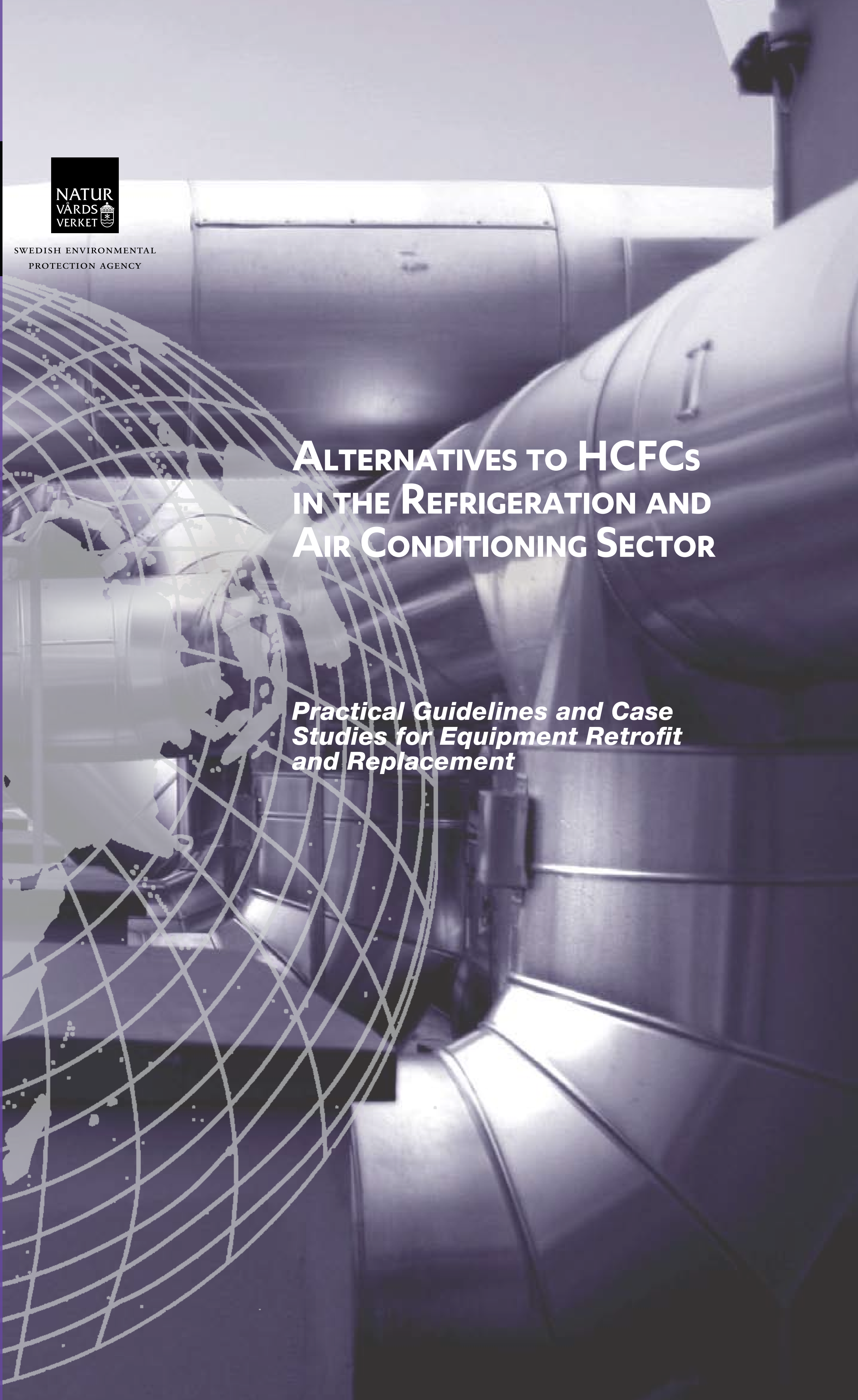

UNEP

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SWEDISH ENVIRONMENTAL PROTECTION AGENCY

Alternatives to HCFCs in the Refrigeration and Air Conditioning Sector

Practical Guidelines and Case Studies for Equipment Retrofit and Replacement

United Nations Environment Programme

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Alternatives to HCFCs in the refrigeration and air conditioning sector

Practical Guidelines and Case Studies for Equipment Conversion, Retrofit and Replacement

Introduction

HYDROCHLOROFLUOROCARBONS (HCFCS) are ozone depleting substances (ODS) controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer that are widely used in refrigeration and air conditioning, foam blowing and solvent applications.

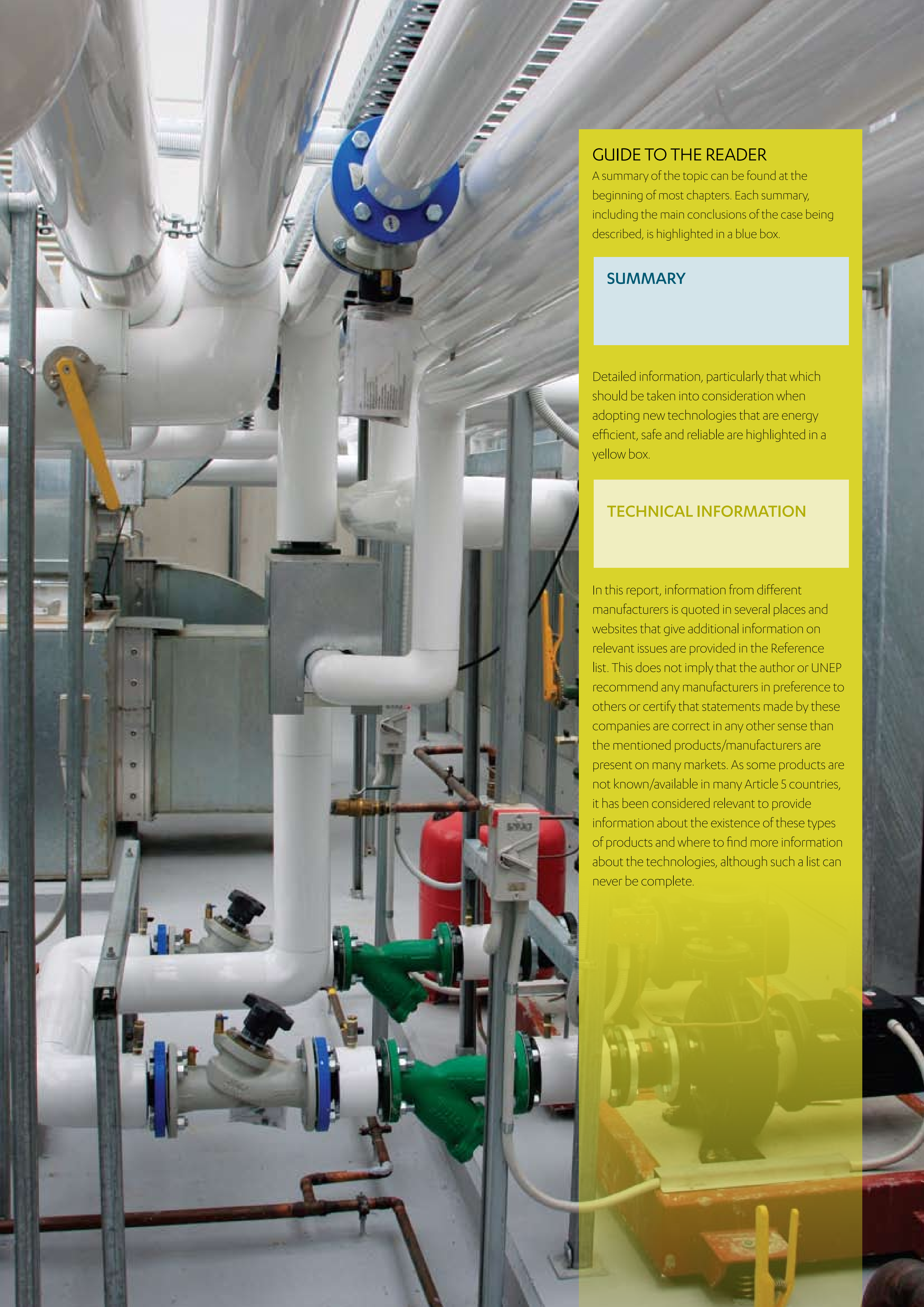
In September 2007, the Parties to the Protocol accelerated the phase-out schedule for these chemicals through Decision XIX/6. Developing countries operating under Article 5 of the Protocol (Article 5 countries) now have to freeze by 2013 their HCFC production and consumption to the average of their 2009-2010 levels, followed by a 10 percent reduction by 2015, by 35 percent by 2020, by 67.5 percent by 2025, and a 100 percent phase-out by 2030 (with 2.5 percent allowed, if necessary, for servicing existing equipment until 2040). The same decision requires developed countries to accelerate their phase-out schedule by 10 years to completely eliminate HCFCs by 2020) with 0.5 percent allowed, if necessary, for servicing existing equipment until 2030).

Action on HCFCs is important in that these chemicals have an impact on both ozone depletion and climate change. In terms of direct impact, the most commonly-used HCFCs have ozone depleting potentials (ODPs) ranging from 0.02 (HCFC-123) to 0.11 (HCFC-141b) and global warming potentials (GWPs) ranging from 76 (HCFC-123) to 2270 (HCFC-142b). Equipment using HCFCs consumes energy, which contributes to indirect global warming impacts.

The refrigeration and air conditioning (RAC) sector was the biggest consumer of CFCs and in preparation for the total CFC phase-out on January 1, 2010, it gradually shifted to the alternative refrigerants, including HCFCs. Today the sector has become one of the primary consumers of HCFCs and will need appropriate assistance to enable it to comply with the accelerated phase out.

UNEP DTIE in cooperation with the Swedish Environmental Protection Agency (SEPA) has produced this publication to provide decision makers in Article 5 countries, the end-users and the service technicians a comprehensive source of information on alternative technologies that can be adopted to phase out HCFCs in the RAC.

The report contains a section on alternative technologies including technical aspects and information on current market situation in developed countries (Article 2 countries) and Article 5 countries. Another section covers a collection of industry case studies that exemplifies state-of-the-art solutions using different technologies for different market segments.



GUIDE TO THE READER

A summary of the topic can be found at the beginning of most chapters. Each summary, including the main conclusions of the case being described, is highlighted in a blue box.

SUMMARY

Detailed information, particularly that which should be taken into consideration when adopting new technologies that are energy efficient, safe and reliable are highlighted in a yellow box.

TECHNICAL INFORMATION

In this report, information from different manufacturers is quoted in several places and websites that give additional information on relevant issues are provided in the Reference list. This does not imply that the author or UNEP recommend any manufacturers in preference to others or certify that statements made by these companies are correct in any other sense than the mentioned products/manufacturers are present on many markets. As some products are not known/available in many Article 5 countries, it has been considered relevant to provide information about the existence of these types of products and where to find more information about the technologies, although such a list can never be complete.

Executive Summary

THE PHASE-OUT of chlorofluorocarbons (CFCs), one of the most aggressive Ozone Depleting Substances (ODS), is now almost completed in accordance with the Montreal Protocol. The focus is now gradually shifting towards the phase-out hydrochlorofluorocarbons (HCFCs) whose phase-out schedule has been accelerated by the Parties to the Protocol in Spetember 2007 through Decision XIX/6. Developing countries operating under Article 5 of the Protocol (Article 5 countries) now have to freeze by 2013 their HCFC production and consumption to the average of their 2009-2010 levels followed by a 10 percent reduction by 2015; 35 percent by 2020; 67.5 percent by 2025 and a 100 percent phase-out by 2030 (with 2.5 percent allowed, if necessary, for servicing existing equipment until 2040). The same decision requires developed countries to accelerate their phase-out schedule by 10 years to completely eliminate HCFCs by 2020) with 0.5 percent allowed, if necessary, for servicing existing equipment until 2030).

HCFCs are widely used as a refrigerant in refrigeration and air conditioning systems and equipment as well as a blowing agent in the flexible and rigid foam sector.

The first target in the refrigeration and air conditioning sector should be to minimize the installation of new HCFC systems. Considering that the pre-charged air conditioning systems constitute the biggest sub-sector, minimising their production will create a specific challenge in non-producing Article 5 countries. **The amount of HCFCs contained in these systems when imported will not be included in the calculation of the importing country's HCFC consumption baseline for the years of 2009-2010. However as these systems grow old, demand for HCFCs to service them will increase significantly, particularly after the freeze in 2013 and throughout the phase-out period**. On the other hand, countries that export pre-charged systems will start with a high HCFC consumption baseline but they will be able to comply easily with the phase-out schedule by simply converting their production processes to use non–ODS technologies.

There are well established alternative substances to R-22 applications in the refrigeration and air conditioning sector. The prominent group of alternative substances are HFCs which are synthetic refrigerants with similar characteristics to HCFCs but no ozone depleting potential (ODP). As HFCs have a high global warming potential (GWP) there is a strong interest to minimize the introduction and emissions of HFCs. Other alternatives with lower or near zero ODP are available but are all associated with challenges that have to be overcome in order for them to play a major role on the market. Alternatives with negligible or zero GWP are ammonia, carbon dioxide and hydrocarbons. These are often called "natural refrigerants". Only hydrocarbons have similar technical characteristics to HFCs that could allow them to be used without major technology changes. Hydrocarbons are flammable and safety precautions need to be considered during design, manufacturing, installation, service and decommissioning. For larger systems ammonia is well established on many markets but several Article 5 countries lack qualified technicians. Most countries need to increase the focus on training for all technologies and good practice to facilitate the use of the best alternatives for different applications. There is no "one-size-fits-all" solution.

All the HCFC alternative technologies require Article 5 countries to upgrade the capacity of the servicing sector. In spite of the activities conducted during the phase out of CFCs, most of the Article 5 countries have a workforce that, to a large extent, still do not work according to internationally accepted good refrigeration and air conditioning paractises. The shortcomings in training, tools and enforcement of good practises cost industry and consumers large amounts of money in increased failure rates and unnecessary high energy consumption. The strong focus on initial cost often results in poorly optimised systems and little interest to train staff.

The industrialised countries have in most cases introduced certification schemes and restrictions on who can do certain activities related to ODS as well as HFCs. The alternatives all require special competencies to be used in an environmentally acceptable and safe way. A significant upgrade of the competence level has taken place during the last 10 years in many non-Article 5 countries, where the use of virgin HCFCs have mostly been eliminated or totally phased out. Due to the challenges in upgrading the industry which mainly consists of small and medium enterprises (SMEs) most Article 5 countries are only beginning this process. In order to phase out HCFCs and improve reliability as well as energy efficiency, it is important for the industry to upgrade its competence in all alternative technologies as there is no single technology to date that can provide the ideal solution for all applications. To justify investment in tools and training in alternative technologies, it is important to create an environment where it is good business to do good practise. Providing clear regulatory frameworks and information to equipment owners is important to make necessary investments attractive for the industry. If purchasing environmentally hazardous refrigerants and working in the industry with little training and tools persist, the change will be very slow as there are many equipment owners with limited awareness and competence. Moreover, the high energy consumption and unnecessary short lifespan of equipment are factors that are often unknown to many.

Contents

01 Alternatives to HCFCs in refrigeration and air conditioning

1.1 Background

UNDER THE MONTREAL PROTOCOL on Substances that Deplete the Ozone Layer, developing countries (i.e. countries that operate under Article 5 of that agreement) have developed strategies and successfully implemented measures which have phased out chlorofluorocarbons (CFCs) - ODS with high ODP – by 1 January 2010. In the coming years, the focus will be to move away from the HCFCs, substances with lower ODP values which have been used as transitional replacements while CFCs were being phased out. In Article 5 countries, HCFCs are scheduled to be completely phased out by 2030 (with a small servicing tail of only 2.5% allowed from 2030-2040). This might seem to be a long time, but many countries are increasing their consumption of HCFCs rapidly and risk building an HCFC-based infrastructure that can be costly and complicated to convert to non–ODS refrigerants in the future. The freeze in 2013 (baseline is the average HCFC consumption between 2009 and 2010) will become a challenge if measures are not initiated immediately. It is important to ensure that all HCFC consumption (production and import - export) is correctly reported prior to baseline of 2009-2010 and freeze year of 2013, and that early actions are taken to reduce new HCFC consumption to a minimum.

The first priority should be to stop all new installations using HCFCs as soon as possible. There is a special challenge for countries importing HCFC-22 (R-22) equipment as they are shipped pre-charged with the refrigerant and does not count in the calculation of the country's HCFC consumption baseline. As these equipment become old and servicing needs increase, only a limited quantity of HCFCs will be available on the market. Many Article 5 countries have no HCFC equipment production, but imports of R-22 air conditioning units are quickly increasing. Equipment that use alternative refrigerants are readily available for a slightly higher price, but it should also be kept in mind that R-22 equipment on the market are of an older design, whereas newer models have been redesigned to meet much higher energy efficiency standards. Therefore the installation of such equipment, while slightly higher in cost, will lead to additional energy savings in the long run. Many of the substances used to replace HCFCs have a significant GWP which should be taken into account when alternative technologies are evaluated. The selection of alternative substances and technologies will significantly affect the future impact on the climate from this sector. Both the direct impact from the chosen substances and the energy consumed will depend on the technologies selected.

Technologies to move away from HCFCs are well-known and proven in the industrialised countries and many of the alternatives are already partly introduced in developing countries due to influences from neighbouring markets and international companies. The strongest incentive for the continuous growth of markets for HCFCs is the lower initial price of both the substance and the equipment intended for use with HCFC (although this is often only in a short –time perspective as long-term energy and future retrofit cost will be high). R-22 is also a product that the entire industry is familiar with. Alternatives with less environmental impact are often associated with slightly higher initial cost and a need for technical know-how to be dispersed to a large number of technicians. This creates an uncertainty in the market that can be taken advantage of by competing companies by preserving "old technologies" at minimal cost. For some of the environmentally-preferred solutions, there are also safety barriers to be addressed to make these alternatives viable solutions. A more extensive list of alternatives to HCFCs are listed in Appendix I - List of refrigerants. In Article 2 (i.e. developed country) markets, the transition has been happening over the last 15 years, so the commercial alternatives are well-proven. For example, in Europe a ban on the installation of HCFCs has been in place since 2004 and a total ban on the use of virgin HCFCs began in 2010.

The following HCFCs are the most commonly used in the different sectors:

Different sectors where HCFCs are most commonly used.

SECTOR	TYPE OF HCFC
Refrigeration (manufacturing and service)	
Domestic refrigeration	Limited use of service drop-in blends (never used in equipment production) (HCFC-141b in appliance insulation foam)
Commercial Refrigeration	HCFC blends in service, (HCFC-141b in foam)
Industrial refrigeration	HCFC-22, R-502 (a blend of CFC/HCFC), HCFC blends, (HCFC-141b in foam)
Transport refrigeration	HCFC-22, R-502, HCFC blends, (HCFC-141b foam)
Stationary Air Conditioning	
Residential and commercial AC	HCFC-22
Chillers	HCFC-22, HCFC-123
Mobile air conditioning	None or minimal (poor compatibility with hoses)
Foams	HCFC-141b, HCFC-142b, HCFC-22
Medical Aerosols	None
Non-Medical Aerosols	HCFC-22, HCFC-141b, HCFC-142b
Fire Protection	HCFC-123, HCFC-124, HCFC-22 (blends)
Solvents	HCFC-141b, HCFC-225ca, HCFC-225cb

HCFCs have traditionally been the global solution in sectors that are now rapidly growing in many developing countries, such as stationary air conditioning and large commercial and industrial refrigeration. In the later applications, HCFCs have been competing with ammonia, another well-proven "mature" technology. Other applications are new, since HCFC has been used as a replacement to facilitate the phase-out of CFC. Traditionally the retail food sector mostly uses R-12 (CFC) and R-502 (containing CFC) but moved to R-22 as a transitional product before non-ODS alternatives such as R-134a and R-404A/R-507 were accepted.

HCFCs are used as a component in a large number of refrigerant blends, often designed to match the behaviour and performance of R-12 and R-502. These are often called service or drop-in blends as they are intended to facilitate an easy replacement of CFCs in existing plants with minimal changes to the system.

HCFC is also used as feedstock for the production of plastics and other chemicals.

When replacing HCFCs it is important to evaluate the environmental impact of the alternatives since the most common replacements are hydrofluorocarbons (HFCs) which have a significant Global Warming Potential. The impact of alternative refrigerants and the energy consumption of selected system solutions should also be evaluated to minimize their total impact on the environment.

Adopting measures to reduce the refrigeration and air conditioning loads through good building design and processes are obviously the most efficient way of reducing the environmental impact of these technologies.

1.2 HCFCs used in the refrigeration and air conditioning sector

SUMMARY HCFCs USE IN THE RAC SECTOR

HCFCs are widely used over the entire industrial and commercial refrigeration sector including for food processing, distribution, storage and retail (shops and supermarkets). In air conditioning, HCFCs have played a dominant role in unitary-, split- and chiller- type systems for air conditioning in private homes, hotels, office buildings, restaurants and other public buildings.

R-22 is by far the most commonly-used HCFC in this sector. Other HCFCs such as R-124 and R-123 have been used in smaller quantities for special applications. Still other HCFCs such as HCFC-141b and HCFC-142b have been used as blowing agents in refrigeration equipment insulation after the phase out of CFCs, sometimes in mixtures with R-22.

Refrigeration and air conditioning equipment is globally one of the sectors with the highest electrical power consumption. The rapid growth in this sector in many countries will result in a need to expand power production and distribution systems. The energy consumption of countries in this sector also contributes significantly to global warming. With the expected requirements in the global agreements on reduction of green house gases the emissions of refrigerants such as HCFCs and HFCs as well as energy consumption in this sector will play a significant role in whether these agreements achieve its targets.

ASIDE FROM BEING ONE of the major ODS-consuming sectors the refrigeration and air conditioning sector (RAC) including heat pumps and dehumidifiers, also uses 15% to 20% (IIR, 2002) of global electrical energy. The economic growth in many Article 5 countries in hot climates results in a corresponding growth of the RAC sector. The applications where HCFCs are used are important to reduce the losses in the food production and distribution chain. There are also many applications that are essential for industrial production and human comfort where HCFCs play an important role today. The growth will result in increasing energy consumption if measures to improve efficiency – including the introduction of more energy-efficient technologies - are not implemented effectively/appropriately. **There are well-proven technologies available to replace HCFCs with non-ozone depleting substances as well as to improve energy efficiency in all refrigeration and air conditioning applications.** Alternatives such as HFCs can be used with minimal changes to the existing technology, but have a high GWP. Refrigerants with a low or zero GWP should be the preferred solution when they can be used in a safe and cost-effective manner without resulting in higher energy consumption. High GWP refrigerants should only be used when technical, economic or safety reasons require them, and in such cases they should be used in systems with minimized leakage and emissions during service and at the end of equipment life.

Fig. 1.1 (opposite page) HCFCs are used in all refrigeration and air conditioning equipment that in turn is used everywhere in society.

The emissions should be minimized through implementation of good servicing practices and effective re-use schemes.

The main HCFC commonly used in air conditioning and refrigeration applications before 1985 was R-22. The main sectors where R-22 was the preferred refrigerant were in the air conditioning and industrial systems sectors where it was also competing with ammonia. When CFCs were identified as powerful ODS and a global phase-out was agreed under the Montreal Protocol in 1987, HCFCs were identified as less harmful substances and introduced in several sub-sectors that were not traditional HCFC applications. As a result, R-22 and HCFC-containing drop-in blends are now found in commercial refrigeration and to some extent in transport refrigeration. The result is that replacement of HCFCs will have an impact on many sectors and to some extent the alternatives used will sometimes be the alternatives designed to replace CFCs rather than those designed for R-22 applications. The main focus in this report will be on segments where R-22 has a significant market share but in order to give a more complete "update", other sectors will also be covered, although with less attention.

1.2.1 AIR CONDITIONING AND INDUSTRIAL REFRIGERATION – TRADITIONAL R-22 SUB-SECTORS.

THE PHYSICAL PROPERTIES of R-22 result in good performance in a wide range of applications but with a limiting factor caused by the high temperatures occurring during compression. In refrigeration applications where the temperature difference between the desired temperature and the surroundings is high, the risk of unacceptable conditions and failures increases. In hot climates, the challenge in commercial refrigeration applications increases significantly more than in air conditioning systems. In industrial applications R-22 was an alternative to ammonia where it provided better cooling capacities than R-12 and was more readily available and cost less than R-502. In large installations the high temperatures could be handled with different technical solutions, but it was not as cost-effective in smaller commercial systems where R-12 and R-502 were more common.

1.2.2 SPLIT AND UNITARY AIR CONDITIONING SECTOR (INCLUDING AIR-TO-AIR HEAT PUMPS)

SUMMARY SPLIT AND UNITARY SYSTEMS

R-22 is used mainly in split and unitary air conditioning equipment (see Figure 1.2). The quantity used in this application is sometimes underrated because in the manufacturing/exporting country the initial charge is considered 'consumption' whereas it is not considered as such in the importing country where the equipment will be installed and serviced.

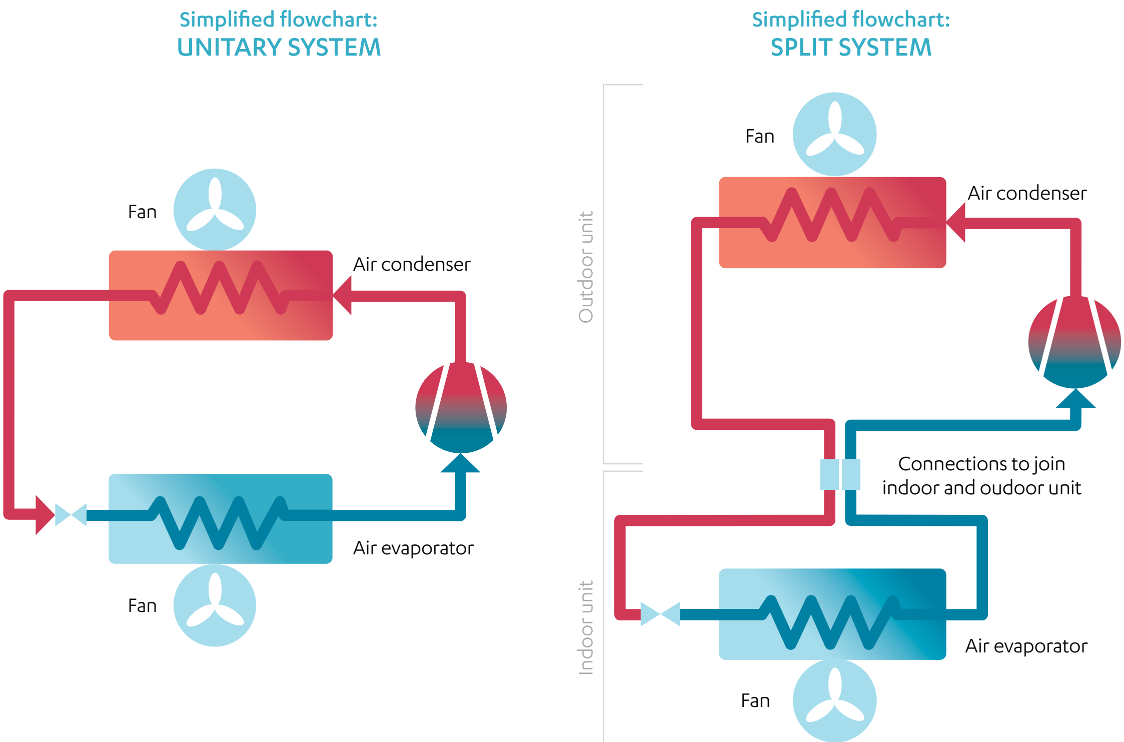
In new systems alternatives are readily available. Most often R-22 is replaced with R-410A or R-407C. Large volumes of R-22 systems are still being installed in some markets due to lower investment outlay and less-informed customers. As these units age, they can be expected to play a significant role in the consumption of HCFCs, once the freeze in HCFC consumption (this is usually equivalent to "imports" in most Article 5 countries) in 2013 takes effect. One of the priorities should be to stop the introduction of new R-22 equipment. The sooner legislation to ban the import, marketing and installation of new R-22 systems is established, the easier the transition will be. The cost for transition will be lower as the added initial cost is much lower than the cost to retrofit the system.

THIS MARKET IS DOMINATED by large volume production, mostly from Asia, but in some markets, small local manufacturers are also present (see 2.1 "The transition in the unitary and split air conditioning market"). The price competition is extremely tough and quality/performance is not always a factor that the customer can evaluate. These systems are installed in offices, hotels, restaurants, bars,shops and private homes. The numbers of suppliers/installers/service providers involved are high and the level of competency is often low. Global players have local representation in many countries either through their own subsidiaries or through local distributors, but significant volumes are traded by less skilled and specialised companies competing in segments with low pricing, which makes this sector challenging and diversified.

A significant part of the market will be focused solely on low initial price at the expense of equipment efficiency. As this market rapidly grows in many countries, so does the number of units installed each year increase. Therefore this sector can play a significant role as the limit on imports of HCFCs for servicing comes into effect. These units are supplied with a full refrigerant charge and the HCFCs contained therein are not counted as part of the imported HCFC quantities, but their leakage rates can be expected to increase gradually through the year as the units grow old.

The leakage rates are further increased due to the often low skills of the installers, particularly for split units, as they are installed on site with one component located outside and the other inside the building. For more than ten years, ODS-free but high GWP HFC-based alternatives such as R-410A and R-407C have been available in this sector. However, due to the cost of retrofit and relatively low value of old units, retrofits to HFCs have not been the preferred solution on most markets since these systems will often already be old before the phase out of R-22 becomes urgent. On the other hand, in Article 5 countries, the price of labour is relatively low and retrofits can be a more interesting option than replacements. This will be described further in the section presenting the case studies on retrofit methods, options and available solutions for existing equipment.

Fig. 1.2 Unitary systems (left) are mounted "through the wall" without the need to connect the refrigeration system on site. Split systems (right) are assembled on site.



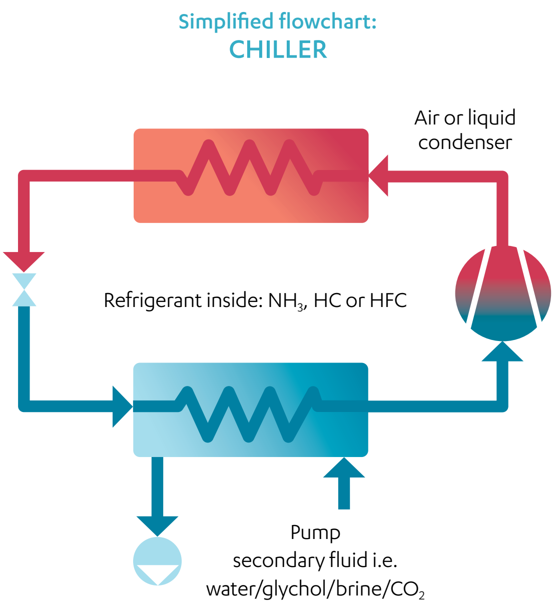
1.2.3 VRV/VRF/MULTI-SPLIT SYSTEMS (INCLUDING HEAT PUMPS)

THESE ARE SYSTEMS that have been developed from the split systems (Daikin Industries developed and launched "Variable Refrigerant Volume" and protected the use of the acronym "VRV" so other manufacturers use "VRF" for Variable Refrigerant Flow). These system designs are characterised by one unit cooling (and sometimes heating) several rooms and adapting its capacity to the variations in the demand. These units have a lot in common with split systems, but are dependent on complex electronic controls and have an intricate design, which will make them more difficult to retrofit. This is because oil transport and control behaviour could be affected and difficult to predict unless there is access to design info and proper test facilities or support from the manufacturer. For obvious reasons, the manufacturers are rarely interested in investing the resources required to extend the life of existing equipment.

1.2.4 CHILLERS IN AIR CONDITIONING AND COOLING APPLICATIONS (INCLUDING HEAT PUMPS WITH INDIRECT SYSTEMS).

CHILLERS ARE SYSTEMS THAT INDIRECTLY cool a building or a process. Typically they are used in larger systems and the "cooling" distributed with water or a mixture of water and anti-freeze when it is necessary to work at low temperatures. Chillers are mainly factory-built units that are intended to cool a liquid such as water or, if a lower temperature is desired, fluids with lower freezing points. Chillers can be air-cooled, i.e. where the condenser is directly cooled by air, or water-cooled, where the condenser is cooled by circulating water (possibly with freeze depression if the climate is such that the water would risk freezing in the winter). Their main applications are for air conditioning in larger buildings, i.e. hotels, offices, hospitals, military complexes, etc. or for process cooling in various industries. This solution is often associated with a higher investment cost than solutions with split systems for air conditioning or smaller units for each object in need of cooling in the industry. In many cases, small non-chiller RAC units can be installed gradually and often by tenants, thus eliminating the need for the owner to invest and charge costs to the tenants. Central systems with chillers are often preferred in larger systems where the possibilities of more stable operation by balancing cooling loads over time (as the loads are not occurring simultaneously over the whole building), reducing maintenance cost are preferred as it also avoids noise and/or esthetical drawbacks of having large numbers of split/unitary systems. This option is often used in larger buildings operated by owners with the capability to invest in more long term solutions. Chillers are globally used in central air conditioning systems where R-22 is one of the most commonly used refrigerants, apart from CFCs which are still present in large quantities in the old chiller equipment in both developed and developing countries. Apart from their use in the air conditioning sector, HCFC chillers using R-22 are also common in the food processing industry as well as in other industries where processes need to be cooled. At one point a large chiller segment using R-11 was to some extent converted to R-123 which is an HCFC, but has low ODP and low GWP. At the time this report was

Fig. 1.3 Chillers use secondary fluid to indirectly cool the room or object.



written, there were no known alternatives to R-123 suitable for existing systems.

R-245fa is an HFC alternative that can be used in low pressure chiller applications but has a higher pressure making it unsuitable for most existing systems. With the current information it can be expected that in this sector existing systems using R-123 will be maintained with minimum leakages until the end of their life. In most developing countries the introduction of R-123 has been limited although in some markets low pressure R-123 chillers could be a segment that will require special attention due to the challenges to replace it. As there are only a few suppliers that produce R-123 chillers, six according to James M. Calm (James M. Calm, 2002), it would be possible to identify exactly how many units of this system are in operation and where they were installed by contacting the manufacturers/importers.

As the use of indirect systems make it possible to more freely locate refrigeration units with toxic or flammable refrigerant, chillers using ammonia and hydrocarbon refrigerants are becoming more common.

Fig. 1.4 A commercial refrigeration installation using R-22 in a hot climate. This model requires a water spray on the condenser to avoid high presssure and overheating of the compressors. However this causes corrosion and wastes water that is often in short supply. In this case increased electrical hazards are obvious and 'Good Practice' has not been properly considered.

1.2.5 HCFCS IN COMMERCIAL REFRIGERATION

IN MANY ARTICLE 5 COUNTRIES, commercial refrigeration has traditionally been dominated by smaller plug-in systems and display cases cooled by individual condensing units. The introduction of larger central systems was limited to newer and larger supermarkets.

These systems in stores and shops were often cooled with R-12 and to some extent R-502 in the low temperature applications. With increasing pressure to phase out CFCs, transition to R-22 had occurred in many countries before R-404A or R-507 were accepted as the refrigerants for this sector. In the process of phasing out R-22 from commercial systems, R-404A and R-507 are being used as alternatives more frequently than in air conditioning. The use of R-22 in commercial refrigeration is significantly more challenging than the refrigerants it replaced and the non-ODS alternatives developed for this sector. This is due to the properties of R-22 which cause higher compressor temperatures requiring significant changes to the system's design or "quick fixes" such as installing water sprays for the condensers as shown in Fig. 1.4.

1.2.6 OTHER HCFC-USING SUB-SECTORS IN THE RAC SECTOR

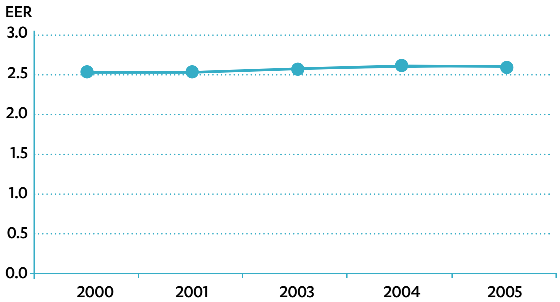
SMALLER VOLUMES of HCFCs are used in almost all other RAC sectors. Both R-22 and HCFC-containing service blends are used to replace R-12 and R-502. In transport refrigeration some manufacturers have converted to R-22 while the majority went directly to R-134a and R-404A. In some niche markets such as the high temperature air conditioning in the industry, there are applications where CFC refrigerant R-114 was replaced with R-124, which is an HCFC.

1.3 Energy efficiency of air conditioning equipment

ONE REASON WHY R-22 still prevails in the new installation market in many Article 5 countries is the lack of energy efficiency requirements and the low awareness of customers about the cost of running the systems. In this situation, the equipment purchase price becomes the only criterion for equipment selection. The more energy efficient state-of-the-art, non-ODS equipment then has to compete with the low cost R-22 equipment. The price difference is not mainly due to the change of refrigerant but rather to the larger heat exchangers and often to design improvements that reduce energy consumption and noise to meet international market demands. A report of the International Energy Agency (IEA)

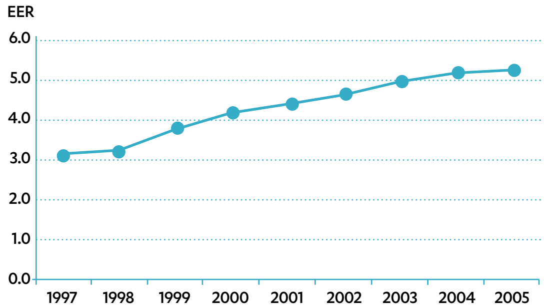
[IEA, SATORU KOIZUMI, 2007] evaluated the impact on energy consumption of increased efficiency requirements in Article 5 countries. The report gave the example of Ghana, an Article 5 country which imports its AC equipment and needs stronger national energy efficiency requirements. It demonstrated why the efficiency of installed equipment in the country is lower than that of the equipment available on the market.

Fig. 1.5 Development of energy efficiency of AC equipment in Ghana. The country has no domestic equipment production.



In comparison, Japan, which has clear and strict energy efficiency requirements, showed a rapid improvement of energy efficiency despite the fact that from the beginning the country already had a significantly better performance rate than Ghana. The Japanese air conditioners used 50% less electricity than those installed in Ghana. The expected

Fig. 1.6 Development of energy efficiency of AC equipment in Japan.



rapid increase in use of air conditioning systems in many Article 5 countries will result in drastically higher electricity consumption. The use of low efficiency equipment will be costly in terms of energy consumption. Furthermore, the often weak infrastructure used in producing and distributing electricity will be frequently overloaded by excessive energy demands coming from high air conditioning loads. An introduction of efficiency requirements and labelling schemes to improve efficiency is vital for Article 5 countries.

For Ghana, an enforcement of minimum energy standards in installed air conditioning units was estimated to reduce the country's total need for generated electrical power by 8%. The report contains an evaluation of barriers and possible counter-measures to introduce higher efficiency equipment.

1.4 Alternatives to HCFCs in air conditioning and refrigeration

SUMMARY ALTERNATIVES TO HCFCs

There is not and will most likely never be one refrigerant that can be used to replace all HCFC applications, since the use is so widespread and the requirement for better energy efficiency will result in an increased demand to adapt the technologies to the actual operating conditions.

Each system, or at least each type of system, needs to be evaluated from several perspectives to find the environmentally and technically best option that can be used safely at an acceptable investment and operating cost.

When evaluating the impact of RAC equipment on the climate, the direct GWP of the refrigerant used as well as the system's total energy efficiency should be measured. A system using a refrigerant with a higher GWP can be more energy efficient and have a lower total impact on the climate.

Using a lower GWP refrigerant in a safe and energy efficient way at an acceptable cost is a preferable solution to using high GWP alternatives such as HFCs. HFC emissions must be minimised and should only be used in systems with minimum leaks and where leak controls and recovery schemes are in place. HFCs are among the controlled substances under the Kyoto Protocol and can be expected to be charged with increased regulatory controls in the future.

There is always a number of alternative technologies that can be used. The easiest route would seem to be to choose the alternatives that require no or minimal system changes but it is important to realise that new technologies are continually being introduced and that the industry will eventually have to keep its knowledge abreast with these new technologies. An evaluation of environmental impact including energy efficiency, cost, technical as well as safety risks is required. The outcome will be different for different operating conditions and will depend on where the equipment is installed and how it is used. Generalisations often result in poor decisions and that is why it is important to establish industry standards to have acceptable service availability and to make the required training of the service sector manageable.

DUE TO THE HUGE NUMBER of applications for refrigeration and air conditioning systems with different operating conditions and requirements, it is practically impossible to find a single ideal refrigerant. The ideal refrigerant would need to have the following properties and characteristics, among others:

- Zero Ozone Depleting Potential (ODP)
- Energy efficient = have high Coefficient of Performance (COP), i.e. low indirect Global Warming Impact
- Zero or low Global Warming Potential (GWP), i.e. low Direct Global Warming Impact
- Chemically stable at all temperatures and environments
  - including contaminated systems
- Compatible with all materials
  - metals
  - elastomers (plastic/rubber materials)
  - oil, including suitable miscibility/solubility with oil
- Non-toxic
- Non-flammable
- Low cost
- Commercially available

The above list does not reflect an order of priority as this cannot be defined on a general level. Obviously, refrigerants with high flammability and toxicity can be easily handled in some applications and may be more or less impossible to be applied in others, at least without a significant increase in energy consumption and/or cost. Zero ODP is a legal requirement in many countries already. The total warming impact of a refrigeration air conditioning system will consist of a direct effect from released refrigerants and an indirect effect from carbon dioxide emissions during the production of energy used to operate the system. The combined effect of Direct and Indirect warming effect is often calculated as the **Total Equivalent Warming Impact or TEWI** (see Abbreviations and definitions)

TEWI takes into consideration leakage rates, emissions from the site where systems are scrapped and energy consumption. As these factors are different for each system and difficult to estimate, TEWI is often calculated based on statistical values and experience. The result will be affected by how the different factors are estimated. Factors like leakage and recovery rate are dependent on the quality of installation and service. This will change over time as service is improved through training in combination with regulations that require end-users and contractors to keep records, discourage emissions and enforcement actions. To assume leakage rates of 30% common on many markets or 5% achieved in others will drastically change the balance between direct emissions from leakage and indirect emissions from energy consumption. Few Article 5 countries have so far been successful in implementing functional refrigerant re-use schemes that reprocess significant volumes. As the average recovery rate in Article 5 countries is currently low the relative impact of direct emissions is high. With a strong focus on the introduction of good practice, the relative impact of GWP is expected to decrease although energy consumption also decreases with improved service practice. If a low-GWP refrigerant can be used safely at the same or lower energy consumption level with an acceptable investment, this will obviously be the solution with the lowest TEWI.

Energy efficiency is becoming more and more the focus when selecting refrigerants but it is important to realise that efficiency is only, to a small part, a result of the refrigerant selection. Typically the different refrigerants' theoretical impact on the total performance varies within a few percent, whereas the difference between various technical solutions of equipment design with a given refrigerant can be 20-30% or more. The solution that is 20% better in one application can also be significantly worse at other operating conditions. Simplified generalisations of performance that is not specifically referring to a specific application should be viewed with scepticism. **"If it sounds too good to be true, it probably isn't"**.

In the technical sections and case studies below, a number of technical and commercial aspects to be considered will be covered. In many countries there is a need to establish or increase local capacity to evaluate the suitability of different alternatives and to implement them in different systems. It is important to evaluate not only the lowest investment options but also the energy efficiency and cost effectiveness of the different options.

Therefore, it is easy to conclude that the ideal "one-size-fits-all" refrigerant does not exist and that some refrigerants will be more suitable in some applications than others. All refrigerants have their advocates on the market and there are interest groups promoting the different technologies. It is important that the refrigeration and air conditioning sector and equipment owners do a proper evaluation of the total environmental impact of using different alternatives. Any attempt to come up with one solution for all applications will with almost certainly not be the most environmental nor the most cost-effective option.

The opportunity to make improvements to the system in terms of efficiency when they are replaced or retrofitted should not be neglected. The pay off time for such improvements is often short when done in connection with other work on the plant. Ensuring a proper commissioning and adjustment of controls can often in itself save a significant amount of energy.

THERE ARE FOUR MAIN ROUTES TO REPLACING HCFCS IN THE RAC SECTOR

1	Ammonia	NH_3 (R-717)
2	Hydrocarbons	Isobutane (R-600a), propane (R-290), propylene (R-1270), blends, etc.
3	Carbon dioxide	CO_2 (R-744)
4	Hydrofluorocarbons	HFCs (i.e. R-134a and blends such as R-407C, R-410A)

Due to the phase-out of R-134a in the automotive air conditioning sector, a new low-GWP HFC alternative named HFO-1234yf has been developed by DuPont and Honeywell. At this stage it is not clear if the automotive industry will go this way or move to CO_2. As of March 2010 several HFO (hydrofluoroolefine) components are also being considered/studied for RAC applications. There is no sufficient information available to date whether HFO1234yf, by itself or in mixtures with other refrigerants, is a good solution for the RAC sector or if and when it will be commercially available. If the automotive industry takes this route it will require large amount and production capacity: It will take time to establish this to satisfy MAC demand increasing from 2011 as the quantities required in this sector are significant. Introducing additional products in the stationary sector will not be the highest priority in that scenario. It can be expected that the development work in the RAC sector, if it takes place, will require several years of additional research and development. The interest on the market will be dependent on how cost effectively these substances are in design of highly efficient equipment.

‘ANY ATTEMPT TO COME UP WITH ONE SOLUTION FOR ALL APPLICATIONS WILL ALMOST CERTAINLY NOT BE THE MOST ENVIRONMENTALLY-FRIENDLY NOR THE MOST COST-EFFECTIVE OPTION’

1.4.1 AMMONIA

SUMMARY AMMONIA

Ammonia is a well-established refrigerant requiring special personnel competencies and system design. There are a number of experienced companies and technicians with these competencies. An increased use of ammonia will depend on more technicians and engineers receiving training in this sector.

There are environmental benefits from the use of ammonia because it has zero ODP and negligible GWP. Technically it is a good refrigerant, but it has some safety drawbacks and technical challenges associated with material compatibility and high temperatures occurring during compression.

The investment cost is typically higher than for conventional systems, at least in lower capacities. Well designed systems can have very good energy efficiency and new designs are extending the application range with lower charge and new oils suitable for non-flooded evaporators. The flooded systems typically require procedures for oil return and are typically used in locations where there are qualified personnel on site.

Fig. 1.7 Ammonia installation typical for industrial applications.

AMMONIA IS A WELL-PROVEN refrigerant in larger commercial and industrial applications. Ammonia has technical properties that make it considered incompatible with copper which is a preferred material for tubing and motor winding for mass produced hermetic systems. The toxicity and risk to human safety if released, limit the applications where ammonia can be used safely and at an acceptable cost. The extremely strong and irritating odour emitted by ammonia when released may incite people to panic as they try to evacuate the area. On the positive side however, this odour also acts as a useful early warning signal in case of system leakage. The use of ammonia in its traditional sectors has increased on many markets due to the desire to avoid the use of high GWP refrigerants such as HFCs. Ammonia is still used mainly in the traditional application of larger industrial refrigeration systems although it has also been introduced in certain new segments such as large central air conditioning systems and smaller commercial systems on some markets. One way of reducing the risk when using ammonia is to minimize the charge by building compact chillers that can be placed in machine rooms specially designed for the purpose of eliminating the risks. There are also systems designed to absorb any releases of ammonia in water sprays before it can reach the area with public access.

The introduction of soluble oils for ammonia resulted in the development of "dry expansion" systems with lower charge and simplified oil return versus flooded systems with non-miscible oil.

1.4.2 HYDROCARBONS

SUMMARY HYDROCARBONS

Hydrocarbons are good refrigerants with zero ODP and negligible GWP. Their flammability requires specific competencies in design, manufacturing and service. To ensure safe use, there are restrictions on where and how they can be applied. Hydrocarbons as refrigerants are gradually being covered in International Standards detailing the necessary requirements for safe use (i.e. in EN 378 and ISO5149).

Isobutane (R-600a) has become the standard refrigerant in new domestic appliances in many markets. The small amounts used in a domestic appliance are not considered to be a significant risk after redesign of the refrigerators where all switches (e.g. thermostats and lamp switches) have been removed from the refrigerated compartment. A leak into the room where the unit is placed will disperse and not result in dangerous concentration.

Propane (R-290) and Propylene (R-1270) have more appropriate properties to replace R-22. Several hydrocarbon mixtures were also introduced as replacements for CFCs and HCFCs. On several markets hydrocarbons have been used in smaller commercial refrigeration equipment and air-cooled chillers.

Safe use of hydrocarbons requires training of those involved in the design, installation and servicing the equipment. Standards and regulations adapted for use in RAC systems are important so as to avoid the exposure of technicians and users to danger due to irresponsible practice.

Today there are international product standards that cover small hermetic systems (having a charge of approximately less than 150 grams) that allow them to be installed in most places provided that proper design precautions have been taken. For larger systems the product standards refer to "relevant national and international standards i.e. EN378 and ISO 5149" (GTZ-Proklima, 2008).

If the charge of hydrocarbons can be kept low versus the air volume in the room (typically 8 grams/m3) the risk of creating flammable mixtures is eliminated.

The compatibility of oils in connection with hydrocarbons is sometimes an underestimated question since high levels of miscibility have caused many system failures when hydrocarbons have been introduced without proper redesign.

This report will not discuss the retrofit of existing HCFC systems to hydrocarbons as the evaluation of an old unit designed and located without consideration to the refrigerant flammability is in most cases complex and will need to be done in accordance with international as well as national legislation. It can be said that there is obviously much less risk involved in systems with a charge below that which can create an explosive environment in the room or if the whole refrigeration system is placed outside i.e. air cooled chillers. The information on design of hydrocarbon systems presented here will be relevant in considering when hydrocarbons are used, but additional requirements will often apply. Safety related to operation as well as service must always be carefully evaluated before a flammable refrigerant is applied. There are several markets where retrofits are carried out and the information is often available on the internet. See www.Hydrocarbons21.com.

INTERNATIONAL STANDARDS have to some extent been adapted to accommodate safety requirements for hydrocarbons but uncertainty on regulations still remain in some applications. There is a significant interest in hydrocarbons on the market since they are good refrigerants, and as a result the number of components and systems is gradually increasing. However due to safety considerations and the small market outside domestic appliances, many components are not approved by the manufacturers. There are concerns over liability and unclear regulations even if the components function. Due to the potential damage a failure can cause the requirements are higher, in many cases, for components for flammable refrigerants than for those that are non flammable. If there is a lack of approvals the challenges for the technicians involved increase as they cannot fully rely on manufacturers' validation which specifies that the particular component fulfils all relevant pressure and safety standards. For most applications the relevant components are available from some source, but they can be more difficult to find and the cost is sometimes higher. For systems with refrigerant charges above 150 grams and/or a charge over approximately 8 grams/m^3 air in the room (charge limitations can vary depending on country and application) the safety requirements increase and it often becomes necessary to make a risk assessment to ensure that risks are acceptable. On most markets hydrocarbons are rarely introduced in existing equipment as electrical systems and controls are often not suitable and need to be redesigned. There are systems that after careful evaluation can be modified to be safe but the challenges are much bigger than in new systems designed for a flammable refrigerant. Extensive presentation of hydrocarbons as an option in RAC systems can be found in (GTZ-Proklima, 2008).

TECHNICAL INFORMATION

For an unventilated area the allowed refrigerant charge in kilograms to avoid flammability is:

$m_{max} = 0.25 \times LFL \times A \times 2.2$ [T. JABBOUR, D. CLODIC]

Where LFL is the Lower Flammability Limit in kg/m^3 and A is room area in m^2.

For propane (R-290) LFL = 0.038 kg/m3
For Isobutane (R-600a) LFL = 0.043 kg/m3

The safety limit of 0.25 is used to compensate for the differences in density resulting in an increased concentration near the floor.

For example, in a room that is 3x4 meters the maximum allowed charge of R-290 is 250.8 grams, not taking into account the increased safety measures according to standard IEC 60335-2-40 [IEC, 2005].

The hydrocarbons most commonly used in traditional HCFC applications are:

Propane (R-290) having characteristics similar to those of R-22 has been introduced in a wide range of commercial and air conditioning applications. The cooling capacity is typically significantly lower than R-22 and performance (COP) in the range of -2 to +6% relative to R-22 [Bitzer, 2008]. Propane has been introduced in a wide range of applications and when proper consideration of high solubility in oils has been taken good operating experiences are reported.

Propylene (R-1270) has higher cooling capacity and lower boiling temperature than propane and is the preferred option by some manufacturers. The higher pressures and discharge temperatures need to be taken into consideration especially for use in hot climates.

Hydrocarbons are often claimed to be compatible with all commonly used oil (mineral, alkyl benzene and ester oils). This statement is very questionable as not all oils will give a reliable function with hydrocarbons. Use of hydrocarbons with traditional oils without changing oil viscosity and/or making system design modifications has in many cases resulted in high failure rates caused by the extreme miscibility between oils and hydrocarbons resulting in increased wear in compressor. Besides redesign or relocation of electrical systems and controls, it is often advisable to also increase the viscosity of the oil and ensure sufficient superheat through a suction gas heat exchanger [Bitzer, 2008].

1.4.3 CARBON DIOXIDE (CO_2)

SUMMARY CARBON DIOXIDE

Carbon dioxide technology is currently the most innovative area in refrigeration. CO_2 is not a new technology, but it has been widely used in the RAC sector for a long time because there have been easier and lower cost competing technologies. However, with an increased movement to reduce the use of HFCs and the search for non-flammable, non-toxic refrigerants, CO_2 has become an interesting alternative with zero ODP and insignificant GWP. The two main challenges involved are the high system pressure at normal operating temperatures and the low energy efficiency (COP) for a standard refrigeration cycle.

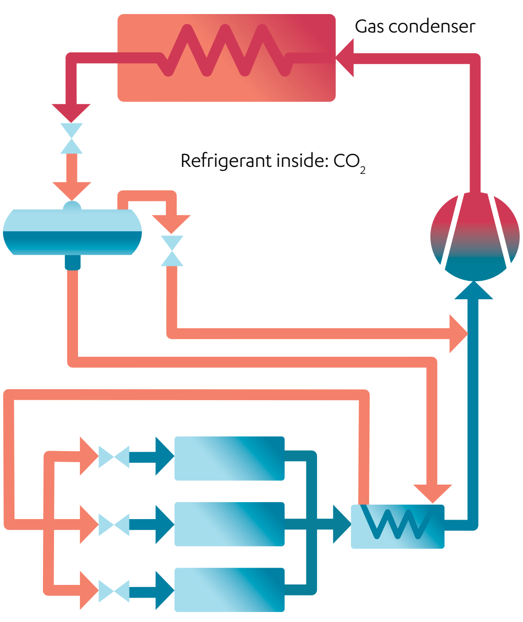
It is possible to design new equipment to make it suitable for higher pressures and more and more manufacturers are offering components and systems for CO_2 making it possible to design a wider range of applications. CO_2 is introduced in different applications both as single stage "supercritical" refrigerant, part of a cascade with a second refrigerant and as secondary fluid in indirect systems with a different refrigerant in the compression cycle.

The challenge and what is going to define the future market share for CO_2 is determining at what cost it will be possible to achieve competitive energy efficiency in field conditions.

The special characteristics of CO_2 and the need to design the systems with consideration to the local conditions to achieve competitive COP will (even more than for conventional technologies) make it necessary to evaluate solutions application by application. Discussion is ongoing if supercritical CO_2 system will be energy efficient in warm climates.

Special training is required to design, build and service systems for CO_2 and high pressures. This includes not only dealing with the high pressures but also the technical know how to make the system energy efficient.

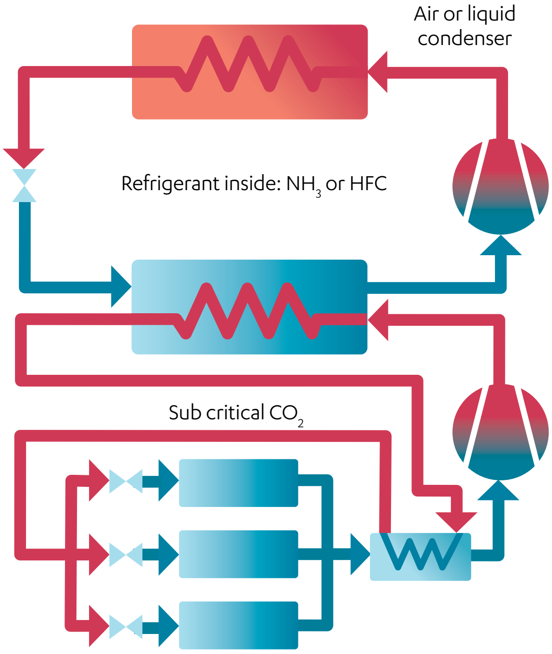
Fig. 1.8 Supercritical CO_2 system with gas cooler operating at pressures 2 to 3 times that of conventional systems.



CARBON DIOXIDE has a negligible GWP but will operate under significant higher pressure than the traditional refrigerants and cannot be used in existing equipment. As CO_2 has a low "critical point" the behaviour will be different to traditional refrigeration systems. Above 31°C the system will work in "supercritical" (sometimes called "trans-critical") conditions, i.e. traditional condensing will not take place. There are several applications where CO_2 can be considered as a commercially-available alternative although the price level is often higher than that of conventional technologies. The ongoing discussion is in which applications the energy efficiency will be comparable with the one achieved in other alternative technologies. In the commercial refrigeration sector, much of the development is focused on this refrigerant due to the negligible direct GWP. The applications with the longest experience are where CO_2 is used as secondary fluid in indirect systems and at low temperature industrial/commercial refrigeration in "cascade system" with ammonia (or HFC) in the high stage. A significant number of supercritical CO_2 systems have been installed and several reports on the coefficient of performance (COP) of these systems have been published. The statements on efficiency vary depending on the source, and further development and more documentation from commercial installations is needed before actual COP, cost and reliability in different systems and conditions are established. It should be noted that the relative energy efficiency versus other technologies will depend on the climate where the system operates (warm climate will have a more negative effect on COP in supercritical CO_2 than in conventional HFC systems).

In Japan, CO_2 heat pumps with supercritical operation for domestic hot water have found a large market (their development and introduction have been promoted with the help of subsidies from government and utility companies). This technology has also been introduced in

Fig. 1.9 CO_2 in sub-critical operation in cascade with hydrocarbon, ammonia, or HFC refrigerant.

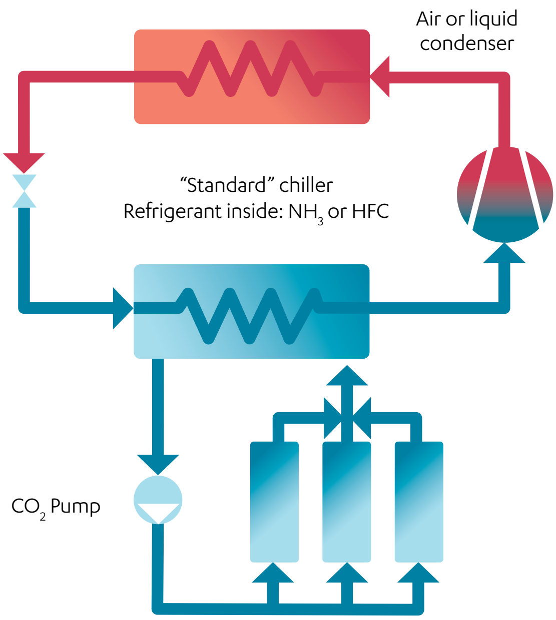


Europe where these heat pumps are used for combined hot water and space heating.

CO_2 is also used as a secondary fluid in low temperature applications as it can reduce the energy consumptions for pumps and tube dimensions in indirect cooling systems. The use of indirect systems is increasing as it reduces the refrigerant charges and leak risk significantly and is preferred in several applications on some markets. Indirect systems also give more flexibility in the selection of refrigerants as the risks and costs of using flammable (HCs) and toxic (NH3) refrigerants decrease.

CO_2 is also a leading candidate as an alternative to R-134a in automotive air conditioning as the latter will be phased out in new car models in the EU from 2011.

Fig. 1.10 CO_2 as secondary fluid in an indirect system.



1.4.4 HFC ALTERNATIVES USED IN NEW AND RETROFITTED SYSTEMS WITH NEW OIL

SUMMARY HFCs

HFCs are by far the most common replacement of HCFCs in new equipment and a wide range of such equipment has been available on the market for the past 15 years.

The relatively high GWP of HFCs have increased the pressure on finding alternatives with lower impact on climate and the development efforts have increased as climate change has become the number one environmental challenge.

The arguments used in favour of HFCs are that they can be used safely and cost effectively in all applications where CFCs and HCFCs have been used with minimal technical changes. As the focus on climate change increased, this also resulted in an increased focus on energy efficiency. In many applications the energy efficiency of today's HFCs

systems is much higher than that of the HCFCs systems they are replacing. In many sectors there are requirements on minimum efficiencies expressed as Seasonal Energy Efficiencies, for example. In some markets, the government offers tax exemptions or subsidies to high energy efficiency solutions.

In most applications the energy consumption will be the major contributor to global warming from a RAC system. TEWI (see Abbreviations and definitions) as well as the Life Cycle Analysis (LCA) of cost and environmental impact are important factors to consider when comparing different alternatives.

The most common HFC alternatives in new applications and retrofits with change of oil to a polyol ester oil are:

Split and unitary air conditioning units	R-407C and R-410A
Heat pumps	R-134a, R-407C and R-410A
Display cases and small systems	R-134a and R-404A/R-507
Chillers, air conditioning	R-134a, R-407C and R-410A
Chillers, commercial	R-134a and R-404A/R-507
Central system commercial	R-404A/R-507
Industrial	R-404A and R-507

Out of the HFC refrigerants listed above only R-410A requires components designed for significantly higher pressure.

Service blends intended for use in existing systems are listed in the next section.

The introduction of "good practice" and functional re-use schemes is essential to achieve minimal emission and high energy efficiency.

THE ONLY MARKET segments where ODS have been replaced widely by non-HFC alternatives are domestic appliances and some "plug-in" display cases that have changed from R-12 to isobutane (R-600a). In markets where flammability and toxicity have been considered difficult and/or costly to handle safely the transition has been to HFCs. As new technologies are developed and mature and more technicians receive training and become familiar with non-HFC alternatives, these "not-in-kind" alternatives can be expected to increase their market share. As the HFCs are not compatible with traditional refrigeration oils the introduction of HFC normally requires a change to ester-oils (e.g. PAG-oils are used with R-134a in the automotive sector). There is a special range of HFC refrigerants called "drop-in" or "service-blends" that are tailored to allow the use of HFCs with traditional mineral oils by adding a component to address oil transport characteristics (see service blends below).

In most R-22 applications the two dominating HFC alternatives for new installations are R-407C and R-410A. The former is closest to R-22 in terms of capacity and pressure. Provided the change to an ester oil has been made, R-407C gives a similar capacity and performance as R-22 but presents a special characteristic. As it is a zeotropic blend – i.e. it has a gliding temperature during condensation and evaporation (glide) - it is less suitable for some applications. R-410A was introduced later and it requires redesign to handle the higher pressure but has an advantage of higher capacity and insignificant glide. R-407C has lost a significant part of its initial markets to R-410A, but is still the preferred solution in several segments such as small- and medium-sized chillers and water/brine heat-pumps. R-410A, on the other hand, has taken most of the market in smaller air conditioning systems of unitary and split type.

In commercial applications that traditionally used R-12 and R-502, R-22 is normally replaced by R-404A/R-507.

In some traditional R-22 segments such as larger chillers R-134a has taken a significant market share.

1.4.5 HFC "SERVICE BLENDS" USED IN EXISTING SYSTEMS

SUMMARY HFC SERVICE BLENDS

"Service blends" are developed to offer a "drop-in" technology that lowers cost as compared to changing the oil, which is required, when adopting the same HFC alternatives used in new systems.

"Retrofit" is the term often used to describe the procedure in which the refrigerant and the oil are changed (and, if necessary, certain parts of the equipment are also replaced). In this report,"retrofit" refers only to this procedure and not to the one using service blends. Most service blends are proprietary products marketed as a low-cost, easy-to-use solution, so sometimes the technicians using them do not have a full understanding of their characteristics and limitations.

To overcome the need to change to ester oils when ODS are replaced by HFCs, a number of service blends have been developed to replace the HCFCs. One component (often a hydrocarbon), which changes the characteristics of the oil-refrigerant mixture in the system, is added. These alternatives are sold with the advantage that they offer a cost effective option to replacing ODS. A change in refrigerant will result in a change in the characteristics of the oil which affect oil transport and lubricity. It is recommended that before any decision to introduce a service blend is taken, an evaluation be conducted to determine whether the system will be significantly affected by the change in oil transport and lubrication.

The first criteria when evaluating options for replacing HCFCs is to define the status of the existing system. Always check that the existing system is in sufficiently good shape to justify the required investment.

Investment, even if limited, in equipment that is about to fail is a waste of money. The energy efficiency and historical leakage rates are important factors to consider before any decisions are made. If the equipment's condition is such that replacement with a service blend is deemed the best option, additional measures to be taken in connection with the change should also be evaluated in order to minimize leaks and extend the equipment's life time.

The service availability during the remaining life time of the equipment should be ensured to avoid that a future lack of availability forces additional investments. The number of blends offered on the market makes the storage of service quantities a challenge for the service providers unless some standardisation occurs in the market.

Below are the most commonly considered service blends for replacing R-22.

R-417A	R-22 Replacements targeting small direct expansion systems
R-422A	R-502 and low temperature R-22 replacement
R-422D	R-22 Replacements in for example chiller applications
R-424A	R-22 Replacements targeting small direct expansion systems
R-427A	R-22 Replacements
R-428A	R-502 and low temperature R-22 replacement
R-434A	R-22 Replacements in for example chiller applications
R-438A	R-22 Replacement targeting a wide range of operating conditions

THE FIRST SO CALLED R-22 "drop-in" alternatives or "service blends" was the R-417A, but lately R-422A, R-422D, R-424A, R-427A, R-428A and R-434A have been launched to offer alternatives tailored to general or specific R-22 applications. Almost all service blends (except R-427A) have a similar approach in composition where one or two components are added (often hydrocarbon). This part of the blend composition is extremely soluble in the oil which results in the viscosity of the oil not increasing when the HCFC is replaced with a non-soluble HFC. This strategy has proved to be functional in many systems, but there also have been reports of problems in some applications. There is limited unbiased information readily available and it is obvious that success stories are more widespread than those describing problems that should be avoided. Several factors should be taken into account when evaluating the service blend option and when deciding to what extent case studies can be considered relevant for the applications under consideration.

TECHNICAL INFORMATION

Factors to consider besides capacity, COP and discharge temperature with service blends are:

The component (often a hydrocarbon) absorbed by the oil does not make the oil miscible with the refrigerant, but it “adjusts” the viscosity to be more similar to the old oil/refrigerant mixture for which the compressor was designed and to improve oil transport, particularly in the evaporator and suction line where a “thicker” oil increases the risk of poor oil return. Since in most cases the component introduced to decrease the oil’s viscosity is a flammable substance, there are limits on how much of this component can be added before there is a risk of explosion, especially if leakage outside the equipment occurs.

At the same time the ratio between oil and refrigerant will affect how diluted the oil is, e.g. if the oil charge is relatively small as compared to the refrigerant charge, the oil-refrigerant mixture will have lower viscosity than if the oil content is significantly higher relative to the refrigerant charge.

The oil that is circulated normally has a lower density than the refrigerant and if there are stable liquid levels, e.g. in the receiver, tube or shell condenser, the oil will tend to float on top of the refrigerant liquid and can accumulate to an extent where the compressor will eventually fail.

In complex refrigeration systems there are cases that have been reported where the oil accumulated in the evaporator and suction lines.

In systems with tubes with rifles/grooves to enlarge tube surface and improve heat transfer, there have been reports where heat transfer was drastically affected due to blocking of the grooves with oil.

Therefore, the claims that service blends are easy to use and do not require the same careful evaluation as a retrofit to standard HFC refrigerants can often be questioned.

Some of the differences in recommendations between suppliers of different service blends can probably be more related to policies and risk assessment rather than technical differences between the alternatives.

Some compressor and/or refrigerant manufacturers recommend that alkylbenzene oils be used with HFC service blends and/or that a part of the old oil is replaced with ester oils. The importance of clean and dry systems and the risks associated with converting old systems of often questionable condition should not be underestimated. The consequence of these aspects is not that service blends cannot be used; rather their suitability should be evaluated versus the system in question to avoid risk of failures. The evaluation of the different commercially-available options is difficult to do as objective information is lacking. All suppliers of service blends are focusing on success stories and there is a tendency to try to minimize any concerns.

In operations on mixtures of old and new oils, there is the risk of a chemical break down of the oil caused by contaminants in the old oil. There is also a risk that new oil will dissolve and transport deposits to the compressor. Suction filters during the change over procedure can be used to reduce this problem.

1.5 Oils in refrigeration and air conditioning systems

SUMMARY OILS IN RAC SYSTEMS

With a few exceptions, RAC systems contain an oil to seal and lubricate the compressor. A small amount of oil will always leave the compressor and will be transported around the system (even with oil separators, a small amount will circulate in the system).

In most systems, oil return requires that the oil is miscible with the refrigerant. The miscibility also decreases the negative impact of oil in the heat exchangers.

The oils used with CFCs and HCFCs are not miscible with HFCs, which makes an oil change required to achieve the same characteristics.

The Mineral oil (MO), alkylbenzene (AB) and sometimes Poly-alfa-olefins (PAO) oils used with CFC or HCFC refrigerants are most commonly replaced with Polyolester (POE) oils when HFCs are used. Also Polyalkylene glycols (PAG) oils and Polyvinylethers (PVE) are used for HFCs. PAG is the oil used in automotive air conditioning.

"Service" or "drop-in" blends are designed to achieve a behaviour similar to that of HFC/MO or HCFC/MO to avoid the cost of changing the oil to a miscible oil. It should be noted that there will be significant differences that will affect some systems considerably.

The new oils for HFCs are hygroscopic and require training and proper handling to avoid increased failure rates. Large cans of oil that cannot be emptied at one installation should not be used unless oil is moved to a pressure vessel, i.e. a two port refrigerant cylinder where it can be kept under overpressure with nitrogen.

WHEN EVALUATING ALTERNATIVE refrigerants for different applications, careful consideration should be paid to the oil properties and how they are affected by the different refrigerants. How a refrigerant behaves in a system is significantly easier to predict than how the mixture of oil and refrigerant will behave. It is easy to define the properties of a refrigerant or pure oil at different pressures and temperatures. It much more complex to predict and test lubrication properties in the compressor and oil transport in the system after the refrigerant and oil has mixed. The selection of oil must take into account all aspects to ensure long term reliability of the system. Many systems have failed because end users have not considered the interaction between the oil and the refrigerant.

TECHNICAL INFORMATION

Some key properties are listed below:

- **Lubricating properties** are important to create a reliable system with a long life. The lubrication is strongly affected by the refrigerant in the system when there is a miscible oil-refrigerant mixture. The miscibility is important due to the requirement to have acceptable oil transport throughout the system. The amount of the refrigerant dissolved in the oil is affected by pressure and temperature, which means that the lubrication varies with the operating conditions. Sometimes compressor manufacturers require different oil based on the operating conditions. The miscibility of the refrigerant in oil is an important factor to provide the right lubrication properties when the refrigerant is dissolved in the oil at all pressures and temperatures that can occur in the compressor's operating envelope. Also, the CFC or HCFC refrigerant by itself affects the lubrication properties as the chlorine from the CFC or HCFC acts as an anti-wear additive.
- **Chemical stability** in the system in the presence of refrigerant and all materials that could be used over the whole operating envelope. This must also take into account the presence of moisture and contaminants that can occur in a refrigeration/air conditioning system. This is a key concern as contaminants drastically decrease stability. Poor practices applied during manufacturing, installation and servicing results in a decreased life expectancy for the system. Unless practices are improved, the phase out of ODS will result in an increased failure rate as the new oils are more sensitive to poor handling. On the other hand, with the introduction of good servicing practices, the life of RAC systems can often be many times what was expected with CFC or HCFCs and old servicing methods.
- **Miscibility - Oil transport.** As there will always be a small amount of oil that leaves the compressor with the compressed refrigerant it is essential to ensure that it comes back. If the oil is not transported around the system, the compressor will eventually run out of oil and fail. Oil in the heat exchangers will also have a negative impact on the heat transfer and decrease the energy efficiency. Normally the oil transport problem will be critical at low evaporation temperatures and low capacity and could occur after a long time when the system operates under specific conditions.
- **Elastomers compatibility** with oils is an important issue, in particular in old systems where O-rings and other seals can be affected by a change of oil. There are some commonly used materials like Viton™ (a trade name of special fluoropolymer offered by DuPont) that are not recommended together with POE and PAG oils. If these oils are introduced in systems with unsuitable elastomers, the risk of increased leaks is obvious. These elastomers are often used in gaskets/seals in solenoid and other valves. They can also be used on sight glasses applied in liquid lines and receivers. There are also elastomers used in the service ports (so-called Schrader valves) and in the caps for these. **As a rule these caps and/or cap seals should be replaced when refrigerant and oil are replaced with new combinations that can be more aggressive to elastomers.**

THE NEED TO ensure lubrication and oil transport creates a challenge in RAC systems as the lubricating properties will vary greatly, depending on operating conditions. It is therefore not uncommon that compressor manufacturers will recommend different oils for different applications. Neglecting the importance of oil properties has resulted in a large number of failures in systems that use alternatives to R-22 including HFCs, service blends and hydrocarbons. There have been serial problems in new HFC and new hydrocarbon systems, as well as in connection with different service blends. The oil behaviour in the refrigeration systems is often significantly more complex and challenging than the refrigerant's behaviour.

When a system is modified, it is important to consider how this will impact lubrication and oil transport. When there is information from the compressor and/or oil manufacturer, this should be taken into account. System manufacturers should be consulted if they are aware of any problems with their particular system although some do not consider it to be in their own interest to extend the life of old (often inefficient) equipment or to assume responsibility for advice that will involve some risk of problems.

Ester oils and HFCs act as a solvent in the system and there is a risk that debris and contaminants that have accumulated in the system over time are dissolved and transported around the system. This can result in compressor failures or poor functioning of expansion and solenoid valves. The use of filters in the suction line, and replacement of both the filters and the filter driers, are often recommended. If retrofits are done with flushing (as described in the following sections) the risk from old contaminants decreases.

It would be an advantage to avoid oil totally, and there are a few types of oil-free systems on the market. These designs have been used in large centrifugal compressors that operate without oil (except for small amounts in shaft seals that can enter into the system in small quantities). Lately a new type of smaller (a few hundred kW cooling capacity) oil-free semi hermetic centrifugal compressors with magnetic bearings has been introduced in the RAC market.

1.6 Retrofit procedures

THE PROCESS OF changing a refrigerant should in theory be an easy operation, but in a reality the situation is more complex because the alternatives to ODS developed for new systems require a different type of oil. This report uses the term "retrofit" to describe the process of changing refrigerant and oil; it uses the term "conversion to non-HCFC" to describe the change of service blends that do not require oil change.

The retrofit of an old system is a challenging task in many respects, since the status of the old system is often unknown from the start and the new refrigerant as well as the oil has different properties. Equipment owners consider replacing the refrigerant for different reasons. The policies of the equipment owner as well as his/her economic situation often play a major role when it comes to the evaluation of the available options. The owners often decide to change the refrigerant in a system for the following reasons:

- An urgent need to do major repairs of the system, which makes a conversion at the same time easier.
- The equipment owner is dissatisfied with leak rates of regulated substances and their high costs, and therefore wants to avoid releases of large amounts of ODS.
- The equipment owner has environmental policies and wants to make a long-term plan to move out of ODS. Multinational companies often have global policies to reduce their carbon footprint, and improving their RAC systems can have a significant positive impact.
- The equipment owner wants to avoid the risk of a work standstill due to future shortage of ODSs when they have an urgent servicing need.
- The equipment owner is pushed by authorities and/or regulations to phase out all ODSs.

The age of the equipment, the time perspective and financial situation of the system owner will result in anything from low cost "fix it cheap" solution to the replacement of the whole system to obtain a high energy efficiency.

It is always important to evaluate the suitability of the existing plant before a retrofit is made. The age and status of the system are key factors in the decision-making process.

For the first project, a carefully followed procedure might take some extra time but it will quickly pay off, since a failure to do the proper "homework" tends to result in an increased failure rate. If the documentation of performance and operation is not done prior to retrofit, there is no possibility to build experience for the future. If a failure or problem occurs it is often impossible to know afterwards if the cause of the failure was due to the change of refrigerant, the servicing methods used or if the problem existed before the refrigerant change started, in which case the system would have failed anyway. The contractor, refrigerant or method used can then be incorrectly blamed even if the reason was that, for example, the compressor was in poor shape.

The following steps should be considered before undertaking any retrofit (adapted to the size, status and cost of equipment):

P. 1.11 For old plants in poor condition and/or with high leakage rates, retrofits might not be a justified option even if the cost is limited. Often the better energy efficiency of a new system can quickly compensate for the additional capital investment.

‘IT IS ALWAYS IMPORTANT TO EVALUATE THE SUITABILITY OF THE EXISTING PLANT BEFORE A RETROFIT IS MADE’

Fig. 1.12 R-22 plant in a warm climate might not have pressure vessels with sufficient design pressure to be used with R-404A. In those cases these vessels should be changed if a retrofit to R-404A is to be done. All pressure vessels should have a plate stating the maximum allowed pressure as shown above.

Before refrigerant change

01. A "Performance Inspection" or at least a careful status check of the old system will document if there are components that are not functional and should be changed during the retrofit process. For systems that are old and/or in poor shape, it might be more cost effective to replace them than spend money when the remaining life time is short and the energy efficiency is poor.

02. A leak inspection will make it possible to correct leaks at the lowest possible cost during the retrofit procedure to decrease emissions and cost after the retrofit.

03. It will be necessary to check with suppliers about the list of components to determine if there are any incompatibilities between the components and the new refrigerant and oil. This inspection should include validating that the pressure vessels are compatible with the new pressures of the system. This is particularly true if there is a change from R-22 to R-404A, which has a higher pressure level than R-22 in the condenser. Each pressure vessel should have a label stating maximum allowed pressure. A failure to ensure a compatible pressure level can be dangerous.

04. Plan the change and consider what measures to reduce leaks and improve efficiency are cost effective in connection with a change of refrigerant.

05. If a retrofit (e.g. an oil change) is the preferred route, select the method of oil change and set a target for the remaining content of the old oil remaining in the system (e.g. 1-5°C). If a service blend will be used, check what the refrigerant and compressor suppliers recommend with respect to the oil.

Refrigerant change

06. Change the oil either with repeated oil changes or by "flushing" if this was the route chosen (see the section on oil change).

07. Correct problems and leaks, if any.

08. Replace the drier and any incompatible or defective components.

09. Evacuate the system carefully, using the dry nitrogen and double vacuum method.

10. Start up with care.

After the refrigerant change

11. Measure the performance/behaviour and adjust the system to optimize the performance and reliability

12. Document all relevant parameters of the operation so they are available for reference before future servicing.

13. Label the system with correct refrigerant, charge and oil type and content.

14. It can advisable to take oil sample after approximately 100 hours of operation. This sample can be analysed later if a problem occurs or it can be sent for analysis at once. Keep a sample of the oil can: if there is an indication of a problem, it is important to validate that the retrofit was performed to an acceptable standard.

1.6.1 DOCUMENTATION OF STATUS AND PERFORMANCE

MANY SERVICE journals are not useful for evaluating how a system works since they lack information on how the values were taken and provide no information on the stability of the system's operation. There are options to do the evaluation with a more detailed commissioning sheet or in more detailed way with a "Performance Analyser" so that the pre- and post-retrofit status of the system can be documented.

This can be done manually with a protocol like the one below, or - as presented in some of the case studies of conversions/ retrofits - with a computerised "Performance Analyser" that measures the pressures and temperatures in the system and analyse them on-line, so (for example) cooling capacity, COP, compressor efficiency and adjustment parameters are documented before and after the retrofit.

Maintenance log, bases for Performance Inspection

Unit Inspection: Location:

Performance	**Nominal**	**Measured**[1]			
Secondary side		Measured [2]	Measured [3]	Measured [2]	
Temperature in cold side (air /secondary)					°C
Temperature out cold side (air /secondary)					°C
Temperature in warm side (air /secondary)					°C
Temperature out warm side (air /secondary)					°C
Refrigerant circuit Refrigerant:					
Compressor discharge temperature					°C
Compressor suction line					°C
Refrigerant Liquid Temperature					°C
Refrigerant High Pressure/midpoint temp					Bar(g)/°C
Refrigerant Low Pressure/midpoint temp					Bar(g)/°C
Super heat (suction line - dew point evap)					K
Sub Cool (bubble point cond -liquid temp)					K
Power input					
Electrical Active Power [4]					kW

[2] Each set of measurements should be taken in as short period of time as possible and there should be a time interval of 1 - 2 minutes.

[3] The test conditons should be as stable as possible. Secondary side should if poossible not change more than 1 K or 0.2 Bar between each set of readings. If system can not be stabilised this should be taken into account when evaluated.

[4] If there is no possibility to measure Active Power currents/voltage can be used with consideration of power factor.

Comments:

Inspection Performed by:

Date:
Name:
Service Enterprise:
Adress:

1.6.2 HOW TO REPLACE THE OIL DURING RETROFITS

SUMMARY OIL CHANGE METHODS

The change of the oil is the major obstacle to retrofit an HCFC system to the "standard" HFC refrigerants used in new plants, since it is not easy to get the old oil out of the system.

The oil in a refrigeration system is distributed over the whole system even if a majority will typically be in the compressor. Most small systems have no ports designed to drain the oil out of the compressor. On larger systems, ports or valves are common, however only 40 to 80% of the oil can be drained through these.

For a retrofit to a standard HFC refrigerant, the refrigerant manufacturers recommend that 95- 99% of the old oil should be replaced, by using polyolester oil, e.g. only 1-5% of mineral oil should remain after the retrofit.

Oil changes can be performed through one of the following methods:

A. Repeated oil change. The number of changes are determined by the targeted maximum content of the old oil. Typically the number of oil changes vary between three and eight, depending on configuration of system.

B. Flushing with the old refrigerant using a "flushing unit" designed for this purpose. This method requires that the technicians have access to equipment and are specially trained to apply it. The advantage with this method against the one described below is that no cleaning solvent is introduced and that the waste is separated in a recycled HCFC fraction and an oil fraction on site. The HCFC can then be re-used after validation of the quality.

Flushing with solvent using a flushing unit designed for this purpose requires that technicians have access to the equipment and are properly trained on this procedure. The solvents often contain HFC (and/or HCFC) and need to be handled in a responsible way after use. National and international regulations apply for the use and transports of different solvents. Some of the solvents can be reprocessed by the manufacturer. The responsible use must be ensured in each market to make this option an acceptable solution. The service company and/or equipment owner should verify the compatibility of any solvent used with all components, refrigerant and oil. Some proposals to flush with nitrogen have been made but no documentation of this method have been found by the author. Additionally, since nitrogen will be injected as vapor it cannot be expected to move much of the oil out of the systems unless there are small diameter tubes where a sufficient velocity can be created. Moreover, it cannot be used to move oil or contaminants that have accumulated below the drainage points which is the benefit of flushing. Obviously nitrogen can be used in connection with oil change to speed up the oil drain.

THE MAIN TECHNICAL challenge is neither to recover the old refrigerant nor to charge the new refrigerant. The issues the technicians and end-users need to deal with are the evaluation of the best option for a particular system and how to cost effectively go through the required steps. The main question is often whether the existing oil can be used or if it has to be removed. If an oil change is necessary or preferred, the challenge is how to remove the old oil. The complexity and cost of replacing the old oil is often the main factor in the decision whether the "standard" refrigerants commonly used in new systems of the same type (e.g. R-407C or R-404A) could be used, or if a "service" refrigerant blend should be used. From the point of view of service availability, it is an advantage to move directly to the same refrigerants that are used in new systems if it can be done at an acceptable cost. Also, some of the uncertainties with oil transport in connection with service blends are avoided.

The oil in an RAC system will mainly be in the compressor, but a significant amount will be distributed around the system. In larger systems there are frequently oil plugs or valves, but even in those cases 20 to 50% of the oil will often remain after the oil has been drained through these ports. For hermetic compressors there are rarely any possibilities to drain any oil. Some components such as oil separators and receivers can sometimes contain more oil than in the compressor and frequently there are no possibilities to drain them without application of special methods. The maximum level of mineral oil for safe operation, when changing from HCFCs to HFCs, is system-dependent and affected by the status of the oil remaining in the system. "The cleaner the better" rule is valid, 1% is considered as a preferred level whereas 5% is often deemed acceptable if the old oil is not heavily contaminated with acid, moisture or wear particles.

1.6.3 RETROFIT WITH THE "OIL CHANGE METHOD"

THE FIRST METHOD to remove the mineral oil from the system and replace it with ester oil was to conduct repeated oil changes. The advantage of this method is that all servicing technicians are familiar with how oil is changed. There are also some obvious disadvantages:

- The oil is expensive.
- It is often time consuming to travel repeatedly to the site to do the oil changes.
- During the oil change process, the new ester oil is mixed with a sometimes heavily contaminated mineral oil and may start deteriorating quickly.
- During the oil change, the system is normally run on the old refrigerant until the mineral oil content is sufficiently low. During that time viscosity of the ester oil can decrease due to excessive miscibility with CFC or HCFC.

An often discussed issue is how many oil changes are required to achieve a given target for mineral oil content. Sometimes different sources generalise the number of oil changes more or less regardless of system design, which would result in very different results. It is important to adapt the number of oil changes to what is needed to achieve the targeted mineral oil content. As discussed in section 1.6.2 the target should be set first and then appropriate method to achieve it should be selected. The number of oil changes required can vary between one and seven or more, depending on methods and system design. Oil changes and the flushing methods below can also be used in combination with each other to achieve the most cost effective retrofit.

1.6.4 RETROFIT THROUGH FLUSHING WITH THE "OLD" REFRIGERANT

THERE ARE FLUSHING units/methods designed to circulate the "old" refrigerant through the system and bring the oil and contaminants to the flushing machine, which is also a recycling unit that can separate the contaminants before the cleaned refrigerant is re-injected again (fri3oil). With properly trained technicians, this method has proven to effectively clean refrigeration systems to low levels of mineral oil in a limited period of time, thus reducing the number of oil changes required. In many systems, levels of 1-2% of mineral oil can be achieved in one flushing. In systems with 10-20 kg of refrigerants this can often be done in less than one or two hours. This method can also be used to flush the system after compressor burnout. After the flushing is completed the mineral oil will be separated from the refrigerant that is also recycled. In some markets this has been a commonly used method to retrofit R-12 and R-502 systems during the CFC phase out.

1.6.5 RETROFIT THROUGH FLUSHING WITH A SOLVENT

THERE ARE SEVERAL flushing agents available on the market often based on HFCs or HCFCs. As these are controlled substances it is important to ensure what national regulations stipulate on their use. There can be national regulations controlling the use of these substances as solvents and how to handle the material after use. Some flushing units are developed to separate contaminants from the solvent used to facilitate repeated reuse of the solvent (Honeywell, 2009) and adapted flushing units that separate oil from the flushing agent so it can be reused (Ekotez). After flushing, the solvent will be contaminated with chlorine-contaminated oil and must be handled in accordance with national regulations on waste products. If the waste product needs to be exported for proper handling, the transports need to be done with appropriate permits from the authorities of the exporting, transit and importing countries.


CHILLED WATER RETURN
CHILLED WATER SUPPLY

1.6.6 NUMBER OF OIL CHANGES REQUIRED

SUMMARY NUMBER OF REPEATED OIL CHANGES OR FLUSHES REQUIRED

It is possible to calculate the number of oil changes required to achieve a targeted level of remaining mineral oil. The lower the target of remaining mineral oil is set, the more the system will be protected from future problems but the cost to achieve the target will increase. Factors affecting the selection of the target level include how much acidity, moisture and other contaminants there are in the old oil, and how high the temperatures will be for the system's operation. This, together with the age and value of the equipment and cost to achieve a certain level remaining mineral oil, will define the cost effective target.

A level of maximum 1% is by most sources considered an ideal level.

A level of 5% is considered acceptable by several compressor manufacturers if the old oil is of acceptable quality, e.g. it does not contain too many contaminants that can trigger chemical reactions in the system after retrofit.

Two clean oils in a dry system under normal temperatures are not expected to cause chemical stability problems, so the level of contaminants in the old system is an important factor.

IT IS POSSIBLE to calculate the number of oil changes required to achieve a targeted level of remaining mineral oil.

The number of oil changes or flushes required to achieve the target level can be calculated based on two sets of information:

A. The amount of oil in the system.

B. How much oil that can be removed during one oil change or flush.

The lower the target of remaining mineral oil is set the safer the system will be for future problems but the cost to achieve the target will increase. Factors affecting the selection of target level are how much acidity, moisture and other contaminants there is in the old oil and how high temperatures the system will work on. This together with the age and value of the equipment and cost to achieve a certain level of remaining mineral oil will define the cost effective target.

The relative quantity of oil that can be removed will depend on:

- The oil plug position.
- The evaporator design and suction line length and size.
- Whether oil separators/receivers and suction accumulators are used.

A maximum level of 1% is by most sources considered a ideal level.

A level of 5% is considered acceptable by several compressor manufacturers if the old oil is of acceptable quality, e.g. it does not contain too many contaminants that can trigger chemical reactions in system after retrofit.
Two clean oils in a dry system under normal temperatures are not expected to cause chemical stability problems, so the level of contaminants in the old system is an important factor.

If properly done, the repeated oil changes should then lead to <1 to 5 % remaining mineral oil (based on the target set).

More precisely, the required number of oil changes or number of flushes with refrigerant or solvent is a function of the amount of the total oil volume that can be removed in each change/flush.

REMOVED % OF OIL CHARGE	REQUIRED NO. CHANGES/FLUSHES TO REACH 1%	TYPICAL INSTALLATIONS
50 %	7	Supermarket direct expansion with oil separators
60 %	5	Large chillers and heat pumps
70 %	4	Small chillers and condensing units
90 %	2	Flushing large direct expansion systems with oil separators
99 %	1	Flushing compact systems (unitary/split/chillers)

1.6.7 METHODS OF OIL ANALYSIS AND MOISTURE CONTENT IN OIL

STATISTICS FROM a database of 1000 oil samples from retrofitted systems showed a very clear correlation between two factors and successful retrofits. Systems with a low humidity level in the oil and low degree of contaminants would give reliable operation whereas systems with both high humidity and presence of contaminants would have a high likelihood to have a rapid breakdown. The interaction between moisture and contaminants was obvious, so it is worth trying to ensure clean and dry systems as far as possible (Herbe Lars, 1997).

It is easy to apply a simplified retrofit procedure with minimum requirements and in most cases there will be no immediate effects of operating with ester oils with high concentrations of mineral oil. Some systems will run well even in the long term if the oils are of good quality, the system is dry and oil transport is easy. In the other systems where the old oil contains some acid or/and moisture and working at high temperatures may be expected, a failure is very likely.

Sight-glasses have an indicator for moisture, but old sight glasses for CFCs and HCFCs cannot be expected to be reliable for new oils and refrigerants, so whenever possible a change of sight glass should be evaluated.

Test kits to detect moisture in refrigeration systems are available from suppliers of servicing equipment.

There are also three commonly-used methods to analyse how much of the old mineral or alkylbenzene oil remains in the system after oil change.

1.6.8 LABORATORY TESTS

THE MOST ACCURATE and reliable method is to send samples to a laboratory. This is associated with a cost but this cost is minimal as compared to a compressor failure or losses of goods that a work standstill can cause. Laboratories doing oil tests for the industry are often capable of testing an ester oil for the remains of mineral oil. For these tests one sample of the old oil and one of the pure new oil as references are needed. These tests also often include a test of the moisture level in the oil which is a key parameter for long term chemical stability of the system. These oil laboratories also offer analysis of equipment wear which is valuable to evaluate the status of larger equipment before decisions on repair, retrofit or replacement are taken. Note that oil samples should never be exposed to ambient air as they absorb moisture (in particular ester and PAG oils). Careful sampling procedures are important and proper sample bottles must be used. Contact oil laboratories for advice.

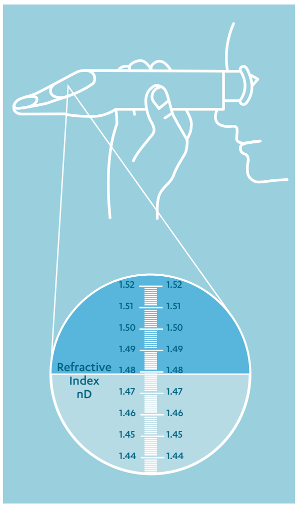


Fig. 1.13 Refractometer is an excellent tool to measure remaining mineral oil content in the field.

1.6.9 REFRACTOMETER TEST

A REFRACTOMETER is an easy-to-use tool that can determine in the field the level of mineral/Alkyl benzene oil in an ester oil.

By comparing a sample of the clean ester oil with a sample taken after oil change the level of mineral oil can be determined.

1.6.10 TEST KIT

SOME SUPPLIERS of oil and service equipment offer test kits where you add a sample taken after oil change and get a pass or fail indication. These kits are typically specific for a particular oil and will not give a correct result on other oils.

‘ENERGY EFFICIENCY IS BECOMING MORE AND MORE THE FOCUS WHEN SELECTING REFRIGERANTS’


2

02 Case studies Alternative technologies in different applications

Introduction

THIS SECTION PROVIDES examples of the application of alternatives to HCFCs in the air conditioning and refrigeration sector. Since the most widely used HCFC refrigerant is R-22, the focus is on applications where R-22 is commonly used. In many applications where CFCs were used prior to the CFC phase out, a change to HCFCs took place. In these applications, e.g. commercial refrigeration, the alternatives designed for commercial refrigeration (e.g. to replace R-12 and R-502) will be a preferred solution rather than those developed for R-22, e.g. air conditioning applications. The technology used to retrofit from HCFC is to a large extent the same as when retrofitting from CFC-based systems. One major difference is that the properties of currently-available HFC alternatives are not as close to R-22 as R-134a is to R-12 and R-404A/R-507 is to R-502.

As the development of refrigeration systems for low-GWP alternatives such as hydrocarbons, ammonia and carbon dioxide progressed, their market presence increased rapidly although starting from a very low market share. The case studies do not reflect the market shares of the respective technologies, but are selected to show the technologies available on the commercial market today.

Since the alternative HFC technologies for two main R-22 sectors, i.e. split air conditioning and chillers are well established and have been readily available on the market for more than ten years, the cases selected for these sectors are more of a general nature. These non-ODS systems can be used to replace R-22 in new installations with minimal technology and cost differences. The remaining case studies have been selected to illustrate alternatives for replacement in existing equipment, and how non-HFC alternatives (often called "natural refrigerants") can be used. Each case has some elements that have been considered to be of special interest to illustrate the technologies that are now entering the commercial market after often extensive research and field testing. When it comes to hydrocarbons and carbon dioxide these products are proven in several applications, but there are divided opinions on their cost effectiveness and energy efficiency in different applications. There are strong commercial interests in favour and against different solutions, and un-biased information is often hard to find. The case studies presented here represent technologies currently offered on the commercial market, even if they do not have big market shares at present. The descriptions, results and arguments for the selection of the particular technology have been supplied by companies that have been involved in the projects, and this information, although edited, has not been validated by the author or UNEP. To reflect the arguments used, it was considered important to describe the complexity of situation in the market where several new technologies are competing for market shares, with an overall drive for decreased environmental impact including improved energy efficiency.

Fig. 2.1 Service of a split system rarely includes recovery in most Article 5 countries. "Release, service and recharge" is common, but should be avoided.

2.1 The transition in the unitary and split air conditioning market

THIS SEGMENT REPRESENTS the largest number of systems using R-22. The annual global production is around 50 million "mini splits" a year, half of which are produced in China (BSRIA, 2009). This market was traditionally 100% R-22 but there has been a gradual change to R-410A and R-407C in this segment. For more than ten years, a wide range of non-ODS products have been available, but at a premium in terms of cost. Often the initial higher cost is more related to the enhanced energy efficiency than to the refrigerant. These systems are charged with refrigerant in the factory and will not result in consumption at the time of installation in an importing country, and thus will not affect the baseline consumption of 2009-2010. On the other hand, future consumption related to servicing can be expected to be significant during the phase out period after 2013. The consumption in the exporting country is obviously less of a problem from a compliance perspective as it usually contributes to a high baseline consumption that can be decreased by converting the manufacturers to alternative refrigerants, which is generally fairly easy. The phase out of production of split air conditioning equipment containing HCFCs gives the RAC equipment producing countries a significant quota to cover servicing needs whereas the importing countries need to take serious actions to avoid future shortages. In many Article 5 countries, this sector increases drastically with 10-30% increase per year, and due to a slightly lower cost and lack of awareness of future challenges, R-22 is often still the preferred option. The risk of quickly increasing the stock of installed R-22 in this segment will be a major challenge during the phase out period when the stock of equipment reaches an age when the leakage rate can be expected to rise. It is extremely difficult to raise the awareness of this sector as a standard split air conditioning unit often contains only 0.5 to 1.5 kg of refrigerant, and such units are owned by consumers, small businesses as well as hotels and other more professional operators. Companies that have a large number of units will be easier to target with information about different options and more capable to evaluate the competencies of technicians they hire for servicing. Awareness about the high leakage rates of some equipment, as well as of the need of taking the energy efficiency into account, can be improved by ensuring that technicians apply good servicing practices. The first target in this market segment should be to **minimize or avoid the installation of new HCFC systems, because it will result in increased demand for HCFCs for servicing after the freeze period starts in 2013.**

2.1.1 THE TRANSITION IN THE UNITARY AND SPLIT AIR CONDITIONING MARKET

SUMMARY RETROFIT OF R-22 TO R-407C WITH OIL CHANGE THROUGH FORCED FLUSHING WITH R-22

Split and unitary air conditioning systems are numerically the largest sector by far using R-22. In many markets, this sector has been increasing drastically in the last years, posing a significant challenge for the future since the systems are now new and can be expected to have average low leaks and limited service needs. After the freeze year 2013, the amount of refrigerant required to service these units can be expected to increase. The limitations on consumption can thus be expected to force a change of refrigerant in a significant number of these systems. There are two routes available if R-22 should be replaced: either to use the drop-in/service blends or to replace the refrigerant with R-407C and the existing oil with an ester oil. The service blends are perhaps the most commonly proposed route with the advantage of an easier recommended procedure that mainly involves the replacement of the refrigerant and filter drier.

The case described below shows the method for a change to R-407C, which is an alternative used for new systems (the most similar in capacity and pressure to R-22 in air conditioning applications). The advocates of this method argue that the advantage of flushing is that you start with a minimal level of old contaminants in the system in a cost effective way. If by doing this the old oil can be removed more cost-effectively than with repeated oil-changes, and if the system is also cleaned, there is no reason not to use the "standard" refrigerants and ester oil. These retrofits with flushing can be done in the field or by bringing the systems in for upgrading and do the retrofit in a workshop. A conversion with a drop-in/service blend is described later in this report in the case study describing the retrofit of a chiller.

It should also be noted that in a new system, the additional cost for non-HCFC technology is minimal and significantly lower than any future conversion/retrofit. A continued installation of R-22 equipment - in spite of the availability of alternatives - will increase the challenge to achieve the freeze level in 2013, since regardless of retrofit method there is a cost and some risk of decreased performance.

Background data/information given for this installation comes from the CSF, SA in Spain. The description is based on the data received from the company, but as regards the selection of information and interpretation, the responsibility is with the author of this report.

THIS RETROFIT WAS PERFORMED to demonstrate the feasibility of retrofitting a standard R-22 split system to R-407C (one of the HFCs blends used in manufacturing of new units) without doing repeated oil changes. The method implemented was "forced flushing" with a flushing unit developed to use the existing refrigerant to remove the old oil and contaminants from the system. This method has been used extensively on some markets (in particular Sweden, Norway, Germany and Spain) in the transition from CFC/HCFCs to HFCs as well as for flushing after compressor failures (so-called "burn outs"). The method minimizes the number of oil-changes required and makes it in many cases possible to perform a complete retrofit to the new oil and refrigerant in one visit. As the old oil often can contain contaminants from many years operation, it is an advantage to minimize the amount of the old oil mixed with the new. In most cases there is no need to use suction line filters if the system is efficiently flushed clean prior to the change of oil and refrigerant.

In this particular case, the system retrofitted was a Hitecsa unit (model ACHB 1001 – 1011013) with a nominal cooling capacity of 29.6 kW. The nominal charge of refrigerant was 7.8 kg.

To ensure that the system was in good shape before initiating the retrofit, it was analysed with a Performance Analyser system that can be connected in 20 minutes on site without pre-installed equipment (ClimaCheck™). To document the performance before the retrofit is important to ensure that the system is in good shape and has acceptable performance to ensure that a retrofit is really justified – see chapter 1.6.1 for more details. In case there are problems in the system, it is important and cost effective to correct these in connection with the retrofit. In case of serious problem or low efficiency it is better to invest in new equipment rather than spending money on an inefficient unit.

Fig. 2.2 Flushing unit designed to flush out the oil from the system with the "old" refrigerant.

Fig. 2.3 Documentation of performance prior to retrofit to ensure that system may be retrofitted

Tested Equipment

Performance Inspection with ClimaCheck

Refrigerant: R22

Term. eff.: 0.93 | Elec. eff.: 1.00 | Stab COP: [illegible] | Accept Stab: 0.02 | Auto Trig: 0.00 | Annual Cooling Demand (kWh): 150000 | Electrical cost (xx/kWh): 0.12 | CO2 per kWh (kg/kWh): 0.47

Min / Max — No of Scans: 10 | Super heat: 2.0 / 7.0 (4-7) | Sub cool: 3.0 / 10.0 (3 - 6) | Ref Comp out: 36 / 120 | Comp Isen. eff.: 55 / 75 (50-75) | Power input: 0.1 / 1000 | COP Cool: 1.0 / 6.0 (0.8 - 7.0) | COP Heat: 1.8 / 8 (1.8 - 8.0) | Operating cost: Euro

Date	Time	SecC Evap in (°C)	SecC Evap out (°C)	Ref Low press. (Bar(g))	Ref Evap Midpoint (°C)	Ref Comp in (°C)	Super heat (K)	SecW Cond in (°C)	SecW Cond out (°C)	Ref High press. (Bar(g))	Ref Cond Mid point (°C)	Ref Exp. Valve in (°C)	Sub cool total (K)	Ref Comp out (°C)	Comp Isen. eff** (%)	Power input Comp. (kW)	COP Cool	Cap. Cool (kW)	COP Heat	Cap. Heat (kW)	TT_X8	Annual operating hours Cooling (h)	Annual operating cost cooling (xx/year)	Annual CO2 emiss. Cool (kg/year)
		Evap. Sec.		Low Pres. Ref				Cond. Sec.		High Pressure Ref.				Compressor								Operating cost		
Mean		8.6	6.0	4.06	0.5	10.8	[illegible]	11.2	23.0	11.60	32.2	21.4	10.8	69.2	65.6	10.2	5.17	52.7	6.10	62.2	12.1	2847	3482	13639
Max		8.9	6.2	4.09	0.7	11.4	[illegible]	11.2	23.1	11.63	32.3	21.6	11.0	69.7	66.9	10.2	5.18	52.8	6.11	62.3	12.1	2857	3495	13690
Min		8.5	5.8	3.98	0.1	10.2	[illegible]	11.1	23.0	11.54	32.0	21.2	10.7	68.6	64.9	10.2	5.15	52.5	6.08	62.0	12.0	2840	3473	13603
05/03/2009	19:17:00	8.5	5.8	3.98	0.1	10.2	[illegible]	11.2	23.0	11.59	32.2	21.5	10.7	68.6	66.9	10.2	5.18	52.7	6.11	62.1	12.1	2849	3473	13603
05/03/2009	19:16:50	8.6	5.9	4.04	0.5	10.4	[illegible]	11.2	23.0	11.59	32.2	21.5	10.7	68.7	65.9	10.2	5.18	52.8	6.11	62.3	12.1	2841	3478	13622
05/03/2009	19:16:45	8.5	5.9	4.06	0.6	10.6	[illegible]	11.2	23.0	11.57	32.1	21.3	10.8	69.9	65.4	10.2	5.18	52.8	6.11	62.3	12.1	2840	3476	13615
05/03/2009	19:16:40	8.6	5.9	4.05	0.5	10.7	[illegible]	11.2	23.0	11.61	32.2	21.5	10.7	68.9	65.7	10.2	5.17	52.7	6.10	62.1	12.1	2848	3479	13624
05/03/2009	19:16:35	8.6	5.9	4.06	0.6	10.8	[illegible]	11.2	23.1	11.54	32.0	21.3	10.7	69.1	64.9	10.2	5.16	52.5	6.09	62.0	12.1	2857	3490	13671
05/03/2009	19:16:30	8.6	5.9	4.05	0.5	10.9	[illegible]	11.2	23.1	11.61	32.2	21.3	10.9	69.2	65.6	10.2	5.17	52.6	6.10	62.1	12.1	2854	3483	13641
05/03/2009	19:16:25	8.5	6.0	4.08	0.7	11.0	[illegible]	11.2	23.1	11.63	32.3	21.2	11.0	69.4	65.3	10.2	5.17	52.7	6.10	62.2	12.1	2846	3483	13642
05/03/2009	19:16:20	8.7	6.1	4.06	0.6	11.2	[illegible]	11.2	23.1	11.63	32.3	21.6	10.7	69.6	65.7	10.2	5.17	52.7	6.10	62.2	12.0	2845	3482	13639
05/03/2009	19:16:15	8.7	6.2	4.07	0.6	11.2	[illegible]	11.1	23.1	11.63	32.3	21.3	10.9	69.7	65.3	10.2	5.15	52.5	6.08	62.0	12.0	2856	3495	13690
05/03/2009	19:16:10	8.9	6.2	4.09	0.7	11.4	[illegible]	11.1	23.0	11.62	32.2	21.3	10.9	69.7	65.2	10.2	5.17	52.8	6.10	62.3	12.1	2841	3484	13645

Fig. 2.4 Documentation of performance after retrofit shows slight differences in capacity and COP largely explained by slight differences in operating conditions. By optimisation of superheat control the system could be further enhanced

Tested Equipment

Performance Inspection with ClimaCheck

Refrigerant: R407C.MIX

Term. eff.: 0.93 | Elec. eff.: 1.00 | Stab COP: [illegible] | Accept Stab: 0.02 | Auto Trig: 0.00 | Annual Cooling Demand (kWh): 150000 | Electrical cost (xx/kWh): 0.12 | CO2 per kWh (kg/kWh): 0.47

Min / Max — No of Scans: 9 | Super heat: 2.0 / 7.0 (4-7) | Sub cool: 3.0 / 10.0 (3 - 6) | Ref Comp out: 35 / 120 | Comp Isen. eff.: 55 / 75 (50-75) | Power input: 0.1 / 1000 | COP Cool: 1.0 / 6.0 (0.8 - 7.0) | COP Heat: 1.8 / 8 (1.8 - 8.0) | Operating cost: Euro

Date	Time	SecC Evap in (°C)	SecC Evap out (°C)	Ref Low press. (Bar(g))	Ref Evap Midpoint (°C)	Ref Comp in (°C)	Super heat (K)	SecW Cond in (°C)	SecW Cond out (°C)	Ref High press. (Bar(g))	Ref Cond Mid point (°C)	Ref Exp. Valve in (°C)	Sub cool total (K)	Ref Comp out (°C)	Comp Isen. eff** (%)	Power input Comp. (kW)	COP Cool	Cap. Cool (kW)	COP Heat	Cap. Heat (kW)	TT_X8	Annual operating hours Cooling (h)	Annual operating cost cooling (xx/year)	Annual CO2 emiss. Cool (kg/year)
		Evap. Sec.		Low Pres. Ref				Cond. Sec.		High Pressure Ref.				Compressor								Operating cost		
Mean		7.8	5.4	3.36	-4.1	10.4	[illegible]	10.2	19.7	11.29	28.9	19.9	6.4	61.5	70.1	9.6	5.01	48.0	5.94	56.9	9.9	3126	3595	14079
Max		8.1	5.7	3.38	-4.0	10.6	[illegible]	10.3	19.8	11.35	29.1	19.9	6.5	61.6	70.5	9.6	5.05	48.5	5.98	57.4	9.9	3143	3613	14152
Min		7.5	5.0	3.34	-4.2	10.2	[illegible]	10.1	19.7	11.25	28.8	19.8	6.2	61.4	69.8	9.6	4.98	47.7	5.91	56.6	9.8	3093	3563	13957
06/03/2009	19:51:00	7.5	5.0	3.36	-4.1	10.2	[illegible]	10.3	19.7	11.35	29.1	19.9	6.5	61.6	70.1	9.6	4.98	47.8	5.91	56.6	9.9	3136	3613	14152
06/03/2009	19:50:50	7.5	5.1	3.35	-4.2	10.2	[illegible]	10.3	19.7	11.27	28.9	19.9	6.3	61.5	69.8	9.6	4.98	47.7	5.91	56.7	9.9	3142	3612	14146
06/03/2009	19:50:40	7.6	5.2	3.36	-4.1	10.3	[illegible]	10.3	19.7	11.27	28.9	19.8	6.4	61.5	69.8	9.6	4.99	47.8	5.92	56.7	9.9	3137	3606	14123
06/03/2009	19:50:30	7.8	5.3	3.36	-4.1	10.3	[illegible]	10.3	19.8	11.28	28.9	19.9	6.4	61.6	69.9	9.6	4.99	47.7	5.92	56.6	9.9	3143	3605	14121
06/03/2009	19:50:20	7.9	5.4	3.37	-4.0	10.4	[illegible]	10.3	19.8	11.31	29.0	19.9	6.4	61.6	69.9	9.6	5.00	47.9	5.93	56.8	9.9	3133	3601	14105
06/03/2009	19:50:10	7.9	5.4	3.34	-4.2	10.4	[illegible]	10.2	19.8	11.27	28.9	19.9	6.3	61.5	70.4	9.6	5.02	48.0	5.95	56.9	9.8	3127	3587	14049
06/03/2009	19:50:00	7.9	5.5	3.37	-4.1	10.5	[illegible]	10.2	19.7	11.31	29.0	19.9	6.4	61.5	70.4	9.6	5.03	48.2	5.96	57.1	9.8	3113	3579	14016
06/03/2009	19:49:50	8.0	5.6	3.37	-4.0	10.5	[illegible]	10.2	19.7	11.25	28.8	19.9	6.2	61.5	69.9	9.6	5.02	48.2	5.95	57.1	9.8	3118	3584	14038
06/03/2009	19:49:40	8.1	5.7	3.38	-4.0	10.6	[illegible]	10.1	19.7	11.32	29.0	19.8	6.5	61.4	70.5	9.6	5.05	48.5	5.98	57.4	9.8	3093	3563	13957

Fig. 2.5 A performance analyser device was used to ensure that the system was in good working order before retrofit and was correctly functioning after the work had been completed.

The measurements before the retrofit showed acceptable operation so the retrofit was carried out.

The conclusion of the retrofit and performance analysis was that the unit behaved with similar performance after the retrofit. The differences documented were a slightly lower COP (3%) and a capacity (9%) below that of R-22. But a closer look also show that the incoming air (SecC Evap in) temperature is one degree lower than before the retrofit which affect the evaporation and thus the performance as well as a two degree higher superheat. There are possibilities to optimise the operation further by adjusting the superheat control for the new refrigerant to achieve the same performance in this particular system.

Another conclusion is that documentation of performance offers a potential to improve energy efficiency and reliability of systems in connection with retrofits.

With this type of flushing unit the R-22 is recycled and can be available for re-use. The oil is degassed and should be dealt with according to regulations for waste oil in the country.

‘MINIMIZE OR AVOID THE INSTALLATION OF NEW HCFC SYSTEMS, BECAUSE IT WILL RESULT IN INCREASED DEMAND FOR HCFCs FOR SERVICING AFTER THE FREEZE PERIOD STARTS IN 2013’

2.2 Chillers with HFCs

SUMMARY CHILLERS WITH HFCs

R-22 is one of the most common alternative refrigerants in small and medium-sized chillers. For more than 10 years, a wide range of non-HCFC chillers has been available on the market. This includes chillers using HFCs, hydrocarbons and ammonia. These new chillers are often developed to have higher efficiencies than older chiller designs. Chillers are used mainly in centralised air conditioning systems and process cooling. For most chillers (except for those with R-123) there are several options: either to retrofit to the HFCs used in new systems or make a conversion to service blends. Before a decision to invest in a retrofit is taken, the status and performance of the existing plant should be evaluated. State-of-the-art designs often have 20-40% lower energy consumption than 10 year old designs. In the new system, the additional cost for non-HCFC technology is limited and significantly lower than that of a future retrofit. A continued installation of R-22 equipment will increase the country's challenge to achieve the HCFC freeze in 2013.

Fig. 2.6 An older model of an air-cooled chiller assembled from "condensing units" used for wine production in Georgia.

CHILLERS ARE often (but not always) factory-built units that are intended to cool a liquid that can be water, or if at a lower temperature than approximately 5°C, a glycol or brine fluid. They can be air-cooled (i.e. the condenser is directly cooled by air) or water-cooled (i.e. the condenser is cooled by circulating water) with freeze protection if the climate is such that the water would risk freezing in winter. Their main application is for air conditioning in larger buildings, e.g. hotels, offices and public buildings such as hospitals and military complexes, and for process cooling in industries.

2.2.1 LARGE LOW PRESSURE CHILLERS

TRADITIONALLY THE MARKET for larger chillers (from around 500 - 1000 kW) was dominated by R-11. R-11, which is a CFC, operates at lower pressures than other used refrigerants in centrifugal compressors. With the phase out of CFCs, some manufacturers replaced R-11 with R-123, which is an HCFC. There are currently no suggested replacements for R-123 so these systems will most likely have to be kept operating with R-123 until they are decommissioned at their end of life. Due to technical designs less suitable for this refrigerant, as well as concerns about toxicity and a reluctance to introduce a transitional HCFC product, most manufacturers have converted their production to R-134a chillers. For these larger systems, screws and centrifugal compressors are typically used. Due to the low efficiency of many old chillers and the lack of options for direct replacements retrofits in these type of chillers, they are more often replaced by new chillers: a state-of-the-art chiller system will often use 30% less energy than an old chiller installation, which often result in a short payback time on the additional investment to replace rather than retrofit an old unit (Gartland, Lisa, Positive Energy).

Fig. 2.7 Older standard air-cooled chiller manufactured in Europe with R-22, installed in Montenegro.

2.2.2 MEDIUM-SIZED AND SMALL CHILLERS

IN THE SEGMENT of lower capacity chillers that traditionally used R-22 or R-12, non-ODS chillers have been available for the last 15 years, at the same time as R-22 chillers were still being introduced in some markets. The main alternatives are R-134a, R-407C and to some extent R-410A. R-134a is most common in equipment of larger cooling capacity and is often used with screw or centrifugal chillers, where the larger volume flow required does not affect the cost as much as it does with reciprocating compressors. R-134a also has the advantage that it is suitable for use in flooded evaporators, which is not the case with R-407C that has a significant temperature glide. This temperature glide is not a significant technical challenge when used in counter flow heat exchangers with dry expansion, i.e. plate heat exchangers, as well as in many air heat exchangers that are not designed to be reversible. In systems that are designed to be used as both air conditioners and heat pumps, the challenge to use glide refrigerants becomes much more significant and R-134a or R-410A becomes a more attractive alternative. The challenge with R-410A is the significantly higher pressure, which might not be an issue for small split air-to-air systems but requires significant redesign of the pressure vessels. The designs for non-HCFC chillers are well-proven, not only in industrialised countries, but also in most Article 5 countries where have been commonly installed for several years in parallel with the old systems based on R-22 technology. The price difference is small and the HFC technology is more often developed with today's energy efficiency requirements taken into account. Newer development of equipment with higher energy efficiency has also introduced technologies to minimize leaks and reduce charge.

Fig. 2.8 A smaller sized standard air-cooled chiller installation with R-407C installed in 2005 in Montenegro to air condition a public building.

Fig. 2.9 Standard water cooled chiller at an IKEA store in Sweden. The system uses R-134a and is indirect for the evaporator and condenser, minimizing the charge of HFC. It operates as a heat pump in winter and as an air conditioner in summer. To minimize energy consumption, a ground "storage" with drilled holes is used for "free cooling" until the ground temperature increases in late summer when the chiller must start.

2.3 Fruit Storage with hydrocarbon chillers at Nickle farm in UK

SUMMARY HYDROCARBON CHILLER WITH HYDROCARBONS USED IN FRUIT STORAGE

A hydrocarbon chiller was selected to minimize the direct global warming impact from the refrigerant. By using an indirect system, the primary refrigerant charge could be minimized (each circuit contained 5.5 kg). With chillers placed outside the building the risks are reduced. The remaining risks are associated with ensuring that a leak into the water circuit cannot be vented inside a space where it could form flammable concentrations, or that improperly trained service technicians might make mistakes that could be dangerous. These risks are not considered to be difficult to handle.

The use of an indirect system and the proper design of the electrical installation on the chiller eliminated most risks associated with the use of a flammable refrigerant. The drawback was the introduction of an extra heat transfer that - if not compensated - would in theory result in a higher indirect global warming from energy consumption.

By using a salt brine (potassium acetate) instead of glycols, the energy consumption for pumps and extra heat transfer was minimized. At the same time, a factory-assembled indirect system can often be more tightly optimised and more easily controlled, which can result in an improved total efficiency in spite of extra heat transfer and pumps.

The fact that the refrigerant circuit was compact, factory made and easy to control was an important factor to improve reliability and decrease service costs.

Background data/information given for this installation comes from Alan Colbourne, from the contractor SRS in UK (SRS). The description is based on the data received from the contractor, but as regards the selection of information and interpretation, the responsibility is with the author of this report.

Fig. 2.10 State-of-the-art cold store design to minimize the carbon footprint by using energy efficient hydrocarbon chillers.

Fig. 2.11 Five air cooled chillers with potassium acetate as brine and hydrocarbon R-1270 as. refrigerant.

THESE FIVE hydrocarbon-based chillers with a total capacity of 1175 kW are used in a fruit storage and handling facility with a capacity of 260 000 tonnes of apples per year. The hydrocarbon used is propylene (R-1270). The chiller cools a potassium formate brine solution.

Presented with the opportunity of specifying the refrigeration for its new factory and being conscious of the failings of the DX (Direct Expansion) refrigeration systems, the customer was determined to ensure that any future system should provide the best in energy efficiency, flexibility, reliability and minimise the long-term environmental impact of HFC refrigerant gases with high-GWPs.

The company - a food production factory – was subject to the CCL (Climate Change Levy) taxes imposed in the UK which heavily affected its production costs and had to be minimized. Furthermore, the company was within a very competitive marketplace and therefore the allowable capital cost envelope for the whole installation was tightly controlled and presented a challenge to meet the given criteria.

With a storage capacity of 20 000 mt, the new building comprised refrigerated food preparation areas and various chill cold rooms operations, which narrowed down the options for systems that fully met the client's required specification. The options considered included the traditional refrigeration systems designed on DX which use the HFC refrigerant R-404A or the natural refrigerant ammonia (NH3). However, the alternative that was finally selected was an indirect refrigeration system with propylene as the refrigerant in the chiller.

Because HFC refrigerants are now subject to the new European Union F-Gas Regulation, some industries are now becoming reluctant to use these synthetic gases due to pressure to ensure their environmental credentials. Furthermore, the prospect of future EU Directives imposing increased restrictions on the use of such synthetic refrigerants encourages the industry to further consider the use of secondary refrigerant system engineering.

Ammonia (NH3) is considered to be one of the most effective natural refrigerants available, but does present some challenges. It is toxic, caustic and hazardous, and therefore sometimes not considered as user friendly as the CFCs/HCFCs/HFCs. Ammonia systems also have additional requirements (which vary from country to country) to address the refrigerant's flammability.

After careful consideration of all pros and cons, the selection of an indirect system gave the food plant owner (F.W. Mansfield and Son) the opportunity to comply with criteria they considered important, such as:

- The potential for reducing energy consumption by selecting state-of-the-art chillers - in this case, standard hydrocarbon chillers with a COP of 3.5 at 7°C exiting water and 30°C ambient temperature were used, manufactured by Frigadon, Sweden.
- Lower service and maintenance costs compared to DX systems.
- Operation with an environmentally friendly refrigeration system.
- Opportunity of using natural refrigerants such as hydrocarbon R-1270.
- Using five standard hydrocarbon chillers allowing for a low charge per circuit, close control of temperature, and redundancy in case one system stops.
- Opportunity of using biodegradable, non-toxic heat transfer fluids - in this case, food safe Hycool® fluid was used.
- Minimisation of the carbon footprint.
- Opportunity to demonstrate the system's environmental responsibility to its clients.

The indirect system technology using hydrocarbons proposed by SRS Refrigeration Engineering was believed to provide the most cost-effective approach for reducing the overall climate impact.

The benefits gained from choosing this refrigeration engineering technique resulted from the way in which all equipment was brought together in one compatible design.

The introduction of the hydrocarbon chillers was facilitated by the fact that the installer offered a complete design service taking into account all necessary requirements to use the system in a safe and energy efficient way. Each of the five hydrocarbon chillers has four refrigerant circuits with 5.5 kg of R-1270 each. Each such unit has a cooling capacity of 235 kW at temperatures 32°C (ambient) and 0 to -4°C (in brine).

2.4 Cold store with low charge ammonia chillers

SUMMARY

A large cold store company selected two low charge ammonia chillers to replace two old R-22 chillers that had been retrofitted to R-404A six years earlier. A key factor in the company's decision to change to ammonia was the high leakage rates of the old retrofitted R-22 chillers.

In cold stores, HCFCs has been extensively used in some markets, whereas ammonia has remained a preferred alternative in others. The use of ammonia requires special training and in some markets, there is a lack of trained staff and training facilities, which can limit the possibility of a transition to ammonia unless the training capability is initiated or strengthened.

New developments in this sector include minimum charge chillers with compact design. In the case presented here, the low ammonia charges minimized the risks. The charges could be minimized with plate heat exchangers and dry expansion (use of expansion valves and soluble oils). This case also shows how variable motor speed was applied to optimise performance and allow stable control of the cooling process.

Background data/information given for this installation comes from Kenneth Weber, from the contractor ETM Kylteknik, (ETM Kylteknik AB). The description is based on the data received from the contractor, but as regards the selection of information and interpretation, the responsibility is with the author of this report.

THIS COLD STORAGE is operated by one of the major cold store/transport companies in Sweden and located in Jordbro, a suburb of Stockholm. The system was cooled by an installation with semi hermetic screw compressors chillers and a secondary fluid to cool the storage areas.
The chiller had been moved to this site and retrofitted from R-22 to R-404A in 2001. The maximum cooling demand is approximately 350 kW. They operated with R-404A for several years but there were significant leakage rates due to leaks around the electrical connection of the motor. The local authorities required the operator to take action to reduce the leaks of the high-GWP refrigerant R-404A. When it turned out to be difficult to fix this problem, the company decided to install a new refrigeration plant. To achieve a redundancy and capacity for potential changes in the future, it was decided that two chillers would be installed.

After evaluating several options, a solution with a combination of several relatively new but commercially available and proven technologies was selected.

A. It was desired to use a low-GWP refrigerant in line with the policies of the companies to minimize their environmental impact, so ammonia was selected.
B. As there was also a concern for the risk associated with ammonia, it was decided to minimize the charge in the chillers by using welded plate heat exchangers with dry expansion technology, with electronic expansion valves. The charge reduction is significant compared to the flooded evaporators traditionally used with ammonia. To do this, it is necessary to use a soluble oil that can be transported back to the compressor automatically. The charge and associated risks of using ammonia could thus be minimized. The oil used is a PAG oil. These chillers have each a total charge of 30 kg while for a direct evaporation system the ammonia charge could be around 1000 kg on

Fig. 2.12 The cold store. The "dry" coolers are on the roof and the low charge anmmonia chillers inside.

Fig. 2.13 Low charge ammonia chiller with dry expansion, welded plate heat exchangers and a variable speed drive on the compressor.

‘IN COLD STORES, HCFCs HAS BEEN EXTENSIVELY USED IN SOME MARKETS, WHEREAS AMMONIA HAVE REMAINED A PREFERRED ALTERNATIVE IN OTHERS’ such a plant and for chillers with a flooded system it could be expected to be 140 to 150 kg ammonia.

C. To improve the energy efficiency, the chillers were equipped with inverters which facilitate a stable operation, thus avoiding start and stop operation as well as minimising the temperature differences in the heat exchangers.

D. To optimise the energy efficiency and get early warning if any component's performance deteriorates, a web-based remote monitoring system was installed. This allows the contractor as well as end user to monitor efficiency and also receive alarms if any values went out of normal range.

Fig. 2.14 Schematic flow chart from a web-based monitoring system showing relevant parameters for supervision and performance optimisation.

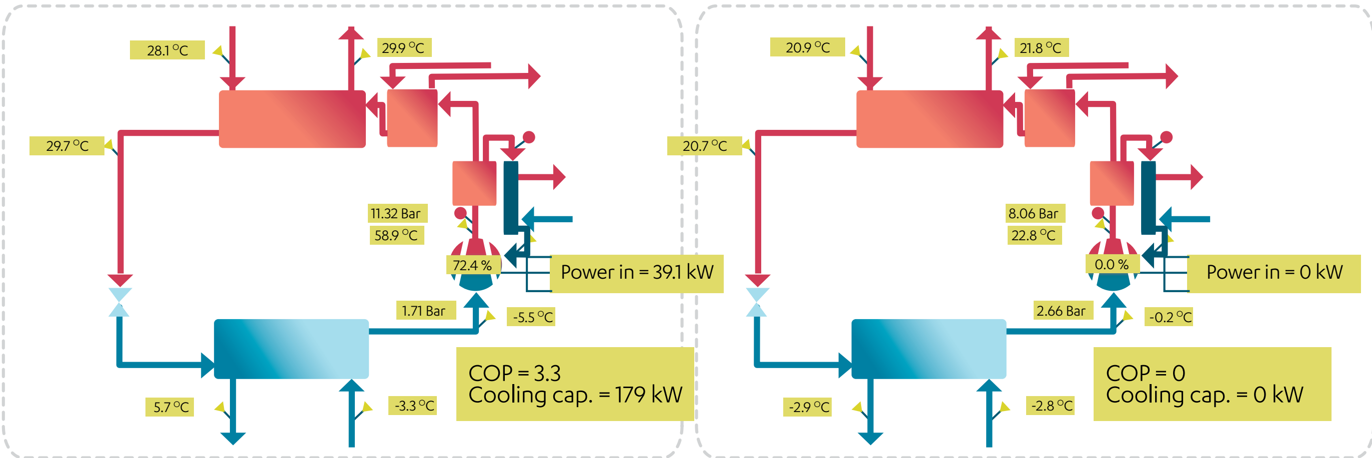
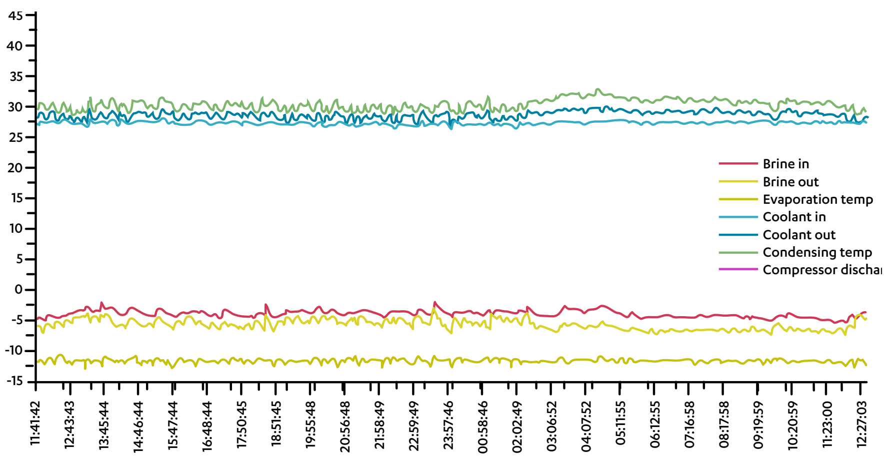


Fig. 2.15 shows that the close control of temperatures in the system is possible with the inverter controlled compressor. The evaporation varies by approximately one degree with an average of -11.4 °C at a secondary temperature of -6.1 °C leaving the evaporator.

The two ammonia chillers installed had been in operation for two years showing an improved energy efficiency and reliability relative to the old system. As the systems are factory-built, compact units with remote monitoring required little from the local operators. Supervision is mainly done remotely on the internet and the local staff can, if needed, request support from the manufacturer or contractor at any time if any value is out of limits or to discuss opportunities for energy optimisation.

The COP of the ammonia chillers when supplying -6°C brine at condensing temperature 30°C is in average 3.0. The two compact low charge ammonia chillers operate reliably with minimum service requirements.

Fig. 2.15 Graph of evaporation (green) and secondary temperatures show a stable operation during 24 hours without any compressor start/stops.



2.5 Retrofit of R-22 chiller to R-422D (oil change not required)

Fig. 2.16 Chiller used for 20 years with R-22 that was retrofitted to R-422D.

SUMMARY A FINANCIAL INSTITUTION REPLACED ITS R-22 IN CHILLER WITH A VARIABLE SPEED TO "DROP-IN"/"SERVICE" BLEND DEVELOPED TO MINIMIZE COST OF RETROFIT

This case describes the conversion of a 20 year old R-22 close control chiller that the end user decided not to replace (due to its good track record), but instead to extend its life by changing to a non-ODS service blend. After evaluating available alternatives, the decision was to replace the R-22 with R-422D - a service blend that can be used with the existing oil. The change was done according to the recommendation of the refrigerant supplier. The result was that R-422D worked well in this application and the method could be carried out in a cost effective way. The system has been running trouble free for one year after the change.

Background data/information given for this installation comes from Mike Creamer, Business Edge Ltd (Business Edge Ltd) located in Waterlooville, UK. The description is based on the data received from the company, but as regards the selection of information and interpretation, the responsibility is with the author of this report.

IN LONDON A LARGE R-22 chiller with an inverter was retrofitted to R-422D with good performance documentation before and after. The change of refrigerant was conducted on a machine originally installed in 1988 and the machine has run successfully 24 hours/7 days a week for 20 years. The machine comprises two Bock compressors, each driven by 37.5 kW motors with power inverters to allow variable speed. The approximate cooling capacity is 400 kW. This case describes the retrofit project, which has been executed in London by the Business Edge Technical Team in June 2008.

The machine is water cooled and is served by large cooling towers on the roof of the building. This water chiller is unusual insofar as it is probably the only Variable Refrigeration Flow (VRF) water chiller to have been constructed in the UK at that time. Even now it is fairly unique as it is such a large machine and features variable speed reciprocating compressors rather than screw, scroll or centrifugal compressors.

The control technology provides for full floating suction and floating head pressure control and delivers water at 8°C to a very precise steady state accuracy, this being a requirement of the project in order to prevent excess latent cooling within the machine/data rooms that it serves. These data rooms are critical to the large financial institution, which rely on this machine extensively to support their business.

Following initial research, it was agreed that the most appropriate refrigerant would be Isceon™ MO29 (ASHRAE Reference Number R-422D).

Given the critical nature of the application, it was decided that it would be wise to prepare all tools and equipment, consumables and recovery cylinders in such a way as to enable the machine to be retrofitted with R-422D and then run a performance evaluation test using ClimaCheck™ Performance Analyser. If this would identify that there was a problem with the R-422D, either in terms of its thermal performance, power input, COP and so on, or even worse, problems with oil return at low refrigerant velocity when the machine runs at prolonged low capacity and low speed, it would then be possible to recover the R-422D and reinstitute the R-22 immediately, in order to

keep the machine running.
The VRF technology uses a special lubricating oil and a special expansion valve, in order to allow the compressors to run at only a few hundred RPMs for extended periods.

Oil separators are fitted to each compressor. The return of oil to the compressor crank-cases is vital and given that the large shell and tube evaporator is below the compressors, the lift of this oil via adequate suction pipe velocity and miscibility was very important to consider.

2.5.1 DESCRIPTION OF CONVERSION PROCEDURES

PRIOR TO RETROFIT, the performance of the chiller was documented with a ClimaCheck™ Performance Analyser to ensure that the system was in good shape. To initiate a retrofit if the compressor has a low efficiency already or heat exchangers are fouled can risk that the contractor would assume responsibility for a problem already existing but not detected in the system. It is also interesting to have a baseline performance to compare before and after retrofit.

Recovery of the R-22 refrigerant was first undertaken to make the machine ready for the first stage of work, which included the replacement of a number of peripheral items such as shut off valves, oil line pipe work, oil line filters, high and low pressure switches, etc. These measures was done partly in line with normal maintenance and partly to upgrade the system to minimize leaks. To change filters are good practice in connection with oil and refrigerant change. The replacement of tubes an pressure switches were done as many lines to controls were old capillary tubes that are vulnerable to vibrations and not considered good practice. Old pressure switches are a significant risk for large losses of refrigerant as the bellows can burst often with loss of total charge so it was deemed worth to replace these lines and switches in connection with the change of refrigerant. Some of the old valves had O-rings that are not optimal for HFCs which can result in increased leakage (Viton™ that was commonly used for CFC/HCFC is not a preferred solution with HFC). The replacement refrigerant lines were run in copper with suitable anti-vibration loops or were run in flexible plastic tubing. Flexible plastic tubing is quick and easy to use to connect, i.e. pressure switches gauges and similar equipment and they will not break because of vibrations. It is a more expensive solution, but it is one way of reducing the problem of loss of refrigerant from broken capillary tubes. The replacement of certain equipment components described above was not inevitable in the operation of changing the R-22 refrigerant to a drop-in blend, but inspection of the equipment before conversion revealed that certain components would need replacement even if the refrigerant was not changed.

Once all the replacement of auxiliary components and interconnecting pipe work had been fitted, a pressure tightness test was applied to the system as a whole. However, the compressors were isolated via their service valves for the following reasons:

- The compressors were known to be sound in terms of their leak-tightness as a result of recent and regular service visits.
- It had been previously noted that the compressor shaft seals can leak when subject to nitrogen pressure testing, yet do not leak when under refrigerant/oil pressure. It was decided that these would be checked with an electronic leak detector, once the system had been charged, re-commissioned and put into service.

After the pressure test of the refrigerant system the condenser water flow switch had been observed sticking on occasion and this was replaced.

A leak test pressure of 8 bars was applied over an extended time period and, in addition, all new joints were checked with leak test solution. A minor leak was detected at a compression joint at a T-connection for the flexible tubing. This was repaired and the system again pressurised for the final pressure tightness test.

Once all the joints had been leak tested, the leak test solution residue was carefully cleaned up.

Three high performance vacuum pumps were used to evacuate and dehydrate the system to less than 4 mbar / 6 Torr.

Having achieved a satisfactory vacuum and having held this for a Vacuum Rise Test, charging with the new refrigerant R-422D started.

The refrigerant was supplied in cylinders with a single valve/ single port type arrangement with a dip tube to enable liquid to be drawn from the cylinder without the need to invert.

The ClimaCheck™ Performance Analyser was set up to monitor the refrigerant charging process and the general operating condition of the water chiller.

The machine was operated under controlled speed conditions after injecting the first liquid charge directly at the large liquid line drier Schrader valve connection. This was done after ensuring that the chilled water pumps and condenser water pumps were operational and that the cooling towers were also functional.

As the operating conditions settled towards normal levels, it was immediately apparent that discharge temperature was low when compared to that of refrigerant R-22. While it was too early to finalise the commissioning and associated readings at this point, the first impressions were very favourable.

The refrigerant charge and superheat was gradually adjusted and came under excellent and steady control initially to 7°C.

The final refrigerant charge was recorded at 61kg, but this was with only one of the two compressors running and then at only 780 rpm, as opposed to its full capability of 1800 rpm.A validation of the commissioning at high ambient will be done with the ClimaCheck™ Performance Analyser and if required adjustment of the refrigerant charge to meet higher load conditions.

2.6 Carbon dioxide heat pumps for domestic heating and tap water

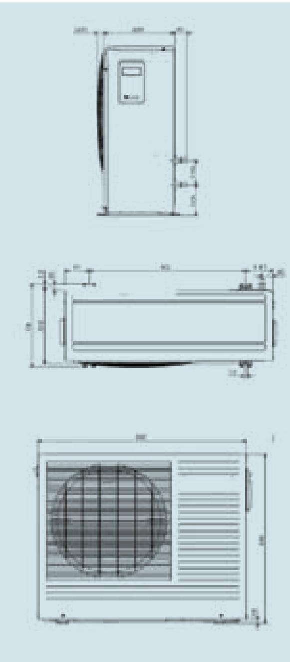


Fig. 2.17 The CO_2 hot water heater pumps have a design very similar to the external part of a split air conditioner.

SUMMARY HEAT PUMP USED FOR HEATING AND HOT WATER PRODUCTION WITH SUPERCRITICAL OPERATION WITH CO_2 (R-744)

There is much interest in carbon dioxide as a low-GWP refrigerant that can replace CFCs, HCFCs and HFCs as an alternative refrigerant with a lower impact on the environment. The discussions focus on which applications CO_2 can be used with a good energy efficiency as the indirect contribution to the global warming from the consumed energy is significantly bigger than that of the refrigerant. A low-GWP refrigerant is preferable when it can be used with comparable energy efficiency. The ongoing research and field tests are now focusing on establishing the application where the technology has reached a level where it can compete as an environmentally good and cost effective solution. In several applications CO_2 has reached acceptance in the market.

Background data/information for this case on CO_2 heat pumps comes from Yang Chen, from the Department of Energy at the Royal Institute of Technology in Stockholm [Yang et al. , 2009]

NB:The description is based on the data received from the researcher, but as regards the selection of information and interpretation, the responsibility is with the author of this report.

ONE OF FIRST mass-produced products with CO_2 as a refrigerant was a heat pump marketed under the name Eco-cute™, which was introduced on the market 2001 designed for hot water production by the Denso Company in Japan. This heat pump was developed through a project sponsored by utility companies and the government to reduce the energy consumption for domestic hot water production. In 2005, there were 225 000 of these heat pumps supplied to the Japanese markets through several of the leading brands. There were several cultural and economic reasons why this development and rapid market introduction took place in Japan:

- The normally large hot water consumption in Japanese families due to the habit of taking hot baths.
- A dense population in many areas living in relatively small apartments with a high square meter price.
- High electricity prices and competition on the energy market from natural gas.
- Pressure and subsidises from government to reduce fossil fuel.
- Utility companies wanting to compete with natural gas supporting the development and subsidising installation.

CO_2 offers an attractive solution as it can generate very high water temperatures reducing the required storage volume significantly versus HCFC/HFC options. The unit is physically similar to the external unit of a split air conditioner.

The performance of supercritical operation with CO_2 compared to the HCFC/HFCs will be relatively better if high water temperature is required. In the case of water being heated from 10°C to 90°C hot water, CO_2 will work well whereas it would not easily be achieved with conventional technologies. It would be possible to achieve maximum around 70°C with R-134a in standard systems. The COP of lower temperature lift will increase significantly more for HFC than for CO_2 and the higher direct global warming would need to be evaluated versus the lower direct energy consumption i.e. indirect effect on global warming.

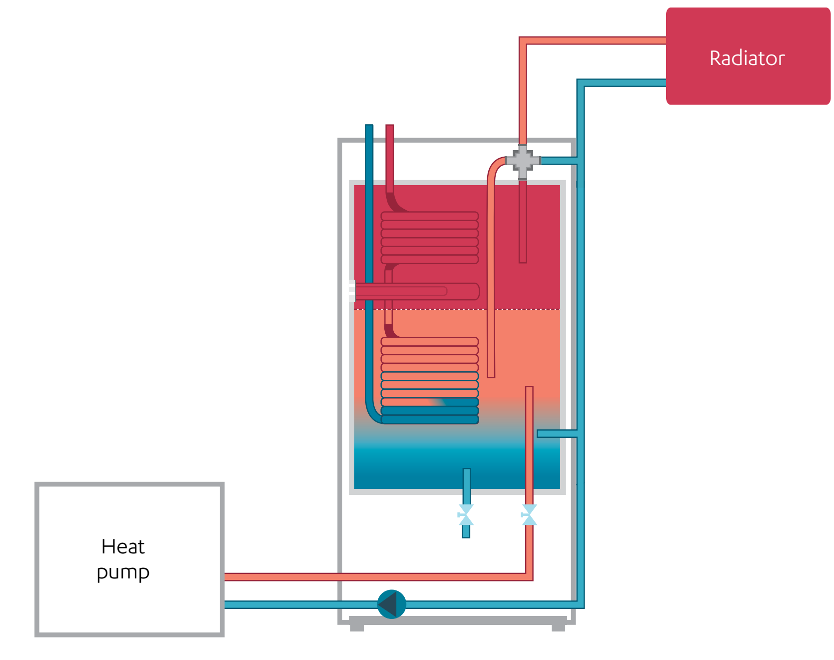
The compressors used in these heat pumps are two-stage compressors with a direct current (DC) motor designed for variable speed.

The heat pumps marketed in northern Europe are modified specially to adjust to the hot water tank and be more suitable for the application in buildings where the larger part of the energy is used for heating rather than for hot water.

The hot water tank used for the heat pump in the tested system had a volume of 223 liters.
These heat pumps have been evaluated in detail in a project at the Department of Energy at The Royal Institute of Technology in Stockholm [Yang et al. , 2009].

Some of the conclusions are highlighted below. The test aimed at evaluating the CO_2 heat pump with a heating capacity of 4.7 kW versus a traditional heat pump used for space heating and hot water production under Northern European conditions. The experiences of that test give indications under which conditions CO_2 with the technology available today could be competitive and how standards (e.g. EN 14511) developed to test traditional systems might not give a good or "fair" indication on the possible benefits of a new technology. CO_2 has different characteristics from traditional systems so the performance will be less dependent on the exiting temperature of air or water in the condenser but more dependent on the inlet temperature. Current standards are developed for the existing systems and are not adapted for products that would benefit from a changed strategy to operate the system. These different characteristics change the optimum design of the whole system where the CO_2 heat pump is applied. Without changing the test conditions and/or system, design tests will not give a good indication on how the heat pump would work in neither new nor existing systems.
It is important not to evaluate new technologies based only on old standards. At the same time many published comparative tests use references that might not describe the best available alternative technology. It is easy to find a poor system to compare with and generalise based on a specific case (authors comment).

Fig. 2.18 Heat pump system with CO_2 and tank for hot water production.



The conclusions of the independent analyses performed in this test are that for conventional northern European houses with a relatively high heating demand, this CO_2 design does not achieve the same annual COP, but if the main demand is hot water production, the characteristics are more favourable and good COPs can be achieved with CO_2. Measured COP at 0°C ambient temperature and 31°C water in to gas cooler and 61°C water out was 2.51 which at this water temperatures would be acceptable relative conventional technologies. The water flow in these tests was much lower than what would be used in most systems. If the same heat rejection would be desired in the radiators with a higher flow the conventional heat pump would use 20% less energy whereas the CO_2 heat pump would not increase its performance due to higher return temperature. With the ongoing development of low energy housing, the amount of heating needed is decreasing which will make the ratio of hot water versus heating more favourable than in most existing houses. Future optimisation of installations in the house and CO_2 heat pumps will show where they will be competitive, but carbon dioxide is expected to be one of the refrigerants used in future heat pumps in particular if high water temperatures are required.

More and more compressors and other components designed for carbon dioxide systems are becoming available in the market and the products for new segments are being developed.

2.7 Carbon dioxide in supermarkets

SUMMARY RESEARCH PROJECT EVALUATING TWO SUPERMARKETS WITH CARBON DIOXIDE REFRIGERATION OPERATING IN SUPERCRITICAL SYSTEMS IN SWEDEN, AND A FIELD TEST IN SIX STORES IN NORWAY

The reports evaluate the technology and environmental impact of these systems, and also provide an LCC analysis.

At higher temperatures, carbon dioxide as a primary refrigerant is one of the more innovative technologies developed to reduce the use of high-GWP refrigerants such as HCFCs and HFCs. This has required the development of new components for the high pressure side including compressors, heat exchangers and control valves. There are two main characteristics to take into consideration the low critical point (31.3°C) and the high pressures. The low critical point and high pressure result in a need to redesign the heat exchanger and a rethink on how to use CO_2 without causing increased energy consumption.

CO_2 supercritical systems are introduced in many countries in supermarket refrigeration and many evaluations are on-going. Different studies and reports are showing different results.

The development is rapid and further improvements of the technology can be expected as it becomes more established.

The conclusion of one independent evaluation reported below is that the tested stores would have higher energy consumption than those using conventional technologies and that calculations indicated that the use of CO_2 in the low temperature stage and another refrigerant in the high temperature stage would have a better energy performance. This solution would often result in a more complex system and thus be less attractive than a single stage system. The COP of a CO_2 supercritical system will depend on the climate where the installation is installed. A warmer climate will have a more negative impact on COP in these systems than on a conventional system making it more difficult to make them competitive from energy consumption point of view. Due to the characteristics of the supercritical process the possibility for heat recovery is very good which can be beneficial for the total system efficiency if it can be used.

One cited evaluation of a number of Norwegian stores with CO_2 indicate a better performance than similar stores with conventional systems. CO_2 will - when used in supercritical systems - operate at higher pressures than other refrigerants traditionally used in the RAC industry. Moreover, the supercritical process requires a different control strategy to achieve an acceptable performance. To introduce CO_2 on the market will require that these and other competencies to use CO_2 are spread to the RAC servicing sector.

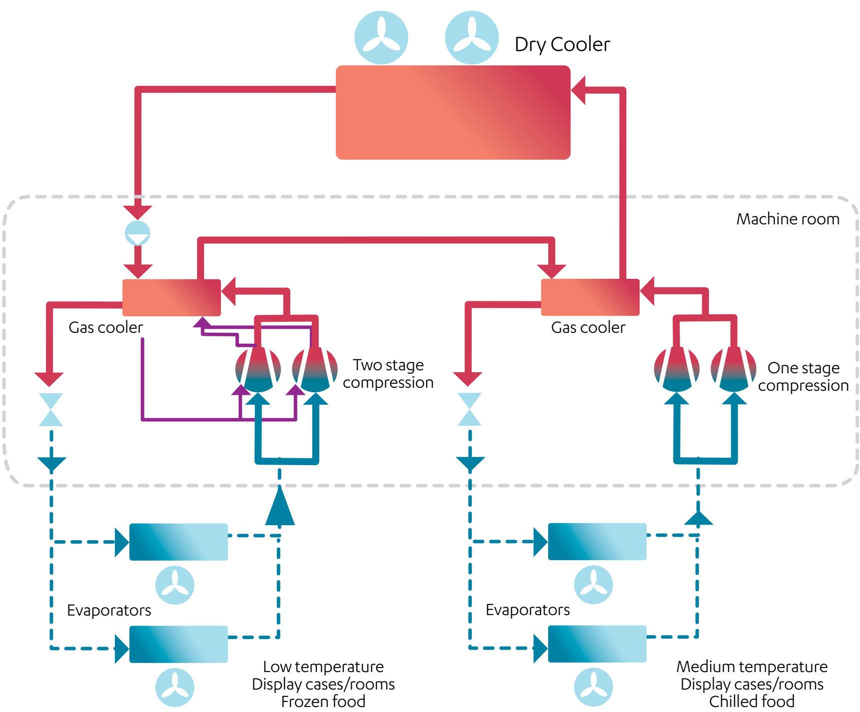
A full range of systems for CO_2 both with cascade and supercritical systems are commercially available today.

Background data/information given for this case comes from a report by Jaime Arias et al., from the Department of Energy at the Royal Institute of Technology in Stockholm (Arias et al, Energiteknik, 2007). Information is also from Green&Cool and their Norwegian partner Kulde Teknisk regarding the six Norwegian stores. The description is based on the data received from these sources, but as regards the selection of information and interpretation , the responsibility is with the author of this report.

2.7.1 EVALUATION OF CARBON DIOXIDE SUPERMARKET IN SWEDEN

THE RESEARCH project "Evaluation of two stores with supercritical systems with CO_2 as refrigerant" (Arias *et al*, Energiteknik, 2007) collected and evaluated data from two supermarkets, one store owned by COOP in the northern part of Sweden, Luleå and one ICA store in the southern part, Gothenburg. The work was carried out in a research project sponsored by the three leading supermarket chains in Sweden and the Swedish Energy Agency. The result reported here is from the COOP store in Luleå where they had most recorded data.

Fig. 2.19 Schematic flow chart of type of supercritical supermarket CO_2 system installed in Luleå. The system is also connected to the heat recovery system (not shown).



The measurements from the plant were logged on site and a model of the plant built up in a simulation tool "CyperMart" developed by the Department of Energy, Royal Institute of Technology in Stockholm.

Calculations of the TEWI value show the impact of how the electricity is produced. The factor used for power generation depends on the production mix. The average for Sweden is low due to the fact that most of the electricity in the country is produced from nuclear or hydroelectric power plants. Also the Nordic mixture is low for the same reason. The European production mix results in a significantly higher value as the production is more dependent on fossil fuels.

Fig. 2.20 TEWI calculations for the supercritical system and an indirect system with R-404A. The leakage rate was assumed to be 12% for the indirect R-404A system and 15% for the direct CO_2 system.

	INDIRECT SYSTEM R-404A			DIRECT SYSTEM SUPERCRITICAL CO_2		
Region	**Sweden**	**Nordic**	**Europe**	**Sweden**	**Nordic**	**Europe**
CO_2 kg/kWh	0.041	0.15	0.50	0.041	0.15	0.50
Indirect emissions	165 312	604 800	2 016 000	192 290	703 500	2 345 000
Direct emissions	317 856	317 853	317 856	336	336	336
TOTAL EMISSIONS	**483 168**	**922 656**	**2 333 856**	**192 626**	**703 836**	**2 345 336**
DIRECT/TOTAL	**65.8%**	**34.5%**	**13.6%**	**0.2%**	**0.0%**	**0.0%**

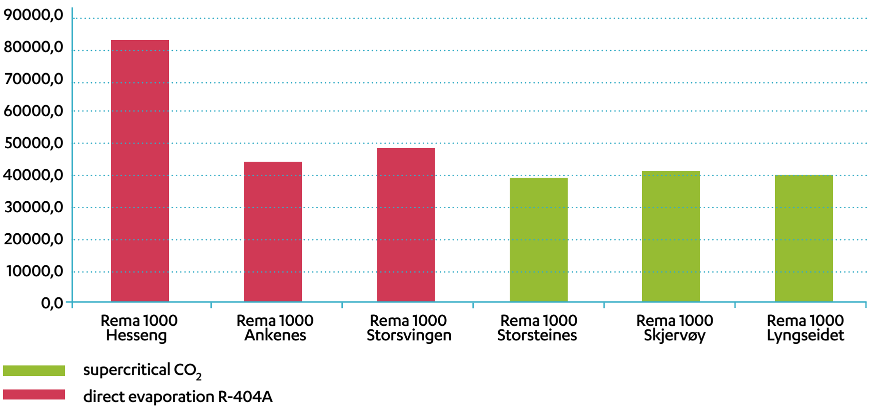
The installation cost of the CO_2 installation was, as stated by supermarket owner, approximately 20% higher than the indirect R-404A plant. The LCC analysis based on a 10 year perspective showed an 18% higher cost with CO_2 than for indirect solution.

The conclusions made in the survey were that with the technology installed in this plant (2006) the CO_2 system was more expensive and could be expected to have a slightly lower efficiency than the theoretical reference system used for comparison. Since the original installation of this plant there has been an ongoing development of supercritical as well as cascade systems with CO_2, so the situation is changing. Also, the installation in this plant has been modified and the manufacturer, Green&Cool, claims that the average COP of this plant now is better than a conventional R-404A indirect plant. It is also expected that the price on CO_2 components and systems will decrease relative to conventional technologies.

It should always be considered that in refrigeration and air conditioning there are many technical options and climate as well as possible heat recovery can drastically change the outcome of any comparisons. Neither the CO_2 solution selected nor the indirect R-404A system used in this comparison might be considered the lowest cost or most energy efficient options in a particular market (author's comment). The local climate and need for heat recovery will have an impact on the comparison of different technologies. In general, the carbon dioxide process as a one –stage supercritical process will have relatively better COP at low ambient temperatures. In the case where there is a need for high temperature in the heat recovery this is often beneficial for CO_2 in a comparison with conventional alternatives.

2.7.2 EVALUATION OF THREE CARBON DIOXIDE STORES IN NORWAY

Fig. 2.21 Comparison of energy (kWh) consumption in six medium-sized supermarkets in Norway.



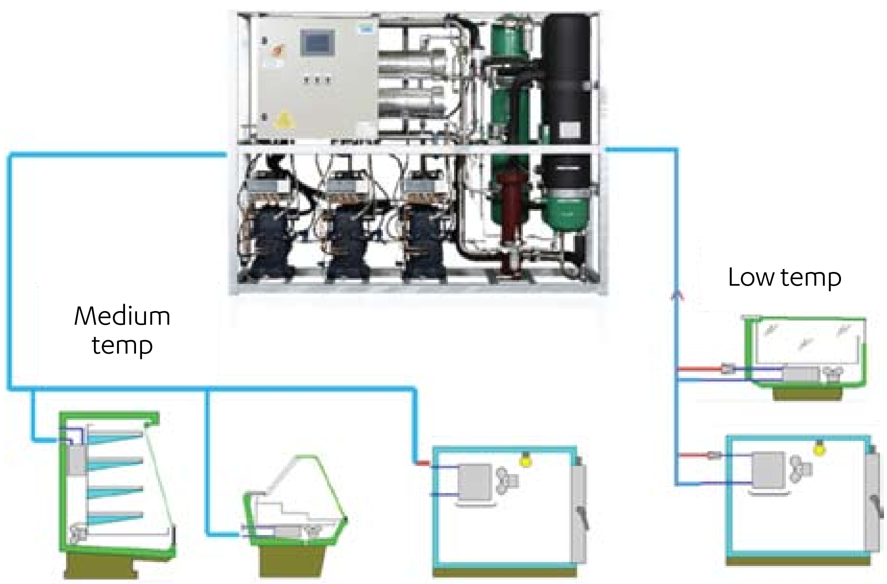
TO TEST THE EFFICIENCY of supercritical CO_2 systems, the Norwegian supermarket chain "Rema" selected six medium sized stores for comparison between three supercritical CO_2 systems compared to three direct evaporation R-404A systems. The result is presented in a presentation by the contractor (Kuldeteknisk AS, 2009).

The design was with air cooled gas-coolers and built in heat exchanger for heat recovery (desuper heater) with the intention to make cost effective installations with good energy efficiency.

The results show that the total energy consumption in the three stores using CO_2 were all lower that in similar stores using R-404A (of which one is using significantly more energy without clear explanation and was not used in the comparisons).

The plants are factory-built packs with the tubing to the display cases and cold rooms built on site. The operating experience of these plants are reported to be positive and the higher cost of the CO_2 packs are compensated by the lower installation cost of the tubing (which have smaller dimensions with CO_2 compared to tubes required for R-404A) and lower energy costs. The LCC is reported to be favourable with CO_2. To handle standstill without increase of pressure above acceptable limits the systems are equipped with "stand by" cooling units supplied with back-up power (UPS) in case of power failure. This will cool the system to avoid the pressure to increase at stand still. A pressure increase could result in that safety valves open and require recharge of system.

Fig. 2.22 Factory-built CO_2 system with combined low and medium temperature circuit.



2.7.3 MARKET SITUATION FOR CO_2 AS A REFRIGERANT IN SUPERMARKETS

THERE ARE SEVERAL suppliers of factory-built CO_2 systems and a significant number of supermarkets have installed them on many different markets in industrialized countries. The challenges with CO_2 increases at high ambient and the high pressure requires that staff of installation and service companies are trained to work with these systems. The currently higher investment has also been a negative factor when it comes to the introduction in Article 5 countries. The product development is continuing and several different system designs are in production, including both supercritical and sub critical systems in cascade with other refrigerants. In cascade systems, the CO_2 is used sub critical in combination with any type of refrigerant such as hydrocarbons, ammonia or HFCs in the high stage. By using the CO_2 as a low cost and environmentally benign medium to distribute the cooling in the store, the charge and leakage risk of the media in the high temperature stage can be minimized. This reduces the potential leakage problems associated with using hydrocarbons, ammonia, and HFCs. As the charge of ammonia or hydrocarbon would be low, the risks are easier to manage and with use of CO_2 as media to transport the cooling the systems can be placed in safe areas where the risks of flammability or toxicity are relatively easy to handle and servicing is easy to perform. By combining the CO_2 designs with improved control systems and effective heat recovery, good energy efficiency have been reported. Nevertheless, there is a debate on the cost aspects and what system will give the best efficiency, in particular in hot climates. In any case, development gradual improvements can be expected as well as decreased prices as the technology matures. Some argue that if an additional investment is made, there could be other improvements that would change the TEWI and/or LCC analyses between the different design options, so the discussion on CO_2 competiveness in the supermarket and other sectors is ongoing. It can be expected that this technology will mature and stabilise during the next few years. With a standardisation and increasing volumes the prices should also decrease.

2.8 Retrofit of R-22 supermarket in Romania to R-404A

SUMMARY RETROFIT OF R-22 SYSTEMS IN SUPERMARKET TO R-404A

The supermarket had two central systems for cooling. One system was medium temperature (chilled food at approximately 4°C) and one low temperature (freezing at approximately -20°C).

The transition to R-404A was chosen as the oil change and use with a "standard" refrigerant with a soluble oil was considered a better option than using a drop-in replacement with the existing oil. The uncertainty of the oil transport and requirement to secure future service availability with a service blend not widely used was considered more important than the cost to replace the oil.

The oil change was done first once when the system was decommissioned by draining at all available taps/valves and then with a follow up the oil change.

The system was found to work well on R-404A after the retrofit.

In this case, several seals and components were replaced but no pressure vessels had to be changed on this installation.

Fig. 2.23 Typical supermarket display cases for a central system with "low temperature" cases in the front and "medium temperature" in the back.

Background data/information given for this installation comes from Adrian Balaoi. The description is based on the data received from the company, but as regards the selection of information and interpretation, the responsibility is with the author of this report.

CONSTANTA IS A port town on the coast of the Black sea in Romania. The supermarket in the Tomis Mall had two central refrigeration plants operating on R-22: one for medium temperature (MT) and one for low temperature (LT). Both systems had four semi hermetic compressors. The supermarket owner wanted to select an alternative technology that would allow them to be in line with their environmental strategies and to avoid a future unplanned retrofits to replace R-22 in case of a failure or large leak. The decision was to retrofit to R-404A so that they would be using the same refrigerant as they use in new plants. Drop-in blends were not considered to be a viable option due to lack of experience and uncertainty of future availability and price. The retrofit was carried out through traditional oil changes.

The retrofit was done during a renovation of the store while it was out of use.

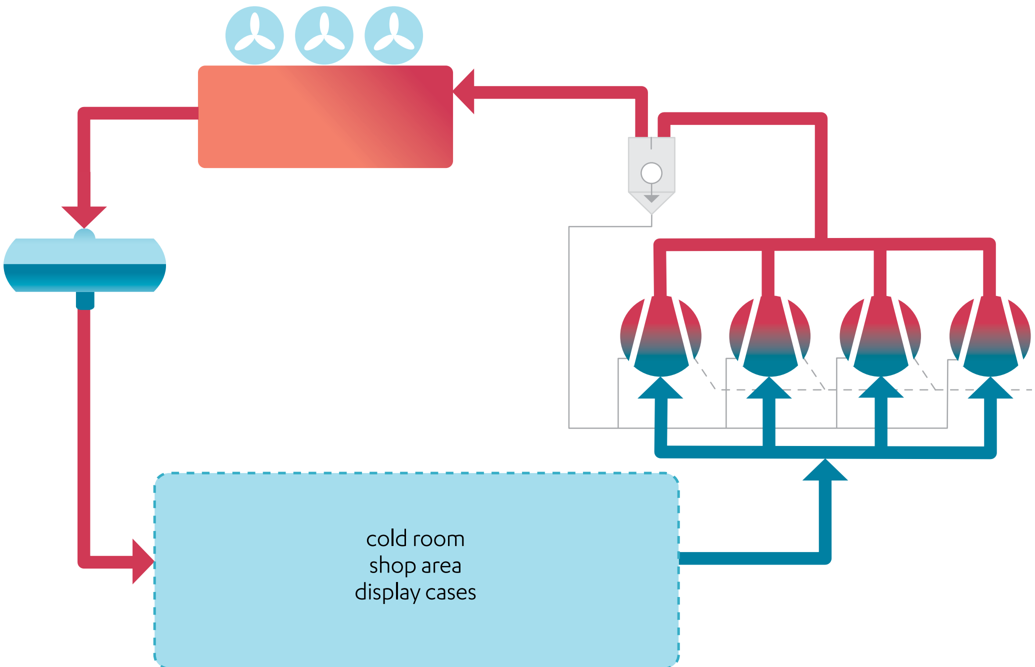
The first step was to evaluate the system and replace a number of gaskets and stop valves. The oil was replaced during the major upgrade of the plant. As the last step before restarting the plant, the oil was changed through drainage from oil reservoir, suction-, and liquid receiver through their drain plugs.

The new polyol ester oil (Triton™ SEZ 32) was introduced in the oil reservoir by applying a vacuum.

After two days of running the plants, the oil was changed once again. Approximately 50 litres of oil was required.

The results of the pre-retrofit calculations and the follow up after retrofit are shown in the two tables below, one for the medium and for the low temperature system.

Fig. 2.24 Supercritical CO_2 system with gas cooler operating at pressures 2 to 3 times that of conventional systems.



2.8.1 RESULTS OBTAINED FOR THE REFRIGERATION CIRCUIT OPERATING AT MEDIUM TEMPERATURE

NR. CRT	EQUIPMENT	CURRENT - R 22	PROPOSED – R 404A	RESULT AFTER RETROFIT
1	Evaporators – refrigerating rooms	Roller To = -8°C DT = 8°C Qo = 2,17KW	Roller To = -8°C DT = 8°C Qo = 2,26KW	**$Qo_{R\ 404A}$ = +4%**
2	Evaporators – refrigeration cabinets	Asim Roller DHN 602L To = -7°C DT = 8°C Qo = 4,50KW	To = -7°C DT = 8°C Qo = 4,68KW	**$Qo_{R\ 404A}$ = +4%**
3	Group of compressors	**4 x Copeland Discus, D3DC4 – 1000 each** To = - 12°C Tc = + 45°C $T_{subcooling}$ = 3°C Qo = 18KW/buc Pel = 7,16KW/buc COP = 2,51	**4 x Copeland Discus, D3DC4 – 1000 each** To = - 12°C Tc = + 45°C $T_{subcooling}$ = 3°C Qo = 19,1KW/buc Pel = 8,0KW/buc COP = 2,39	**$Qo_{grup\ R\ 404A}$ = +6%** **$Pel_{grup\ R\ 404A}$ = +12%**
4	Condensers	1 buc - 2 x 3 fans Asim Guntner GVV 050.1C / 2 x 3 LWE Tc = + 45°C Text = + 35°C	1 buc - 2 x 3 fans Asim Guntner GVV 050.1C / 2 x 3 LWE Tc = + 45°C Text = + 35°C	**$Qc_{R\ 404A}$ = -2%**
5	Required refrigeration power / circuit	$Qo_{required\ circuit}$ = 65,42KW	$Qo_{required\ circuit}$ = 65,42KW	**$Qo_{required\ circuit}$ / $Qo_{grup\ R\ 404A}$ = 65,42/76,4 = 86%**
6	Required condensing power / circuit		$Qc_{required\ circuit}$ = 86%x 1.02 x 108,4KW = 95KW	**Safety factor $_{(R\ 404A)}$ = 100,6 / 95KW = 1.059% (+6%)**

CONCLUSIONS FOR THE MEDIUM TEMPERATURE STAGE: Existing equipment parts are, from a mechanical point of view, completely functional with the R-404A refrigerant, provided that the technician follows the proper cleaning procedures, oil changes, filters, settings on the mechanical safety and control elements. The air cooled condenser may be used in the installation, with R-404A, up to temperatures of the external air (coil inlet) at most equal to +36°C, and only in case all fans are functional, and the surface of the coil is maintained under normal cleaning conditions.


CHILLED WATER SUPPLY
CHILLED WATER RETURN

2.8.2 RESULT OBTAINED FOR THE FREEZING CIRCUIT (LT)

NR. CRT	EQUIPMENT	CURRENT - R 22	PROPOSED – R 404A	RESULT AFTER RETROFIT
1	Evaporators – refrigerating rooms	Roller To = -28°C DT = 8°C Qo = 2,31KW	Roller To = -28°C DT = 8°C Qo = 2,36KW	**$Qo_{R\text{-}404A}$ = -2%..+2%**
2	Evaporators – refrigeration cabinets	Asim To =-32°C DT = 8°C Qo = 3,20KW	To = -32°C DT = 8°C Qo = 3,17KW	**$Qo_{R\text{-}404A}$ = -2%..+2%**
3	Group of compressors	**4 x Copeland Discus, D3DA4 – 500** To = - 37°C Tc = + 45°C $T_{subcooling}$ = 20°C $T_{super\ heating}$ = 20°C Qo = 3,77KW/buc Pel = 3,16KW/buc COP = 1,19	**4 x Copeland Discus, D3DA4 – 500** To= - 37°C Tc = + 45°C $T_{subcooling}$ = 20°C $T_{superheating}$ = 20°C Qo = 5,03KW/buc Pel = 3,78KW/buc COP = 1,33	**$Qo_{grup\ R\text{-}404A}$ = +33%** **$Pel_{grup\ R\text{-}404A}$ = +20%**
4	Condensers	1 buc - 1 x 3 fans Tc = + 45°C Text = + 35°C	1 buc - 1 x 3 fans Tc = + 45°C Text = + 35°C	**$Qc_{R\text{-}404A}$ = -2%**
5	Required refrigeration power / circuit	$Qo_{required\ circuit}$ = 14,74KW	$Qo_{required\ circuit}$ = 14,74KW	**$Qo_{required\ circuit}$ / $Qo_{grup\ R\text{-}404A}$ = 14,74/20,65 = 71%**
6	Required condensing power / circuit		$Qc_{required\ circuit}$ = 71% x 1.02 x 29,6KW = 21,55KW	**Safety factor $_{(R\text{-}404A)}$ = 21,08 / 21,55KW = 0.98% (-2%)**

CONCLUSIONS FOR the low temperature stage: Existing equipment parts are, from a mechanical point of view, functional with the R-404A refrigerant, under the condition of proper execution of the cleaning procedures, oil changes, filters, settings on the mechanical safety and control elements.

Appendix I List of refrigerants

COMMON SUBSTANCES WITH R NUMBERS

The following numbering is based on the standard ISO 817:2003 (also ASHRAE Standard 34). The lists do not include all refrigerants, but aim to reflect those that are commonly used or discussed as replacements to HCFCs in the RAC sector.

COMMON SUBSTANCES WITH R NUMBERS	
RED	indicate ODS that will be phased out.
GREEN	indicate alternatives with neglectable environmental impact (can be flammable or toxic).
BLUE	indicates substances with zero ODP that are most common alternatives in the RAC sector today.
WHITE	are non-ODS which are mainly used as a components in blends or blends that have limited market presence at this time.

Low-GWP "natural" refrigerants

REFRIGERANT NUMBER	COMPOSITION DESIGNATING PREFIX	CHEMICAL NAME	CHEMICAL FORMULA	MOLECULAR MASS (G/MOLE)	NORMAL BOILING POINT[a] (°C)	ODP	GWP (100 YEAR) IPCC 1996
Ethane series							
R-170	HC	ethane	CH_3CH_3	30.0	−89	0	3
Propane series							
R-290	HC	Propane	$CH_3CH_2CH_3$	44.0	−42	0	3
Unsaturated organic compound in propane series							
R-1270	HC	propene (propylene)	$CH_3CH = CH_2$	42.1	−48	0	0
Butane series							
R-600	HC	n-Butane	$CH_3CH_2CH_2CH_3$	30.0	−89	0	3
R-600a	HC	Isobutane	$(CH_3)_2CH_2CH_3$	30.0	−89	0	3
Inorganic compounds							
R-717		ammonia	NH_3	17.0	−33	0	0
R-723		ammonia/ dimethyl ether*	NH_3/DME	23	-26	0	8
R-744		carbon dioxide	CO_2	44.0	−78	0	1

*a mixture of inorganic and organic compounds

Low-GWP synthetic refrigerants

REFRIGERANT NUMBER	Low-GWP replacements to R-134a proposed by DuPont/Honeywell for Mobile air conditioning where EU has a future ban. Currently not commercially-available/tested in stationary RAC systems but could possibly be a future alternative					
	Group	Chemical name	Chemical formula	ODP	GWP	Group ISO 817
HFO-1234yf	HFO	2,3,3,3-tetrafluoropropene	$CF_3CF{=}CH_2$	0	4	A2L (slightly flammable)

Several other HFOs are under evaluation and there are also evaluated mixtures with HFO1234yf to achieve better match with existing products.

HIGH-GWP REFRIGERANTS – SYNTHETIC REFRIGERANTS CFC, HCFC AND HFC USED AS HCFC ALTERNATIVES

Numbering based on standard ISO 817:2003 also ASHRAE Standard 34, the lists are not complete but aim to reflect those that are commonly used or discussed as replacements in the RAC sector.

Below the list is separated between products with and without glide as this is an important factor in evaluation of what product to use and if any consideration to glide is required. Glide means that the boiling point of the different components will be noticeable during condensing and evaporation. These refrigerant has a R-4xx number. Mixtures that behave like one substance without glide are called azeotropic blends and will be listed as R-5xx refrigerants.

PURE SUBSTANCES AND NON-AZEOTROPIC BLENDS (E.G. BLENDS WITHOUT A TEMPERATURE "GLIDE")	
RED	indicate ODS that will be phased out.
GREEN	indicate alternatives with neglectable environmental impact (can be flammable or toxic).
BLUE	indicates substances with zero ODP that are most common alternatives in the RAC sector today.
YELLOW	are the so called service blends intended for use in existing systems with no or partial oil change.
WHITE	are non-ODS which are mainly used as a components in blends or blends that have limited market presence at this time.

REFRIGERANT NUMBER	GROUP	CHEMICAL NAME	CHEMICAL FORMULA	NORMAL BOILING POINT[a] °C	ODP	GWP (100 YEAR) IPCC 2001
R-22	HCFC	chlorodifluoromethane	$CHClF_2$	−41	0.055	1700
R-124	HCFC	2-chloro-1,1,1,2-tetrafluoroethane	$CHClFCF_3$	−12	0.022	620
R-32*	HFC	Dichlorodifluoromethane (methylene fluoride)	CH_2F_2		0	550
R-125	HFC	pentafluoroethane	CHF_2CF_3	−49	0	3400
R-134a	HFC	1,1,1,2-tetrafluoroethane	CH_2FCF_3	−26	0	1300
R-141b	HCFC	1,1-dichloro-1-fluoroethane	CH_3CCl_2F	32	0.11	700
R-142b	HCFC	1-chloro-1,1-difluoroethane	CH_3CClF_2	−10	0.065	2400
R-143a	HFC	1,1,1-trifluoroethane	CH_3CF_3	−47	0	4300
R-152a*	HFC	1,1-difluoroethane	CH_3CHF_2	−25	0	120
R-507A	HFC	R-125/143a (50%/50%)			0	3850

* Classified as A2/A2 = slightly flammable

NON-AZEOTROPIC BLENDS (E.G. BLENDS WITH A TEMPERATURE "GLIDE") GWP data can vary slightly depending on source as calculations are based on different integrations and periods and has been updated in different sources at different times

REFRIGERANT NUMBER	GROUP	NOMINAL COMPOSITION	COMPOSITION MASS (%)	BUBBLE POINT/ DEW POINT (°C)	ODP	GWP (100 YEAR) IPCC 2001) EXCEPT *
R-401A	HCFC/HFC/HC	R-22/152a/124	(53/13/34)	-34.4/-28.8	0.037	1130
R-401B	HCFC/HFC/HC	R-22/152a/124	(61/11/28)	-35.7/-30.8	0.040	1220
R-401C	HCFC/HFC	R-22/152a/124	(33/15/52)	-30.5/-23.8	0.030	830*
R-402A	HCFC/HFC/HC	R-125/290/22	(60/2/38)	-49.2/-47.0	0.021	2690
R-402B	HCFC/HFC/HC	R-125/290/22	(38/2/60)	-47.2/-44.9	0.033	2310
R-403A	HCFC/PFC/HC	R-290/22/218	(5/75/20)	-44.0/-42.3	0.041	2680*
R-403B	HCFC/PFC/HC	R-290/22/218	(5/56/39)	-43.8/-42.3	0.031	4310
R-404A	HFC	R-125/143a/134a	(44/52/4)	-46.6/-45.8	0	3780
R-406A	HCFC/HFC/HC	R-22/600a/142b	(55/4/41)	-32.7/-23.5	0.057	1760*
R-407A	HFC	R-32/125/134a	(20/40/40)	-45.2/-38.7	0	1990
R-407B	HFC	R-32/125/134a	(10/70/20)	-46.8/-42.4	0	2700
R-407C	HFC	R-32/125/134a	(23/25/52)	-43.8/-36.7	0	1650
R-407D	HFC	R-32/125/134a	(15/15/70)	-39.4/-32.7	0	1420*
R-407E	HFC	R-32/125/134a	(25/15/60)	-42.8/-35.6	0	1360*
R-408A	HCFC/HFC	R-125/143a/22	(7/46/47)	-45.5/-45.0	0.026	3820
R-409A	HCFC	R-22/124/142b	(60/25/15)	-35.4/-27.5	0.048	1540
R-409B	HCFC	R-22/124/142b	(65/25/10)	-36.5/-29.7	0.048	1430*
R-410A	HFC	R-32/125	(50/50)	-51.6/-51.5	0	1980
R-410B	HFC	R-32/125 (45/55)	(1.5/87.5/11.0)	-51.5/-51.4	0	1835*
R-411A	HCFC/HFC/HC	R-1270/22/152a	(3/94/3)	-39.7/-37.2	0.078	1503*
R-411B	HCFC/HFC/HC	R-1270/22/152a		-41.6/-41.3	0.052	1602*
R-412A	HCFC/PFC	R-22/218/142b	(70/5/25)	-36.4/-28.8	0.055	2040*
R-413A	HFC/PFC/HC	R-218/134a/600a	(9/88/3)	-29.3/-27.6	0	1920
R-414A	HCFC/HC	R-22/124/600a/142b	(51.0/28.5/4.0/16.5)	-34.0/-25.8	0.045	1200*
R-414B	HCFC/HC	R-22/124/600a/142b	(50.0/39.0/1.5/9.5)	-34.4/-26.1	0.042	1100*
R-415A	HCFC/HFC	R-22/152a	(82.0/18.0)	-37.5/-34.7		550*
R-416A	HCFC/HC	R-134a/124/600	(59.0/39.5/1.5)	-23.4/-21.8		950*
R-417A	HFC/HC	R-125/134a/600	(46.6/50.0/3.4)	-38.0/-32.9	0	2240
R-418A	HCFC/HFC/HC	R-290/22/152a	(1.5/96.0/2.5)	-41.2/-40.1		1740*
R-422A	HFC/HC	R-134a/125/600a	(11.5/85.1/3.4)		0	3040
R-422D	HFC/HC	R-125/134a/600a	(65.1/31.5/3.4)		0	2620
R-424A	HFC/HC	R-125/134a/600a/600/601a	(50.5/47.0/0.9/1.0/0.6)		0	2440*
R-427A	HFC	R-32/125/143a/134a	(15.0/25.0/10.0/50.0)		0	2010
R-428A	HFC/HC	R-125/143a/290/600a	(77.5/20.0/0.6/1.9)		0	3600*
R-434A	HFC/HC	R-125/143a/134a/600a			0	3238*
R-438A	HFC/HC	R-32/125/134a/n-butane/i-pentane	8.5/45/44.2/1.7/0.6		0	2100*

Data from Swedish Code of Practice referring to ISO standard and Bitzer Refrigerant Report (Bitzer, 2008) or supplier data. Data is based on IPCC 2001 100)year integration unless there is an * when for unusual or new products where this data has not been available often then IPCC1996 is the bases.

These are not all options on the market but they are the most commonly discussed. As the R-22 is the largest volume product in the industry there are a significant number of alternatives proposed - many more than the industry can handle from the point of service availability. There is a need for stakeholders in the industry to carefully evaluate the offerings from all perspectives and avoid premature decisions based on promotional material that often present a simplified information.

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Abbreviations and definitions

AB Alkyl benzene

Article 2 countries
Parties to the Montreal Protocol that do not operate under Article 5. "Article 2 countries" refer to developed countries.

Article 5 countries
Developing country Parties to the Montreal Protocol whose annual per capita consumption and production of ozone depleting substances (ODS) is less than 0.3 kg to comply with the control measures of the Protocol, are referred to as Article 5 countries. Currently, 147 of the 196 Parties to the Montreal Protocol meet these criteria. Article 5 countries are eligible to receive technical and financial assistance from the Multilateral Fund Secretariat, as per Article 10 of the Protocol.

Azeotrope refrigerant
A refrigerant that is a blend of several components and will behave as a single component refrigerant.

CFCs Chlorofluorocarbons

COP Coefficient of Performance (how much energy is required to create a unit of cooling or heating)

Elastomer Polymer with the property of elasticity (rubber/plastic often used to seal).

Glide See Temperature glide

GWP Global Warming Potential

HCs Hydrocarbons

HCFCs Hydrochlorofluorocarbons

HFCs Hydrofluorocarbons

IEA International Energy Agency

IIR International Institute of Refrigeration

LCA Life Cycle Analyses

LCC Life Cycle Cost

MO Mineral Oil

ODP Ozone Depletion Potential

PAG Polyalkylene glycols

POE Polyolester Oil

PVE Polyvinylether Oil

RAC Refrigeration and Air conditioning

Temperature glide
For a refrigerant that consist of two or more components that do not behave as a single component (non-azeotrope = zeotrope). The difference between dew point and bubble point of a "zeotrope" refrigerant at a given pressure. In a condenser this is the correct definition. For an evaporator the definition according to the AREP (Alternative Refrigerant Evaluation Program) is the difference between temperature at evaporator inlet and dew point. The evaporation is slightly higher than bubble point.

TEWI Total Equivalent Warming Impact

$$TEWI = (GWP * L * n) + (GWP * m [1-\alpha_{recover}]) + (n * E_{annual} * \beta)$$

Leakage	Recovery loss	Energy cons.
direct global warming potential		Indirect global warming potential

GWP	= Global warming potential	[CO_2-related]
L	= Leakage rate per year	[kg]
n	= System operating time	[Years]
m	= Refrigerant charge	[kg]
$\alpha_{recover}$	= Recycling factor	
E_{annual}	= Energy Consumption per year	[kWh]
β	= CO_2-Emissions per kWh	[Energy – Mix]

VRF Variable Refrigerant Flow, abbreviations used to describe systems with variable capacity.

VRV Variable Refrigerant Volume (Daikin's name for VRF)

Zeotropic (non-azeotropic) refrigerant
A refrigerant that has a temperature "glide" during condensing and evaporation. The consequence of the "glide" is that system designs need to take this into account and be designed with counter flow heat exchangers. Zeotropic blends also need to be handled with care to during charging to avoid concentration shift. Leaks and repeated recharge can also affect the composition.

About the Swedish Environmental Protection Agency

The Swedish Environmental Protection Agency, created in 1967, is the national agency for environmental protection and nature conservation as well as outdoor recreation and hunting issues. Its key tasks are to present proposals for environmental policy and legislation to the Swedish Government and ensure that environmental policy decisions are implemented. The Agency complies with the ISO 14001 environmental management standard and EMAS for both direct and indirect environmental impact.

The Swedish EPA supplies expert knowledge and proposals to central government in its national, EU and international work on environmental issues. Nationally the Agency regulates, sets standards and acts as a guide, coordinator and evaluator. Some 100 Swedish EPA employees are involved as experts and Swedish representatives in EU-related work and in international multilateral or bilateral cooperation.

Funded by central government, the Swedish EPA is an independent authority acting on the basis of a government ordinance that defines its terms of reference.

Areas of responsibility:

- Providing guidance on environmental and regulatory issues to other national agencies as well as to regional and local authorities
- Evaluating the effectiveness of different measures in attaining the National Environmental Quality Objectives and proposing new measures where necessary
- Monitoring and reporting on the state of the environment
- Developing environmental policy instruments, including environmental legislation
- Appearing in courts of law (principally on licensing matters)
- Promoting sustainable treatment of waste
- Funding environmental research
- Communicating expert knowledge
- Funding environmental protection (i.e. liming of acidified lakes, site remediation and grants to local climate investment programmes)
- Protecting land and water (including Natura 2000 sites)
- Dealing with hunting and wildlife issues
- Promoting outdoor recreation
- Cooperating multilaterally and bilaterally with other countries

For more information, see
www.naturvardsverket.se

About the UNEP Division of Technology, Industry and Economics

The UNEP Division of Technology, Industry and Economics (DTIE) helps governments, local authorities and decision-makers in business and industry to develop and implement policies and practices focusing on sustainable development.

The Division works to promote:

> sustainable consumption and production,
> the efficient use of renewable energy,
> adequate management of chemicals,
> the integration of environmental costs in development policies.

The Office of the Director, located in Paris, coordinates activities through:

> **The International Environmental Technology Centre** - IETC (Osaka, Shiga), which implements integrated waste, water and disater management programmes, focusing in particular on Asia.
> **Production and Consumption** (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.
> **Chemicals** (Generva), which catalyzes global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.
> **Energy** (Paris), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.
> **OzonAction** (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.
> **Economics and Trade** (Generva), which helps contries to integrate enviromental consideration sinto econimic and trade policies, and works with the finace sector to incorporate sustainable development policies.

UNEP DTIE activities focus on raising awareness, improving the transfer of knowledge and information, fostering technological cooperation and partnerships, and implementing international conventions and agreements.

For more information,
see **www.unep.fr**

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Hydrochlorofluorocarbons (HCFCs) are chemicals controlled by the Montreal Protocol on Substances that Deplete the Ozone Layer, which are widely used in refrigeration and air conditioning around the world. Developing countries must freeze their HCFC consumption and production by 2013 then make step-wise reductions in 2015, 2020, and 2025 until HCFCs are totally phased out in 2030. Early action to reduce HCFCs is important since these chemicals have an impact on both ozone depletion and climate change. UNEP OzonAction in cooperation with the Swedish Environmental Protection Agency has produced this publication to provide decision makers, end-users and servicing technicians in developing countries with information on alternative technologies that can be adopted to phase out HCFCs in refrigeration and air conditioning. The report provides information on technical information on the technologies, details about their current market situation in developed and developing countries, and industry case studies that exemplify state-of-the-art solutions using different technologies in different market segments.

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