PUTTING THE FREEZE ON HFCs

2016 UPDATE: LOW-GWP SOLUTIONS FOR HIGH AMBIENT CONDITIONS

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RESOURCES & CASE STUDIES ONLINE

GLOBAL DIGEST OF HFC-FREE ALTERNATIVES

"Putting the Freeze on HFCs: A Global Digest of Available Climate-Friendly Refrigeration and Air-Conditioning Technologies" and other resources are available at www.eia-global.org.

COOL TECHNOLOGIES

EIA and Greenpeace have jointly launched an online research database of case studies on HFC-free alternatives in the refrigeration, air-conditioning and foam sectors. The database can be viewed online at www.cooltechnologies.org.

ABOUT EIA

EIA is an international campaigning organization founded in 1989, with offices in Washington, D.C. and London, UK. We work worldwide—protecting the global climate, forests and threatened species with intelligence—for the benefit of people and wildlife. EIA has amassed an impressive series of exposés and victories, from its key role in securing the 1989 international ivory trade ban and helping to bring in legislation to protect the world's precious forests to pushing whale meat off the menu in Japan. EIA has been involved in investigating and combating illegal trade in ODS since the mid 1990s.

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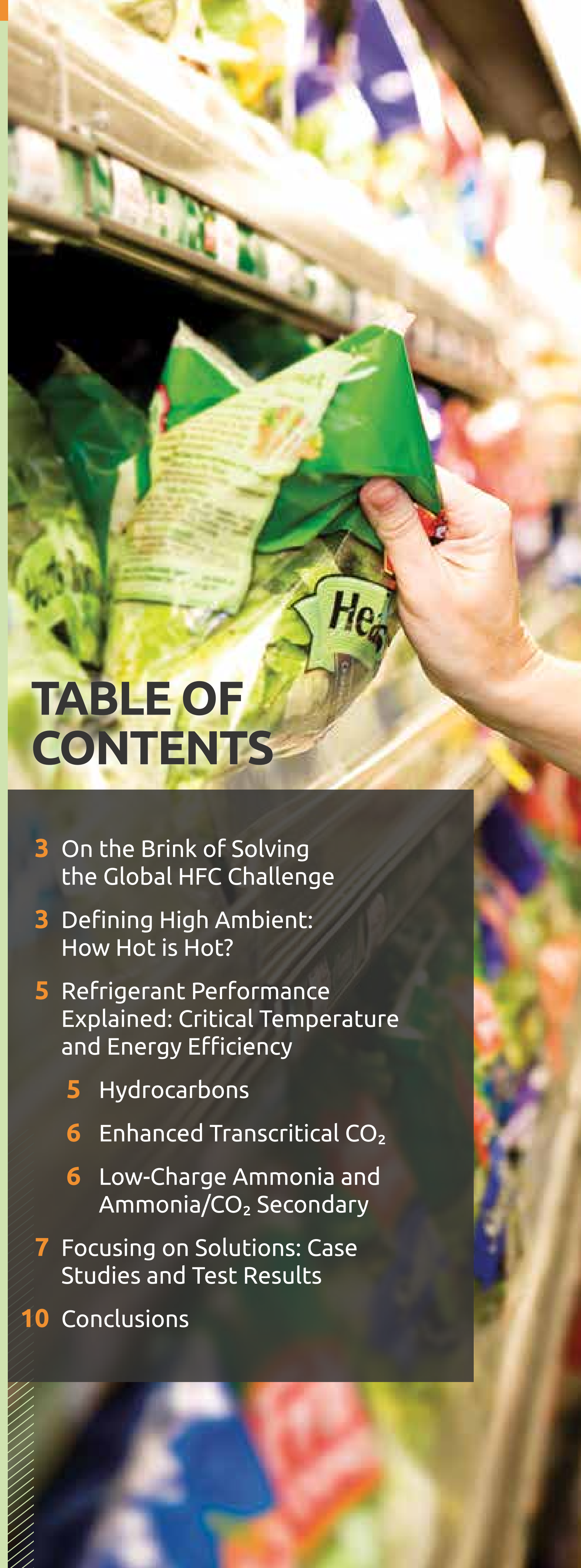

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On the Brink of Solving the Global HFC Challenge

The Dubai Meeting of the Parties to the Montreal Protocol in November 2015 marked a major turning point in the global movement toward phasing down hydrofluorocarbons (HFCs), the super-greenhouse gases used in refrigeration and air conditioning. At this meeting, the Dubai Pathway for an HFC amendment in 2016 was agreed, and countries will now discuss issues relevant to managing HFCs under the Montreal Protocol.[1] Among the issues to be evaluated is the availability of low-global warming potential (GWP) alternatives for high ambient temperature countries that can deliver sufficient cooling while maintaining high energy efficiency. This issue is important not only to the feasibility and fairness of an HFC phase-down, but will be pivotal to maximizing potential emissions reductions. In particular it will affect indirect emissions due to the energy efficiency gains that could be achieved under an HFC Amendment, with up to 100 billion tonnes of CO_2 equivalent projected to be achievable.[2]

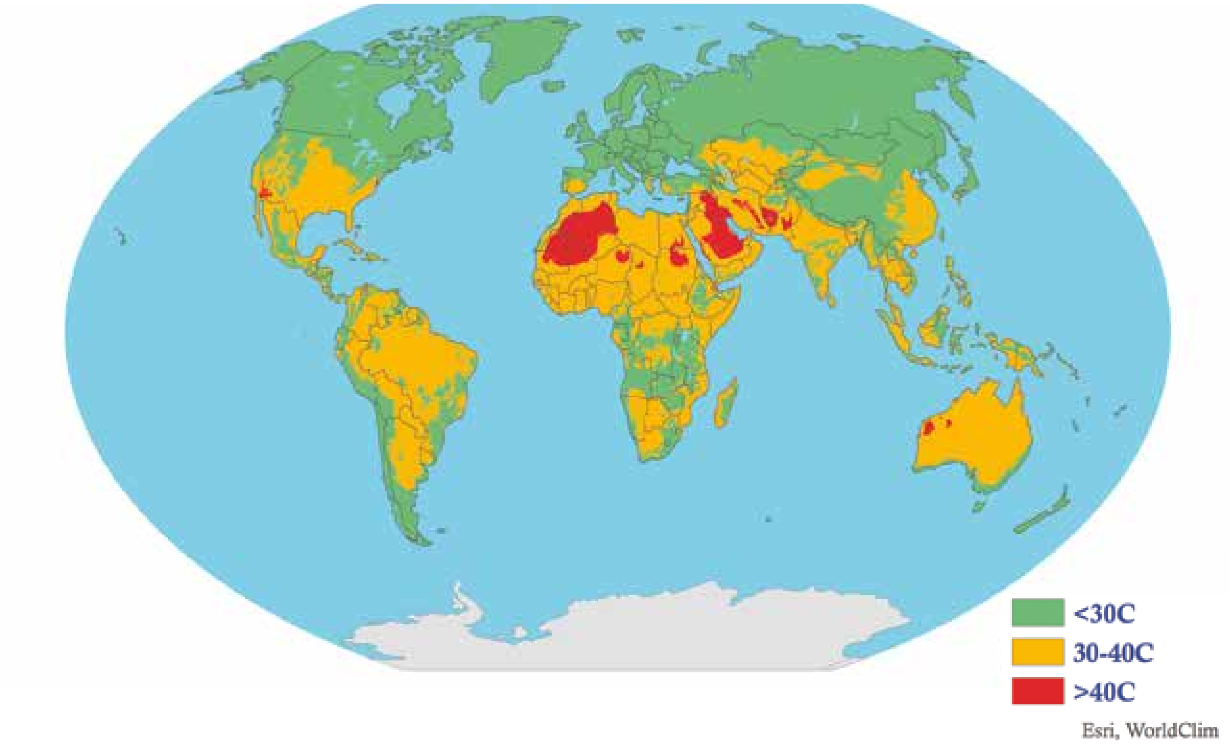
This briefing provides an overview of the factors influencing refrigerant performance, and a sampling of the technologies available to address the high ambient challenge. Natural, low-GWP refrigerants including hydrocarbons and ammonia have properties that are well suited to operating efficiently under high ambient conditions, while carbon dioxide (R-744) solutions are also emerging as a viable option in many hot climates (up to 40°C) when paired with efficiency enhancing technologies. Ammonia/CO_2 secondary loop systems are another promising solution for applying CO_2 in hot climates. Finally, non-vapor compression technologies such as evaporative cooling[3] and district cooling can also play a significant role in meeting the cooling needs of high ambient countries energy efficiently.

Defining High Ambient: How Hot is Hot?

High temperatures have always impacted refrigerant performance, but became a particular issue for the phase-out of HCFCs when it was found that some alternatives, including HFC-410A have significantly deteriorating energy efficiency at high temperatures, particularly above 40°C.[4] While there is no single definition of a 'high ambient climate', regions of the world that experience average high temperatures above 30°C during the hottest summer month grapple with this issue in choosing alternatives to HCFCs and HFCs, while regions that experience average high temperatures exceeding 40°C during the hottest summer month have a reduced portfolio of available alternatives. The map below depicts average high temperatures in the hottest month of the year for both Northern and Southern Hemispheres, illustrating the regions that experience these conditions. According to the most recent TEAP Report, to address the high ambient challenge and achieve additional energy-efficiency benefits of an HFC phase-down, some countries must be able to select from available alternatives designed to perform efficiently at up to 46°C, and maintain operability up to extreme conditions of 52°C.[5]

For purposes of evaluating the performance of various low-GWP alternatives, it is helpful to distinguish between "hot" and "extreme" ambient conditions. Test conditions used to evaluate alternatives by the Oak Ridge National Laboratory for instance, were conducted at "medium" and "hot" conditions of 27.8°C and 35°C as well "extreme" conditions of 52°C and 55°C.[6] Some alternatives, such as carbon dioxide, perform optimally below 30°C, and can also be engineered to perform well at temperatures between 30°C and 40°C, but perform poorly under hot to extreme conditions above 40°C. Others such as hydrocarbons and ammonia and ammonia secondary loop systems can be engineered to achieve good energy efficiency even in hot to extreme temperature conditions.

Average High Temperatures for the Hottest Month in Each Hemisphere (°C)



The map is a merged representation of average high temperatures (1950-2000) in January in the Southern Hemisphere and July in the Northern Hemisphere, the hottest months of the year in each hemisphere. Given current technologies, green areas on the map represent climates optimal for efficient operation of transcritical CO_2 systems as well as all other low-GWP technologies, orange represents areas that transcritical CO_2 systems should be used with energy efficiency enhancing technologies (parallel compressors, adiabatic cooling, etc.) or other low-GWP technologies should be considered, and the red areas represent regions where other low-GWP refrigerants are recommended or where CO_2 may be used as a secondary refrigerant.[7]

Refrigerant Performance: Critical Temperature & Energy Efficiency

The ability of a refrigerant to perform efficiently at a given temperature depends on its thermodynamic properties, and in particular on its critical temperature. The critical temperature is the temperature above which there is no difference in the density of the liquid and gas phase of the refrigerant, and therefore, above which it is no longer possible to return the gas phase back to a liquid in a vapor compression cycle.[8] A refrigerant's efficiency declines rapidly as the ambient temperature approaches its critical temperature. Therefore, the higher a refrigerant's critical temperature, the more efficiently it ordinarily will perform under high ambient temperature conditions.

As illustrated in Table I, HCFC-22 has a critical temperature of 96.1°C which made it a very energy efficient refrigerant for high ambient climates. However, the most common HFCs introduced to replace HCFC-22 for many air conditioning applications, such as HFC-410A and HFC-32, have significantly lower critical temperatures of only 71.4°C and 78.1°C respectively which causes their efficiency performance to deteriorate much more quickly than HCFC-22, particularly in temperatures above 50°C.[9] Hydrocarbons and ammonia on the other hand have critical temperatures that match and exceed HCFC-22, making them very well suited to hot conditions.

Refrigerant	Critical Temp. (°C)	100-yr GWP	ASHRAE 34 Classification
HCFC-22	96.1	1810	A1
R-290 (Propane)	96.7	3	A3
R-600a (Isobutene)	135.0	3	A3
R-1270 (Propylene)	91.7	<2	A3
R-717 (Ammonia)	132.2	0	B2
R-744 (CO_2)	31.0	1	A1
HFC-32	78.1	650	A2L
HFC-410A	71.4	1900	A1
HFC-404A	72.07	3922	A1

Table I: Comparing Refrigerant Properties

Hydrocarbons: Small and Medium Applications

Both propane (R-290) and isobutane (R-600a) have a critical temperature similar or higher than HCFC-22, and as depicted in Table II to the right, tend to perform very well in high ambient conditions — significantly better than HFC and HFC blends. With GWPs from zero to four, they are also future-proof alternatives from a climate standpoint. Hydrocarbons have been proven safe and effective refrigerants to use in many kinds of small to medium sized equipment for domestic and light commercial uses, including stand-alone commercial refrigerators and freezers, vending machines, water coolers, ice makers, and room air conditioners.

Refrigerant	Condensing Temperature (°C)		
	35°C	**60°C**	**65°C**
HCFC-22	5.08	2.64	2.29
Propane (R-290)	5.09	2.58	2.23
HFC-32	4.85	2.43	2.09
HFC-410A	4.80	2.32	1.95

Table II: Refrigerant Efficiencies at Various Condensing Temperatures (COP)[10]

Source: Lambert Kuijbert, Roberto Peixeto: XIX/8 Report on HCFC Alternatives for High-Ambient Temperature Regions, Presentation at OEWG-30, Geneva, 15-18 June 2010.

Carbon Dioxide (R-744): Enhanced Transcritical CO_2 for Hot Climates

Carbon dioxide (R-744) is a natural, inexpensive, non-toxic, non-flammable refrigerant that has been used since the mid-nineteenth century. Although R-744 faces limitations in operating under high ambient conditions due to its low critical temperature, it transfers heat very efficiently. Innovative technologies have recently been developed that significantly enhance CO_2's energy efficiency in warm climates, allowing transcritical CO_2 systems to outperform HFC-404A systems at conditions of 32°C and above (See Table III).

System	Energy CO_2 vs. 404A	Compressor Savings: CO_2 vs. Booster
Booster	-11%	0%
Parallel Compression	7%	15%
Gas Ejector	10%	18%
Liquid and Gas Ejector	22%	27%

Table III: Energy Savings of Enhanced Transcritical CO_2 Technologies at 32°C

Source: Danfoss[13]

These efficiency enhancing technologies include parallel compression, mechanical sub-cooling, adiabatic condensers, and ejector technology. Parallel compression improves efficiency by using additional compressors at higher temperatures that compress excess gas to high pressures. By using parallel compression, the energy efficiency of transcritical CO_2 systems is increased by 10% or more under >27°C conditions.[11] Booster systems employing parallel compressors are able to exceed the energy efficiency of an HFC-404A system up to ambient temperatures of 38°C.[12] Ejector technology, when added to a system using parallel compression can boost energy savings by an additional 3%. Finally, when the high heat energy of R-744 is captured in a system that reclaims it for use in heating water for another use, the overall efficiency of a building or system can be further improved.

Low Charge Ammonia and Ammonia/CO_2 Secondary Loop Systems

Ammonia (R-717) is the most thermodynamically efficient refrigerant at high ambient conditions, with its critical temperature of 132°C. Ammonia is used in 90% of industrial refrigeration systems in developed countries and in 40% of those in developing countries.[14] Ammonia has been the most common refrigerant used in many industrial applications, such as cold storage and food processing for more than 150 years. Now, two new technologies, low charge ammonia and secondary loop systems, are making ammonia a viable choice for a broader range of industrial, commercial, and even domestic applications.

Low charge ammonia systems are available in various types of refrigeration and air conditioning systems including direct expansion, ammonia/CO_2 cascade systems, ammonia/CO_2 brine systems, and packaged systems and chillers.[15] Packaged ammonia chiller systems achieve the lowest charge per ton of cooling of an product on the market today at 2.5 to 3 pounds per ton of cooling capacity.[16] Next generation ammonia systems expected to come to market in the near future promise substantially lower, 'ultra-low' charge sizes down to 0.5 pounds per ton.[17] Packaged ammonia systems in particular have been shown to achieve 20-25% reductions in energy consumption and have a 50-75% reduction in charge size.[18]

Ammonia/CO_2 cascade and secondary loop systems similar to the Lackland Airforce Base case study discussed below may also be a scalable alternative to transcritical CO_2 for commercial refrigeration in countries that frequently experience temperatures above 40°C during summer months. In these systems, a relatively small charge size of ammonia is used as the primary refrigerant for the high-side, which is confined to a machine room or located outside of a building or on the roof, separating it from any occupied space. The ammonia loop serves to cool a secondary refrigerant loop of CO_2 which acts as a highly efficient secondary refrigerant to be pumped throughout the store to cool display cases.

Focusing on Solutions: Case Studies and Test Results

Sprouts Farmers Market: Transcritical CO_2 with Adiabatic Condensing (Georgia, USA)

Opened in July, 2014, the Sprouts Farmers Market near Atlanta, Georgia was the first CO_2 transcritical booster supermarket refrigeration system installed in a hot climate in the United States. Summer high temperatures in Atlanta (nicknamed 'Hotlanta') average around 32°C. The Sprouts Farmers Market is approximately 29,000 square feet and uses a transcritical CO_2 system designed by Hillphoenix with an adiabatic TrilliumSeries adiabatic condenser designed by the Baltimore Aircoil Company added to ensure that the system operates efficiently in high-ambient temperatures.[19] The system was expected to operate about 6% more efficiently than a traditional HFC-407A system.[20]

Image courtesy of Hillpheonix[21]

ADIABATIC COOLING FOR HIGH AMBIENT CONDITIONS

Adiabatic cooling is a simple technology that can enhance the energy efficiency of any air-cooled refrigeration or air conditioning system in high ambient conditions.[22] It works by using the cooling effect of water evaporation to pre-cool the hot ambient air being pulled into a system by up to 20°C.[23] There are different types of adiabatic cooling. Some systems work by passing incoming air through a saturated cooling pad, while others work by spraying a fine mist of water into the incoming air stream which instantly evaporates, cooling the air as it enters. This significantly reduces the work that has to be done by a mechanical vapor compression cycle, making the system much more energy efficient. An air-conditioner modified with an evaporative water nozzle tested under 50°C conditions shows increases in efficiency — coefficient of performance (COP) — of 44.5% compared to the baseline system.[24] Closed-loop adiabatic systems also economize water use by capturing and recirculating up to 98% of the water lost in open loop systems.[25] There are many applications for adiabatic and evaporative cooling from supermarket systems to domestic air conditioning to industrial process cooling and data centers.

Godrej Eon Balance AC[29]

Bottle Cooler by The Fridge Factory [33]

Bahrain World Trade Center[37]

Godrej: Propane Split Air Conditioners and Domestic Refrigerators (India)

Indian company Godrej & Boyce Manufacturing has sold more than 100,000 split air conditioners using R-290 (propane)[26], most of which are used in India where average summer high temperatures in most parts of the country range between 30-40°C. These units have been awarded a 5 star energy efficiency rating in India. Godrej chose propane as its refrigerant over HFC-410A due to better performance at higher ambient temperatures. Their propane AC units are available in four models that comply with European safety standard EN378 with an average charge size of only 360 grams of hydrocarbons and use brazed micro-channel heat exchangers to ensure energy efficiency while minimizing refrigerant charge.[27] These units consume 23% less energy than conventional HFC units with the same energy efficiency rating.[28] (See box on page 9.)

The Fridge Factory: Hydrocarbon SolarChill Refrigerators and Vaccine Coolers (Swaziland)

Swazi refrigeration manufacturer The Fridge Factory (formerly Palfridge) was supported by a partnership between GIZ Proklima, Greenpeace and the Global Environment Facility to transition some of its production lines to hydrocarbons in domestic fridges, commercial refrigerators, and bottle coolers.[30] The project also helped fund development of solar powered refrigerators and vaccine coolers. These products are designed to operate efficiently up to 48°C.[31] The SolarChill vaccine coolers, powered by two photovoltaic cells, were successfully field tested in Senegal, Indonesia and Cuba at 32°C and found to maintain the required 2-8°C temperature range needed to ensure vaccine integrity.[32]

Bahrain World Trade Center: Water from District Cooling

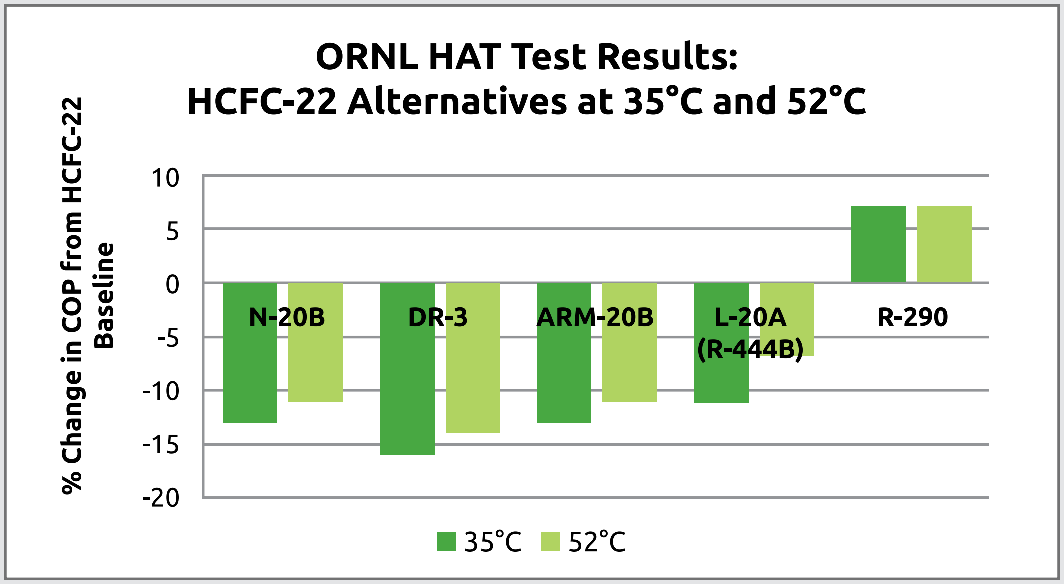
The two 50-story tall office towers of the Bahrain World Trade Center are cooled entirely by chilled water provided by a central district cooling system known as the Tabreed Northshore District Cooling Project completed in 2010.[34] The district cooling system pulls in deep seawater from the Gulf which is then further chilled by a central plant.[35] The chilled water is then piped to the buildings, serving as the refrigerant for each building's variable volume chilled water pump system.[36] The buildings also feature reflection pools at the building entrance which provide local evaporative cooling effects.

TEST RESULTS SHOW PROMISE OF PROPANE (R-290)

Recent test results published by the Oak Ridge National Laboratory (ORNL) evaluated the performance of propane (R-290) and four other HFCs and HFC blends as alternatives to HCFC-22 in mini-split air conditioners. The tests were conducted in 'soft optimized' units under 'moderate', 'hot', and 'extreme' ambient conditions ranging from 27.8°C to 55°C. The test results took into account variables of energy efficiency (as measured by COP), cooling capacity, and discharge temperatures.

R-290 was the only refrigerant in the group that outperformed the energy efficiency (COP) of HCFC-22 under 35°C, 52°C and 55°C ambient conditions.[38] As illustrated in the graph below, at the high-moderate and hot conditions of 35°C and 52°C, R-290 achieved 7% COP gains, while the other four alternatives experienced declines between -7% and -16%.[39]

The discharge temperatures of R-290 were also lower than those of the other alternatives, a factor which may suggest greater reliability and a longer lifetime[40] for equipment using propane compared with the other alternatives. As discussed in the summary of ORNL test results, the COP losses experienced by the other synthetic alternatives are particularly important results of this testing, as losses in COP are typically more difficult to recover through optimization than losses in cooling capacity.[41] This suggests that optimization of units for R-290 will result in better efficiency, similar capacity, and greater reliability due to lower discharge temperatures in high ambient climates than other alternatives. Final test results from "Promoting low GWP Refrigerants for Air-Conditioning Sectors in High Ambient Temperature Countries" (PRAHA) and "Egyptian Project for Refrigerant Alternatives" (EGYPRA) are forthcoming and will provide an additional point of comparison.



Source: ORNL HAT Test Results, Table ES.3. and ES.4.

Schematic of Ammonia/CO_2 system installed at Lackland Airforce Base

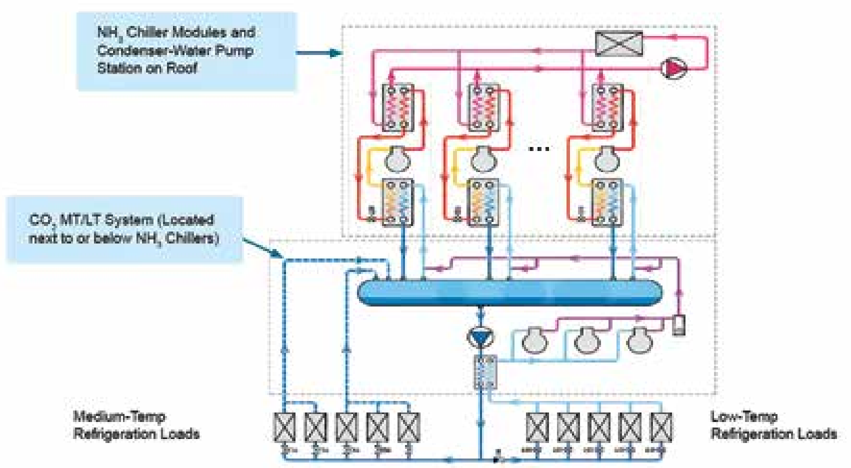


Diagram of the NH_3/CO_2 cascade system to be installed at the Lackland commissary. FMI Energy & Store Development Conference presentation, September 2012, Phoenix, Arizona.

Lackland Airforce Base Commissary: Ammonia/CO_2 System (Texas, USA)

The United States Defense Commissary Agency (DeCA) replaced an HFC-404A system in its 117,000 square foot commissary with an ammonia/carbon dioxide (CO_2) cascade system. The commissary is located in San Antonio, Texas, which experiences average high temperatures of 35°C in July.[42] DeCA chose the new system to achieve its goals of controlling future capital and operating costs and to help meet energy reduction goals set by the U.S. Government of 20% for remodeled buildings.[43] While energy efficiency data from an installed sub-meter for the first full year of the system's operation has not yet been released, DeCA expects at least 8% energy savings[44] and anticipates ammonia/CO_2 systems becoming their standard refrigeration systems for all commissaries in hot climates.

Conclusions

These case studies show that energy efficient solutions are available for transitioning to low-GWP cooling across most applications for refrigeration and air conditioning in both hot and extreme ambient regions. Hydrocarbons and ammonia have ideal thermodynamic properties for high ambient conditions and enhanced technologies for transcritical CO_2 are allowing these systems to perform well in all but the hottest conditions above 40°C. Countries experiencing >40°C average high temperatures during the hottest months of the year face a slightly narrowed portfolio of low-GWP alternatives. However, hydrocarbons, low charge ammonia, ammonia/CO_2 systems and non-vapor compression technologies like district cooling are available to meet most of the cooling needs of these countries. This report provides just a sampling of the technologies that have been developed or improved in the last few years. Under a global HFC phase-down, these and other low-GWP technologies will become ever more cost-effective and widely available to Article 5 countries for tackling the high ambient challenge.

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