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Successful Conversion of Railway Air-Conditioning Unit to Transcritical R744 Technology

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Outline

- Background and motivation
- Objective: Convert existing HFC rail passenger car AC unit to R744 technology while improving COP and maintaining existing unit weight
- System design
  - Component selection: New fan and blower technology, compressor selection
  - R744 technology: IHX, high-side pressure optimization, gas cooler design
- Prototype R744 unit fabrication
  - Size and weight reduction potential with R744 unit
- Experimental demonstration of capacity and COP improvement with R744 unit

Motivation and Objectives

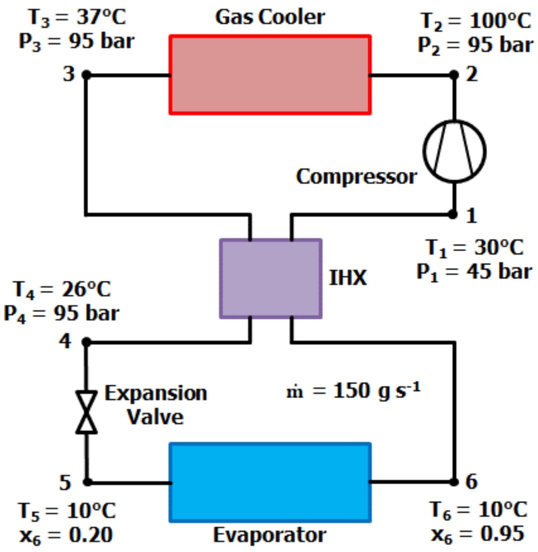
- Most existing railway and other mass transit air-conditioning units use HFC's
  - HC's and NH_3 are generally not acceptable for mass transit applications because of safety concerns, leaving CO_2 (R744) as the natural refrigerant solution
- Objective: Convert existing R407C unit for high-speed rail passenger cars to R744 technology meeting the following performance metrics:
  - Meet capacity target of 44 kW at design point (29°C/35°C indoor/outdoor temp, 60 % RH) between two dual circuits
  - Achieve COP improvement of at least 5 % over baseline HFC unit
  - Demonstrate potential to reduce unit size by 10 % with no increase in weight compared to baseline

Example rail AC unit mounted on top of passenger cars

Baseline R407C unit for high-speed rail passenger car AC

System Design and Performance Prediction

- Single-stage transcritical R744 cycle architecture with IHX selected for each refrigeration circuit



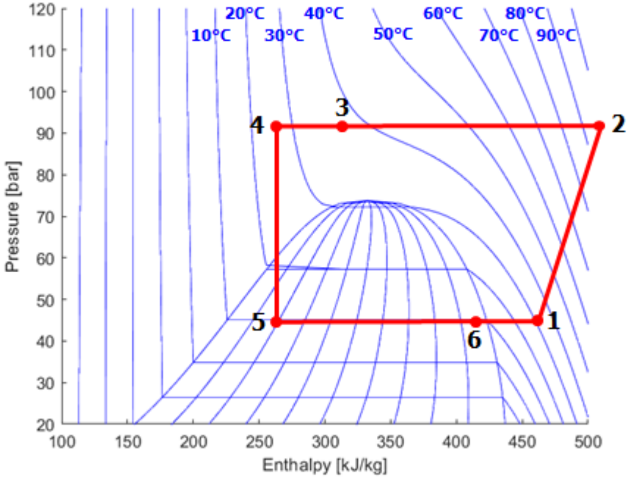
- Predicted capacity and cycle COP meet target values based on realistic component performance assumptions ($\Delta T_{gc,approach}$ = 2 K, η_{comp} = 0.67, ε_{IHX} = 0.8, $\Delta T_{evap,ref\text{-}air}$ = 20 K)

Q_{evap} = 22.6 kW

Q_{gc} = 30.1 kW

Cycle COP = 3.02

(COP does not include fan or blower power)

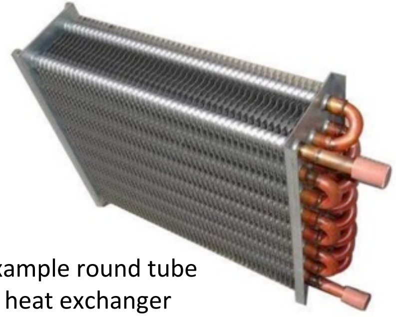


R744 Technology for Improved Unit Performance

- Compressor was selected based on lowest weight option and reliability in mobile applications
  - Very limited selection of hermetic transcritical R744 compressors available, but not in the right capacity range or approved for mobile applications
  - There is opportunity to develop light weight R744 options targeting the mass transit industry

Example semi-hermetic reciprocating compressor

- Gas cooler custom designed using CTS' in-house tools to optimize mass flux and minimize approach temperature
  - Round-tube coils chosen for reliability (microchannel technology not currently accepted by railway community due to concerns of corrosion and air-side blockage)
  - Multiple rows of fins used to reduce conduction between first rows of refrigerant tubes



Example round tube heat exchanger

R744 Technology for Improved Unit Performance

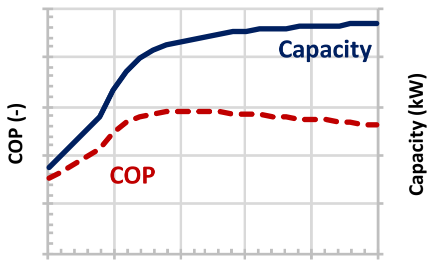
- Internal heat exchanger or **IHX** (use cool suction gas to further cool fluid from gas cooler below ambient temp)
  - Brazed plate as an IHX provides a light-weight, compact method to significantly boost capacity and COP by up to 20 % each or even higher

Example brazed-plate HX

- Electronic expansion valve (EEV) to **optimize high-side pressure** for different ambient conditions and system loads
  - Balance increasing capacity and compressor power as high-side pressure increases to maximize COP
  - Secondary benefit of high-side pressure control with IHX is opportunity to overfeed evaporator and raise evaporator pressure

Example EEV

simulated COP optimization at 35°C



Improved Fan and Blower Technology

- Light weight fans and blowers are available specifically for railway applications, helping to reduce weight and improve energy efficiency compared to the older technology of baseline unit
- Blade material is polyamide plastic (non-flammable as required by railway industry)
- Electronically commutated motors for improved efficiency over wide range of speeds

Axial fans

Centrifugal blowers

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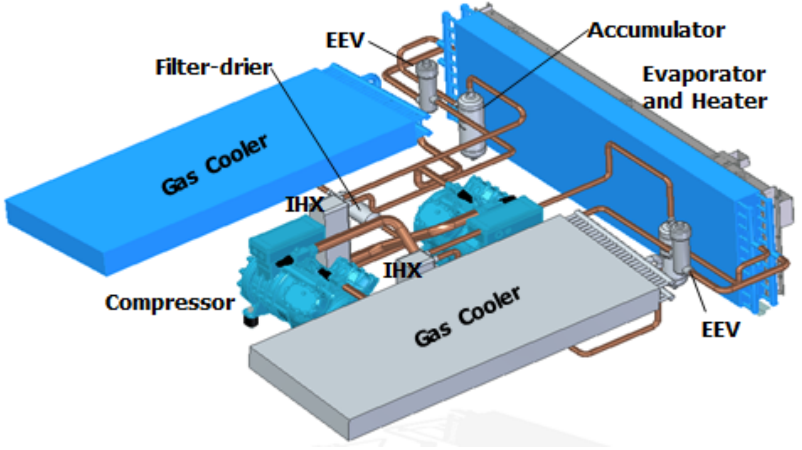
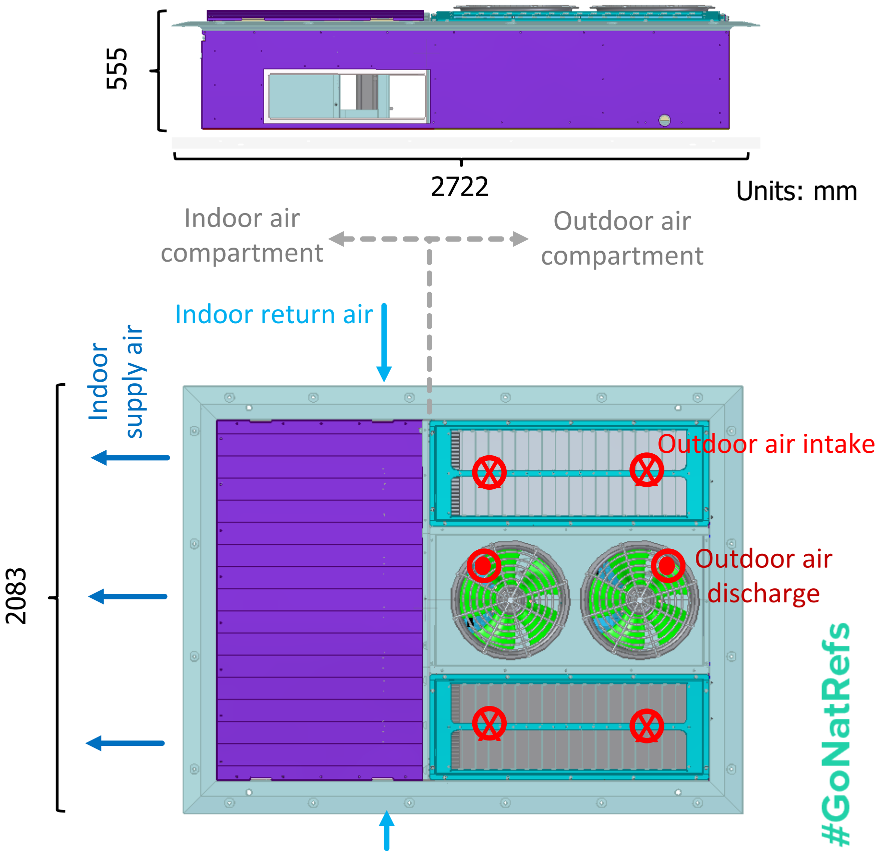
Unit Configuration and Layout

- Components arranged in dual-circuit system
- Evaporator, valves, and accumulators placed in indoor compartment, compressors, IHX’s, and gas coolers placed in outdoor compartment





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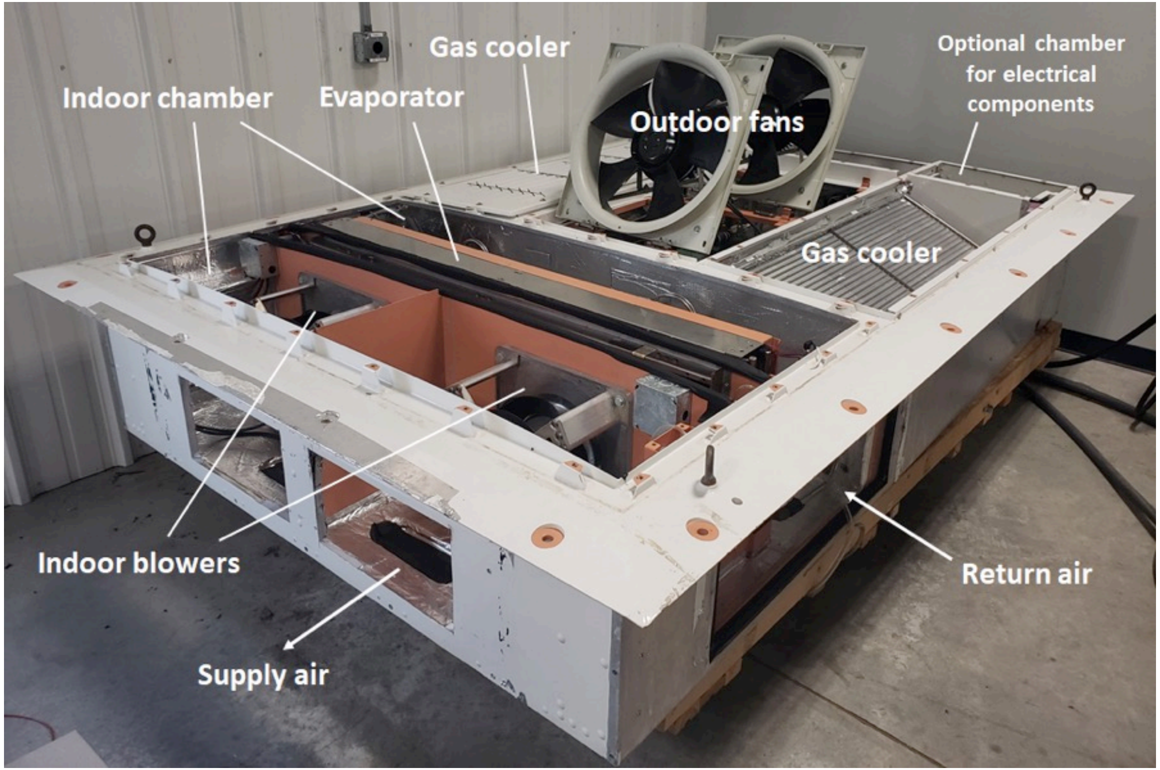
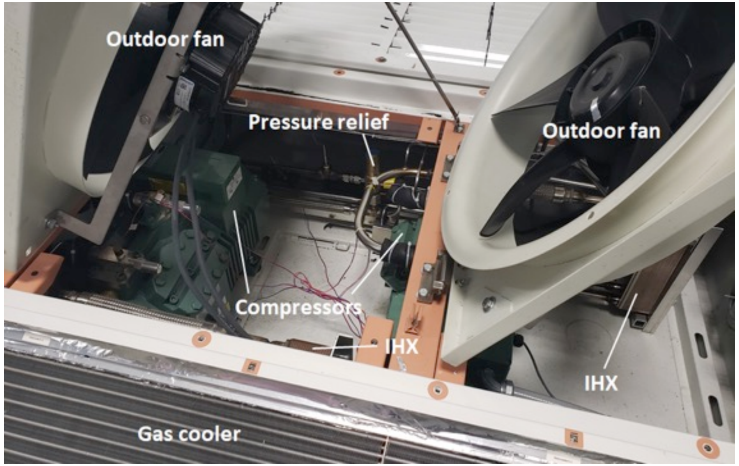
R744 Rail AC Unit

- Fully-functional prototype R744 unit was fabricated for demonstration and evaluation
- Covers removed to see interior components

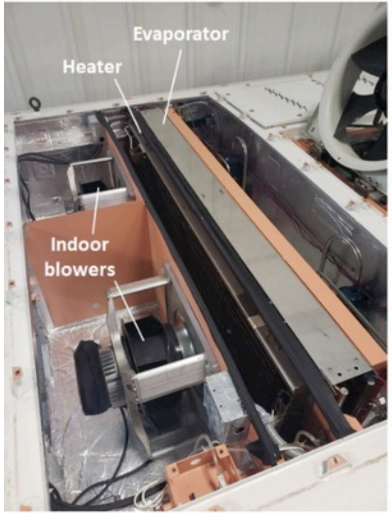


R744 Rail AC Unit

Outdoor air compartment



Indoor air compartment



R744 unit has significant savings in size and weight compared to R407C baseline

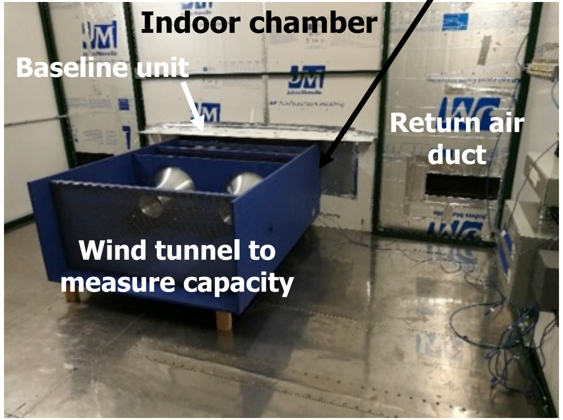
- Total length and volume of unit reduced by 13 %
- **Additionally, weight reduction of several percent** achieved despite switch to high-pressure R744 components, helped by newer fan and blower technology, optimized HX design, & reduced unit size

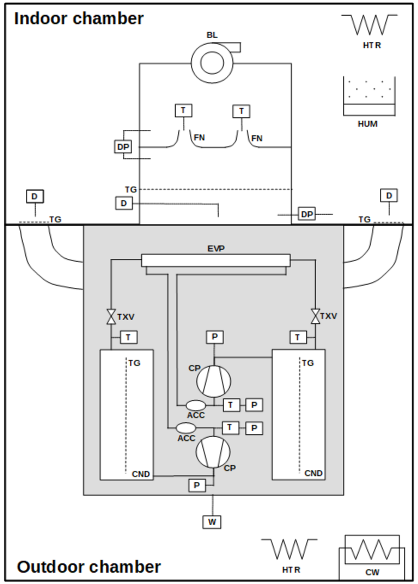
Unit dimensions

	R407C Baseline	R744 Unit
Width	2.1 m	
Length	3.1 m	2.7 m
Height	0.6 m	

Unit Performance Evaluation in CTS Rail A/C Test Facility

- Units were instrumented and placed in environmental chambers to control ambient and indoor conditions
- Capacity was measured with TC grids and flow nozzles





ACC: Accumulator
BL: Air blower
CND: Condenser
CP: Refrigerant compressor
CW: Chilled water heat exchanger
D: Dew point sensor
DP: Differential pressure sensor
EVP: Evaporator
FN: Air flow nozzle
HTR: Electric resistance air heater
HUM: Humidifier
P: Pressure sensor
T: Type-T thermocouple
TG: Thermocouple grid

R744 Unit Performance and Comparison to Baseline

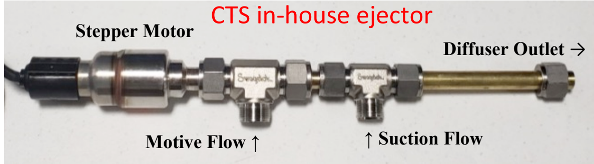
- **Very significant improvements in capacity (14 %) and unit COP (16 %)** show great potential for R744 unit to replace HFC units
- Prototype meets capacity target of 44 kW
- Unit COP includes fan and blower power

	R407C Baseline	R744 Unit	Improvement with R744 Unit
Indoor temp.	29°C		-
Wet bulb	23°C		-
Outdoor temp.	35°C		-
Capacity	39.1 kW	44.7 kW	**+ 14 %**
COP	1.96	2.28	**+ 16 %**

- Improvements in capacity and efficiency of R744 unit aided by use of newer components (e.g. fans, blowers, heat exchangers) and increased cycle and control complexity

Opportunities for Further Improvements in Railway AC Technology

- Design reversible AC/HP system: R744 performance in heat pump mode is very favorable and can be used to improve heating efficiency of unit in winter
- Ejector: Use two-phase ejector for significant improvements in COP and capacity, especially at high ambient temperature or under heat pump mode (realistic COP improvements of 10 – 20 %)



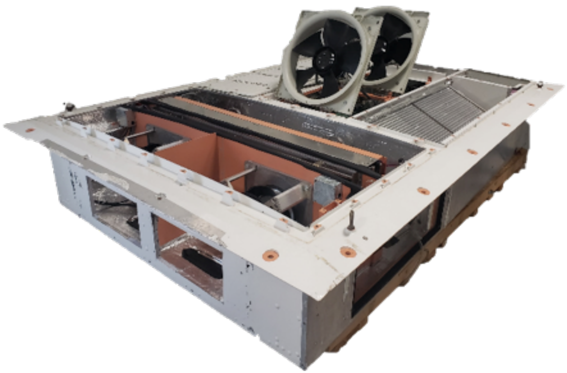
- Microchannel heat exchangers: Small-to-moderate improvement in heat transfer but very significant reduction in weight

Conclusions

- This investigation has shown the very promising potential that the natural refrigerant CO_2 (R744) has to replace HFC's and HFO's in mass transit AC systems, such as the high-speed rail AC unit that was the focus of this study

- The R744 prototype railway passenger car AC unit has achieved performance improvements of 14 % in capacity and 16 % in COP while reducing size by 13 % and weight by several percent, all of which exceed the design objectives set by the railway industry

- Much opportunity for future development: Reversible AC/HP system design; light-weight compressor development; ejector technology; microchannel heat exchanger technology



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Thank you for listening!