UNEP

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

Lower-GWP Alternatives in Commercial and Transport Refrigeration: An expanded compilation of propane, CO_2, ammonia and HFO case studies

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This project was managed by the following UNEP OzonAction Branch team:

Shamila Nair-Bedouelle, Head
James S. Curlin, Network and Policy Manager
Ezra Clark, Programme Officer
Ruperto de Jesus, Capacity Building Assistant

This document was researched and written by:

Walid Chakroun, *Department of Mechanical Engineering, College of Engineering and Petroleum, Kuwait University, and ASHRAE Director for Region at Large*

This document was reviewed by:

Canada: **Philippe Chemouny**
Canada: **Marla Desat**
Canada: **Colin McLeod**
Environmental Investigation Agency: **Christina Starr**
Environmental Investigation Agency: **Mark W Roberts**
National Resources Defense Council: **Alex Hillbrand**
shecco: **Klara Skacanova**
US Environmental Protection Agency: **Apurva Dave**
US Environmental Protection Agency: **Cindy Newberg**
US Department of State: **John Thompson**

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Art direction and design by:
Sue Cowell, Atomo design (first edition)
Aurélie Ek: (first edition design updates)
Graphic Design Unit, United Nations Office at Geneva: (second edition)

Executive Summary

The Climate and Clean Air Coalition (CCAC) adopted a range of activities to initiate action in key countries and within specific sectors to improve understanding of high global warming potential (GWP) HFC use and create incentives to encourage the development and transition to climate-friendly alternatives to high-GWP HFCs. The CCAC Working Group approved funding for various capacity building activities related to low-GWP alternatives to HFCs. One of these activities included the creation of a compilation of case studies on alternatives to HFCs in the commercial refrigeration sector. UNEP DTIE OzonAction worked in cooperation with the CCAC to publish this compilation in 2014.

The present publication comprises an expanded and updated compilation of case studies on lower-GWP energy efficient alternatives and technologies in the commercial refrigeration as well as the transport refrigeration sectors. It provides a number of new commercial refrigeration case studies as well as case studies from the transport refrigeration sector, including alternatives not previously considered in the first volume, to provide better geographical spread and present a more comprehensive overview of lower-GWP alternatives adopted.

This publication comprises two sections. Section 1 on commercial refrigeration, specifically retail food refrigeration firstly provides a brief sector overview and includes six new case studies and the original five case studies. The information is presented in a consistent and structured manner for each case study to allow easy comparison and cross-referencing. These new case studies cover a carbon dioxide (CO_2) / hydrofluoroolefin (HFO) blend cascade system, two different ammonia and CO_2 cascade systems, a CO_2 transcritical system, a propane system, and a retrofit of a centralised direct expansion refrigeration systems from an HFC to a lower GWP HFC/HFO-blend refrigerant. These supplement the original case studies which covered the following technologies: two transcritical CO_2 systems, a CO_2 cascade system with HFC, a chiller using HFO-1234ze system and a Propane system. Section 2 provides an overview of the Transport Refrigeration Cold Food Chain sector and three case studies on transport refrigeration. These cover two CO_2 systems and a liquid nitrogen system.

Each case study provides information on the type of facility and refrigerant used, an explanation and background is provided of how the transition was decided upon, designed and carried out. Information on performance and economic considerations are also included. Contact details are provided for the reader to seek out more information from the enterprises, as appropriate.

This updated compilation is primarily intended to assist relevant decision makers, especially those in developing countries, in selecting the most appropriate climate-friendly alternatives in both the commercial refrigeration as well as the transport refrigeration sectors.

Introduction

A note on this edition

This booklet presents an expanded compilation of case studies on lower-GWP alternatives in commercial and transport refrigeration and provides an update to the first set of case studies which was published in 2014 by UNEP DTIE OzonAction/CCAC (*Low GWP Alternatives in Commercial Refrigeration: Propane, CO_2 and HFO Case Studies*, available at: www.unep.org/ccac/portals/50162/docs/Low-GWP_Alternatives_in_Commercial_Refrigeration-Case_Studies-Final.pdf).

Section 1 of the booklet provides a number of new commercial refrigeration case studies, including alternatives not previously considered, as well as all the initial case studies from the first compilation. Section 2 provides case studies from the transport refrigeration sector.

The Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) is a unique global effort supporting fast actions to mitigate the impacts of short lived climate pollutants, such as black carbon, methane and many hydrofluorocarbons (HFCs) and addressing near-term climate change and air pollution at the same time. The CCAC is a voluntary partnership bringing together over 50 country and Regional Economic Integration Organization (REIO) partners and 61 non-state partners including intergovernmental organisations, representatives of civil society and the private sector.

The CCAC has launched a transformative initiative (entitled *'The HFC Initiative, Promoting HFC Alternative Technology and Standards'*) for rapid implementation aimed at promoting HFC alternative technologies and standards to significantly reduce the projected growth in the use and emissions of high-global warming potential (GWP) HFCs in coming decades relative to business-as-usual scenarios. The objectives of the initiative are to mobilise efforts of the private sector, civil society, international organisations, and governments to:

- Promote the development, commercialisation, and adoption of climate-friendly alternatives to high-GWP HFCs;
- Encourage the uptake of climate-friendly alternatives that could support national, regional and global policies or approaches to reduce reliance on high-GWP HFCs;
- Overcome barriers that limit the widespread introduction of these climate friendly technologies, including those related to the establishment of standards; and
- Encourage the responsible management of existing equipment and better designs for future equipment in order to minimize leaks.

The HFC Initiative will help achieve these objectives by improving global understanding of current and projected future use of HFCs, by sharing lessons on the design and implementation of policies to reduce their emissions and use, by addressing barriers, including reforming standards, and by validating climate-friendly technologies in key areas of HFC use or projected growth.

As countries phase out hydrochlorofluorocarbons (HCFCs) under the Montreal Protocol on Substances that Deplete the Ozone Layer, they often need to make choices between high-GWP HFC alternatives and, when available, more climate-friendly alternatives. Depending on the alternatives selected, the increase in HFC emissions could partly offset the climate benefits achieved by the earlier reduction in ozone-depleting substance (ODS) emissions under the Montreal Protocol.

In order to assist in planning and implementing ODS transitions that minimise climate impacts, OzonAction/CCAC has developed this booklet of case studies on lower-GWP energy-efficient technologies that have been adopted in the commercial and transport refrigeration sector as alternatives to replace or avoid high-GWP HFCs. Given that the commercial refrigeration sector has a number of climate-friendly refrigerant alternatives that are already commercialised or near commercialisation in some countries and regions, the booklet presents lessons learned from real cases in commercial refrigeration and aims to stimulate further investigation to enable a smooth transition away from high-GWP refrigerants and assist in the selection of future refrigerants. The case studies offer information for system purchasers and operators to consider when upgrading or replacing existing equipment with newly designed systems that decrease impacts on the ozone layer and climate change. Even though the majority of cases are from industrialised (Non-Article 5) countries, the information and experiences presented are relevant to all countries to help users, technical managers, consultants, engineers, designers and equipment suppliers in their assessments and understanding of these technologies in order to achieve similar success. The issues discussed in the case studies are primarily related to transitioning to climate-friendly refrigerants and also include innovative technologies, methodologies and concepts which enhances the overall sustainability of commercial and transport refrigeration systems. These examples from end-users can help build confidence in, and illuminate pathways toward, more climate-friendly commercial and transport refrigeration.

SECTION 1:
COMMERCIAL REFRIGERATION

A note on Section 1

This section presents six new case studies (case studies 1 to 6) of technologies and approaches of implementation of lower GWP alternatives in the commercial refrigeration sector, specifically retail food refrigeration, not covered in the first volume to provide better geographical spread and present a more comprehensive overview of lower GWP alternatives adopted. In addition, all the initial case studies that were included in the first compilation of Commercial Refrigeration case studies which was published in 2014 in: *Low GWP Alternatives in Commercial Refrigeration: Propane, CO_2 and HFO Case Studies* are included (case studies 7 to 11).

Sector Overview

The commercial refrigeration sector comprises the equipment, technologies and services used to store and dispense frozen and fresh foods at the appropriate temperatures. This sector includes stand-alone or self-contained systems, condensing unit systems, and centralised or 'multiplex rack' systems. According to the 2014 assessment of the Montreal Protocol advisory panel, the Technology and Economic Assessment Panel (TEAP) Technical Option Committee, commercial refrigeration is one of the sectors where the refrigerant demand is the highest for servicing, as a result of the high emission levels of refrigerants from supermarket systems. Also the special report of the Intergovernmental Panel on Climate Change (IPCC)/ TEAP[1] indicated that on a global basis, commercial refrigeration is the refrigeration subsector with the largest CO_2-equivalent emissions, representing 40% of total annual refrigerant emissions. These emissions are categorised as direct and indirect emissions. Direct emissions refer to emissions of the refrigerant itself during system manufacturing, operation, and disposal at end-of-life. Indirect emissions refer to the emission of carbon dioxide and other greenhouse gases (GHGs) that result from the energy consumption (usually electricity) of the system over its lifetime. Reducing the leakage rates through better design and installation practices will reduce the direct emissions. As reported by the IPCC, the refrigerant emissions might represent 60% of the total emissions of GHGs resulting from system operation, the rest being indirect emissions generated by power production. A higher Coefficient of Performance (COP = heat removed/ required work) for the refrigerated system will help in reducing the indirect emissions since the amount of work required to remove the heat will decrease.

Research was conducted to generate a list of potential case studies for consideration taking into account all of the currently available zero- and lower-GWP refrigerants in commercial refrigeration applications, including "natural" or non-fluorinated refrigerants, such as hydrocarbons, carbon dioxide (CO_2), ammonia, and R-290 (propane) as well as the other major category of alternatives comprising man-made chemicals such as the unsaturated HFCs known as hydrofluoroolefins (HFOs) which include R-450A and R-449A. HFOs are a new class of unsaturated HFC refrigerants which have shorter atmospheric lifetimes and lower GWPs when compared to other HFCs. Some criteria such as geographic location, refrigerant used and available information of the proposed applications were taken into consideration when selecting the case studies. These chosen case studies examine energy efficiency benefits of alternatives, as well as cost, safety, availability, maintainability, life expectancy and other sustainable and environmental considerations. Robust technical information was collected in the chosen case studies based on data provided by the source. These case studies also provide a detailed analysis for the system components, methodologies, and controls technology to optimise energy efficiency and continually update with new developments. An overview of the refrigeration cycles that are used in supermarkets is provided below.

The case studies that are covered in this section (Section 1) of the booklet address mainly centralised systems used in supermarket stores, as well as stand-alone units. The technologies presented in these case studies are only some examples of the many available options for zero- and lower- GWP substances, taking into account all design criteria, such as system performance, environmental impact, and cost analysis. The cases presented here focus on CO_2, hydrocarbons and unsaturated HFC refrigerants, and other options

[1] IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons. 2005. Cambridge University Press, UK. pp 478

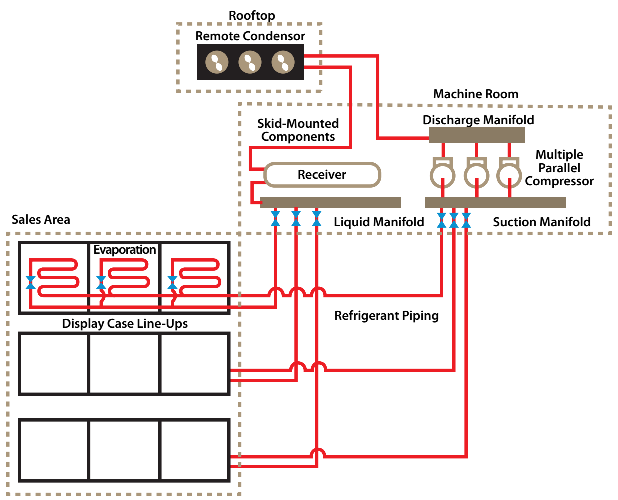
which deploy ammonia and other configurations of refrigerants. Some of the case studies also provide a sustainable holistic approach with state-of-the-art energy design methodologies and tools such as computational models such as simulations techniques as well as computational air flow dynamics (CFD) and lighting simulations. All these refrigerants still have many challenges that should be considered in the design such as their flammability, toxicity, lower efficiencies in some cases, and cost. Balancing the safety, energy efficiency, cost, and environmental impact of refrigerants using a consistent and comprehensive methodology across all refrigerants and system types is essential in assessing alternatives. Good design is also important for reducing refrigerant emissions and preventing refrigerant loss during installation, operation, maintenance, decommissioning and end-of-life disposal. There are also several ways to reduce the refrigerant charge in a supermarket, such as proper piping design, type of condenser used, use of electronic expansion valves, and an efficiently designed distributed system. All these are measures to reduce refrigerant charges and therefore decrease the overall CO_2 footprint of the system.

Types of Commercial Refrigeration Systems

Most supermarkets use centralised direct expansion (DX) systems to chill their products. Typically, these refrigeration systems are charged with 1,360 – 1,815kg of refrigerant and can leak in excess of twenty percent of their charge each year. Commonly used refrigerants include ozone-depleting HCFC refrigerants, often HCFC-22, and blends consisting entirely or primarily of HFCs. Both HCFCs and HFCs are potent greenhouse gases. Fortunately, in recent years there have been advances in refrigeration technology that can help food retailers reduce both refrigerant charges and refrigerant emissions. Below is a general description of a centralised DX system as well as an overview of the different advanced refrigeration options.

- Centralised DX System
- Distributed System
- Secondary Loop System
- Transcritical CO_2 system
- Cascade System

Schematic of a Centralised DX System



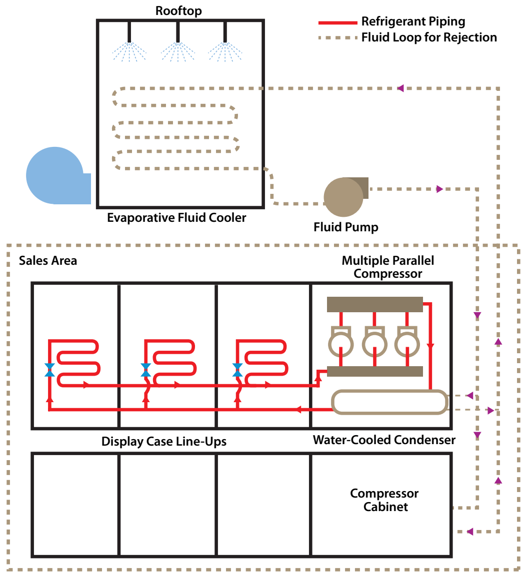
Source: International Energy Agency (IEA). 2003. "IEA Annex 26: Advanced Supermarket Refrigeration/ Heat Recovery Systems, Final Report Volume 1-Executive Summary"

Centralised Direct Expansion System

A large number of supermarkets use centralised DX systems to cool their display cases and walk-in refrigerators. In a DX system, the compressors are mounted together and share suction and discharge refrigeration lines that run throughout the store, feeding refrigerant to the cases and coolers. The compressors are located in a separate machine room, either in the back of the store or on its roof, to reduce noise and prevent customer access, while the condensers are usually air-cooled and therefore placed outside to reject heat.

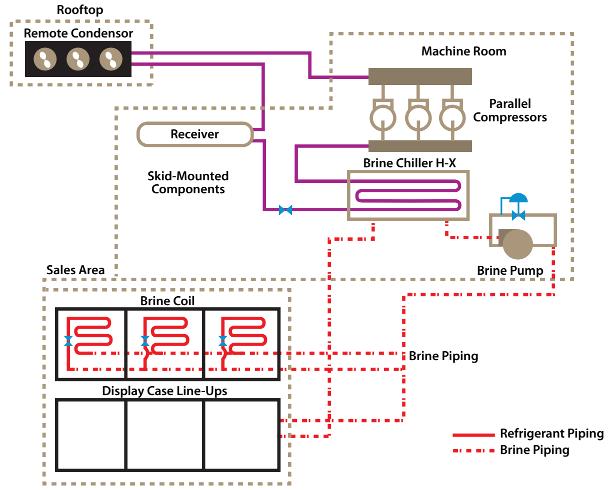
The multiple compressor racks operate at various suction pressures to support display cases operating at different temperatures. The hot gas from the compressors is piped to the condenser and converted to liquid. The liquid refrigerant is then piped to the receiver and distributed to the cases and coolers by

Schematic of a Distributed System



Source: International Energy Agency (IEA). 2003. "IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems, Final Report Volume 1-Executive Summary."

Schematic of a Secondary Loop System



Source: Southern California Edison and Foster-Miller, Inc. 2004. "Investigation of Secondary Loop Supermarket Refrigeration Systems." Report prepared for California Energy Commission, Public Interest Energy Research Program.

the liquid manifold. After cycling through the cases, the refrigerant returns to the suction manifold and the compressors. Supermarkets tend to have one DX system for low-temperature refrigeration (e.g., ice cream, frozen foods, etc.) and one or two DX systems for medium temperature refrigeration (e.g., meat, prepared foods, dairy, refrigerated drinks, etc.).

Distributed System

Unlike centralised direct expansion refrigeration systems, distributed systems use multiple smaller units that are located close to the display cases that they serve. For instance, compressors in a distributed system may be located on the roof above the cases, behind a nearby wall, or even on top of, or next to, the case in the sales area. The close proximity of the compressors to the cases and coolers allows the system to use less piping and a smaller refrigerant charge than traditional DX systems. This reduction in charge often results in a decrease in total refrigerant emissions.

Secondary Loop System

Secondary loop systems use a much smaller refrigerant charge than traditional direct expansion refrigeration systems, and hence have significantly decreased total refrigerant emissions. In secondary loop systems, two liquids are used: a primary refrigerant and a secondary fluid. The secondary fluid is cooled by the primary refrigerant in the machine room and then pumped throughout the store to remove heat from the display equipment. Secondary loop systems typically operate with two to four chiller systems depending on the temperatures needed for the display cases.

Transcritical CO_2 system

Refrigeration systems that use CO_2 as a primary refrigerant are commonly referred to as transcritical CO_2 systems. In transcritical CO_2 refrigeration systems CO_2 is the sole refrigerant, evaporating in the subcritical region and rejecting heat at temperatures above the critical point in a gas cooler instead of a condenser. In addition to having a simple concept, this system has considerable environmental benefits in terms of reducing HFC usage completely.

Cascade System

Cascade systems consist of two independent refrigeration systems that share a common cascade heat exchanger. Each of the two systems uses a different refrigerant that is most suitable for a specific temperature range. High temperature systems use high boiling point refrigerants such as R-404a, R-507a, R-134a, propane, butane, and ammonia, whereas low temperature systems use low boiling refrigerants such as R-744 (CO_2) and R-508B. The advantages of a cascade system include a reduction in the refrigerant charge and a reduced carbon footprint.

CASE STUDY-1

Auchan – City center mall, France

Name of the Store/facility:

Auchan – City center mall

Location:

Epinay sur-Seine, France

Contact information:

Name: Robert Kebby
Email: robert.kebby@honeywell.com
Designation: Global Marketing Manager – Commercial Refrigeration

Type of Facility:

New build Hypermarket, Area: 8000m^2
Refrigeration System type: Centralised packaged CO_2 / Solstice® N13 R-450A Cascade refrigeration system

Refrigerant Used:

The store was originally planned to use HFC-134a / pumped Carbon dioxide (CO_2) Cascade system where HFC-134a has a Global Warming Potential (GWP) of 1430. The decision was made to use Solstice® N13 (R-450A) - a lower GWP hydrofluoroolefins (HFO) blend from Honeywell - in place of HFC-134a in the store. Solstice® N13 (R-450A) is a Zeotropic blend of HFC-134a and HFO-1234ze (Solstice® ze). (42% HFC-134a / 58% R-1234ze). Solstice® N13 is A1 and has a GWP of 547: a near 62% reduction (883) in the GWP level of R134a with an expected, slight 3% Co-efficient of Performance (COP) improvement validated by independent party

Fig. 1 Auchan Hypermarket, Paris

The system in operation showed a slight improvement in performance, a lower condensing temperature than HFC-134a and reduced oil temperature – meaning less 'wear and tear' on the compressors / longer system life. Pressures, saturated temperatures and mass flow of the refrigerant Solstice® N13 was very similar to that of HFC-134a.

New System/Installation:

Groupe Auchan worked alongside its refrigeration partner Axima Refrigeration to develop a more environmentally conscious system for the Epinay sur-Seine store that combined the lower GWP and slightly better energy efficiency of a new refrigeration HFO blend named Solstice® N13 – and the proven performance of pumped CO_2. Solstice® N13 has a critical temperature of 104.4 °C and critical pressure of 38.2 bar.

The system uses Solstice® N13 in a liquefaction unit to

DESCRIPTION	MEDIUM TEMPERATURE	LOW TEMPERATURE
Refrigerant	Solstice® N13 (R-450A)	CO_2
Refrigerant charge	1,200 kg	Secondary MT circuit = 2,000 kg
LT Cascade circuit = 2,000 kg		
Refrigeration power	800 kW	105 kW
Consumption power	350 kW	21 kW
Regime (evap. /condensing temp)	-11°C / +45°C	-45°C / +35°C
Compressor type and manufacturer	Screw / Bitzer	Semi-Hermetic Piston / Bitzer
No. of compressors	6 in 2 packs	3 in 1 pack

Table 1 Medium and Low Temperature system details

All components used for the Solstice® N13 system were pre-approved by manufacturers to ensure consistent operation.

To support the yearly energy saving objectives of the project, the system includes a floating high pressure, a floating low pressure, as well as variable speed control on the compressors of the negative CO_2 rig, on the positive N13 compressor and on heat recovery units. Fig. 2 shows a schematic diagram of the refrigeration system.

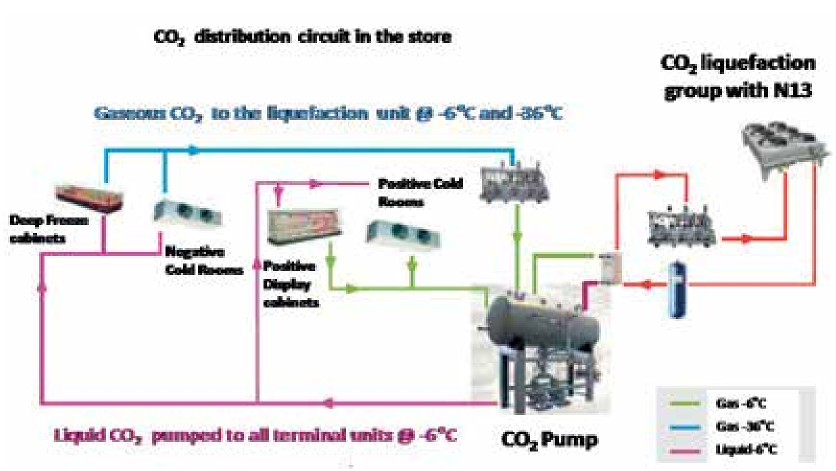


Fig. 2 Schematic Diagram of the Refrigeration System