Testing of alternative refrigerants for unitary air-conditioning and heat pump applications

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Koura

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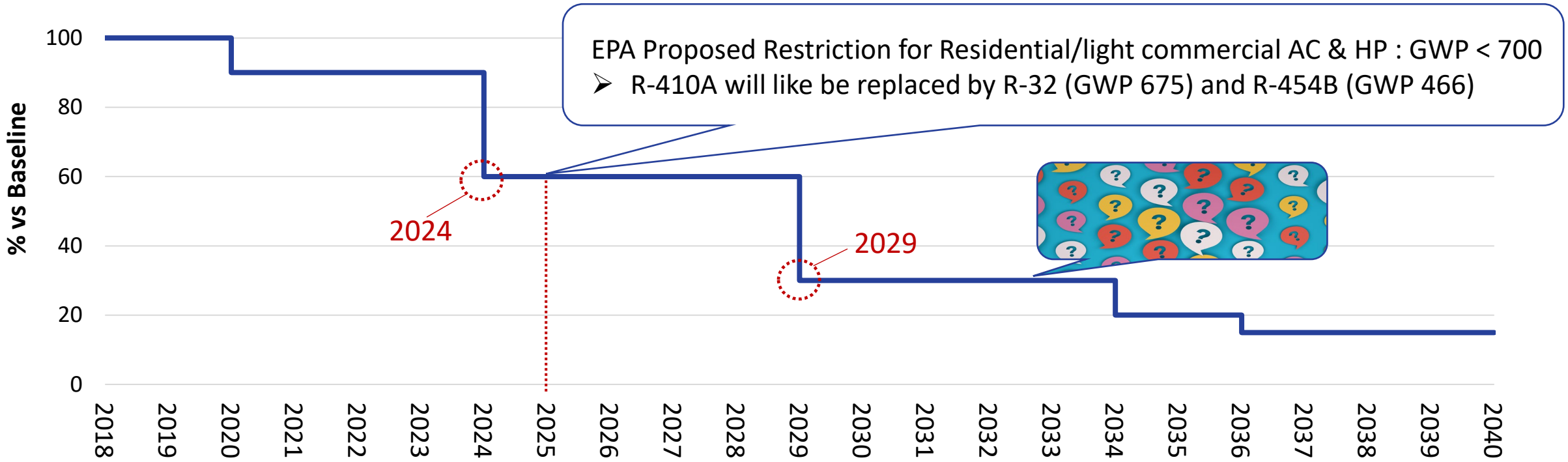
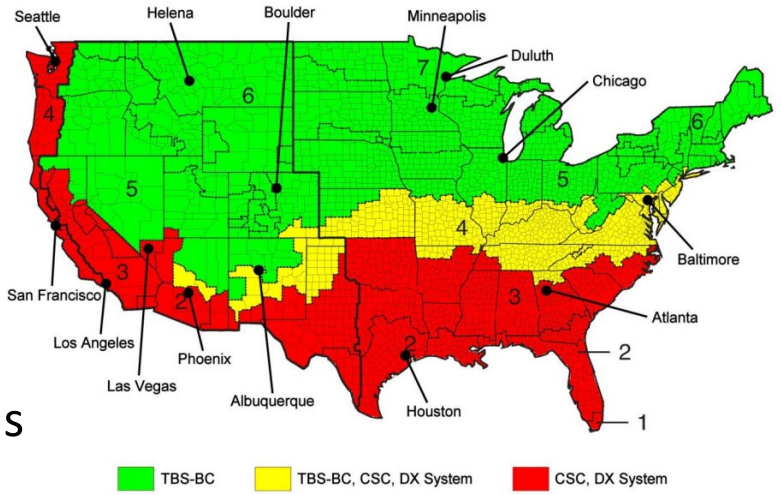
Introduction

AIM Act HFC Allowance



R-744 (CO_2) Refrigerant

- A1, GWP = 1
- Low critical temperature of 31°C and high pressure
- Transcritical operation – not as effective in warmer climate
- Complex system structure requiring a gas cooler
- Adopted for use in commercial refrigeration (EU) and hot water needs
- Not as widely adopted in air-to-air heat pumps

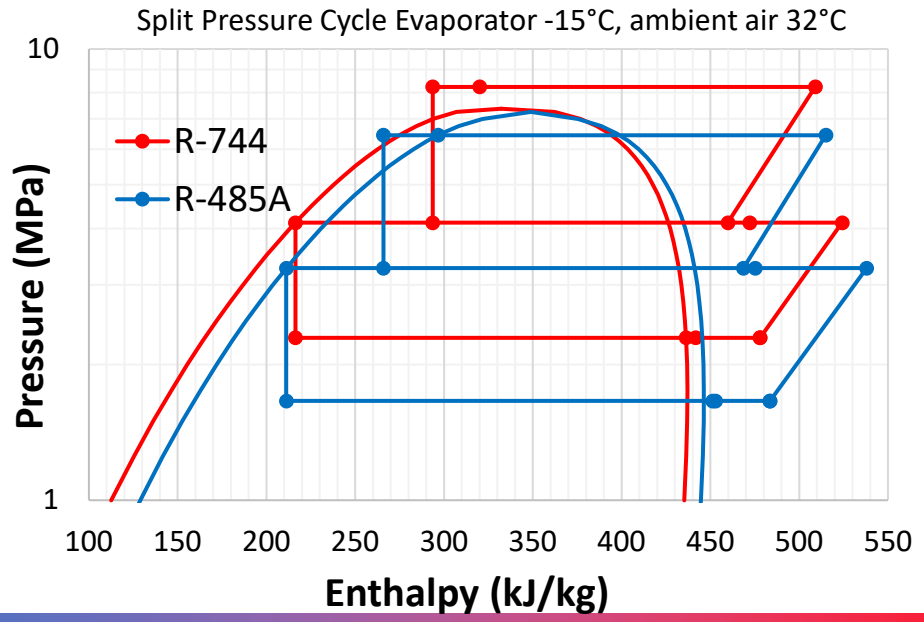


2014 ORNL study[1] suggested transcritical R-744 viable only in green regions

1 Sharma et al, International Journal of Refrigeration 46, October 2014, Pages 86-99

R-485A (LFR3)

- **Composition: R-744/1132a/32 (69/10/21%)**
- **ISO 817 - A1/A2L classification - Non-flammable in handling and in system**
- **Vapor pressure 15% lower than R-744**
- **Critical point 10K higher than R-744**



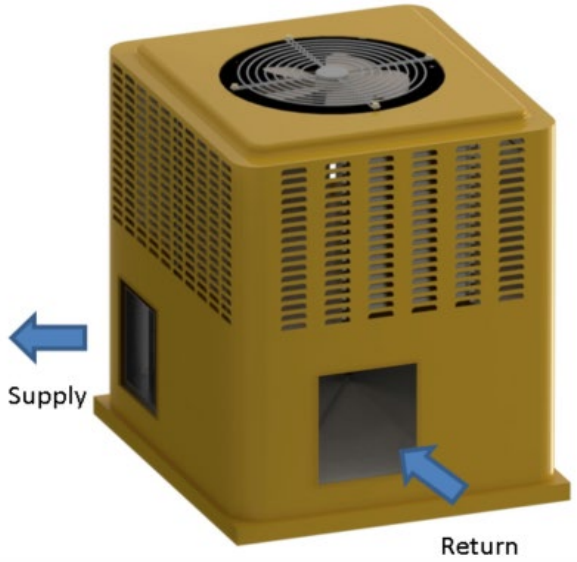
Property	Units	R-744	R-485A
GWP		1	143
Molecular mass	g/mol	44.0	47.0
Critical temperature	°C	31.0	41.2
Critical pressure	kPa	7377	7170
Liquid density (0°C)	kg/m^3	927	935
Bubble pressure (-40°C)	kPa	1004	842
Bubble pressure (0°C)	kPa	3485	2875
Isentropic index (C_p/C_v) (saturated at 0°C)	---	2.14	1.89
Latent heat at 0°C	kJ/kg	231	231
Evaporator Glide (2800kPa)	K	0	~5

Project Goals

Phase 1. Drop-in evaluation of R-410A low GWP alternative, R-468C

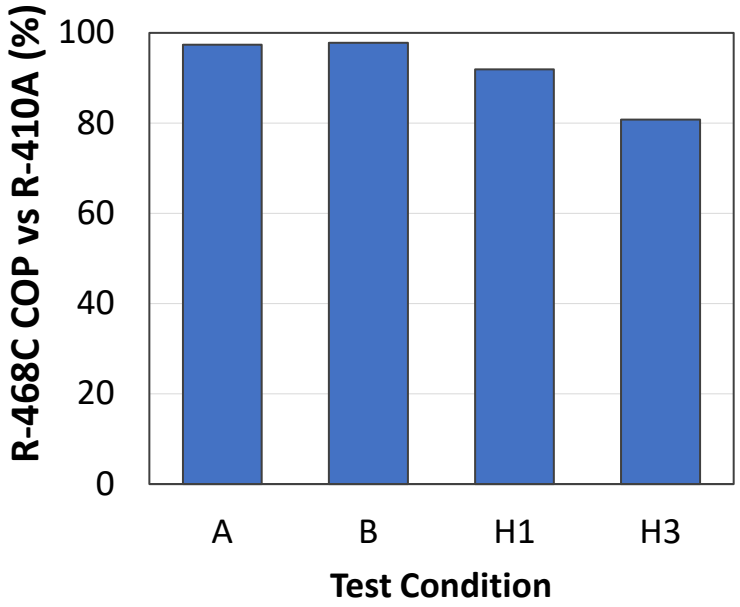
Phase 2. Investigate feasibility of using R-744/485A in the same frame with matching capacity

Property	Units	R-410A	R-468C
Composition		R-32/125 (50/50%)	R-1132a/32/1234yf (6/42/52%)
GWP		2088	286
ASHRAE 34 Classification		A1	A2L
Molecular mass	g/mol	72.6	73.7
Critical temperature	°C	71.4	77.0
Critical pressure	kPa	4900	4880
Boiling point	°C	-51.5	-56.6
Vapor pressure (@25°C)	kPa	1657	1644
Vapor density (@25°C)	kg/m^3	66	53
Liquid density (@25°C)	kg/m^3	1059	984
Evaporator Glide (Average temp 12°C)	K	0.1	<8

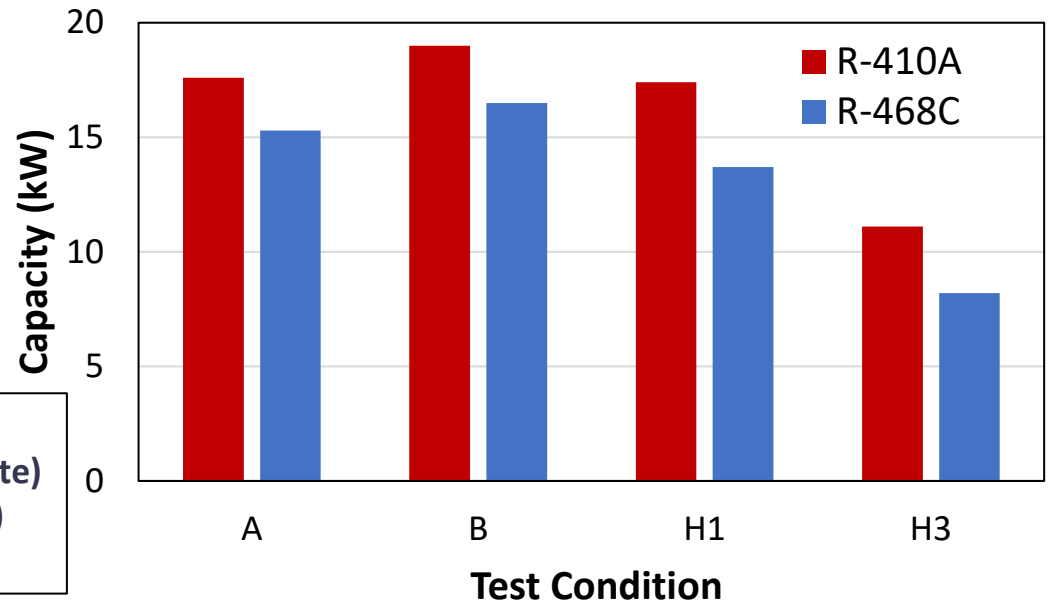


5TR (17.6kW) R-410A Packaged Unit

Phase 1. R-468C Drop-in Evaluation



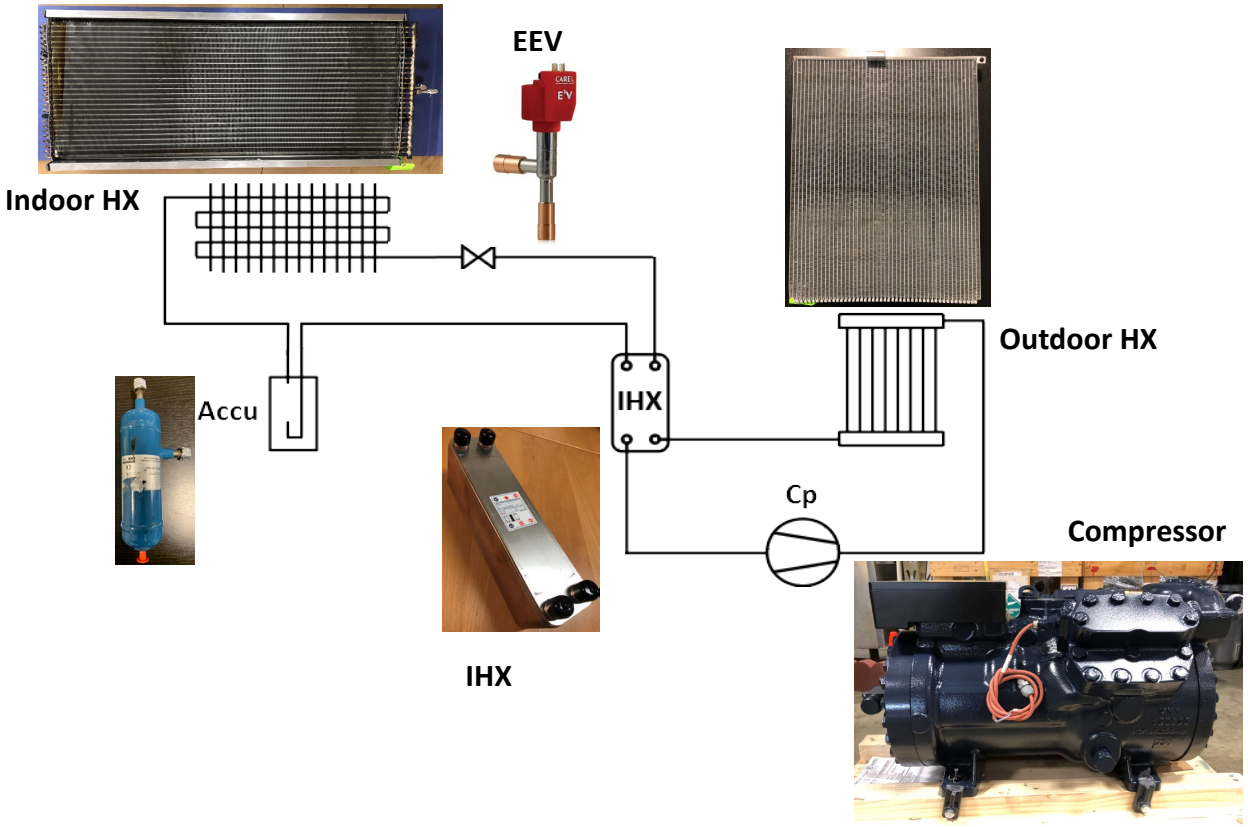
A (Hot)
B (Moderate)
H1 (Warm)
H3 (Cold)

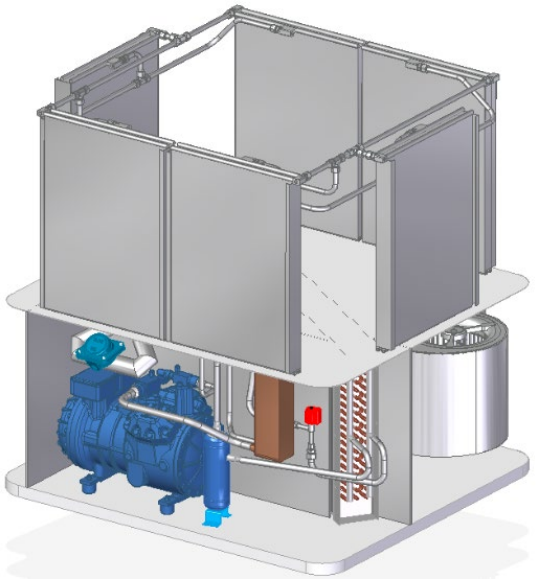


- R-468C showed matching cooling COP, but lower heating COP than R-410A
- R-468C capacity was 15~25% less vs R-410A
- The lower than expected performance of R-468C especially in heating mode is likely due to the charge optimization and TXV setting at the A condition. The HX flow directions must also be considered for refrigerants with higher glide

Phase 2. Prototype Unit Construction

- Upon completion of Phase 1, parts were replaced with R-744 components inside the same frame

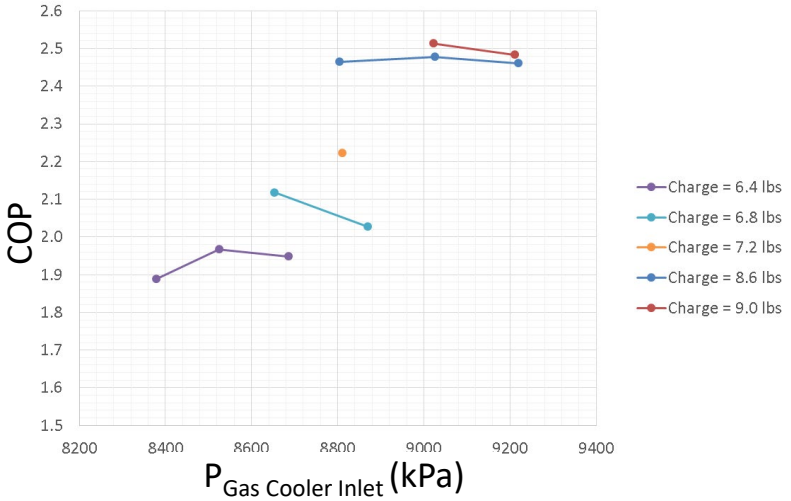




Phase 2. Charge Optimization

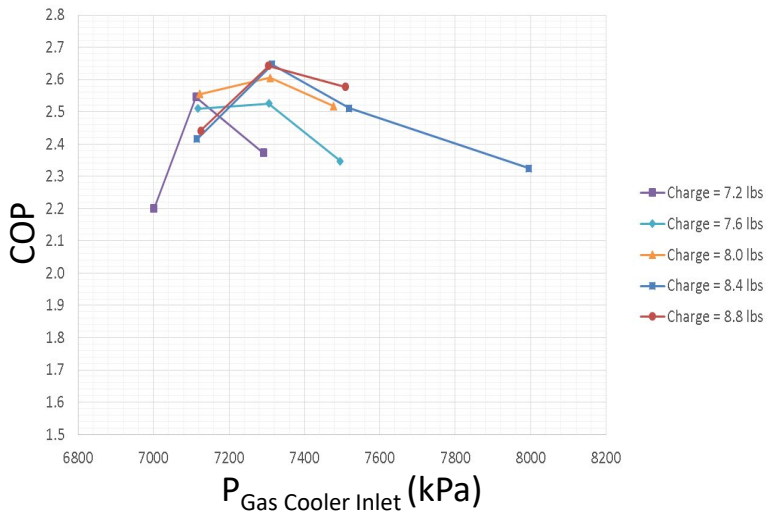
- Charge optimization was carried out with fixed 17.6 kW cooling capacity at A condition
- Compressor speed and gas cooler inlet pressure were adjusted via EEV to maximize COP

R-744



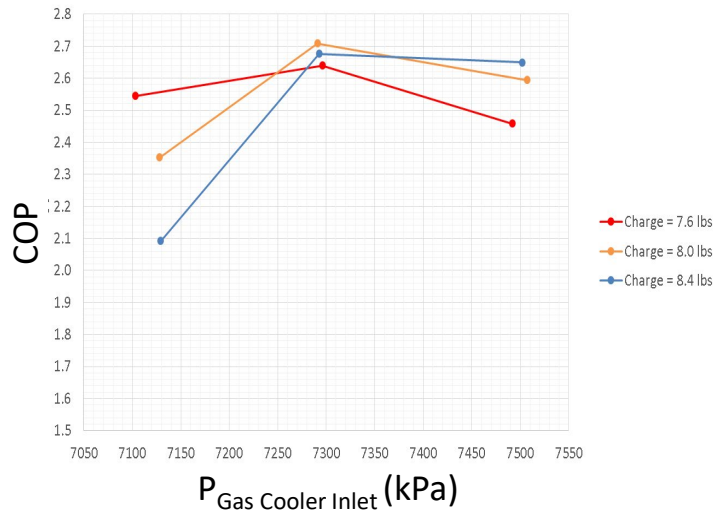
- Optimal gas cooler pressure 90 bar
- COP = 2.51
- Charge 4.1 kg (9.0 lbs)

R-485A



- Optimal gas cooler pressure 73 bar
- COP = 2.64
- Charge 4.0 kg (8.8 lbs)

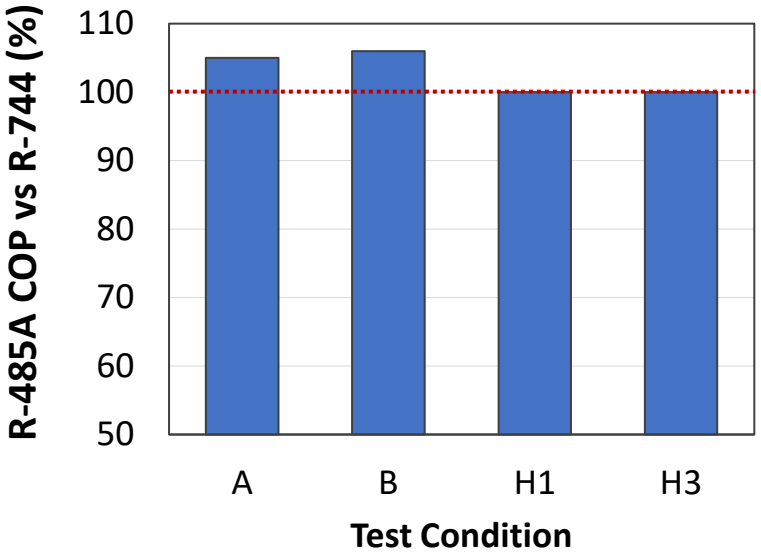
R-485A (w/o accumulator)

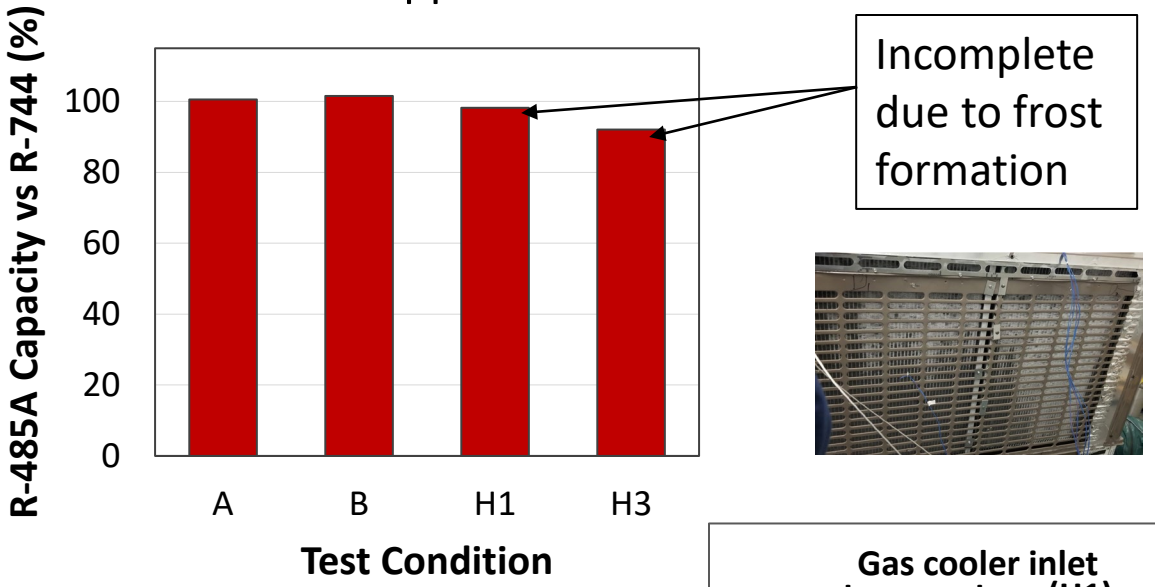


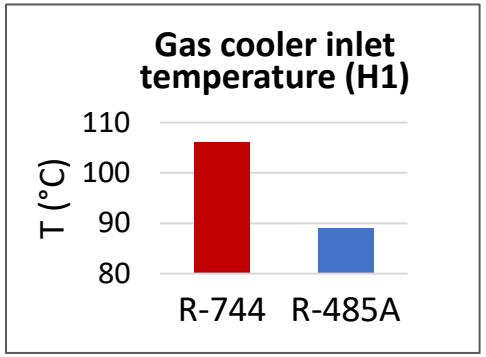
- Optimal gas cooler pressure 73 bar
- COP = 2.68
- Charge 3.8 kg (8.4 lbs)

Phase 2. Heat Pump Performance

- Compressor speed and refrigerant charge found from condition A were applied to all conditions

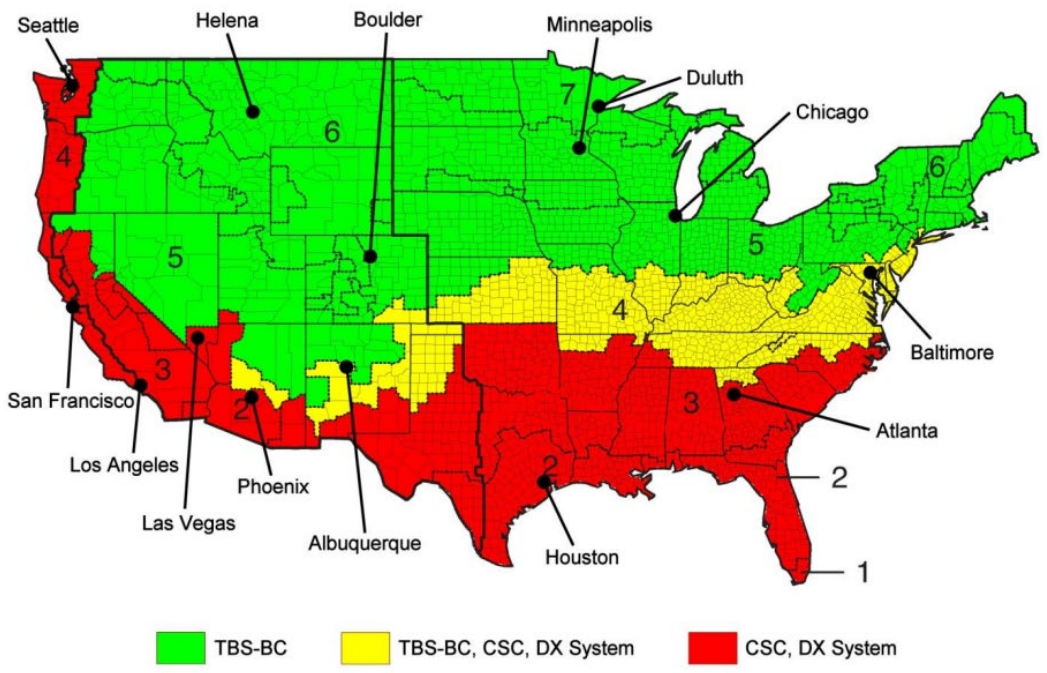




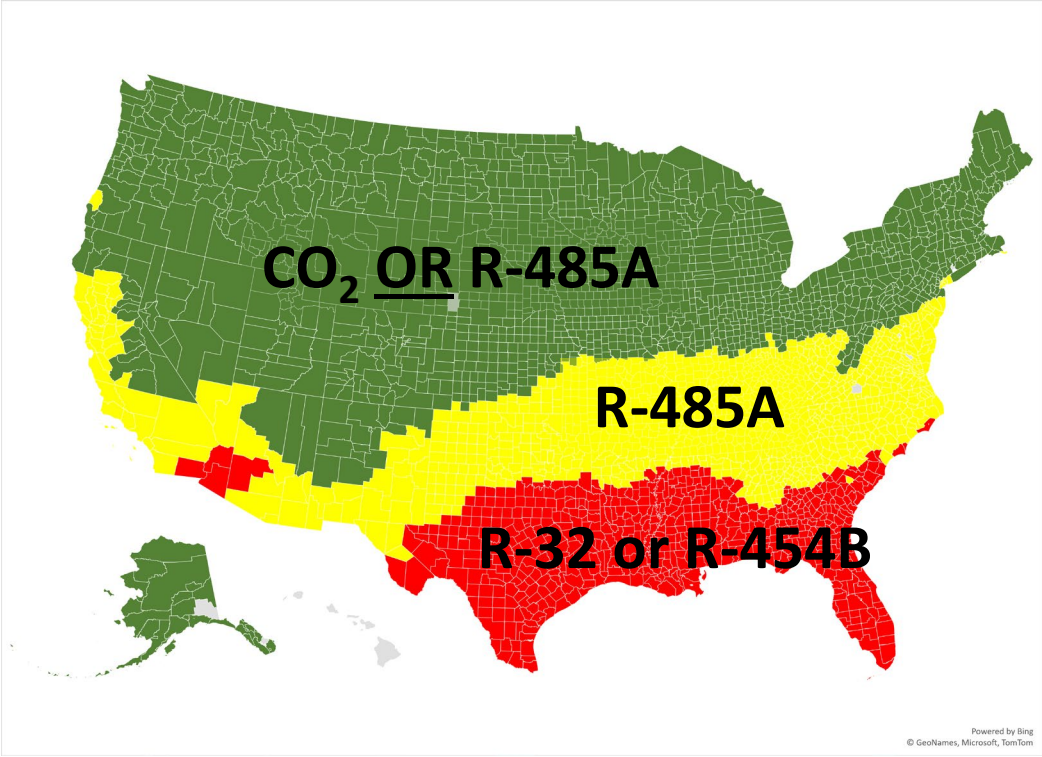


- R-485A showed cooling performance improvement over R-744
- Heating mode gas cooler pressure optimization could not be completed
  - Cooling mode optimization (refrigerant charge, HX sizing) likely hurt the heating performance of R-485A
  - The flow direction (counter flow in indoor and parallel flow in outdoor) worked against R-485A
  - Frost on the coils due to the lower evaporator inlet temperature should have negative impact on COP

R-485A – Moving CO_2 Latitude South

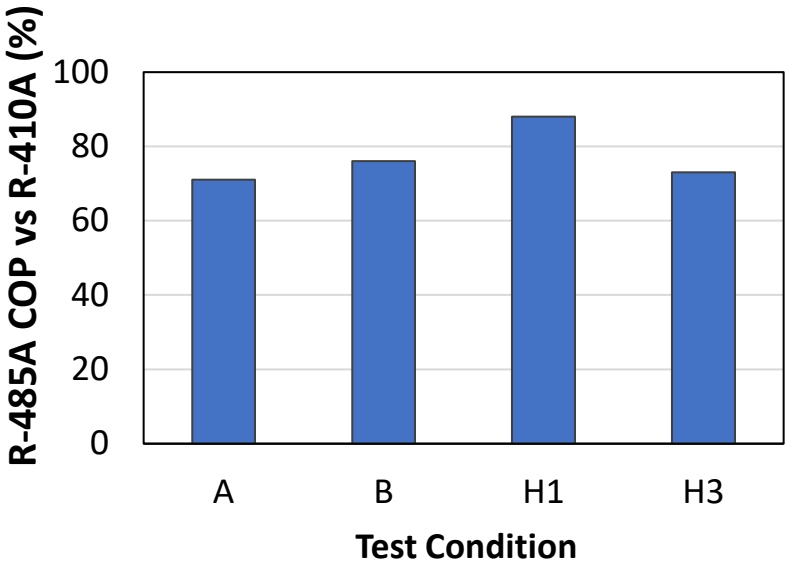


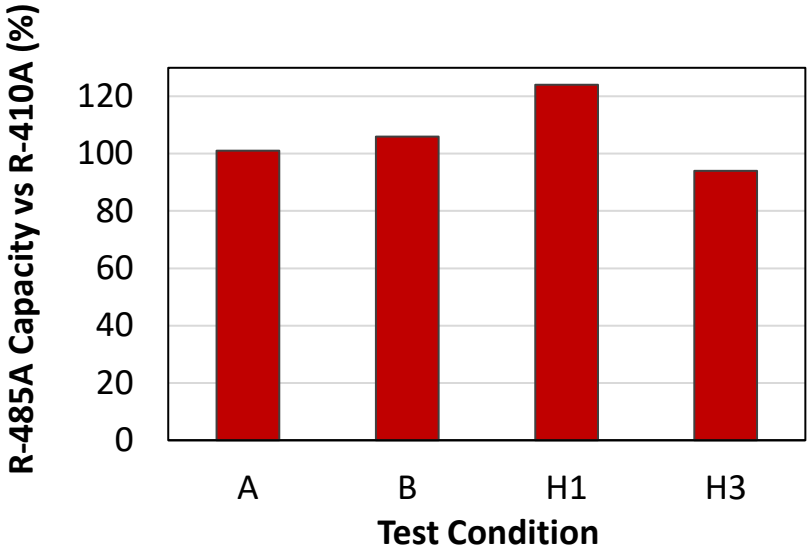
CO_2 Comfort Cooling HP



R-485A Comfort Cooling HP

Phase 2. R-485A vs R-410A





- R-485A's first prototype unit showed promising COP especially at moderate cooling (B) and heating (H1) demand
- R-485A was able to match or exceed R-410A's capacity even at H3, which had to be cut short due to frost formation
- The lower isentropic and volumetric efficiency of the R-744 semi-hermetic reciprocating compressor vs R-410A scroll compressor also allows room for improvement

Conclusion

- R-468C showed comparable drop-in performance vs R-410A with 85% GWP reduction
  - Drop in capacity can be made up with run time without energy penalty

- R-485A prototype generation 1 showed promising initial results
  - GWP<150 and A1/A2L safety classification
  - Provided matching or higher capacity vs R-410A in same frame/footprint
  - Next step: Optimization around heating
  - Room for further efficiency improvement
    - Flow direction match to benefit from the higher critical temperature and glide
    - Implementation of compressor with higher efficiency

- R-485A has the potential to move the "CO_2 border" south for all regions outside of the Gulf Coast.

Thank you

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