Energy & Store Development Conference

E+SD 2016

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HFOs: The Future of Sustainable Supermarket Refrigeration

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Agenda

- Introduction
- Supermarket refrigeration system architectures
- Performance and Environmental Impact
- Retrofit Options

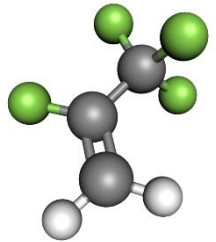
Introduction

- Interest in reducing the environmental impact on our atmosphere has initiated a search for new refrigerant alternatives, especially for commercial refrigeration.
- Three hydrofluoroolefin (HFO) molecules with an ultra-low GWP have been developed: **R1234yf | R1234ze(E) | R1233zd(E)**
- These fluids are used in low, medium and high pressure applications as single fluids or blend components:

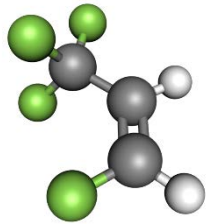
	Application	Current refrigerants	Lower GWP option
Low pressure	Chillers	R123, R245fa	R1233zd(E)
Medium pressure	Mobile AC MT Refrigeration	R134a	R1234yf, R1234ze(E), R450A, R515A, R513A
High pressure	Air-conditioning Refrigeration	R22,R404A, R410A	R407 blends, R448A, R449A, R449B

- New technologies will enable the use of totally different heat transfer fluids (mildly flammable HFOs, CO_2, HCs, …) to achieve good performance and low overall GWP.

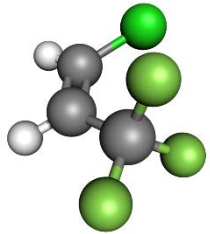
R1234yf



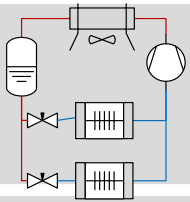
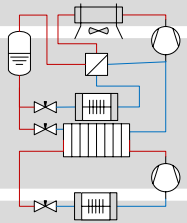
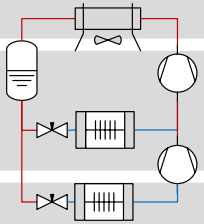
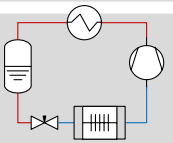
R1234ze(E)



R1233zd(E)



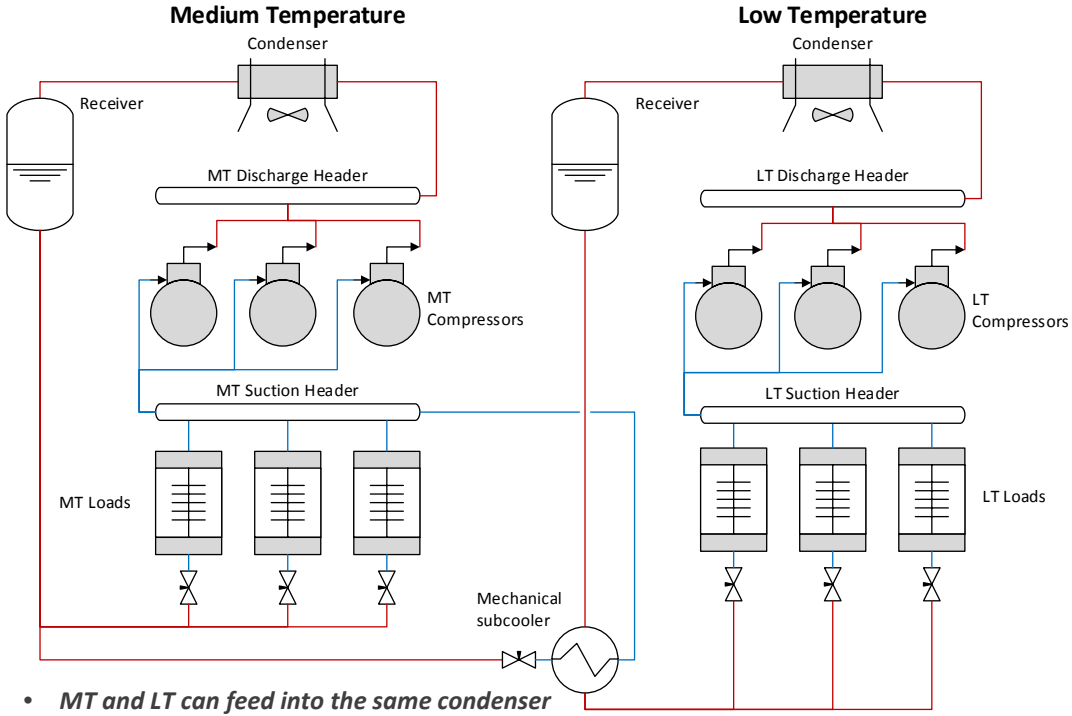
Supermarket refrigeration | Refrigerant Options

Application	Current refrigerant (GWP_{AR5})	Lower GWP Option		Schematic
		Refrigerant (GWP_{AR5})	Flammability	
Conventional DX System	**R404A /R507** (3943/3985)	**R407F** (1674) **R448A** (1273) **R449A** (1282) **R449B** (1296)	A1	
	R22 (1760)			
Cascade System/ Hybrid	**R134a** (1300)	**R513A** (572), **R515A** (403)	A1	
		R450A (547)	A1	
		R1234ze(E) (<1)	A2L	
Booster	**CO_2** (1)	**CO_2** (1)	A1	
Self-contained	**R404A** (3943)	**R448A** (1273), **R449A** (1282), **R449B** (1296)	A1	
		R455A (146)	A2L	

Supermarket Architectures

Centralized Direct Expansion (DX)

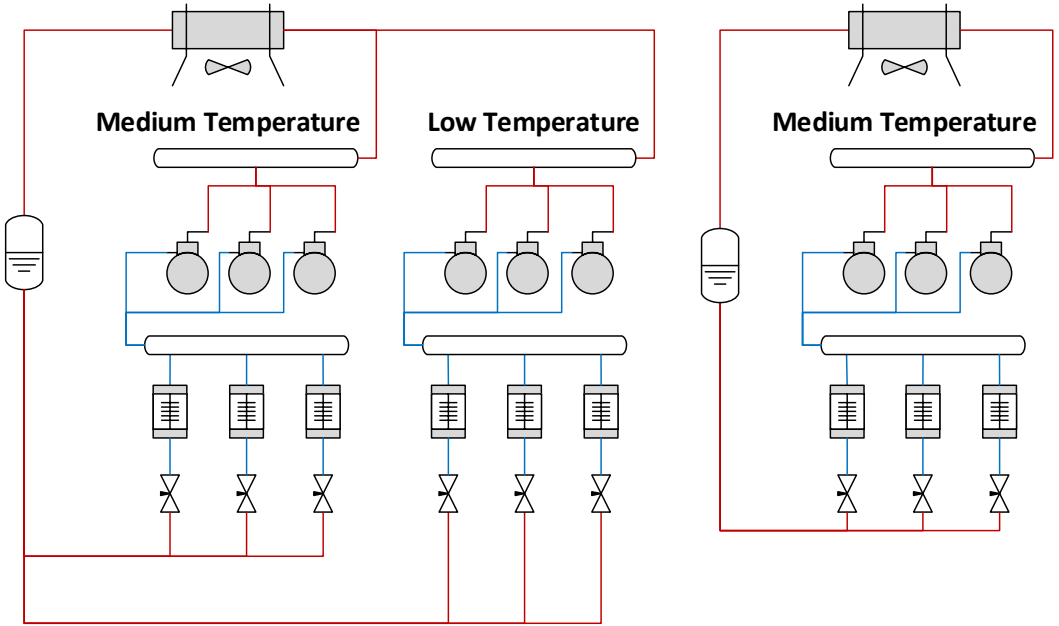
Category	Characteristics
Features	• DX system providing refrigeration to MT and LT cases • Centrally located in machine room with lines feeding into the cases
Pros	• Convenient installation in most buildings – in common practice • Very familar to store owners and contractors
Cons	• Longer refrigerant lines • Larger refrigerant charge • Higher leak rates
Current	• R404A • R22 • R134a • R407A • R407F
Future	• R448A, R449A, R449B • R450A, R513A, R515A



- ***MT and LT can feed into the same condenser***
- ***1-3 racks per store***

Distributed Direct Expansion (DX)

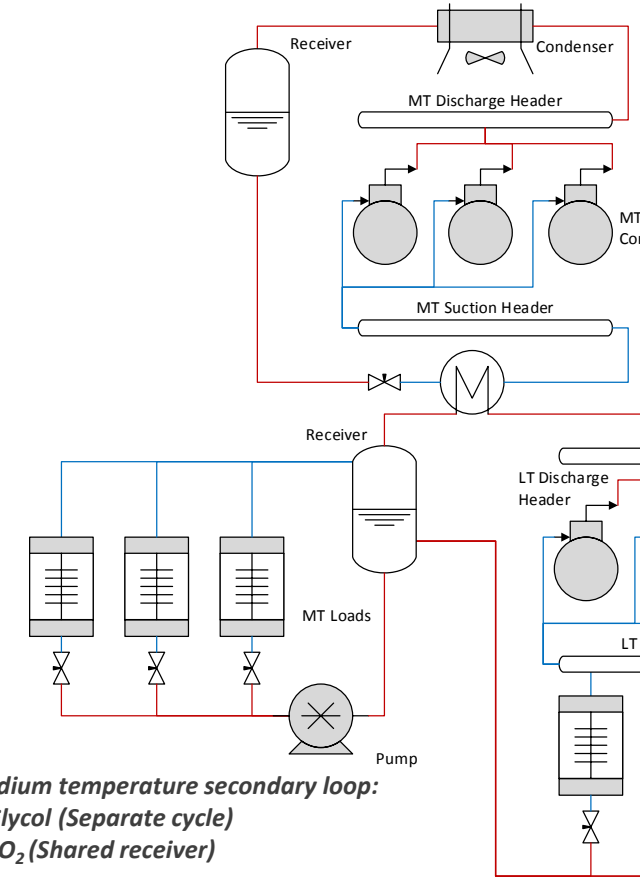
Category	Characteristics
Features	• Compressor inside small controlled units near cases and condenser in rooftop right above • Short connecting lines
Pros	• Lower refrigerant charge (about 1/2 of centralized systems or lower) • Lower leak rates since condensing units are factory assembled • Potentially more efficient than centralized – better match of suction groups, shorter lines
Cons	• Not always feasible in some buildings • Higher initial cost
Current	• R404A • R407A • R407F
Future	• R448A, R449A, R449B • R450A, R513A, R515A



- ***Separate racks for the load requirements not feeding into the same suction group.***
- ***1-8 per store***

Cascade/ Hybrid System

Category	Characteristics
Features	• Secondary fluid (glycol/ CO_2) for medium temp cases • Mildly flammable fluid providing cooling to MT and LT stage • Short connecting lines on the refrigerant side
Pros	• Very low refrigerant charge • Very low leak rates • Refrigerant confined in machine room may allow flammable options with very low GWP • Higher efficiency, particularly in warm climates
Cons	• Higher initial cost
Current	• R404A • R407F • R134a
Future	• R448A, R449A, R449B • R455A • R450A, R513A, R515A • R1234yf, R1234ze(E)



Medium temperature cooling cycle:
- ***HFC/ HFO-Blend***
- ***Mildly flammable fluid not in retail area***

Low temperature:
- ***Separate vapor compression (CO_2)***

Medium temperature secondary loop:
- ***Glycol (Separate cycle)***
- ***CO_2 (Shared receiver)***

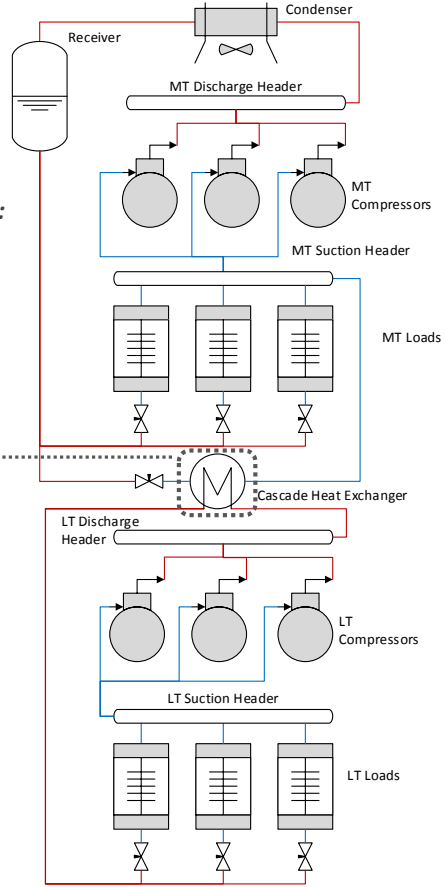
Direct Expansion Cascade System

Category	Characteristics
Features	• MT DX cooling provided directly by HFC, non-flammable HFO-blend • LT DX system benefits from good CO_2 performance and low temperatures • Cascade HX to remove heat from LT stage
Pros	• Very low overall GWP • Low refrigerant charge • High system efficiency
Cons	• Non conventional • Higher initial cost • Two refrigerants in the store
Current	• R448A, R449A, R449B • R450A, R513A, R515A
Future	• Non-flammable, low GWP HFO-blend/ CO_2, R290

Medium temperature cooling cycle:
- ***HFC/ HFO-Blend***
- ***Non-flammable fluid option can be routed to sales area***

MT and LT stage are coupled through cascade heat exchanger

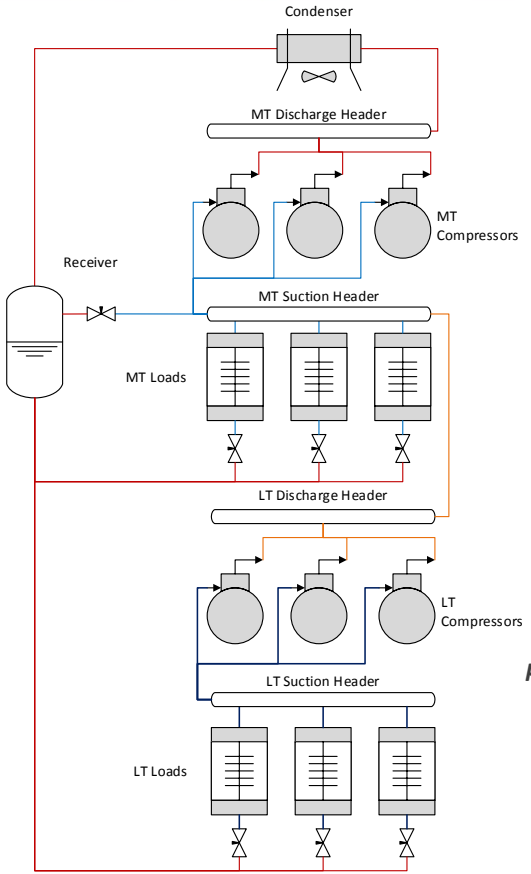
Low temperature:
- ***Separate vapor compression (CO_2)***



CO_2 Booster

Category	Characteristics
Features	• Two stage design with booster compressors elevating pressure from LT level to MT level
Pros	• Non-flammable working fluid • Low overall GWP
Cons	• Very high operating pressure • CO_2 has lower system efficiency at higher ambient condition • Additional system modification and investment might be necessary to be competitive in enery efficiency • Higher initial, servicing, operating cost
Current	• CO_2
Future	• CO_2

System rejects heat at very high discharge pressures of >1500PSI depending on ambient condition in a transcritical gas cooling process.

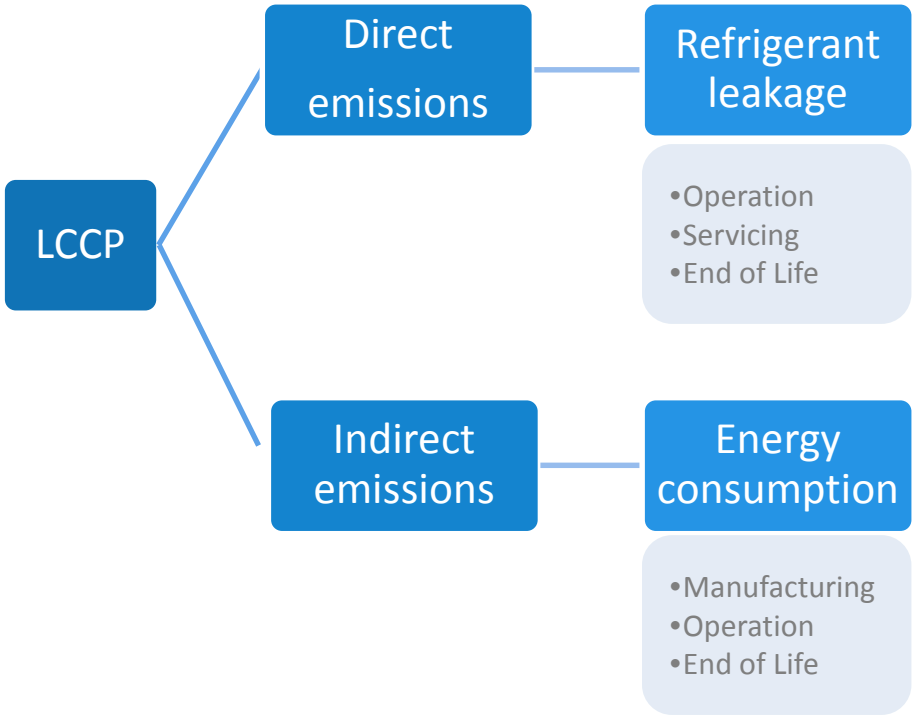


LT compressors "boost" the evaporation pressure and feed into the MT compressors.

System Performance and Environmental Impact

Life cycle climate performance (LCCP)

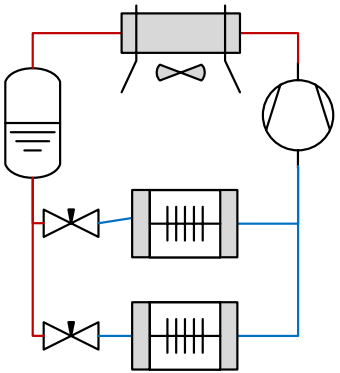
- Environmental impact of a refrigeration system during its lifetime (CO_{2eq})
- Direct and Indirect Effect
  - Direct emissions
    - Refrigerant leakage
    - Global warming potential (GWP)
  - Indirect emissions
    - Emissions due to energy consumption during lifetime
    - CO_2 emissions due to power generation
- Both low GWP and high efficiency are essential for a low environmental impact (LCCP)



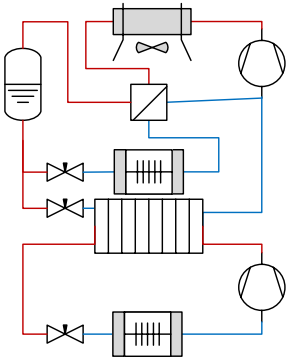
LCCP | Assumptions

- Typical store size with MT/LT
- Bin temps., emission factors and electricity rates based on stores in Buffalo, NY and Phoenix, AZ
- TD, SH=10F; No SC
- CO_2: TD_{TC}=5F, TD_{SC}=10F
- No pressure drop
- Leak rates: 15% (Centr., CO_2 booster), 10% all other
- Charge: Centr.,Booster: 3,000lbs; Distr.: 1,500lbs; Cascade: 2,000lbs
- 20 year lifetime

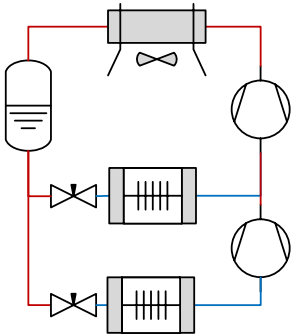
	Medium temperature	Low temperature
Evap. Temp. [F]	17.6 (CO_2: 18.6F)	-25 (CO_2: -24F)
Isen. Eff. [-]	0.7	0.67
Load	64%	36%



Centralized system

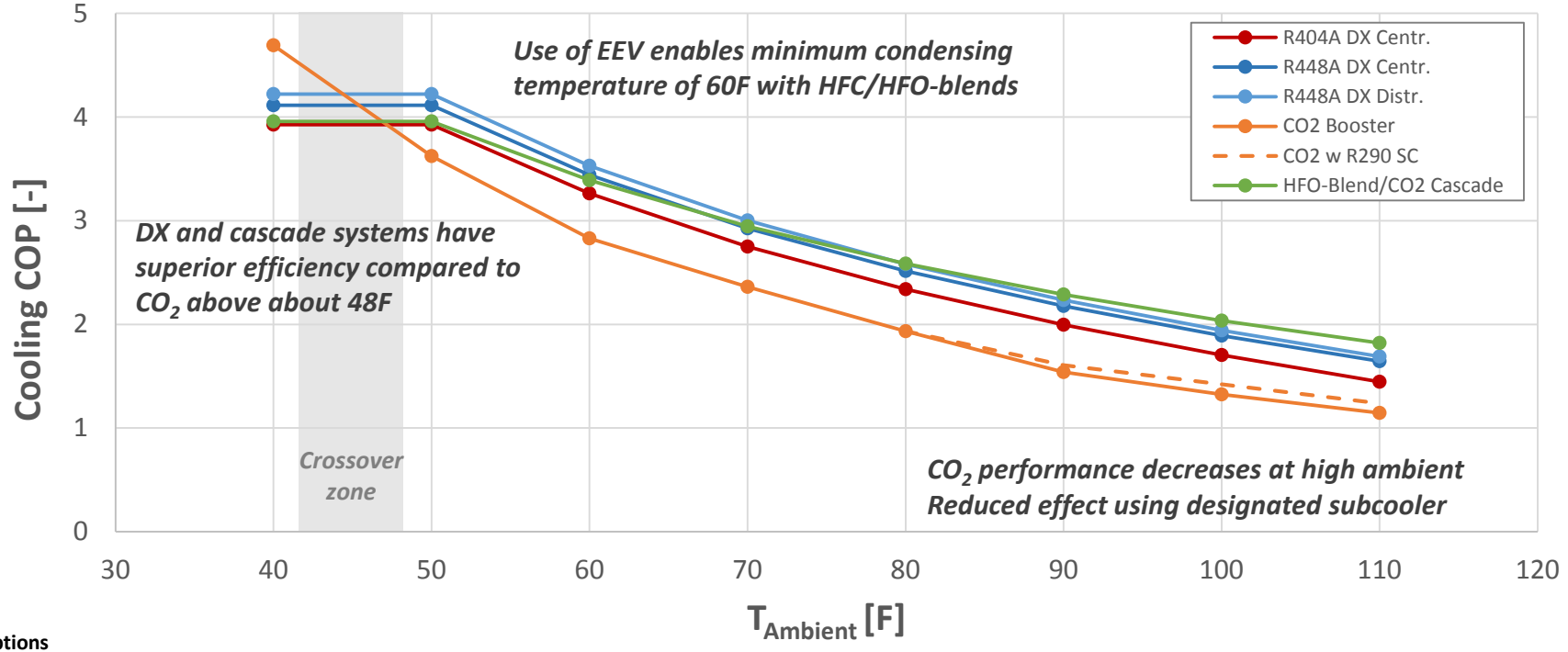


Cascade system



CO_2 booster system

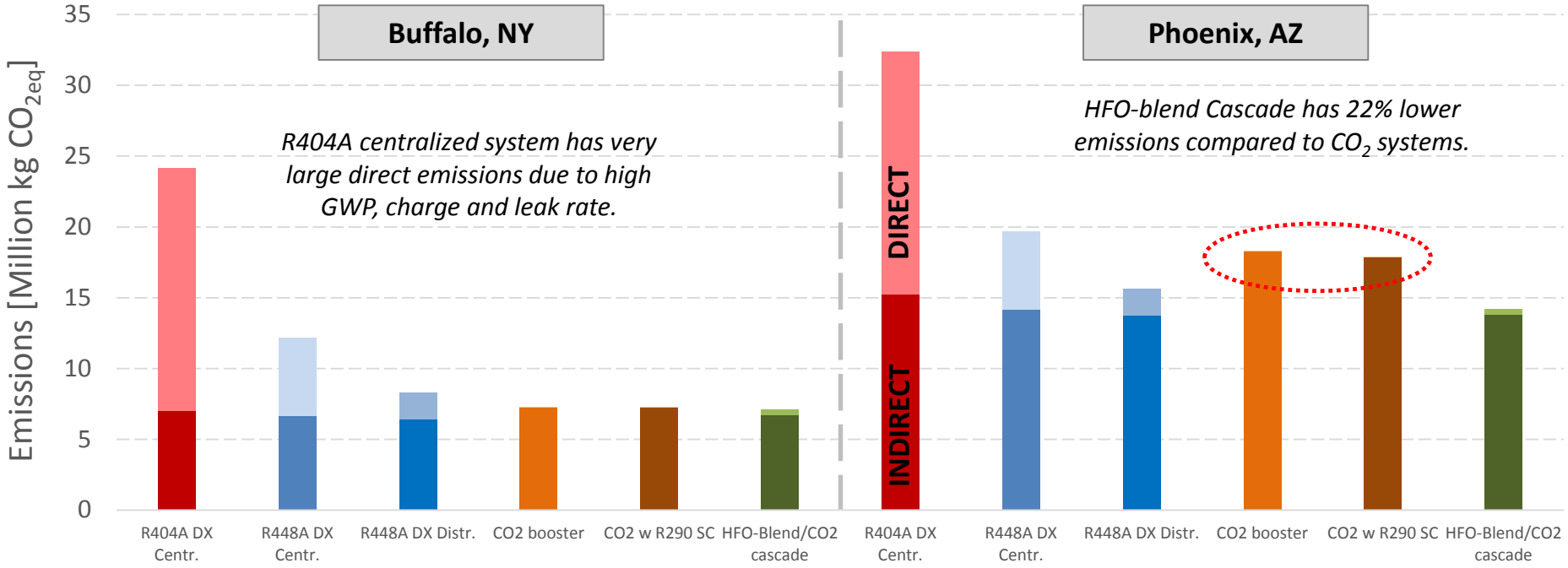
System performance at varying ambient temperatures



Assumptions

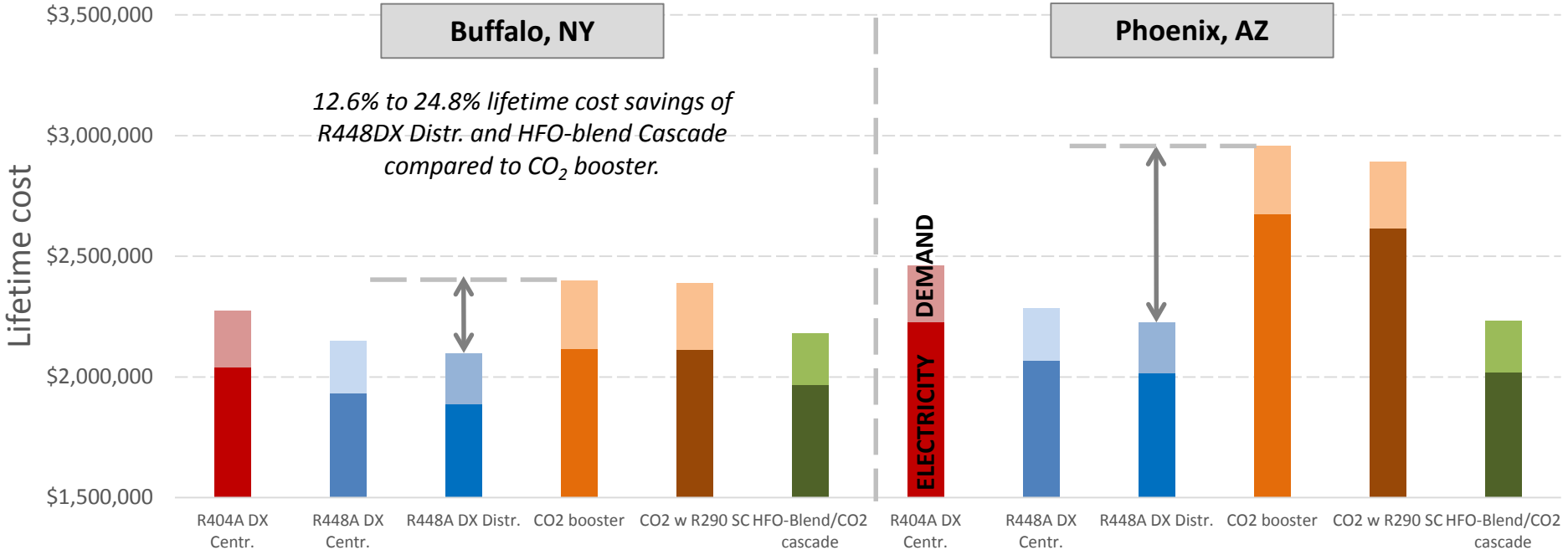
- Conditions: Evaporation temperature: MT/LT, 17.6F/-25F; Superheat: 10F; TD: 10F
- Other: No pressure drop, Isent. Eff.: MT/LT, 0.7/0.67; Load distribution: MT/LT, 0.66/0.34

LCCP | Direct and Indirect Emissions



R448A Distr. and HFO-blend cascade show similar emissions at low temperatures and reduced impact at high temperatures compared to CO_2.

20-year Lifetime Operational Cost (Electricity + Demand)



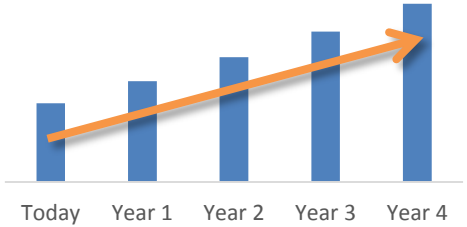
R448A Distr. DX and HFO-Blend cascade have significantly lower cost over its lifetime compared to CO_2 systems at both low and high ambient conditions.

Growing your Business while reducing Environmental Impact

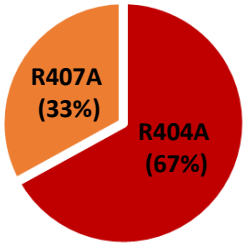
HFO Blends as a Retrofit Option

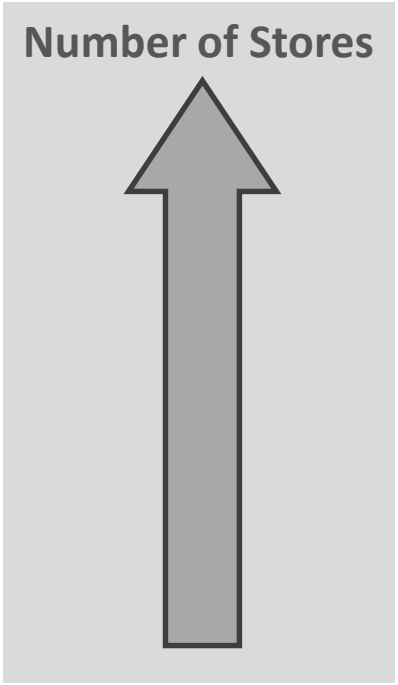
Growth vs. Carbon footprint | An example

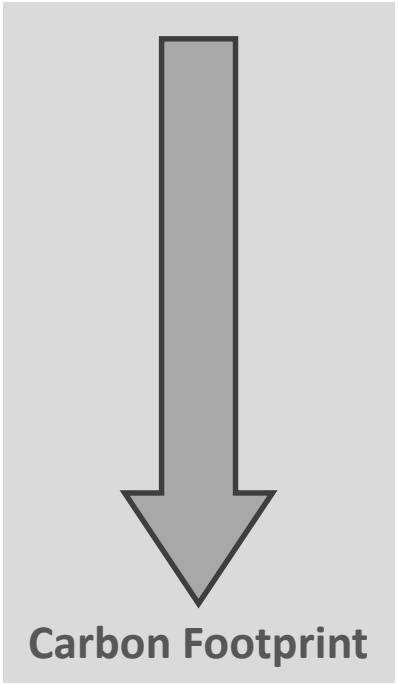
- Supermarket chain with 1400 stores and 8% growth/year



- Small Format Store with 350lbs refrigerant charge
- Annual Leak Rate: 15% of charge
- Initial Install Base:





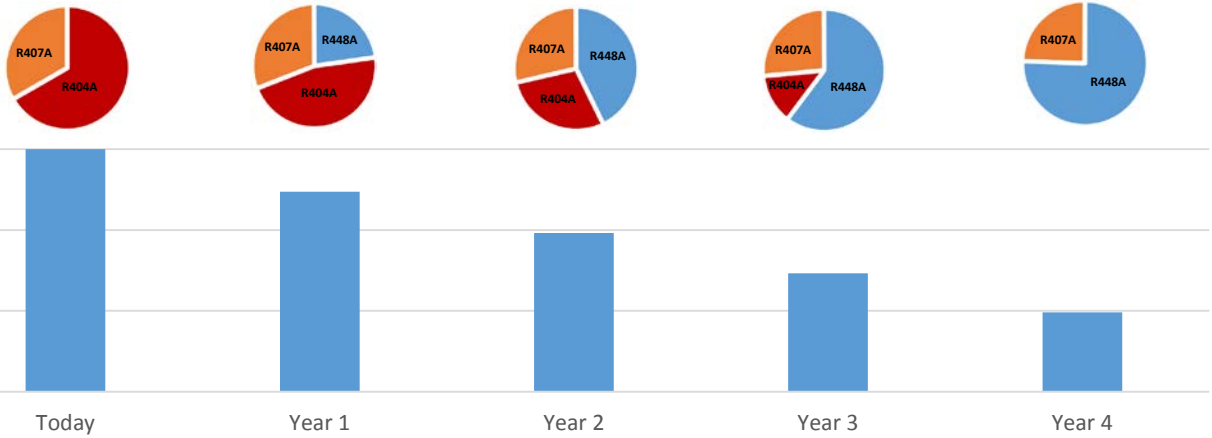


Option | Retrofit with HFO-Blend

- Retrofit 25% of R404A Stores to R448A annually
- New stores installed with R448A

	Today	Year 1	Year 2	Year 3	Year 4
Stores	1400	1512	1633	1764	1905
Refrigerant [lbs]	490k	529k	571k	617k	667k
Emissions CO_{2eq} [tons]	120k	108k	95k	83k	72k

Composition



40% Reduction in Direct Emissions by retrofitting with R448A while Increasing the Number of Stores by 36%.

20% emission increase would have resulted from a retrofit with R407A.

Retrofit Highlights and Best Practices | R404A to HFO Blend (R448A)

- Recover R404A using industry best practices (Green Chill Guidelines)
- Evaluate expansion devices
- Replace filter driers and oil system filters if required
- No oil change required. Same oil as with R404A
- Charge the system with R448A (typically 0+4%)
- Set controller to p-T curve of R448A (average)
  - Set all operating controls/valves
- Always consult with compressor/equipment manufacturer

Supermarket Retrofit Case Study: R404A to R448A

Case Study with Distributed System

System Description

- US Supermarket store located in Midwest US
- Baseline R404A system with MT/LT cases (70/30)
- System instrumented with pressure and temperature sensors, kWh and amp meters

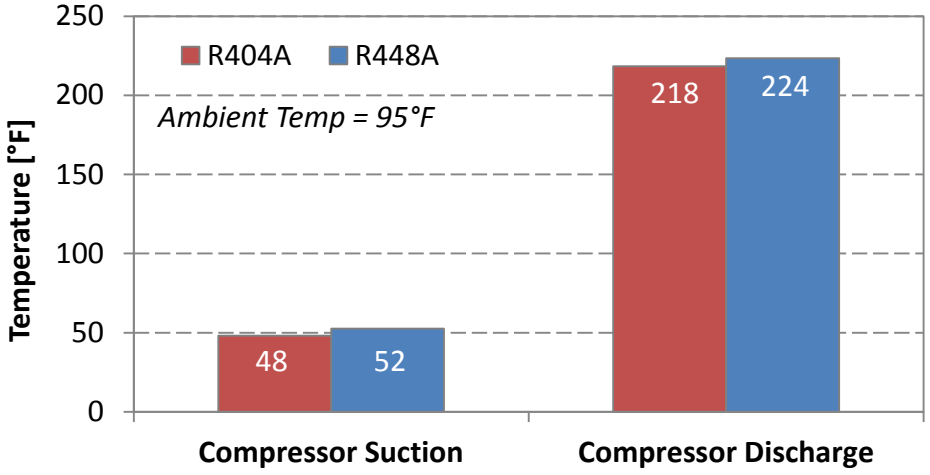
Retrofit Highlights

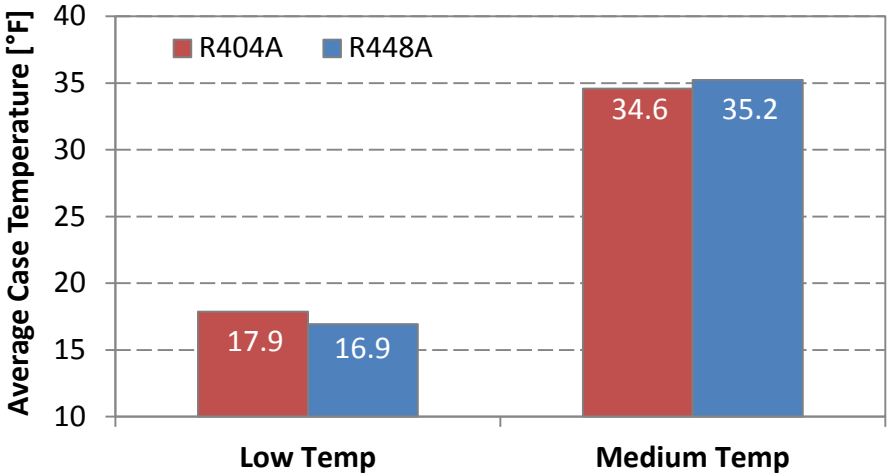
- Same POE oil used for R448A
- Minor adjustments to controls
- R448A p-T table uploaded into rack controller

Performance Metrics

- Data collected over about 4 months for each refrigerant.
- Ambient temps ranging from 5 to 95°F.
- Analysis prepared for normalized temperature bins

Case study | Temperatures



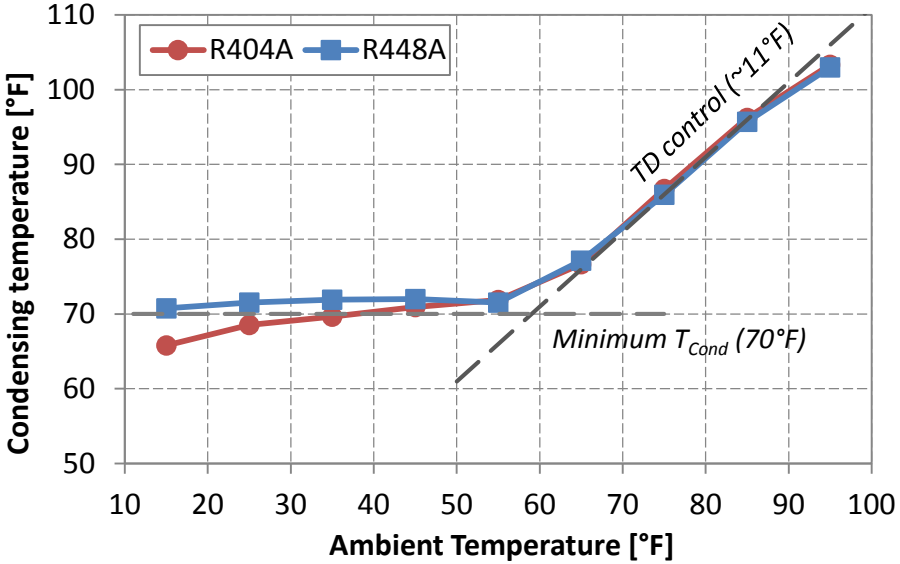


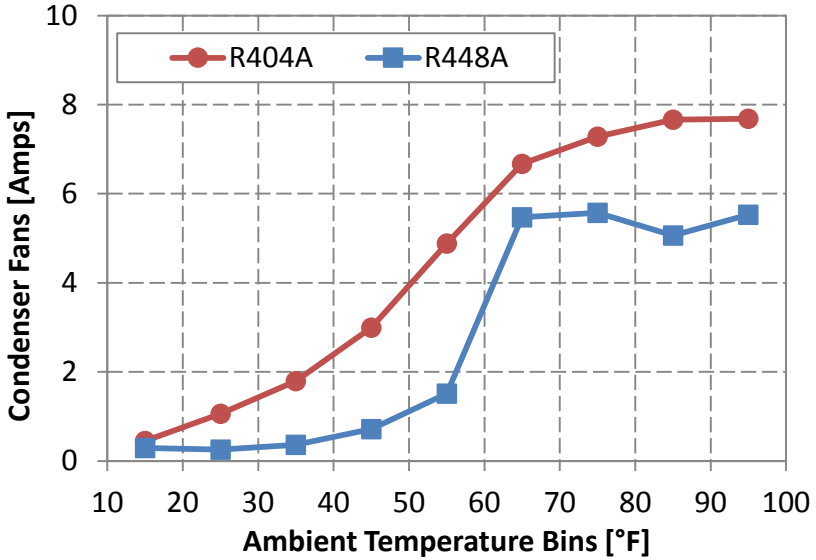
- Discharge temp at 95°F bin slightly higher than R404A, below maximum allowed by compressor manufacturer
- Liquid injection installed, not triggered during R448A operation due to good system design

- Case temperatures were matched within 1°F

Case temperatures were matched; Higher compressor discharge temps manageable

Case study | Condenser performance

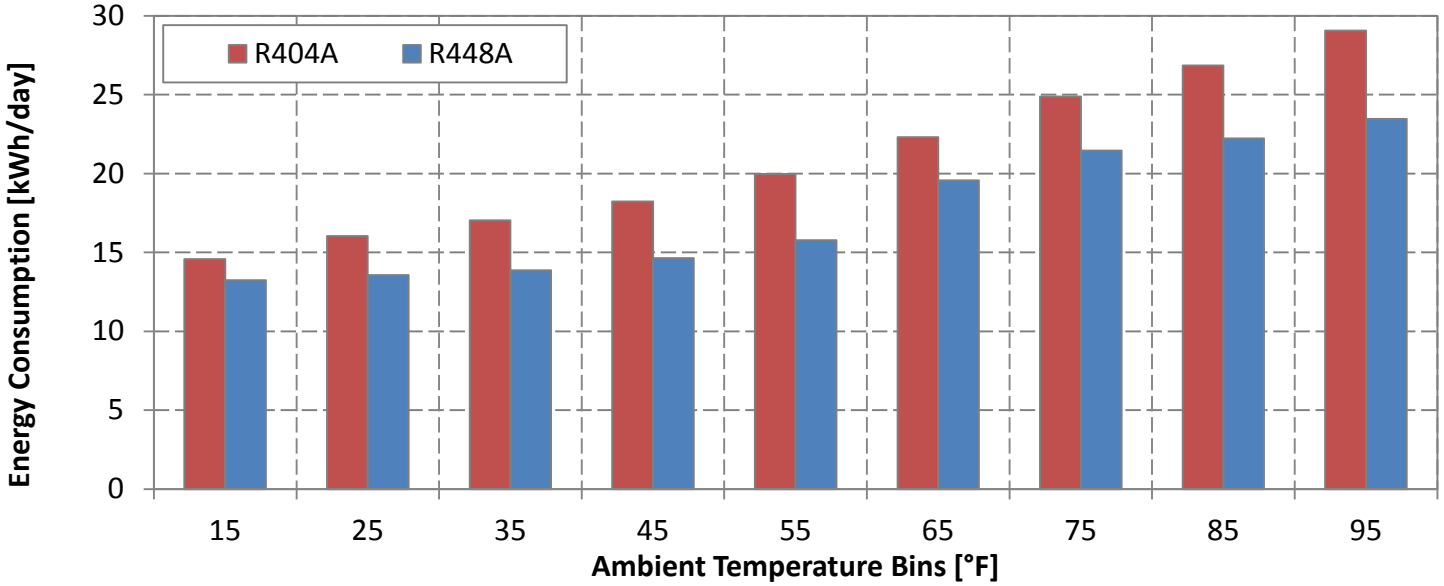




- Appropriate TD and minimum condensing temp control with R448A
- Similar condensing temps

- Higher energy efficiency of R448A reduced the condenser load, resulting in lower condenser amps over entire range

Case study | Energy consumption



- R448A shows lower energy consumption in all ambient temperatures
- Energy savings range from 9 to 20%*

* Results can vary depending on system variables. Typical savings range from 5% to 11%.

Concluding remarks

- HFO blends used in conventional and new commercial refrigeration system architectures can reduce the environmental impact through superior efficiency and lower GWP.
- Sophisticated designs using CO_2 have higher environmental impact and lifetime cost compared to HFO blend options.
- Many successful retrofits from R404A to HFO blend options confirm reduced energy consumption while matching system requirements.

HFO blend options are available today to reduce environmental impact and lifetime cost compared to R404A and natural alternatives.

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