Accounting

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Aluminium

Automotive

Aviation

Chemicals

Coal

Construction

Consulting Engineering

Electricity

Fertilizer

Finance and Insurance

Food and Drink

Information and Communications Technology

Iron and Steel

Oil and Gas

Railways

• Refrigeration

Road Transport

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Industry as a partner for sustainable development

Refrigeration

International Institute of Refrigeration/
Institut International du Froid (IIR/IIF)

Developed through a multi-stakeholder process facilitated by:

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Industry as a partner for sustainable development

Refrigeration

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Disclaimer

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Contents

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* ASHRAE: American Society of Heating, Refrigerating and Air-conditioning Engineers
** UNEP: United Nations Environment Programme
***AREA: Air-conditioning and Refrigeration European Association

Part 1: Foreword and executive summary

1.1 Foreword

The scope of refrigeration is far-reaching. It has applications embracing a huge range of fields we all encounter in our everyday lives. Refrigeration:

- reduces post-harvest losses, preserves foods and makes it possible to provide the safe, wholesome food all consumers have the right to expect;
- plays a key role in the healthcare sector, safe vaccine storage, cryosurgery and cryotherapy have been made possible by the advent of advanced refrigeration technology;
- promotes economic and social development in hot countries thanks to air-conditioning,
- is used in many industrial processes in the food, chemical, plastics and many other industries;
- heat pump technology can in fact be used for heating, heat pumps provide energy-efficient heating using renewable energy sources and waste heat;
- enables liquid natural gas, an environmentally friendly source of energy, to be transported and stored;
- enables superconductivity to be applied in the medical field and other important applications.

During the World Conference on Refrigeration for Development organised by the International Institute of Refrigeration (IIR) in 1986, Prof Gustav Lorentzen, one of refrigeration's greatest innovators, aptly described refrigeration as an 'invisible industry', adding that 'very few have an idea of the immense importance of refrigeration to our quality of life'. He highlighted the importance of refrigeration using three figures:

- annual production of compressors around 70 million units;
- annual investment in refrigerating equipment around USD100 billion;
- The value of refrigerated foodstuffs: USD500 billion to USD1,000 billion.

Today, annual investment in refrigerating equipment totals about USD200 billion and the value of refrigerated foodstuffs at least USD1,200 billion.

Unfortunately, these figures mask a huge gap, in terms of equipment, knowledge and training, between developed and developing countries. The sheer size of this gap has dictated the need to divide the key sections of this report into two parts in order to enhance its clarity: developed and developing countries. In some cases, specific issues affecting least developed countries are also addressed in this report.

The refrigeration sector expanded fast in developed countries after the Second World War. Cold chains were set up at that time. However, evolution of technologies and refrigerants was far less striking. It was only in 1987, when the Montreal Protocol became a driving force that the refrigeration sector began undergoing the profound changes that have given rise to today's broad range of new refrigerants and alternative technologies.

The aim of this report is to examine how the refrigeration sector fits into overall sustainable development and to what extent the aims set out in Agenda 21 are implemented within the refrigeration sector. It reviews progress achieved within the framework of Agenda 21, the key challenges to be met and actions to be implemented.

IIR invited to write this report by the United Nations Environment Programme (UNEP), is an intergovernmental organisation linking 61 member countries, accounting for 80% of the global population. Its mission is to promote progress and expansion of knowledge on refrigeration technology and all its applications on a worldwide scale. Annexe 4 provides a fuller description of the IIR.

In this report, the term 'refrigeration', when used alone, covers all refrigeration technologies (all refrigerating equipment including heat pumps) and all refrigeration applications, including air-conditioning.

1.2 Executive summary

1 Foreword

The scope of refrigeration is far-reaching. Refrigeration has applications embracing a huge range of fields we all encounter in our daily lives, particularly in the food, health and indoor environment fields. Refrigeration plays an essential role in sustainable development. However, there is a wide gap between industrialised and developing countries in terms of the availability of refrigerating equipment, knowledge and training.

2 The three dimensions of sustainable development

The goals that are defined by Agenda 21 cover three dimensions: social, economic and environmental.

The impact of the refrigeration and air-conditioning sector on the social dimension has numerous facets: In industrialised countries, the following aspects can be stressed:

- the refrigeration sector generates jobs, particularly in the industrial, commercial and service fields;
- by making it possible to preserve perishable foods at all stages from production to distribution, refrigeration vastly improves food supply to populations;
- thanks to improved food safety, to the development of new equipment and tools in the medical sector (such as MRI, cryosurgery and cryotherapy) this sector promotes health;
- air-conditioning makes it possible to create working environments with the desired temperature and humidity levels.

In developing countries, the impact of refrigeration, even if less marked than in industrialised countries, notably due to a lack of equipment and insufficient technology transfer, is nevertheless significant in the following fields:

- in the health field, the role of refrigeration in the immunisation of populations against infectious diseases thanks to refrigerators for vaccine storage can be highlighted and linked to increasing life expectancy. A striking example is the contribution of refrigeration to the eradication of poliomyelitis: in 2000, the number of cases of poliomyelitis occurring worldwide was less than 3,500, which is a 99% decrease in comparison with the 350,000 cases registered in 1988;
- Air-conditioning contributes to social and economic development in hot, humid regions;
- Refrigeration technologies have a vital role to play in many spheres, notably in the food field where reduction of post-harvest losses, improved food safety and hygiene, promotion of international trade, and improved food supply to the cities must be considered as top-priority objectives. The same is true in the health field where foodborne diseases caused by pathogenic micro-organisms must be prevented.

From an economic point of view, the following figures summarise and highlight refrigeration's role: today, there are 700 million to 1,000 million household refrigerators, 240 million air-conditioning units, 300,000,000 m^3 of cold-storage facilities operating worldwide.

A tentative table showing the annual sales of refrigeration, air-conditioning and heat-pump equipment (which had not been published previously) has been prepared by IIR and is provided in this report. It shows that total annual sales are around USD200 billion (average figures for 2000), this being roughly one third of the automobile industry's annual sales (excluding commercial vehicles).

However, the gap between developed and developing countries remains wide. A striking example is the number of domestic refrigerators manufactured annually. In 1996, only 33% of these appliances were for developing country markets, even though 80% of the global population lived in developing countries.

From an environmental viewpoint, refrigeration-related activities, in a sustainable developmental framework, have two main components: atmospheric emissions of certain refrigerant gases used in refrigerating plants and the CO_2 emitted in generating the energy required to operate these plants.

CFC emissions, and to a lesser extent HCFC emissions, exert ozone-depleting effects. These two refrigerant families also exert global-warming effects. HFCs were developed in order to replace CFCs and HCFCs and have no ozone-depleting potential. However, they also have direct global-warming effects. Via the Montreal Protocol that was adopted in 1987, 177 countries (as of 31 July 2001) committed themselves to measures designed to protect the ozone layer. This protocol calls for the gradual phase-out and total banning of CFCs followed by HCFCs, with a longer time frame for Article 5 (developing) countries.

The objective of the Kyoto Protocol, which has yet to be ratified by a sufficiently large number of countries in order to enter into force, is to reduce, in 39 developed countries, emissions of six greenhouse gases by at least 5% between 1990 and 2008 to 2012. HFCs are among these six greenhouse gases.

The improvement of the energy efficiency of refrigerating plants is a vital process, since it reduces the main contribution of the refrigeration sector to global warming, that is. indirect emissions of CO_2 induced by the production and the consumption of the energy needed to operate the refrigerating plants. Emissions of CO_2 are evaluated as being 80% of the total contribution of the refrigeration sector to global warming.

Other indirect impacts should be mentioned such as pollutants (SO_2, nitrous oxide) emissions related to components production and waste products associated with the destruction of refrigerants, oils and the equipment itself.

3 Means of implementation: Strategies, achievements and limits

Among refrigeration stakeholders' recent achievements within the framework of sustainable development, the most significant is the industry's landmark contribution to the implementation of the Montreal Protocol on the substances that deplete the ozone layer. The refrigeration industry, over a decade, has completely changed the refrigerants from CFCs and HCFCs to ozone-friendly substances to protect the global environment. This contributed to lowering the chlorine concentration in the stratosphere and reducing ozone layer depletion that threatened life on Earth.

Industries also took the opportunity of changing over to second generation and more energy-efficient technology over the last ten years. Refrigeration is one of the unique sectors that witnessed complete technology overhaul that was environmentally friendly. This has been made possible through co-operation between developing and developed countries through the Montreal Protocol, through funding of new technology by the Multilateral Fund, and through international co-operation between organisations like IIR, UNDP, UNEP, UNIDO, the World Bank, WHO and many others.

The industry is now gearing up to face another environmental challenge of the next millennium: global warming. In order to combat global warming the main strategies are reductions in energy consumption, reductions in refrigerant emissions, research and development on new refrigerants and not-in-kind (NIK) technologies, new developments in the cold chain and new developments in air-conditioning and heating systems.

The environmental benefits of the strategies implemented have to be evaluated using an objective measure of environmental merit. This measure must be based on a 'true life cycle' assessment: it must take into account the overall environmental impact throughout the life cycle of the refrigeration or air-conditioning system. Thus, concerning the greenhouse effect, Life Cycle Climate Performance (LCCP), which is a measure of total greenhouse emissions ('from cradle to grave'), is no doubt the most objective criterion.

In industrialised countries, initiatives aimed at reducing energy consumption have led to measures that cover all phases in the life cycle of refrigerating equipment:

- during the design phase, features enabling refrigerating system and component performance to be enhanced;
- during installation and commissioning, application of stringent plant acceptance procedures taking into account measurement of the energy consumption of a plant;
- during maintenance and servicing, application of stringent operating procedures.

Standardisation provides a means of obtaining objective benchmark performances of equipment. Quality procedures are increasingly including training followed by proficiency-based certification of technicians and installers. This process needs to be more widely applied and the harmonisation of standards also needs to be expanded.

Several figures provide striking evidence of achievements in the field of energy savings. The coefficients of performance (COPs) of refrigerating equipment are constantly being enhanced, but much remains to be done in this field.

Emissions-reducing initiatives are applied throughout the life cycle of a plant:

- during the design and manufacturing phases, manufacturers' Research and Development (R&D) departments focus on optimising plant tightness and reducing the refrigerant charge and the length of piping used in the circuits in order to reduce emissions and to facilitate maintenance and servicing during plant operation;
- during installation of the plant, stringent qualitative procedures are applied to an increasing extent, particularly with regard to containment of the refrigerant;
- during maintenance and servicing, the emphasis is on plant tightness, thanks to regular controls and systematic refrigerant recovery whenever maintenance or repairs are performed. Thanks to training of installers, owners and operators in the handling of new refrigerants and raising of their awareness of the environmental dimension, considerable progress has been achieved, but much remains to be done;
- During disposal of equipment, recovery of the refrigerant, and recycling or reclaiming whenever possible (or destruction if this is not possible).

In terms of achievements, the impact of CFCs, HCFCs and HFCs on ozone depletion and global warming has` decreased in a striking manner, as demonstrated by several indicators: decreased production of these refrigerants (weighted according to their respective impacts on these two phenomena) starting in

1988 and 1989, and the diminishing percentage of these refrigerants in total greenhouse-gas emissions.

The refrigeration sector's initiatives in the field of NIK technologies and alternative refrigerants (new HFC refrigerants and alternative refrigerants to fluorocarbons) are also an important breakthrough since they lead to reduced adverse effects on the environment.

Among non-HFC refrigerants developed to replace fluorocarbon refrigerants, the focus is above all on ammonia, hydrocarbons and carbon dioxide (CO_2).

In the field of NIK technologies that provide suitable alternatives to vapour compression, key research focuses include advanced absorption and adsorption technology, solar refrigeration, desiccant cooling, air cycles, the Stirling cycle, thermoelectric cooling, etc.

New developments in the cold chain can be highlighted: increasing importance is now attached to cleanability in order to prevent contamination of foods, flexibility of equipment, regulation of ambient conditions, traceability of foods, consumer information and interface management.

New developments in air-conditioning and heating systems can also be stressed. Indoor air quality (IAQ) and its relationship with occupant comfort, health and productivity has received increased attention in recent years. New developments related to ventilation, source control, humidity management and filtration/air cleaning have been achieved. Energy efficiency is becoming increasingly important within the sustainable building approach, and several developments such as 'low-temperature heating' and 'high-temperature cooling' are taking place. Developing countries joined the industrialised countries in the last decade to phase-out ozone depleting substances. Among the several positive activities that have been carried out to respond to the challenges of the sustainable development are:

- The financial and technical resources that were made available through the Multilateral Fund of the Montreal Protocol were leveraged to transfer ozone-friendly technologies to the developing countries. Of USD1.3 billion spent by the fund so far, nearly 60% is used for refrigeration sector;
- Through the collaborative efforts like UNEP's OzonAction Programme and IIR's world wide networks of experts, Refrigerant Management Plans (RMPs) have been set up in many countries. Each RMP involves an initial diagnosis phase that is an essential prerequisite to actions and training initiatives designed to achieve sustainable development; implementation of training programmes addressing refrigeration technicians' and custom officers' needs.

However, the development of the refrigeration sector in developing countries has limits that should be emphasised:

- education for refrigeration technicians in good practices and installers is not available to all;
- insufficient maintenance, causing high leakage of refrigerant and other plant anomalies;
- regeneration and refrigerant destruction plants are too few and scattered.

A per-sector approach (detailed in Annexe 3) (domestic refrigeration, commercial refrigeration, cold storage, industrial refrigeration, unitary air-conditioning, water chillers, transport, mobile air-conditioning) makes it possible to identify the actions implemented, in each sector, in order to meet the defined objectives: emissions reductions, energy-efficiency measures, development of new technologies and new refrigerants, retroconversion of plants in order to use new refrigerants.

4 Challenges

Sustainable development-driven challenges confronting the refrigeration sector in years to come will be numerous; they include the addressing of issues that require sustainable solutions (covered in Part 2) and the expanding of actions that have already been implemented (focused on in Part 3).

Industrialised countries

Most specialists are of the opinion that vapour-compression systems are likely to be the dominating trend over the next 20 years. The challenge to be met is to develop vapour-compression systems that are environmentally friendly, energy-efficient, robust and sustainable, cost-effective and safe for users. Bearing in mind these challenges, here are some objective challenges for the next 20 years, with 2000 as baseline year:

- to reduce energy consumption by 30% to 50%,
- to halve refrigerant leakage,
- to improve LCCP (Life Cycle Climate Performance) by 30% to 50%,
- to reduce the refrigerant charge by 30% to 50%.

However, defining quantitative objectives is useful only if reliable benchmarks are defined and validated. Some technologies and applications using vapour-compression systems have an important role to play in order to meet these objectives, for example:

- sustainable building. Sustainable building can only be achieved if energy efficiency is taken into account right from the outset of the building design process;
- mobile air-conditioning. It is forecast that in 2010 emissions of refrigerants from vehicle air-conditioning equipment in Europe will represent about 50% of all refrigerant emissions. In order to reduce CO_2 emissions, means of reducing fuel consumption related to air-conditioning should also be given serious consideration. This area represents one of the biggest future challenges in the sector under consideration;
- heat pumps are an efficient tool to reduce CO_2 emissions. The potential for reducing CO_2 emissions assuming a 30% share in the building sector using technology presently (1997) available is about 6% of the total worldwide CO_2 emissions of 22,000 mt/y. With future technologies up to 16% seem possible in residential, commercial and industrial applications.

This report also explores promising refrigeration technologies and applications using non-vapour-compression technology that will undoubtedly also play important roles in ensuring sustainable development.

- absorption and adsorption cooling systems, which quite often are fuel-fired, are a practical means of providing both commercial and industrial cooling without imposing a major drain on a developing electric infrastructure and therefore a major drain on the limited developmental capital available to most developing countries. Absorption-based air-conditioning, in the form of large absorption chillers for major commercial-building or industrial applications, is the most widespread application of these technologies today. Low energy efficiency is still the major drawback of this technology. Further development and simplifications are needed in order to enable this technology to be more widely applied;
- solar refrigeration is technology that should be given priority when choosing sustainable development options in developing countries. The growing demand for ice for the conservation and transportation of perishable products, the development of cold storage for food storage, the freezing of fresh and cooked products, space air-conditioning, among other refrigeration applications, are only a sample of the potential applications of this technology.

The establishment of the infrastructure required for the production of solar refrigeration units and the setting up of educational programmes and training in the operation and maintenance of solar plants as well as in the design and instrumentation aspects are priority actions;

- desiccant technology includes a broad spectrum of systems providing cooling, dehumidification, and ventilation in order to control the quality of the indoor environment in the industrial and commercial sectors. But many production and technical issues still have to be addressed;
- trigeneration (combined cooling, heat and power) has considerable benefits from an energy standpoint. It makes it possible to totally or partially utilise the heat rejected to ambient as waste heat generated during electrical power production and use part of it in refrigerating applications. The development of high-performance absorption plants will enhance the benefits of trigeneration plants;
- cryogenics is a field encompassing all refrigeration technology used to achieve temperatures below 120K (-150°C) down to 4.2K, and has paved the way to a huge range of sustainable-development-promoting applications. Superconductivity is one of the most promising cryogenic technologies. Cryomedicine and its cryosurgical component are making and will continue to make a valuable contribution to sustainable development;
- many other technologies that will promote sustainable development are being developed or are the focus of research projects, notably air-cycle and Stirling-cycle refrigeration, and thermoelectric cooling;

The priority actions to implement in developing countries are:

- reduction of post-harvest losses. Perishable foodstuffs represent 31% of the total volume of foods consumed in developing countries. In developing countries, only one-fifth of perishable foodstuffs is refrigerated, meaning that high losses are incurred following harvest, slaughter, fishing, milking, then during transportation and finally during sale. Refrigeration is one of the most effective tools enabling loss reduction to be achieved. However, economic aspects should be dealt with;
- development of cold chains. Ensuring both food quality and safety to five billion inhabitants of developing countries thanks to the setting up of effective cold chains is a major challenge for the refrigeration sector;
- technology transfer. One avenue for enhancing developing country initiatives is through the sharing of developed-country industrial technology, know-how and information, including standards and certification programmes;
- strengthening of structures. It is important to define a ministry in charge of handling refrigeration policy at national level. Trade organisations and associations play an indispensable role in federating refrigeration stakeholders. A state-approved, neutral, authoritative national refrigeration association is also necessary. An interministerial and interprofessional organisation such as a national refrigeration council can play an important role in defining refrigeration plans that include inventories of existing equipment and a long-term developmental plan;
- data collection. A precise inventory of the needs of developing countries is an essential preliminary step in order to facilitate the design of focused programmes and activities in the various fields concerned: structures, technologies, training.

In industrialised countries as well as in developing countries, education is the cornerstone of development in all aspects of refrigeration: design, installation, running and maintenance of refrigerating equipment.

In conclusion, the major challenges to be met by the refrigeration sector can be summarised as follows.

Developed countries:

- to address the environmental impact of refrigerating systems by using the LCCP concept and standardising its calculation and to promote application of this concept among all stakeholders;
- to consider the whole system and not just the refrigerant;
- to design equipment with a reduced refrigerating capacity as far as practicable, for instance by attaching great importance to well-calculated and efficient insulation;
- to bear in mind that the primary goal of a refrigerating plant is to make it possible to supply high-quality foodstuffs or to ensure high indoor air quality;
- to give top priority to proper maintenance: such practice reduces leakage and improves energy efficiency;
- to recover, recycle, regenerate or destroy, following standardised procedures, refrigerants, lubricants and materials used in refrigerating plants;
- to further improve energy efficiency and performance;
- to use the capabilities of heat-pump technologies for reducing energy consumption by utilising renewable energy sources and waste heat.

Developing countries:

- to make refrigeration available in the developing countries, particularly in the least developed countries for food preservation, industry and air-conditioning purposes;
- to set as a rule that developing countries have the same rights to refrigeration technology as developed countries;
- to take advantage of current technological achievements in order to enable 'leap-frogging' to environmentally friendly, reliable, robust and cost-effective practices through promotion of technology transfer and increased training and education;
- to avoid dumping old polluting, high-energy-consuming technology in developing countries, even if initial costs appear to be attractively low.

Part 2: The three dimensions of sustainable development

2.1 Introduction

Agenda 21 was adopted by more than 178 countries at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, on 3 to 14 June 1992. It addresses the pressing problems of today and aims at preparing the world for the challenges of the 21st century thanks to sustainable-development strategy.

Sustainable development has been defined as the fulfilment of current needs without compromising the ability of future generations to fulfil their own needs. The goals that are defined by Agenda 21 cover 3 dimensions: social, economic and environmental.

The refrigeration sector is actively involved in many issues inherent in each of these dimensions. This report highlights key refrigeration sector actions with respect to each dimension. In this report, we point out the most significant ones for each dimension.

A distinction has been made between developing countries and industrialised (or 'developed') countries due to the gap in terms of equipment and knowledge. In some cases, specific issues affecting 'least developed countries' have been addressed. The list of developing countries is provided in Annexe 2.

Before examining the challenges to be met by the refrigeration sector, it is useful to identify the stakeholders in this sector.

2.2 Refrigeration stakeholders: Categories

In order to gain an insight into the social and economic impacts of the refrigeration sector, it is essential to consider refrigeration stakeholder categories.

There are four main categories of refrigeration stakeholders.

1. Manufacturers of refrigerating equipment and refrigerants

Stakeholders falling into this category increasingly tend to be multinational corporations.

- refrigerant manufacturers (which manufacture refrigerants, secondary refrigerants, lubricants, etc.) are very large corporations. Refrigerants are manufactured by 15 to 20 very large firms. Firms based in developed countries have combined forces within AFEAS (Alternative Fluorocarbon Environmental Acceptability Study) in order to conduct research and to provide global figures on production and consumption;
- because of the very costly infrastructures required, liquefied gas, and particularly liquefied natural gas, manufacturers tend to be multinational corporations;
- component (compressors, exchangers) manufacturers tend to be multinationals with manufacturing plants in various parts of the world but can also be small and medium-sized enterprises (SMEs);
- assemblers of components used to manufacture refrigerators and air-conditioning equipment also tend to be large corporations, but SMEs are also involved;
- assemblers of more specialised equipment (refrigerated display cabinets, milk chillers, insulated refrigerated-vehicle bodies, vending machines) may be multinationals, but tend to be SMEs. They cover a broad company-size range.

2. Refrigeration contractors

This group comprises many smaller stakeholders. These are generally small family businesses employing up to 20 persons. Refrigeration contractors play a vital role in ensuring sustainable development: they are responsible for the correct installation of plant, including initial reception following a suitable procedure, for maintenance according to good practice and for disposal at the end of the plant life cycle, again in compliance with good practice. These measures reduce refrigerant emissions and energy consumption. Contractors also play a key role as end-user advisers.

3. Users

Users comprise a broad range of economic players including the following among many others.

3.1 The food sector (from producer to consumer):

- users of agricultural equipment, milk chillers, dairy-farm cold rooms;
- fishermen, cold rooms on ships, ice boxes;
- food processors, dairy, meat, fish, fruit and vegetable processing, bread and pastry manufacturing, the canning industry, winemaking, breweries, fruit-juice manufacturing, freeze-drying plants, etc;
- food cold-storage operators, refrigerated storage facilities used for chilled and frozen foods, fruit-packing stations, abattoirs, etc;
- ice manufacturers;
- refrigerated-transport operators, road, rail, marine, air and intermodal transport;
- small-scale commercial equipment, small businesses (butcheries, bakeries, fish shops) and supermarkets (convenience stores, supermarkets, hypermarkets), vending machines;
- restaurants, cold rooms, display cabinets, wine-storage equipment, beverage chillers;
- users of domestic appliances, domestic refrigerators and freezers, wine-storage appliances.

3.2 In the food-processing, the chemical, and the mechanical-engineering industries:

- processing industries;
- the mechanical-engineering industry (hooping and dipping of parts, surface treatment);
- the rubber industry (deburring of parts);
- the plastics industry (cooling of moulds, hydraulic presses and extruded parts);
- the building industry and public works sector (ground stabilisation using freezing, freezing of concrete);
- waste treatment (solvent-vapour collection, purification of aqueous waste using crystallisation or freezing processes).

3.3 In the health and biological sectors:

- vaccine storage;
- air-conditioning in hospitals (operating suites, patients' rooms);
- cryosurgery and cryotherapy;
- conservation of sperm, gametes and embryos (endangered species);
- blood conservation;
- organ conservation.

3.4 In the indoor-air quality field:

- air-conditioning in the tertiary (offices, computer rooms) and residential sectors,
- air-conditioning of industrial premises,
- mobile air-conditioning (vehicles, ships, planes),
- clean rooms.

3.5 In the leisure sector:

- skating rinks,
- artificial snow.

4. Other players in the refrigeration sector

These players have key roles in the implementation of measures ensuring sustainable development, in design, in training and in the promotion of enhanced awareness of sustainable development.

- refrigerating equipment and installation designers. Designers must provide owners of installations with sound advice in order to ensure that sustainable technology (that is reliable, robust, energy-efficient and

environmentally friendly) is selected and installed;
- researchers. A great deal of research remains to be performed on traditional vapour-compression systems, refrigerants and non-vapour-compression technologies;
- university professors and teachers. The training of young people is primordial. Priority must be given to the implementation of training programmes in developing countries;
- international organisations (FAO, UNDP, UNEP, UNFCCC, UNICEF, UNIDO, World Bank, WHO);
- non-governmental organisations (NGOs), especially environmental organisations, have an undeniable influence: they considerably raise awareness of the need for sustainable development.
- ministerial departments and agencies handling the preparation of regulations and responsible for controlling their application;
- standardisation organisations in charge of developing standards and publishing good practice manuals;
- testing laboratories and certification organisations that test, classify, label, certify equipment and personnel, and promote transparency from user and manufacturer viewpoints;
- trade organisations and associations that play an important role in examining industry concerns and spreading knowledge among their members.

2.3 The social dimension

2.3.1 Industrialised countries

The impact of the refrigeration and air-conditioning sector on the social dimension has numerous facets:

- this sector generates jobs, particularly in the industrial, commercial and service fields;
- by making it possible to preserve perishable foods at all stages from production to distribution, refrigeration vastly improves food supply to populations;
- thanks to improved food safety, this sector promotes health;
- air-conditioning makes it possible to create working environments with the desired temperature and humidity levels.

2.3.1.1 Refrigeration and employment

In industrialised countries, the number of jobs in the refrigeration and air-conditioning sectors can be roughly calculated as follows, but differs according to the branch examined (equipment manufacturers, installers and operators, end-user industries):

- manufacturers of refrigerating equipment and components. This sector is not labour-intensive, but generates a number of jobs that is by no means negligible: roughly one in 1,000 jobs in industrialised countries. It is a sector characterised by:
  - slow growth in terms of job creation,
  - highly skilled personnel;

- Installers and maintenance firms which are experiencing significant growth in terms of job creation. In the United States, according to the Department of Labor, heating, air-conditioning and refrigeration mechanics and installers held about 286,000 jobs in 1998; more than half of these worked for cooling and heating contractors. All United States technicians who purchase or work with refrigerants must be certified in their proper handling. To become certified to purchase and handle refrigerants, technicians must pass a written examination specific to the type of work in which they specialise. Exams are administered by organisations approved by the Environmental Protection Agency. The United States industry has recently announced the adoption of one standard for certification of experienced technicians: the Air-conditioning Excellence Program, which is offered through North American Technician Excellence (NATE). In the United States, employment of heating, air-conditioning and refrigeration mechanics and installers is expected to increase about as fast as the average (that is an increase of 10% to 20%) for all occupations up to and including 2008.

In Europe, a survey conducted by AREA (Air-conditioning and Refrigeration European Association) among national refrigeration associations in 12 countries (Belgium, Denmark, Finland, France, Germany, Greece, Hungary, the Netherlands, Norway, Spain, Sweden and the United Kingdom) involving 312 million inhabitants provided the following information:

- number of specialised firms, 5,000;
- personnel employed by these firms, 73,000;
- total turnover: €20 billion.

- End-user industries:
  - these industries have a strong impact on job creation thanks to the large number and wide variety of refrigeration users on an industrial scale,
  - growth in terms of job creation and enhanced skills varies greatly according to the sector considered.

2.3.1.2 Refrigeration and food

In the past, people cultivated the foods they ate. The number of farmers has gradually decreased: in developed countries today, less than 5% of the population is involved in agriculture. Moreover, land, sea and air transport have expanded, making it possible to transport foodstuffs over increasingly large distances. Cold chains, vital to the ensuring of the safety, organoleptic quality and market value of perishable foodstuffs, have been set up in this context of long-distance transport. Therefore refrigeration plays an indispensable role in the food supply chain of developed countries.

Starting with production (fruit and vegetable harvesting, slaughtering of animals, fish harvesting and milking) perishable foods are chilled or quick-frozen. Roughly 75% of the foods we consume have been processed. In food processing plants, refrigeration is a vital element in the manufacturing process. Most manufacturing processes use successive heating and cooling cycles.

Following manufacturing, foods are stored in cold stores or cold rooms several times before reaching the consumer (in the manufacturer's premises then at supermarket distribution-hub level or retail-store cold-room levels). Foods are also transported several times. Firstly in long-distance vehicles and afterwards in local-delivery vehicles. A given food or ingredient is considered to be transported 2.5 times. Certain exported foods are transported in marine or air-freight containers. At retail outlets, perishable foods are then displayed in refrigerated display cabinets.

It is estimated that in developed countries approximately 70% of all foods are chilled or quick-frozen when produced and that about 50% of all food sold (in terms of value) requires refrigerated display at retail level. Extrapolation of national figures concerning several countries implies that the value of chilled and quick-frozen foods in the housewife's shopping basket is roughly USD1,000 per capita per year. There are 1.2 billion people living in developed countries; this means that annual purchases of chilled and quick-frozen foods in these countries total around USD1,200 billion.

Providing the consumer with wholesome, safe food is a major challenge to be met by governments and food-industry stakeholders. In this context, the setting up of tailored cold chains is a vital tool enabling overall policy to be implemented.

2.3.1.3 Refrigeration and health

Refrigeration inhibits the development of bacteria and toxic pathogens, and therefore prevents foodborne diseases. Consumers and the media attach a great deal of importance to foodborne diseases in particular and health hazards in general: food safety is a major issue in today's society. The following aspects need to be given full consideration:

- certain bacteria are able to develop at low temperatures (0-3°C). *Listeria monocytogenes* and *Yersinia enterocolitica* fall into this category;
- certain foodstuffs are now more likely to transmit foodborne diseases than previously: this is because less additives (or no additives at all) are used, sell-by dates are longer and prepared foods are cooked at lower temperatures in order to improve their sensorial properties;
- domestic refrigerators provide an excellent means of preserving perishables. However surveys have demonstrated that in most households, refrigerators are operated at average temperatures that are higher than those recommended for perishable foods. Insufficient user awareness seems to be the cause of this situation: users do not keep their refrigerator settings at a sufficiently low level. The consumer needs to be provided with better information;
- improving the cold chain from producer to consumer is one of the refrigeration industry's prime objectives.

Cryosurgery is a technique that is easy to use, relatively inexpensive and requires only fairly basic equipment.

2.3.1.4 Comfort cooling

People feel comfortable within a certain temperature and humidity range and need a specific quantity of fresh air for breathing. The required temperature and humidity range is much smaller than the range for survival, especially when people have to perform demanding manual or mental work. This is why social development, followed by technological and industrial development, started in temperate climate areas and expanded in cold climates. Hot areas and zones with high air humidity have developed economically since the introduction of air-conditioning technology over the past five to six decades.

The oldest example is the 'sun-belt' in the southern United States, followed by South Japan and south-east Asia, encompassing areas such as Singapore, Hong Kong, South China, Indonesia, etc. The same situation then arose in central and southern America, in India, in the Arabic area and now in Africa. Air-conditioning is therefore an important tool for economic and social development in hot and humid areas of the world. Most major developing countries are in these areas of the world.

High air quality in a space can be achieved by decreasing the pollution sources, by increasing the ventilation rate, or by cleaning the air. Several independent studies document that the quality of indoor air has a significant and positive influence on the productivity of office workers [Fanger, 2000]. However, air-conditioning is not only important for human health and human effectiveness, but also has a major influence in the industrial area, in particular in new high-tech branches, including the whole information technology (IT) branch.

2.3.2 Developing countries

The impact of refrigeration is less marked in developing countries due notably to a lack of equipment and insufficient technology transfer. In these countries, the refrigeration sector has a vital role to play in the food sector and the health sphere. In the least developed countries (LDCs), the refrigeration sector must become a major driver of social and economic development. However, the lack of financial resources is the main obstacle to overcome.

2.3.2.1 Refrigeration and employment

It is difficult to obtain reliable figures on the number of jobs in the refrigeration sector. The figures supplied by certain countries do not take into account the informal sector that probably involves many technicians in these countries. Technicians trained in refrigeration-plant procedures tend to be scarce. Few refrigeration operators are certified, particularly in countries characterised by large informal sectors.

Benin is a case in point. The population of Benin was 6.2 million in 1999 and the number of refrigeration technicians has been evaluated as being 700, of whom only about 100 are certified refrigeration technicians [UNEP, 2000]. Other African countries are encountering similar situations.

The situation is likely to improve in these countries, however, thanks to rapid expansion of the refrigeration sector. Training needs to be expanded in order to train refrigeration technicians and raise their levels of qualification. Raising awareness concerning the benefits of refrigeration at governmental, industrial and end-user levels is also important.

2.3.2.2 Refrigeration and food

Refrigeration technologies have a vital role to play in developing countries. The four main stakes for refrigeration sectors can be summarised as follows [Billiard, 1999].

- Reduction of post-harvest losses

Global agricultural and fish production (see figure 1 in Annexe 1) reached a level of 5,165 million tonnes in 1997 (FAO, 1998). Of the total amount of cereals produced, it is estimated that 50% of the quantity is destined for human consumption and the rest is for animal feed, seed production, processing in non-food applications, or is lost [Alexandratos, 1995]. If the fact that 25% of root and tubercle production, 50% of fruit and vegetables and 100% of very perishable foods (meat, fish and milk) require refrigeration is considered [Jul, 1985], this represents 31% of all agricultural and fish production, that is 1,600 million tonnes that need to be refrigerated in order to reduce the considerable losses taking place at present. In reality, only 350 million tonnes are refrigerated [Mattarolo, 1990]. Kaminsky [1995] estimated total losses worldwide as being 30% of primary production in general and 40% in the case of fruit and vegetables. Kaminsky [1995] also considers that about 300 million tonnes of produce are lost annually through non-use of refrigeration, above all in developing countries.

These figures clearly demonstrate that the policy adopted so far is to keep raising production by using more and more land for cultivation purposes (more often than not to the detriment of forestry), and by increasing yields thanks to the development of new varieties of produce and the use of irrigation, fertilizers and pesticides, etc. Unfortunately, this promotion of raised production has not gone hand-in-hand with the implementation of means of reducing post-harvest losses [Okezie, 1998]. It has to be stressed that it is economically sounder to implement better preservation of foodstuffs that have been produced thanks to considerable efforts in terms of growers'/farmers' time and costly irrigation, fertilizers and pesticides, etc., rather than to accept losses as inevitable.

Avoiding waste is part and parcel of sustainable development. This is where refrigeration techniques play a key role. Many consider that ancient methods (salting, drying, storage in the ground, etc.) should be promoted in developing countries. These techniques alter the original qualities of the foodstuff and have not been proven to be effective. Other specialists consider that inhabitants of developing countries have the same right to food preservation technologies (including refrigeration technology in particular) as those that have been put to the test and proved successful in developed countries [Cleland, 1998]; [Djiako, 1999].

- Improved food safety and hygiene

Foods of animal origin are highly perishable, particularly in countries with hot climates where bacterial growth is rapid. The use of refrigeration substantially reduces microbial growth in foods and thus reduces both food losses and the number of cases of foodborne diseases. It is difficult to determine the number of persons affected by foodborne diseases worldwide, or the cost to society in terms of working days lost and medical care, but intestinal disorders are clearly endemic in developing countries and are at least partially directly related to insufficient food hygiene. Such illnesses are often debilitating enough to make sufferers vulnerable to other diseases such as tuberculosis.

To cite just one example, FAO and WHO [1992] figures indicate that 70% of the 1.5 billion cases of diarrhoea in children under five years of age (leading to three million deaths per year) are caused by insufficient food hygiene. It is plain to see that refrigeration would have a highly beneficial impact on food safety, if applied.

Meat consumption is rising in developing countries and this is good news, given that meat provides certain amino acids that are vital to growth and the sustaining of life; these amino acids are not present in foods of plant origin. In China, for instance, consumption of products of animal origin has risen from 481 kJ per capita/day in 1970 to 1445 kJ per capita/day in 1992 [FAO, 1994]. It is important not to waste these nutritionally valuable foods; implementation of refrigeration technologies avoids waste.

• Promotion of international exchange

Marine refrigerated transported freight is growing at a rate of 5% per year [Stera, 1999]. Forty-three million tonnes of freight were transported in 1993, and this figure will be approximately 50 million tonnes in 2001. International trade in refrigerated produce provides a means of exporting perishable very high-added-value produce and facilitates food imports.

Concerning exports, tropical produce – including fruit such as pineapples, mangoes, avocados and papaya, as well as vegetables, fish and cut flowers much of which come from developing countries – is increasingly popular in developed countries and is a source of revenue for the exporting countries. Provided that suitable logistics and a commercial framework are implemented and suitable quality standards adopted, such produce can bring in hard currency both for growers and the country itself, thus creating jobs. However, tropical produce is particularly perishable and therefore requires a flawless cold chain. It is also important to note that the production and storage technologies applied to this export produce can also form the basis for development of applications for local non-exported produce.

Imports of refrigerated foodstuffs can also play an important economic role. Even though governments may understandably consider that a country's self-sufficiency in terms of food is desirable from a security point of view, such policy is not always rational in that any one country is not always potentially capable of producing all types of foods. It is often more profitable to export produce that can be grown inexpensively in a given country (thanks to its soil type and climate) and to buy products that can not be economically produced in this country. Food prices are tending to drop and this reinforces the soundness of such an approach. These days, for instance, many developing countries import frozen fish products and meat.

• Improving food supply to the cities

Urban populations have exploded in developing countries, rising from 17% of the total population in 1950 to 35% in 1990 and, according to UN estimates, will have grown to 54% in 2020. This represents a 12-fold increase from 295 million inhabitants in 1950 to 3,580 million inhabitants in 2020 [United Nations, 1998].

In order to meet the new urban nutritional needs, greater and greater quantities of food, including perishable food, will have to be transported over longer distances and the duration of transport will also increase considerably. Refrigeration limits losses due to handling, shocks, temperature rises and the duration of transport. Refrigerated storage at the production site, followed by refrigerated transport, avoids temperature rises and preserves the quality of the produce.

2.3.2.2.1 Refrigeration and food in the least developed countries

In the least developed countries, agriculture plays a vital role. It is in most cases subsistence agriculture that primarily provides food for the farmer's family. Over 60% of jobs in the least developed countries are in the agricultural sector, compared with fewer than 2% in developed countries such as the United States and Canada. One reason this subsistence agriculture is practiced is the lack of technology.

Refrigeration is a technology that can contribute to the development of commercial agriculture, that is agriculture undertaken primarily to generate products for sale from the farm.

2.3.2.3 Refrigeration and health

Over the past 40 years, life expectancy has risen to a greater extent in developing than in developed countries. Table A illustrates this trend. Progress achieved in terms of life expectancy is directly related to progress in the medical field and to improved hygiene. However, the gap between life expectancy at birth in developed and developing countries is still very wide.

The contribution of refrigeration to sustainable health policy is undeniable.

- foodborne diseases caused by food contaminated with pathogenic micro-organisms are widespread and the cost to society is high. It is up to governments to ensure that the food supplied within their countries is wholesome and that balanced diets can be achieved. Perishable foods are high-risk foods because bacteria, including pathogenic bacteria, and toxins, tend to develop in them. In order to prevent multiplication of these bacteria, fresh foods should be consumed rapidly (this being increasingly difficult in large cities due to time delivery considerations), kept refrigerated, or cooked longer. Cooking destroys pathogenic bacteria, but in many regions where wood is the only source of thermal energy, resources are becoming scarce;
- refrigeration also makes it possible to store vaccines. Vaccines must be stored within a temperature range of 0-8°C, a temperature range that can be achieved only by using refrigerators. Several technologies are available. The most commonly used is the vapour-compression cycle using a refrigerant such as HFC134a, a non-ozone-depleting substance. This type of system has a major drawback: it requires electrical energy and is thus vulnerable to power cuts. Photovoltaic refrigerators are also used for vaccine storage. The World Health Organisation (WHO) encourages the use of these refrigerators for its Expanded Programme of Immunisation (EPI) and has published the first specifications for solar medical-use refrigerators [WHO/UNICEF,

Table A: Life expectancy at birth (UN, 1998)

Period	More developed regions (years)	Less developed regions (years)	Least developed regions (years)
1950 to 1955	66.5	40.9	35.5
1990 to 1995	74.2	62.1	49.7
Gain	7.7	21.2	14.2

1997]. At the end of 1985 there were about 600 solar refrigerators installed worldwide. By the beginning of 1993, the number of systems in operation had risen to about 3,700, with half of these in Africa [IIR, 1999]. At the end of 1997, total installed photovoltaic solar devices were estimated at about 7,000.

However, few solar refrigerators are in use. In India, for instance, of the 40,000 refrigerators and ice chests used to store vaccines, only 32 use solar energy [WHO, 1997]. However, in recent years, the trend is towards rising use. A particularly striking example is the role played by refrigeration in the eradication of poliomyelitis. In 2000, the number of cases of poliomyelitis occurring worldwide was less than 3,500, which is a 99% decrease in comparison with the 350,000 cases registered in 1988 [WHO, 2001]. Therefore refrigeration, through a reliable cold chain for vaccines and thanks to the extreme efficacy of WHO, fully participated in this achievement.

2.4 The economic dimension

The social and economic dimensions of sustainable development are closely linked: the social benefits and jobs generated by the refrigeration sector have positive spin-offs in the economy as a whole. The same is true in the food and health spheres. These aspects are dealt with in the section devoted to the social dimension and are not reiterated in this section.

2.4.1 Worldwide

Table B on p22 provides an overview of refrigeration and air-conditioning worldwide. No such table showing the annual sales figures for refrigeration, air-conditioning and heat-pump equipment has been published to date. This should be considered as a tentative table that needs to be regularly improved and updated.

According to these estimates, total annual sales of refrigeration, air-conditioning and heat-pump equipment amount to almost USD200 billion, this being roughly one-third of the automobile industry's annual sales.

2.4.2 Developing countries

It is difficult to characterise the refrigerating equipment used in developing countries. Data are unfortunately extremely fragmentary and make it difficult to provide an accurate picture of the overall situation in developing countries. Certain data are available concerning two links in the cold chain in developing countries: cold storage and domestic refrigeration.

Billiard [1999] evaluates the refrigerated storage capacity of developing countries as being 36 to 45 million m3, this being eight litres per inhabitant (compared with 220 litres per inhabitant in developed countries). Some data are available and deserve to be cited: Cao Desheng [1999] estimates that China's refrigerated storage capacity in 1997 was 20 million m^3 (for 1,236 million inhabitants), or 16 litres of refrigerated storage space per inhabitant. Morocco has a cold storage capacity of 1,356,000 m^3 for 26 million inhabitants, this being 52 litres per inhabitant [ANAF, 1994].

At the other end of the cold chain, household refrigeration is developing fast. In 1992, 28% (18 million appliances) of all domestic refrigerators worldwide were manufactured in developing countries mainly for local sales, while in 1996 this figure had risen to 33% (26.9 million appliances) [UNEP, 1998]. Domestic refrigerators enable users to reduce losses of food at home and to become more aware of the benefits of refrigeration; the expansion of domestic refrigeration is generating user expectations concerning a complete cold chain.

The number of supermarkets located in large cities in developing countries is on the rise, but global data on this trend are scarce.

Table B: Refrigerating systems: worldwide figures on equipment in use	
Sector of activity	Number of equipment and plants in service
Domestic refrigeration	700 - 1,000 million units (1)
Commercial refrigeration	
Supermarkets	117,000 units (2)
Condensing units	2,850,000 units (3)
Stand-alone display cabinets	10,000,000 units
Miscellaneous	13,250,000 units (4)
Agri-food	
Bulk milk coolers	5,000,000 units (1)
Industrial refrigeration	
Cold storage	300 million m^3 (5)
Air-conditioning (air-cooled systems)	
Room air-conditioners	79 million
Duct-free packaged and split systems	89 million
Ducted split systems	55 million
Commercial unitary systems	16 million
Air-conditioning (water chillers)	856,000 units
Refrigerated transport	
Marine containers	410,000 units (6)
Reefer ships	1,088 ships
Refrigerated railcars	80,000 units
Road transport	1,000,000 units
Merchant marine	30,000 ships (7)
Buses and coaches	320,000 units
Liquified gas tankers	71 units (8)
Mobile air-conditioning	
Passenger cars and commercial vehicles	380 million (9)
Heat pumps	
Residential heat pumps	110 million (10)
Heat pumps in commercial and institutional applications	15 million (10)
Industrial heat pumps	30,000 (10)

All figures come from UNEP [1998] except those for which other sources are mentioned
(1) IIR estimation
(2) Sales area of over 400 m^2
(3) Small cold rooms, vending machines, etc
(4) Ice makers, etc
(5) [L. Mattarolo, 1990]
(6) Actual units, regardless of size
(7) Ships in excess of 300 gross tonnes with cold rooms and air-conditioning
(8) [Crosnier, 1992]
(9) 51,7 % of the estimated 740 million passenger cars and commercial vehicles in 2000 (Delphi Automotive Systems, 2002)
(10) IEA/Heat Pump Centre (2001)

Table C: Estimation of the annual sales of refrigeration, air-conditioning and heat-pump equipment			
Equipment	Annual production (M = million)	Average wholesale price (USD)	Total (USD billion)
Domestic refrigerators	82 M (1)	400 (2)	32.8
Commercial refrigeration equipment			18.6 (3)
Bulk milk coolers			2.4
Cold storage	15 M m^3 (4)	133 (2)	2.0
Absorption chillers	8,600 (5)	93,000 (5)	0.8 (6)
Centrifugal chillers	8,000 (5)	116,000 (5)	0.9 (6)
Reciprocating, screw chillers	114,000 (5)	20,000 (5)	2.3
Room air-conditioners	29.9 M (7)	700 (8)	20.9
Packaged Air-conditioners	9.8 M (7)	1,600 (8)	15.7
Rooftops			6.5 (6)
Refrigerated transport vehicles	135,000 (9)	15,500 (9)	2.0
Refrigerated containers	50,000 (9)	24,000 (9)	1.2
Passenger car air-conditioning	31 M (11)	900 (10)	27.9
Commercial vehicle air-conditioning	11 M (11)	1500 (2)	16.5
Railway car and coach air-conditioning	40,000 (2)	7000 (8)	0.3
Residential heat pumps	12.3 M (12)	1000 (2)	12.3
Commercial heat pumps	1.5 M	3000 (13)	4.5
Industrial heat pumps	4000	250 000 (13)	1.0
Installation of refrigerating plant			30.0 (2)
Total			198.6

(1) 1996 world production (UNEP, 1998)
(2) estimation
(3) www. profound.com: includes display cabinets (USD3 billion), reach-ins and walk-ins (USD4.95 billion), vending machines (USD2.5bn), ice machines (USD1.35 billion) and parts (USD6.8 billion) (1999 value)
(4) 1/20th of world cold store capacity
(5) 1997 world production: JARN, 25 November 1998
(6) 1997 world value: JARN, 25 November 1998
(7) 2000 world shipments: JARN, 25 May 2001
(8) Estimation calculated from JARN figures
(9) Carrier Transicold (2001) – condensing unit + insulated body
(10) 1999 Automotive News Market Data Book
(11) Delphi Automotive Systems
(12) IEA/HPP – 2001
(13) price depends greatly on size, especially for commercial and industrial heat pumps

2.5 The environmental dimension

The refrigeration industry is addressing a complex set of environmental issues and is evolving within an increasingly complex regulatory context at domestic, regional and international levels.

At environmental level, the impact of refrigeration is twofold due to:

- atmospheric emissions of certain refrigerant gases used in refrigerating installations. These emissions arise due to leaks occurring in insufficiently leak-tight refrigerating installations or during maintenance-related refrigerant-handling processes, and depending on the refrigerants concerned, can have an impact on:
  - ozone depletion,
  - global warming, by exerting an additional greenhouse effect.

  A loss of refrigerant may also induce a loss in efficiency, particularly in critically charged systems;
- The energy consumption of these refrigerating installations that contributes to CO_2 emissions and reduces global energy resources.

Other indirect impacts should be mentioned such as pollutants (SO_2, nitrous oxide), emissions related to component production and waste products associated with the destruction of refrigerants, oils and the equipment itself.

2.5.1. Atmospheric emissions of refrigerant gases

Refrigerating installations known as vapour-compression installations are by far the most commonly used. These installations use fluids called 'refrigerants', without which cooling is impossible. The basic process by which refrigerants induce cooling involves liquid-gas phase change, that is evaporation. The whole refrigerating cycle involves evaporation, compression, condensation and expansion of the refrigerant.

Certain refrigerants used in refrigerating installations exert adverse effects on the environment when released into the atmosphere, by contributing either to ozone depletion or global warming. These gases belong to the fluorocarbon family:

- CFCs (chlorofluorocarbons); these refrigerants were developed in the 1930s. In 1974, Rowland et Molina showed that CFCs have an impact on ozone depletion; moreover, they also exert global-warming effects;
- HCFCs (hydrochlorofluorocarbons); these refrigerants were developed more recently. These refrigerants have a considerably smaller ozone-depleting effect and a less marked direct global warming effect than CFCs;
- HFCs (hydrofluorocarbons); these refrigerants have no ozone-depleting effects and have been developed as alternatives to CFCs and HCFCs. However, they do contribute to global warming but to a lesser extent than CFCs.

Atmospheric emissions of refrigerant gases arise in several ways: poor plant tightness, or operating, incorrect or negligent refrigerant handling, insufficient plant maintenance, etc. Actions designed to reduce emissions must thus be implemented throughout the plant life cycle:

- during the design and manufacturing phases,
- during installation and operation,
- during disposal of plant.

2.5.1.1 Ozone depletion

A brief explanation of this phenomenon

The ozone present in the stratosphere (the part of the atmosphere located at an altitude of roughly 12km to 50km) protects us from the harmful effects of short wavelength ultraviolet solar radiation (UVB). Stratospheric ozone levels vary according to the altitude, and are extremely low, being of the order of one molecule of ozone per two million molecules of oxygen. CFCs are extremely stable and reach the stratosphere unchanged over a five to seven year period following release into the atmosphere. CFC and HCFC molecules are then broken down under the influence of UVB solar radiation, and chlorine is released. This chlorine in turn breaks down ozone molecules (a single chlorine atom can trigger 100 to 10,000 ozone breakdown reactions). CFCs and HCFCs have long atmospheric lifetimes (50 to 100 years or more for CFCs and 14 to 20 years for HCFCs), and their ozone-depleting effects are thus very long-lasting.

The Montreal Protocol

In order to combat ozone depletion, the international community adopted the Montreal Protocol on Substances that Deplete the Ozone Layer on 16 September 1987, this protocol being one outcome of the Vienna Convention of 22 March 1985. It has been modified and completed by several amendments. Thanks to the Montreal Protocol, as of 31 July 2001, 179 countries are committed to implementing concrete measures designed to protect stratospheric ozone known as 'the ozone layer'. Among these measures is the gradual phase-out then banning of CFCs and HCFCs within defined time frames.

Countries that have adopted the Montreal Protocol fall into two categories:

- developing countries (covered by Article 5 of the Montreal Protocol); countries with annual ozone-depleting substance (ODS) consumptions of under 0.3 kg per capita on the date on which the Montreal Protocol entered into force;
- developed countries (covered by Article 2 of the Montreal Protocol).

The key measures defined by the Montreal Protocol are:

- developing countries (Article-5 countries):
  - CFCs, total ban on production and consumption as of 1 January 2010,
  - HCFCs, total ban on consumption as of 1 January 2040.
- Developed countries:
  - CFCs, total ban on production and consumption as of 1 January 1996,
  - HCFCs, total ban on consumption as of 1 January 2030.

The quantitative objectives and corresponding time frames specified by the Montreal Protocol and its amendments are shown in figure 2 in Annexe 1.

Certain countries or regional economic integration organisations have reinforced the measures defined in the Montreal Protocol or have added regulatory measures governing the use of CFCs and HCFCs. This is the case for the European Community that on several occasions has adopted regulations applying to its 15 member states. The latest one is Regulation 2037/ 2000 on Ozone-Depleting Substances dated 29 June 2000 that comprises the following key measures:

- CFCs, a total ban on use for maintenance and servicing of equipment as of 1 January 2001;
- HCFCs, a total ban on production as of 1 January 2025; a ban on use of virgin HCFCs in maintenance and servicing of equipment as of 1 January 2010; a ban on the use of HCFCs for the production of new equipment from 1 January 1996 to 1 January 2004 according to applications.

The United States approach is noteworthy. Whenever a new amendment to the Montreal Protocol is submitted for ratification by the parties, the United States immediately implements the new measures without waiting for them to enter into force; this keeps the number of ratifications required to a minimum.

The impact attributed to the refrigeration sector

The impact of an ozone-depleting substance (ODS) is quantitatively measured using its Ozone Depleting Potential (ODP). This potential provides a quantified evaluation of the destructive effect of the substance in question compared with that of CFC11 used as a reference.

Figure 3 in Annexe 1 shows the ODP of the most commonly used CFC and HCFC refrigerants. Most CFCs have an ODP of 0.6 - 1. The most widely used HCFCs have ODPs ranging from 0.02 to 0.055. Refrigeration and air-conditioning-related emissions represented 64% of all CFCs and HCFCs produced [AFEAS, 2001].

2.5.1.2 Global warming

A brief explanation of this phenomenon

The sun emits radiation with a short wavelength comprising ultraviolet, visible and near infrared radiation; 50% of solar radiation reaches the surface of the earth. The earth absorbs this radiation then re-emits radiation with a longer wavelength (far infrared radiation) and certain gases present in the atmosphere absorb part of the latter: these are called 'greenhouse gases'. The atmosphere acts as a transparent medium for short wavelength radiation, that is it behaves like a greenhouse; on the other hand, the atmosphere absorbs the long-wavelength radiation re-emitted by the earth in the same manner as a greenhouse. This 'greenhouse effect' exerts a temperature-raising effect.

The greenhouse effect is necessary up to a point: without it, the mean temperature on earth would be -18°C and life on earth would be impossible. But the amplification of the greenhouse effect that has been observed over the past century is exerting adverse 'climate-change' effects including global warming and a sea-level rise.

Global warming is now at least partially attributed to anthropogenic causes, above all CO_2 (carbon dioxide) emissions derived from the combustion of fossil fuels such as coal, oil or natural gas. CFCs, and to a lesser degree, HCFCs and HFCs, contribute to global warming and are thus considered as being greenhouse gases.

The Kyoto Protocol

One concrete outcome of the Earth Summit held in Rio de Janeiro in June 1992 is the adoption of the United Nations Framework Convention on Climate Change (UNFCCC); the objective of this convention is to 'stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'.

The Kyoto Protocol was adopted on 11 December 1997 within the framework of this Convention, but has yet to enter into force because the number of countries having ratified it is insufficient (December 2001). The objective of the Kyoto Protocol is to reduce, in 39 developed countries, emissions of a basket of six greenhouse gases by at least 5% between 1990 and 2008 and 2012. HFCs are among the six greenhouse gases covered by the Kyoto Protocol. CFCs and HCFCs are not included in the basket of Kyoto-controlled gases because the Montreal Protocol already covered them.

The impact attributed to the refrigeration sector

The impact of greenhouse gases on global warming is measured using their Global Warming Potential (GWP) defined as being the radiative forcing (additional greenhouse effect) caused by a substance over a specific period. GWP is expressed with respect to the radiative forcing exerted by the same quantity of CO_2, used as a reference gas. This definition enables comparison of various gases with variable atmospheric lifetimes. GWPs are calculated for specific time horizons (20, 100 or 500 years). The 100-year time horizon is that which is the most widely used. Figure 3 in Annexe 1 shows the GWPs of the most widely used refrigerants.

However, the use of GWP measurements has its limitations; GWP measurements provide information on the properties of a gas (in particular its ability to absorb infrared radiation and its lifetime), but do not make it possible to quantify the overall greenhouse effect of a refrigerating plant using the refrigerant in question.

Total Equivalent Warming Impact (TEWI) is a concept introduced in 1989. It takes into account not only direct, but also indirect, emissions of greenhouse gases attributed to refrigerating plant. The mean values concerning direct and indirect emissions have been estimated as follows:

- direct emissions (leaks) of refrigerants contained in refrigerating installations account for about 20% of the overall impact of the refrigeration sector on global warming,
- indirect CO_2 emissions generated by the production of (essentially electrical) energy required to operate refrigerating equipment account for about 80% of the overall impact of the refrigeration sector on global warming, [IIR, 2000].

Life Cycle Climate Performance (LCCP), is a concept that emerged more recently and enables more comprehensive evaluation, since it covers all emissions throughout the life cycle of the installation ('from cradle to grave') including emissions occurring during the manufacturing of various chemical installation components, as well as emissions occurring during scrapping or recycling of its components.

2.5.2 Energy consumption

Refrigeration requires energy. Vapour compression is the most widely used refrigeration technology. It requires energy in order to operate the compressor used in the plant, and to a lesser extent, to operate other components of the plant (pumps, fans, defrosting heaters). Electrical energy is that which is the most commonly used, but in road-, marine- and air-transport applications (transport of perishable foodstuffs, air-conditioning) petrol or diesel fuel energy sources are used. In absorption technology, thermal energy is used to operate the desorber.

The energy efficiency of a refrigerating plant is measured using the coefficient of performance (COP). This COP describes the relationship between the refrigerating capacity provided by the plant and the energy consumed by the compressor, both types of energy being expressed in the same units. The COP reflects the efficiency of the plant and is usually greater than one.

The COP of a typical commercial vapour-compression refrigeration plant, operating with a temperature lift of about 40K between condenser and evaporator, is roughly three. In other words, a refrigerating plant with an electric power input of 1kW is generating a refrigerating capacity of 3kW. The COP of a refrigeration plant using absorption technology for conventional systems is often about 0.7. With new advanced multi-effect systems it is possible to reach 1.5. When the energy efficiency of a refrigeration plant is improved, the energy consumption of the plant drops; clearly, less energy needs to be consumed in order to operate the plant.

Thus, when one considers a refrigeration plant running on electricity, it is important to bear in mind that the efficiency of most electric power plants using fossil fuels such as coal, oil and natural gas, these being the most widely used worldwide, is at best 40%; however, new combined gas-vapour plants can reach close to 60%.

The refrigeration and air-conditioning sectors consume about 15% of all electricity consumed worldwide [IIR, 1997]. This figure illustrates the importance of achieving optimal energy efficiency for refrigerating plants. Beyond the positive impact on the earth's energy resources, by improving the energy efficiency of installations, one is also able to exert a positive effect on the indirect emissions of CO_2 that is the main component (80% over the overall impact) of the refrigeration sector on the greenhouse effect and global warming.

The refrigeration industry is thus faced with a daunting array of complex environmental issues to be addressed and is responding by constantly developing new technologies and raising energy efficiency. Part 3 covers ongoing achievements and actions worldwide.

Part 3: Means of implementation: Strategies, achievements and limits

3.1 Introduction

This section provides a summary of refrigeration stakeholders' recent achievements within the framework of sustainable development. Most of these achievements, particularly those related to the environmental dimension of sustainable development, are constantly evolving; past efforts will need to be maintained and new initiatives launched. These challenges are presented in Part 4.

This section provides an overview of strategies developed to date and recent achievements within the refrigeration sector, and then provides a per-sector analysis.

Among refrigeration stakeholders' recent achievements within the framework of sustainable development, the most significant is the industry's landmark contribution to the implementation of the Montreal Protocol on substances that deplete the ozone layer. The refrigeration industry over a decade has completely changed the refrigerants from CFCs and HCFCs to ozone friendly substances to protect the global environment. This contributed to lowering the chlorine concentration in the stratosphere and reducing ozone depletion that threatened life on Earth.

Industries also took the opportunity of changing over to second generation and more energy-efficient technology over the last ten years. Refrigeration is one of the unique sectors that has witnessed a complete technology overhaul that was environmentally-friendly. This has been made possible through co-operation between developing and developed countries through the Montreal Protocol, through funding of new technology by the Multilateral Fund, and through international co-operation between organisations like IIR, UNDP, UNEP, UNIDO, the World Bank, WHO and many others.

Unprecedented technological developments took place in the refrigeration industry that included retrofitting the existing equipment with ozone friendly refrigerants to more complex technology using vapour absorption and NIK technologies such as thermoelectric cooling. Technologies were disseminated and deployed widely through global co-operation catalysed by the Montreal Protocol. UN agencies, government, industry associations and NGOs contributed immensely to these efforts that are a unique experience of the last decade.

The industry is now gearing up to face another environmental challenge of the next millennium, global warming. In order to combat global warming the main strategies are the following:

1. reductions in refrigerant emissions,
2. reductions in energy consumption,
3. research and development on new refrigerants and new technologies,
4. new developments in the cold chain,
5. new developments in indoor air quality.

The first three achievements have been made possible by taking into consideration all phases (design, manufacture, installing, operation and disposal) in the life cycle of refrigeration and air-conditioning systems and require concerted efforts involving all refrigeration stakeholders: researchers, designers, manufacturers, distributors, plant operators and end users. The strategies used within these three fields of achievements have led to the development of new refrigerants and new equipment.

The positive environmental benefits must be considered using an objective measure of environmental merit. This measure must be based on a true life cycle assessment. It must take into account the overall environmental impact throughout the life cycle of the refrigeration or air-conditioning system. Thus, concerning the greenhouse effect, life cycle climate performance (LCCP), which is a measure of total greenhouse emissions ('from cradle to grave'), is no doubt the most objective criterion.

Air-conditioning and refrigeration systems can contribute to global warming gas emissions in three ways. Firstly, during the manufacture of refrigerants and components, secondly, in the production of electric power required to operated the equipment, and thirdly, through leaks and other emissions of refrigerants from the device itself. LCCP is a measure of those total emissions and is more encompassing than GWP, which only accounts for the global warming properties of the refrigerant itself. By using LCCP as a measure of merit, it is easier to see for instance where replacing a higher GWP refrigerant with a lower GWP refrigerant in some applications can result in greater emissions elsewhere in the chain. For example, replacing a refrigerant with one of lower GWP could reduce the system efficiency, resulting in greater energy use and greater emissions of CO_2 at the power plant.

The initiatives implemented within the context of these strategies have involved adaptation of previously used technologies and equipment, and beyond the investment costs and researchers' time devoted to this development, have led to profound changes in all refrigeration stakeholders' attitudes, particularly at end-user level. For instance, when it proved necessary to replace CFC12 and HCFC22, a whole range of new refrigerants was developed and in many cases comprised mixtures of refrigerants with often more complex properties than pure refrigerants. New knowledge had to be acquired and new ways of operating equipment had to be found.

Within this context, information dissemination is vital. It is necessary to raise decision-makers' and users' awareness of the adverse effects of formerly-used refrigerants. The retrofitting of existing plants in order to use a new refrigerant implies explaining new operating principles and training staff in the use of new operating methods. In terms of information and knowledge sharing, the refrigeration sector is now highly mobilised thanks to:

- global scale co-operation catalysed by the Montreal Protocol on substances that deplete the ozone layer;
- national and international conferences enabling researchers, manufacturers and industrialists to remain updated on the state-of-the-art in order to address the issues confronting them;
- information exchange and knowledge management networks of international associations like IIR and UNEP OzonAction Programme under the Multilateral Fund of the Montreal Protocol, ARI, ASHRAE and a number of national associations;
- training of staff at corporate level (within the industry, tertiary firms) and at all levels (maintenance and servicing staff, managerial staff, decision-makers).

Making information, knowledge-sharing, and training available to all refrigeration stakeholders is a vital action, particularly in developing countries with needs that will increase in the years to come (see Part 4). This is the International Institute of Refrigeration's mission.

3.2 General approach

3.2.1 Industrialised countries

3.2.1.1 Emissions reductions

Actions implemented

These actions include various initiatives implemented in order to reduce atmospheric emissions of refrigerants in general, and CFCs and HCFCs in particular, given the adverse effects of the latter on the ozone layer and on global warming, and HFCs, which are greenhouse gases. These initiatives concern all phases (design, manufacture, installing and disposal) in the life cycle of refrigeration and air-conditioning systems.

Design and manufacture

Optimisation of tightness

Right from the refrigerating system design phase, all potential sources of leaks should be eliminated. Refrigerating equipment manufacturers' R&D teams are developing systems with a minimum number of leak-prone joints and connections, and where joints are required, reliable joining techniques are used. Ongoing research is being conducted on ways of monitoring the refrigerant charge (the quantity of refrigerant) in refrigerating plant, thus enabling leak detection. Cooling system manufacturers have defined minimum tightness requirements to guarantee permanent operation during defined periods. Reference to these requirements must be extended.

It is difficult to implement overall indicators demonstrating achievements in the field of installation tightness – plants and the measures needed differ greatly. However, we can cite results of surveys conducted on installation tightness [UNEP, 1998]:

- Climafort (a French association of chiller operators) has published figures on the air-conditioning field; chiller leaks have been halved between 1987 and 1994. However, leakage remains at a level of around 10% and varies widely according to applications.
- United States EPA has provided figures on the commercial refrigeration sector (in which the leakage rate is generally high due to the layout and size of installations) and mentions a 15% leakage rate in 110 stores in the United States following the implementation of strict equipment selection procedures (such as selection of equipment with brazed valves), a vast improvement over the average leakage in the same sector (considered as being 25%).

Minimisation of refrigerant charges

The higher the refrigerant charge in an installation, the more refrigerant is released into the atmosphere when a pipe burst occurs. Reducing the initial charge used is thus a major objective, but until recently was no doubt not given the consideration it deserves, given the stakes involved.

A highly useful ratio is that reflecting the relationship between the refrigerant charge and the refrigerating capacity. In medium-temperature commercial refrigeration (used for chilled foods), this ratio is often around 1.5 kg/kW [UNEP,1998]. With air-conditioning water chillers, this ratio is much lower (0.25 kg/kW) because these units provide indirect cooling using water as a secondary refrigerant and contain a much lower charge. These chillers are also fully prefabricated and factory-tested.

However, when reducing charges, other factors related to energy consumption need to be taken into consideration. For instance, a low-refrigerant-charge system using a secondary refrigerant may require more energy because of the additional heat exchange taking place between the primary refrigerant and the secondary loop.

Charge minimisation remains a field of great interest in terms of R&D and innovation to be achieved.

Minimisation of piping

The shorter the piping used in refrigerating systems, the less refrigerant is likely to leak. Moreover, detecting leaks is easier in more compact systems. The development of systems employing secondary refrigerants, particularly in supermarket and food industry applications (fruit-packing stations, abattoirs, dairy installations) is a source of progress in this respect as the refrigerating equipment is confined to a machinery room. However, these systems tend to use a little more energy: (i) additional electrical energy is required to drive additional equipment such as pumps, and (ii) the temperature difference between condensing and evaporating temperatures increases, thereby reducing the COP. Such systems lead to lower direct emissions of refrigerant but to higher emissions of CO_2 linked to additional consumption of energy. Improved heat exchangers compensate at least partially for the drawbacks associated with the additional heat exchange.

Adapting equipment in order to facilitate maintenance operations

Designers of refrigerating equipment are now working on making maintenance and servicing easier and reducing the risk of triggering emissions of refrigerants, for instance by locating valves both at the low point of the installation and at each vessel for efficient refrigerant recovery [UNEP, 1998].

Installation and commissioning

Optimal refrigerant containment

The best way to ensure that equipment is as leak-tight as possible is to ensure that it is precision-manufactured complying with strict qualitative procedures. For this reason, domestic appliances are generally entirely welded, and manufacturers pay particular attention to the quality of the welding in order to achieve zero leakage to the greatest extent possible.

Detection of leaks into the ambient atmosphere

In large plants and all machine rooms, multiprobe sensing of ambient conditions normally provides the most reliable system of monitoring. Air-flow patterns should be investigated in order to select sensor sites where the refrigerant, usually heavier than air, tends to concentrate. This monitoring known as 'threshold monitoring' requires highly sensitive and accurate detectors (low ppm), suitable for use with new HFC refrigerants.

In the refrigerant-leak-detection field, considerable progress has been achieved recently. Care must be taken when choosing a detection system: it must be suitable for the plant layout in question and the type of refrigerant used. Many standards (such as ASHRAE standards) now provide for automatic refrigerant-leak detection

Rigorous acceptance of new plant

At the time of plant commissioning, it is vital to check the manufactured quality achieved, particularly in terms of tightness. The energy efficiency should also be carefully examined (see section 3.2.1.2). The current trend is to implement acceptance procedures based on standards or specifications, particularly in the case of industrial installations. A defined acceptance process makes it possible to check that the performance of the plant is that claimed by the manufacturer and also provides a basic benchmark for subsequent performance, enabling preventive or corrective measures to be implemented where necessary.

Servicing/maintenance

Monitoring of plant tightness

Reliable monitoring of refrigerating plant tightness should be performed within the framework of a leak-management programme. This programme requires the setting up of the following actions for a given plant:

- for each refrigerant, an inventory of all equipment and piping used should be prepared;
- for all equipment, specifications defining monitoring methods should be prepared;
- corrective measures to be applied when anomalies are detected during the monitoring process (maintenance, repairs, component replacement) must be defined;
- a maintenance record system should be used in order to note all the monitoring tests performed;
- a refrigerant record-keeping system

must be implemented;
- staff operating the equipment should be given prior training in these methods.

Leak-management programmes are being set up to an increasing degree in large plants, and this trend should be extended to all corporations. In the leak-management field, the initial driving force is in some cases simply the industry's response to regulatory requirements such as those inherent in the European Regulation 2037/2000 governing ozone-depleting substances. This regulation came into force on 1 October 2000 in all 15 EU countries, and stipulates that all fixed refrigerating, air-conditioning and heat-pump equipment with a charge of at least 3kg must be subjected to annual testing in order to detect any leakage that may be present.

Leak detection can be facilitated, or even performed, in a predictive manner by monitoring other indicators, particularly refrigerant pressure drops and reduced oil quality. The monitoring, whenever conditions make this method reliable, of refrigerant concentrations in machine rooms using fixed high-sensitivity detectors, is an optimal measure.

Remote plant management enables detection of anomalies and alerts maintenance staff to the need to act; use of this technology is on the increase, particularly where safety parameters need to be monitored.

Systematic refrigerant recovery during maintenance and repair operations

In order to achieve emissions reductions, good practice procedures must be applied, including refrigerant recovery during all refrigerant-handling operations associated with the running of plants. Recovery, at end-user level, can only be achieved where operators have been trained in recovery techniques. In several countries, the authorities have backed the refrigeration industry's actions by implementing financial incentives promoting refrigerant recovery.

Most developed countries have opted for regulations making it compulsory, for many types of plants, to recover used refrigerants in order to comply with Montreal Protocol commitments. Within this context, the EU, through its Regulation 2037/2000 on ozone-depleting substances that entered into force on 1 October 2000, made it compulsory to recover CFCs and HCFCs from all refrigeration and air-conditioning equipment. This regulation will also apply to domestic refrigerators and freezers as of 1 January 2002.

Progress can be achieved in this field only if installers and operators are aware of the environmental consequences of venting certain refrigerants into the atmosphere. The effect of refrigerant management programmes and policies in developed countries are generally positive, even though the approaches in terms of avoidance of emissions, programme organisation and control, responsibility levels, regulatory legislation, financing arrangements, and operating procedures, differ considerably. There is also a lack of information on the environmental and economic benefits [IEA, 2001].

Disposal of equipment at the end of its life cycle

Refrigerant recovery

The recovery of refrigerants from plants prior to disposal is vital: without such recovery, the refrigerants are released into the atmosphere. For some years now, manufacturers have been offering a wide range of recovery equipment (with a wide price range).

Standards for measuring recovery and recycling performances have been designed: ISO 11650, the international standard or ARI 740-95 (United States) can be used and are based on the same elements. The efficacy of presently used recovery equipment has now been demonstrated as being 92% to 97%

[UNEP, 1998]. Even better results can be obtained using equipment that operates over longer periods (recovery of the vapour phase).

Recovery must be performed by specially trained personnel. In the United States, Section 608 'Refrigerant Recycling Rule' of the Clean Air Act of 1990 (EPA) defines the rules to be complied with in terms of minimum qualification of the technicians authorised to perform recovery, and also defines the minimum recovery rates to be achieved. Section 608 also defines specifications to be complied with in terms of component certification.

As described above, raised user awareness of the adverse environmental effects of certain refrigerants is the key to prevention of the venting of refrigerants into the atmosphere.

Financial incentives and regulatory obligations are fuelling achievements, as illustrated by the figures on the quantities of CFCs and HCFCs recovered in France, (French decree dated 7 December 1992 making recovery from plant with a refrigerant charge of over 2kg compulsory) (see Table D).

A substantial quantity of clean refrigerant is also recovered and immediately reused in the plant.

Recycling

Once a refrigerant has been recovered, it can be recycled, provided that this is in compliance with national regulations and the manufacturer's recommendations. In the regulatory field, in the United States, Section 608 of the Clean Air Act of 1990 (EPA) defines the rules to be complied with in terms of recovery-equipment certification and certification of the technicians authorised to perform recycling.

The introduction of recycling processes has led firms to set up staff certification programmes involving training plans and resulting in enhanced skills at staff level. Manufacturers are now offering a wide range of recycling equipment. The entering into force of the European Regulation 2037/2000, which defines CFCs as waste, as of 1 January 2001, bans the recycling of CFCs and imposes their destruction.

Destruction

When a recovered CFC or HCFC cannot be recycled or reclaimed (processed to new product specifications), it must be destroyed. Although progress has been achieved in the field of destruction technology, destruction is still expensive and there are a limited number of suitable plants. Much remains to be done in this field, and financial incentives will no doubt be needed in order to make destruction technology more accessible and prevent the venting of refrigerants into the atmosphere and illegal exports, particularly to developing countries.

Overall achievements

Beyond achievements within the framework of the previously described actions, a good indicator of achievements in terms of emissions reductions is the recently observed decrease in the chlorine concentration of the stratosphere.

Overall achievements can, be evaluated by examining figures on the contribution of fluorocarbons (CFCs + HCFCs + HFCs) to ozone depletion and the greenhouse effect. In order to illustrate the contribution of

Table D: Quantities of CFCs and HCFCs recovered in France

Year	1990	1991	1992	1993	1994	1995	1996
Tonnes of CFCs and HCFCs recovered	150	260	250	300	420	500	550

fluorocarbons to ozone depletion, figure 4.1 in Annexe 1 shows the evolution of production of CFCs and HCFCs, with weighting based on these refrigerants' respective ODPs. A peak occurred in 1988 then was followed by a decreasing trend reflecting the actions implemented in compliance with commitments within the framework of the Montreal Protocol; this decreasing trend is continuing to emerge. These figures demonstrate that post-1989 production is markedly lower than the objectives defined by the Montreal Protocol.

In order to demonstrate the contribution of fluorocarbons to the greenhouse effect, figure 4.2 in Annexe 1 illustrates evolution of production of CFCs, HCFCs and HFCs, with weighting based on these refrigerants' respective GWPs. The same diminishing trend as that observed for ozone depletion emerges: starting in 1989, a marked decrease in the greenhouse effect is observed.

The proportion of all fluorocarbons in annual greenhouse gas emissions can also be evaluated. The proportion of fluorocarbons has dropped rapidly over the past decade or so: 14.6% in 1988 (the year during which emissions peaked), 9.3% in 1992, 6.5% in 1995. However, it covers several applications (refrigeration, insulation, aerosols).

3.2.1.2 Reductions in energy consumption

Indirect emissions of CO_2 account for approximately 80% of the overall global warming impact of refrigerating systems. Actions applied in order to reduce refrigerant emissions are applied at all stages in the life cycles of plants and the same is true for initiatives implemented in order to raise plant energy efficiency.

Actions implemented

Design and manufacturing

Manufacturers' R&D departments have performed a great deal of work on component design, in order to improve energy efficiency. In the case of technologies based on vapour compression, research has above all focused on improving the performance of components of refrigerating systems:

- in the compressor field, an important breakthrough has been the development of electronically regulated variable-speed compressors; the efficiency of pumps and fans has also been raised thanks to improved regulation;
- in the evaporator and condenser fields, the development and optimisation of plate heat exchangers has made it possible to increase the heat exchange coefficients, consequently to reduce the difference between condensing and evaporating temperatures and therefore to raise efficiency;
- the use of floating condensation, particularly where electronic valves are used, has made it possible to raise energy efficiency, particularly in the commercial-refrigeration sector;
- the performance of systems using secondary refrigerants has been significantly improved by the development of new heat-transfer fluids. Within this context, ice slurries (two-phase liquid water/ice mixtures with marked energy-storage properties) and CO_2 in low-temperature cooling systems are promising;
- Electricity meters installed in the refrigerating part of installations make it possible to monitor and manage follow-up. Heat pump technology is also a good example of a field in which design is aimed at reducing energy consumption.

Installation – commissioning

Acceptance of plant is a vital phase that is covered by good practice procedures. Measurement of the energy consumption of a plant is an essential benchmark in the acceptance process. Electricity meters installed in the refrigerating part of installations make it possible to monitor and manage follow-up. Other measurements performed during later stages make it possible to detect anomalies and to apply corrective measures.

Maintenance and servicing

Refrigeration practitioners involved in maintenance and servicing are now more aware that high-quality operating procedures need to be implemented in order to reduce the energy consumption of refrigerating plants. Many factors affect plant efficiency and refrigeration engineers have focused on some of these factors in particular in recent years.

Charge optimisation has now become a major concern for all those operating installations. Installations are increasingly designed to use low charges and consume as little mechanical energy as possible; long-term charge monitoring is therefore of vital importance. Keeping exchangers clean, preventing air from entering plant and the ensuring of smooth operating optimal regulation are all key parameters that must be checked by plant maintenance and servicing personnel.

Energy consumption record keeping is becoming a widely used strategy that makes it possible to monitor all parameters relating to plant energy consumption: early detection of anomalies is easier and solutions can be applied faster.

Installation maintenance (defouling and cleaning exchangers) or use of larger sized exchangers enables gains of 2°C to 3°C to be obtained between condensation and evaporation temperatures; given that a gain of 1°C at -30°C raises the COP of the installation by 4 to 6% and that a gain of 1°C on the condensation side raises the COP by about 3%, it is obvious that substantial savings can be achieved [ECSLA, 2000].

Many installations are now remotely managed thanks to remote processing systems. As mentioned in section 3.2.1.1 on refrigerant leak prevention, remote systems that were originally designed to meet safety requirements must also address energy-efficiency needs.

Standardisation – regulations

Beyond initiatives implemented in order to improve the energy efficiency of refrigerating plants, it is necessary to establish a benchmark capable of accurately and objectively assessing the performance of a plant. This is where standardisation comes into play.

If we examine the case of refrigerators, thanks to studies performed in laboratories, standards governing energy-use (and thus efficiency) measurement methods have been developed. Appliance performances can thus be reliably measured, and labelling can be used to provide potential purchasers with information enabling them to choose, if they so wish, an appliance that may initially be more expensive but will be less expensive in the long-term thanks to energy savings.

The United States' approach in this respect is noteworthy: government/industry partnerships have led to large energy savings. The refrigeration and air-conditioning industry successfully uses voluntary initiatives such as standards, guidelines and certification programmes and governmental participation to address its sustainable-development responsibilities. The Air-Conditioning and Refrigeration Institute's 80 standards and guidelines and 25 product certification programmes provide the means by which manufacturers test and assign energy efficiency ratings to air conditioners and heat pumps.

These ratings allow educated consumer choices and provide benchmarks for energy efficiency. The ratings known as SEER (Seasonal Energy Efficiency Rating) and HSFP (Heating Seasonal Performance Factor) are adopted by the United States government and various states through two laws: The United States National Appliance Energy Conservation Act of 1987 (NAECA) and the United States Energy Policy Act of 1992 (EPACT). They apply to home and commercial equipment.

Training – certification

Quality procedures are now widely used, particularly in large corporations. Heating and cooling plants were often formerly neglected in these procedures but are now included in them. Quality procedures increasingly include training of technicians and installers followed by certification. This approach constitutes a major achievement in the refrigeration world.

In the United States, more than 10,000 refrigeration and air-conditioning technicians and installers have demonstrated their proficiency by achieving North American Technician Excellence (NATE) certification. In time, hundreds of thousands of technicians and installers are expected to be NATE certified.

NATE testing and certification encourages proper installation and servicing of air-conditioning and refrigeration equipment. As a result, equipment owners enjoy energy savings and can be assured that refrigerant is not vented to the atmosphere, in accordance with United States regulations. NATE is endorsed by the United States Department of Energy because equipment that is properly installed will operate at peak efficiency, helping utilities achieve load and energy goals.

In Europe, the CEN/TC 182 Committee is preparing a prEN 13313 standard called Refrigerating systems and heat pumps – Competence of personnel.

The Air-conditioning and Refrigeration European Association (AREA) has finalised guidelines (AREA, 2001) for 'emission control of stationary refrigeration and air-conditioning systems and heat-pumps with a refrigerant fluid charge of more than 3kg' advocating each European member state to appoint one or more national organisations responsible for delivering and controlling mandatory or voluntary certifications to refrigeration companies and personnel.

Efforts must, of course, continue on a global scale and would be facilitated by the development of common internationally recognised certification standards defining practitioner certification.

Overall achievements

The best performance indicator for overall achievements in the energy-efficiency field is the coefficient of performance (COP). An excellent example illustrating such progress is commercial refrigeration. The mean COP of installations (for a temperature lift of 30 K) was roughly 2.5 during the 1960s. In the 1990s, this COP had risen to about 3.3. Today, it has increased to approximately 3.8.

Certain figures provide striking evidence of achievements in the field of energy savings. During the period 1977 to 1999, refrigeration and air-conditioning industry and governmental initiatives resulted in a reduction of energy intensity (a unit of energy producing USD1 of GDP) by 42% and of carbon intensity (carbon emissions per unit of GDP) by 47%. One example is that by increasing chiller (large air-conditioner) efficiency by 20% globally, greenhouse emissions by utilities is reduced by about ten million tonnes of CO_2 and more than 80 and 34 billion grams of SO_2 and nitrous oxide respectively.

According to the Association of Appliance Manufacturers in the United States, a typical new American refrigerator (in 1997) consumed 48% less energy than its ancestor manufactured in 1980. Given that the 112 million United States refrigerators consumed 151TWh in 1997, it can be seen that the benefits, in terms of energy saving, of current achievements in the field of energy efficiency, are enormous.

In Europe, energy labelling of new refrigerators has brought about average energy savings of 15.5% in new refrigerators purchased between 1992 and 1995 in Germany, and similar energy saving is being achieved in neighbouring countries [Lebot, 1998].

When one considers that 1m^3 of refrigerated storage space consumes roughly 40 kWh/year and that a 300-litre European refrigerator consumes 560 kWh/y, it can be calculated that the refrigerator consumes 45 times more energy per volume unit and that considerable savings can be achieved, even if the entire environment equipment, operating conditions and use patterns, etc. are by no means comparable.

In the United States, the Air-Conditioning and Refrigeration Institute's (ARI) Heating, Ventilation, Air-conditioning and Refrigeration Research for the 21st Century Programme has an ambitious objective – to reduce household/building operating, maintenance and energy costs by 50% within ten years. Given that in commercial buildings, the energy requirements, in terms of heating, refrigerating and air-conditioning are colossal (estimated to be 1,610TWh in commercial buildings and the residential sector in the United States), it can be seen that huge progress is on the horizon [ARI, 1997].

A final important point: the United States Department of Energy has proposed to raise the minimum SEER (seasonal energy efficiency ratio) from ten to 12Btu/(Wh) (which is equivalent to a cooling COP of 2.93 to 3.52) as of 2006. The EER is defined as the quotient (at standard rating conditions) of the two quantities: capacity in Btu/h and power input in watts.

This brief overview of energy issues would not be complete without mentioning that the 125 million heat pumps currently in use enable 800 TWh/y of heating to be produced and reduce CO_2 emissions by 130 Mt per year.

3.2.1.3 Alternative refrigerants and not-in-kind technologies

Actions implemented

R&D achievements were described in parts 3.2.1.1 and 3.2.1.2. The objectives of the actions leading to these achievements were:

- to reduce direct emissions and thus reduce the direct effects of these emissions,
- to improve the energy efficiency of refrigerating installations, and by doing so, to reduce the indirect effects exerted by vapour-compression installations.

Actions leading to the use of not-in-kind technologies and alternative refrigerants should also be envisaged. These actions have been implemented within the framework of three strategies developed in order to meet regulatory requirements, particularly those on ozone depletion and global warming:

- new HFC refrigerants developed in order to replace CFCs, HCFCs and equipment designed to use these refrigerants;
- alternative refrigerants to fluorocarbons;
- new technologies that do not use refrigerants.

New HFC refrigerants

HCFCs were the most widely used alternatives to CFCs initially; now, they are being replaced by HFCs. Put simply, the first phase in managing the transition to environmentally friendly refrigerants thus involved the phase-out of CFCs and the introduction of HCFC mixtures, and the second phase involved the phase-out of HCFCs and the introduction of HFCs. The development of these new refrigerants involved taking into account a whole set of parameters and has ensured that the user can strike the best balance in terms of compatibility with existing equipment, cost, safety and energy efficiency.

Refrigerant choices are often thought of in terms of fitness for service, environmental protection and cost. Safety is also a major factor in refrigerant choice and use, and needs to be considered along with the social, economic and environmental dimensions of choosing the most appropriate refrigerant. Safety issues are typically addressed through national and international technical standards. Addressing these criteria has led to the introduction of refrigerants that are in most cases binary or tertiary mixtures. These mixtures are generally more complex to use than pure refrigerants. Where pure refrigerants are used, plant operation is relatively simple; in the case of many refrigerant mixtures, operators need to be trained to handle more complex operating procedures.

Alternative refrigerants to fluorocarbons

Actions enabling fluorocarbon refrigerants to be replaced are focusing on the following in particular:

Ammonia

Of the traditional refrigerants, ammonia is the only one to remain in widespread use. Usage of ammonia in the industrial field is increasing and ammonia is being introduced in indirect systems in commercial fields and air-conditioning chillers. Ammonia has zero ozone-depleting and zero global-warming effects. However, ammonia is acutely toxic and must be applied with care.

The advent of the screw compressor, which overcomes the high discharge temperature problems, and the introduction of plate-type heat exchangers containing very low volumes of refrigerant, make it possible to design very simple low-charge ammonia systems. Ammonia is not suitable for use with thermostatic expansion valves [Pearson, 1999] and is not used in low-capacity applications. It remains to be seen if ammonia can take a significant share of the air-conditioning market. Due to its zero-GWP and ODP and its inherent good efficiency, this refrigerant may be considered for wider use provided that safety issues and staff training are well handled.

Hydrocarbons

Hydrocarbons are natural substances that have excellent thermodynamic properties and good miscibility properties with inexpensive mineral oil. They have zero-ODP, negligible GWP and inherently good efficiency. They are highly flammable and this restricts the way in which they can be used. The two main hydrocarbons used as refrigerants are isobutane and propane. HC mixtures and propene are also used.

- isobutane is used in low- and medium-sized domestic refrigerators. In Europe, isobutane refrigerators make up 35% of European output (UNEP, 1998). In the United States, isobutane is being used to a limited extent due to flammability concerns. Production of HC refrigerators and freezers is also increasing in Japan and south-east Asia;
- propane has several applications. It is a niche market for small commercial appliances. Propane is also used in residential heat pumps. They are usually connected to a hydronic system for heat distribution in the building, and are often installed outside or in a separated ventilated machine room, usually above ground level. Propane is also used in large industrial plants that are sited in flameproof areas.

Carbon dioxide

Carbon dioxide is one of the classic refrigerants which had fallen into almost complete disuse, but which is likely to make a comeback. The major objection to the use of carbon dioxide as a refrigerant is its low critical point and its high operating pressure compared with other refrigerants. Carbon dioxide is likely to be used in three distinct ways:

- as a supercritical refrigerant for automobile air-conditioning. A significant number of developmental efforts are directed towards this application;
- as a low-stage refrigerant in a cascade system using a more conventional refrigerant such as HFC or ammonia in the high-temperature stage. Cascade carbon

dioxide systems are in use in about 20 supermarket installations in Europe;
- as a refrigerant operating on a large scale with heat rejection in the supercritical field. The high pressure would be in the range of 70 to 100 bars. Refrigerating equipment for such pressure levels is not yet available at economic prices today [Pearson, 1999].

Water

Water is a non-toxic, non-flammable, environmentally friendly refrigerant for use at temperatures above 0°C. The major disadvantages of water as a refrigerant are its high specific volume due to the very low pressure at which it must be evaporated. Low-pressure systems using large centrifugal or axial compressors are being developed. It remains to be seen whether the capital cost and reliability of water refrigerating systems will be acceptable [Pearson, 1999]. In addition, water has been used as refrigerant in water/lithium bromide absorption systems for years.

Non-vapour-compression technologies

In the field of technologies that provide suitable alternatives to vapour compression, key research focuses include absorption and adsorption technology, solar refrigeration, desiccant cooling, air cycles, the Stirling cycle, and thermoelectric cooling. These technologies are presented in section 4.2.2.

The introduction of alternative refrigerants and technologies involves the implementation of actions involving various refrigeration stakeholders at various levels.

Obviously, these actions can only be implemented where the prerequisite investments (within a long-term strategic framework) are available. The changing regulatory environment has made it increasingly difficult to define investment policy. The long-term use of HFCs is being debated in some countries. HFCs were developed, following extensive research and development, in order to address Montreal-Protocol commitments; however, they are now in the Kyoto-Protocol basket of six greenhouse gases and should be mitigated.

In certain countries, regulations specifying restrictions or a ban on the production of HFCs (Denmark, Austria, United Kingdom, Switzerland, Ireland, Luxembourg) are being considered, or taxes on HFC use (Denmark, Norway, Sweden, Ireland, Japan) have been adopted.

Achievements

Beyond the achievements realised thanks to actions at all levels in order to develop new technologies and alternative refrigerants, figures on CFC and HCFC consumption and production provide an excellent summary of progress.

CFCs

The objectives governing the use of CFCs in

Table E: Actions implemented in order to phase-in alternative refrigerants and technologies

Stakeholders	Actions
Researchers	R&D of sustainable refrigerants and technologies
Designers and manufacturers	R&D enabling retrofitting/design of alternative refrigerants, equipment and technologies
Distributors	Setting up of the logistics required Providing of information for users
Plant operators	Retrofitting (where possible) or replacement of
Maintenance companies	the existing plant
End users	Training of service and maintenance technicians

developed countries were defined by the Montreal Protocol in 1987. Following the adoption of the Montreal Protocol, production and consumption of CFCs decreased rapidly as of 1988. Overall, on a global scale, the total production of CFCs in 1999 represented only 4% of the 1988 (the peak production year) production level [AFEAS,].

HCFCs

The time frame for HCFC phase-out was specified in 1992 by the Copenhagen Amendment to the Montreal Protocol.

HCFCs, thanks to their far less adverse impact on ozone depletion, were adopted by the refrigeration industry as an alternative to CFCs; new mixtures were developed in order to address rising demand, and production increased accordingly. This trend that was followed by a levelling off, then decreasing production starting in 1997.

3.2.1.4 New developments in the cold chain

Present progress is the result of efforts in the food industry and supermarkets and is mainly driven by consumer needs. Authorities also exert a strong influence via regulations, but voluntary measures are gradually emerging to an increasing extent. Salient developments that should be mentioned are:

- cleanability; increasing importance is being attached to cleanability in order to prevent contamination of foods. Improvements concern shapes of connecting areas, adjustment of panels, possibility of dismantling systems for cleaning, fitting of cleaning systems on the equipment, recording of cleaning operations on logbooks;
- flexibility of equipment, examples are the multi-compartment and multi-temperatures refrigerated vehicles, swap bodies in combined transport and direct access storage in cold stores instead of mass storage. Flexibility means equipment that can meet several functions. Flexibility entails a better return on investment and is finally more sustainable;
- regulation of ambient conditions, examples are controlled atmosphere for preservation of fruit and vegetables or clean rooms in the food industry;
- traceability of foods; traceability of temperatures during the cold chain is part of the global concept of traceability;
- consumer information; labelling of temperatures, thermometers attached to display cabinets or refrigerators, labelling of energy consumption of household appliances are examples;
- interface management; complying with the cold chain in refrigerated areas (cold stores, refrigerated transport vehicles, display cabinets) is quite well mastered. However, it is more difficult to limit temperature rise at interfaces. Valuable development in design and operation (codes of practice) has been achieved.

All these developments are key facets of sustainable preservation of foods. Energy consumption of processes and systems should be also addressed.

3.2.1.5. New developments in air-conditioning and heating systems

Indoor air quality (IAQ) and its relationship with occupant comfort, health and productivity has received increased attention in recent years. Assuring proper IAQ involves handling various factors: ventilation, source control, humidity management and filtration/air cleaning [Schultz, 2001].

Ventilation air (outdoor or fresh air) has historically been used to assure acceptable IAQ. This works on the principle of dilution of indoor-source contaminants with relatively clean outdoor air. But the use of ventilation air for dilution can significantly increase the cooling and heating load. Increased emphasis on the use of energy-recovery technologies has helped to reduce the energy penalty associated with dilution ventilation.

To assure IAQ through dilution ventilation, firstly the proper amount of ventilation air must be introduced to the system and, second, the proper amount of ventilation must be delivered to the zone. But buildings often do not run under the conditions for which the air-conditioning systems were designed.

Dynamic control, that is real-time sensing of airflow, occupancy, and air quality along with real-time calculation of required airflow is being introduced. It represents opportunities to assure IAQ at all operating conditions without energy-wasteful over-ventilation.

Source control includes the building, equipment and people. Building products and equipment used within buildings are evaluated for contaminant generation. The air-conditioning systems themselves can become a significant source of contaminants – particularly those associated with microbiological contamination – without proper unit design and maintenance. Research is still needed to identify construction materials that inhibit the growth of microbes inside air-conditioning systems. This includes drain pans, insulation, blowers, coils, duct materials and filters. Investigations on cost-effective anti-microbial materials to assess their impact on IAQ are also required [ARI, 1997].

Humidity management can become a serious issue with the introduction of significant amounts of ventilation air, especially in humid climates. Air cleaning is the only option when outdoor air of unacceptable quality must be used for ventilation. There is currently a significant amount of research in commercial air cleaning to remove gaseous contaminants as well as particulate matter. Air cleaning technology exists today and has been used for many years in industrial and military applications. The next step will be to bring it into commercial air-conditioning applications cost effectively.

Energy efficiency is becoming increasingly important within the sustainable building approach, and several developments such as 'low-temperature heating' and 'high-temperature cooling' are taking place. Special developments include:

- separation of fresh air and re-circulated air,
- separation of dehumidification and removal of the cooling load by means of cooling ceilings,
- thermally activated parts of the building such as walls and concrete ceilings,
- internal storage systems,
- external storage systems (in-ground storage with direct cooling at least at the beginning of the cooling season),
- improved cooling tower concepts,
- improved exhaust air heat (and 'cold') recovery systems,
- fresh air heating systems for low-energy buildings,
- open and closed cycle ground-source systems.

3.2.2 Developing countries

3.2.2.1 Actions implemented

In order to respond to the challenges of sustainable development, several positive actions have been carried out in developing countries:

- within the framework of the Multilateral Fund set up in the context of the Montreal Protocol, and under the auspices of UNEP, Refrigerant Management Plans (RMPs) have been set up in many countries. These programmes have made it possible to prepare inventories of existing equipment. This initial diagnosis is an essential prerequisite to actions and training initiatives designed to achieve sustainable development;
- implementation of training programmes addressing refrigeration technicians' and customs officers' needs;

- adoption of regulations that in many cases go beyond the scope of the Montreal Protocol;
- publication of statistics on the production and consumption of CFCs and HCFCs;
- production and consumption of CFCs: The Vienna Amendment, adopted in 1995, stipulates 100% phase-out of CFCs in Article-5 countries as of 2010. The results show that during the 1986 to 1995 period, production and consumption of CFCs gradually rose, and have been dropping since 1996;
- production and consumption of HCFCs: The Vienna Amendment, adopted in 1995, stipulates that the phase-out of HCFCs shall start in 2010 and that 100% phase out of HCFCs shall be achieved as of 2040.

3.2.2.2 Limits

However, the development of the refrigeration sector has limits that should be emphasised here:

- the training of technicians in recovery techniques is a vital measure, but not enough basic training for refrigeration technicians and installers is available at the moment. Current training is made up of short courses. However, long-term programmes are necessary in order to turn out skilled refrigeration technicians.
- more courses and training programmes on ammonia, HFCs (particularly refrigerant mixtures) and hydrocarbons are needed.
- the certification of refrigerating-plant operators and maintenance technicians is not common practice and tends to be too infrequently applied. The consequences of insufficient certification range from high plant leakage to plant anomalies.
- the relatively low cost of CFC refrigerants (which will not be banned until 2010) in developing countries is not an incentive to plant containment and refrigerant recovery during maintenance operations and disposal of plant. Conversely, refrigerating plant is expensive and this situation does not encourage replacement of equipment once it becomes obsolete. Investing in recovery and recycling equipment also tends to be prohibitive for developing countries;
- sales of obsolete, environmentally unfriendly equipment in developing countries;
- regeneration and refrigerant destruction plants are scarce in developing countries.
- at present, actions designed to implement true cold chains lack overall co-ordination.

3.3 Approach on per-sector basis

Refrigeration and air-conditioning application fields have been divided into eight sectors. For each sector we have mentioned the main changes, achievements and limits. A more detailed report on each sector is provided in Annexe 3.

3.3.1 Domestic refrigeration

- starting in 1992-1994, developed countries moved to new refrigerants, particularly HFC134a, following the ban on CFCs;
- certain countries, especially in Europe, have opted for widespread use of HC600a (isobutane), a refrigerant with no greenhouse effect but which is a flammable gas;
- higher refrigerator energy efficiency has been achieved over the last 30 years.

3.3.2 Commercial refrigeration

- small shops are mainly equipped with self-contained display cabinets using HFC134a. A few of them use HFC404A or hydrocarbons. However, many shops are still equipped with CFC12 appliances;
- supermarkets are mainly equipped with central machinery rooms. The most common refrigerant is now HFC404A in replacement of CFCs or HCFC22;
- indirect systems using HFCs, ammonia or HCs as the primary refrigerant and single-phase liquid or phase-change binary ice or

CO_2 heat-transfer fluids, are increasingly being used;
- great improvements in the quality of the cold chain and in the achievement of better levels of food-product temperature have been obtained;
- a huge gap still remains between developed-country distribution systems and those in developing countries.

3.3.3 Cold storage

- the phase-out of CFCs and the planned phase-out of HCFCs have led to an overall increase in the use of ammonia. HFC404A and HFC507 are also used;
- progress has been achieved in the field of energy efficiency thanks to new design and new logistics systems.

Again in this sector, the gap between developed and developing countries is a concern.

3.3.4 Industrial refrigeration

From a refrigerant viewpoint, the situation encountered in this sector is similar to that seen in the cold-storage sector. Ammonia has now become the most widely used refrigerant in this field.

3.3.5 Air-conditioning (air-cooled systems)

- up until its phase-out became compulsory within the framework of the Montreal Protocol, HCFC22 was (and still is) the most widely used refrigerant in this sector. Mixtures of HFCs have been developed in order to replace HCFC22;
- in developing countries, the demand for HCFC22 is likely to rise over the next few years.

3.3.6 Air-conditioning (water chillers)

- HFCs are now the most widely used replacements for CFCs and HCFCs, but HCFCs are still used;
- in developing countries the demand for CFCs has decreased markedly.

3.3.7 Transport

- before the signature of the Montreal Protocol the main refrigerants utilised were CFC12 for chilled foods and CFC502 and CFC500 for frozen foods. After a short transition period during which HCFC22 and HCFC blends were used, HFC404A is the main refrigerant in current use in road vehicles and HFC134a is widely used in refrigerated containers;
- developing countries have very poor refrigerated road and rail transport networks and this is another area requiring addressing.

3.3.8 Mobile air-conditioning

- since 1995, in developed countries, all new air-conditioned cars have been utilising HFC134a instead of CFC12;
- CO_2 and hydrocarbons are now being intensively investigated;
- a lot has been done in order to reduce both refrigerant charges and emissions.

Part 4: Challenges

4.1 General challenges

The main general challenges can be summarised as follows.

Developed countries:

- to address the environmental impact of refrigerating systems by using an overall life cycle approach such as the LCCP concept for greenhouse impact. To this end, the standardising of its calculation and promotion of the application of this concept among all stakeholders is important;
- to consider the whole system and not just the refrigerant;
- to design equipment with a reduced refrigerating capacity as far as practicable, for instance by attaching great importance to well-calculated and efficient insulation;
- to reduce leakage thanks to better design;
- to bear in mind that the primary goal of a refrigerating plant is to make it possible to supply high-quality foodstuffs and to ensure high indoor air quality;
- to give top priority to proper maintenance: such practice reduces leakage and improves energy efficiency;
- to recover, recycle, regenerate or destroy, following standardised procedures, refrigerants, lubricants and materials used in refrigerating plants;
- to further improve energy efficiency and performance;
- to use the capabilities of heat-pump technologies for reducing energy consumption by utilising renewable energy sources and waste heat.

Developing countries:

- to make refrigeration available in developing countries for food, industry and air-conditioning purposes;
- to set as a rule that developing countries have the same rights to refrigeration technology as developed countries;
- to take advantage of current technological achievements in order to develop directly new environmentally friendly, reliable, robust and cost-effective technology thanks to technology transfer and increased training and education provided by developed countries;
- to avoid dumping old polluting, high-energy-consuming technology in developing countries, even if initial costs appear to be attractively low.

4.2 Industrialised countries

Sustainable development-driven challenges to be met by the refrigeration sector in years to come will be numerous; the durably addressing of issues that so far have no long-term solutions constitutes a major challenge (covered in Part 2) and so does the expanding of actions that have already been implemented (focused on in Part 3). In this section, we will explore several refrigeration technologies and applications that will undoubtedly play important roles in ensuring sustainable development, drawing the following distinctions:

- applications using vapour-compression technology; these are well-known, but still have many inherent challenges to be met in terms of sustainable development;
- technology and applications based on non-vapour-compression systems, which, even if certain systems are already in use, still require concerted research, developmental and promotional efforts.

4.2.1 Technologies and applications using vapour-compression systems

4.2.1.1 Introduction

Most specialists are of the opinion that vapour-compression systems are likely to be the dominating trend over the next 20 years. The challenge to be met is to develop vapour-compression systems that are environmentally friendly, energy-efficient, robust and sustainable, cost-effective and safe for users.

In developing countries, there are additional issues to be addressed: environmentally friendly technology has to be made available (and should not be technology discarded by industrialised countries), training in the installation, maintenance and good-practice procedures has to be provided, and the cost must be tailored to suit low budgets. Bearing in mind these challenges, here are some global objective challenges for the next 20 years, with 2000 as baseline:

- to reduce energy consumption by 30% to 50%,
- to halve leakage,
- to improve LCCP by 30% to 50%,
- to reduce the refrigerant charge by 30% to 50%.

However, defining quantitative objectives is useful only if reliable benchmarks are defined and validated. In this field, at national, regional and global levels, structures and procedures enabling benchmarking to be performed should be set up and periodic assessment should be performed in order to monitor progress.

Refrigerant selection is only one facet of an overall system-focused approach. When assessing the environmental impact, the entire system must be examined. The life cycle concept, on which the LCCP concept is based, takes on its full meaning in this approach, and should be widely applied and used as a benchmark by refrigeration contractors.

It is important to choose between several refrigerants and to opt, according to the applications and the desired temperature levels, for the refrigerant with the optimal profile in terms of LCCP, safety, cost-effectiveness and reliability. Being able to choose between several refrigerants makes it possible, according to the applications, to opt for the most energy-efficient and the most environmentally friendly solution.

The challenges to be met for vapour-compression systems are the following:

- to promote R&D in certain specific fields, for instance the development of low-capacity ammonia compressors or high-capacity CO_2 compressors;
- to develop international standards promoting the application of the life cycle assessment to the design of refrigerating systems;
- to raise manufacturers', installers' and users' awareness of the LCCP concept in order to improve refrigerant containment and raise energy efficiency;
- to give higher priority to international regulations than to national regulations;
- to promote the development of international standards on refrigerating systems and equipment and refrigerants to a greater extent than national standards; international standards or codes on hydrocarbon and ammonia use would be particularly valuable;
- in developing countries, to promote the transfer of technology with proven reliability (such as vapour-compression systems) and the use of new refrigerants;
- to provide suitable training, along with technology transfer.

4.2.1.2 Air-conditioning and sustainable buildings

General solution strategies [ASHRAE/IESNA, 1989]:

- consider energy efficiency from the outset of the building design process;
- seek the active participation of members of the design team including architects, engineers and builders;
- consider building attributes such as building function, form, orientation, window/wall ratio and HVAC system types early in the design process;
- minimise heating and cooling loads by analysing the external and internal loads both for peak-load and part-load conditions;
- consider how to reclaim, redistribute and store energy for later use;
- transporting energy from production and availability locations to locations of demand should be considered instead of the purchase of additional energy;
- never reject waste energy at temperatures usable for space conditioning without calculating the benefits of energy recovery or reuse;
- make use of heat pumps for upgrading waste heat to the temperature level required for further use;
- maintaining good indoor air quality (IAQ) by introducing the outside air flow recommended in standards. The energy cost for greater quantities can be disproportionate;
- Apply new concepts such as low-temperature heating and high-temperature cooling;
- Use design solutions that are easily understood by building occupants.

Principles of design – building envelope [ASHRAE/IESNA, 1989]:

- the building design should attempt to offset gains and losses of heat, light and moisture between the interior and exterior of the building, among interior spaces and over time;
- in energy design, the desired goal should be to produce a controlled membrane that allows or prevents heat, light and moisture flow so as to achieve a balance between internal and external loads. Thus the envelope becomes an integral part of the building's environmental conditioning system;
- traditional building components must be used – insulation, caulking, weather stripping and solar shading devices;
- thermal conductivity should be controlled through the use of insulation, thermal mass and/or phase-change thermal storage at levels that minimise net heating and cooling.

Principles of design – Air-conditioning systems [ASHRAE/IESNA, 1989]:

- major heat-generating equipment (computer centres, kitchen areas, etc.) should, where practical, be located where it can offset heat losses;
- the supply of zone cooling and heating should be sequenced to prevent the simultaneous operation of heating and cooling systems for the same space;
- controls should be provided to allow systems to operate in an occupied and an unoccupied mode.

4.2.1.3 Mobile air-conditioning

Environmental impact

Assumptions made by Ecofys Energy and Environment [Harnisch; Hendriks, 2001] are interesting. According to this report, by 2010 the total quantity of HFC refrigerant in mobile air-conditioning in Europe will be 73,630 tonnes and total emissions 10,120 t/y (not including decommissioning estimated as being 3480 t/y). The amount of HFCs contained in all the other refrigeration and air-conditioning equipment (domestic, commercial, transport and industrial refrigeration, stationary air-conditioning and heat pumps) is estimated to be 75,800 tonnes and total emissions 7,940 tonnes.

These figures show that in terms of the amount of refrigerant in use and emissions occuring, the impact of mobile air-conditioning (cars and utility vehicles) in 2010 would be approximately equivalent to that of all other refrigeration and air-conditioning sectors. The share of new vehicles equipped with air-conditioning is estimated in this report to have increased from 10% in 1993 to 50% in 1997 and assumed to further increase by 2% per year thereafter.

Socio-economic stakes

Automobile air-conditioning provides additional comfort and tends to significantly reduce the number of accidents: many insurance companies now offer reduced insurance premiums for owners of air-conditioned vehicles. However consumer demand and manufacturers' designs favour use of more glass and this trend raises heat penetration.

Challenges

The first challenge to be met is to reduce the additional fuel consumption of the vehicle related to the operating of the air-conditioning system. This additional consumption, at present evaluated as being 6% of the total annual fuel consumption, is likely to be substantially reduced in years to come thanks to improved refrigerating-system COPs. This value is given for an HFC-134a air-conditioning system weighing 15kg in a United States made car driven 16.400 km per year.

Some progress should be made concerning the passenger compartment in order to reduce warming of the vehicle when it is stationary (insulation, glass radiation, etc.).

Another challenge is improving component tightness in the vehicle's air-conditioning system. Although significant progress has been achieved in this field (new vehicles emit only 4% to 7% of the emissions of pre-1994 vehicles – see Annex 3), a lot more progress remains to be realised, particularly in terms of widespread use of brazed piping instead of flexible hoses or metallic bellows.

Another major challenge is user safety: the safety of environmentally friendly, but flammable, hydrocarbon refrigerants in vehicle air-conditioning systems needs to be addressed. Another option under development is the use of CO_2 as a refrigerant for automobile air-conditioning.

4.2.1.4. Heat pumps

A heat pump is a device suitable for both heating and cooling. At present about 125 million heat pumps with a thermal output of 1,300TWh/y are in operation worldwide, reducing CO_2 emission by about 130Mt/y thanks to reductions in primary energy consumption.

The diffusion of the heat pump is negligible in the transport sector, low in industry and agriculture, but already substantial in the residential/commercial sector of some countries. Whereas in the residential sector there are typically a large number of small units, in industry there are a relatively small number of large heat pumps.

Residential and commercial applications

The main application of heat pumps is the residential and commercial sector. The thermal global output relating to residential applications is 750TWh/y and that of commercial applications is 350TWh/y. Concerning the residential applications, the majority of heat pumps in operation are reversible air-to-air conditioners for both heating and cooling.

In the United States, Japan and in the south-east Asia, a continuous changeover from cooling-only to heating and cooling air/air units has taken place. The units have been improved by advanced compressor and heat exchanger technologies. Concerning outside air units the introduction of the inverter technology, (compressor speed control), means an improvement in efficiency as well as comfort. In some large buildings, chillers have been modified to heat pumps for both heating and cooling. In Stockholm, Sweden, large heat pumps supply about 35% of the total annual district heating demand.

Industrial applications

Industrial Heat Pumps (IHPs) are a useful technology option for recovering industrial waste heat. The five main configurations are closed-cycle compression, mechanical vapour recompression (MVR), thermal vapour recompression (TVR), absorption, and absorption heat transformation.

The primary applications for IHPs are food processes, chemical processes, pulp and paper processes, petrochemical and refining processes, drying processes. Surveys [IEA/HPC, 1995] have found that about 30,000 IHPs are now in use worldwide. Their heating capacity ranges widely from 100kW to a few MW. IHPs are employed in all major industries, but the largest number of installations is in the lumber industry. The total heat demand in industry supplied by IHPs also ranges widely from almost negligible to 15% (Norway).

Stakes and challenges

Heat pumps are an efficient tool to reduce CO_2 emissions. Comparing heat delivery by means of heat pumps with conventional methods, (burning fossil fuels), one can easily show that with heat pumps, primary energy consumption can be at least cut in half.

The potential for reducing CO_2 emissions assuming a 30% share in the building sector using technology presently available is about 6% of the total worldwide CO_2 emission of 22 000 Mt CO_2/y (1997).

With future technologies up to 16% reduction seem possible: 2,000Mt CO_2/y in residential applications, 1,100Mt CO_2/y in commercial application and 200Mt CO_2/y in industrial applications [IEA, 2000].

- In residential and commercial applications, great efforts remain to be made to raise the penetration of this technology, especially in Europe where heat-pump technology diffusion is still very low.
- In industrial applications, the overall use of IHPs, to date, has been far below their true technical and economic potential. IHPs can reduce total industrial process heat energy consumption by an average of 2% to 5%. This equates to 1,300 to 3,100 PJ/year worldwide. At the individual plant level, an IHP will make energy savings of 15% to 30% of that required for process heat [IEA, 2000]. Despite the technical and economic benefits of IHPs, relatively few IHPs are used in industry worldwide. Factors explaining this situation include:
  - lack of suitable hardware in some types of applications;
  - lack of demonstration plants in different types of industries;
  - lack of combined knowledge of process technology and heat pump technology in industry, consulting firms, etc;
  - lack of system suppliers (typically components are assembled on the spot);
  - lack of suitable alternative refrigerants for high temperature (above 80°C) closed-cycle compression applications.

Organisations that support the industrial sector, particularly those with the capacity to provide financial assistance, for instance government agencies, and utilities can play important roles in helping to realise the potential benefits of IHPs. These organisations can:

- help reduce the perceived risk or uncertainty associated with IHPs by sponsoring demonstration projects and by helping in the information dissemination and awareness raising process;
- increase the financial attractiveness of IHPs by providing financial assistance to defray investment costs or by applying lower energy rates to lower energy costs.

Organisations outside of industry, for instance government, utilities and engineering firms can also actively support continued IHP technology development to ensure improvements in performance and to extend the range of IHP applications such as in high-temperature processes.

4.2.2 Non-vapour-compression systems: Technology and applications

4.2.2.1 Absorption-adsorption

Absorption and adsorption cooling systems are generally fuel-fired systems that provide the most practical means of providing both commercial and industrial cooling without imposing a major drain on a developing electric infrastructure and therefore a major drain on the limited developmental capital available to most developing countries.

These systems can directly use various fuels including natural gas, oil, and indirectly coal or other solid fuels such as biomass and combustible waste as a heat source; they can also be fired from the waste heat given off from industrial processes or electric generation, providing a very efficient 'cogeneration' system. Cogeneration systems provide the greatest potential advantages by providing high efficiencies unachievable with other technologies (see section 4.1.2).

For all these reasons, adsorption and absorption systems are widely used today in areas where restraining the demands on the electric distribution system has been a priority. However, to accelerate the implementation of these systems, a number of technical issues need to be addressed.

Technology status

Adsorption and absorption technologies are two refrigeration disciplines that have traditionally commanded only a niche position on the world market. Based on thermally activated cycles, they are represented on the market by a relatively broad range of products covering capacities from small residential appliances to large industrial refrigeration plants.

These technologies are still wrestling with two problems responsible for the lower acceptance of their products on the current market; their higher cost and lower efficiency as compared with continuously improving mechanically-driven air-conditioning and refrigeration technologies.

Absorption and adsorption are the only two practical approaches to heat-activated systems. They have often been relegated to applications where thermal energy was free or cheap. Currently, this translates into an asset that can play a significant role in reducing thermal pollution.

One area where this potential could and is being realised is its application in systems combined with power generation.
There, improvements in the efficiency of primary energy use are significant. However, even where thermal energy is not cheap, for instance in Japan, absorbers are widely used to control electrical power demand. The same is true in China, where the motivation is the cost of expanding power supply. These technologies are used in different ways and their benefits are so significant that further development would definitely be warranted.

Adsorption technology issues

In the adsorption/desiccant area the major objectives are:

- simplification of packaged units and their controls so that the overall cost could be reduced,
- less expensive components would be desirable,
- improvements in operating characteristics would be needed to reduce the influence of auxiliary power requirements on the operating costs.

Absorption technology issues

Absorption based air-conditioning in the form of large absorption chillers for major commercial buildings or industrial applications is the most widespread application of these technologies today. Technical developments needed to make this equipment more widely applied must address the following issues:

- higher efficiency absorption systems are larger, more material intensive, and therefore more expensive than their electrically powered counterparts. Developments in system simplification and cost reduction are essential;
- Absorption systems must be developed that are practical for the smaller commercial structures. This is the key to bringing the advantages of these systems to smaller businesses that are more likely to be locally owned. Of particular interest would be a small-capacity fuel-fired air conditioners, requiring no electrical connections, suitable for application to small storefronts;
- Adaptation of fuel-fired absorption refrigeration systems for food preservation, particularly in rural locations where no electricity is available, should be a tremendous aid in improving the efficiency of food distribution in the developing world. Reduced food spoilage will increase food supplies, and decrease the retail cost of foods, while improving agricultural profitability. With proper development, this technology should be practical in small low-cost systems appropriate for smaller farms or rural cooperatives;
- Development of high efficiency absorption cycles that can be operated without consuming and evaporating fresh water for heat rejection. Such 'air-cooled' systems would be more suitable to areas where fresh water is in short supply.

Absorption air-conditioning and refrigerating systems can be of significant assistance in cutting the cost and time required to develop critical infrastructures in developing nations. However, this technology needs to be developed in directions that serve this market.

Absorption applied to chillers

Absorption chillers convert heat energy into useful refrigeration with minimal electricity requirement. Absorption chillers also employ environmentally benign working fluids and produce very little noise. These factors make absorption chillers attractive wherever electricity is expensive, unavailable or unreliable.

Absorption chillers are 25% to 100% more expensive than conventional vapour-compression chillers with absorption chillers becoming relatively more cost-effective in the larger (greater than 1MW) size range. Consequently, selection of an absorption chiller must be justified by either energy cost savings, government incentives, electrical reliability/scarcity problems or environmental benefits.

Energy savings can be obtained in geographic locations where fuel is less expensive than electricity (electricity to fuel kWh price >5) or where waste heat of low value is used to fire the absorption chiller.

Environmental issues

The principal environmental concern is the emissions of carbon dioxide (CO_2) caused by the energy consumption of absorption chillers, compared with conventional vapour-compression chillers. While vapour compression chillers are a lot more efficient, they consume electricity, which is normally more carbon intensive than heat. Multi-stage absorption cycles can also be used to improve energy efficiency in absorption chillers and reduce CO_2 emissions. Hence carbon emissions comparisons must take into account the efficiency (COP) of the absorption unit, the fuel source and the carbon intensity of the national electricity network.

Technology advances

Over the next ten years, there is expected to be a shift away from large centralised power stations towards smaller on-site power generation. New power generation technologies (such as. micro-turbines, fuel cells, renewables, Stirling engines), economies of mass production, electricity industry deregulation, and concerns over power reliability, are expected to drive this 'distributed generation' (DG) revolution. Indeed, developing countries have an opportunity to leapfrog the large centralised power generation economy and move directly to a distributed economy. This can benefit local communities and it avoids huge transmission infrastructure investment.

Solar air-conditioning

Solar heated absorption chillers would provide an excellent low emissions technology for air-conditioning if this could be achieved in a cost-effective manner. It also eliminates the need for transmission infrastructure in developing countries.

Improved efficiency

The bulk of industrial absorption chiller research has been directed at developing more efficient chillers. A number of companies are close to commercialising three-stage gas-fired absorption chillers. With COPs of about 1.4, CO_2 emissions can be brought down to about 150 kg/MWh of refrigeration. Similarly, a number of generator, absorber heat-exchange (GAX) cycles are being developed, particularly using the ammonia/water refrigerant absorbent pair for residential/light commercial heat-pump applications. The ability to operate below 0°C is advantageous for heat pump applications in cold climates.

Unfortunately, improved efficiency generally requires increased heat transfer surface area, this raises the cost of the system.

Conclusion

Absorption chillers are environmentally attractive in many situations. New absorption cycles and new equipment designs are constantly being investigated to optimise the cost, size and operability of absorption chillers. This work should continue.

4.2.2.2 Solar technology

In spite of the development of solar cooling units in the 1930s, the growing technological knowledge of absorption refrigeration, and the technological advances made by solar technology, until now it has been difficult to develop a single solar cooling technology that satisfies the needs of developing countries. Although development has encountered many obstacles, solar refrigeration now enables millions of doses of vaccines to be stored in hot countries.

Among key achievements in the solar refrigeration field is the development of absorption air-conditioning systems operated with lithium bromide-water solutions. These systems work with simple flat-plate solar collectors at operating temperatures of 75°C to 100°C. Several units are operating satisfactorily worldwide.

The refrigeration technologies considered to have the best perspectives for use with solar energy systems are: a) absorption cycles, b) desiccant cooling, c) new cooling cycles with liquid absorbents, d) solid sorption closed cycles (thermochemical reactions and adsorption), e) advanced ejection vapour cycles at low generation temperatures, f) advanced combined cycles such as dehumidification with conventional temperature control.

For the operation of solar refrigeration systems that use thermal energy, the temperature range required is 75°C to 90°C, operating with a lithium bromide-water system, in order to obtain chilled water at a temperature of 8°C to 10°C, for air-conditioning facilities and the operating temperature range of 120°C to 160°C in the case of low-temperature production (-10°C to -30°C) where an ammonia-water system is used.

For ice production (-10°C), an ammonia-water absorption cycle is proposed, with solar collector concentrators or with vacuum collectors that reach temperatures of 120°C to 130°C. With vacuum collectors, or with compound parabolic solar collectors (CPC), it is possible to eliminate problems associated with the use of a solar tracking system. At present, this technology is in an industrial developmental phase and it is expected that these solar devices will above all be used in cooling cycles, due to their simplicity, easy handling and possible low cost in comparison with other solar heating systems available.

Among the main arguments in favour of the development of solar cooling systems are the following:

- environmental aspects; the use of solar heat reduces the fossil energy demand;
- solar industry aspects; the solar collectors industry has developed in the last 15 years in certain countries. Their high-efficiency, reliable products and decreasing prices have made their systems a permanent feature on some markets. Another important factor is the experience acquired in big solar plants where some thousands of square meters of solar collectors have been installed and are working satisfactorily;
- integral design; the new concepts of integral design, as well as the capacity of complex technical systems of control with support of on-line units, open new possibilities for the good integration of solar active components for some facilities, such as cooling. This new focus on the integral system, more than on a specific technology has been developing strongly in the last years. This has produced facilities with an efficient operation and a consequent energy saving with a minimum environmental impact.

By using photovoltaic conversion, solar energy can also be employed to operate refrigerating cycles. Photovoltaic conversion allows the operation of cooling units based on mechanical vapour compression as well as of thermoelectric refrigerators. The latter are now used in hospitals and rural clinics in isolated regions, for vaccine and medicine storage complying with the standards set by the World Health Organization.

It is difficult to estimate the potential market for solar refrigeration in developing countries. However, the growing demand for ice for the conservation and transportation of perishable products, the development of cold storage for food storage, the freezing of fresh and cooked products, space air-conditioning, among other refrigeration applications, are only a sample of the potential applications of this technology. Many regions in developing countries have numerous clear days annually, with an average solar irradiation of over $700W/m^2$.

Local companies or joint ventures involving local and foreign companies will focus on the development of the technology and installation of concentrator solar collectors of the compound parabolic type (CPC) that will be the most suitable for solar cooling. The technological problems to overcome will be the design and production of control devices, particularly for the production of low-capacity units, which have drawbacks: their impact will be smaller they will cost more.

To be able to achieve the implementation of the above-mentioned strategy, it is necessary to carry out:

- a market study on various aspects of cooling demand, with priority given to ice production, proposing cooling units producing 2 tonnes to 5 tonnes of ice per day, for the supply of small fishing businesses, for example;
- to establish the infrastructure required for the production of solar refrigeration units by existing industrial plants and to obtain support from foreign companies where possible;

- important aspects include the sharing of the technological and economic benefits of solar refrigeration technologies, as well as the obtaining of financing and the investigation of the rate of recovery of the initial investment;
- to propose educational programmes and training in the operation and maintenance of solar plants as well as in the design and instrumentation aspects;
- in the case of the conservation of perishable products using ice, it is important to have access to cold-store design, construction and instrumentation technology.

4.2.2.3 Desiccant cooling

Desiccants, or more specifically desiccant technology, include a broad spectrum of systems designed with desiccant components to provide cooling, dehumidification, and ventilation functions to control the quality of the indoor environment in the industrial and commercial sectors. These are cooling systems that provide latent and sensible load from fresh air make up. Enthalpy exchangers either remove or conserve moisture for the controlled space.

New desiccant materials such as titanium silicate have much higher affinities for water than previously used desiccants such as silica gel. The higher efficiencies of these newer desiccants make it possible to design practicable air-conditioning systems [UNEP 1998]. According to Wurm (1999), in the United States, annual production of desiccant systems and components in 1997 was worth nearly USD100m, representing about 1% of all United States HVAC & R market shipments, and is expected to more than triple by the year 2003.

Desiccant cooling systems are an interesting solution, especially for hot and dry regions; high humidity limits the cooling capacity. Hybrid systems, combinations with compression or sorption machines, where the excess heat is used for driving the desiccant system, can be an excellent solution. Another advantage of desiccant systems is that no cooling tower is necessary.

But many production and technical issues still have to be addressed. Among the most important goals are the reduction of rotor matrix costs for dehumidifiers and enthalpy exchangers, and a continuous effort of educating architects and engineers on the equipment and the benefits it can bring to the customer.

Air-conditioning packagers, operators and users need to have an opportunity to acquire confidence in performance and economics of desiccant equipment. Suitable tools have only recently become available. The most important tools in the United States are the rating and testing standards (ASHRAE 139 and ARI 940) that will establish benchmark performance for systems and components of desiccant technology. The GRI/DOE demonstration programmes have been organised to promote confidence in desiccant technology.

4.2.2.4 Trigeneration (combined cooling, heat and power)

Cogeneration is simultaneous production of mechanical energy (often converted into electricity) and thermal energy (heat). The heat is produced at a temperature level such that it can be used to heat premises or employed in industrial processing plants. What was waste heat, becomes useful heat.

This technology is optimised, in order to obtain as much energy as possible, and has considerable benefits from an energy standpoint. In the cogeneration process, when one adds the recovered 'waste heat' to the efficiency of the power production (the optimal efficiency of gas turbines being 32% to 42% and that of gas or diesel thermal engines being 35% to 37%), an overall efficiency of 70% to 85% is achieved.

But this overall efficiency is useful only if both heat and electricity are required at the same time. Thus, in many residential or tertiary-sector applications (offices, hospitals etc), this waste heat can only be utilised in winter and this reduces cogeneration's attractiveness.

It is possible to make further use of the benefits of combined power and heat by using excess heat in refrigerating applications, and this is known as trigeneration. Trigeneration technology has been made possible by the development of absorption units used to produce chilled water, particularly in tertiary sector: office buildings, hospitals, airports and shopping malls. Trigeneration is used in air-conditioning applications and industrial refrigeration (for instance -20°C).

The optimal approach is to employ absorption units using a water-lithium bromide working pair or, in the case of commercial refrigeration, units using an ammonia-water working pair. The mean COPs of these units is 0.7 for simple-effect plant, or one for double-effect plant. The overall refrigerating capacity thus depends on the efficiency of the absorption plant used and the operating conditions such as generator temperature, cooling water temperature and refrigerating temperature.

It is likely that even higher COPs will be obtained by using a triple-effect plant and a such plant is being developed at the moment in which COPs of 1.5 are expected [Meunier, 1999]. However, double- and triple-effect systems will require higher temperature heat input for their operation, which will have an adverse influence on the cogeneration plant operation.

Considerable R&D remains to be performed in this field and the profitability of these systems also requires further investigation. In addition calculation should take into consideration all operating conditions and not just optimal conditions.

Trigeneration systems have important potential advantages. By providing high efficiencies that are unachievable with other technologies, trigeneration reduces overall emissions, including carbon dioxide, reduces water use for heat rejection, reduces fuel consumption and the hard currency drain needed for imported fuel, as well as electric demand, compared with conventional systems. Seizing cogeneration or trigeneration technology now, while electric systems are being developed, can provide developing nations with an advantage in terms of global economic competitiveness through energy efficiency.

4.2.2.5 Cryogenics

The field of cryogenics encompasses all refrigeration technology used to achieve temperatures below 120K, and has paved the way to a huge range of sustainable development promoting applications. Here we give an overview of two of the most promising cryogenic technologies: superconductivity and cryomedicine.

Superconductivity

This is probably the best-known cryogenic effect. It has received industrial attention since the development of NbTi wires and Nb_3Sn tapes, in the 1960s. Direct currents higher than 1,000 A flow without losses in cables of less than 1 mm in diameter when maintained at liquid helium temperatures, that is 4.2K. Use of superconducting materials has made it possible to develop magnetic systems producing intense magnetic fields with various applications.

Here is an overview of some recently developed applications.

- the largest routine application of superconductivity in medical research is

Magnetic Resonance Imaging (MRI) tomography, which has considerably renewed medical radiology in the last 15 years. About 10,000 systems are now in use, and 1,000 are sold every year [Hebral, 1997];

- a widely developed application of superconductivity is the laboratory production of large magnetic fields with small coils. Large magnetic field gradients are accessible with superconducting systems. They have been used for medical applications, for example for the guiding of catheters giving rapid access to a brain aneurysm. Special magnetic guns for launching mini satellites at low cost are another possible application;
- large-scale applications require giant superconducting magnets. CERN (Centre Européen de Recherches Nucléaires/European Center for Nuclear Research) is now operating superconducting capacities to produce the very large electric fields needed to accelerate particles. Also at CERN, the Large Hadron Collider (LHC) project will give access to the high energies needed to test the fundamental theories of particles. For controlled fusion, which could provide access to an essentially infinite source of energy, a new tokamak, ITER, is now under consideration;
- in the case of electrical engineering, several machine prototypes have been developed over the last 15 years, thanks to the availability of high-performance conductors. Generators with superconducting rotating field wiring or both superconducting field winding and armature have been tested, with powers of 10 to 100kW being typically reached. In Japan, for example, units of 70MVA are being tested in the Super GM project;
- for static electrical engineering, several applications have attracted attention as superconducting transformers. The most promising system, at the moment, seems to be the superconducting current limiter. For example, during a thunderstorm, it turns back to the normal state above the critical current, in order to protect the high-voltage distribution lines after lightning, and recovers towards the superconducting state in a few seconds. Such a limiter has been successfully tested up to 40kV;
- the discovery in 1986 of the so-called high Tc superconductors triggered intense research into these compounds. Critical temperatures have been raised from about 25K to roughly 110K. Today, very significant progress has been made and tapes of 1,000m are now produced with valuable properties. Thanks to these properties, the refrigeration difficulties encountered when using liquid helium are much easier to overcome and should simplify applications and reduce the operating costs, since for superconductors with a critical temperature Tc above 77K, liquid nitrogen can be the cooling agent.

Most of these projects need international teams to handle the current developmental challenges of such unique research on the cutting edge of many cryogenic superconductivity, refrigeration and instrumentation technologies.

Cryomedicine – cryobiology

Cryomedicine comprises two domains – cryobiology, in which cryocooling is used for preservation, and cryosurgery, in which cryocooling is used for destructive purposes. In between these two extremes, cryotherapy makes use of cold as an anti-inflammatory treatment in the fields of rheumatology and functional re-education.

In the cryosurgical field, new high-performance equipment has been developed. The advent of miniaturised probes has made it possible to cryosurgically treat obstructive lesions (more often than not benign or malignant tumours) in hollow organs, particularly the bronchi. Echographic guidance has opened up new cryosurgical applications, particularly in the treatment of urological and hepatic disorders. The synergic effects of cryosurgery, chemotherapy and radiotherapy used to treat cancer appear to be clinically confirmed.

Cryomedicine and its cryosurgical component are making, and will continue to make, a valuable contribution to sustainable development, not only in the health sector, but also from sociological and economic standpoints. The efficacy of cryosurgery is not its only benefit: it is also easy to use, safe and does not induce complications. Besides these benefits, it is important to bear in mind that the initial investment cost of cryosurgical equipment and maintenance costs are relatively low.

In developing countries, cryosurgery can be a therapeutic option that is less expensive and therefore more accessible, provided that the refrigerant gas required can be supplied.

Again in the context of a therapeutic approach taking into account sustainable development, cryosurgery must continue to evolve. In the equipment domain, manufacturers must continue to innovate in order to produce high-performance equipment through miniaturisation, probe flexibility, regulation of the temperature and the speed at which the freezing interface advances, evaluation of the target volume.

In medicine, the objective is to clearly define the indications, to perform more thorough evaluation of the effects of associated therapy by performing clinical and experimental trials, and to set up research on the immunological effects of cold, to define tissue cryosensitivity, to publish the results obtained and to promote cryotechnology by expanding teaching programmes and obtaining research funding.

In the context of healthcare economics worldwide, the aim is to raise awareness of a technique that is generally easy-to-use, relatively inexpensive, requiring basic equipment with a wide range of applications, and to promote the use of cryotherapy in developing countries.

Cryobiological applications should also be mentioned here: animal and plant reproduction, research on therapies, preservation of rare and endangered species.

4.2.2.6 Other technologies

Many other technologies that could contribute to sustainable development are being developed or are the focus of research projects. Here are a few examples of emerging technologies.

Air cycle

Air cycle refrigeration was one of the earliest practical cycles and is one of the simplest. No change of state is involved. The efficiency of the system is greatly dependent on compressor and expander efficiencies. In general, an air-cycle system would only be about one-third as efficient as a vapour-compression system.

The relatively low efficiency of the air cycle has restricted its use to certain niche applications:

- where an abundant supply of pressurised air is available, as in a gas turbine before the combustion stage, a proportion of that air can be used to operate an air-cycle system; this is the dominant air-cooling method in jet aircraft where safety issues are of prime concern. Air cycle refrigeration units have recently been applied in the air-conditioning of the German high-speed train;
- air cycles could be of value where a large temperature range is sought [Pearson, 1999].

Stirling cycle refrigeration

The Stirling cycle refrigerating system operates by compressing and expanding a gas at constant temperature.

The Stirling cycle can produce high efficiencies comparable with those of the vapour-compression cycle. It is particularly appropriate for the production of refrigeration at low temperatures. The major disadvantage of the Stirling cycle is that it is difficult to scale up to large size. The Stirling cycle refrigerator appears to have a secure niche application in the production of cryogenic temperatures on a small to medium scale. It is unlikely that the relatively complex Stirling cycle will ever compete effectively with the vapour-compression system for conventional refrigeration [Pearson, 1999].

Thermoelectric cooling

The refrigerating capacity of equipment using the Peltier effect is rather low, but progress is being achieved. The Peltier effect involves absorption of the heat produced by an electric current passing across junctions between two dissimilar metals, alloys or semiconductors. For instance, a Swedish firm is manufacturing cooling trays for drinks and sandwiches, the capacity of which is 300W. Ten years ago, the maximum capacity achieved was only 150W.

Wind refrigeration

Small-scale wind-powered ice-producing systems have excellent potential, especially for small fishing ports in areas where there is a shortage of electricity. The use of ice produced in such wind-powered refrigerators can reduce losses in the quality of fish.

4.3 Developing countries

4.3.1 Education and training

Education is the cornerstone of development in all aspects of refrigeration, including design, installation, and the running and maintenance of refrigerating equipment. In 1986, the IIR launched a large-scale refrigeration-promoting campaign called Refrigeration for Development. A. Gac presented the results of this campaign in 1987 [Gac, 1987]. Based on the data used by A. Gac and updated to take into account current demographics, the present population, the annual deficit of trained staff amounts to roughly 65,000 people. Details are given in table F.

Table F: Assessment of the present situation and annual training requirements in order to provide sufficient refrigeration and air-conditioning specialists worldwide

	Senior staff (1)			Senior technicians (2)			Skilled workers (3)		
	Present	Requi-rements	Total deficit	Present	Requi-rements	Total deficit	Present	Requi-rements	Total deficit
	Persons/y per million inhabitants		Persons /y	Persons/y per million inhabitants		Persons /y	Persons/y per million inhabitants		Persons /y
Least developed countries (4)	0	4	3,200	1	8	5,600	1	7	5,600
Other developing countries (5)	1	3	12,600	3	5	21,000	4	4	16,800
Total			15,800			26,600			22,400

(1) needs estimated as being four people per year per million inhabitants
(2) needs estimated as being eight people per year per million inhabitants
(3) needs estimated as being eight people per year per million inhabitants
(4) 0.8 billion inhabitants
(5) 4.2 billion inhabitants

Over the past few years, short courses have been set up in order to train personnel in good practices in general, and refrigerant recovery, in particular. However, these short courses are no substitute for the basic long-term education of designers, technicians and specialised installers and maintenance personnel. Bilateral and multilateral funding provide the opportunity to train refrigeration technicians and engineers in designing, installing and maintaining equipment; providing suitable refrigeration with the required temperature and humidity levels; ensuring servicing and maintenance at appropriate intervals thanks to good spares management; ensuring optimal energy consumption thanks to optimal design and maintenance.

Such approaches appear very basic in the industrialised world, but implementing them in order to ensure sustainable development in developing countries is in reality a major challenge. Suitable courses and training programmes are currently too scarce: priority must be given to the providing of more education.

4.3.2 Reduction of post-harvest losses

Perishable foodstuffs represent 31% of the total volume of foods consumed in developing countries; these perishable foodstuffs provide 7.5% of the total energy value derived from foods (Jul, 1985). Although perishable foods are low-energy foods, they have other benefits that are sometimes vital in ensuring that a balanced diet is available, since they provide proteins, fibres, vitamins, micronutrients, and a pleasant flavour.

In developing countries, only about one-fifth of perishable foodstuffs is refrigerated, meaning that high losses are incurred following harvest, slaughter, fishing, milking, then during transportation and finally during sale (in markets and stores with no refrigerating equipment).

The challenge to be met is the reduction of these losses and refrigeration is one of the most effective tools enabling loss reduction to be achieved, provided that the value of the perishable foodstuffs justifies the outlay. The higher the price fetched by a foodstuff, the greater is the justification for refrigeration, and conversely, for inexpensive foods, refrigeration may well not be warranted.

Food losses due to non-utilisation of refrigeration were estimated to be about 300 million tonnes of perishable foodstuffs in developing countries [W. Kaminski, 1995]. A reasonable objective for the next 20 years would be to reduce by 30 to 50% losses of perishable foodstuffs (fish, meat, fruit and vegetables) thanks to the setting up of appropriate cold chains.

4.3.3 Development of cold chains

Ensuring both food quality and safety to five billion inhabitants of developing countries, thanks to the setting up of effective cold chains, is a major challenge for the refrigeration sector. The Rome Declaration on World Food Security published on 13 November 1996 reaffirms the right of everyone to have access to safe and nutritious food. The heads of states and governments that signed the Rome Declaration committed themselves to reducing the number of undernourished people to half the November 1996 level by no later than 2015, thus reducing the number of undernourished persons from 800 million to 400 million.

Post-harvest losses (from the field to the table) can be reduced, thanks to implementation of sustainable cold chains and thanks to international trade in the chilled and frozen-food sectors meeting both import and export needs.

Certain links in the cold chain do in fact exist in certain countries. For instance, domestic refrigerators, refrigerating plants for dairy products and meat products, a few cold stores (above all in port facilities and food-processing plants) are in use in developing countries to variable degrees. Other links in the cold chain are often non-existent or scarce: such links include cold storage at production sites, refrigerated road transport and most retail premises.

The setting up of cold chains takes decades and usually requires development plans associated with financial incentives (provided by the state) fuelling investment.

4.3.4 Technology transfer

The refrigerating and air-conditioning systems produced in developing countries are generally based on the technology used in developed countries – mostly because many firms in developing countries, are subsidiaries of corporations based in developed countries. This situation means the specific needs of developing countries are not always sufficiently taken into account. For example, the local temperature and humidity conditions imply that cold-storage facilities require better insulation and insulated flooring. The refrigerating equipment used needs to be more powerful, more robust, and longer-lasting and must also require less maintenance because technicians are few and far between.

Whether or not developing countries should invest in technology that is destined to be phased out in the long-term (for example HCFC systems) that developed countries are already phasing out: this issue merits debate. A better approach would be to provide technology transfer, thus enabling developing countries to use technologies that are currently being used in developed countries (HFCs, ammonia, etc.); such technology transfer also involves adapting equipment to meet specific local needs.

Developing countries have an opportunity to leapfrog the situation encountered in industrialised countries (retroconversion and phasing out of existing equipment) and to embrace sustainable technology directly.

The expansion of solar refrigeration in developing countries has to overcome a number of difficulties, particularly in terms of capacity: solar equipment tends to be of a lower capacity than commercial and industrial ranges. It may be premature to consider that developing countries should be promoting technology that, even in developed countries, has yet to be proven to be fully reliable and profitable.

Technology and information transfer, particularly to developing countries, can speed benefits derived in developed countries. Of particular interest to the air-conditioning and refrigeration industry are developing country initiatives to address ozone depletion and global warming. One avenue for enhancing developing country initiatives is through the sharing of developed country industry technology and information, including standards and certification programmes. Industry has found that developing countries are generally willing to consider adoption of existing industry standards and certification programmes, since country resources are scarce, and the shared information and technology transfer can accelerate the learning curve.

With the adoption of internationally recognised industry standards and certification programmes, the harmonisation process is accelerated and mutually beneficial policies addressing sustainable development are more rapidly implemented.

4.3.5 Strengthening of structures

Government and trade organisations play key roles in the promotion of refrigeration and the setting up of cold chains. In most countries, several ministries are in charge of the refrigeration sector, and usually comprise the ministries of agriculture, industry, trade, health, the environment, transport and fisheries, etc. It is important to define a ministry taking the lead in determining refrigeration and air-conditioning policy at national level.

Trade organisations and associations play an indispensable role in federating refrigeration stakeholders. A state-approved, neutral, authoritative national refrigeration association is also necessary: these bodies play consultative roles in collaboration with government departments and provide their members, and more widely, all refrigeration and air-conditioning stakeholders, with the information they need.

An interministerial and interprofessional organisation, such as a national refrigeration council, can play an important role in co-ordinating actions and defining refrigeration plans that include inventories of existing equipment and a long-term developmental plan. This type of structure can be effective only if it comprises a secretariat that handles the advisory dimension and implements decisions. Such an essential structure should benefit from multilateral or bilateral funding.

Excellent symbiosis can be achieved by organising forums enabling country representatives faced with similar challenges to meet and exchange viewpoints. In this respect regional refrigeration organisations play highly useful roles.

4.3.6 Data collection

Governments should improve information collection, enabling the drawing up of a precise inventory of the needs of developing countries. It is an essential preliminary step in order to facilitate the design of focused programmes and activities in the various fields concerned: infrastructures, technologies, training.

For example, the setting-up of cold chains involves establishing inventories of existing equipment, followed by the scheduling of needs within defined time frames on a geographical basis within refrigeration management plans. These plans must benefit from reliable technology transfer tailored according to bilateral or multilateral funding programmes

Conclusion

The contribution of refrigeration to sustainable development with respect to the 40 actions defined in the Agenda 21 can be summarised as follows.

Action 2: International co-operation to accelerate sustainable development in developing countries

International standards in the field of refrigeration and air-conditioning, such as ISO standards and international regulations, such as the Montreal Protocol, the Kyoto Protocol and the ATP Agreement on the refrigerated transport of perishable foodstuffs, promote a global approach and are conducive to international trading.

Action 4: Changing consumption patterns

People's diet in developing countries is poor in quality, quantity and diversity. Refrigeration raises the available food supply by ensuring better preservation, by improving quality (safety and wholesomeness) and by developing the diversity required in order to ensure that a balanced diet can be achieved. For instance, fish consumption could certainly be developed, even in countries located far from fish resources, thanks to a reliable cold chain.

Action 6: Promotion and protection of human health

Improved preservation of perishable foods reduces health risks from pathogenic micro-organisms. It also decreases food losses – which are too high and very costly at present.

No-one questions the efficacy of vaccines in protecting millions of inhabitants of developing and developed countries from a number of life-threatening diseases. But vaccine storage requires refrigeration and equipment providing optimal storage conditions is sorely lacking in many hot countries. Solar refrigerators are gaining ground but a number of obstacles need to be overcome, not the least of which is their cost.

Cryosurgery is a technique which is easy to use, relatively inexpensive, requires relatively basic equipment, and has a wide range of applications. This technology deserves much wider application, especially in developing countries.

Action 7: Promoting sustainable human settlement development

Refrigeration technologies may significantly contribute to sustainable human settlement. Vapour-compression technologies which have been proven in industrialised countries can be tailored to meet specific needs or particular local requirements with moderate investments.

Absorption-adsorption technologies, in conjunction with solar energy, are promising sustainable technologies for cooling in tropical climates or heating in cold climates (heat pumps) thanks to their low-emission characteristics. However, these technologies require further research and development.

Action 9: Protection of the atmosphere

In the field of protection of the atmosphere, the advent of more sustainable equipment and the implementation of more sustainable practices, including highly significant emissions reductions, and raised energy efficiency, may have far-reaching positive results.

Action 14: Promoting sustainable agriculture and rural development

Reducing the considerable post-harvest losses, thanks to better preservation of agricultural and fish products is part of sustainable development. Refrigeration is a key technology ensuring better preservation of foodstuffs.

Action 15: Conservation of biological diversity

Cryopreservation of gametes and embryos of rare and endangered species, through low-temperature gene banks, contributes to biodiversity.

Action 31: The scientific and technical community

International networking, international working parties, either at worldwide or regional levels, are essential to the exchange of knowledge and the sharing of experiences. The Internet facilitates the expansion of networking between stakeholders in developing and developed countries.

Action 34: Transfer of environmentally sound technology

The first step is education, followed by technology transfer. The technology transferred to developing countries needs to be tailored, thanks to two-way co-operation, in order to meet local needs, and must also be cost-effective, reliable, and environmentally friendly.

Technology transfer is extremely important in the refrigeration field; however, its success depends on the approach adopted by refrigeration stakeholders. Only technology that has proven to have the necessary benefits should be transferred: emerging technology that has not been subjected to thorough testing is doomed to failure. The introduction of technology which is not suitable to local conditions, the local climate and local logistics is also doomed to fail.

Article 35: Science for sustainable development

A multidisciplinary approach is important for sustainable development. An example is the necessary co-operation between air-conditioning engineers, researchers and architects for designing sustainable building.

Action 36: Promoting education, public awareness and training

More short courses and short training programmes are needed in developing countries. However, the cornerstone to the education of design engineers and servicing and maintenance technicians in developing countries must be long-term courses.

Raising stakeholder and public awareness of the consequences of venting non-environmentally friendly refrigerants into the atmosphere requires information providing at several levels both in developed and developing countries. Without facilities for recycling and destroying refrigerants and replacement equipment, environmental protection is impossible to achieve. Education needs backing up with tools enabling skills and new knowledge to be applied.

Action 37: Capacity building in developing countries

Programmes aimed at defining refrigeration structures to be set up in developing countries, long-term Refrigeration Management Plans (RMPs) are examples of useful actions for capacity building.

Action 39: International legal instruments and mechanisms

The Montreal Protocol is a good example of a successful international legal instrument which promotes sustainable development. It is hoped that the Kyoto Protocol will be also a successful legal instrument once ratified.

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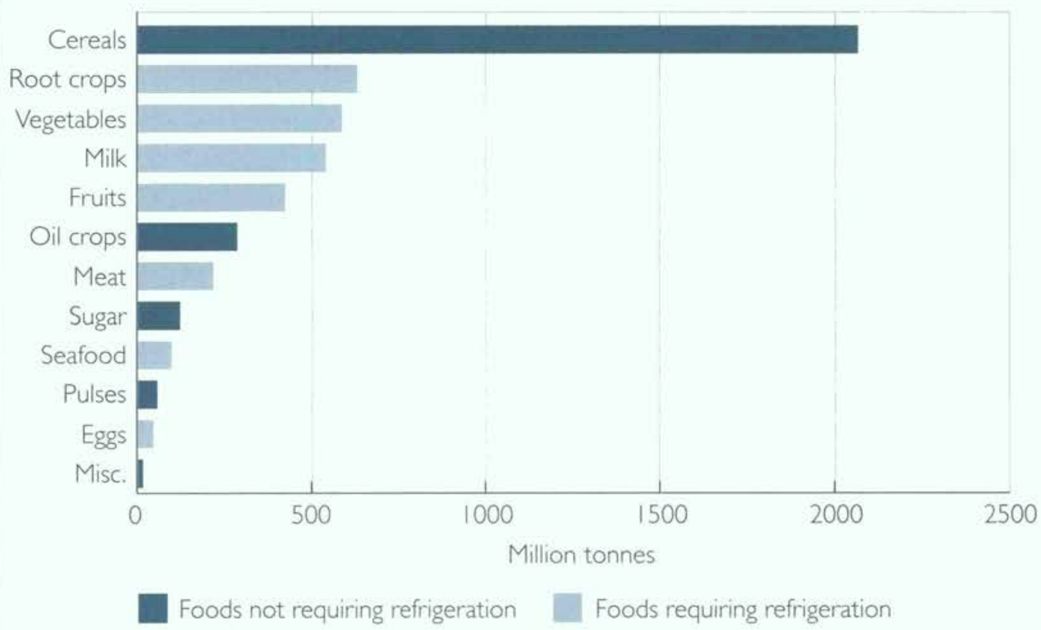
Annexe 1: Figures:

Figure 1: Global agricultural and fish production in 1997 (million tonnes)



Source: FAO; 1998, Yearbook - Production 1997, vol 51, Rome

Figure 2: Objectives specified by the Montreal Protocol

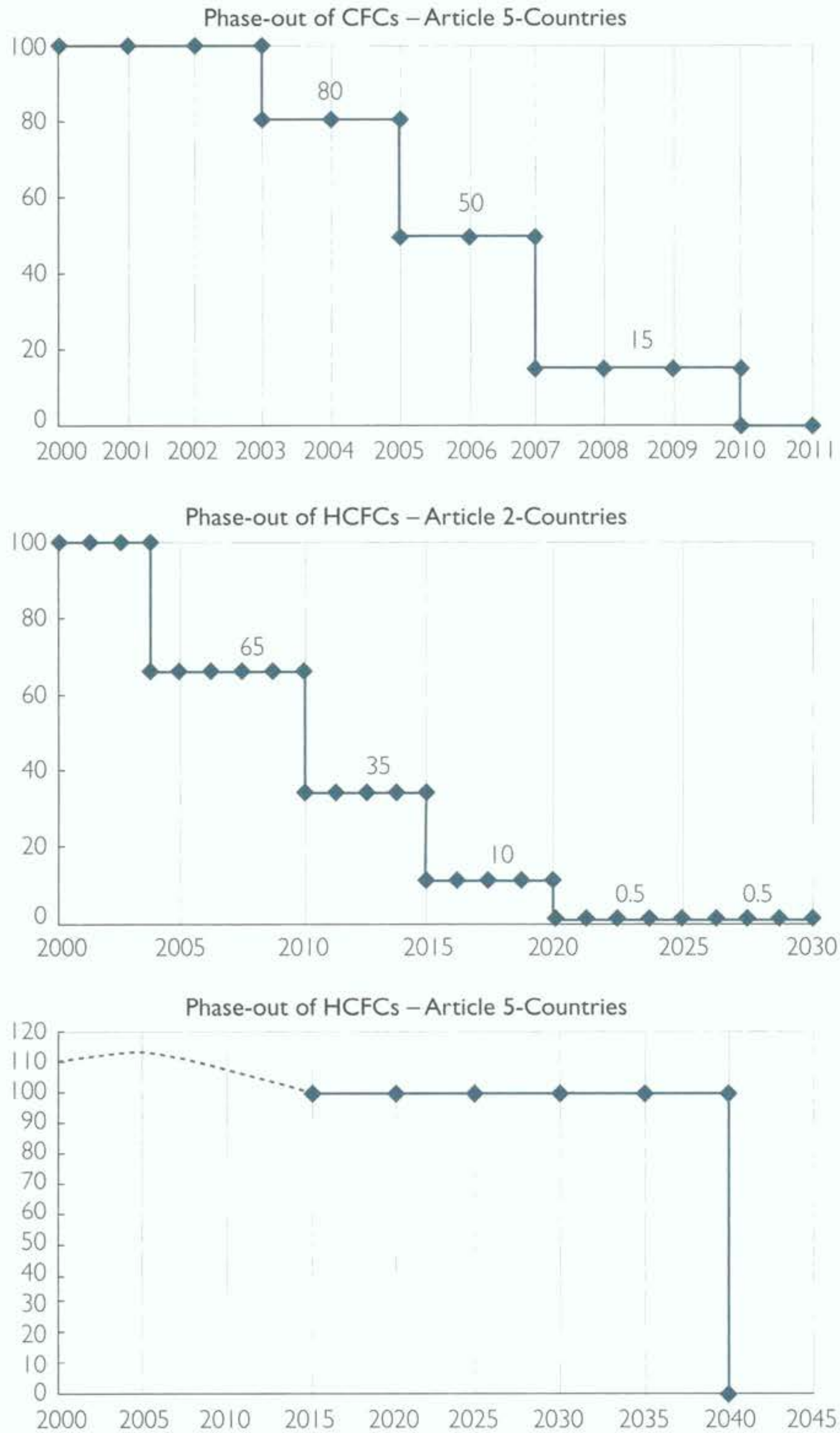
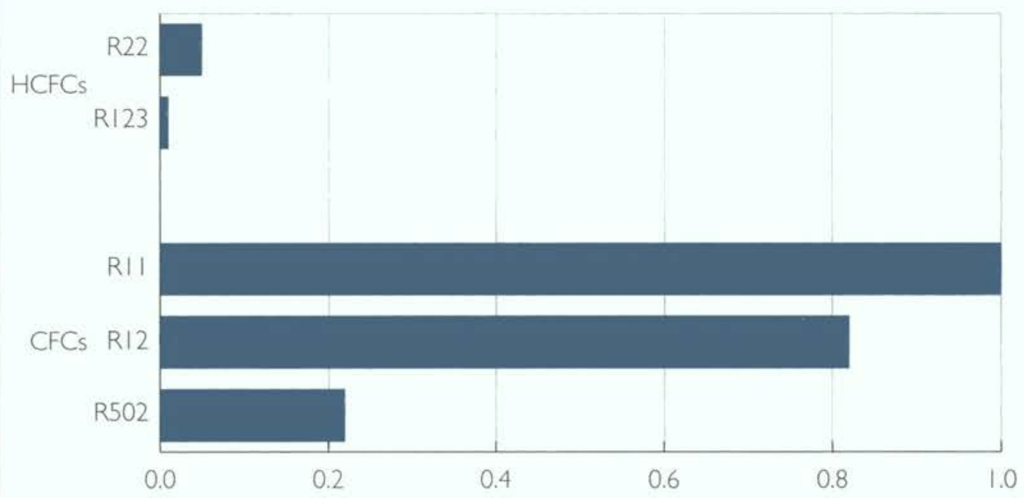
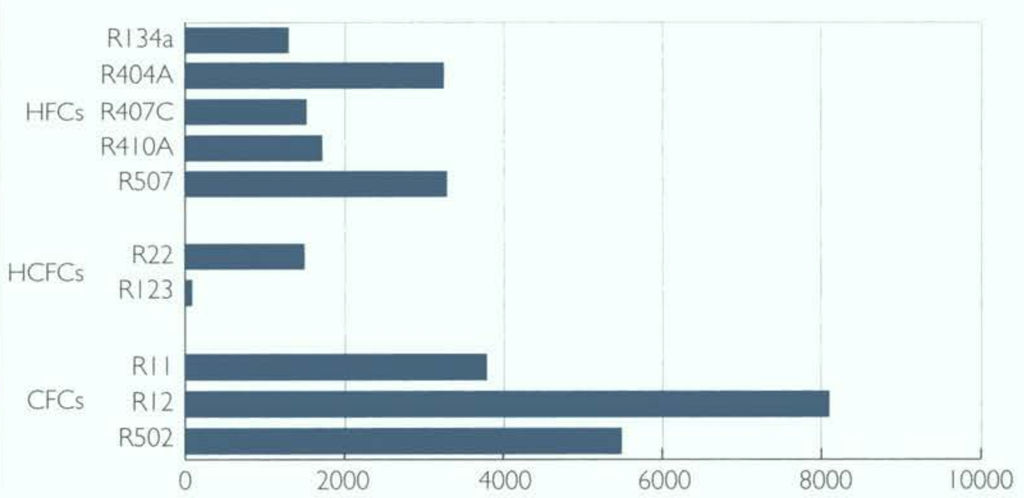


Figure 3.1: Ozone Depleting Potential of several HCFCs and CFCs (HFCs have an ODP of zero)



Source: UNEP, 1998: 1998 Report of the Refrigeration, Air-conditioning and Heat Pump Technical Options Committe

Figure 3.2: Global Warming Potential (100 yr) of several HFCs, HCFCs and CFCs



Source: IPCC, 1995: Climate Change 1995, Contribution of working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change

Figure 4.1: Evolution of ODP-weighted production of CFCs and HCFCs

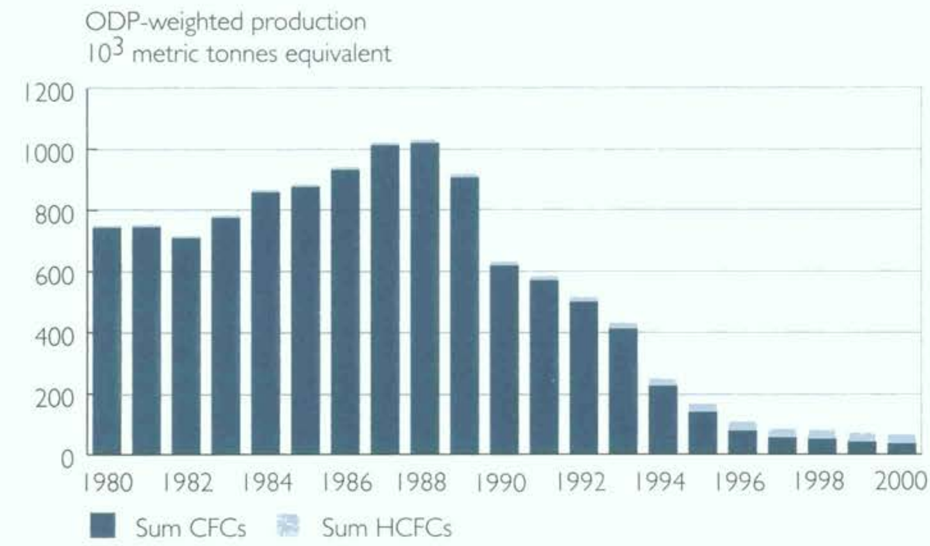


Figure 4.2: Evolution of GWP-weighted production of CFCs, HCFCs and HFCs

Source: AFEAS; 2001: Issue Areas: Production and Sales of Fluorocarbons, http://www.afeas.com

Annexe 2: Developing countries and territories – DAC list (Development Assistance Committee of OECD), as of 1 January 2000

Least developed countries	Other low income countries	Lower middle income countries and territories	Upper middle income countries and territories	High income countries and territories
Afghanistan	Armenia	Albania	Anguilla	Malta
Angola	Azerbaijan	Algeria	Antigua & Barbuda	Slovenia
Bangladesh	Cameroon	Belize	Argentina	
Benin	China	Bolivia	Bahrain	
Bhutan	Congo, Rep.	Bosnia & Herzegovina	Barbados	
Burkina Faso	Côte d'Ivoire	Colombia	Botswana	
Burundi	East Timor	Costa Rica	Brazil	
Cambodia	Ghana	Cuba	Chile	
Cape Verde	Honduras	Dominica	Cook Islands	
Central African Rep.	India	Dominican Rep.	Croatia	
Chad	Indonesia	Ecuador	Gabon	
Comoros	Kenya	Egypt	Grenada	
Congo, Dem. Rep.	Korea, Dem. Rep.	El Salvador	Lebanon	
Djibouti	Kyrgyz Rep.	Fiji	Malaysia	
Equatorial Guinea	Moldova	Georgia	Mauritius	
Eritrea	Mongolia	Guatemala	Mayotte	
Ethiopia	Nicaragua	Guyana	Mexico	
Gambia	Nigeria	Iran	Montserrat	
Guinea	Pakistan	Iraq	Nauru	
Guinea-Bissau	Senegal	Jamaica	Oman	
Haiti	Tajikistan	Jordan	Palau Islands	
Kiribati	Turkmenistan	Kazakhstan	Panama	
Laos	Vietnam	Macedonia	Saudi Arabia	
Lesotho	Zimbabwe	Marshall Islands	Seychelles	
Liberia		Micronesia, Fed. St.	St Helena	
Madagascar		Morocco	St Kitts and Nevis	
Malawi		Namibia	St Lucia	
Maldives		Niue	Trinidad and Tobago	
Mali		Palestinian Adm.Areas	Turkey	
Mauritania		Papua New Guinea	Turks & Caicos Islands	
Mozambique		Paraguay	Uruguay	
Myanmar		Peru	Venezuela	
Nepal		Philippines		
Niger		South Africa		
Rwanda		Sri Lanka		
Samoa		St Vincent & Grenadines		
Sao Tome & Principe		Suriname		

Least developed countries	Other low income countries	Lower middle income countries and territories	Upper middle income countries and territories	High income countries and territories
Sierra Leone		Swaziland		
Solomon Islands		Syria		
Somalia		Thailand		
Sudan		Tokelau		
Tanzania		Tonga		
Togo		Tunisia		
Tuvalu		Uzbekistan		
Uganda		Wallis and Futuna		
Vanuatu		Yugoslavia, Fed.Rep.		
Yemen				
Zambia				

Annexe 3: Achievements and limits: Approach on a per-sector basis

1. Domestic refrigeration

The main changes, achievements and limits are:

- before CFCs were banned, in domestic refrigeration the most widely used refrigerant used to be CFC12. Starting in 1992/1994, developed countries moved to new refrigerants, particularly HFC134a;
- certain countries have opted for widespread use of HC600a (isobutane), a refrigerant with no greenhouse effect but which is a flammable gas. Hydrocarbon (HC) domestic refrigerators make up 35% of European output [UNEP, 1998]. Production of HC refrigerators and freezers is also increasing in Japan and south-east Asia. Now, 10% of domestic refrigerators worldwide are presumably hydrocarbon refrigerators [UNEP, 1998];
- manufacturers of insulating foam blowing agents have moved from CFC11 to cyclopentane and to HCFC141b. The former is largely utilised in Europe and the latter in United States and Japan. It is worthwhile to mention that the mass of blowing agent in a refrigerator is approximately four times the mass of refrigerant. Better insulation means that the refrigerating capacity of the appliance is lower and consequently that energy demand is also lower;
- thanks to multilateral funds, many manufacturers in developing countries have shifted from CFC12 as a refrigerant to either HFC134a or hydrocarbons;
- many countries have set up regulations on the labelling of annual energy consumption in standardised conditions. These rules have shifted the purchases of consumers towards lower energy consuming refrigerators. This is particularly important as refrigerators consume about 4% to 5% of all electricity consumed in developed countries;
- higher refrigerator energy efficiency has been achieved over the last 30 years. According to AHAM (Association of Home Appliances Manufacturers), a typical United States refrigerator-freezer uses 30% of the energy required by a typical 1972 United States production model [UNEP, 1998] and a typical new American refrigerator (in 1997) consumed 48% less energy than its ancestor manufactured in 1980. Given that the 112 million United States refrigerators consume (1997 figures) 151TWh, it can be seen that the benefits, in terms of energy saving, of current achievements in the field of energy efficiency, are enormous.

In developed countries, all households have refrigerators. In developing countries that are more often than not located in hot regions of the world, the refrigerator is rightly considered to be the one vital appliance everyone needs in order to achieve a satisfactory level of comfort and food safety.

2. Commercial refrigeration

The development of supermarkets began 40 to 50 years ago. Today, in developed countries about 70% of fresh and frozen foods are sold through supermarket outlets. The traditional retail network is rapidly declining, with consequences on employment and downtown activity.

The main changes, achievements and limits are:

- small shops (bakers, butchers) are mainly equipped with self-contained display cabinets using HFC134a. A few of them use HFC404A (for low-temperature applications) and some of them use hydrocarbons. However, many shops are still equipped with CFC12 appliances. The great advantage of self-contained cabinets is the very low leakage rate;
- supermarkets are mainly equipped with central machinery rooms. The most

widespread design is a direct system where the refrigerant circulates from the machinery room to the display cabinets. The most common refrigerant is now HFC404A. It has replaced CFC502, CFC12 and HCFC22. Other new concepts are developing;

- indirect systems using HFC404A, ammonia or hydrocarbons in a primary circuit and then a heat transfer fluid to cool products in display cabinets. Advantages are a low rate of leakage of refrigerant and good control of leakage in the machinery room equipped with sensors. A drawback is increased energy consumption due to the double heat transfer. Plate exchangers may reduce this penalty. A number of plants using CO_2 as a refrigerant or as a heat transfer fluid are operating now;
- in order to reduce the refrigerant charge, another concept consists in several distributed small circuits within the supermarket instead of a single centralised plant. The refrigerant charge is reduced by almost 50% in comparison with a central system [UNEP, 1998];
- open display cabinets are taking the lead on closed display cabinets. The main goal is to increase sales. The sustainability of open equipment regarding energy consumption and product temperatures needs further investigation. Studies indicate that the energy consumption of open-type cabinets is greater than that of glass-door types [Ramin, 2002];
- great improvements in the quality of the cold chain and in the achievement of better levels of food product temperature have been obtained. This is of great importance: it makes it possible to deliver safe and wholesome foods to consumers. These improvements have been achieved thanks to regulations, standards, regulatory controls and consumer awareness.

In this field, the concern is certainly the huge gap between the developed country distribution system in which about 50% of consumer purchases involve perishable products preserved using a high-quality cold chain, and that in developing countries, where foods are generally sold in traditional markets with an almost total lack of refrigeration. Therefore, the loss level is high and losses in quality and safety are also no doubt high.

3. Cold storage

Cold storage is an important link in the cold chain. The main changes achievements and limits are:

- before the signature of the Montreal Protocol, the main refrigerants utilised were ammonia, CFC502 and HCFC22. The phase-out of CFCs and the planned phase-out of HCFCs has led to an overall increase in the use of ammonia refrigeration, even if regulations vary greatly from one country to another, and are sometimes probably too stringent. HFC404A and HFC507A are also used to replace CFC502;
- energy efficiency progress has been achieved thanks to new design (high-rise cold stores) and new logistics systems (small doors, rapid opening systems, double doors). Cold storage energy consumption as low as 16 $kWh/m^3/y$ instead of an average consumption of 60 $kWh/m^3/y$ is quoted [Young, 1997];
- supermarkets have developed new hubs between production and delivery. The consequence is a very fast rate of vehicle loading, less lorries on the roads and finally a better usage of energy.

Again in this sector, the gap between developed and developing countries is a concern. Cold storage in developing countries is mainly geared to imported refrigerated foods (chilled and mainly frozen), with facilities in ports and large cities. Cold stores on production sites are scarcely equipped and this is another area of concern. The preservation of foods and the achieving of reductions in post-harvest losses are both essential components of sustainable development.

4. Industrial refrigeration

- from a refrigerant viewpoint, the situation encountered in this sector is similar to that seen in the cold-storage sector. Ten years ago, ammonia, CFC502 and HCFC22 were the three common working fluids, with hydrocarbons being used in the chemical industry. The phase-out of CFCs and HCFCs means that ammonia has now become the most widely used refrigerant in this field. Ammonia was formerly widely used in a number of countries, and is now commonly used in countries such as the United States or Japan where it was little used until recently. HFC404A is sometimes used even in flooded systems;
- the food processing industry is part of industrial refrigeration. As developing countries have economies largely based on agriculture, promotion of sustainable food processes is to be encouraged both for local consumers and exportation. The use of ammonia refrigeration for medium- and large-range capacity plants is a sustainable process provided training of personnel is organised.

5. Air-conditioning and heat pumps

Up until its phase-out became compulsory within the framework of the Montreal Protocol, HCFC22 was (and still is) the most widely used refrigerant in this sector. Pure HFCs and mixtures of HFCs have been developed in order to replace HCFC22.

In low- and medium-capacity air conditioners and heat pumps, HFC410A and HFC407C are the leading refrigerant candidates. HFC410A, due to its higher pressure, needed longer component developments than HFC407C which gives pressures similar to those of HCFC22.

HFC134a is commercialised in large-capacity unitary products (>100 kW). For example, in Japan there has been a substantial shift to non-ODP technologies, with approximately 15% of Japanese unitary products now using HFCs (HFC407C or HFC410A) [TEAP, 2000].

In the United States, the penetration of non-ODP technologies is expected to increase significantly between now (about 5% of HCFC22 usage was replaced by HFC refrigerants in 1999) and 2006.

In Europe, the transition from HCFCs to HFCs and to a lesser extent hydrocarbons, is occurring at a much faster pace as a result of regulations requiring accelerated HCFC phase-out in new equipment, and at a later stage, also for servicing [TEAP, 2001].

In developing countries, the demand for HCFC 22 is likely to rise over the next few years. Hydrocarbon refrigerants are in use in some product categories: air-to-water heat pumps and in air-to-air systems with a very low charge.

Carbon dioxide is the focus of significant research activities. Challenges in developing air-to-air carbon dioxide systems have been low operating efficiencies, high operating pressures and the availability of components designed for carbon dioxide systems: compressors, exchangers, etc. [TEAP, 2001].

Significant progress is being achieved in gas-fired absorption technology. Challenges are cost-effectiveness and energy efficiency.

6. Air conditioners (water chillers)

Water chillers have a long lifetime. As a result, the shift towards new technologies and new refrigerants is rather slow.

The vapour compression cycle remains the predominant technology. Refrigerant choice is linked to the type of compressor and to the refrigerating capacity.

For centrifugal water chillers the pure refrigerants HCFC123 and HFC134a have been the leading candidates over the last few years. There are discussions about the favourable global environmental properties of HCFC123 even if it contains chlorine (but has a low ODP of 0.014) and if in compliance with the Montreal Protocol it should be phased-out.

For reciprocating, screw or scroll compressors, depending upon a number of factors, HFC407C, HFC410A, HFC134a and less commonly HFC404A, ammonia and propylene [TEAP, 2001] are considered and used in water chillers.

There is a clear trend to improve the energy efficiency of chillers. Data for the highest efficiency chillers show a 33% reduction in energy consumption from 1978 to 1998 [Bivens, 1999]. The United States decision to raise the minimum SEER (Seasonal Energy Efficiency Ratio) from 10 to 12 and to make it effective from 2006 will undoubtedly accelerate this trend.

Absorption chillers with steam, natural gas or waste heat as an energy source are also available. The market for absorption chillers is greatest in Asia (Japan, China, South Korea) but remains much smaller elsewhere. Challenges are cost effectiveness and energy efficiency.

In developing countries, where chillers are less widely used than in developed countries, thanks to technology transfer, the demand for CFCs has decreased markedly [UNEP, 1998].

7. Transport

The main changes, achievements and limits are:

- before the signature of the Montreal Protocol the main refrigerants utilised were CFC12 for chilled foods and CFC502 and CFC500 for frozen foods. After a short transition to HCFC22 and HCFC blends, HFC404A is the main refrigerant in current use. This refrigerant is popular in this field because of its flexibility (medium- and low-temperature applications) and its safety. HFC134a is also used, particularly in refrigerated containers;
- the high GWP of HFC404A may be a concern due to the high leakage level in refrigerated transport, even if great improvements have been achieved at this level. Some developments with HFC410A and hydrocarbons are quoted;
- the development of multi-temperature and multi-compartment vehicles allows a better level of loading of vehicles (fewer vehicles, less energy);
- work on energy labelling of refrigerating units is under way;
- intermodal transport, and particularly rail-road transport, has expanded only in countries that have made this form of transport compulsory through regulations. The natural laws governing the market have not proved sufficient to attract users. Cost and insufficient flexibility are the two drawbacks of rail-road intermodal refrigerated transport;
- here again, good improvements in cold-chain quality have been achieved. The development of temperature recorders has provided a useful tool making it possible to monitor temperatures during journeys (time-temperature history);
- marine refrigerated transport is expanding at the rate of 5% per year [Stera, 1999];
- air transportation of perishable products is also expanding. Considering that each tonne of freight moved by plane uses 49 times as much energy per kilometre than when it is moved by ship [French, 1999], a thorough comparison between slow marine transport with high-quality preservation processes and rapid air transport should be made.

Developing countries have poor refrigerated road and rail transport networks and this is another area requiring addressing. Furthermore, refrigerated transport equipment is rather expensive and needs a well-structured maintenance network which more often than not is unavailable in developing countries.

8. Mobile air-conditioning

The main changes, achievements and limits are:

- since 1995, in developed countries, all new air-conditioned cars have been utilising HFC134a instead of CFC12;
- a lot has been done in order to reduce both refrigerant charges and emissions. In terms of global warming, new air-conditioning systems have an impact which is far lower than that of the air-conditioning systems before 1995, due to the shift from CFC12 to HFC134a which has a GWP which is one-sixth of that of CFC12 and due to great improvements in tightness of equipment. The 1998 UNEP Report [UNEP, 1998] gives the following example: before 1994 when CFC12 was used, total needs during the lifetime of a car were calculated as being four times the mean charge, that is 4.72 kg of CFC12. Today, CFC12 has been replaced with an HFC-refrigerant (HFC134a) and thanks to improved designs the total needs are estimated as being 1.26 to 1.92 times the initial charge, that is 1.15 to 1.75 kg of HFC134a. In terms of emissions expressed in CO_2 equivalents, new vehicles emit only 4% to 7% of the emissions of pre-1994 vehicles (4.72 x 8100 = 38 230 kg of CO2 for CFC12 and 1638 to 2496 kg of CO2 per year for HFC134a);
- new designs have been explored for several years: transcritical carbon dioxide systems and hydrocarbons with or without the use of a secondary coolant loop. Both of these systems need additional studies and development. The critical point will be energy consumption, this being crucial in order to preserve natural resources and to reduce carbon dioxide emissions.

Annexe 4: Presentation of the International Institute of Refrigeration (IIR)

The International Institute of Refrigeration (IIR) is a scientific and technical intergovernmental organisation enabling pooling of scientific and industrial know-how in all refrigeration fields on a worldwide scale.

Its mission is to promote progress and expansion of knowledge and to disseminate information on refrigeration and air-conditioning technology and applications for the benefit of humanity. IIR is committed to improving both quality of life and the environment in which we live.

Members of IIR include member countries (of which there are 61). Member countries take part in IIR activities via the commission members they select. There are also other IIR members: associate members, collective (corporate) or benefactor members (companies, laboratories, universities) or private (individual) members.

IIR provides its members with tailored services meeting a wide range of member-country, national and international organisation, decision makers', researchers' and refrigeration practitioners' needs.

Its most important services are:

- networking with specialists and experts worldwide,
- access to the IIR Web site which provides a wide range of services and information,
- the Fridoc database specialised in the full spectrum of refrigeration fields (over 60,000 entries),
- conferences and congresses,
- recommendations,
- working parties and workshops,
- training designed to meet users' needs,
- information resources.
- Publications:
  - Bulletin of the IIR,
  - *International Journal of Refrigeration:* this journal is focused on new technology,
  - IIR Newsletter,
  - Technical books and manuals,
  - Conference and congress proceedings,
  - IIR informatory notes on major current refrigeration-related issues.

The structure of IIR comprises the general conference, which brings together member countrys' delegations every four years; the executive committee and the management committee that manage IIR between meetings of the general conference. The scientific council coordinates the scientific and technical activities of IIR's five sections and ten commissions.

The bylaws of IIR as an intergovernmental organisation were defined by an International Agreement signed on 1 December 1954, and an Application Protocol signed on 20 November 1956.

The IIR Strategic Plan 2000-2003, endorsed during the XXth IIR International Congress of Refrigeration in Sydney, Australia, defines the guidelines governing IIR activities over the coming years.

UNEP contribution to the World Summit on Sustainable Development

The mission of the United Nations Environment Programme (UNEP) is to provide leadership and encourage partnerships in caring for the environment by inspiring, informing, and enabling nations and peoples to improve their quality of life without compromising that of future generations. **The UNEP Division of Technology, Industry and Economics (DTIE)** contributes to the UNEP mission by encouraging decision-makers in government, business, and industry develop and adopt policies, strategies and practices that are cleaner and safer, make efficient use of natural resources, ensure adequate management of chemicals, incorporate environmental costs, and reduce pollution and risks for humans and the environment.

This report is part of a series facilitated by UNEP DTIE as a contribution to the World Summit on Sustainable Development. UNEP DTIE provided a report outline based on Agenda 21 to interested industrial sectors and co-ordinated a consultation process with relevant stakeholders. In turn, participating industry sectors committed themselves to producing an honest account of performance against sustainability goals.

The full set of reports is available from UNEP DTIE's web site (http://www.uneptie.org/wssd/), which gives further details on the process and the organisations that made it possible. The following is a list of related outputs from this process, all of which are available from UNEP both in electronic version and hardcopy:

- industry sectoral reports, including
  - accounting
  - advertising
  - aluminium
  - automotive
  - aviation
  - chemicals
  - coal
  - construction
  - consulting engineering
  - electricity
  - fertilizer
  - finance and insurance
  - food and drink
  - information and communications technology
  - iron and steel
  - oil and gas
  - railways
  - refrigeration
  - road transport
  - tourism
  - waste management
  - water management
- a compilation of executive summaries of the industry-sectoral reports above;
- an overview report by UNEP DTIE;
- a CD-ROM including all of the above documents.

UNEP DTIE is also contributing the following additional products:
- a joint WBCSD/WRI/UNEP publication entitled *Tomorrow's Markets: Global Trends and Their Implications for Business*, presenting the imperative for sustainable business practices;
- a joint WB/UNEP report on innovative finance for sustainability, which highlights new and effective financial mechanisms to address pressing environmental, social and developmental issues;
- two extraordinary issues of UNEP DTIE's quarterly *Industry and Environment* review, addressing key regional industry issues and the broader sustainable development agenda.

More generally, UNEP will be contributing to the World Summit on Sustainable Development with various other products, including:
- the Global Environmental Outlook 3 (GEO 3), UNEP's third state of the environment assessment report;
- a special issue of UNEP's *Our Planet* magazine for World Environment Day, with a focus on the International Year of Mountains;
- the UNEP photobook *Focus on Your World*, with the best images from the Third International Photographic Competition on the Environment.

Sustainability profile of the Refrigeration industry

• Achievements

- A marked reduction in the production and consumption of CFC and then HCFC refrigerants, a process involving all refrigeration stakeholders, has since 2000 been reversing the previously ever-rising stratospheric chlorine concentration, responsible for ozone depletion.
- Major developments in the cold chain – equipment design optimisation, traceability of foods, consumer information – are enabling sustainable preservation of foods in industrialised countries.
- In the health field, refrigeration is making a major contribution to sustainable health policy, notably in the immunisation of populations against infectious diseases thanks to refrigerated vaccine storage in the developing countries.

• Unfinished business

- The refrigeration sector's energy efficiency and alternative refrigerant-development initiatives must continue: they are protecting the environment and preventing global warming.
- Actions designed to reduce refrigerant emissions leakage throughout the plant life cycle must be expanded.
- Heat pump technology, which is an efficient tool enabling reductions in energy consumption, must be more widely diffused.

• Future challenges and possible commitments

- To develop more environmentally-friendly, energy-efficient vapour-compression systems with ambitious objectives: reduction of energy consumption by 30-50 %, and reduction of refrigerant leakage by 50%.
- To further develop promising non-vapour compression refrigeration technologies and applications including absorption and adsorption, solar refrigeration, desiccant technology, trigeneration, cryogenics and many others.
- To make refrigeration widely available in developing countries in order to set up viable cold chains, reduce food losses, and encourage environmentally-friendly technology through technology transfer and increased training provided by developed countries.

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