Hydroflouroolefins (HFOs) as Low GWP Refrigerants for Residential Heat Pump Water Heaters

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ACEEE Hot Water Forum 2017

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- Performance comparisons
- Summary

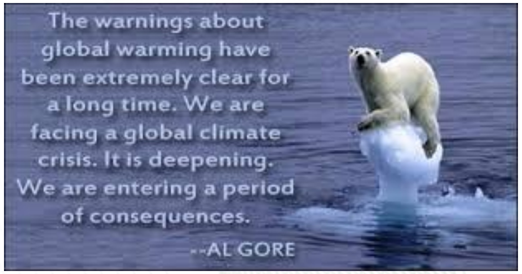
Acknowledgements

- DOE Building Technologies Office, Emerging Technologies – Antonio Bouza
- Dr. Omar Abdelaziz (ORNL)

Consequences of Global Warming

- Glacier retreat
- Sever weather
- Droughts and large scale fires

Alaska's Pedersen Glacier as it looked in the 1920s-1940s (left) and as it looked when photographed in 2005 (right). About 90 percent of the world's glaciers are shrinking, and their reduction in size worldwide has accelerated rapidly since the 1970s, according to the Worldwide Glacier Monitoring Service. (Photo by USGS/Bruce Molnia)



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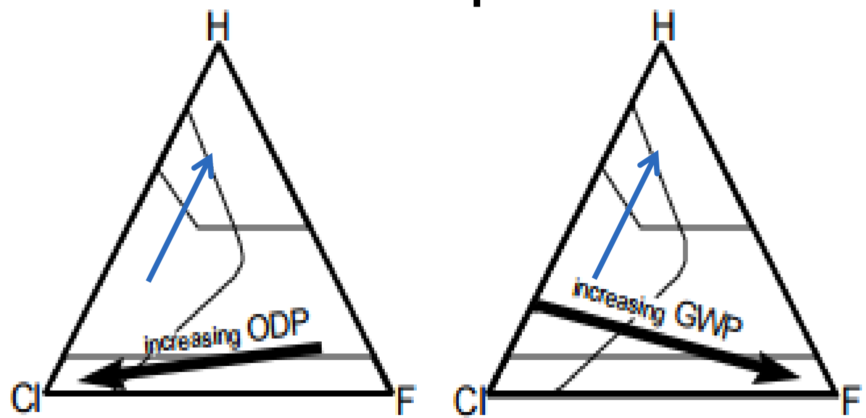
Next Generation Refrigerants

Refrigerant	GWP_{100}
CO_2	1
R-22	1760
R-134a	1300
R-410A	1924

- Hydrofluoroolefins (HFOs)
  - Fluorinated propene isomers
    - R-1234yf ($CF_3CF = CH_2$)
    - R-1234ze ($CF_3CH = CHF$)
  - GWP < 4
  - Mildly flammable

Chemical compounds



Moving away from Chlorine (ODP) and Fluorine (GWP) inevitably leads to flammability

- Natural Refrigerants

Goals

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

- **Demonstrate an environmentally friendly ENERGY STAR®-qualified residential HFO refrigerant-based HPWH**
  - Low GWP, no direct environmental impact
  - No major modification of existing system
  - FHR and EF performance should be comparable

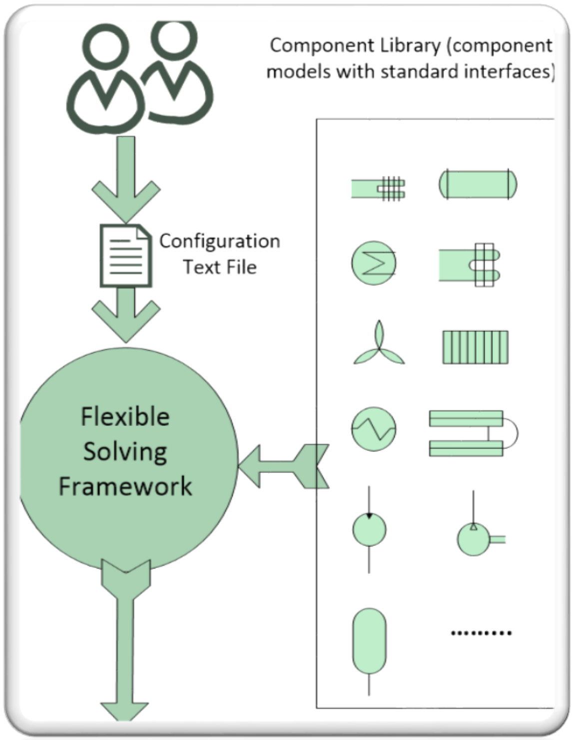
Alternative Refrigerants

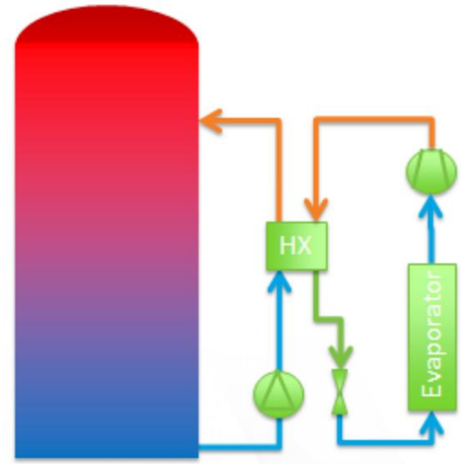
Refrigerant	Composition (mass %)			at 45 F				at 155 F
		T_c(K)	P_c (Mpa)	P_{sat} (Mpa)	h_{fg} (KJ/kg)	P_{vap} (kg/m^3)	Vol. Cap (KJ/m^3)	P_{sat} (Mpa)
R134a	Pure	374.21	4.06	0.3774	193.17	18.66	3604.55	2.04
R1234yf	Pure	367.85	3.38	0.4006	158.52	22.253	3527.55	1.9725
R1234ze	Pure	382.51	3.64	0.2803	179.49	15.004	2693.07	1.551

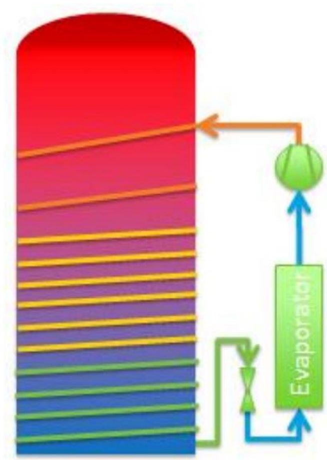
Component-Based Flexible Modeling Platform for HPWHs – ORNL Flex HPDM

Component-Based

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



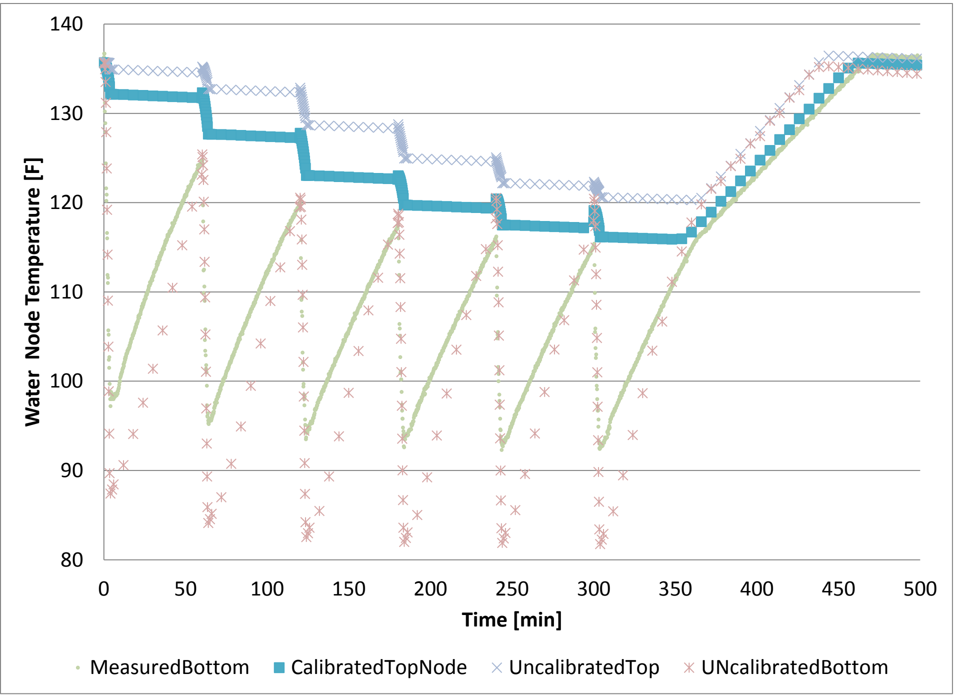




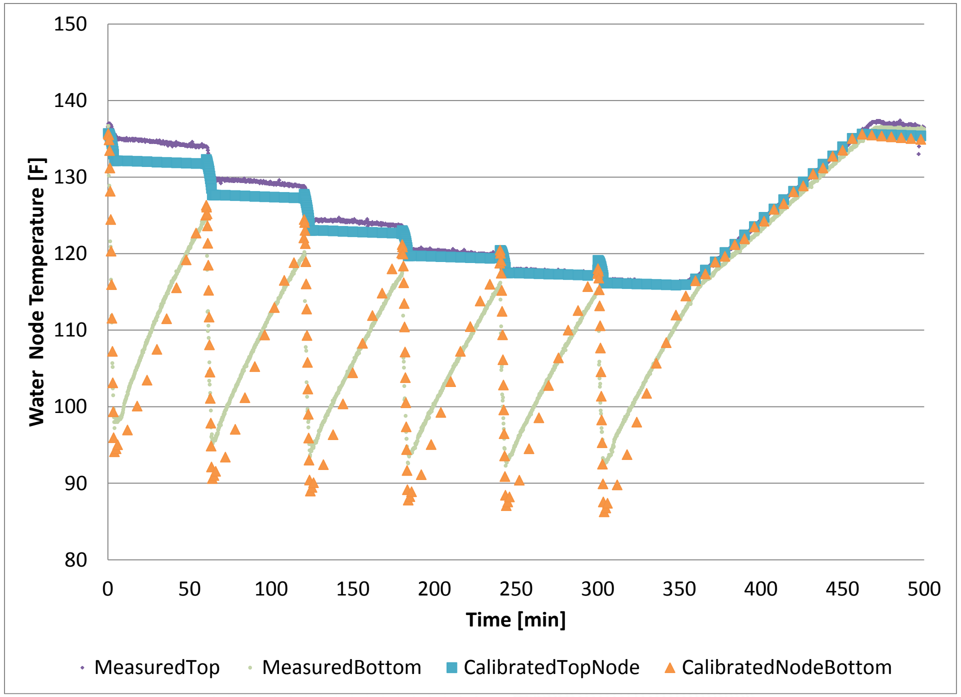
Automatically connect components into required system configuration by user input file.

Model Calibration with Experimental Data

- Matching the measured water stratification profile



-Uncalibrated tank model



-Calibrated tank model

Water Draw Patten is based on Pre-2015 EF evaluation criteria

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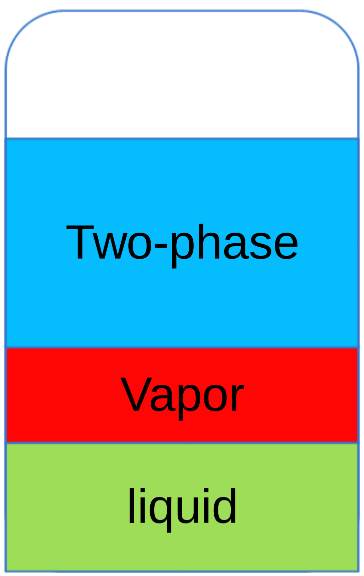
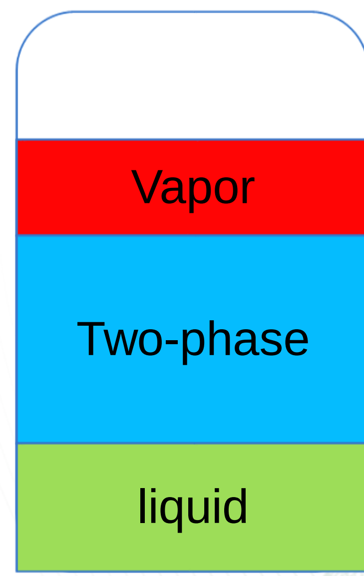
Design Parameters

- 46-gallon water tank
- 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 heat loss factors from tank (0.90 and 0.95)
- Two different condenser coil wrap patterns (parallel, counter)
- Two different evaporator sizes and air flow rates (Evap 1 & 2)
- Two different condenser tube sizes (0.31, 0.5 in Nominal)

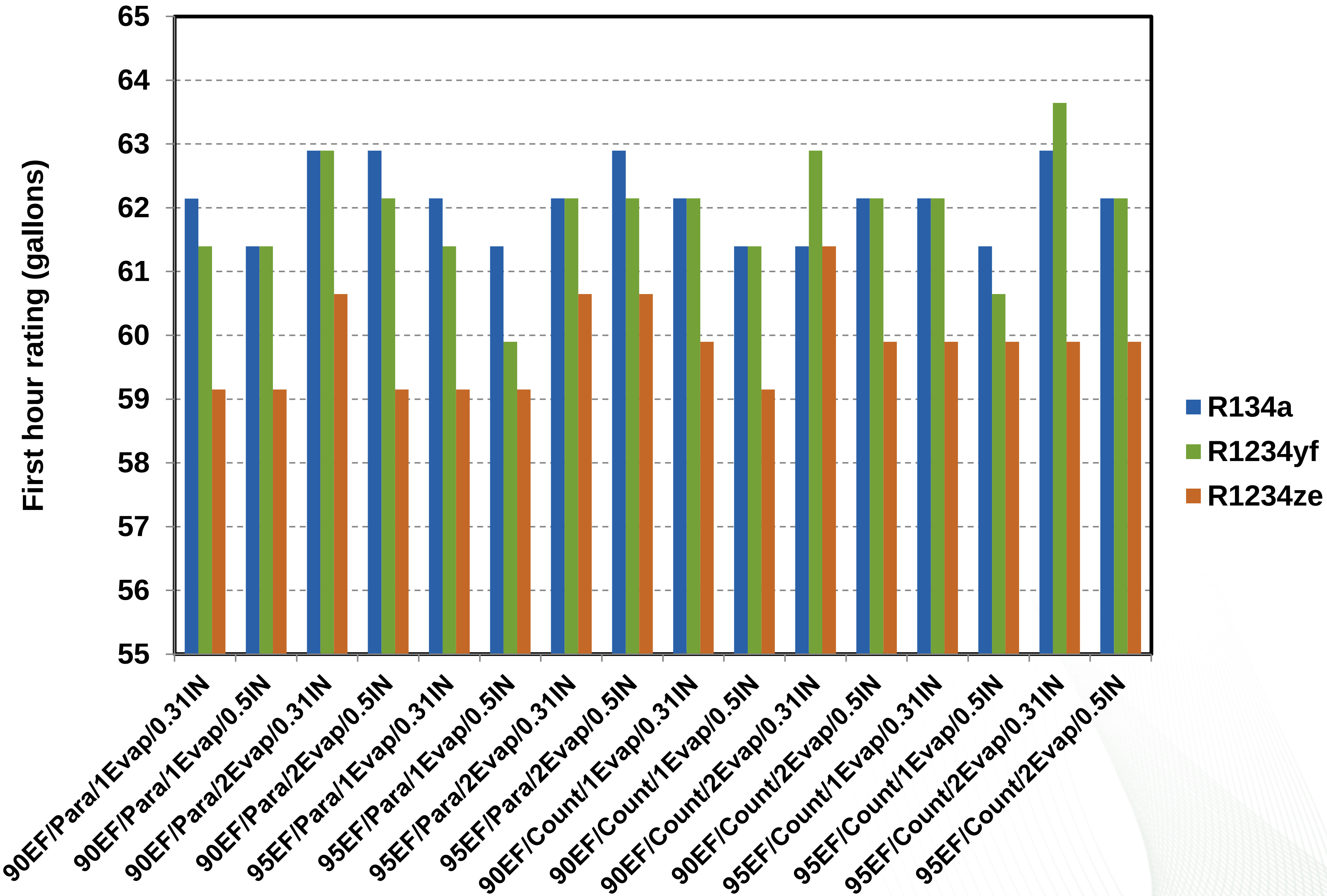
Parallel vapor to two-phase wrap



Counter vapor to two-phase wrap



First Hour Rating (FHR)



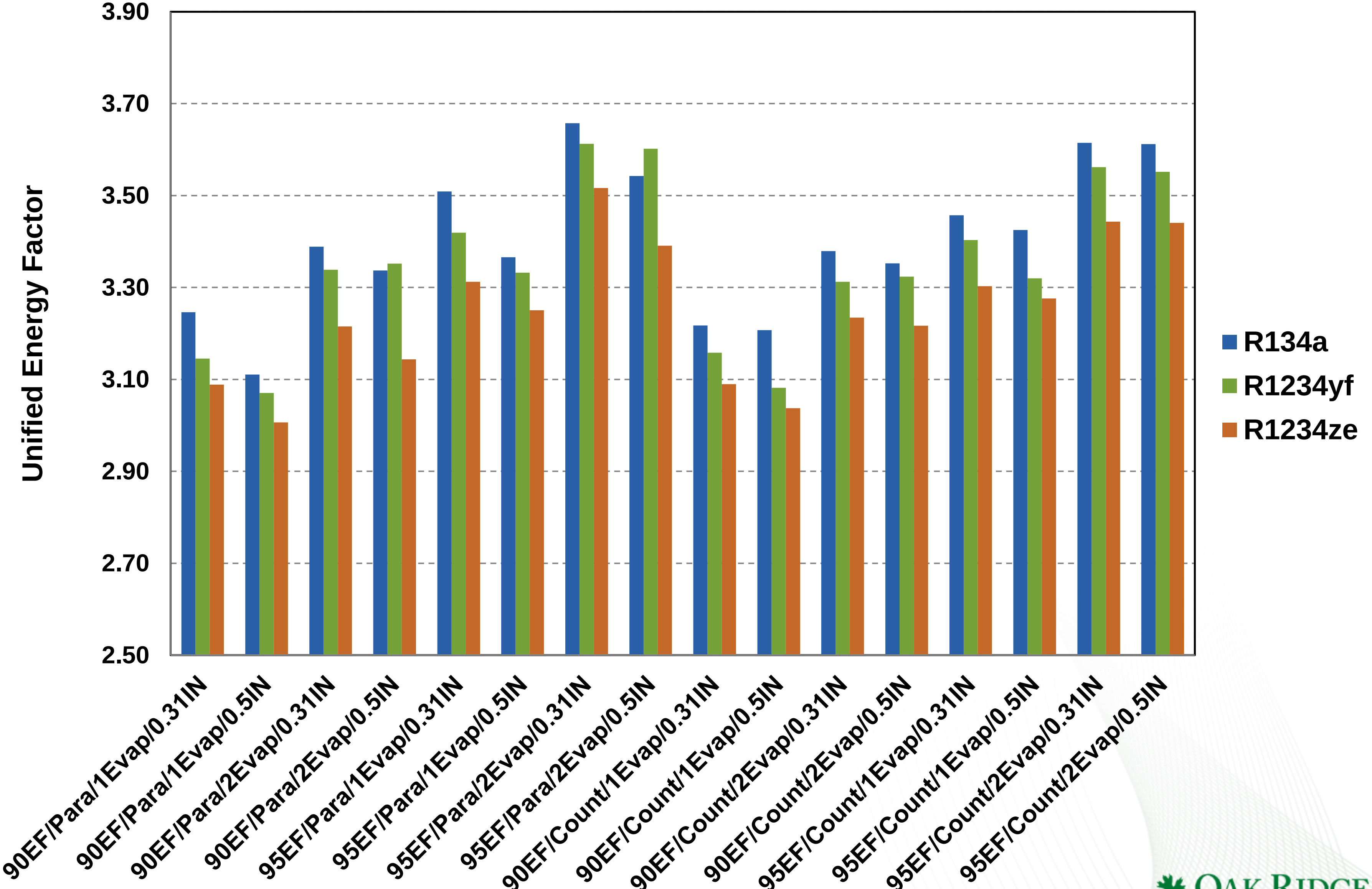
Performance Evaluation Criteria

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

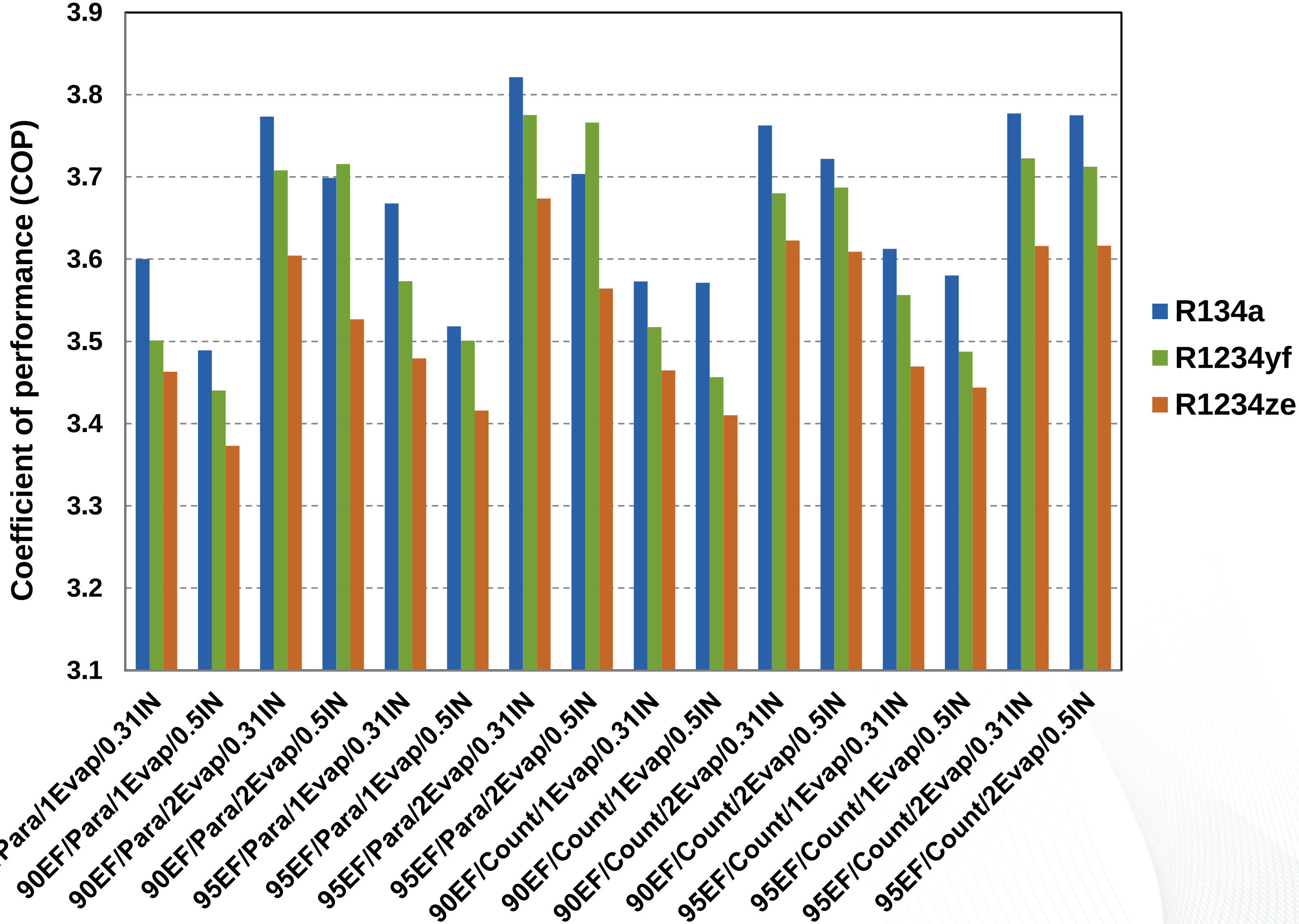
Medium usage draw pattern

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)			

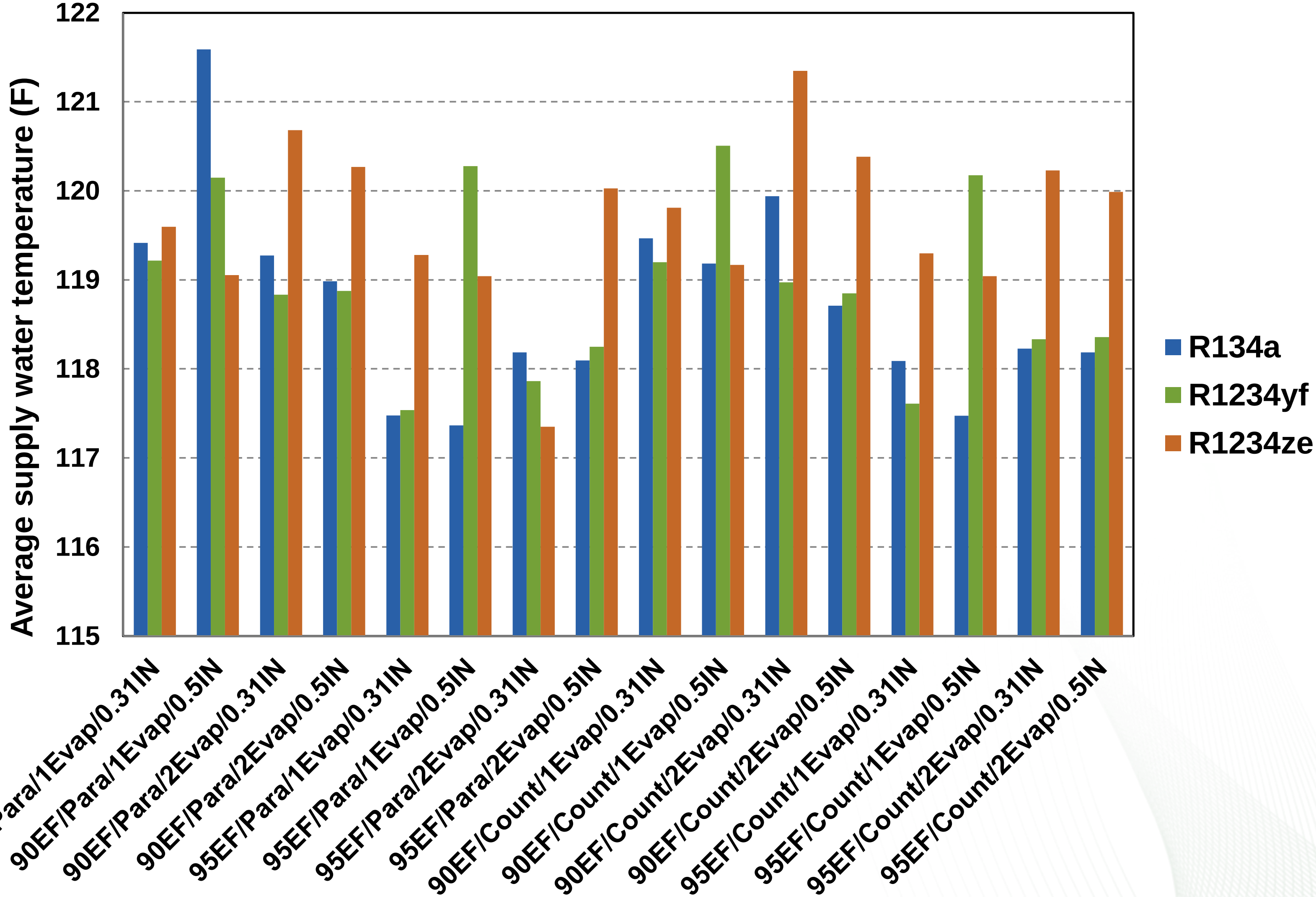
Unified Energy Factor



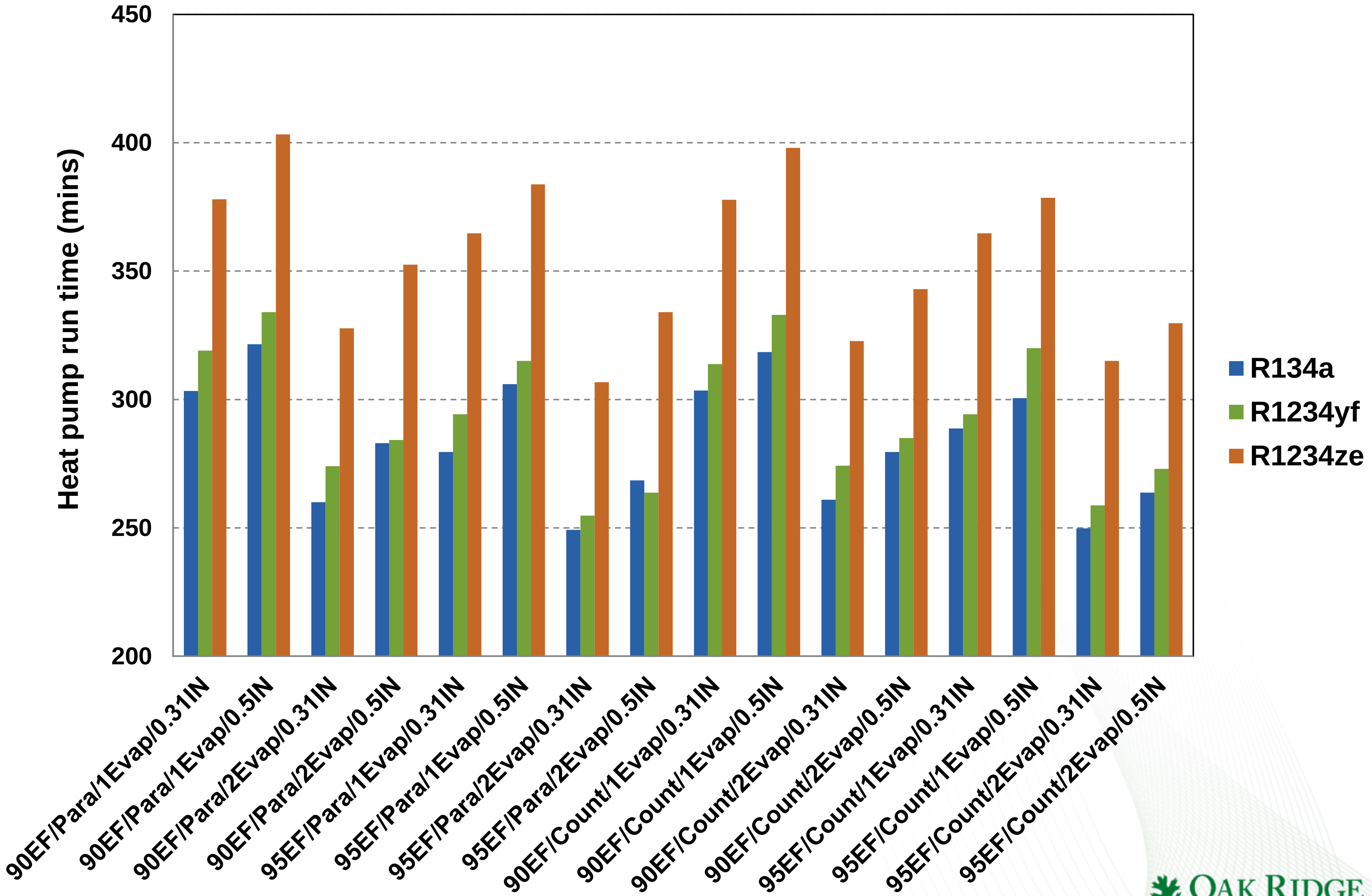
Coefficient of Performance



Average Supply Water Temperature



Heat Pump Run Time



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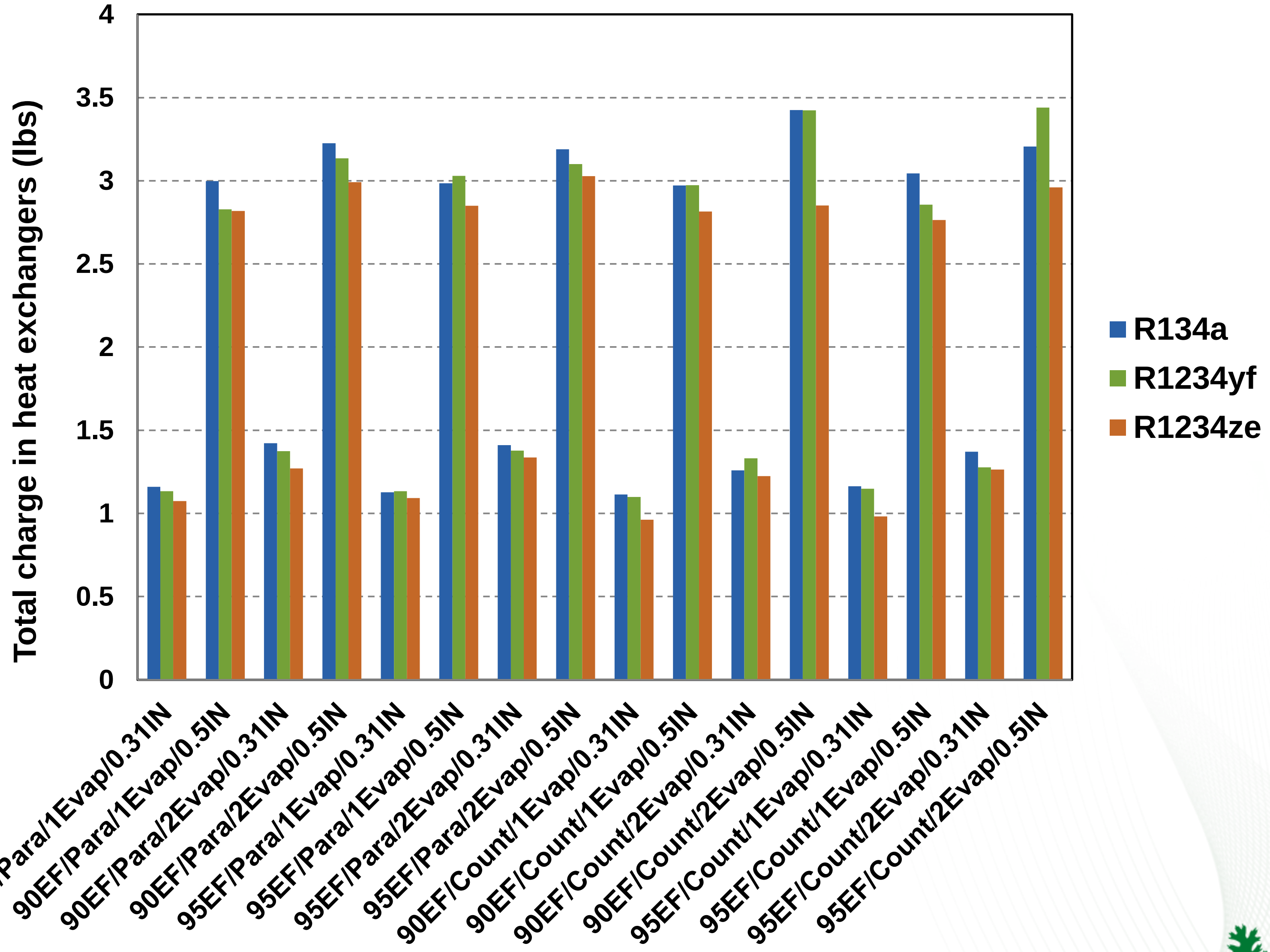
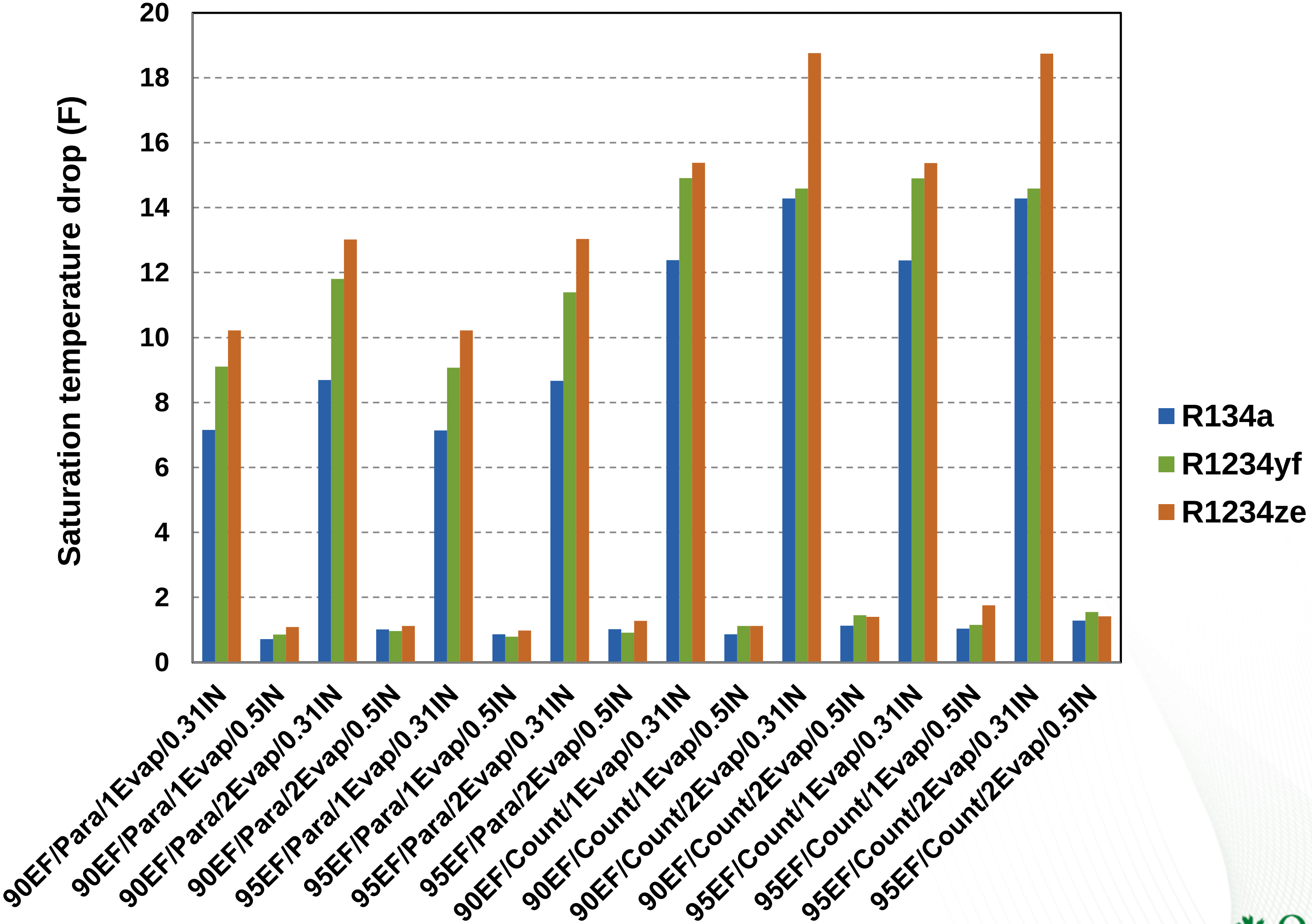
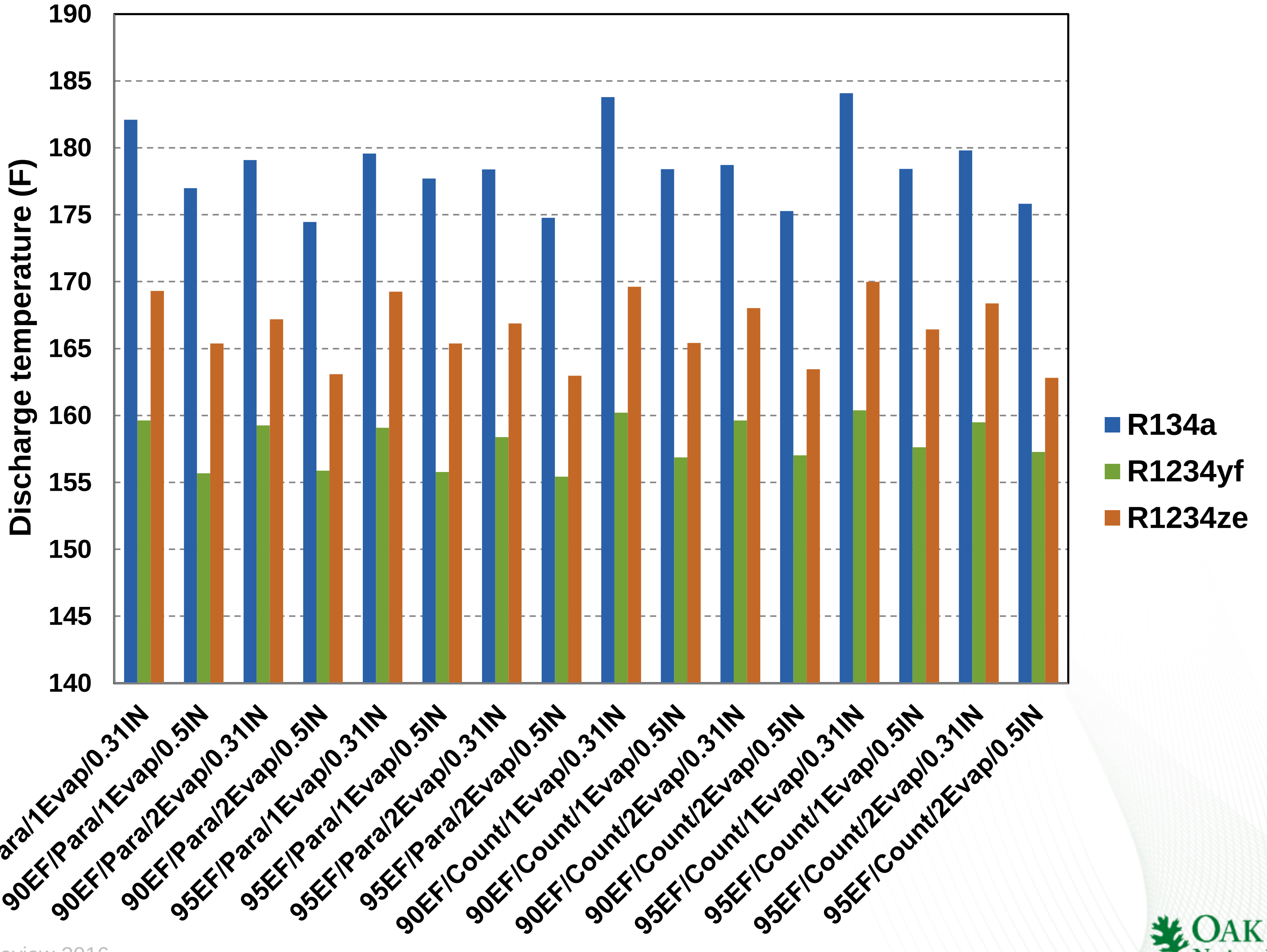
Total Charge in Both Heat Exchangers



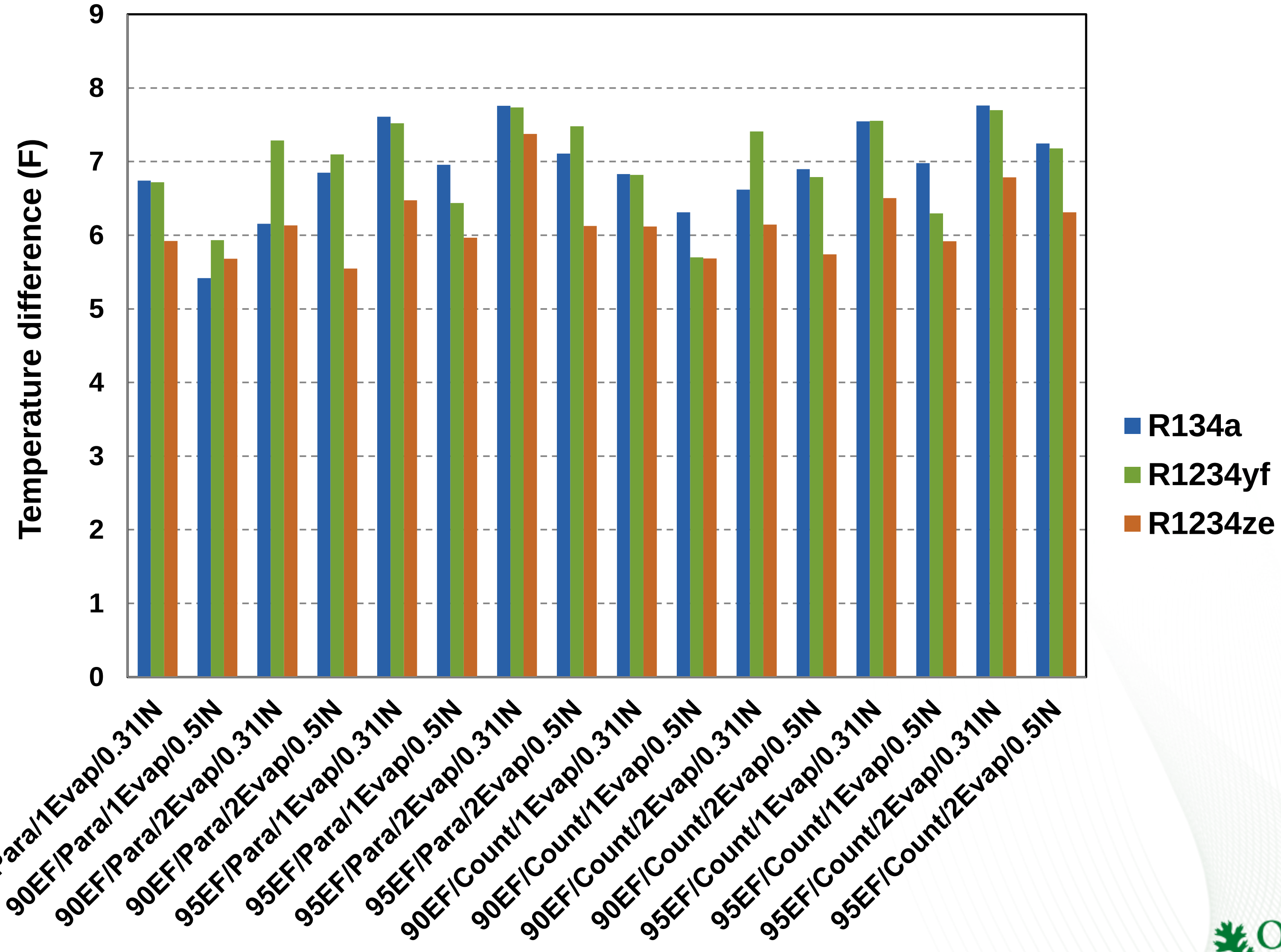
Max. Condenser Sat. Temperature Drop



Max Compressor Discharge Temperature



Average Difference between Supply and Tank Bulk Water Temperature



Conclusions

- R-1234yf can be used as drop-in replacement for R-134a with approximately 2% lower energy factor, and slightly longer heat pump running time due to the reduced capacity.

- R-1234ze performance is comparable as well. However relatively longer HP runtime is disadvantages caused due to relatively lower volumetric capacity of the refrigerant.

Further Developments

Lab testing of the prototype HPWH will confirm the findings and will highlight any potential issues due to the relatively higher flammability of the HFO refrigerants.

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