COOL TECHNOLOGIES: WORKING WITHOUT HFCs : PART TWO

Examples of HFC-Free Cooling Technologies in Various Industrial Sectors

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Introduction
Just as there was no single "magic bullet" to replace CFCs, there is no single solution to replace HCFCs. But there is a wide variety of environmentally superior and technologically proven HCFC and HFC-free technologies to meet our cooling needs. Alternatives include natural refrigerants (CO_2, hydrocarbons, ammonia, water); secondary cooling systems; desiccant cooling; evaporative cooling, absorption cooling; and innovative building designs that eliminate the need for mechanical cooling.

The following sampling of companies and enterprises using HFC-free technologies is provided to demonstrate that there is already a wide array of safe and commercially proven HFC-free technologies available to meet human needs that were formerly met by fluorocarbons.[2] (please see disclaimer below)

HFC-free cooling related technologies exist in the full spectrum of applications, such as:

- Domestic Refrigeration and Air-Conditioning
- Commercial Refrigeration and Air-Conditioning
- Industrial production
- Mobile Air-Conditioning
- Insulation Foam Blowing

[1] Cool Technologies: Working Without HFCs takes its title from a Greenpeace video and report produced in 2000. Copies of the video are available from Greenpeace (contact Janos Maté at jmate@telus.net).

[2] Greenpeace disclaimer: The inventory presented is not meant to be all-inclusive nor is the inclusion of any enterprise an endorsement by Greenpeace of any company or its products.

And new HFC-free products are entering the market almost on a weekly basis. These technologies are presently primarily used in industrialized countries, but there is no reason why they can not be used worldwide, including in developing countries.

Developing countries would benefit greatly by leap-frogging HFCs altogether and going straight from HCFCs to long term solutions that rely on natural refrigerants and foam blowing agents. They could thus avoid reliance on more expensive, less efficient, high-GWP HFC substitutes which will need to be phased-out due to their significant contributions to global warming.

A. DOMESTIC REFRIGERATION AND AIR CONDITIONING

A.1 Greenfreeze Hydrocarbon Domestic Refrigeration: There are over 250 million hydrocarbon, or Greenfreeze, refrigerators in the world today. The Greenfreeze technology was developed by Greenpeace in 1992. Greenfreeze refers to refrigerators that contain no fluorocarbons. Typically they use cyclopentane for the foam and isobutane for the refrigerant. The refrigerant charge of 30 to 60 gramms varies according to the size of the refrigerator. Greenfreeze refrigerators are available in all sizes with all the regular and luxury features, including automatic defrost systems.

All major European, Japanese and Chinese manufacturers now produce Greenfreeze refrigerators. The technology now dominates the European market, and is prominent in the markets of Japan and China. Greenfreeze refrigerators are also produced in India by Voltas and Godrej. Though Greenfreeze refrigerators are sold in Europe, Asia, and Latin America the technology has not yet penetrated the North American market. Approximately 30% of global fridge production is Greenfreeze.

A.2 Hydrocarbon domestic air-conditioning: Since 1995, the large Italian manufacturer De'Longhi has sold its popular propane cooled portable air conditioners called Pinguino ECO on the European market. Addionally, Elstar Company of the UK is producing a variety of hydrocarbon based split-air conditioners for both home and office use.

B. COMMERCIAL REFRIGERATION & AIR CONDITIONING

B.1 *Refrigerants, Naturally!* : Refrigerants, Naturally! is a global initiative of multinational corporations that aim to replace the use of HCFCs and HFCs in their point-of-sale cooling applications. The initiative is supported by Greenpeace and the United Nations Environment Program (UNEP). Current partners include: Coca Cola, Unilever, McDonald's, IKEA, Carlsberg and Pepsico.

By 2008 Unilever has placed up to 275,000 hydrocarbon ice-cream coolers in the field. These coolers contain approximately 100 grams of hydrocarbons, and have a 9% energy savings over their HFC counterparts.[3]

Coca Cola has developed a new, high efficiency, CO_2 technology for vending machines, and plans to have up 30,000 CO_2 vending machines in the field in 2008. All the machines at the 2008 Beijing Olympics will be HFC-free.[4]

In 2003 McDonald's opened the "first fluorocarbon free restaurant" in Vejle, Denmark. The company has reported 15% energy savings on the refrigeration equipment compared with an HFC reference restaurant. The company is currently building another HFC-free restaurant in Denmark and plans to only purchase HFC-free equipment in Europe after 2010.

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[3] http://www.unilever.com/ourvalues/environment-society/case-studies/climate-change/hydrocarbon-ice-cream-cabinets.asp

[4] ACR News (2007) 'Coca-cola's Olympic coolers 100% HFC-free'

Pepsico is currently testing new vending machines using natural refrigerants. Carlsberg and IKEA are both investigating ways they can achieve their aim to replace HFCs in their point-of-sale applications.

B.2 Nestlé : The world's largest food processing company, Nestlé, announced on October 1, 2001 that "wherever possible, Nestlé will use natural refrigerants in new industrial refrigeration systems"… with a preference for "using the combined characteristics of ammonia and carbon dioxide…" Nestlé stated: "The future of many replacement refrigerants, such as HFCs, is in doubt due to global warming concerns." The statement from the company emphasizes the technical reliability, efficiency and safety of natural refrigerants. Nestlé is also testing HFC-free technologies in commercial equipment, such as ice-cream freezers.

B3 Commercial Hydrocarbon Equipment on the market: The UK based Earthcare Products Ltd. is marketing a wide range of commercial cooling equipment that use hydrocarbons (e.g. wall mounted and ceiling mounted air conditioners, dehumidifiers, mobile air conditioning, sliding door display coolers, bottle chillers, wine cooler dispensers, glass door merchandiser, mini bars, deli display cabinets, chest chill cabinets, defrost type freezer chillers, multi-deck display cabinets, freezers, ice cream conservators and water coolers).

The Danish manufacturer Vestfrost produces hydrocarbon display cabinet bottle coolers featuring a high efficiency Danfoss variable compressor. Elstar also manufactures hydrocarbon commercial drink cabinets.

B.4 Commercial Air-Conditioning with Natural Refrigerants: *There are numerous supermarkets, office buildings, public institutions and other commercial enterprises in various countries that have installed HCFC/HFC-free cooling technologies.* HFC-free alternatives include, among others, carbon dioxide based coolers, hydrocarbon or ammonia based secondary cooling systems, desiccant cooling, evaporative cooling, and absorption cooling. Consumers of cooling technologies must ensure that they chose the best available solution for their specific needs.

Secondary cooling systems use coolants such as water, brine, glycols, silicon oils, or Flo-ice™ to circulate through refrigeration cabinets. The coolant itself is chilled, through a heat exchanger, by a primary refrigeration circuit using ammonia or hydrocarbons. The primary circuit is usually located in a safely isolated plant room in the back of the store. Non-fluorocarbon refrigerants such as ammonia and hydrocarbons are used as the primary refrigerants. Using secondary cooling significantly reduces the volume of primary refrigerant needed.

B.5 Examples of commercial enterprises using hydrocarbon refrigerants:
Earthcare Products Ltd. of the UK have installed split system air conditioning using hydrocarbon refrigerants in a wide variety of settings, including: Middlesex University, Great Ormond Street Children's Hospital, University College in London, Pembury Hospital in Kent, Her Majesty's Customs and Excise offices, Confectionary Factory in York, Horsham Arts Centre. Government Laboratory in Birmingham, Alverston Library in Derby, London Transport in West Kensington, DVLA Oxford, Brighton Library, Shropshire County Council, DEFRA Whitehall, Pharmaceutical Company in Welwyn Garden City, Government Laboratory in Chepstow, DFT in Westminster, National Trust, in Swindon.
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Other companies that have installed hydrocarbon cooling systems include: REWE Supermarket (Germany): Edeka Supermarkets (Germany): Frucor Processors (Hastings, New Zealand) : Tip Top Bread (Auckland, New Zealand): Kiwi Co-operative Diaries Ltd, (Hawera, New Zealand): Bodo Airbase (Norway): Backhammars Bruk (Sweden): AG-Favor (Sweden): PUB Department Store (Sweden): Sainsbury's Supermarkets (UK): Tesco's Supermarkets (UK): Out of This World Stores (UK): Iceland Supermarkets (UK): National Trust (UK): Royal Institute of British Architects (UK): National Hospital (UK): Chartered Society of Physiotherapy (UK): London Transport (UK): Esso Gas Station Supermarkets (UK), Church of England (UK).

Hydrocarbon chillers are available in a wide variety of sizes, with the largest being around 1000kW.

***B.6 Examples of commercial enterprises using CO2 refrigerants**:*

CO_2 technology is rapidly gaining market share in the global cooling industry. Recent examples include:

- In March 2006, several major UK supermarket chains announced their decision to phase-out their use of HFCs in cooling equipment and to convert to natural refrigerants such as carbon dioxide. ASDA, Marks & Spencer, Sainsbury's, Somerfield, Tesco and Waitrose emphasized that a further use of hydrofluorocarbons (HFCs) in commercial refrigeration was incompatible with increasing concerns over climate change.

- Europe's 3rd largest food trader REWE has announced that from 2008 on it will use CO_2 (R744) refrigeration in new small-sized supermarkets in Germany[5].

- In 2008, Drakes supermarket in Australia installed a transcritical $CO_2$2-only cooling system without any back-up system in its North Adelaide store.[6] This is the first of its kind in Australia.

- Australia's largest food retailer Woolworths announced that it plans to install CO_2 cascade systems in new stores after the success of its pioneer "green supermarket" in Sydney.[7]

- ABN Amro Data Centre, UK: The Dutch bank ABN Amro works with 15 high-performance servers at the data centre of its London branch. To provide a controlled climate for this hardware, the refrigeration systems manufacturer Star Refrigeration built a low-energy-consumption carbon dioxide facility. Star Refrigeration designed a refrigeration system that uses carbon dioxide to generate a total output of 300 kilowatts. The carbon dioxide is recondensed with water at 6°C via an indirect chilling cycle. The cooling is handled by ventilator units on the back of the server cabinets, where the carbon dioxide evaporates at 14°C and absorbs the heat siphoned off by the fans. [8]

B.7 New developments in CO_2 Cooling Equipment:. CO_2 technologies exhibited at the 2008 Mostra Convegno Expocomfort in Milan included:[9]

- Swep: The Swedish supplier exhibited its CO_2 Gas Cooler for transcritical systems, which is already part of several supermarkets installations all over Europe.

- HPH: An Italian SME (small to medium enterprise), exhibited its own models of copper-based R744 Heat Exchangers for industrial applications.

- Embraco: the Brazilian manufacturer showcased its CO_2 Compressor for light commercial applications, including the display of a Casette system for vending machines. At the same time, the company is working on electronic control of the systems' performance (VCC), which helps improve efficiency by better monitoring the system.

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[5] www.r744.com/news/news_ida260.php REWE Group Chooses Co2 for its new "City Markets"

[6] www.r744.com/news/news_ida302.php. Industry Visits Australia's first CO_2 only supermarket

[7] www.r744.com/news/news_ida302.php Industry Visits Australia's first CO_2 only supermarket

[8] eurammon: Example provided by eurammon, the European initiative for natural refrigerants, www.eurammon.com/ß

[9] www,r744,com/news/news_ida312,php Milan Expo features CO_2 Technology

- Bitzer: Exhibited its CO_2 Compressor range for refrigeration, covering all temperature ranges and suitable to different types of systems, including cascade and transcritical systems.

- Lu-ve: The Italian company showcased CO_2 gas coolers for large industrial installations.

- Emerson: Displayed compressors under the Copeland brand, for subcritical CO_2 systems. The company also confirmed its cooperation with Rivalco, Italian supplier of Commercial Refrigeration equipment.

B.8 Examples of Ammonia Air-Conditioning in Commercial Enterprises

Ammonia has been used in refrigeration since 1850s. It has superior thermodynamic properties and is highly energy efficient. The most prominent example of the use of ammonia in air-conditioning is in the **international space shuttle**. Other examples from around the world include universities, hospitals, hotels, office buildings, convention centers, airports:

CANADA:Campbell's Soup - Toronto, Ont.- office building : **DENMARK**:Hvidovre Hospital, Copenhagen University Rigshospitalet , Ilum and Magasin Department Stores, Scandic Hotel Copenhagen, SDC Bank (data bank for financial institutions), Copenhagen Airport, Danish National Television, SAS Building, Aarhuz **GERMANY**: Hannover Trade Fair Building (One of the largest commercial ammonia air-conditioning systems in the world , using two and a half tonnes of ammonia to generate 3.5 megawatts of cooling), Leipzig Trade Fair Building, Lindplatz Centrum-Berlin-shopping center, Casino & Supermarket, Monsdorf,, **JAPAN**: Ashai Brewery – Nogano **LUXEMBOURG**: Palais Grande Ducal and Parliament, Cactus Supermarket, Match Suoermarket, IBM Luxembourg, ASTRON Building, Imprimerie St. Paul, City Concorde, Banque Van Lanschot, Dresdner Bank, Husky, Amro Bank **NORWAY**: Oslo Airport, Kodak Norge Office **SPAIN**: Carlos III University in Leganes **SWEDEN**: Arlanda Airport-Stockholm, KF Stores UK: Middlesex University **UNITED STATES**: Biosphere II Oracle , Tucson, AZ (space a/c); McCormick Place Convention Center , Chicago, IL(convention center); Stanford University, Palo Alto, CA,(district cooling -multiple buildings); Montgomery College, Germantown, MD (district cooling); USF&G, Baltimore MD (office building); Rockford Arts & Science Museum-Rockford, IL (ice storage/space cooling); University of Miami, Miami, FL marine studies center); Blue Cross Blue Shield-Chicago, IL(office building); Xerox Office Complex, -Los Angeles, CA-office building; Montgomery County College, Maryland; Trinity College, Hartford, CT; Montgomery County College, Maryland. **UNITED KINGDOM**: Roche Products/UK, company headquarters at Welwyn Garden City:

B.9 Examples of Recently Installed Applications of Ammonia in Refrigeration and Freezing[10]

- Spiral chiller with finless evaporator for Food Freezers (Developed by Grasso GmbH Refrigeration Technology): Usually heat transmitters have fins that increase the evaporator's surface. However, this also facilitates the deposition of microorganisms and makes the facility harder to clean. Thus, there is demand for finless alternatives offering the same level of efficiency in the foods industry. The heart of the prototype is a spiral chiller equipped with a finless evaporator. The evaporator is tested by cooling 8,000 regular ice-packs from ambient temperature to -37 degrees Celsius in 30 minutes. The refrigeration energy is furnished by an ammonia/carbon dioxide cascade: ammonia for the high-temperature cycle, carbon dioxide for the low-temperature cycle. The advantage: only 40 kilograms of ammonia are used, and remain confined to the central machine room while the freezer is supplied with carbon dioxide.

[10] eurammon: Examples provided by eurammon, the European initiative for natural refrigerants, www.eurammon.com/ß

- Poultry Producer in Germany: The new production facilities, with a total floor space of approx. 5,000 m², were to be equipped with a number of different refrigeration and processing rooms. The spectrum of required temperatures extended from -30°C to 7°C. Kältetechnik Dresen + Bremen built a three-stage ammonia refrigeration plant with a glycol cycle. Four screw compressors and one piston compressor were used to control the various temperature level requirements of the system, which was charged with 2,850 kg of ammonia. The deep-freeze warehouse and the shock-freeze rooms with a refrigeration output of 410 kW at -40°C are directly supplied with ammonia. An ethylene glycol cycle with a flow temperature of -12°C cools the production rooms, e.g. filleting, fresh storage and packaging rooms, and an integrated ventilation system with a total refrigeration output of 2,190 kW. In a spray humidified chilling tunnel that is also linked into the cycle, roughly 9,000 chickens per hour are cooled down to a temperature of 2°C.

- Process refrigeration for a Confectionery : A leading German confectionery manufacturer erected a new production building in Halle/Westphalia, Germany. Here Dresen + Bremen installed a refrigerating plant for process refrigeration and air-conditioning, using the natural refrigerant ammonia. Process refrigeration is responsible for controlled heat removal during the production of chocolate, sweets and fruit gums, and for cooling the machines. The focal element of the central plant consists of four frequency-controlled screw compressors. The consumers are supplied with refrigeration via two liquid circuits at temperatures between 5°C and 11°C. The process refrigeration circuit uses cold water, while the air-conditioning system works with a propylene glycol circuit.
- Dairy produce manufacturing in France: Danone, a producer of fresh dairy products headquartered in Paris, operates a plant for manufacturing yoghurt and cottage cheese in Fèrrieres en Bray, Northern France. Refrigeration France. The refrigeration system consists of liquid chilling units using ammonia, which supplies 400 cubic meters per hour of chilled water at 1 degree Celsius. The chilled water is conducted to various consumers like cold stores and specific rooms through a piping network. As the demand for cold energy varies over the day, Axima Refrigeration France supplied an ice storage tank that stores the extra cold energy and releases it again when demand is high.
- Edeka Meat processing plant in Germany: A system consisting of refrigeration and deep-freeze rooms that would meet all technical requirements while remaining efficient and inexpensive was needed. Johnson Controls Systems & Service realised a two-stage ammonia system involving screw compressors. It produces refrigeration output of 5,500 kW with a refrigerant charge of 10,000 kg. The cooling fluid piped through the processing rooms is ethylene glycol (34 %).

- Zipf Brewery in Austria: The Zipf brewery, a Brau Union Österreich AG brand, relies on an ammonia plant with slurry ice as coolant for its refrigeration needs. The retrofit was realised by Austria's KWN Engineering GmbH. The existing refrigeration system was kept, but the coolant cycle as well as part of the ammonia pump system was replaced with slurry ice – a mix of ice, refrigerants and anti-corrosives. Most of the existing pipelines were kept, as were the heat exchangers on the beer tanks and in the refrigeration rooms. New installations included two 230-kilowatt ice generators and air coolers supplied by Güntner. A 110 m³ silo with a refrigeration capacity of 2,800 kW was added to serve as an ice bank.
- The Guinness Brewery in Dublin: Guinness planned to increase the production volume of its world-famous Guinness Stout beer to twelve million barrels per year. Star Refrigeration extended the 5 megawatts system up to 8.9 megawatts, which complements the existing facilities perfectly. The refrigeration specialists installed six additional variable speed drive glycol pumps and increased the condenser capacity. The modernized system now has a refrigeration capacity of 8.9 megawatts at an evaporating

temperature of -4.5 degrees Celsius, without noticeably increasing the ammonia refrigerant charge in the system.

- Asda Distribution Centre in Lutterworth, UK: Beginning in 2002, the British supermarket chain Asda has had Star Refrigeration replace all refrigeration units which use the hydrochlorofluorocarbon (HCFC) R22 at its distribution centres, as part of a long-term modernisation programme. Star Refrigeration designed a central refrigeration system which supplies liquid carbon dioxide at -31°C to six air coolers in the cold store. It also supplies carbon dioxide as a volatile secondary refrigerant at -5°C to 20 air coolers in three chill rooms. The cascade facility's low temperature circuit yields a refrigerating capacity of 820 kW, while the high temperature circuit produces 2,700 kW.

- Pasta & Co. in Austria: For the manufacturing of filled fresh and frozen pasta, and to store the raw materials that go into them, the Austrian market leader Recheis Teigwaren GmbH required conditioned storehouses, regular and deep-freeze storehouses and a combined spiral/freezer-cooler. The company required an economical and environmentally friendly refrigeration facility that complies with Austria's F-Gases regulation. To furnish all the cold energy demand without using HFCs, the KWN Engineering-Gesellschaft mbH designed a refrigeration facility using the natural refrigerant ammonia. A carbon dioxide-cascade was additionally installed for the deep-freeze storehouse and the spiral freezer and cooler

D. DESICCANT, EVAPORATIVE AND ABSORPTION COOLING IN THE UNITED STATES:

Desiccant cooling is widely used in the United States by supermarkets, chain departments stores such as WalMart, restaurants, hospitals, community centers, and office buildings.

Evaporative water coolers are one of several alternatives to current models of refrigerators and air conditioners. In the United States more than 70 companies manufacture evaporative air conditioners for residential, automotive, commercial and industrial markets. Direct, or single-stage, evaporative coolers are used on tens of thousands of homes in the western US, as well as thousands of commercial establishments-shops, restaurants, dry cleaners, offices, warehouses, factories.

Indirect-Direct, or two-stage, evaporative air conditioning systems are also used in numerous applications such as; schools, office buildings, commercial buildings, and homes.

Absorption systems typically use water as the refrigerant and lithium bromide as the absorber. Most of the installations noted use natural gas-fired chillers, some use high pressure steam. They are used a wide variety of commercial settings; banks, airports, office buildings, apartment buildings, hospitals, convention centers etc.

E. CO-GENERATION COOLING:

Air-conditioning technologies based on the use of waste heat from on-site electricity generation have the potential to greatly reduce energy consumption. This eliminates HFC use in many large-scale applications immediately.

- The Banque Generale du Luxembourg has installed a gas fired co-generation system that produces 90% of the Bank's energy needs and 100% cooling and heating. The cooling is provided with three absorption chillers using lithium bromide as the absorbent. The bank estimates that it save 1 million dollars in energy costs, and reduces CO2 emissions by 6500 tons a year. The system is American designed and installed by Trane.

- Ashai Brewery announced in 1999 that the company was installing a co-generation energy system at the Nagoya plant, using ammonia absorption for air-conditioning and

hydrocarbons for the beer vending machines. The company expects to save 400 million yen a year from the resultant energy savings.

F. DISTRICT COOLING SYSTEMS (DCS):

"District cooling system (DCS) distributes thermal energy in the form of chilled water or other media from a central source to multiple buildings through a network of underground pipes for use in space and process cooling. The cooling or heat rejection is usually provided from a central cooling plant, thus eliminating the need for separate systems in individual buildings."[11]

District Cooling Systems today rely on a variety of cooling agents, including HFCs, ammonia, water, or the use of absorption chillers. However, the use of HFCs for DCSs is unnecessary since natural refrigerants, are available and can be safely applied in large chillers. And DCSs using absorption chillers can use mixture of lithium bromide and water, "which is a more environmentally benign alternative than the cooling agents used in building-specific compressor plants, is used as a cooling agent in absorption chillers."[12]

Regardless of the refrigerant used, District Cooling Systems are a highly efficient way of delivering cooling services with potential to reduce consumption of electricity for cooling purposes by as much as 90 per cent.[13] A centralized cooling systems provides greater quality control in maintenance and servicing, reducing the rate of refrigerant leakage.

"District cooling systems displace peak electric power demand with district cooling and storage using ice or chilled water. This benefits the local power grid by reducing peak power demand and alleviating power congestion due to power transmission limitations in cities. So district cooling not only helps cool cities, it helps alleviate the challenges posed by high electric consumption.

The economic benefits can be experienced by both the owner and the tenant, where the capital costs of control panels, internal power distribution, annual maintenance and power consumption inside the building are reduced and the cost of chillers are eliminated."[14] Benefits of District Cooling include:

* Better quality of cooling
* Maximum cost effectiveness
* Capital cost elimination
* Space saving
* Decrease in sound pollution
* Environmentally friendly

"Common applications involve District Cooling utilities that sell chilled water to numerous customers, as well as single owner-operator-customer systems such as universities, hospitals, airports and industrial facilities. District Cooling systems often facilitate the use of other beneficial technologies, such as non-electric and hybrid (electric and non-electric) chiller plants, cogeneration and trigeneration, and Thermal Energy Storage."[15]

District Cooling Systems exist in many parts of the world. There are about 100 District Cooling systems in Europe[16] and approximately 2000 in the United States. They have also been installed in the Middle East and in Singapore.

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[11] National Climate Change Committee, Singapore : www.nccc.gov.sg/building/dcs.shtm
[12] www.helsinginenergia.fi/kaukojaahdytys/en/os4_1.html
[13] www.helsinginenergia.fi/kaukojaahdytys/en/os4_1.html
[14] www.tabreed.com/districtCoolingDistrictCoolingBenefits.aspx
[15] www.coolsolutionsco.com/district_cooling.htm
[16] www.euroheat.org/

F.1 Examples of District Cooling Installations

- Cool Solutions, a company based in Lisle, Illinois, USA has participated in the installation of DC systems in Chicago, Illinois (21,000 tons), Cincinnati, Ohio (7,500 tons), Lansing, Michigan (12,000 tons), Oklahoma City, Oklahoms (18,500 tons), Orange County, Florida (21,000 tons), Orlando, Florida (5,700 tons), Washington, D.C. (10,000 tons).[17]

- Baltimore Aircoil Company has completed "more than 2500 installations worldwide "of high efficiency [= 34°F (1°C) supply water] ice storage systems for district cooling…BAC has supplied ice storage systems for a wide range of projects, including office complexes, hospitals, universities, sports arenas, as well as utility districts (some as large as 125,000 ton-hours)."[18]

- Singapore: District Cooling Systems can be found in the Changi Business Park and Changi Naval Base in Singapore.

- Dubai: Palm District Cooling Co. of Dubai is working on several DCS projects in Dubai for Nakheel (a large Dubai development company) , which when completed will provide combined 500,000 refrigerated tonnage. Nakheel DCS projects include Palm Jumeirah, Jumeirah Lake Towers, Jumeirah Village, Discovery Gardens and Dubai Metals and Commodities Centre, Ibn Battuta Shopping Mall and Furnished Apartments.[19]

- United Arab Emirates: "The National Central Cooling Co. (PJSC) – Tabreed - is a UAE public joint stock company established in June 1998 and is now one of the world's largest district cooling utilities. Tabreed provides district cooling services throughout the GCC countries with offices in Dubai, Abu Dhabi, Ras Al Khaimah, Doha, Manama, Khobar and Muscat."[20]

- Helsinki, Finland: Helsinki Energy provides district cooling from its the district cooling plant at the Salmisaari power plant site since 1998. The output has been "10 MW since the first stage of the cooling plant project was completed. The cooling plant has two absorption chillers and a chilled water storage for evening out peak loads. Cooling energy is transmitted via a pipe network to the districts of Ruoholahti and Kamppi. In addition, the outputs of the Pitäjänmäki absorption chillers and the transportable compressor cooling units in the district of Sörnäinen total 5 MW."[21]

- Cornell University in Ithaca, New York, delivers 20,000 tons of DCS cooling to its campus by pumping cold water into a heat exchanger from nearby Lake Cayuga. The City of Toronto is currently installing a similar system which will deliver 50,000 tons of DCS cooling from the waters of Lake Ontario.[22]

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[17] www.coolsolutionsco.com/district_cooling.htm

[18] www.baltimoreaircoil.com/english/products/ice/district/index.html

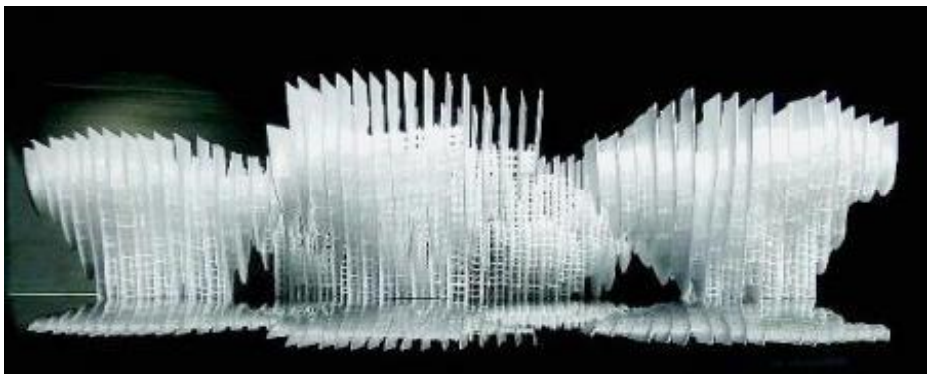
[19] www.palmdistrictcooling.com

[20] www.tabreed.com/aboutus.aspx

[21] www.helsinginenergia.fi/kaukojaahdytys/en/os3_1.html

[22] Information provided by Mr. John Andrepont of Cool Solutions www.coolsolutions.com

G. PASSIVE COOLING:
The architectural redesign of new buildings to make use of natural ventilation, coupled with efficient insulation, can eliminate or reduce the need for mechanical air-conditioning and thus save energy.



Swabhumi Hotel complex (model) in Kolkata, India, designed by architectural firm Morphogenesis, uses innovative building design that simulates the way trees trap winds to deliver cooling services. The firm also designed a Jaipur fashion school where classrooms are cooled to around 25 degrees Centigrade without air-conditioners while ambient temperatures are nearly double outside. [23]

H. MOBILE AIR-CONDITIONING (MACS) AND TRANSPORT COOLING

H.1 Environmental Impacts of HFC Mobile Air-Conditioning*:*

Approximately 50% of global HFC-134a production is for automotive air conditioning, 15% for domestic refrigeration, and most of the remaining 35% for commercial and residential air-conditioning and supermarket refrigeration. A 1997 study by Atlantic Consulting reveals that the HFC-134a leakage from the air-conditioning of cars sold in 1995 in Western Europe alone will generate the CO_2 equivalent emissions of five new power plants, while the HFC-134a leakage from automobiles sold in Japan in 1995 will contribute the CO_2 equivalent of ten power plants, or approximately 16 million tonnes of CO_2.

Though there is substantial variation in estimate of annual leakage rates from MACs, one thing is certain though, the rates are substantial. The US Department of Energy's Energy Information Agency website claims that "Automobile air conditioners are subject to leakage, with sufficient refrigerant leaking out (15 to 30 percent of the charge) over a 5-year period to require servicing." [24] The site also claims that major US car manufacturer General Moters (GM) estimate annual leakage rates of 10 percent per year. "With GM vehicles accounting for about one-third of the U.S. light-duty fleet, the GM emissions estimate implies that total U.S. HFC-134a emissions from mobile air conditioners were equal to about 4,500 metric tons in 1996. Emissions from this source

[23] Vancouver Sun: Reuters report, March 12, 2008
[24] . http://www.eia.doe.gov/oiaf/1605/archive/gg98rpt/halocarbons.html

are expected to continue to increase in the near future, as the replacement of vehicles using CFCs proceeds at a rapid pace."[25]

A study by the School of Chemical Engineering and Industrial Chemistry, University of New South Wales, indicates that hydrocarbon automobile air-conditioners are almost 35% more efficient than HFC air conditioners. They also found that, if countries in Asia used hydrocarbons instead of HFCs in automobile air-conditioners, there would be 3.7 billion tonnes less cumulative CO_2 emissions by the year 2020.[26]

H.1 ***Carbon Dioxide based Mobile Air-Conditioning (MACs)***

German carmakers select CO2 refrigerants to replace HFC-134a in MACs: In response to the European Union's decision to phase out high GWP, HFC-134a in mobile air-conditioning by 2011, in August of 2007 the German car industry decided to use carbon dioxide as the replacement refrigerant.[27] CO_2 was selected over several low GWP HFCs proposed by the Chemical companies, DuPont, Honeywell and Ineos, known in the MAC industry as DP1, H Blend and AC 1.

The choice of next generation refrigerants in industrialized markets now seems to be between CO_2, and HFO 1234yf. CO_2 has been selected by the German carmakers and is also being assessed by all other OEMs worldwide.

The verdict is still out on the latest low-GWP DuPOnt/Honeywell refrigerant HFCO 1234yf. Beside its unknown costs, and overall environmental impacts, concerns over the flammability of HFCO 1234yf as a refrigerant for mobile air-conditioning have also been raised. Recent tests by Obrist Engineering on HFO-1234yf, and CO2 (R744) mobile air-conditioners concluded that "Whereas R744 would increase an air conditioning systems' current safety level in case of a front end accident, using HFO-1234yf (2,3,3,3-Tetrafluoroprop-1-ene) reduces significantly today's safety level in terms of flammability, as it puts human life at risk. Although the HFO-1234yf flammability level is judged to be slightly reduced when compared to R152a, Obrist judges necessary to introduce either an oil free circuit or a secondary loop for the front end heat exchanger to mitigate the risks associated to HFO-1234yf." [28]

The energy efficiency benefits of CO_2 systems have been known for several years. Extensive measurements carried out at the University of Illinois in 1999 showed that CO MACs have at least 30% lower TEWI than HFC systems.[29] Other studies reporting on trials comparing CO2 prototypes against state-of-the R134a system in real situations indicate that the COP of the CO_2 system was typically 25% greater than that of the R134a system. [30] Based on the Life Cycle Climate Performance (LCCP) , a recent study by SINTEF research institute, compared MAC systems' total contribution to global warming in a cradle to grave approach, highlighting several benefits of R744 MAC concerning environmental performance, costs and future potential. Namely, that R744 MAC produced up to 40% less emissions in hot climates (India and China) than R134a.[31]

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[25] . http://www.eia.doe.gov/oiaf/1605/archive/gg98rpt/halocarbons.html

[26] Pham, Tuan and Aisbett, E. : Natural Replacements for Ozone-Depleting Refrigerants in Eastern and Southern Asia: School of Chemical Engineering and Industrial Chemistry, University of New South Wales: to be published by the International Journal of Refrigeration- in press 1998.

[27] UNEP, 2006 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 2006 Assessment

[28] www.r744.com/news/news_ida293.php

[29] (Yin, 1999) need full ref

[30] Notes from Calor Gas reporting on studies by Walter & Krauss, 1999; Walter 1999; DKK 1998) and confirmed on Mercedes (Daimler-Benz web site (http://www.daimler-benz.com/ind_gfnav_e.html?/research/text/80331_e.htm

[31] http://www.r744.com/news/news_ida095.php

In addition to their environmental benefits, CO_2 systems provide a servicing cost benefit as there is no need to recover and recycle the refrigerant at the end of life.[32]

Manufacturers Ready to Produce CO_2 Equipment: Several mobile air-conditioning manufacturers are ready to produce CO_2 systems. These include Behr, Valeo, Calsonic Kansei, and Denso. Reportedly, Calsonic and Denso have already launched CO2 systems in hybrid vehicles in Japan.

Numerous R744 MAC system and component manufacturers have announced their availability for production, such as Ixetic, Behr, Visteon, Modine, Hydro or Doowon.[33] In addition, at the latest international MAC industry gathering in February 2008, the German Car manufacturers and their suppliers announced major steps towards serial production of R744 MAC systems.[34]

Carbon Dioxide Air-Conditioning for Buses: Konvekta, the leading German manufacturer of thermo systems for commercial vehicles has begun to install CO_2 vehicle air conditioning.Type P 7744, to be used with the natural refrigerant CO_2 (R744), features a cooling capacity of 33 kW, and a heating capacity of 38,000 Q 100. Since 1996, it has been running successfully in test fields with a German bus operator to prove its everyday suitability. The operational experience has shown that, compared to the current refrigerant R-134a, R744 is competitive in terms of efficiency and capacity due to a better compressor performance and heat transfer, as well as a lower effect in case of pressure losses. In addition, CO_2 units in reversed circulation can be used for heating purposes, unlike R-134a. After more than 6,000 operating hours of the CO2 prototypes, Konvekta is now preparing for the serial production of its R744 cooling unit.[35]

H.2 Hydrocarbons in Primary MAC Systems:

By 2002 over 300,000 cars had been converted in Australia from CFCs and HFCs to hydrocarbons. Similar conversions are happening in North America without regulatory approval. Hydrocarbons could most likely be safely used in primary MAC systems specifically designed for their usage.

***H.3 Hydrocarbons in Secondary Loop MAC Systems*:**

The application of a secondary loop system would further overcome any outstanding safety concerns. "Designed to accommodate a hydrocarbon, the secondary loop system would completely eliminate HFC-134a use (and emissions). It would be expected to use about 10% more energy for operation than the current system, but would still represent a net savings of at least 80% of equivalent green-house gas emissions associated with current HFC-134a systems that are operated without proper recovery and recycle during service and vehicle disposal.

One noteworthy aspect of using propane, the best hydrocarbon choice for secondary loop systems, is its availability. Propane is used universally for heating and cooking. As a result, its safe handling is widely understood and practiced by the general population in most countries, whether literate or not. This could be an advantage in the developing countries. For systems using propane, the charge for a mid-size vehicle would be relatively small, on the order of 200 grams, based on the molecular weight of the refrigerant and the lower refrigerant charge required by the secondary loop system."[36]

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[32] Multisectorial Initiative on Potent Industrial Greenhouse Gases (MPIGGs) newsletter, 2004: www,mipiggs.org

[33] A good overview of these latest industry developments can be found on R744.com

[34] http://www.r744.com/news/news_ida298.php

[35] http://www.r744.com/news/news_ida319.php

[36] S.O. Andersen, U.S. Environmental Protection Agency, Washington DC, USA, W. Atkinson & J.A. Baker Technical Advisors to the Mobile Air Conditioning Climate Protection Partnership " Existing and Alternate Vehicle Air Conditioning

TransAdelaide Bus Company in Australia has installed hydrocarbon air conditioning in the drivers' compartment, while the passengers compartment is cooled by desiccant cooling.

H.4 Evaporative Cooling for Buses

Evaporative Bus Air-Conditioning: Nearly 500 buses (in Colorado, Utah, California and Texas) and additional buses in Adelaide and Perth, Australia use evaporative or adiabatic air conditioning systems. Companies using evaporative cooling in transport include: Regional Transportation District, Denver, CO; Denver International Airport, Denver, CO; Utah Transit Authority, Salt lake City, UT; University of California at Berkeley, Berkeley, CA; Sacramento Regional Transit, Sacramento, CA; Pacific Gas & Electric Co. CA.

I. FOAMS

A major cause for concern in the foam sector is the pending switch from HCFC-141b for Rigid Polyurethane foam (PUR) foam blowing to potent global warming gases such as HFC-245fa, HFC-365mfc, and if those alternative prove to be inferior, to HFC-134a.

I.1 Construction Foams:

PUR is commonly used in construction as an insulating foam. There are a number of different kinds of foam which are all rigid PUR, most notably, boardstock, sandwich panels and spray foams.

- Boardstock is prominently used in roof and wall insulation in commercial buildings. Sandwich panels, where the foam is sandwiched between facing materials such as steel and aluminium, are used for insulating cold stores, cold rooms and doors. Spray foams are made at the point of use and are literally sprayed into place. They are highly suitable for the insulation of uneven or inaccessible surfaces and are used in storage tanks, pipe work and refrigerated trailers.

- Increasingly, companies are using the hydrocarbon pentane as an alternative blowing agent for both board stock and sandwich panels. In 2005 hydrocarbons were expected to represent over 55% of global blowing agent usage.[37]

- Major US building insulation producing companies, such as Atlas Roofing, Firestone, RMAX, Johns Manville have shifted from HCFC-141b to using pentane. They have concluded that pentane is less costly than HFC-245fa or HFC-365 mfc and that, given the high GWP of these substances, pentane is environmentally more sustainable

- A similar situation is occurring in Europe. Thanex in Denmark have used a mechanical process for producing PUR insulating foam. Recticel (Belgium), the largest manufacturer of PUR foams in Europe, and Bayer, have been producing hydrocarbon blown foams for construction applications for a number of years. The French company Efisole has also switched to using pentane for various polyurethane foam production. German companies have been using hydrocarbons for nearly a decade.

- Alternatively, CO_2 is currently being used as the blowing agent by ICI and Liquid Polymers Group in the UK, ResinaChemie and BASF in Germany and Nassau Doors in Denmark. Carbon dioxide blowing, in combination with process changes, as demonstrated by Windsor Doors in Norway, is a proven technology for spray foams.

Systems

[37] IPCC (2005)

- **Alternatives to foams:** Often the best alternatives to polyurethane boardstock are not foams at all. Magnesium carbonate, as produced by Darchem in the UK, can be made into an insulation product for use in power stations and oil installations. Products such as mineral fiber and fiberboard have always been in competition with polyurethane. Mineral fiber is dominant in insulation products in the UK. Meanwhile, the Swiss company Isofloc produces boardstock panels made out of cellulose. The panels are made out of recycled materials. Extruded polystyrene is also used as a rigid boardstock, where its moisture resistance and strength make it suitable for below ground construction insulation , for example, in foundations. Dow Chemicals and BASF use carbon dioxide technology to produce extruded polystyrene. The product is sold in many European countries.

I.2 Refrigerator and Freezer Insulation:

In most markets, with the exception of North America, the hydrocarbon cyclopentane has now become the standard choice for the blowing rigid polyurethane foams, which continue to be the dominant insulation used in domestic refrigerator-freezers and small commercial equipment. Alternative foam blowing agents include water and CO_2.

I.3 District heating pipes:

More than half of the world production of pre-insulated district heating pipes takes place in Denmark, by four companies: ABB District Heating (I C Moller), Logstor Ror, Tarco Energy and Starpipe (Dansk Rorindustri). As from January 1993 CFCs were no longer allowed for the blowing of insulation foam for district heating pipes in Denmark. HCFCs, as a transitional solution, and CO_2 had been used instead. Now all four companies have developed systems based on cyclopentane or other hydrocarbons. Two of the companies also continue producing CO_2-based pipes.

I.4 Portals, industrial doors:

Two Danish companies, Nassau Doors and Windsor Door, produce industrial portals and doors with sandwich panels containing polyurethane foam. They are now using CO_2.

I.5 Rigid integral foam:

The Danish firm Tinby A/S has a considerable production of rigid integral foam for industry, especially in the graphical industry. They stopped using CFCs in 1993 and have since used CO_2 in the major part of the production, and HCFCs in a minor part.

I.6 Jointing foam

Baxenden Scandinavia produces canister foam sealant (jointing foam) and has, since 1987, produced cans with propane/butane propellant for the Scandinavian market and cans with HCFC for the European market.

I.7 Flexible integral foam :

Baxenden Scandinavia has also developed systems for producing flexible integral foam with isopentane as blowing agent. Additionally, Ecco, a large shoe producer, has, in cooperation with Bayer, developed a technology for producing shoe soles of flexible integral foam, using CO_2 rather than ODSs..

I.8 Flexible foam:

Three Danish companies (Brdr.Foltmar, KBE and Danfoam) are producing flexible slabstock foam at four localities. They stopped using CFCs in 1991 and use CO_2 for most production. Urepol Oy is a Finnish company manufacturing polyurethane insulated steel-faced and flexible faced panels, and one-component PUR foam insulation. The company is now using hydrocarbons to produce products which were previously manufactured with CFCs and HCFCs

I.9 Vacuum insulation:

Vacuum insulation panels, which offer superior insulation for appliances and provide significant energy savings are increasingly being applied. These vacuum panels are filled with e.g. silica, fiberglass, or ceramic spacers.

- NoFrost Co. of the UK launched a new line of hydrocarbon freezers in 1999 using vacuum panels which were developed in cooperation with ICI for insulation, and hydrocarbons for the refrigerant.

- Vacuum panels in appliances are used by General Electric and Owens-Corning in the USA.

- In Japan, Sharp combines the use of vacuum panels with PUR foam blown with cyclopentane in domestic refrigerators. AEG in Germany has introduced some vacuum panel insulated fridges

- The Swiss Ecofridge Project uses vacuum insulation, where the vacuum is filled with diatomaceous earth. The thermal conductivity is about 0.005 compared with 0.020 in

CONCLUSION

There are many more examples around the world where natural working fluids (e.g ammonia, CO_2,, hydrocarbons, water) along with other non-fluorocarbon based technologies are accomplishing the job of providing sustainable, low-GWP, reliable and safe cooling. The above survey is to demonstrate the “possible”. Now is the time to leave behind the fluorocarbon era, and to embrace technologies that do not unnecessarily harm the climate or the environment.

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