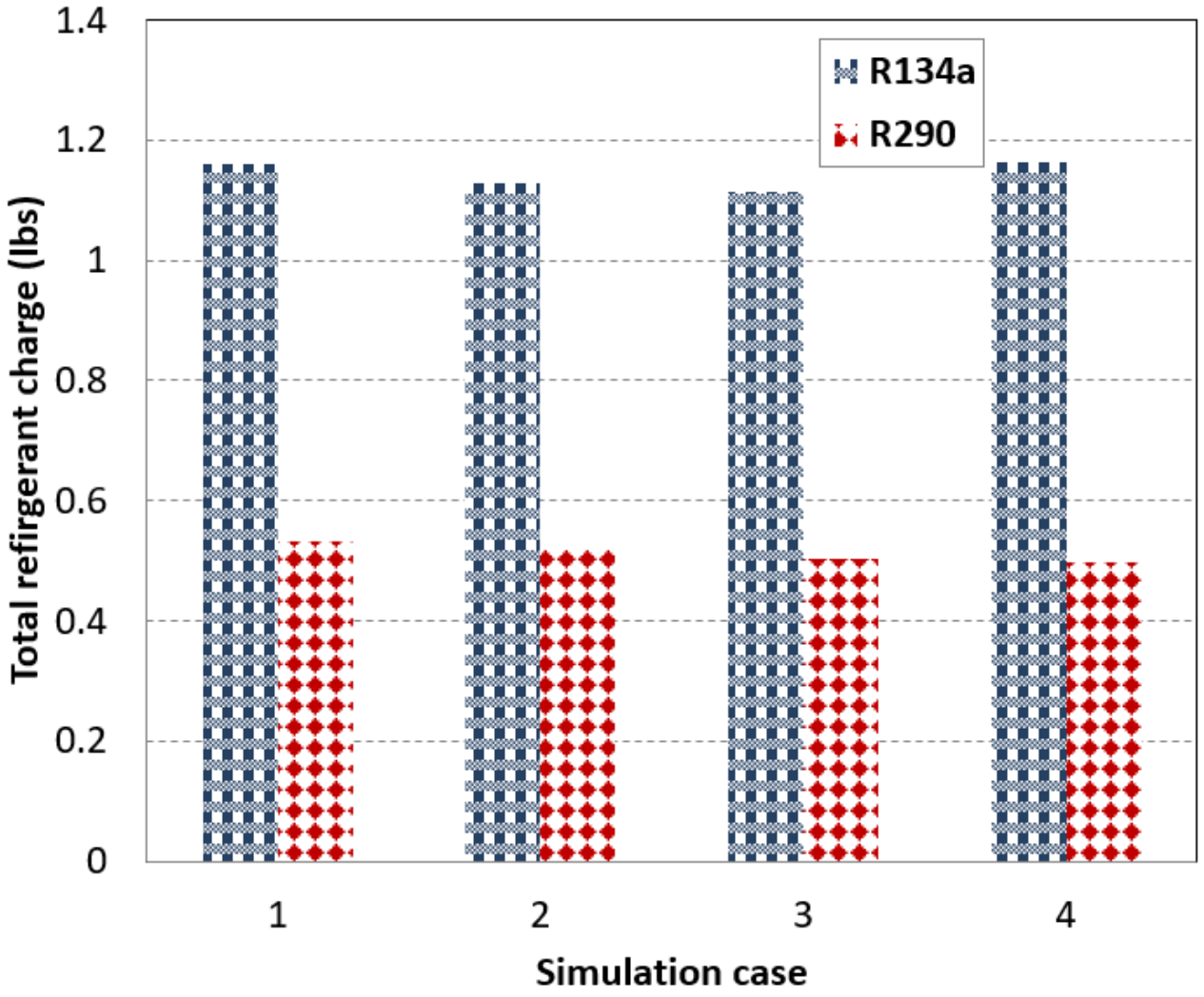


The **Coefficient of performance (COP)** is a measure of the performance of the heat pump.

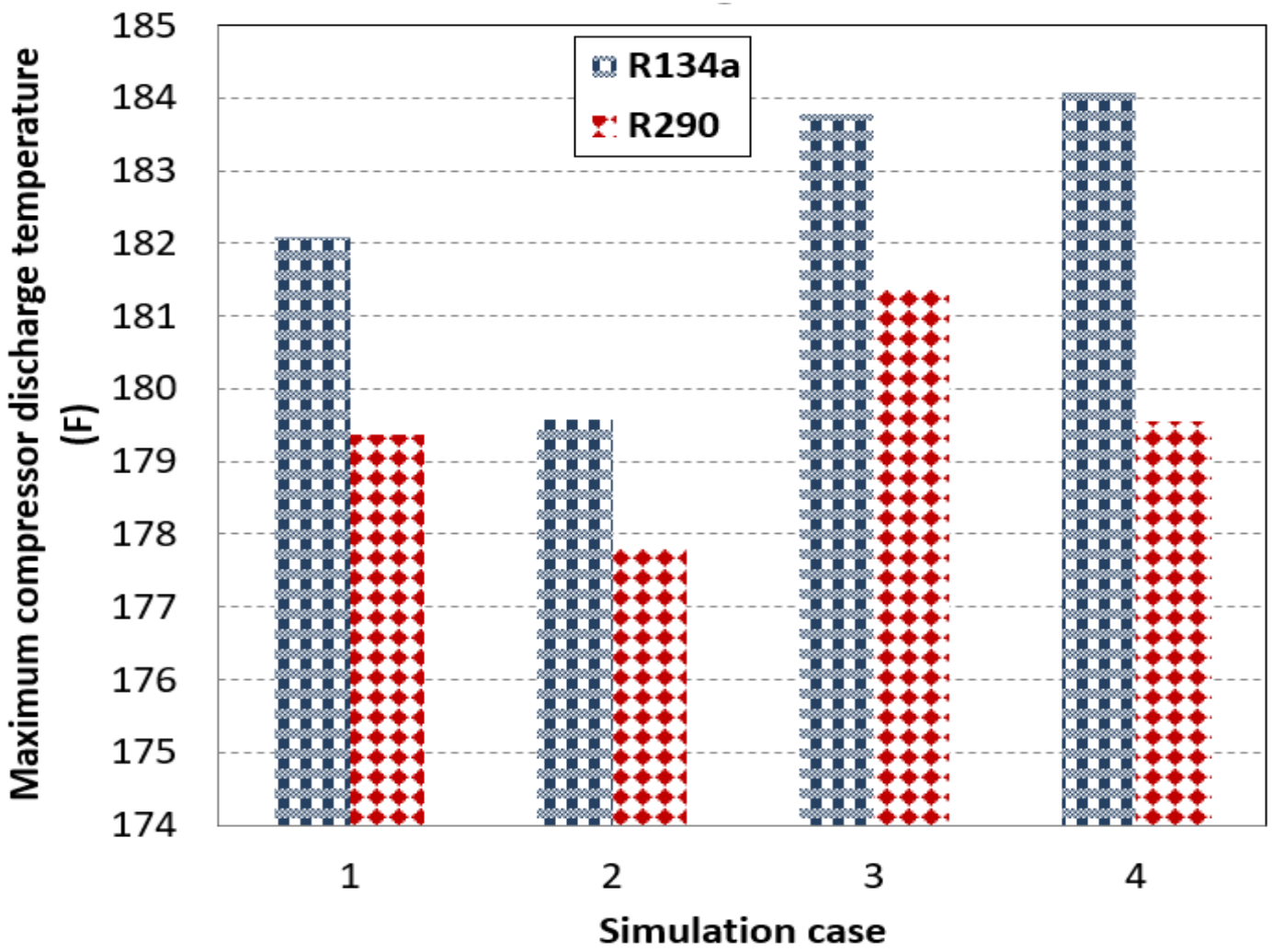
Heat Pump Run Time



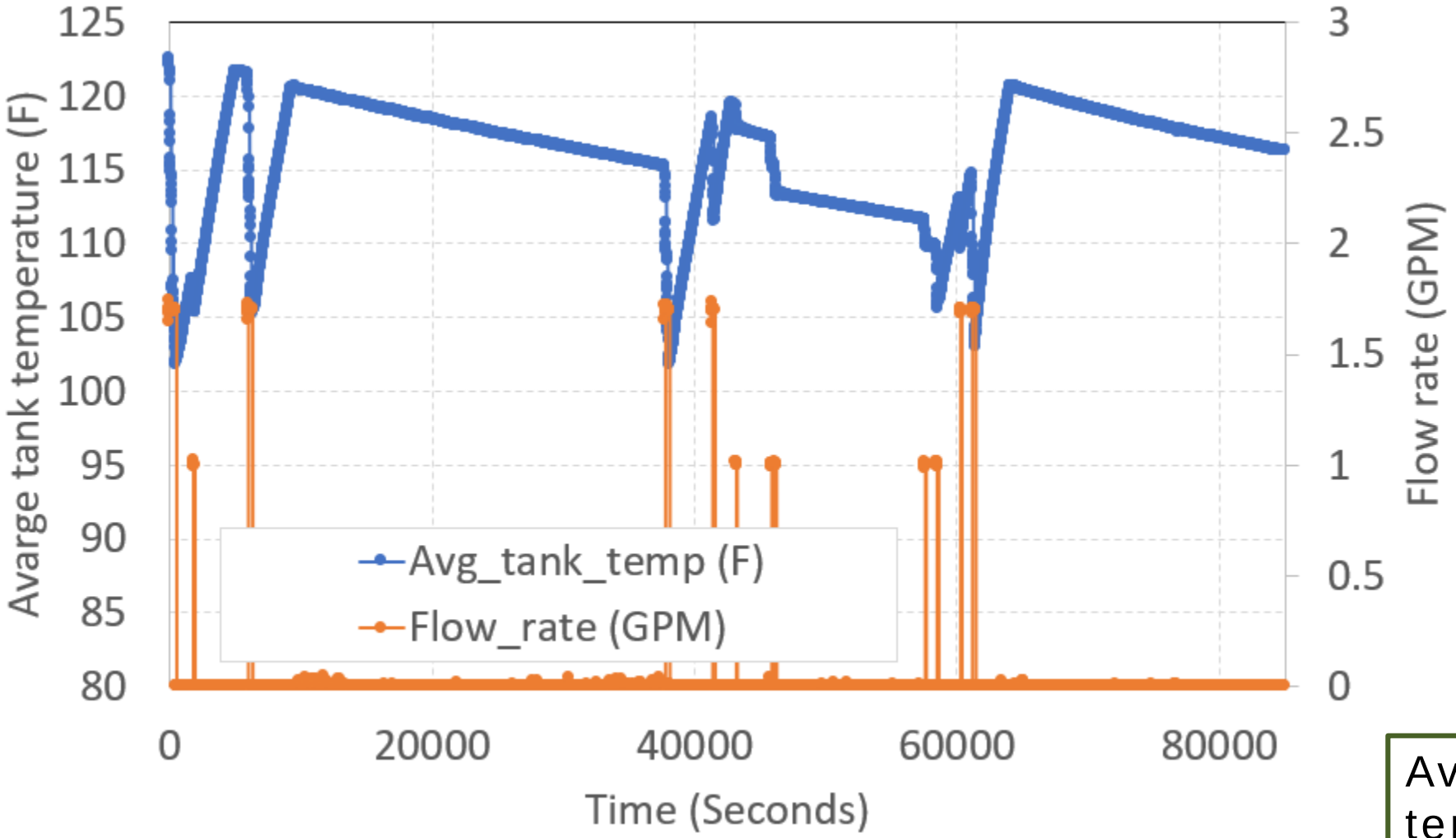
Total Charge in the Condenser and Evaporator



Max Compressor Discharge Temperature



Experimental Validation



Average stored water temperature for propane is comparable to R134a.

Experimental Validation

Parameter	R134a	Propane (R290)
Optimum refrigerant charge	1.68 lbs	0.85 lbs
First Hour Rating (FHR)	66 gallons	64 gallons
Unified Energy Factor	3.44	3.60

Conclusions

- R290 (Propane) is a feasible working fluid for residential HPWHs
- Due to the higher volumetric capacity, the heat pump run time is significantly reduced.
- The total refrigerant charge in the system (Heat exchangers) can be reduced by at least 50%.
- The experimental results validate the simulation findings.

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THANK YOU

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