Use of ozone and climate-friendly HCFC alternatives in commercial refrigeration

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Objectives of the case study

- The overall objective of this activity is to inform the refrigeration & air-conditioning (RAC) community in Central Asian countries with hot climates that it is feasible to replace HCFC technologies in the commercial sector with alternative technologies using carbon dioxide (C02) or ammonia (NH3) and to research a possibility of application of two cascade NH3/CO2 systems in the commercial sector of refrigeration equipment in the high ambient temperature countries.
- The technical study considers the parameters of cascade systems on CO2 and NH3, the climatic conditions of their usage, prices and profitability.

URGENCY

- Commercial sector of refrigeration equipment is the most common sector compared to the rest. The commercial sector evaporates the largest amount of greenhouse gas emissions that deplete the ozone layer and accelerates the global climate change.
- The number of supermarkets with sales area from 500 up to 20000 m2 in the world is estimated to be around 530000 (2006). Its refrigerant bulk is estimated to be 547000 tons distributing for CFC (25 per cent), HCFC (50 per cent), HFC (15 per cent) and others; hydrocarbons or CO2 are not a significant part in this sector. **Due to the high amount of refrigerant leakages, commercial refrigeration equipment promotes more emissions than any other application range of refrigeration equipment.**

Thirtieth meeting of the Open-ended Working Group of the parties of the Montreal Protocol

- During the thirtieth meeting of the Open-ended Working Group of the Montreal Protocol parties, held in Geneva in June 2010, a preliminary study relating the alternatives to hydrochlorofluorocarbons in refrigeration equipment and air conditioning sectors under conditions of high temperature was submitted. The comments were spoke out and related to the following:
- the lack of satisfactory alternatives to HCFCs in high-ambient-temperature applications;
- the resulting difficulties encountered by some parties in meeting their HCFC targets;
- concerns about the accessibility, affordability and maintenance requirements of related new technologies;
- the need for capacity-building; and the need for an in-depth study of alternative technologies and their possible negative effects.

There were given tasks to undertake a study of existing alternatives to HCFC.

Thirtieth meeting of the Open-ended Working Group of the parties of the Montreal Protocol

As for a sector of commercial refrigeration equipment, there were made the following conclusion:

- in stand-alone equipment using existing cooling technologies at high temperatures, four possible refrigerants may easily use : HFC-134a, HC-600a, HC-290 and HFO-1234yf;
- in centralized systems at high ambient temperature conditions, units with the intermediate coolant can be used, as their evaporating temperature ranges within a small range;
- as a possible substitutes for HCFC-22 in large commercial refrigeration equipment mixtures of HFCS with high global warming potential can be used such as R-404A or R-422D or R-427A.

Refrigeration equipment types

- Stand-alone systems
- Condensing Unit Systems
- Distributed Systems
- Indirect Systems
- Hybrid and Cascade Systems

Conditions for the adoption of alternatives for centralized cooling systems in developed countries

- High taxes on use of HCFC and HFC refrigerants.
- The existence of legislation that restricts or completely banning the use of HCFC, HFC refrigerants.
- Special State programs for the control of harmful substances emissions into the atmosphere.
- The availability of modern equipment.
- The availability of qualified staff and financial viability.
- The presence of favorable climatic conditions (average temperatures) for the use of natural refrigerants in the commercial sector.

Economic characteristics of cascade refrigeration systems and other refrigerant systems

- The annual energy consumptions of the refrigerant systems in supermarkets

Refrigerant	Towards **R 404**	Energy consumption **[kWh/m]**
indirect R717	+15 %	3,441
R717/R744 MT+LT	-13 %	2,603
R290/R744 MT+LT	0 %	2,992
Direct R744	0 %	2,992

Energy consumption of cascade systems R717/R744 is 13-18% lower compared with HCFC and HFC equipment. **(A comparative analysis of commercial refrigeration systems and equipment and their impact on climate) (research report Denmark 2009)**

Economic characteristics of cascade refrigeration systems and other refrigerant systems

- Refrigerant charge for indirect cooling systems R717, cascade refrigeration systems R717/R744, R290/R744, as well as the direct cooling systems R744

Refrigerant	Refrigerant charge **[kg/m]**
R404A MT + R744 LT	2.7 kg R404A 0.5 kg R744
R717/R744 MT+LT	0.5 kg R744 0.15 kg R717
R290/R744 MT+LT	1.1 kg R290 0.8 kg R744
direct R744	3.0
indirect R717	0.75

(A comparative analysis of commercial refrigeration systems and equipment and their impact on climate) (research report Denmark 2009)

Economic characteristics of cascade refrigeration systems Supermarkets

Investment costs		
	Growing costs towards R404	Investment costs
Indirect R717	+27 %	472,000
R717/R744 MT+LT	**+28 %**	**474,000**
R290/R744 MT+LT	+15 %	426,000
Direct R744	+20 %	444,000

Annual charges		
	Price for 1 kWt 0.13 €	Total operating costs
Косвенный R717	45,000	8,000
R717/R744 MT+LT	34,000	8,000
R290/R744 MT+LT	39,000	6,500
Прямой R744	39,000	7,800

Economic characteristics of cascade refrigeration systems Hypermarkets

	Growing costs towards R404	Investment costs
Indirect R717	+28 %	1,024,000
Direct R744	+20 %	960,000

Annual charges		
	Price for 1 kWt 0.13 €	Total operating costs
Indirect R717	115,000	20,000
Direct R744	105,000	20,000

Advantages and disadvantages of cascade refrigeration systems NH3/CO2

Among the advantages of cascade NH3/CO2 refrigeration systems there are:

- Low amount of consumed energy - about 13% -18% lower compared with HFC and HCFC equipment.
- Possibility of obtaining low cooling temperatures (-70° C and above).
- Low or full absence of GWP (global warming potential)
- Low or full absence ODP (ozone depletion potential)

Low energy consumption in comparison with HFC and HCFC equipment is definitely a significant advantage. But there are such countries where electricity prices are not so high - this is relevant only if there are high tariffs for electricity.

Advantages and disadvantages of cascade refrigeration systems NH3/CO2

Among the disadvantages of cascade NH3/CO2 refrigeration systems there are:

- High cost of equipment compared with HFC and HCFC equipment.
- Long-term of payback.
- Availability of experienced, certified professionals with special licenses to work with toxic refrigerants and vessels under high pressure.
- The existence of a special lubricant resistant to the ultra-low temperature.
- Among the main disadvantages of cascade refrigeration systems is the high cost of equipment which increases the payback period in times. Many potential buyers of cascade refrigeration systems are hesitant to buy this type of refrigeration equipment because of the high price.

Description of the current situation in the commercial sector of refrigeration in Kyrgyzstan

Application of refrigerants in the refrigeration sector of Kyrgyzstan

Application area	Traditional refrigerants	Alternative refrigerants
Domestic refrigerators	R22	R134a, R600a
Commercial refrigerators	R22, R12	R 22, R134a, R404a
Industrial refrigerators	R12, R22, R717, R502	R717, R134a, R404a, R407a

Application of refrigerants in air-conditioning sector of Kyrgyzstan

Application area	Traditional refrigerants	Alternative refrigerants
Domestic airconditioner	R12	R22, R410a
Central air-conditioner	R22, R12	R22, R134a, R407c, R410a
Air-conditioning systems of public and industrial buildings	R12, R22, R717, R502	R22, R717, R134a, R404, R507,R407c, R410a

Description of the current situation in the commercial sector of refrigeration in Kyrgyzstan

It is necessary to notice that in most of cases in the commercial sector of Kyrgyzstan, HCFC and HFC refrigerants are used such as R12, R22, R404, R410. Today the transition to natural refrigerants such as R744 and R717 (excluding industrial sector) has not yet been implemented due to various reasons such as lack of technologies and components, qualified staff, special environmental programs.

Estimated HCFC Consumption (tons) 2009

Equipment Application Category	**Consumption**
Commercial refrigeration equipment with cooling capacity up to 3000 watt	11.06
Commercial/Industrial refrigeration equipment with cooling capacity above 3000 watt	9.87
Air conditioners	15.00
Refrigerators on trucks	2.56
Service of assembled equipment	23.27
Total Refrigeration Servicing	**61.76**
Total HCFC-22 Consumption	**61.76**

Perspectives of introduction of NH3/CO2 cascade refrigeration systems in the commercial sector of Kyrgyzstan

- Unfortunately, at present, in Kyrgyzstan cascade refrigeration systems on NH3/CO2 are not being currently applied. Within a framework of this case study we could not find the experience of their application in Kyrgyzstan and also in the neighboring Central Asian republics.
- Kyrgyzstan had some experience in the application of cascade refrigeration systems but it was during the Soviet Union times and they worked on CFC refrigerants, such as R12 and R13. But even such experience does not mean that cascade refrigeration systems NH3/CO2 will be used in the commercial sector, as being widely used HCFC and HFC refrigerants have a number of technical and economic advantages compared to the natural refrigerants.

Comparative Indicative Chemical Price Ranges* (US$/kg)

CFC-12	HCFC-22	HFC-134a	HFC-404a	HFC-407c	HFC-410a	HFC-507a	R-600a	Ammonia
8-9	5-6	14-16	20-26	15-16	15-18	15-18	12.00	1.00-2.00

HCFC-141b	C-pentane	N-pentane	HFC-245a	Forane 427	R-422d	R-417a
6.00-7.00	2.75-3.30	1.95-2.20	8.90-9.60	17.00*	35.00*	51.00*

Comparative Indicative RAC Equipment with use of HCFC and its alternatives Cost Ranges (US$/Unit or System)

Equipment Description	HCFC	HFC	Other
Condensing Units (10-16 kW)	1,700-2,000 (HCFC-22)	2,300-2,800 (HFC-404a)	n/a
Cold Rooms (10-15 kW)	4,200-5,200 (HCFC-22)	5,000-7,000 (HFC-404a)	n/a
Chillers (120 kW)	16,000 (HCFC-22)	16,000 (any suitable HFC blend)	n/a

Costs

- The cost of two cascade refrigeration unit NH3/CO2 with capacity 5-15 kWt is 25000-30000 USD
- The cost of HFC refrigeration unit with the same capacity is 2500-3000 USD

Difference in cost complicates the use of cascade refrigeration systems NH3/CO2 in the commercial sector of refrigeration equipment of Kyrgyzstan.

Conclusions

Unfortunately, at present, in Kyrgyzstan cascade refrigeration systems on NH3/CO2 can not be applied.

Among the reasons of the cascade refrigeration systems absence in the commercial sector of Kyrgyzstan we can allocate:

- Long terms of payback (about 75-100 years);
- expensive price compared to the price of HFC and HCFC equipment;
- lack of cascade refrigeration equipment at the market of Kyrgyzstan;
- lack of experience of using cascade refrigeration systems;
- low cost of electricity in Kyrgyzstan;
- legislative barriers.

Two stage refrigeration unit CO2- the perspectives of introduction

- the price of this type of equipment is much lower in comparison with the cascade refrigeration systems NH3/CO2;
- good technological parameters;
- availability of equipment with small and medium cooling capacity from local producers,
- CO2 is not poisonous and combustible refrigerant in comparison with propane, propylene, isobutene and ammonia;
- energy efficiency;
- existence of international experience of using two-stage refrigeration unit working on CO2 in hot climate conditions.

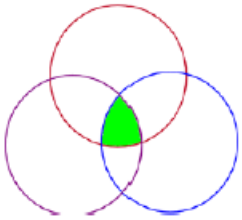
Alternative refrigerants for high ambient temperature countries

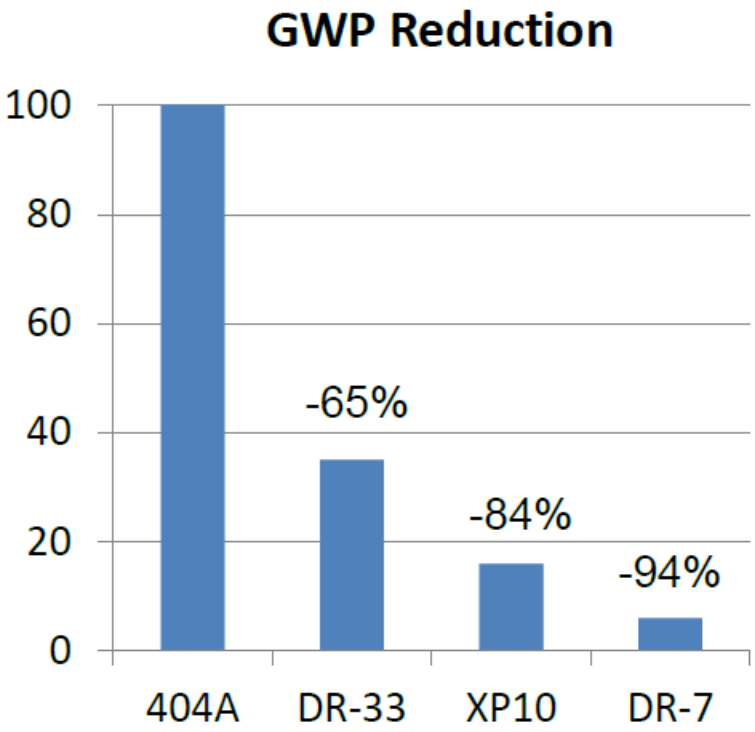
Refrigerant name	GWP	ODP	Refrigerant replacement	Sector of application	Classification of safety
Opteon yf (HFO-1234yf) (Dupont) Solstice yf (HFO-1234yf) (Honeywell)	4	0	HFC 134A	Mobile Air Conditioning	Midly flammable (A2L)
XP 10 (Dupont)	600	0		Hybrid, cascade systems CO2	Non-flammable (1)
DR 2 (Dupont)	10	0		Chillers High Temperature Heat Pumps Heat Transfer Fluid	Non-flammable (1)
N-13 (Honeywell)	600	0		Chillers, MT Refrigeration	Non-flammable (A1)
DR 33 (Dupont)	1400	0	HFC 404A	For retrofit and new systems	Non-flammable (1)
DR 7 (Dupont)	250	0		Smaller charge size equipment (condensing units, self-contained)	Midly flammable (2L)
N-40 (Honeywell)	1300	0		Low-Temp Refrigeration	Non-flammable (A1)
L-40 (Honeywell)	200-300	0		Low-Temp Refrigeration	Midly flammable (A2L)
L-41 (Honeywell)	500	0	HFC 410A	Stationary A/C Applications	Midly flammable (A2L)
DR 5 (Dupont)	500	0			Midly flammable (2L)
N-20 (Honeywell)	1000	0	HCFC 22	Stationary A/C, Refrigeration	Non-flammable (A1)
L-20 (Honeywell)	350	0		Stationary A/C, Refrigeration	Midly flammable (A2L)
DR 3 (Dupont)	150	0			Midly flammable (2L)

Refrigerant Properties

	R-404A	DR-7	DR-33
100 yr GWP	3922	~250	~1400
Flammability	None	2L	None
Boiling Point °C	-47	-48	-46
Critical Point °C	72	81	82
Vapor Pressure at 25°C in kPa	1254	1372	1271
Liquid Density at 25°C in kg/m3	1044	1133	1139
Vapor Density at 25°C in kg/m3	65.3	46.8	48.9

Opteon® Low GWP Replacements for R-404A Leading Candidates





DR-33

- GWP ~ 1400; 65% reduction vs R-404A
- Close performance match to R-404A
- Non-flammable; for retrofit and new systems

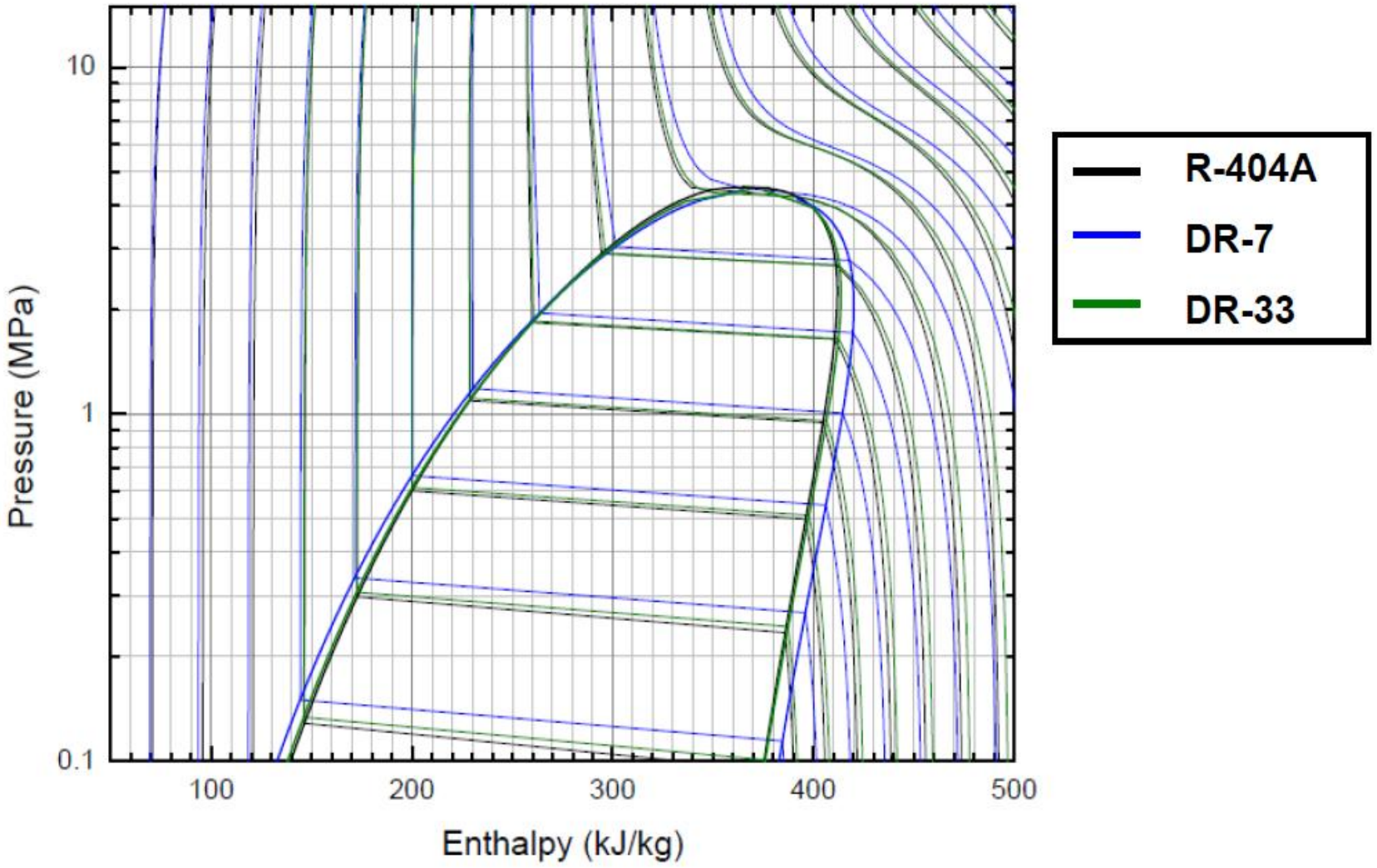
XP10

- GWP ~ 600; 84% reduction vs R-404A
- Close performance match to R-134a; for retrofit and new systems
- Non-flammable; preferred for hybrid CO2 cascade systems

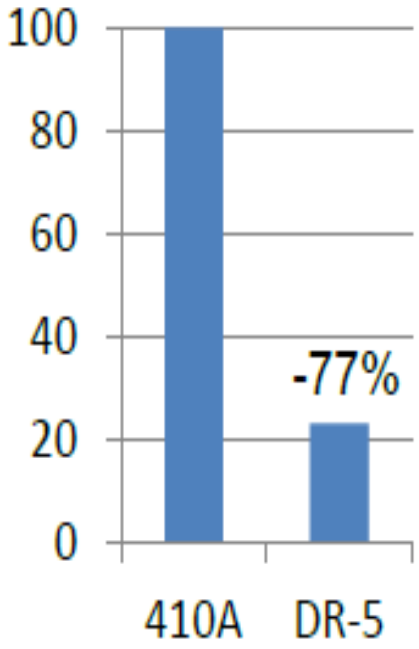
DR-7

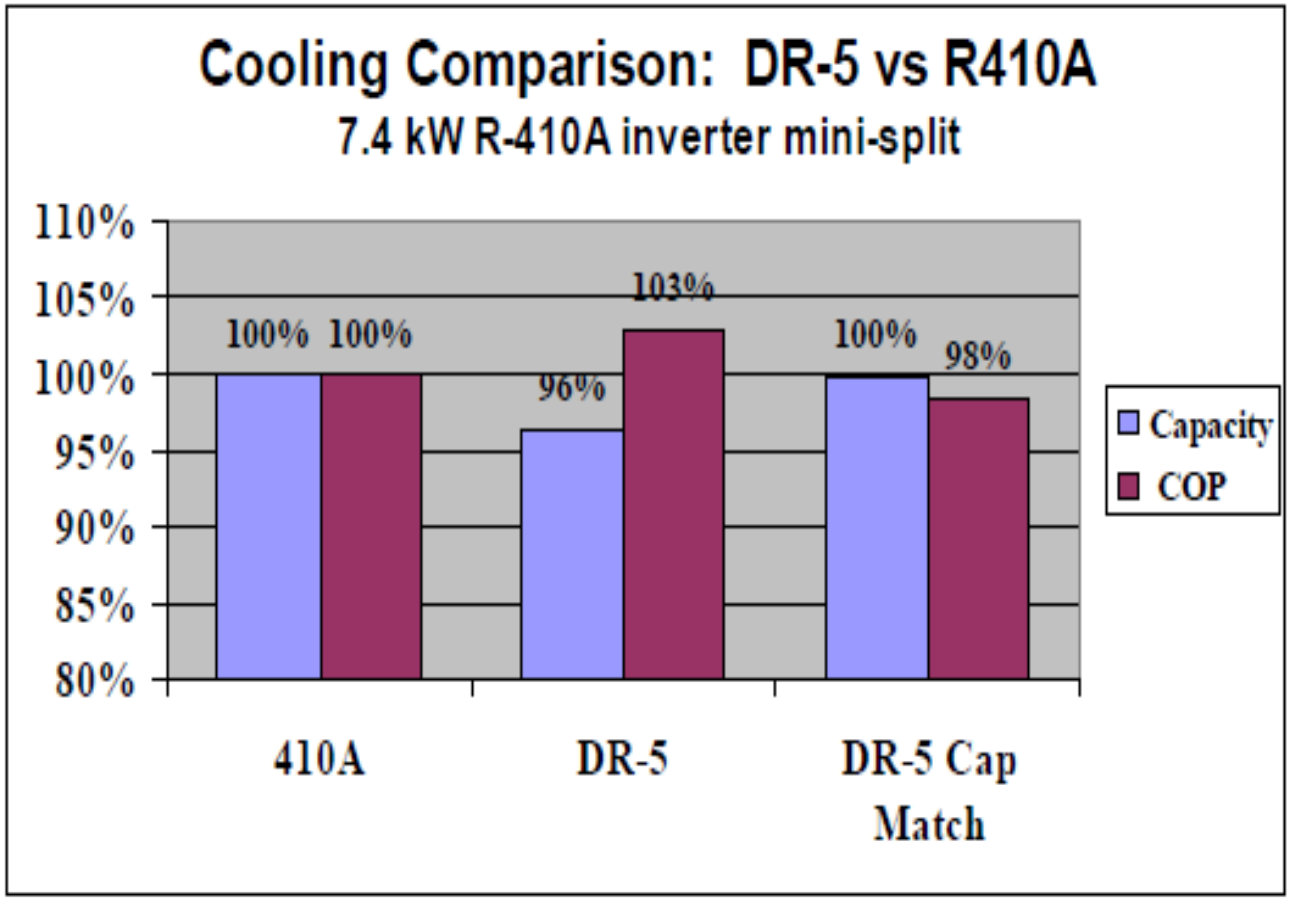
- GWP ~ 250; 94% reduction vs R-404A
- Close performance match to R-404A
- Mildly flammable (ASHRAE Class 2L expected)
- For smaller charge size equipment (condensing units, self-contained)

PH Diagram Compared to R-404A



Opteon® Low GWP Replacement for R410A
Leading Candidate – DR-5





Solstice™ Low GWP Replacements for Chillers

Honeywell

Solstice™ ze

- Equal (or better) efficiency compared to R-134a
- 99.7% reduction in GWP

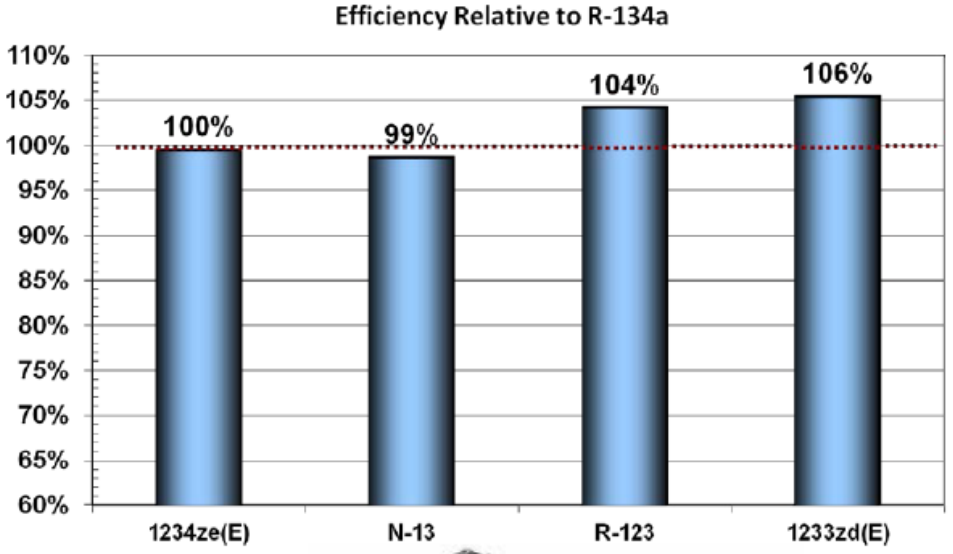
Solstice™N-13

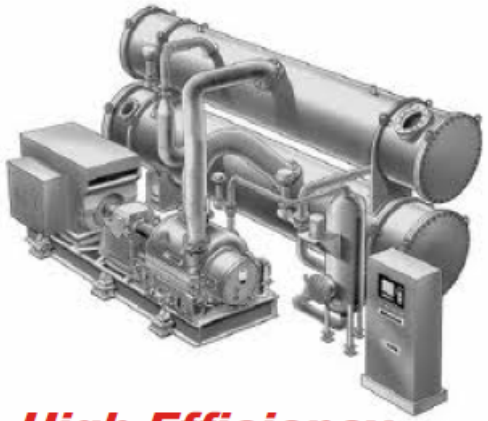
- **Comparable efficiency to R-134a and is non flammable. Potential for retrofit.**
- **~60% reduction in GWP**

Solstice™ zd

- **Higher efficiency than R-123 – the current efficiency leader.**
- **94% reduction in GWP**

Performance of Solstice ze, zd, N-13

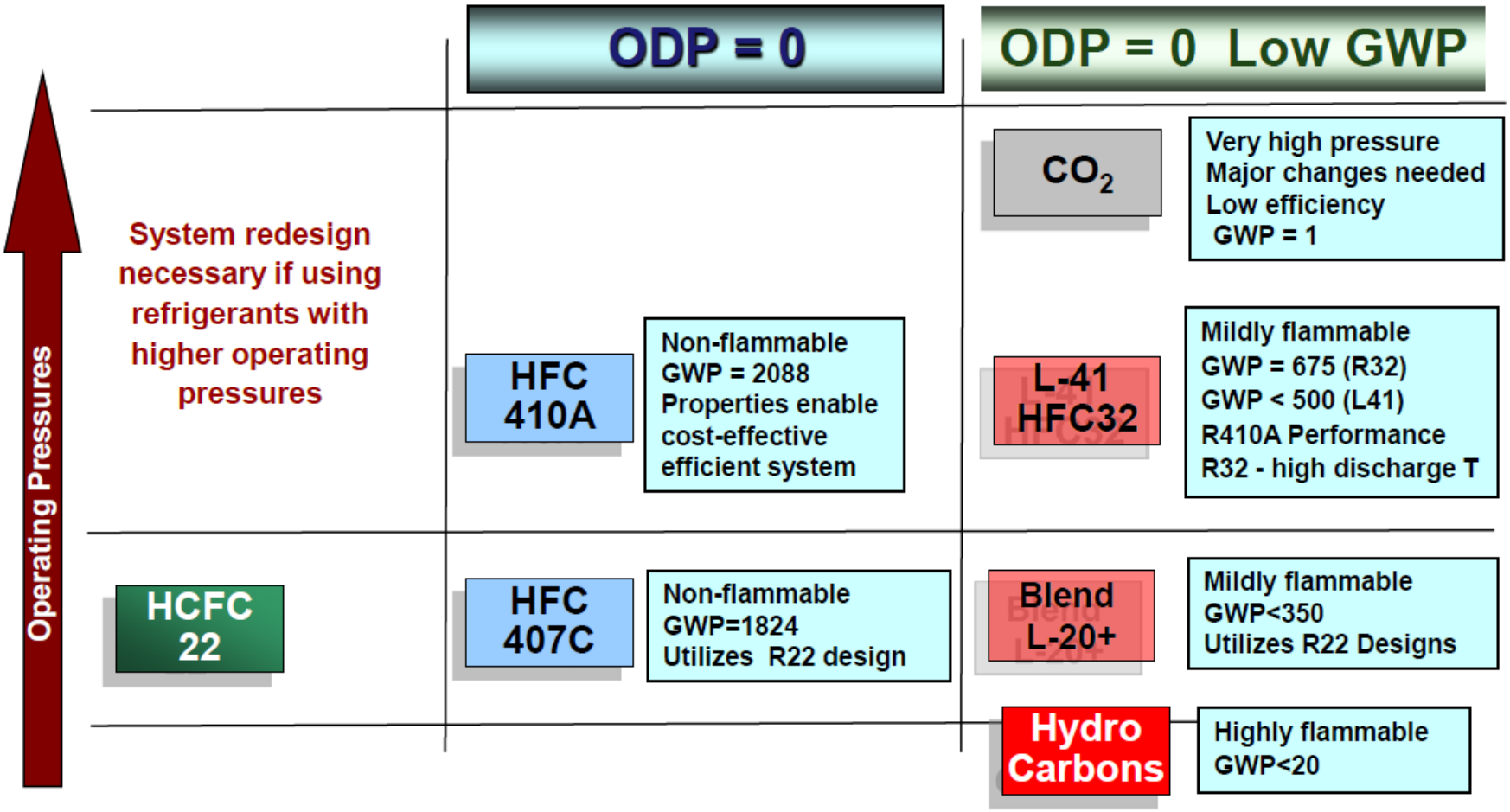




HFOs Offer Large GWP Reductions & High Efficiency

Low GWP Refrigerants in AC Systems

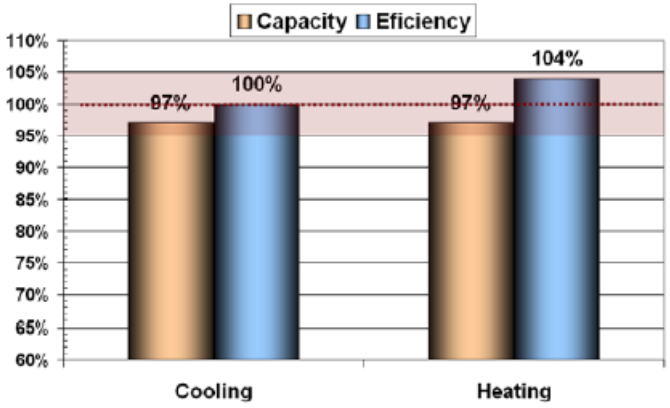
Honeywell



Performance

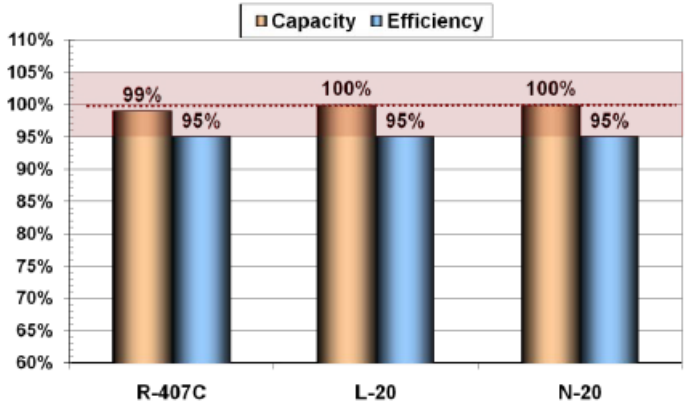
Honeywell

L-41
HFC-410A Replacement



- **L-41** offers good performance and a significant GWP reduction from R-410A (>75%)
- It enables compact high efficiency systems in many regions.
- No problems with high discharge temperatures.

L-20
HCFC-407C Replacement



- **L-20** replaces R-407C in AC systems without significant design changes.
- With a **GWP of 350**, it reduces significantly environmental impact.
- It performs well at high ambient temperatures.
- No problems with high discharge temperatures in the compressor

Haier a/c unit – Solstice L41

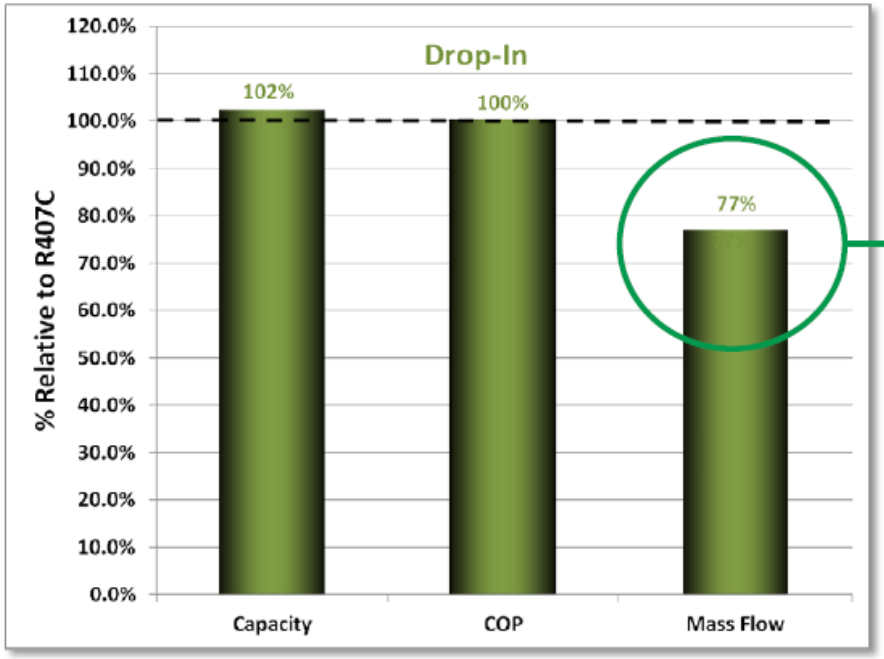
Honeywell

- ✓ Safer than HCs
- ✓ Using R410A technology.
- ✓ More than 75% reduction in GWP versus R410A.
- ✓ 30% reduction in GWP versus R32.
- ✓ Lower discharge pressure than R32.
- ✓ Lower Discharge temperature than R32.
- ✓ Lower power consumption than R410A and R32 at high ambient temperature regions.

Air Cooled Chillers

Honeywell

L20 (R407C Replacement)



- Drop In performance shows higher capacity (102%), comparable COP (100%) and lower mass flow (77%)
- Lower Flow rate flow indicates potential of further improvement in the design of heat exchangers

Conclusions

Honeywell

- Potential replacement fluids for air cooled positive displacement chillers and centrifugal chillers were evaluated

- Medium Pressure Centrifugal Chillers
  - For new equipment Solstice™ ze is a good option due to its high efficiency and chillers using this refrigerant are now on the market
  - N-13 promising option for replacing R134a in existing equipment

- Low Pressure Centrifugal Chillers
  - Solstice™ zd due to its higher capacity with efficiency similar to R123 is a good replacement in low pressure applications

- High Pressure Air Cooled Positive Displacement Chillers
  - L41 good option as R410A replacement. Minor system modifications may be required.
  - L20 shows very promising results as drop-in replacement for R407C, further investigation necessary

Thank you for attention