



Production conversion of domestic refrigerators from halogenated to hydrocarbon refrigerants

A Guideline

On behalf of

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für Internationale
Zusammenarbeit (GIZ) GmbH



Federal Ministry for the
Environment, Nature Conservation
and Nuclear Safety

of the Federal Republic of Germany

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The on-site pictures used in this document are courtesy of Palfridge Fridge Factory, Swaziland.

ABBREVIATIONS

ARC	AREA refrigeration craftsmen/craftswomen
AREA	European Association of National Air-Conditioning and Refrigeration Contractor Associations
ASEAN	Association of Southeast Asian Nations
ASTM	American Society for Testing and Materials
ATEL	Acute toxicity exposure limit
ATEX	“Atmosphere EXplosible” (synonym for the European ATEX Directive)
BMU	“Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit“ (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
CFC	Chlorofluorocarbon
CNS	Central nervous system
CO ₂	Carbondioxide
EEA	European Economic Area
EU	European Union
GIZ	“Deutsche Gesellschaft für Internationale Zusammenarbeit“
GHG	Greenhouse gas
Gt	Gigatonne
GWP	Global warming potential
HCs	Hydrocarbons
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HPMP	HCFC Phase-out Management Plan
IGS	Interfering gas suppression
IIR	International Institute of Refrigeration
ISO	International Organisation for Standardisation
LEL	Lower explosive limit
LFL	Lower flammability limit
LPG	Liquid petroleum gas

MLF	Multilateral Fund
MSDS	Material Safety Data Sheet
NGO	Non-governmental organisation
ODL	Oxygen deprivation limit
ODS	Ozone-depleting substance
ODP	Ozone depleting potential
OFDN	Oxygen-free dry nitrogen
PED	Pressure Equipment Directive
PL	Practical concentration limit
POE	Polyol ester
PPT	Pentane process technology
PTFE	Polytetrafluoroethylene
PUR	Rigid polyurethane foam
PU	Polyurethane
PVC	Polyvinyl chloride
RAC	Refrigeration and air conditioning
TRG	Technical rules for gases
TÜV	“Technischer Überwachungsverein” (Technical Inspection Association)
UEL	Upper explosive limit
UNEP DTIE	United Nations Environment Programme’s Division of Technology, Industry and Economics
VDE	“Verband der Elektrotechnik, Elektronik und Informationstechnik” (German Association for Electrical, Electronic and Information Technology)
VET	Vocational and educational training

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PREFACE

A domestic hydrocarbon conversion project can be segmented into five key areas: Production equipment that involves installation, maintenance and safety; Product that involves refrigerator redesign and test; Process, in terms of operator training and safety; Product support and technician training; marketing and customer education. This guideline aims to provide a general idea of these segments when planning a conversion from an existing production system of domestic refrigerators to one that uses hydrocarbons, such as isobutane (R600a) or propane (R290), and the important aspects that small- to medium-size manufacturers need to consider. The holistic approach of this guideline makes it a good starting point of information, not only for directors and managers of enterprises responsible for technical aspects, product development, production line and training, but also for consultants, training institutions, teachers, lecturers and technicians. Users are referred but not limited to specific handbooks and good practices guides provided in the list of recommended references at the end.

1. INTRODUCTION

Climate change issues and the escalating importance to reduce current and future greenhouse gas (GHG) emissions are increasingly putting pressure on industries to comply with international protocols and regulations. The 1987 Montreal Protocol on Substances that Deplete the Ozone Layer is a landmark agreement that has successfully reduced the global production, consumption, and emissions of ozone-depleting substances (ODSs) that are also greenhouse gases contributing to climate change¹.

1.1 HCFC, HFC, HC

Historically chlorofluorocarbon (CFC) was a common type of refrigerant in most cooling systems. The Montreal Protocol required the phase-out of CFCs that led to several manufacturers introducing hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) as substitutes for either charging new appliances or newly installed systems, or for replenishing the refrigerant in existing systems^{2,3}. Today a typical household refrigerator uses HFC-134a in the refrigeration circuit and HFC-141b as the blowing agent in the polyurethane foam insulation (PUF).

Following the ratification of the Montreal Protocol and the introduction of HFC refrigerants to replace CFCs and HCFCs, the issue of global warming, which was mainly driven by the non-governmental organisations in Europe became prominent, as it was realised that simply substituting HCFC with HFC alternatives offers no benefit in reducing GHG emissions but rather enhances the global warming gases in most cases. Therefore it became increasingly desirable to exploit alternatives that not only have zero ozone depleting potential (ODP) and negligible global warming potential (GWP) but that also offer improvements in potential efficiency, thereby reducing indirect emissions associated with electricity production.

Today there is a wide variety of environmentally-friendly and technologically proven HCFC- and HFC-free alternatives to meet the cooling needs. These include natural refrigerants, secondary cooling systems, desiccant, evaporative and sorption cooling, and innovative building designs that eliminate the need for mechanical cooling⁴. Having been around for more than a decade and used by companies and enterprises, these substitutes are safe, available and commercially proven to not only meet human needs that were formerly met by fluorocarbons but also the needs and requirements of the Montreal Protocol under which HCFCs are deemed to be phased out in developing countries by 2030. It is furthermore intended that these substances will mitigate ozone-depleting effects and reduce GHG emissions.

Many organisations currently promote the use of HFCs and HFC mixture as substitute refrigerants. However, if such replacements are widely adopted, significant implications will arise due to their high GWP. Thus from a global warming perspective, the adopted use of HFCs is not beneficial. Details of ODP and GWP of commonly used substances in refrigeration, and what it implies in terms of a broader climate and environmental impacts is explained in Appendix 1.

A closer look at the warming impact of HFCs indicates that the potential hazard of widespread replacement of HCFCs is more severe than suggested solely through GWP values. Figure 1 shows the actual warming impact following the release of 1kg of various HFCs (which represent the components of the HFC mixture, see Table A1-1 in Appendix 1) and 1000kg of carbon dioxide (CO₂), calculated as the absolute global temperature potential⁵.

Figure 1: Actual warming effect from the release of 1kg of various HFCs and 1000kg of CO₂⁶

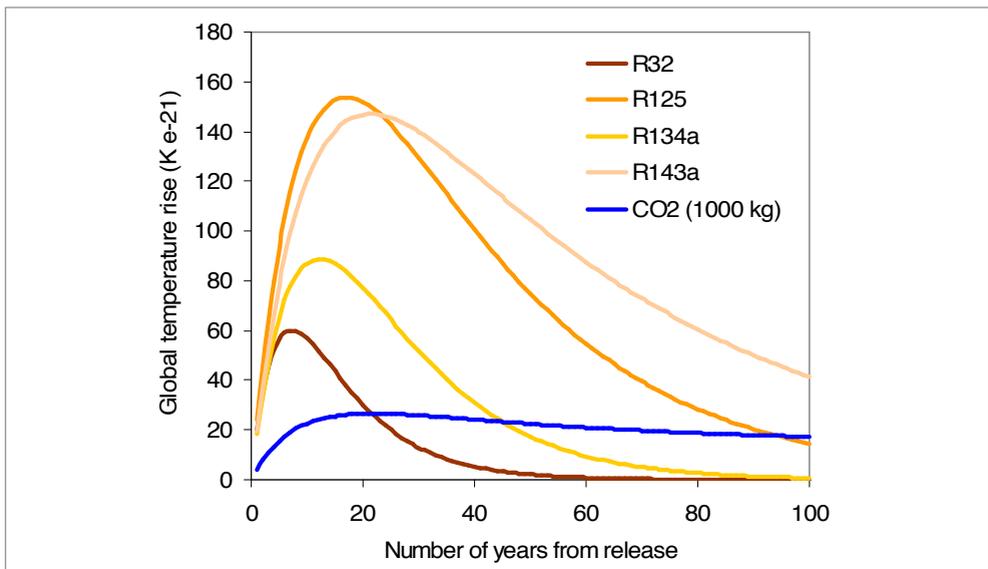


Figure 1 shows that for all HFCs there is an immediate warming impact during the first 20 – 30 years, which then diminishes until decomposition. Due to the use of a 100-year integration period for calculating the GWP of such fluids, this impact is normally hidden. Considering the temperature rise, it can be seen that the immediate effect of emissions of HFCs is up to 3½ times more severe than is implied by the

GWP over 100-year period (relative to CO₂). Given the increasing understanding of the relevance of the feedback mechanisms that are likely to accelerate climate change⁷, this characteristic of high-GWP refrigerants should be taken into account.

If emissions reporting are to be considered, the issue of replacing HCFCs with HFCs is of even greater concern. Since HCFCs are not considered within the Kyoto Protocol emissions reporting requirements, the introduction of gases that do fall under Kyoto will result in the automatic increase of reported emissions. Also, from a general environmental perspective, it is important to note that the manufacture of the most common HFCs, all require the production of HCFCs and/or CFCs⁸ that inevitably results in the emissions of ODS in the manufacturing process and are not controlled by the Montreal Protocol.

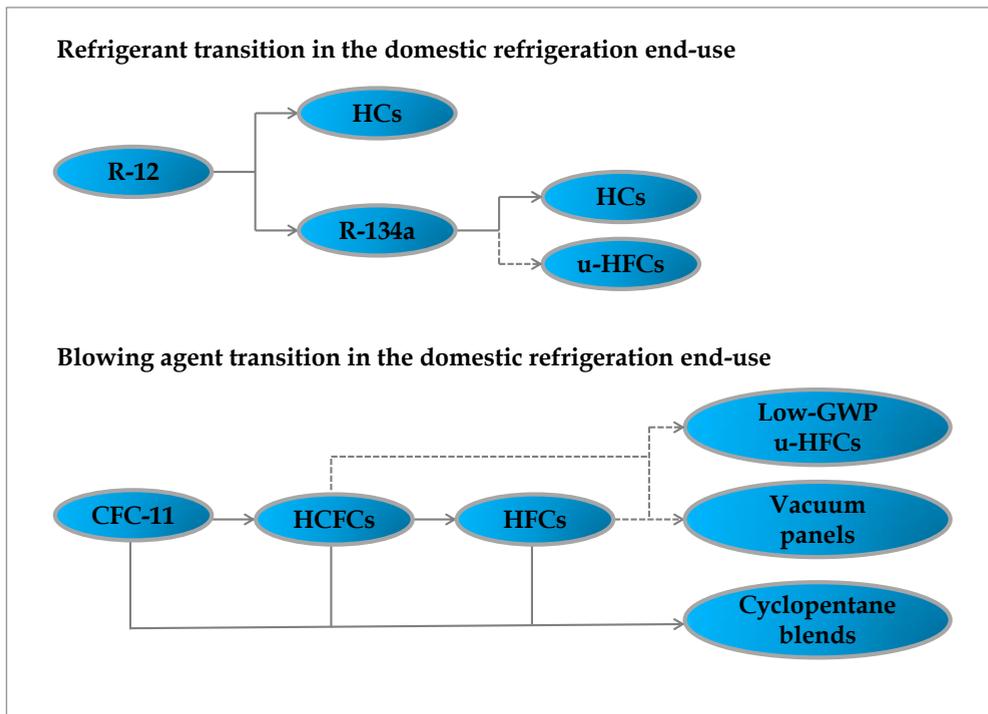
In developing countries, as HCFCs are progressively phased out HFCs are becoming the dominant substitutes, replacing over 75% of the historic HFC consumption with an increasing anticipated consumption overtaking that of developed countries before 2020⁹. Scientific evidence indicates that GWP-weighted HFC emissions alone will reach between 5.8 to 8.8 Gt CO₂ equivalent, or 45% of CO₂ emissions by 2050, thus undermining efforts to combat global warming^{9,10}.

As for HCFC phase-out required by the Montreal Protocol, a concerted effort and agreement to also phase out HFC is fundamental to realise the Kyoto goals. The increasing use of HFCs can be halted and possibly reverted, as there are sufficient alternatives to eliminate to a substantial degree the need for those substances.

The production of refrigerators using hydrocarbon refrigerants originated in Germany and expanded elsewhere within Europe. Today more than a third of the new domestic refrigerators entering the market use isobutane (R600a) that has a GWP of three and ODP of zero (Appendix 1), with majority of the production occurring within Europe, China, Korea and Japan. The sales of these R600a appliances extend to parts of Africa, South America, South East Asia and the Middle East¹¹. The last decade has also seen a surge in developing countries enquiring about the use of hydrocarbons and the peripheral issues related to their use in new equipment and as retrofit refrigerants. In order to implement hydrocarbons and other natural refrigerants safely and successfully, it is essential for government and their agencies, the industry and in particular the relevant technicians to fully understand the issues related to their application¹¹. These technical matters, together with questions of funding further elevate manufacturers' concerns in making the switch.

The transition to low-GWP refrigerants and blowing agents in the domestic refrigeration end-use is summarised in Figure 2. Solid arrows represent alternatives that are already available in the market for these systems, while dashed arrows represent those that are likely to be available in the future. There is a growing trend towards HCs for refrigerants and blowing agents but other denomination, such as unsaturated HFCs (u-HFCs), is also being explored. For foam blowing, vacuum panels with cyclopentane is the latest trend.

Figure 2: Transitions in refrigerants and blowing agents in domestic refrigeration^{11,12}

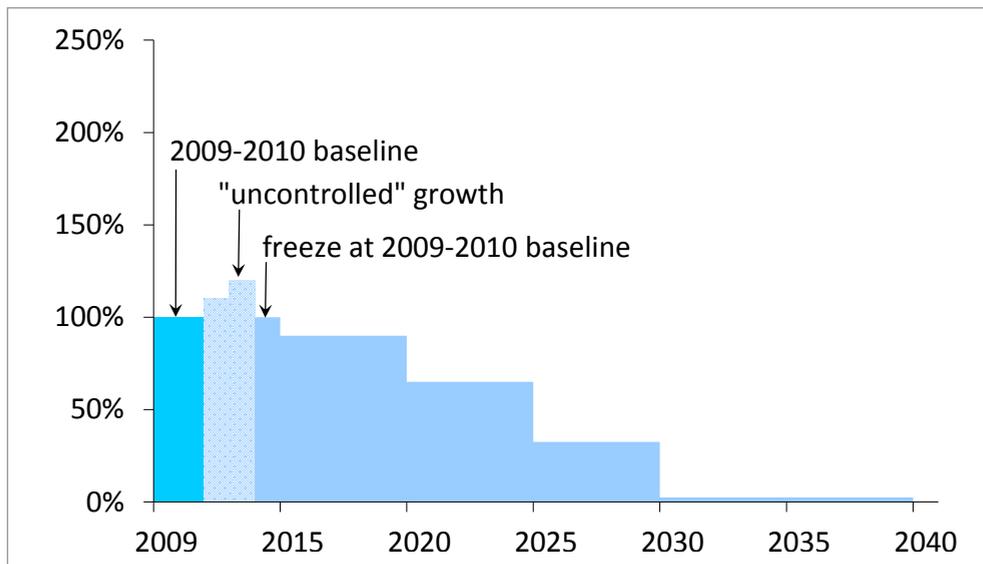


1.2 Climate framework

At the 19th Meeting of the Parties to the Montreal Protocol in 2007, an adjustment was agreed upon to accelerate the phase-out of HCFCs in developing and developed countries¹³, commonly referred to as Article 5 and non-Article 5 countries, respectively. The default replacement of HCFCs in most refrigeration equipment is currently HFCs, which on average have a higher GWP and could therefore increase GHG emissions from this sector if directly substituted, leading to intensified climate impacts arising from the emissions.

Figure 3 presents the current phase-out schedule for HCFCs for Article 5 countries, where there is a freeze in 2013 based on the average of 2009-2010 consumption and production levels, and from 2015 a step down every five years³. From 2030 only 2.5% consumption is permitted for servicing only. Also indicated in Figure 3 is the rate of “uncontrolled growth” of HCFC consumption.

Figure 3: Current HCFC phase-out schedule for Article 5 countries³



Since 1998 a steady growth has been noted in the consumption of HCFCs, equating to around 50,000 tonnes per year, or 35,000 tonnes per year of R-22⁹. Based on 2005 levels, this is an average of around 10% per year, keeping in mind that in certain countries this rate is exceeded and may approach up to 20% per year in some cases³. Extrapolating this trend the business-as-usual scenario suggests that R-22 consumption in 2020 would be twice the 2009-2010 value, implying that significant interventions are necessary now in order for Article 5 countries to achieve the 35% reduction required by the adjustment to the Montreal Protocol.

To assist with the phase-down and eventual phase-out efforts of HFC use in developing countries the United Nations Environment Programme’s Division of Technology, Industry and Economics (UNEP DTIE)^{14, 15}, as well as established organisation like the GIZ, with support from the European Union, have undertaken and successfully implemented projects demonstrating the viability of switching to HC use. This benefits the developing countries by leap-frogging HFCs

altogether to long-term solutions that rely on natural refrigerants and foam blowing agents, thereby avoiding the reliance on more expensive, energy intensive and high-GWP HFC substitutes that will need to be phased-out in the near future.

1.3 Scope of this guideline

There is an abundant supply of reliable information on the use of hydrocarbons in refrigeration sector as specialised know-how in specific areas, mainly in the form of handbooks and guidelines. These range from technical guidance in the operations and servicing, safety measures, design and test of individual components, to the use of correct tools and equipment^{16, 17}.

To date, there is currently no guideline that provides a holistic approach to the conversion process from adaptation or overhauling of the production line, to the changes necessary in key components of the product, to servicing and maintenance, training requirements, through to marketing of the appliances. The present guide-book aims to address these issues towards a successful implementation of the conversion process from conventional refrigerant use to hydrocarbons.

Part 2 introduces the use of hydrocarbons as an alternative refrigerant, highlighting the marketing of hydrocarbon appliances and how manufacturers can bring their products to the consumers without losing their market potential. Key considerations for manufacturers on the conversion and the important barriers that are encountered are also addressed.

Part 3 provides a detail step-by-step guide on important technical changes required for a safe and successful conversion of the production line, as well as the necessary changes in the product components, on-site storage of the finished products, and servicing and training needs.

Part 4 provides a case study from Swaziland as an example to illustrate the implementation of hydrocarbon conversion in a factory. It is also meant to highlight the practical issues of the manufacturer concerns, the problems and setbacks during the course of the conversion process, the perceptions of the manufacturer as much as how the workers perceive the change, and the benefits associated with a successful implementation.

2. HYDROCARBONS AS ALTERNATIVE REFRIGERANTS

Hydrocarbons (HCs) as clean climate-friendly refrigerants are emerging as the choice of alternatives in light of the accelerated phase-out of HCFCs and a foreseeable regulation of fluorinated gas emissions under a future climate change agreement within the Montreal and the Kyoto areas.

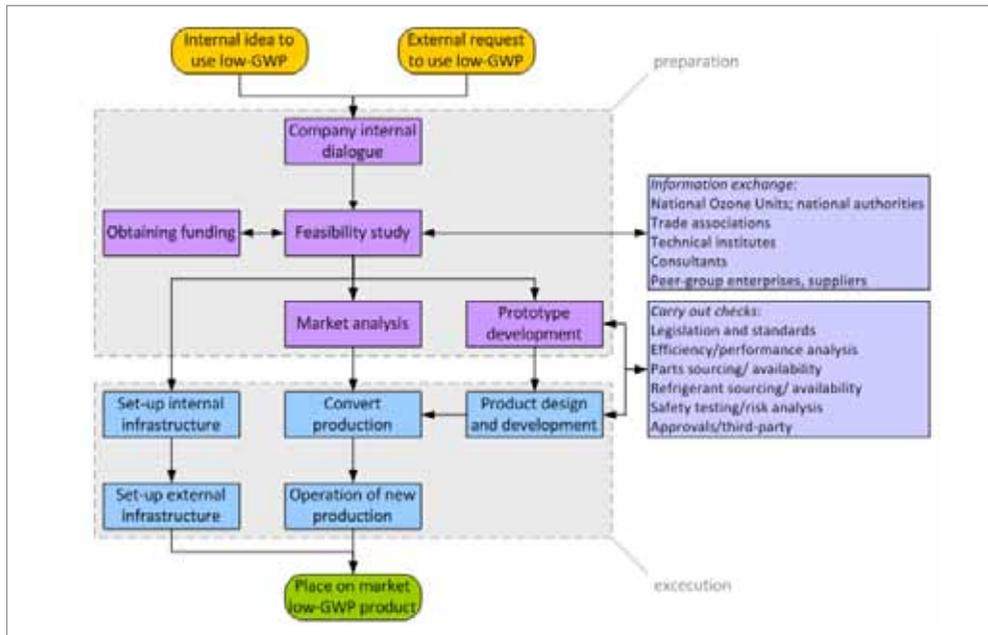
Historically the three main natural refrigerants: ammonia, R717; HC and CO₂, R744 have been used in a large number of situations since the advent of vapour-compression and sorption refrigeration in the mid-1800s⁶. Natural refrigerants are thus available as mature technologies with extensive accumulated knowledge and experience for most applications, both in industrialised and developing countries. However, despite their superior properties in terms of performance and their negligible environmental impact they are not extensively used, largely due to manufacturer concerns on costs, safety, technological status and market impacts.

Before embarking on introducing changes to an existing system and therefore a new product to the market, enterprises must first understand the processes involved. These can be broadly categorised as two phases: the preparation phase and the execution phases, as illustrated in Figure 4. The present chapter aims to explain these phases in detail. **Section 2.1** provides information and facts on the market of HC appliances in domestic and commercial refrigeration; **Section 2.2** highlights the technical and economical considerations for the manufacturers on the conversion of their system and equipment; and **Section 2.3** addresses the barriers towards the application of HC technologies.

2.1 Marketing hydrocarbon appliances

Promoting clean technology through awareness and engaging in national or regional green technology initiatives and programmes is an effective way of marketing HC appliances. ‘Green marketing’ in its traditional sense has been production, promotion and reclamation of environmentally sensitive products in response to consumer concerns about ecological issues. Increasing global pressures from other sectors of society have motivated shifts in firms to engage in better environmental practices and improving stakeholder relationships and management that are necessary for effective organisational performance across markets¹⁸.

Figure 4: Conceptual diagram illustrating the general process involved in planning and executing a conversion project³



To successfully market greener, cleaner products and avoid running into problems, industries must adjust their conventional marketing mind-set. Some of the issues¹⁹ that enterprises need to consider are:

- **Thinking differently about customers:** today there is greater awareness of environmental issues among consumers, which influence their choice of purchase. Hydrocarbon refrigerators have less electricity consumption and lower carbon emissions. This meets customer requirements, as customers seek in particular energy efficient appliances, which offer less energy consumption and environmental benefits at the same time;
- **Customer satisfaction:** although the fundamental aim of marketing is to create consumer satisfaction at a profit, today's consumer satisfaction is more defined in terms of sustainability and efficiency, and depends increasingly on the acceptability of the production process and associated activities of the producer;

- **Products:** marketers have a broader concept of ‘the product’ that encompasses tangible dimension such as packaging, as well as augmented dimensions that consist of supporting services and products. Environmentally concerned customers have shown that their purchase decisions can go beyond these dimensions to take account of the externalities involved in production – meaning that they may reject a technically sound product because of their awareness of the environmental harm caused in production or disposal, or because they may disapprove of some activities of a producer, its suppliers or investors;
- **Pricing and market structures:** markets are driven by prices. Introducing a premium price on alternative products differentiates itself from an existing version on the basis of eco-performance and allows customers wanting to switch to do so in a way that also generates additional margin for the company. Exchanged within markets are non-linear in that the flow of goods and services is not in one direction. A sustainable economy requires ‘closed loop’ supply chains whereby products can be returned for recycling. This needs to be taken into account;

Energy efficiency labelling, such as EU-label in the European Union (EU) used for indicating energy efficiency levels from A+++ (very good) to D (very bad)²⁰, which is amongst others used for fridges and freezers. Setting and adhering to appliance standards can contribute to effective marketing. Environmental groups, while traditionally seen as a threat to businesses, can aid green market initiatives through various types of ‘green alliances’ – collaborative business-environmental group partnerships that pursue mutually beneficial ecological goals.

2.1.1 Current market trends

It is important to recognise that in adopting alternative technologies that deviate from the standard generally attracts higher initial costs, often due to lower scale of economies when introducing HC refrigerators as new production lines.

In 2009, an estimated 1.5–1.8 billion domestic refrigerators and freezers were in operation worldwide, with approximately 100 million new units being produced and sold annually on global scale¹¹. Between 35% - 40% of the global fleet production is HC refrigerators, and today there are over 400 million such appliances in the world²¹. The technology dominates the market in Europe, Japan and China, with 75% of refrigerators in China now using R600a.

Among the air-conditioning and refrigeration appliance, domestic refrigerators have reached by the far the biggest market penetration for HCs as refrigerants. Within industrialised countries isobutane refrigerants have reached a penetration of 55%,

while in the developing countries it is 28%²². The United States is the only major world market where HCs in domestic refrigeration are still banned by law. However, the first U.S. manufacturers such as GE and ice-cream maker Ben & Jerry's have requested approval of the use of isobutane and propane in domestic refrigerators and ice cream freezers. If granted by the U.S. Environmental Protection Agency, the USA is likely to become a key market for HCs, not only in domestic but also in commercial refrigeration.

On a global scale, additional channels for HCs may open up through global initiatives such as "Refrigerants Naturally!", which unites some of the world's leading consumer brands. The likes of Unilever and McDonalds, for example have shown interest to use HCs in ice-cream cabinets and in fast food restaurants, respectively²³. It is predicted that at least 75% of global new refrigerator production will use HC refrigerants in 10 years²⁴.

2.1.2 Energy classification

The introduction of energy classification and labelling of domestic appliances orientates consumers towards purchasing energy efficient products. The energy classes are reviewed periodically, with ever more stringent criteria introduced to keep pace with the development of industry²⁵.

High energy costs have heightened public awareness of the important role energy efficiency plays in controlling costs and meeting energy needs in a reliable manner. Efficiency standards complement consumer education and incentive-based programmes, such as Energy Star and tax credits, and help overcome the market barriers of cost-effective energy savings that include²⁶:

- Lack of awareness and uninformed decision-makers at the point of purchase;
- Third party decision-makers, such as builders or landlords who seek to keep installation costs low without consideration for potential energy bill savings;
- Misinformation about up-front costs versus operating costs over the life of the product;
- Limited stocking of high-efficiency products and limited competition, which keeps initial costs artificially high.

Generally, manufacturers prefer not to be regulated but some corporations have supported standards and deem them to be advantageous to business providing manufacturers with²⁴:

- Clear targets for energy efficiency;
- A level playing field for companies large and small; and
- Incentives to innovate have spurred advances, such as high efficiency, reliability, longer life-time, etc.

2.1.3 Eco-labelling

Many countries have environmental protection agencies within their governments that act as mandated watchdogs of industries and are responsible for propagating environmental standards, either through administering labelling standards or setting minimum requirements for manufacturers.

European Ecolabel²⁷, a voluntary scheme agreed upon at European level, and Green Stickers mandated by law in North America are good examples of labelling systems for consumer products. Other examples include the Nordic Ecolabel or the Nordic swan, which is the official sustainability ecolabel for Nordic countries, introduced by the Nordic Council of Ministers, while in Asia the Association of Southeast Asian Nations (ASEAN) is moving towards adopting the ISO's TC 207 environmental management system^{28, 29}.

Ecolabels are a form of sustainability measurement directed at consumers with the intention to make it easy for them to take into account environmental concerns when shopping. The voluntary nature of, for example the EU Ecolabel scheme, means that it does not create barriers to trade, especially for those producers wishing to sell their products throughout the EU and the EEA countries. Many producers find that it gives them a competitive advantage and helps manufacturers, retailers and service providers gain recognition for good standards, while helping purchasers to make reliable choices.

Thus Eco-labelling can benefit manufacturers not only in marketing their products but also engaging in raising awareness of the public on green technology.

2.2 Considerations for manufacturers

With the heightened global warming impact of refrigerants, refrigeration industries are under increasing pressure to switch to climate-friendly refrigerants. The general market trends, electricity prices, emissions reduction and energy demand are some of the concerns faced by the manufacturers. Furthermore, international treaties that require national actions demand industries to act. Thus there is an escalating interest in and application of HCs in the refrigeration sector. Historically HCs were among the first refrigerant fluids to be used but due to their flammability, their use was abandoned in favour of inert fluids. Compared to HFCs, HCs offer zero ODP, extremely low GWP, high efficiency, reduced charge sizes and have proven to be cheaper.

During the last decade major companies within many countries have successfully implemented HC refrigerants within their refrigeration equipment. Likewise many

national and international end-users are increasingly purchasing and installing such equipment, resulting in many more system component and equipment producers building systems with HCs in response to the customer demands, as much as promoting them according to their own merits, namely lower cost of refrigerants, lower GWP of HC refrigerants and improved energy efficiency¹⁵.

Industries realise their responsibility to also reduce their GHG emissions. Manufacturers therefore are increasingly required to account for and report their emissions. This is a concern albeit not a large one, especially for small-scale emerging manufacturers. An approach to emissions calculation is presented in Appendix 2.

When adopting a new refrigerant, it is necessary for enterprises to accept an obligation – at least at the onset of the project – for increased expenditure, be it in terms of time, finance, material resources, etc., in order to carry out certain work. Indeed this obligation is present under any implementation project from ODS fluids to non-ODP technology. However, in the case of utilising HCs it can be greater.

At the onset of the implementation project, the enterprise should set up a project team, within which a number of activities, most of them technical in nature, need to be carried out. These activities may be broadly described as follows:

- Source agencies/experts/consultants to assist with the work
- Become trained/familiarised with HC technical matters, primarily related to safe design, safety training and the applicable safety standards and regulations
- Analyse each product for its suitability to use HCs and identify the necessary design changes that not only enable conformity to relevant standards but also which can provide additional levels of safety
- Cost analysis of proposed new designs and evaluation of associated alternate design strategies
- Establish whether it is possible to produce the modified appliances using the existing production process and whether changes to the production are viable
- Check supply and availability of new system components, electrical devices and refrigerant, or where applicable possible sources for items that are not readily available
- Identify requirements for a new or modified production line
- Cost analysis for operating a new or modified production line
- Liaise with commercial departments in order to evaluate commercial acceptability of differences in costs for both the additional production features and for the new appliance design
- Identify, characterise and understand the current after-sales infrastructure
- Identify necessary changes to the current after-sales infrastructure, including needs for training, new service tools and equipment

- Formalise revised after-sales infrastructure – allocate responsible person(s) for implementation
- Carry out training for production workers
- Carry out training for sales and marketing staff
- Carry out training for service technicians – both own and external technicians
- Conduct efficiency tests on specific models before and after to ensure benefits are gained

Amongst these activities, a number of other aspects may arise. In addition, the extent of work involved those activities above may vary widely depending upon the existing structure of the enterprise, the number of different appliance designs and the expertise of the staff.

2.3 Barriers to converting

Preceding and during the conversion process, a number of barriers are likely to be experienced at various levels. It is therefore important to be aware of these and anticipate them where relevant. Such barriers may be categorised into various types, including: technical matters, supply and availability, commercial aspects and market-related issues. Barriers which are sometimes experienced are summarised below.

2.3.1 Technical matters

Generally, where HC refrigerants are new to an enterprise, it may be perceived that the design knowhow of systems using flammable refrigerants is not fully established. This is often a result of the technology being new to the region and local peer groups, or even arising from informal discussions amongst individuals within the industry. In fact, when looking at the situation across a broader geographical region, it can be seen that there are numerous companies in different regions that have already adopted HC technology, both within developed and developing countries. As such, it is important to identify enterprises and organisations that have been involved with the technology and thereafter source the relevant technical information. Currently, there are a number of handbooks available from implementation agencies (including GIZ), from refrigeration component manufacturers and also useful articles from technical organisations (such as IIR³⁰), which can assist in building up technical knowledge about the application of HCs.

In principle, it is acknowledged that there is an additional level of complexity involved with working with HCs, since the flammability aspects of these refrigerants must be handled – and this is, of course, different from most conventional refrigerants. However, in most cases it is not technically challenging and there are established ways of addressing the issues, for example, through considered design,

proper selection of components, charge size optimisation and testing. Furthermore, it is essential to conduct quality technical training at all levels (that is: design engineering, production and technicians) and also to carry out trialling and testing of systems in order to gain some firsthand experience.

2.3.2 Supply and availability

In certain regions, it is often the case that obtaining system parts and components and the HC refrigerant itself locally can be problematic, especially if the operation is located within a region where HC refrigerants are not currently manufactured or applied. Normally, this can be resolved through encouraging local producers to develop suitable parts, such as electrical components, by liaising with international suppliers or local distributors or agents for international producers of components for HC systems. In some cases, it can be beneficial to encourage or enthuse such suppliers by demonstrating new market opportunities for them. In terms of absence of refrigerant, it can be worthwhile discussing the matter with local liquid petroleum gas (LPG) producers and refineries, which are often capable of supplying refrigerant-grade product.

There may be hindrances with obtaining the correct servicing equipment and as a result technicians could end up using improper tools and machines; for example, gas detectors, recovery machines and pressure gauge scales. Thus, specific requests should be made to importers or distributors of service equipment to source the appropriate tools and machines. Alternatively, the enterprise may opt to work with local companies who could develop their own service equipment products. Again, amongst implementing agencies and technical institutes, the necessary information for doing this should be available.

Often manufacturers are concerned since they consider that the local industry does not have the capacity to handle flammable refrigerants responsibly. This can be primarily due to the absence of experience within the service sector and also because the basic level of training and technician competence is believed to be insufficient. Addressing these should be dealt with by proper planning and execution of training practices for HCs, ensuring that in one respect, the training is dedicated to HCs (as opposed to “alternative refrigerants” in general) such that the important material is not marginalised by “general” topics. In addition, where needed, the training should be supplemented by basic refrigeration technician training, in terms of system theory, practical handling, brazing, pipe-fitting, system components and so on.

In preparing for the technician training, it can be useful to liaise with national authorities to review the knowledge of teachers/lecturers at colleges or vocational training centres to identify any gaps and to subsequently fill them, as this will ultimately help to raise the level for candidates. Additional options may include

sending local teachers/experts to other regions of countries to receive intensive high level training.

Lastly, it should be emphasised that this supplemental training must not be seen negatively as an additional financial burden, since with an increase in overall competence of technicians, their ability to better maintain and repair refrigeration systems, which can only be a major benefit to the sector as a whole, both environmentally and financially.

2.3.3 Commercial aspects

Due to the greater cost and investment of resources for setting up new or modifying existing production lines and revising the designs of systems, the end cost of products may at first not be competitive. Of course, this largely depends upon the production volume, the extent of external funding available and the approach taken in terms of changes to the production line and the appliance design. Thus, there are often more economical ways of doing things so it is useful to draft in experts to work with the manufacturers, for instance, who may be able to help optimise the revised production process or provide guidance in terms of how to select the cost-optimum system components and parts.

As with the production of systems, the service equipment needed for maintaining and repairing a system using a flammable refrigerant may cost more, although in most cases this should be marginal compared to the total cost for an entire set of tools and equipment. Consideration should be given to searching and sourcing the most cost-effective equipment and in addition, consideration should be given to using the opportunity to encourage local or regional enterprises to begin manufacturing equipment and parts locally.

At a national level, authorities should be encouraged to introduce economic incentives to incentivise the purchase and application of products using natural refrigerants; these could include tax benefits/rebates for companies that adopt HCs, the introduction of GWP-based deposit schemes and subsidies or offsetting of import duties to those that purchase these equipment and parts.

2.3.4 Market

It is often stated that there is no demand for RAC products using HC refrigerants; in which case, there is no justification for an enterprise to invest resources into developing products and associated infrastructure. In this respect, it is important to consider a couple of market dynamics that are currently in progress.

Firstly, there are currently a large number of major end users of equipment, such as multinational corporations, that have or are introducing purchasing policies that specify the requirement of natural refrigerants only (e.g. see Refrigerants, Naturally!³¹). Furthermore, the markets in certain regions, particularly Europe, are gradually moving towards natural refrigerants within the commercial refrigeration sector.

Secondly, it is widely anticipated that there will be a gradual introduction of international and regional legislation that will restrict the application of high-GWP refrigerants or HFCs. In the long term, adopting natural refrigerants at this stage will provide any enterprise with a head-start over competitors, especially once entire sub-sectors are obliged into adopting such technology. It can be observed that in markets where HC become the dominant choice, HC components become cheaper than fluorinated refrigerator components. On a global market it can be observed that HC compressors are already cheaper than the compressors with the same cooling output running on fluorinated refrigerants. Nevertheless, it is essential to recognise that even if parts of the market are not necessarily requesting natural refrigerants within their refrigeration systems, the fact that systems do utilise them – and provided that they meet the necessary safety standards – should in no way inhibit sales.

Under circumstances where it is perceived that there could be a lack of market acceptance of systems using HC refrigerants, further approaches could be encouraged. For instance, manufacturers and other stakeholders should encourage authorities to introduce legislation that prohibits systems using high-GWP refrigerants in particular situations, for example, where the technology is suitable throughout. This would not only ensure a more level playing-field for the sector but also enable it to considerably reduce GHG emissions. Similarly, an interest for natural refrigerants amongst end users could also be encouraged by environmental NGOs. Where they are involved, implementing agencies may try to encourage a number of enterprises to enter the market with HCs at the same time, thereby sharing the “load”.

And finally, sales and marketing staff of the enterprises should become well-orientated with the relevant issues associated with refrigerants such that they can not only adequately respond to concerns, but also promote the significant advantages of natural refrigerants to potential customers, thereby giving their products a commercial edge.

3. CONSIDERATIONS FOR CONVERSION

The introduction of new refrigerants necessitates modification and/or reconstruction of the production infrastructure, as well as design modifications of the product. To identify the critical issues for HC conversion, including safety, one must have some awareness and appreciation of the existing national and international standards for refrigeration equipment.

The first most important task for an enterprise intending to convert their production to HC refrigerators is a review of the baseline situation and making a preliminary risk assessment. This may be carried out by an appointed refrigeration/manufacturing expert, who also designs the new process. The initial assessment should accommodate many constraints, such as site conditions, existing technological processes, plant layout, current production level and capacity utilisation, budgetary constraints dictated by the cost effectiveness threshold, requirements of the new technology, availability of skilled personnel, and raw materials and utilities, such as power, water and steam³².

Depending on individual cases and the results of the review there may not be a need to change the entire production line, although many small to medium enterprises may see this as an opportunity to upgrade their production infrastructure. Testing and compliance with standards and regulations form a critical part of any changes. Special consideration is also necessary for the design and installation of the production and associated areas where charging of HCs take place. Thus the areas that store and transfer the refrigerant and where the refrigerant-filled appliances are worked upon must be addressed¹⁷.

This part of the guideline focuses on the technical challenges associated with the conversion process of the production plant and the products, and presents a generic guide to converting to hydrocarbon production. There are five main areas of concern: design, insulation, production, product and training requirements. These are addressed in the following sections:

Section 3.1 provides information on the redesigning of appliances to be produced and charged with HC refrigerant. A good system should be designed and installed such that it sustains pressure tests, leak checks, performance tests, etc. In other words, the designing of the unit must take into account the need for thicker insulation if necessary, and component compartment size adjustments.

Section 3.2 provides general issues relating to foam blowing process for insulation in refrigeration appliance production. When foaming with blowing agent such as pentane or using water-based technology, changes in the machinery and the work area are needed. It is important to ensure that appropriate foaming equipment is employed and that all safety procedures are followed. Identifying leak areas to reduce emissions and other hazards when working with foam should be of prime importance. The safety and hazard issues are predominantly shared with other relevant changes in the production line. However, foaming process involves additional concerns, depending on the type of technology used. These considerations need to be taken into account, as each requires different conversion strategies. The foaming process thus described in this section is general, with the main focus on domestic production.

Section 3.3 provides information on the changes and modifications that are necessary in the production line of the factory and the related safety measures that should be followed.

Section 3.4 addresses the changes necessary in the components of HC appliances. This section links closely with the designing of the unit but focuses mainly on the key components that should be replaced and the required safety measures.

Section 3.5 provides information on the changes deemed important for the on-site storage of the finished product. This is crucial in light of the emissions associated with the blowing agent. As in all other areas of the production, the on-site storage facility should be assessed for risk and all safety measures duly taken.

Section 3.6 explains the need for servicing and training, as well as after-sales servicing. Training activities in refrigeration sector not only include training of technicians but also training of the trainers, as well as of sales representatives on the product knowledge.

3.1 Unit design

The flammable nature of HCs prompts for redesigning of refrigeration appliances before assembling and charging with HC refrigerants. Changes are necessary to meet the safety requirements, to ensure compatibility with thermodynamic characteristics of HCs and for performance improvement, as the cabinets can be redesigned to boost

energy and reduce noise, for example. In the circuit design, the insulation, as well as space allowances for component replacements, such as compressor compartment, needs to be made.

Further design changes are needed to cater for:

- Hidden evaporator
- Enclosed type or relocated thermostats and other switches to avoid sparking as a source of ignition
- Avoidance of high temperature defrost heaters, which may act as a potential source of ignition
- Sealing of refrigerated compartment, i.e. to prevent ingress HC in the event of a leak
- Changes to compressor swept volume
- Increase evaporator condensate receptacle

The designing of the other components, such as the outer cabinet and door, the inner cabinet or liner, and the exterior and interior fixtures, such as handles and trays remains more-or-less unchanged, and any modification will depend on the types and sizes of units produced by individual enterprises.

3.2 Foam production

The conversion of foam production in domestic refrigeration means replacing the use of fluorinated blowing agent with environment-friendly, zero-ODP alternative. PUR is preferred as insulating materials for domestic refrigerator-freezers and other commercial appliances because, firstly the self-adhesive rigid foam systems allow for a weight-saving sandwich construction to be produced in a single operation, and secondly the good thermal insulating properties permit an optimum relationship between the size and useful volume of the appliances due to the relatively small wall thickness with respect to other insulating materials³³. This implies that the choice of PUR foam, design and therefore mechanical properties of the blowing agent are an important factor in achieving a good refrigerator. Besides ecological consideration, another significant factor is the thermal conductivity of PUF with different blowing agents. Any increase of thermal conductivity of PUR with different blowing agents. It should be noted that the contribution to the overall insulation of the refrigerator is for 30-40% determined by the quality of the door.

A good refrigerator, especially the class A and better, have an excellent balance between the effectiveness of the refrigeration system and overall insulation. The loss of insulation value when changing blowing agent can, in the majority of cases be easily recovered by an increase of effectiveness of the refrigeration system³⁴.

Cyclopentane is the most widely used environmentally compatible blowing agent in the refrigeration sector today, as it offers by far the best cost effectiveness. For some specific applications, other alternatives include HFC-245fa, HFC-365mfc/227ea and the upcoming HBA-2 (unsaturated HFC, Honeywell), FEA1100 (Dupont) AFA-L1 (Arkema). When going towards the high-end domestic refrigerators with energy classes of A++ the technology is used to insert so-called vacuum panels, which have about 50% improvement of the thermal insulation. The reason for this use is in order to avoid the increase of wall thickness and therefore reduction of usable volume (domestic refrigerators width is practically normalised in order to fit them in household kitchens).

The criteria to look at when changing blowing agent can be summarised as follows:

1. Ensure that the raw materials are suitable for the chosen blowing agent. This is the most important selection criteria, as the raw materials determine the quality of the cell structure and flow characteristics;
2. Assess the changes are needed in the design of the cabinet and door;
3. When changing design it is also a good opportunity to critically examine the gain that can be made in the design of the door, especially sealing;
4. Find out if the blowing agent is available in the region;
5. Assess if by improving the refrigeration cycle the enterprise will be able to gain an eventual loss in insulation value or have an overall better performance in order to achieve a better energy class;
6. Assess the financial impact;
7. Ensure that national regulations allow the use of flammable blowing agents in the region where the factory is located.

The differences in thermal insulation value of the foams by changing the blowing agents are more than often negligible with respect to improved design. For reference, a good indication is given in the papers presented in the GIZ Publication Natural foam blowing agents, Dr. Rolf Albach³⁵. It can be noted that where the foam thermal conductivity changes are minimal, the blowing agent thermal conductivity would indicate the contrary. The reason that the best reference is foam thermal conductivity and not blowing agent thermal conductivity lies in the fact that the cell structure is the determining factor and the long term values.

Practically all the new blowing agents including the u-HFC are flammable. The extent of flammability is secondary, as for each chemical used a safety analysis is required in order to determine the location, sources and emissions. Once the emissions are known determining the so-called Zoning according to ATEX Directives (see Appendix 3) and the corresponding preventive measures need to be taken.

3.2.1 Information required

To ensure that a plant conversion is effective, the plant-operating company should provide information on the end products, the foam system used, place of installation, and the existing plant or machine. This is detailed in Table 1.

3.2.2 Emissions source

In chemical processes – and PUR is a chemical process – the industry is obliged to measure the emissions in order to determine the workers exposure to these and the abatement of the latter. The workers exposure also depends on the type of emissions, for example if toxic or other lethal gases are released.

Secondly, the emission is a means to determine the safety requirement for guaranteeing a safe production cycle. In A5 countries drums are still widely used, as opposed to A2 countries where the drums have been replaced by tank transport. This is mainly because of emissions and the stringent requirements on disposal of drums. Cleaning before disposal is expensive. Thus tank transport avoids this necessity thereby reducing costs.

The major sources of emissions are:

1. The drums with raw materials, from the moment these are opened whether there is already a blowing agent contained, an emission will occur;
2. Blowing agents drums;
3. Work-tanks and storage tanks;
4. Safety valves and other devices that will release “gas” contained in a system in order to avoid over-pressurisation;
5. The outlet of the mixing head where the raw materials and blowing agent are mixed under high pressure and then expand to ambient pressure releasing mainly blowing agent;
6. The fixtures containing the cabinets or doors through the vent holes where a mixture of air and nitrogen used for inertisation, blowing agent is released.

Table 1: Information required for foam area conversion³⁶

INFORMATION REQUIRED FOR AN EFFECTIVE AND SUCCESSFUL FOAM AREA CONVERSION	
A. Product information	<ul style="list-style-type: none"> - dimensions of the end products - component weight - quantities/production volume - material consumption
B. Data on the foam	<ul style="list-style-type: none"> - amount of blowing agent in relation to polyol - polyol/isocyanate mixing ratio - density of the foam - operating temperature - blowing agent: C-pentane, N-pentane, I-pentane
C. Information on the place of installation	<ul style="list-style-type: none"> - machine layout, availability of compressed air, e.g. nitrogen supply - factory layout plan - ambient conditions (temperature) - safety analysis of the plant, availability of fire extinguishing systems - electrical system in place, 380V+Neutral+separate earth - form in which polyol, isocyanate and pentane are supplied (typically: drums, containers, tank vehicles), tank storage availability
D. Information on the existing plant or machine	<ul style="list-style-type: none"> - foaming machine type (wet-end), high-pressure or low-pressure - age, manufacturer, type - number of foaming places - description of the dry part, plant components, way of heating the dry part (electrical or water/oil) - description of foam filling (closed or open mould) - type of mixhead guidance (manual or automatic)

From the moment the foam is cured, that is when the chemical process is terminated, the release of emissions is minimal in case of refrigerators, as they contain the foam inside a metal shell. With regards to emissions manufacturers also have to consider the case of the drums and tanks. A used drum that contained a blowing agent (most are heavier than air) once emptied will contain a considerable concentration.

Work-tanks and tanks that contain raw materials and/or blowing agents are pressurised vessels in the majority of cases and are subject to pressure equipment directive (PED). These tanks, every time they are empty, will contain a blowing agent combined with nitrogen in case of flammable blowing agents. From the moment the tanks are refilled the gas inside is displaced to the environment. This is a second main reason why in A2 countries raw materials are transported inside truck tanks – it allows the closed exchange of gas from the storage tank to the truck tank. The raw material supplier will then take care of the disposal of the gases, meaning a zero emission issue for the producer.

3.2.3 Machinery

When using cyclopentane in the production of domestic refrigerators the equipment requires a safety control by the TÜV or other certified organisation that follows the ATEX Directives with regards to safety. With the exception of the USA, 90% of the domestic refrigerators are produced with pentane. The background for this choice lies in the EU regulations, which in 2004 banned the use of HCFC-141b and therefore all the local, as well as international suppliers selected pentane as the most cost effective solution.

With regards to the equipment, emissions should be avoided through the use of special devices. The systems are made of valves and piping and contain work-tanks, pumps and measurement equipment. Specific measures should be taken where the equipment is in contact with the raw materials and the points where emissions can occur. These measures can be:

- Magnetic coupling on pumps and stirrers which lead to 0 emissions;
- Special couplings for the piping which are then considered emission free;
- Pressure transducers with membranes to avoid any emission through the device;
- Temperature sensors with encapsulated bulb;
- Inertisation of the work-tanks and closed fixtures with nitrogen.

These measures make the machinery emission-free and the focus is then on all the electrical parts that are in contact with the raw material, whereby this occurs on the polyol side as normally the isocyanate side does not contain a blowing agent. Should there be an option to also add blowing agent to the isocyanate side than the same is applicable as for polyol.

3.2.4 Safety measures on equipment

All the areas where emissions occur or where equipment is in contact with a flammable blowing agent are subject to ATEX, which determine the safety precautions to be taken. Additionally, there are areas of storage of the finished goods although in case of PUR they are less critical, as the blowing agent is contained inside foam.

Different ATEX zones require different safety measures that can be distinguished as follows:

1. Evacuation of emissions mainly through ventilation systems;
2. According to the zone the use of electrical equipment with the adequate electrical certification;
3. Use of gas sensors for surveillance and detection of flammable gases;
4. Grounding to avoid static electricity build-up (Very Important and in industrialised countries standard practice with or without the need of ATEX);
5. Precautions built in the machinery, mechanical and process technology (software).

The above-mentioned points have to be performed in all the areas where work with flammable blowing agents is carried out. Not only pentane but any blowing agent that has the indication F or F+ in its material safety data sheet (MSDS) belongs to flammable category. The flammability of blowing agents is also identified by a lower explosion limit (LEL) and upper explosion limit (UEL). The level of measures, i.e. number of gas sensors and the amount of ventilation depends on the safety analysis, which determines the emissions and associated risks.

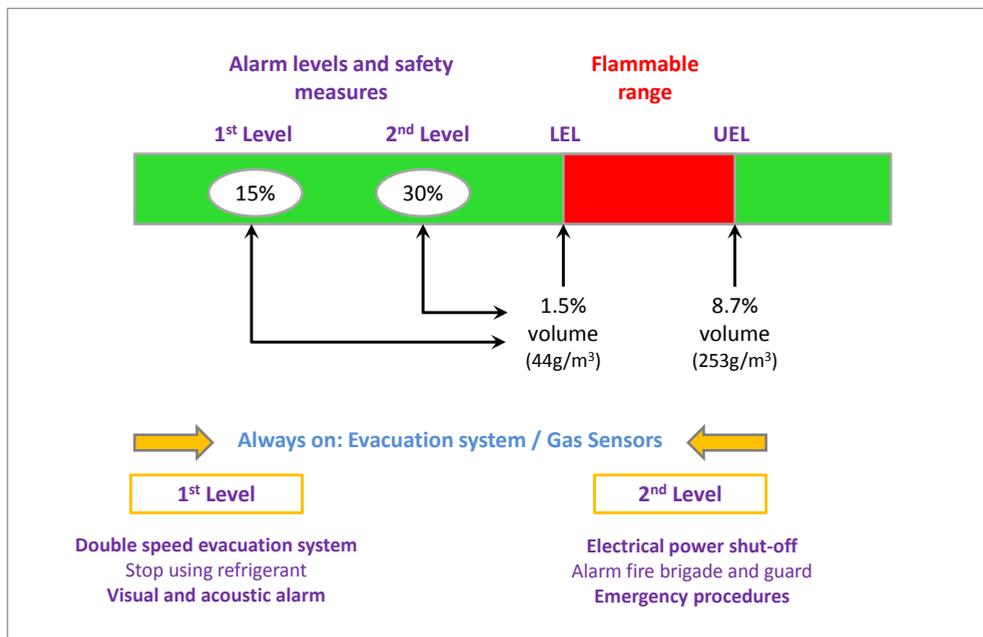
Without going into complicated explanations on the electrical equipment it can be stated that all the electrical equipment in contact with the blowing agents requires an ATEX certification. This can be achieved using Ex-rated certified electrical parts especially on the work-tank, Ex-rated electrical motors and low voltage sensors protected by electrical barriers. A supplier will need to specifically certify that the equipment is suitable for the use with flammable blowing agents.

The responsibility for the use of flammable blowing agents in the end lies in hands of the producer and not the equipment or raw material suppliers. Therefore any producer intending to switch to a flammable blowing agent is advised to verify with the local authorities the suitability of his intention. The major raw material suppliers are more than willing to support and provide assistance. The website of Isopa.org is highly recommended, with regards to the HSE requirement for the use of polyol and isocyanate, which are beneficial for the company and the workers.

3.2.5 Safety system concept

The concept of safety is best described according to Figure 5, whereby cyclopentane is taken as example (CAS nr. 287-92-3).

Figure 5: Safety system concept for foam production



For every flammable blowing agent the LEL and UEL indicate the lower and upper level explosion limits, respectively. This value is expressed in % by volume that can be translated to grams/cubic metre (g/m^3).

The preferable gas sensors are infrared sensors that detect the percentage of flammable agent in the atmosphere and provide a first level alarm at 15% of the LEL. The actions performed at this stage are:

- The evacuation system (ventilation) is set to double speed to evacuate the flammable agent;
- Foaming is stopped;
- Visual and acoustic alarms are on to warn the operators.

The scope of the first level alarm is to remove any flammable agent, should this not succeed then the 2nd level alarm is issued at 30% of the LEL. This alarm triggers:

- Complete electrical power shutoff of the production area to eliminate the main source of ignition;

- An alarm is issued to the fire brigade and guard house of the factory;
- Emergency procedures are triggered, which means evacuation of the area.

The levels of alarm and the gas sensor responsible for triggering the alarm are visible on a safety cabinet that is placed in a safe area. This allows for the safety personnel, fire brigades etc. to verify the status before entering into the area.

Note that a 30% alarm is seldom triggered and would mean that large quantities of flammable substance have been released. The ventilation system is designed in such a way that this situation is avoided. The placement of the gas sensors is therefore to be done by specialists who are able to analyse the area and paths a blowing agent could move to.

3.2.6 Activities and actions

For foaming, a complete cycle needs to be taken into account, from the delivery of the goods until the finished product, to properly understand the relevant activities. Foaming of refrigerators with cyclopentane as blowing agent consists of the following steps:

1. Unloading the chemicals
2. Storage of cyclopentane, polyol or the pre-mixed polyol/pentane and isocyanate in different drums, intermediate bulk containers (IBC) or tank storage
3. Pre-mixing of polyol with pentane
4. Receiving premix for foaming with high pressure equipment
5. Foaming process using the dry part (fixtures or presses in which the cabinets or doors are placed for foaming)

STEP 1

From the moment the raw materials arrive either in drums, IBCs or tank trucks a suitable place must be available for the unloading. This area is designed so as to collect any spillage for suitable disposal (should already be available). In case of flammable blowing agents specific grounding of a truck and protection against lightning need to be added. Additionally, the area should be marked indicating that an unloading is taking place and non-authorised personnel is not allowed to access. It is also required that sufficient fire extinguishers are in place, the relevant personnel wears appropriate clothing and goggles. Signs need to be placed indicating the emergency exits and relevant phone numbers for contacting the safety personnel.

STEP 2:

The material is unloaded and placed inside a storage area or, in case of truck tanks, discharged by means of pumps to tank storage. The storage area for the different raw materials should be physically separated so that in case of a calamity they cannot come into contact with each other. A flammable blowing agent needs to be placed in a room that is equipped with a ventilation system, gas sensors, as well as built according to ATEX Directives and according to the fire department requirements (sprinkler system with fire alarm).

STEP 3:

When polyol/pentane is not provided pre-mixed it needs to be mixed at the factory. For this purpose specific machinery is available that allows for the mixing of the two components in a closed system and feeding them directly to the foaming equipment. Preferably this mixing is done in a separate room with equipment certified for the purpose, as well as a ventilation system and gas sensors. The requirements for the room are the same as for STEP 2.

STEP 4:

The foaming equipment, classical high pressure foaming machine certified for the use according to ATEX Directives, will receive the premixed material and contain it inside the machine work tanks. This machine is placed in a room with the same requirements as described in STEPS 2 and 3. Ventilation and gas sensors are needed. Through metering units the polyol-pentane mixture and isocyanate are pumped to the mixing head, mixed and foam is made. The process of pouring the mixed liquid undergoes a pressure change from the mixing pressure of about 120-150 bar to ambient pressure. This pressure difference always leads to blowing agent being released into the environment, the so-called emission. Therefore, next to the mixing head ventilation and gas sensors are placed as precautions and as required for ATEX zones.

STEP 5:

Foaming is the process whereby the liquid coming out of the mixing head by means of a chemical exothermic reaction forms the foam. During this process the liquid, which has a density of about 1100kg/m³, expands to a density of about 37 to 40kg/m³, which is a normal value for the density of the foam inside a refrigerator. During the formation of the foam there is an additional release of blowing agent, as the agent moves through the cell structure that is under formation.

The mixing head is foaming either into an open mould, typically doors are made in presses which are closed after the foaming, or in a closed fixture for the manufacture of cabinets. For the open mould foaming of doors the situation is less delicate than

for cabinet foaming because of the release of a blowing agent that occurs in open air. With proper ventilation and placement of gas sensors this problem is solved.

With regards to cabinet foaming inside a closed fixture there is a need to make the environment inert with an inert gas (nitrogen) in order to avoid the creation of an explosive atmosphere. For an explosive atmosphere a fuel (the blowing agent), oxygen and a source of ignition are needed. With the use of nitrogen and proper grounding the creation of an atmosphere suitable to fuel combustion and the source of ignition are eliminated. Additionally, vent holes need to be taken care of, as these are present on, as well as, in the open mould after the foaming and the fixture. Through these vent holes blowing agent will be emitted and, by proper ventilation we can eliminate it.

For the cabinet fixtures and presses for the doors special attention is needed for the heating system, preferably using water/oil heating systems. In case of electrical heating, specific measures are required to avoid that the heating system is on during the foaming and curing time. This is to prevent static electricity or sparks being created by the latter.

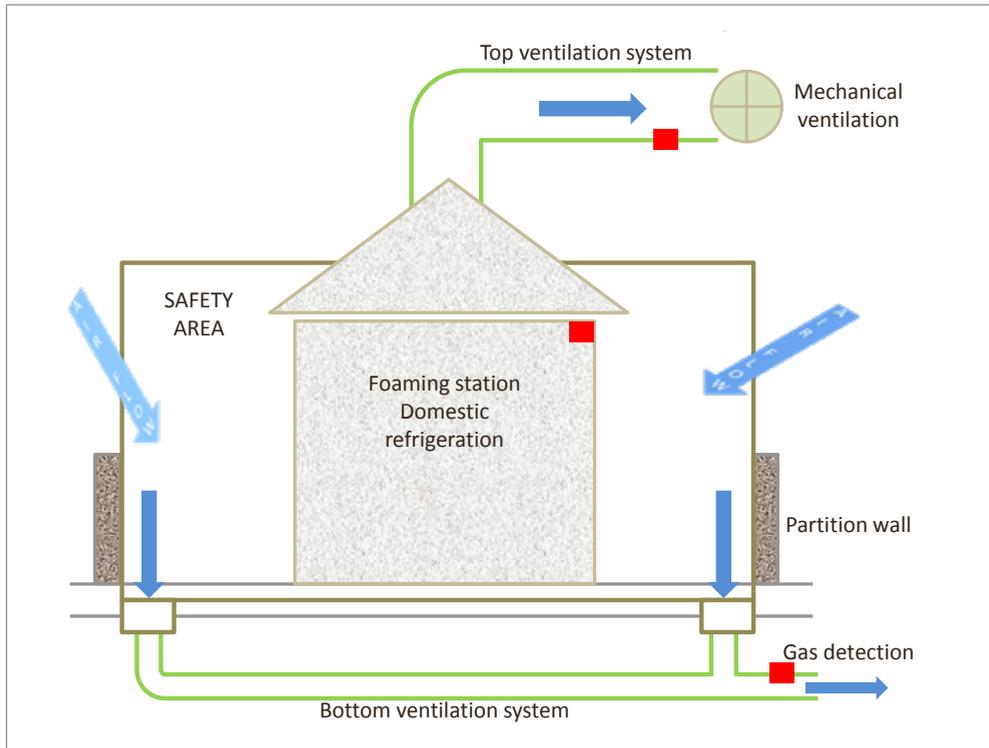
Once the curing process is finished the cabinets and doors are taken out and sent further on the production line for finishing. No specific precautions are required after this point with a good foaming machine, which assures that the polyol-pentane/isocyanate mixture that is used is correct. It is quite rare but in a safety analysis the case is verified that only polyol-pentane is exiting the mixing head.

Figure 6 illustrates a sketch of a pentane-based foaming station and the safety precautions that need to be placed in and around the station.

Around the foaming station a safety area is established by³³:

- placing marked signs and limiting the area by low-partition walls;
- placing exhaust channels that are installed in the ground through which air from the safety area is sucked off, thereby ensuring a good air flow rate that prevents potential formation of an explosive atmosphere;
- installing top ventilation system that ensures an air flow around the refrigerator units after the foaming process starts. It is necessary that good air flow is maintained around the unit, as shortly after the chemical foaming process ends a small amount of pentane gas escapes from the foam. The air flow guarantees that the atmosphere is not explosive even at the surface of the refrigerator. The ventilators of the ventilation systems are explosion-proof.

Figure 6: Sketch diagram of a pentane-based foaming stationⁱ



Overall, for a safe use of flammable blowing agents there is a need for:

1. Proper analysis of the risks
2. Training of personnel in the use
3. Certified equipment and preferably an independent safety review.

NOTE ON SAFETY:

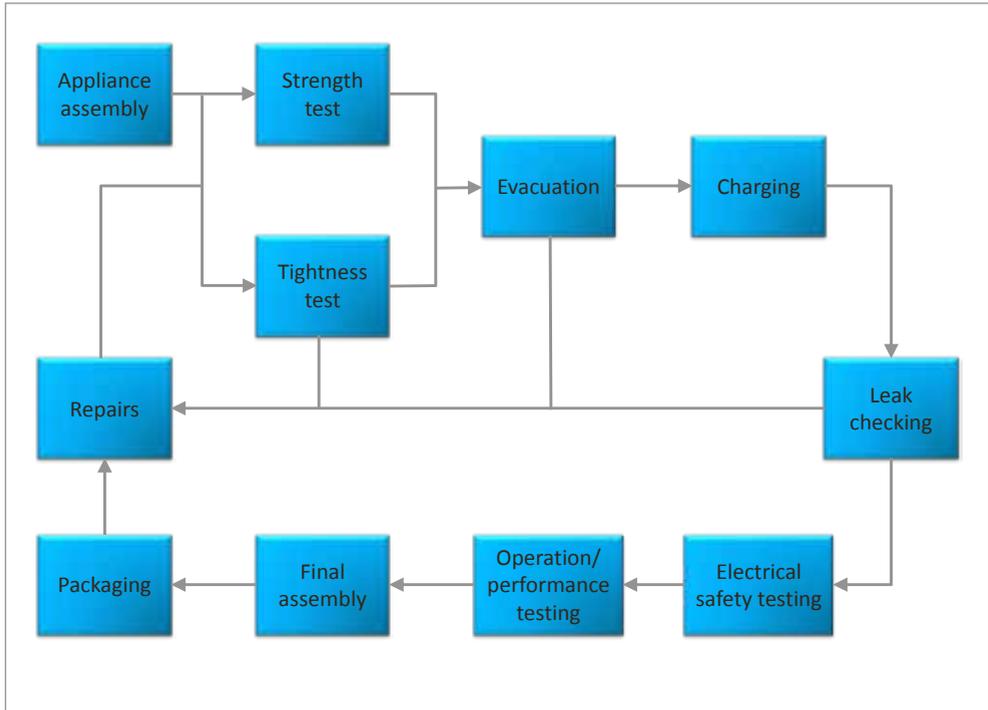
THE MOST IMPORTANT ASPECT FOR THE SAFETY IN THE FOAMING PROCESS IS TO PREVENT AN ATMOSPHERE THAT REACHES A LEL. THERE ARE DIFFERENT MEASURES THAT CAN BE PERFORMED, WHICH MAYBE DIFFERENT FOR INDIVIDUAL FOAMING PLANT. SAFETY REQUIREMENTS SHOULD THEREFORE BE IN STRICT ACCORDANCE WITH NATIONAL AND/OR INTERNATIONAL REGULATIONS AND STANDARDS.

ⁱ Adapted from UNEP, 1994

3.3 Production line

Introduction of new refrigerants and foam blowing agents also necessitates modification and replacement of major production equipment. It is not simply equipment procurement, but rather a complex engineering undertaking³⁷. Figure 7 illustrates a typical manufacturing process. Each of the areas requires attention and/or modification to accommodate safety and efficacy in the use of HCs.

Figure 7: Conceptual diagram illustrating a typical manufacturing processⁱⁱ



Refer to the GIZ Proklima publication “Guidelines for the Safe Use of Flammable Refrigerants in the Production of Room Air Conditioners. A handbook for engineers, technicians, trainers and policy-makers – For a climate-friendly cooling”, 2011 for additional information relating to safe arrangement of production areas using flammable refrigerants.

3.3.1 Refrigerant storage and feeding system

Small and medium-size refrigerator factories either have their HC supply in refrigerant cylinders, 1000 litre (465 kg) HC drums or 2000 litre bulk tanks. To avoid modification costs at a later stage it is recommended that the preferred supply

ii Adapted from Colbourne et al., 2010

option is chosen at the onset of the project prior to the initial construction works. The storage and feeding system should therefore be able to handle the applicable medium safely and in accordance with the safety rules.

The HC feeding system should be able to identify empty bottles or drums and switch over automatically to the full ones to avoid vapour and contaminants coming into the feeding line and thereby damaging the internal parts of the appliance refrigerant circuit. A system with at least three bottles, two drums or a single bulk tank (which is refilled before reaching 20% of the total liquid fill level) is preferred to avoid production halts and, where relevant, to compensate if the operator misses to exchange the bottle. The feeding place must be installed outside the factory hall (Figure 8). Also, to ensure against interruption to the production process it is recommended that a backup pump be installed.

Figure 8: HC storage shed



Hydrocarbon storage area construction:

Design data: The design and calculation of a natural ventilated room for bottle storage, a feeding system, and a second stage drums storage must be carried out by a qualified civil engineer taking into account the local ground. The construction is relevant to safety and hence must be robust in its make.

Construction characteristics: In most cases construction work can be done locally. The supervisor assistance for the conversion project must ensure that this is achieved with the following recommended construction characteristics:

- A lean concrete layer must be laid over the earth first. The surface of the lean should be smoothed and levelled;
- A 1 mm thick polyethylene film should be laid over the concrete lean as vapour barrier;
- The main concrete setting must be suitable for structural construction;
- The reinforcement bars inside the concrete must be connected to the earthing network. To that extent long steel threads will be pre-welded to the re-bars in at least two positions. The threads must protrude at least 50 mm outside the concrete so that copper cables can be easily connected on them using double nuts;
- The floor surface must be smoothed;
- Anchor bolts should be pre-embedded in the plinths for the subsequent installation of the storage roof, and if made with steel, walls for the feeding room. Brick wall can also be foreseen;
- For drum storage later on, a canopy is always suggested in order to reduce the surface temperature during summer season. The canopy can be made of structural steel with a minimum of 3 m height. This is enough to position, or to remove, 1000 litre drums on a rack using an elevator. The canopy should be at least 1 m longer, as well as wider than the drum storage. This canopy will not be closed on the sides in order to allow natural refreshing of the air;
- Metal structures, meshes and metal doors, pipes, bottles and drums and the HC feeding system must be connected to the local grounding system via a copper cable of more than 6 mm²
- The roof covering can be profiled metal sheet, polycarbonate sheet or roof tiles.

Isobutane bottle storage: The technical rules for gases, such as the German TRG 280, require that HC bottles have a safe storage, preferably with devices like secure chains to avoid the bottles falling down. For example, an enclosure with lockable doors, steel roof on concrete ground and the pathway to the storage in 1 kg/cm^2 load. The refrigerant storage area should have ample sign posts, such as zone marking, flammable gas, no smoking, no open fire and one 12 kg fire extinguisher.

Drum storage: This should be constructed such that up to three drums can be stored in open air, preferably with sun roof at least 3 m high and concrete ground of 1 kg/cm^2 load to enable the forklift to move drums from the delivery point to the storage place. At least 5 m around this should be the alarm zone with fence and preferably be able to close with closable gates. Appropriate warning signs must be marked. Inside this zone no open channels for drainage or service pipes openings for covered channels are allowed, except filling by sand.

Bulk tank storage: This should be located within an area of at least 5 m (typically specified by local regulations) covered with stones/chips, surrounded by a bund wall and a fence with access for authorised personnel only and a concrete access of 1 kg/cm^2 load. Beneath the bulk tank should be at least one gas detector feeding an alarm system. Appropriate warning signs must be marked. Inside this zone no open channels for drainage or service pipes openings for covered channels are allowed, except filling by sand.

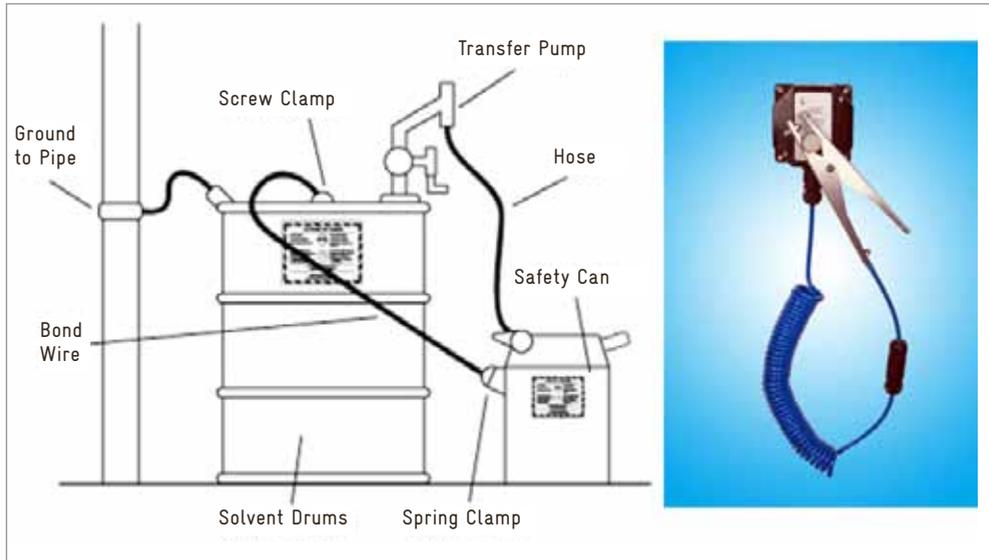
Roof or housing for HC feeding: A roof or natural ventilated house with wall opening on at least two sides made of non-flammable materials, such as bricks, concrete, steel or steel mesh walls closable by locks, could be used for the feeding pump system and the connected bottles. Outside this feeding place, with a minimum distance of 5 m or 3 m if the wall is made by a bricks, the bottles or drums can be stored or even connected to the feeding system.

Control room: This is an option. A lockable small control room with the control board of the feeding area should be made outside the 5 m hazard zone, or on the inside. Alternatively, if the feeding room is built to the walls of the production hall the control board could be placed inside the factory hall upon prolongations of pneumatic controls, tubes, etc., which would facilitate the work and the control of the feeding from the factory hall. It would also be more cost effective.

Secondary grounding circuit: HC drums, bottles, pipes and all steel parts inside the hazard zone of storage and of feeding area must be grounded. The grounding collectors must be connected to the grounding rods or tapes, for example galvanised carbon steel tapes of $25 \times 5 \text{ mm}$, 25 m long in ground or concrete (Figure 9). In addition, grounding copper cable 16 m^2 - for movable bottles and drums - with clamps should be arranged as follows:

- Outside the feeding pump room, 3 pcs. for drums
- Inside the feeding pump room, 3 pcs. for bottles, one for feeding pump and one for ½" pipe
- To all metal constructional parts inside the hazard zone.

Figure 9: Secondary grounding circuit



Typically, a secondary grounding circuit covering the HC storage area is made in accordance with the project drawing. The following are recommended:

- Several metallic rods are to be driven in the ground around the concrete area. The number of the ground rods will depend on the earth conditions. An overall earth resistance of not more than 2.0Ω is requested;
- The earth rods are typically copper plated steel rods; the length and number of these rods must be defined in accordance with the design requirements of 2.0Ω for the secondary grounding circuit;
- A small concrete pit should be built around the upper terminal of the ground rods for easy maintenance and inspection. This well should be filled with sand up to the cover;
- An equalising ring should connect all the ground rods. It should be made of steel bar of at least 25 mm^2 , or copper rope of at least 50 mm^2 ;

- The reinforcement bars inside the concrete will have to be connected to the earth ring. It is necessary to connect at least two points. Threaded rods are pre-welded on to the re-bars prior to the placement of concrete. The thread end must protrude at least 50 mm out of the concrete for easy connection;
- The steel in the storage area must be connected to the grounding ring;
- The pumping facilities installed must be connected to the earth ring. A copper bar should be used to distribute the sub-earth cables to the facilities;
- Earthing cables should go through the concrete through the polyvinyl chloride (PVC) pipes. The cables must not be embedded directly in the concrete;
- An inspection report in the local language, relevant to the installation of the secondary grounding circuit, the construction characteristics, storage areas, etc. must be prepared and signed by all parties present on site.

Lightning protection system: The HC storage area, feeding system and pipelines must be protected against lightning. In particular, its protection cone must cover even the safety valves vent pipe and the HC exhaust ventilation ducts. If this system is installed, it has to be tested by a skilled electrical engineer and certified, in accordance with the local standards. If brand-new, it should be designed, installed and certified. Connection to the grounding system must be guaranteed, with accessibility for inspection by the certification body.

Lighting: Proper lighting is required in the HC storage and feeding areas for maintenance work at night. It should be IP54, if located outside a radius of 4 m or more than 0.5 m height, in every direction from the emission parts (flanges, pump, bottle connectors, safety valve exhausts etc.). If not, it must be explosion-proof in accordance with the local standards.

Fire protection: For outdoor HC storage a water fire extinguisher is recommended to be installed at 8-15 m distance, and if possible, behind a wall or corner of building, to be connected to the cold water mains with sufficient pressure. There should be housing for the hose, or a bigger fire extinguisher on carriage, especially if the water pressure is not sufficient. The type of fire extinguisher and its place and conditions should be discussed with the local fire brigade. Other, more accessible fire extinguishers should be placed on the shed wall, as depicted in Figure 10.

Figure 10: Fire protection for outdoor HC storage



SAFETY:

REFRIGERANT STORAGE AREA SHOULD BE A ZONED AREA ACCORDING TO HAZARDOUS AREA GUIDELINES AND THE ASSOCIATED APPLICABLE RULES SHOULD BE CONFORMED TO. THE AREA SHOULD BE MARKED WITH CLEAR SIGN POSTS

Hydrocarbon feeding system:

In order to transfer the refrigerant from the tanks or cylinders to the charging area, special equipment is required, such as a transfer pump but may also include changeover valves (in the case of two or more cylinders or tanks), pressure regulating valves, pressure relief valves, shut-off valves and pressure gauges. Normally such equipment is housed in a special pump room, which is also classified as a hazardous area (Figure 11). This area should be equipped with appropriate safety features as indicated in Table 2. Additional requirements may be necessary, as dictated by equipment suppliers and national regulations.

Figure 11: HC feeding system



Automatic switch-over: An automatic switch over system on the HC supply is quality relevant. It not only enables continuous refrigerant supply from bottles or drums without any production interruption but is also important in preventing damages like partially-filled refrigerators that must be repaired, or atmospheric contaminants inside the feeding line, which can damage the refrigerant circuit of the appliances. Furthermore, 2-3 hours of production interruption can be avoided for purging of the feeding line. The feeding with automatic switch-over system must be suitable for the specific type of HC in use (R600a, R290, etc.) and must be approved by an authorised body.

A system for three bottles is recommended. This is to avoid line stoppages even if a worker forgets to replace the last emptied bottle, or by accident places an empty bottle. Instead of bottles, drums could be connected. Of relevance is a stabilised pressure on the feeding line fixable between 10 to 15 bar, with 0.1 bar tolerance that is not influenced by varying HC charges on different charging lines. If using feed pump, such as a pneumatic pump, they generally need a minimum pressure at the inlet, depending on the local environmental conditions, such as air temperature, relative humidity, elevation, etc., then there must be devices to elevate heavy bottles on the needed level to feed such a pump in liquid. The important characteristics that must be in order include:

- Open air natural ventilated feeding place
- 5 m hazard zone enclosed by a fence, reducible by brick walls
- Fire detector
- Emergency switch button

Flexible hoses: The feeding system must include three flexible hoses for three bottles with following characteristics:

- The hose material must be suitable for the hydrocarbon in use. For example, anti-static rubber hose with internal or external spiral steel reinforcement that must have good contact with the connectors at both ends, with conductivity lower than 106Ω between the mounting hoses;
- The length of the hose will depend on the distance between the bottles and the rigid pipes to the feeding pump with switch-over system;
- The ends must be spark-free, that is not steel, with self closing to prevent air coming into the hydrocarbon feeding system;
- The hose must be suitable for the maximum and minimum temperature of the locality and made for operation in pressures up to 25 bar (or according to the refrigerant and the local maximum temperature);
- The flexible pipes shall have the following markings: manufacturer name, type, production year, maximum working pressure and conductivity value.

Hoses from drums: If drums are used later on instead of bottles the used hoses must have the same specification as mentioned for bottles but with ½". The recommended distance between the feeding station and the refrigerant drums should be 5 m, reducible by brick walls. These distances should not be taken by flexible hose but by a ½" steel pipe made according to the ASTM International specifications, with conformity approval of manufacturers. As these three pipes and hose sections are closable on both sides, certified safety valves of up to 25 bar (or according to the refrigerant and the local maximum temperature) are needed. To prevent fire passing through the tubes it is highly recommended to add adequate and certified flame arrestors into the tubes. The hoses should be at least 2m long. If the feeding pump needs minimum pre-pressure, the drums must be placed at a height of 1m.

Feed from bulk tanks: The feed lines from bulk tanks should not include flexible hoses but steel piping directly to the pump station.

Quick couplers in system assembly: These are connected from tube to refrigerant hose (Figure 12). The working pressure for these is from 13 mbar to 45 bar.

Figure 12: Quick couplers and their use in system assembly¹⁶

Quick Coupler „Hansen“	Use of quick couplers in system assembling
	
<p>(1) Assembly of quick coupler from tube to refrigerant hose</p>	<p>During brazing, prevent intentional leaks and provide a hermetic system (refrigerant cycle) without screwed connective service ports</p>
	
<p>(2) Clamps directly on straight tubes with diameter 2-10 mm</p>	<p>Connection of quick coupler and refrigerants cycle</p>
	
<p>(3) Same as (2), but for screwing</p>	

SAFETY:

A DRUM SHOULD NEVER BE CONNECTED IN PARALLEL TO A CYLINDER ON THE SAME SYSTEM. IN CASE OF AN INTERCONNECTION ONE CAN BE OVERFILLED, LEADING TO A DANGER OF EXPLOSION IF HEATED OR EXPOSED TO THE SUN

Feed pipeline: The pipework will transfer refrigerant from the refrigerant pump to the charging machines. This should be well designed and sufficiently robust so as to avoid leakage. A steel pipeline is recommended that should be made in accordance with the factory layout and with the required pressure for the HC in use. The pipe specification will vary and must have conformity approval of manufacturers for tubes and fittings. Correctly welded pipeline joints are recommended, except for valves and instrumentation that need to be maintained. The pipeline must have leak tight joints, like flanges with sealing in metal armed non-stick coating, such as polytetrafluoroethylene (PTFE) or SAE with viton or other sealing that is resistant

against pentane and applied pressure, or other technically tight joints, such as conical threads (NPT), double edge cut rings (ISO 8434-1), Whitworth threads according to ISO/DIN 228 or some American high pressure hydraulic joints, which will be controlled by safety auditor.

The HC pipe above ground must be painted with two coats of Epoxy-Tar, each with a minimum of 200µm, total 400µm in colour yellow (RAL1026 or equivalent). This should be as per vendor specification for the roof structures, if made, and must be submitted with the offer for comments. Fire safe shutdown valves at building entry and a standard shut down valve at the end of the rigid pipeline at the hydrocarbon charging place must be installed.

Above or below ground pipeline routing: The entire routing of the pipework must be away from any sources of ignition, and must not pass through areas where a leak could result in a build-up of refrigerant. It should also be protected against mechanical damage and impacts; this typically applies to pipe work close to the ground level in the working areas. Flammable gas warning signs must be applied at regular intervals throughout the length of the piping installation. The entire piping system must be subject to a tightness test and strength test, and throughout its lifetime, subject to regular inspections and leak checking.

SAFETY:

THE PIPE WORK MAY BE FITTED WITH PRESSURE SENSORS TO WARN AGAINST AN INCREASE IN INTERNAL PRESSURE OR A RAPID LOSS IN SYSTEM PRESSURE. A PRESSURE RELIEF DEVICE SHOULD BE FITTED WHERE NECESSARY AND VENTED TO THE OUTSIDE IN CASE OF EXCESS PRESSURE BUILD-UP

Electric grounding: HC pipelines must get an electric grounding, for example every 25 m.

Electric power supply: This is typically specified by the supplier of pump and switch-over system.

Cables and cable channels: These should be installed in all relevant areas, for example in the storage area between the storage control panel and the feeding room, emergency switch, fire detector and gas sensor; between storage control panel and alarm signal lamps and horn, and between storage control panel and alarm board of a HC-charging area.

Pneumatic hoses: These are necessary for connections of machines if the control panel is made inside the factory hall.

Refrigerant fluid transfer pump: The refrigerant transfer pump is connected between the refrigerant tank and the charging unit to keep the refrigerant in the liquid phase and at the correct pressure for optimal speed and accuracy of the charging station. Many transfer pumps use two pistons with different diameters. The smaller one (refrigerant piston) is used to pressurise the refrigerant from the vapour state to a liquid via the larger air-driven piston that can boost the pressure within the pump. The pressure is adjustable to accommodate various refrigerants. An on-board accumulator on the outlet side of the transfer pump, pre-charged with nitrogen, stabilises the pressure when the piston changes direction. On the inlet side of the pump a refrigerant filter eliminates any impurities from the storage tank. It must be ensured that the transfer pump complies fully with the applicable regulations and standards.

HC distribution system: The HC distribution system is defined as the part of the installation between the refrigerant storage tanks and the charging machine. The distribution system should be designed and installed such that it increases the safety of the whole HC line, whereby it is integrated with the charging machine and the supervising safety control unit.

Typically the safety control system comprises the following:

- Pneumatic control valves that work on changes in air pressure and operated manually by the operator, or by the charging machine, or by the over-riding safety control unit (automatic mode);
- Manual control valves;
- Safety valves calibrated to 30 bar;
- Refrigerant fluid filters with filtering capacity of 20µm. There is a manual valve to drain the filter during maintenance operations;
- Pressure gauge to verify the inlet pressure of the refrigerant, which can be bypassed through a manual valve; and
- Semi-flexible connecting tubes to the transfer pumps.

All equipment must be ensured to conform to national regulations and national or international standards. Corresponding spare parts that are recommended for storage and feeding system to avoid unnecessary production stops include:

- Refrigerant filter cartridge
- Filter for charging machine
- Maintenance kit for refrigerant cylinder
- Maintenance kit for air piston

Table 2 Safety features for bulk tanks, cylinder enclosures and pump rooms¹⁷

Safety features	Bulk tanks	Cylinder cages	Cylinder rooms	Pump rooms
A minimum safe distance between the room/cylinders/vessel and surrounding occupancies [†]	X	X	X	X
The surrounding area is fenced and locked and restricted for authorised personnel only	X	X	X	X
Warning signs on entrance		X		
A bund wall to contain any accidental spill	X	X	X	X
Easy access for both deliveries and fire/emergency services	X	X	X	X
A gas detection system and associated alarms	X	X	X	X
Emergency stop buttons	X	X	X	X
Vessels must have pressure relief devices	X	X	X	X
Liquid level indication on the vessel	X			
Warning signs, flammable gas/hazardous area signage on vessel and surrounding area	X	X	X	X
No potential sources of ignition within the area	X	X	X	X
No combustible materials in the immediate area	X	X	X	X
Above-ground and below-ground pipe work is protected against accidental damage and corrosion	X	X	X	X
Use an excess-flow valve on the vessel outlet	X			
No drains or sunken areas	X	X	X	X
Ventilation gaps to the outside			X	X
Ventilation duct system			X	X
Explosion relief			X	X
Fire extinguisher			X	X
Sprinkler system			X	X
Anti-static flooring			X	X

[†] This distance is sometimes in the region of 3–5 m, but it depends very much on the local rules and the conditions associated with the installation.

3.3.2 Refrigerant charging lines

Leakages can occur (such as in case of hoses blasting, unforeseen breaking of pressure transducers, wearing of valves, vibration to joints) that lead to a build up of an explosive atmosphere. A system working with dosing cylinders closed on both sides by valves limit the maximum release of HC in the charging area to smaller quantities, such as 100-300 g, depending on the machine configuration. This approach of limiting the quantity of released refrigerant is recommended, rather than solely relying on other parameters, such as the expected behaviour of operators to keep exhaust doors closed at all times, fail-free maintenance work, gas sensors, double ventilation systems, or on electric power supply. In particular, gas sensors can react slowly and therefore cannot guarantee to initiate the failure alarm. Emergency power generators often fail when needed. A passively safe system not depending much on fail-free work and equipment are strongly recommended, especially in places where there is a danger of constant and unexpected power failures. Also, the shutdown valve at the end of the rigid pipeline inside the factory and at entry to factory hall must close the tube hermetically in case of emergency and during stand-by.

The technical demand on charging machines depends on the accuracies in the charging amount needed on the model with the smallest charge.

Depending on the HC being used, charging machines with the following characteristics are recommended:

- Only HC charging machines with approval from a reputable certification body are acceptable, where the machine details and test reports must be checked and verified;
- All parts of the charging machine that contain HC gas must be enclosed inside machine housing. The HC feeding hose between the rigid end of the HC pipe and the charging machine must be double hosed. Quick couplers like Hansen can be used to connect flexible feeding hose to the rigid HC pipe, which are not considered to be technically tight and therefore could fail. The HC filters in the feeding line can leak during maintenance work and therefore must be enclosed by a small box. So the charging machine inner housing of HC parts, double hose of the feeding hose, small box of Hansen and filters must be connected to the exhaust ventilation;
- In case of any big leaks, such as from a split hose or breakdown of equipment, it must be ensured that all shut-down valves are closed automatically within 0.5 seconds. This action must be independent of any gas sensor signal, which could be too slow to prevent the formation of a large explosive atmosphere;

- Dosing by volume measurement is recommended in order to reduce the quantities of HC remaining in the section valves and thereby becoming a risk in case of leaks;
- Internal leak control (watch dog) on dosing system, filling hose and filling gun must be independent of the installed gas sensor on each charging position. If the level of leak is already a risk, the machine must stop and the shutdown valve at the end of the rigid pipe of the feeding line must automatically be closed;
- Accuracy of the charge must be ± 0.5 g for less than 100 g charge. The local temperature and pressure ranges should be taken into account to compensate for the fluctuations;
- Computer interface and barcode reader is highly recommended. The charging machines are part of a quality control system. A bar code reader and a serial port interface are needed in order to provide serial number and model of the refrigerator and to achieve the vacuum level and HC charge. All the machine intern communication software and description of the data set must be granted to the interface for quality recording and evaluation;
- It is recommended that the charging speed including all connect/disconnect handling time is 30s;
- The charging board and all metals in the charging area must be earthed. Any plastics, hoses etc. must not be charged with static electricity ($\leq 106\Omega$ electric surface resistance).

SAFETY:

- ONLY CHARGING MACHINES INTENDED FOR USE WITH FLAMMABLE REFRIGERANTS SHOULD BE EMPLOYED
- CHARGING MACHINES SHOULD INCLUDE A GAS DETECTOR IN ALL CASES TO INITIATE INTERNAL EXHAUST VENTILLATION IN CASE OF INADVERTANT RELEASE
- CHARGING SHOULD BE CARRIED OUT USING PROPER CONNECTOR TO MINIMISE REFRIGERANT RELEASED UPON DISCONNECTION

3.3.3 Leak tightness lines

Leak detection: Ensuring that systems are tight is essential for all refrigeration systems, including those which use hydrocarbons. Therefore before charging the system with refrigerant, a tightness test should be carried out. In the event that the system is

tight, then charging can proceed, although after charging is complete, a further check should be carried out and again after the appliance has been packaged. In the event that a leak has been detected, further methods, such as using a leak detection fluid can be used within the repair area to identify the exact location of the hole. Figure 13 shows an example of leak detection spray used for identification of leaks in refrigeration systems.

Figure 13: A non-corrosive, high viscosity and non-freezing leak detector spray¹⁶



For the initial tightness test it is usual to apply nitrogen or preferably nitrogen/helium to pressurise the system. Detection of small concentrations of nitrogen is not possible (within an air environment) so nitrogen-only tightness testing can only be used for identifying a fall in system pressure. Conversely, helium can be detected at very low concentrations and therefore a nitrogen/helium mix (typically in a proportion of 95% / 5%, respectively) is the preferred method. However, helium is expensive and it is therefore preferable to recover it after use so as to limit the cost. A leak detection line should comprise:

- A nitrogen/helium charging machine
- A helium gas detector
- A nitrogen/helium recovery machine

Whether two leak detection lines are needed will depend on the selected supplier. In one case all three machines are needed for a second time, while another supplier can

use helium recovery machine for 3-4 lines, using some recovery stations on each line to connect it with the refrigeration system. The latter is cheaper.

Major refrigerator producers use helium charging machine for several quality relevant processes and tests, like control of brazing joints by pressurisation, drying of circuit by nitrogen or dry air and humidity test and testing of capillary tube functioning. At least one supplier has all this functionality within standard machines whilst others may supply it as options. These quality control features are essential for HC appliance production and should be included in the machine configuration.

There are two line configurations: in one the helium charging machine remains connected to the appliance during leak detection and, after helium testing of all joints, recovers the helium out of the system. In the other configuration a small separate pump station for helium recovery is added, so that after helium charge the system is disconnected from the charging board, now free for the next appliance. In this case an expensive helium line gains a double capacity, therefore such a solution is strongly recommended under cost-benefit ratio.

Helium line specification: Two pieces of helium charging machines are recommended, with separate station for helium recovery, either per line or what is generally preferred, centralised. The types and models of these will depend on the supplier. The following options can be included:

- Nitrogen pressure test and trying
- Humidity test
- Capillary tube test by pressure drop
- Pneumatic Hansen couplers
- Computer interface and barcode reader, as the charging machine will be part of quality control system
- A year's spare part package is recommended

Helium pipeline: Different suppliers have different requirements for their lines, therefore welded helium pipeline, both for charge and HC recovery must be according to the specifications fixed by the selected supplier. Normally ½" welded pipe is used for compressed air or nitrogen. Each pipe end gets manual ball valves of ½", as for example used for butane/propane gas pipes, and reducers to fix a fitting in order to connect to a flexible tube joint, all in the leak tight version to avoid loss of costly helium. The layout of the pipeline must be realised according to the customer's drawing. Figure 14 shows an on-site test and recovery for helium.

Figure 14: On-site infrastructure for helium test and recovery



3.3.4 Repair lines

If an already charged appliance needs to be repaired, the HC refrigerant should be removed safely and completely to enable correct recharging. If the HC refrigerant is simply released from the circuit some remains dissolved in the compressor oil, which leads to the wrong recharge amount. This means that the repaired model could have sub-optimal performance and its lifetime could be compromised. Furthermore, there is a high risk of ignition during evacuation.

For these reasons, HC refrigerator manufacturers often threw away the new compressor of appliances which were already charged with a HC refrigerant if their cooling circuit needed to be repaired because of a leak, circuit blockage or faulty evaporator or condenser. To tackle this problem and to avoid throwing away expensive new compressors, special HC discharge pump systems were developed.

Extreme care and caution must be taken when re-evacuating a system charged with an HC refrigerant using a standard vacuum rotary vane pumps, as a very small chance exists that the pump could act as a source of ignition. A pump without failure will not spark but if there is a fault, such as metal scratch or electrical discharge at lower oil level, and if at the time of evacuation there is HC refrigerant present at a flammable concentration, it can ignite. Despite the low risk, prevention measures

have to be taken. Standards for hazardous atmospheres require that the evacuation of systems that are filled with HC, be carried out with Ex-rated pumps. Ex-rated pumps are specially designed such that they do not act as a source of ignition.

A number of solutions can be employed to re-evacuate. These include:

1. Use of Ex-rated pumps, such as Oerlikon-Leybold special ex-rated pumps Trivac D 16 B-Ex with flame resistors ProtegoDR/SV20 and RV/S25 on suction and on the discharge;
2. Standard pump in a strong steel enclosure or behind a concrete wall. For example, pneumatic Venturi pump with timer that allows to pass first the explosion vacuum area and to continue with standard evacuation pump. It needs more work time and if incorrectly made the risk of ignition remains. The discharge of the pump must be piped to the open air, although preferably fed to the roof with 2-3 m Ex-Zone 2 around exhaust pipe. However, the main problem is that it takes a lot of time to remove the refrigerant by evacuation out of the compressor oil. Despite this an amount always remains, in the range of 5-10% of the mass of the original charge, if only evacuation is applied. It is important to know the residual amount since appliances are normally critically charged and over- or under-charging by 1-2% or more can affect the performance. Thus, it is important to know how much refrigerant remains in which model and under which conditions. In laboratory tests such remaining quantities can be determined but it creates difficulties in terms of giving clear work instructions to the staff in the repair lines and for service. Therefore, this is not a very practical way for appliance manufacturing and hence is not recommended.

In the past the problem was solved by compressor run during evacuation so that the remaining HC refrigerant was squeezed out. But this is forbidden by compressor manufacturers, who in this case, remove their guarantee because in the vacuum level of 10-90mbar the ionisation is so high by starting the coil of synchronic motor that the compressor coil insulation can be destroyed and the compressor can break after a short time in use (therefore a case of loss of guarantee).

3. Using a compressor from an already charged model;
4. Using an automatic discharge system, which can automatically perform the evacuation procedure of flammable refrigerants, including those mixed with oil.

The refrigeration circuits designed to be used with HCs such as R600a or R290 normally use a compressor charged with mineral oil or polyol ester (POE).

3.3.5 Strength test lines

Pressure test: There are machines especially designed for testing systems for strength, as well as leak tightness. For example, common models will evacuate the unit under test and pressurise it with helium or hydrogen-air mix and/or nitrogen (dry air). Two connections to the system allow both a quicker charging. The humidity of the gas should also be checked in order to avoid the presence of moisture inside the system. Most machines enable the user to decide and programme not only the parameters for each phase but also the phase sequence and their eventual repetition.

An RS 232 C serial interface is useful, as it can enable the automatic selection of the working cycle by using a bar code reader, as well as sending the process data to a printer and PC. With an electrical cable it is possible to connect an external leak detector, which displays the leak condition.

A special gas humidity kit allows for installation on the unit a helium leak detector and a solenoid valve group equipped with eight sniffer pliers. The pliers are connected by the operator at different points of the circuit to be tested. Unit may perform tests automatically on all the points connected to the circuit indicating the pliers where eventually the leak occurs. After the tests the helium can be exhausted or recovered by using an external helium recovery system.

Tightness test – helium and refrigerant gas detector: Whilst the refrigeration circuits are charged with helium, the production staff must manually sweep the circuit, paying special attention to the joints and other vulnerable locations, in order to detect a release of helium through leak holes. A special helium detector is used for this purpose.

A gas detector that is specifically designed for full time gas detection applications in demanding production environments should be used. Important features of the detector should include:

- Improved system design that compensates for operator error, reducing the potential for missed leaks;
- Multiple alarm functions on the system to make sure that alarms are not overlooked;
- Built-in reference leak allows for easy and fast calibration to the production line at any time;
- A small display in the probe handle shows the leak rate so that the operator can concentrate on the sniffing process and monitor the leak rate at the same time;

- Operator guiding mode to assist the operator in testing the right locations with the correct technique;
- Leak rates displayed in refrigerant equivalents from a gas library;
- Built-in illumination source of the probe helps to position precisely the sniffer tip;
- Low-maintenance type sensors;
- Automatic standby to prevent intake of contaminants into the sniffer probe, thus saving filter and sensor life.

After the initial check with helium, the system is filled with refrigerant at the refrigerant charging station. A refrigerant leak tightness check is carried out in order to determine that no refrigerant is being lost from the charged circuit. A highly sensitive HC gas detector can be used to manually sweep the circuit, paying special attention to the joints and other vulnerable locations, in order to detect a release of refrigerant.

Given that in the production area background gases, such as foaming agents may be present, it is preferable to select a gas detector that can essentially ignore these other substances thereby eliminating false alarms.

Important features a refrigerant gas detector should include:

- Built-in reference leak to enable easy and fast calibration at the production line at any time
- Ability to operate via the probe display and probe buttons without access to the main unit

Spare parts are recommended for the pressure and tightness test to avoid unnecessary production halts.

3.3.6 Evacuation lines

The evacuation process must be restructured according to the HC being used to eliminate non-condensable gases. The existing vacuum pumps must be checked for anti-suck device and should not be used in the production to ensure quality of the refrigeration system. The vacuum time must be prolonged as required. The following equipment in the vacuum area is needed to fill the refrigerators with the HC refrigerant:

- Two-stage rotary vane vacuum pump with anti-suck back device, condensate separator, oil mist filter, hoses with crosses, etc. The pump flow rate and pressure must be checked;
- Vacuum pump oil with low vapour pressure;
- Electronic vacuum gauges;
- Spare oil mist filter inserts and vacuum pump sealing sets.

Need for pump carousels must be assessed and constructed accordingly as per the layout of the factory. Figure 15 illustrates an on-site evacuation line.

Figure 15: On-site evacuation line



Vacuum pump (Figure 16) features a special anti-suck back device that isolates the vacuum systems when the pump is stopped. The vacuum level is kept constant during the stoppage whereby the anti-suck back device prevents any contamination of the product under process. The temperature is kept constant in every section of the pumps through a streamlined forced ventilation system. The constant temperatures help extend gasket and oil life with resulting higher performances and reduced maintenance and downtime costs. The pumps also feature forced lubrication to reduce maintenance downtime.

A vacuum gauge (Figure 16) measures total pressure in the medium and low vacuum range from 100 to 1000 mbar. A backlit LCD display, with analogue and digital readout, will show the measured pressure. Three different measurement units can be selected using the standard small touch panel located on the front of the panel. Some devices also operate as a pressure test system by means of three relays – each with N.O. or N.C. contacts – that can be used to activate remote applications, such as a vacuum valve or an alarm device. HIGH and LOW relays may be activated when the

relevant set-points are been reached, either during the rising (HIGH) or descending (LOW) phase. The two set-points would be defined by the operator and will be shown on the display. Two LEDs, red and green, on the front panel are activated when the relevant relay (HIGH or LOW) is energised.

Figure 16: Example of vacuum pump and gauge display³⁸



The pumps described are of highly flexible pumping groups that can be configured according to the manufacturer's requirement either for fixed installation or for mobile carousels, and can be fitted in the evacuation assembly (Figure 17). The evacuation assembly should be designed to meet the requirements of pre-evacuation and drying phase for refrigerant units in the production line. A typical working cycle when connected to the refrigerant unit lasts until the circuit is perfectly dry. At the end of the vacuum phase the vacuum gauge would display the level of vacuum that has been reached; if this is better than the programme set-point, a good vacuum condition would be indicated.

An appropriate evacuation assembly would enable the functions to be controlled by a microprocessor that provides online operations, parameter settings and diagnostics. The assembly should perform leak detection with the pressure rise method using a Pirani device as pressure sensor and equipped with solenoid valves for gas ballast operations and fitted with various additional accessories, allowing the user to obtain a product with every feature that is required on the production line.

Figure 17: Pumping system in the evacuation area



The recommended spare parts for vacuum pumps include:

- Oil mist filter plastic type
- Vacuum pump seal gasket kit for DN18
- 5 litre mineral oil SH200
- Pirani gauge OG919 female Hansen

3.3.7 Sealing of charged systems

Sealing of HC refrigerators require high accuracy on the sealing materials, joint construction, brazing work and good control on leak detection. Correctly closing the refrigerant circuit is a very important aspect of the appliance quality control. Leaks, especially those not detected during manufacturing, can cause high repair costs in the factory, as well as after sales, leading to a loss in reputation. Due to leak control problems on filling tube sealing, a safe and highly reliable sealing of this tubes after HC charge is strongly recommended. There are three options:

- Crimp and braze
- Lok-ring
- Ultrasonic welding

Crimp and braze method:

The procedure is carried out in the assembly line area where HC is not present.

Brazing (Figure 18) is a metal-joining process whereby a filler metal is heated to high temperature ($> 450^{\circ}\text{C}$ but less than 700°C) and distributed between two or more close-fitting parts by capillary action. The filler metal is brought slightly above its melting temperature while protected by a suitable atmosphere, usually a flux, which then flows over the base metal (known as wetting) and is cooled to join the work pieces together. The selection of a filler metal or brazing alloy will depend on the material of the joints, for example whether working on copper-copper, steel-steel or copper-steel tube joints.

Crimped or pressed connections use special copper fittings that are permanently attached to the rigid copper tubing with a powered crimper. The special fittings, manufactured with sealant already inside, slide over the tubing to be connected. A very high pressure is used to deform the fitting and compress the sealant against the inner copper tubing, creating a gas-tight seal.

The advantages of this method are that it should last as long as the tubing, it takes less time to complete than other methods, it is cleaner in both appearance and the materials used to make the connection, and no open flame is used during the connection process. The disadvantages are that the fittings used are harder to find and cost significantly more than sweat type fittings.

Figure 18: Sealing by brazing¹⁶



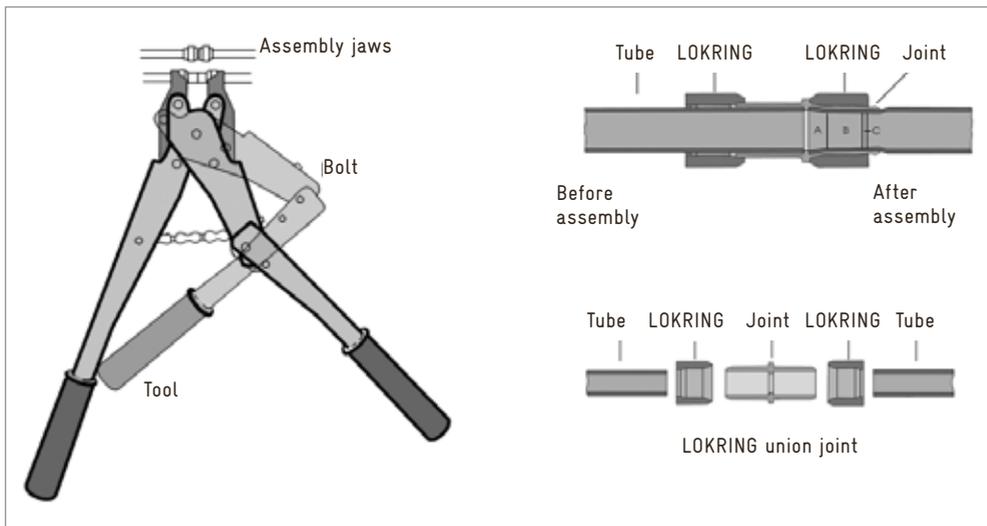
Once the end has been crimped, it should be brazed to seal it permanently. To obtain a high brazing quality, the following factors should be taken into account:

- a) Joints should be free of oil and grease;
- b) Under atmospheric pressure a gap between 0.05 and 0.2 mm should be maintained. It is also important that the person in charge of flux application, as well as the welder should keep the gap visually under control to ensure that the filler material can enter;
- c) Choice of flux and filler brazing alloys that would depend on the joints to be brazed;
- d) The development of correct heat pattern in order to first ensure that all parts of the joint obtain a temperature that is at least equal to the work temperature of the chosen filler alloy, and second to ensure that the location of the filler material to be melted is the last place of joint to achieve brazing temperature;
- e) If possible reworks of joints should be avoided.

Lok-ring method:

Where brazing is not preferred, Lok-ring method can be a very durable and reliable option for tube joining and making system access connections. It requires the use of special hand tools (Figure 19) and associated components (typically from 1.6 mm to 35 mm nominal outer diameter), and is therefore applicable to most domestic and small commercial refrigeration and air conditioning systems. Many different fittings are available, including adapters, elbows, tees, reducers, valves and filter-driers.

Figure 19: Tools required for sealing by Lok-ring method³⁹



Ultrasonic welding method:

This takes place in the charging and sealing area, which is designated an Ex-Zone area, directly after charging of the units.

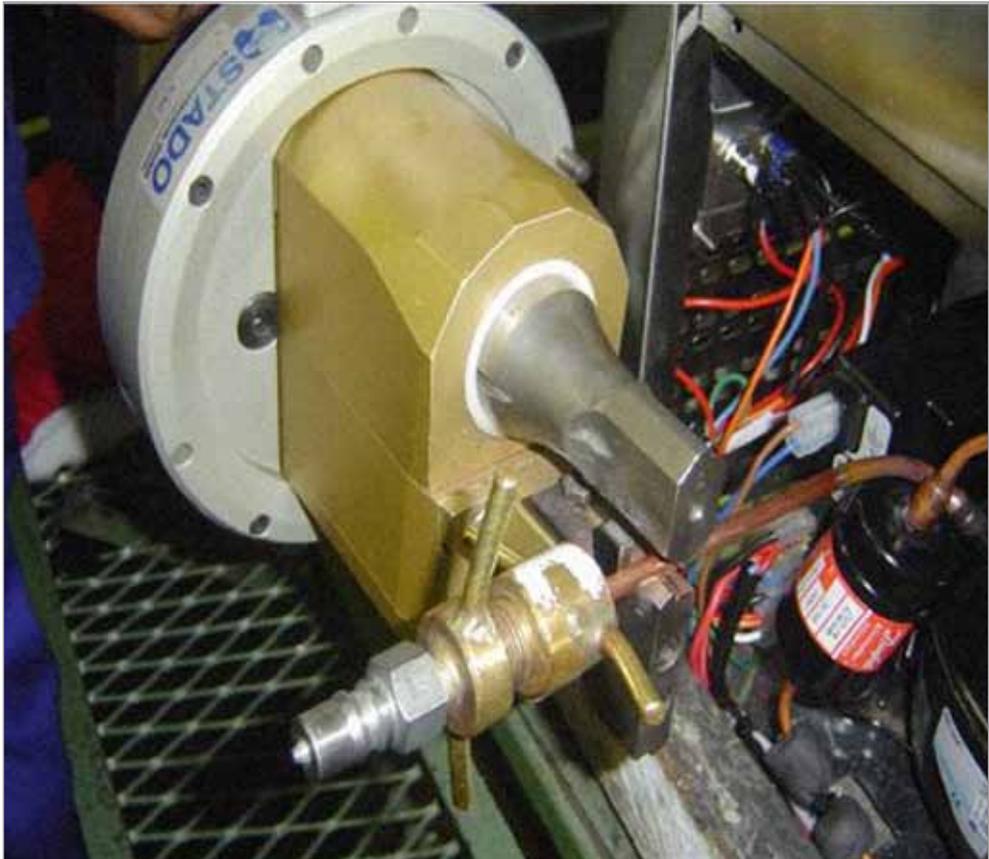
This process belongs to a type of friction welding but in the cold phase. This means that the metal is not melted and no high temperatures are reached during welding. This is relevant if there is a need to close a filling tube of a compressor filled with HC with an ignition temperature of 460°C. The welding pieces are rubbed against each other under pressure by high frequency vibration, which cleans the metal surfaces and whirls the molecules to each other to a fixed and long-lasting joint.

The ultrasonic welding units (Figure 20) require high investment but are reliable and result in significant leak reduction with minimal work and work-related costs. However, the quality of the metal being welded must be high, since even medium levels of contaminants within the metal can result in a poor quality and leaky weld.

In comparison to brazing or soldering, it does not need brazing material and the manufacturer is less dependent on the skills of the operators or the repair personnel. Furthermore, closing tubes already filled with HC using brazing or soldering pose a risk of explosion, which can be avoided by ultrasonic welding.

The investment in such a machine is amortised over a few years from recycling of copper filling tube. Therefore ultra sonic welding machines with spare sonotrodes and anvils are recommended. It is also recommended that spare sonotrode and anvils should be kept in stock to avoid production halts.

Figure 20: Ultrasonic welding machine



3.3.8 Testing, standards, regulations

Electrical safety testing: In addition to tests and declaration of conformity to the standards, the electrical safety test of refrigerators requires that every appliance be tested for the following before it is taken to the markets:

- Earth test and continuity of electric bounding circuit test
- High voltage test, which is flash test or Dielectric strength test
- Insulation test and electric strength

The following further tests are recommended:

- Power and current absorbed test
- Leakage current test
- Residual voltage test, if the refrigerator and compressor performance is improved by a capacitor

To execute the aforementioned test cycles automatically, including a test whether the wiring is correct before powering to avoid damage to the compressor, two pieces of industrial electrical testers are recommended. These testers are also useful for checking if the models correspond to the programmed parameters or fail the test, as well as for handing over the test records to a centralised quality control system through a computer interface and barcode reader. The electric tester (Figure 21) will therefore be part of the quality control system. Figure 22 shows an example of test location at a fridge factory in Swaziland, Palfridge Ltd.

Performance test lines: To improve energy efficiencies of the manufactured models and to make sure that no models leave the factory with performance quality deficits, the performance test lines should be improved and made sensitive. Valid regional and national standards must be used at all times.

Regulations and standards: Compliance with regional and international regulations and standards will apply.

Figure 21: Electric testing machine



Figure 22: Test location at Palfridge Fridge Factory, Swaziland



3.4 Changes in the product components

Due to the inherent flammable nature of HC refrigerants, converting domestic refrigerators from HFC to HC models require special considerations, in particular the components that are likely to spark in the appliances, such as thermostats, compressor relays, over load protectors, door switches, etc. Furthermore, the behaviour of HC refrigerants is different from HFC. This calls for redesigning of the cooling circuit components.

But before proceeding with the design conversion to HC, a few relevant aspects should be taken into consideration. This is summarised in Table 3.

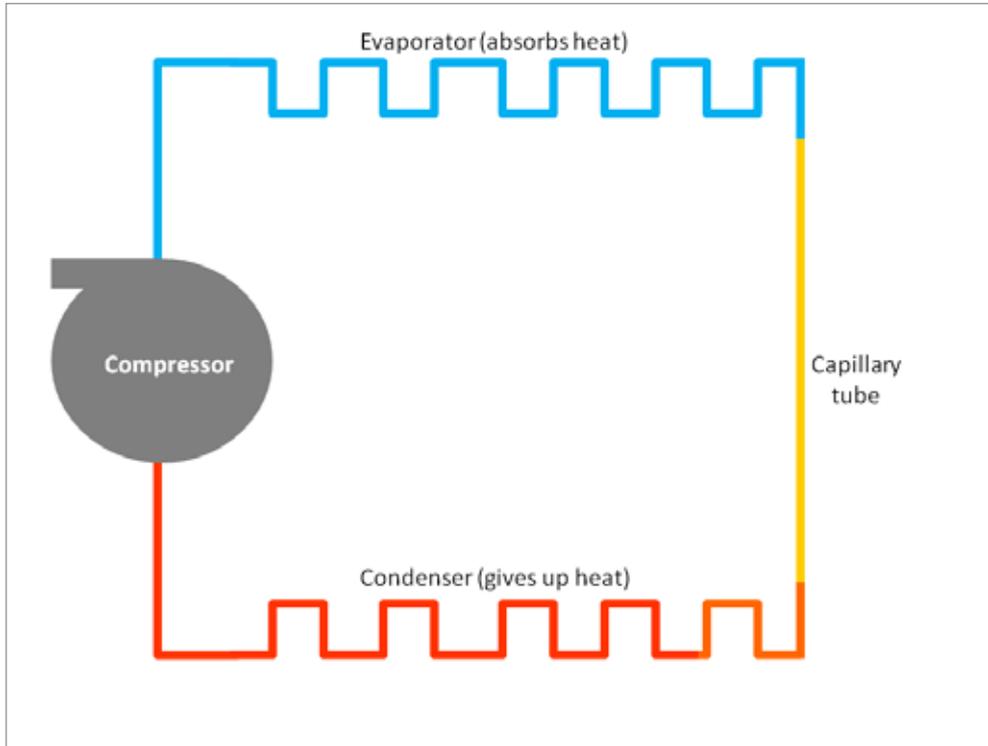
Table 3: Considerations before conversion⁴⁰

CONSIDERATION	PRECAUTION
1. Cabinet, cooling circuit and electrical design	All electrical connections should be separated from the cooling circuit, particularly the joints, to ensure that in case of leaks no explosion can happen. Protection of over electrical components may be used but these are often expensive and have a chance of breaking. Additional tests should be made on the design and on each produced appliance. The HC system must be marked for service reasons.
2. Safety precautions during charging	All relevant safety precautions must be adhered to during charging or works on the circuit filled with HC to prevent explosion.
3. Compressor compartment size	In some cases the compressor compartment size must be accommodated for HC compressor with 70–80% bigger displacement volume. This should be taken into account during the unit design
4. Charge tolerance	The charge tolerance of HC refrigerants is much smaller than the fluorinated refrigerants due to their lower density. However, the requirement on the fine-tuning of the charge quantity is that the charge accuracy should be within the range of 1g and the leak detection within the range of 1g per year.
5. Efficiency	HC systems are at least 5% more efficient than the HFC models with optimised design. Efficiency can be further improved by a run capacitor as in the case of HFC models.
6. Use of mineral oil	Normal mineral oil can be used in the HC compressors, which minimises the problems associated with system cleanliness. Due to a much lower refrigerant quantity, the system performance is more sensitive to impurities. It must be ensured that all non-condensable gases – even those diluted inside the compressor oil – are removed by special evacuation processes. High cleanliness will ensure optimal efficiency.

3.4.1 Key components

There are four basic parts of a refrigeration system, as shown in Figure 23.

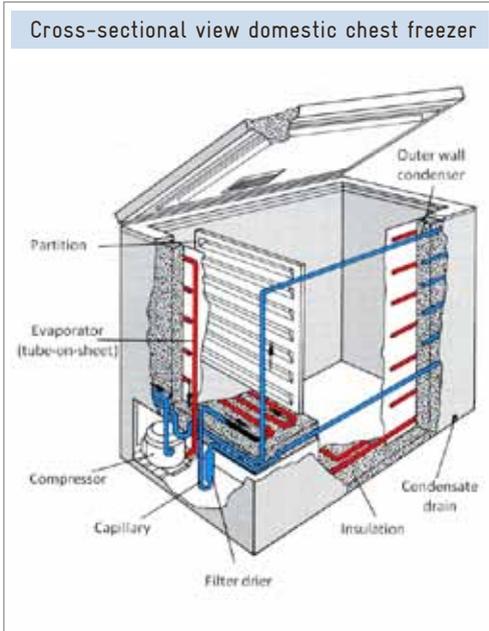
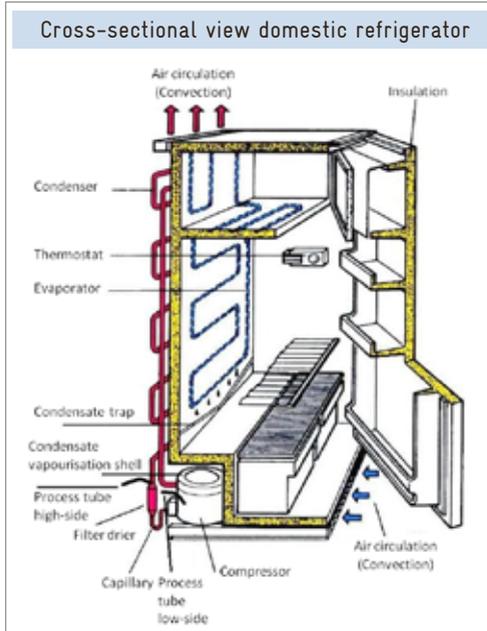
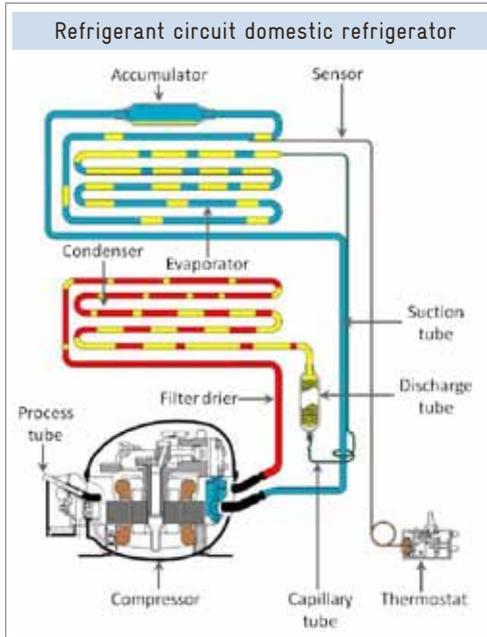
Figure 23: Basic refrigerator cycle



Evaporators are designed so that liquid refrigerant evaporates and leaves the coil as a vapour. The compressor draws the vapour out of the evaporator coil through the suction line and then after compression, discharges it into the condenser. The compression process causes the refrigerant vapour to rise in temperature. As the refrigerant passes through the condenser it rejects heat (which was absorbed from inside the refrigerator and the compressor) to the surrounding air as it condenses into a liquid. The liquid refrigerant passes through the capillary tube where it enters the evaporator as a low pressure, low temperature two-phase mixture.

To produce safe and reliable HC-refrigerant hermetic systems, the cooling circuit components (Figure 24) involved in the basic refrigerator cycle can be optimised through redesign.

Figure 24: Cooling circuits of a domestic refrigerator (top) and a cross-sectional view of domestic cabinet refrigerator (bottom left) and domestic chest freezer (bottom right)⁴¹

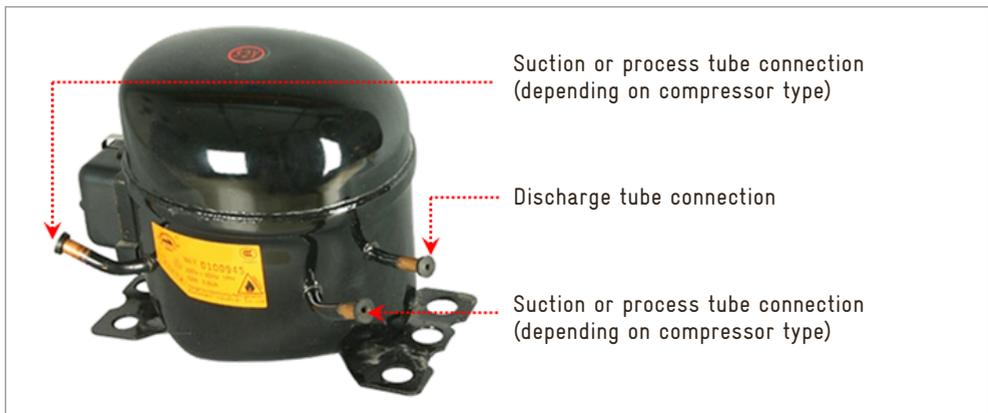


Compressor:

There are a range of compressors available from various suppliers. The compressor is started and stopped by a thermostat or a cold-control through a starting circuit. This normal start/stop cycle is interrupted during defrost cycles if the unit has automatic defrost.

Most small to medium refrigeration appliances use hermetic compressors (Figure 25). This type of compressor is basically an electrical motor attached to a reciprocating type machine, encased within a gas-tight welded steel casing or dome. Inside the casing the compressor and the motor are connected by a common shaft. The motor operates in an atmosphere of the refrigerant. The compressor and motor is not intended to be worked on and if the compressor becomes damaged it is common to replace rather than repair it.

Figure 25: Hermetic compressor



Selecting the correct type of compressor is important. Energy efficiency, reliability and lifetime, dimensions, and investment and costs are some of the criterion for the selection. Table 4 provides a summary of important characteristics to consider when selecting compressors for refrigeration appliances.

Table 4: Compressor characteristics⁴⁰

CHARACTERISTICS	EXPLANATIONS
Refrigeration capacity (according to European standard CECOMEF or American standard ASHRAE)	The correct displacement of the compressor must be selected in order to achieve the desired performance on a given application. Each refrigerant has different thermodynamic properties so it is important to select the correct displacement according to a specific refrigerant.
Coefficient of performance	Ratio between electrical power input and refrigeration capacity output, depending on the standard used. A compressor with a higher COP implies a higher efficiency. However, it is important to select the compressor to match the capacity of the application; over-sizing the displacement can lead to a low efficiency refrigeration system despite the compressor having a high COP.
Noise	HC compressors produce about 2dB less noise than their HFC counterparts. However, there are models that cause slight increase in noise.
Overall dimension	The increase of displacement of a HC compressor cannot always be made inside the same housing and in some cases a step-up in the compressor family is required.
Lubricant	Selection of mineral oil to be used as lubricants in the HC compressor is important, as it will affect the solubility of the refrigerant. HCs are known to be fully miscible with mineral oils and there is a greater reduction in the refrigerant oil mixture viscosity. Therefore it may be necessary to use a slightly higher viscosity grade, for example by 10 cSt.. However, some compressors are supplied with POE oils, which can have lower solubility.
Humidity	Humidity affects the quality of HC systems. Although it can be removed from the evaporator and condenser by dry air, factories find it practically impossible to remove it from the refrigerant and the compressor oil. For this reason, it should be ensured that both the refrigerant and the oil do not exceed 1/10 of dryer capacity, which is about 1 g. This means that the compressor oil should not exceed 100 mg water (125 ppm for 280 ml oil).
Flammability	Outside the compressor shell the overload protector, starting device, thermostat, light switch, the compressor electrical board and other electrical components may be potential sources of ignition and thus should be protected appropriately.
Costs	A compressor is the most expensive part of the system, as it is not designed to be worked on. If damaged it is common to replace rather than repair it.

SAFETY:

- FLAMMABILITY RISK OF HC COMPRESSOR CAN BE PREVENTED BY USING A FLAME-QUENCHING OVERLOAD PROTECTOR AND PTC STARTING DEVICE THAT ELIMINATES ANY IGNITION POINT NEAR THE COMPRESSOR
- HC COMPRESSORS SHOULD BE LABELLED WITH FLAMMABLE GAS SIGN

Evaporator:

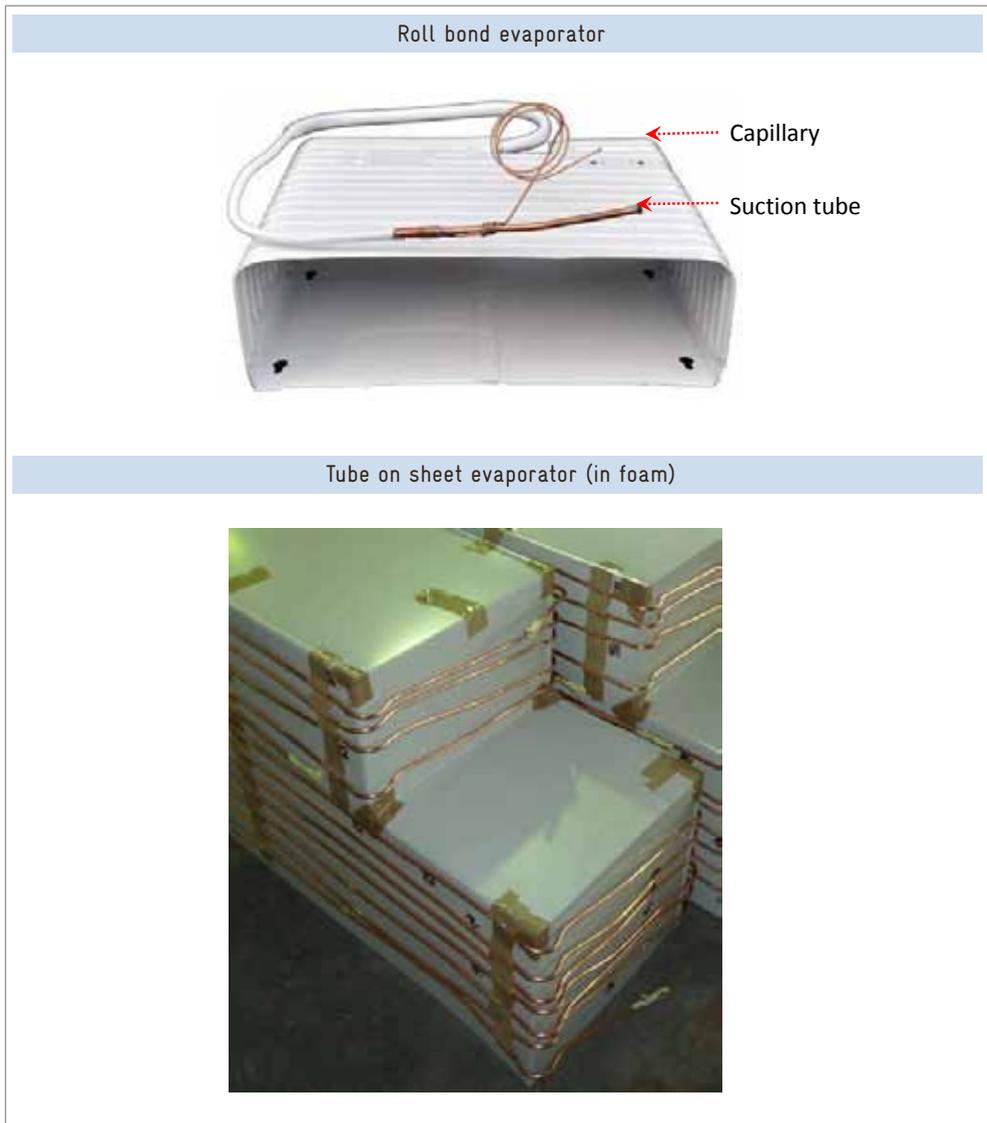
The refrigerant within the evaporator absorbs heat from the surroundings. The heat transfer from the cooled space is maintained by convection and radiation heat transfer. The refrigerant is injected into the evaporator with the capillary tube and vaporises, taking heat for the change of state at the evaporator's surface. Generally, evaporators are manufactured from aluminium or copper, with many possibilities for the design. The selection depends on the constructive features of the appliance and use, whether for use in refrigerator or freezer. Figure 26 shows different types of evaporators.

A common practice for placing evaporators is freely inside the cabinet. It is recommended to place foamed-in evaporators, i.e. placing it behind the in-liner. It is generally assumed that foamed-in evaporators may not provide adequate cooling under extreme ambient conditions, which may necessitate significantly increasing the area of the evaporator.

If the evaporator remains in the cabinet the following measures should be taken:

- a) placing a label inside the cabinet that should provide warning information against damage; the end-user must be informed that an ice-scraper must not be used to clean or defrost the evaporator;
- b) suitable design modification, such as smooth surface on the outside, can provide protection against damage;
- c) placing switches outside and casing the lamp to avoid any free sparking;
- d) improved materials and design should be used, such as thicker wall tubes with a probable safety factor of 5.0 and better joints to prevent leakage;
- e) the joint between aluminium evaporator with copper tubes should be protected to prevent galvanic corrosion. Some manufacturers use a protective polymeric coat on this joint, while others further protect it with a thermally sealed polymeric sleeve to avoid any moisture condensation. The latter approach is preferred for HC refrigerators.

Figure 26: Roll bond and tube-on-sheet evaporator types⁴¹



In case of roll bond evaporators, the volume distribution is usually within 10% tolerance. As the HC refrigerant charge is low, liquid distribution can be a serious problem. Roll bond evaporators therefore should be avoided unless a tolerance of 5% can be obtained. Simple tube and plate evaporators are preferred and recommended. The refrigerant charge should preferably be reduced further by changes in the heat-exchanger and piping layout (explained later) so as to minimise explosions.

Capillary tube:

The capillary tube assembled in a HC refrigerant circuit is acting as the expansion device in the system and enables the provision of the pressure difference between the condenser (high side) and the evaporator (low side). Length and diameter of the capillary tube depends on the refrigerant type and the appliance refrigeration capacity. A typical length would be about 2 to 4 metres with an inner diameter of 0.5 to 2 mm.

With a length of about 1 to 2 metres, the capillary tube is in thermal contact with the suction tube, thereby forming a liquid-suction heat exchanger. It should be noted that often the capillary is inserted inside the suction tube. This “internal heat-exchanger” assembly feature enables cooling of the refrigerant within the capillary, increasing the refrigerating capacity evaporating refrigerant. Another possibility with the same effect is to braze the capillary tube along the outer surface of the suction tube. Instead of brazing a PE shrink film can also be used to connect the suction tube with the capillary tube.

The capillary tube must be correctly sized and this design and calculation feature is carried out with comprehensive research in the factory laboratory performed on the prototype appliances. Finally, the assembly design, the length and diameter of the capillary is optimised for the energy efficient operation of the appliance. The exact amount of refrigerant charge in this relation is, in addition, an important constructional appliance condition. Figure 27 demonstrates an example capillary tube.

Figure 27: Capillary tube



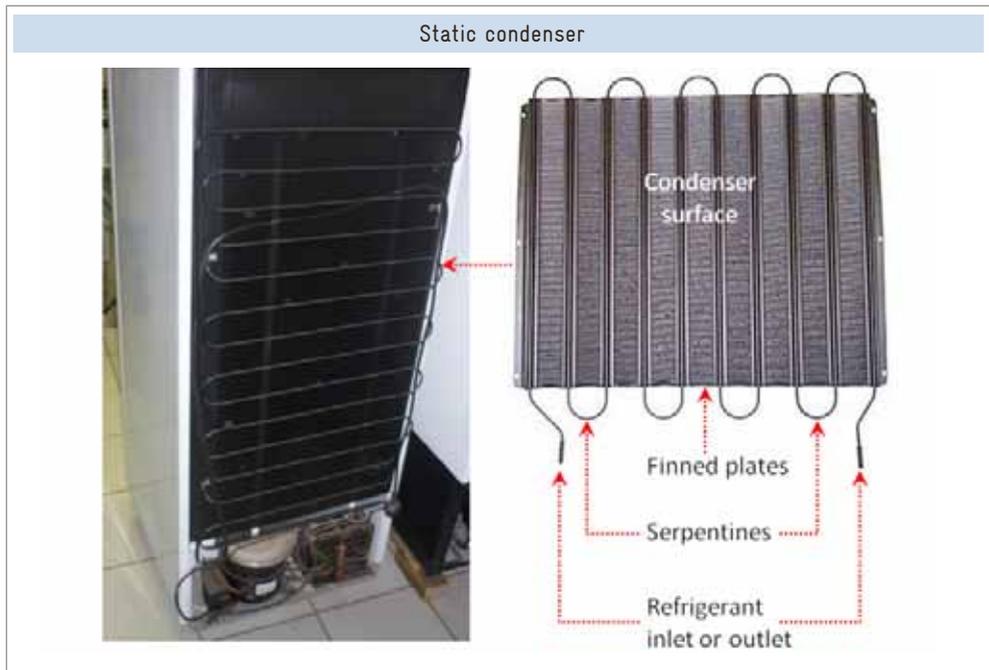
Condenser:

Condensers should be designed with the following consideration:

- a) a protective casing against damage for the condenser jutting out at the back of the refrigerator. The casing should not hinder air convection, and
- b) a higher safety factor against bursting.

Two common types of condensers used for refrigerant circuit assembly are static and fan-cooled. Most domestic appliances use static condensers (no fans), while commercial appliances use both static and fan-cooled. Static condensers are air-cooled condensers for free heat convection and radiation. They release heat from the refrigerant circuit to the ambient air for refrigerant condensation and are typically mounted upright on the back of the appliance. The condenser is manufactured from steel tubes in the design of a serpentine. In order to increase the heat transfer capability, an arrangement of wires or fins is welded onto these tubes. Such condenser is also called tube-on-finned-plate condenser. Figure 28 shows an example of static condenser common in domestic refrigerators.

Figure 28: Static condenser⁴¹

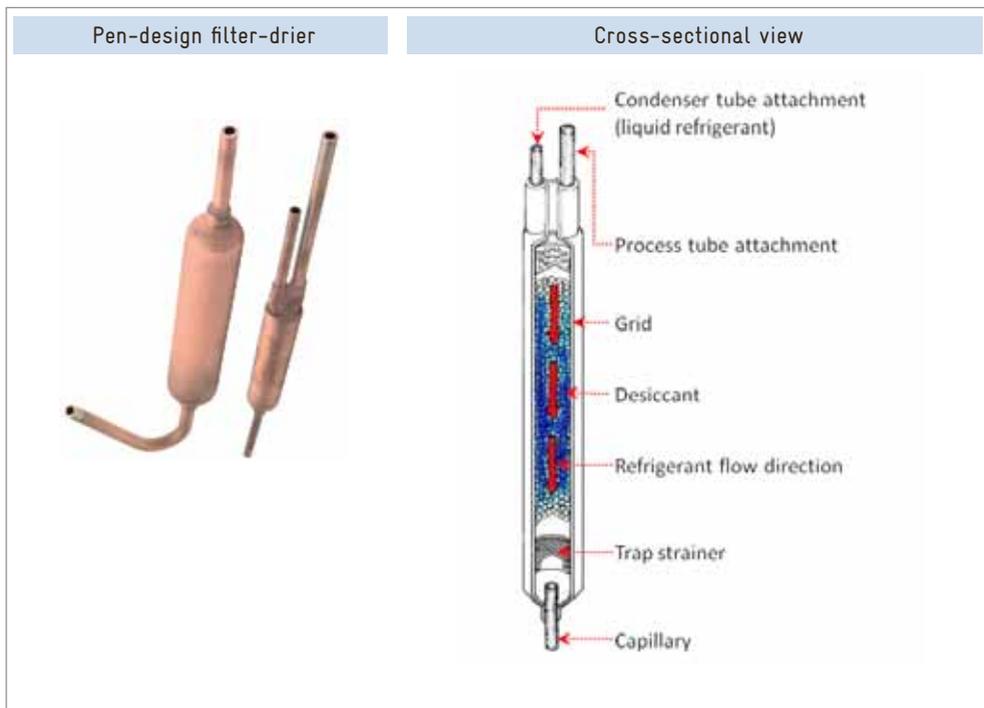


Filter-drier

Filter-driers are placed at the outlet of the condenser in domestic and commercial refrigerators and freezers. They absorb small amounts of water released throughout the life of the appliances refrigerant circuit components by a desiccant within the filter-drier. Apart from this, filter-driers act as trap strainers preventing blockage of the expansion device (capillary tube) inlet thereby avoiding problems with dirt.

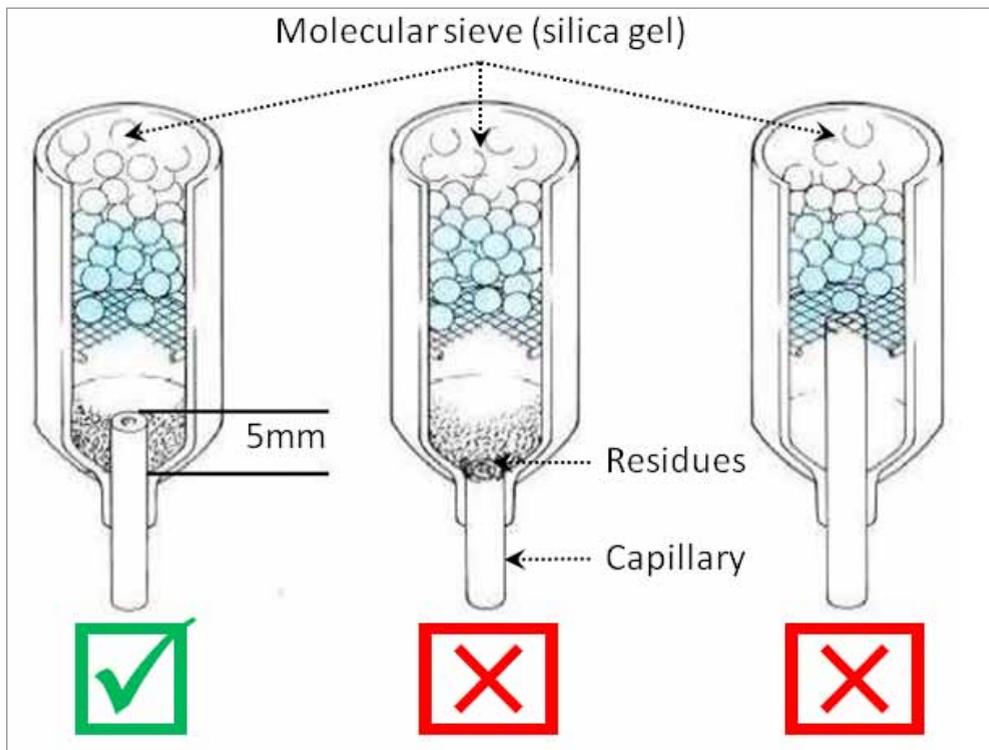
The filter-driers installed to protect the capillary tube can be blocked and the symptoms of this look to a clogged capillary tube. If a filter-drier is partially blocked and creates a pressure drop, it can be coated with frost or just getting cold. Capillary tubes usually block up in the first few centimetres after the drier if the system is contaminated with moisture. Additionally, excessive moisture in the system can freeze and form an ice-plug at the inlet to the evaporator. Figure 29 illustrates example filter-drier.

Figure 29: Example of pen-designed filter-drier⁴¹



If there is a need to replace a filter-drier all refrigerant from the circuit must first be vented or recovered. A capillary tube cutter must always be used to remove the part. A torch should never be used for a filter-drier removal, as heating poses a risk of transferring the absorbed amount of moisture to the system. The possibility of a flammable refrigerant being present must always be considered. Normally a filter-drier can absorb water approximately 10% of the desiccant weight. In most cases this capacity, if clean and dry circuit is maintained, is not utilised. The length of penetration of the capillary tube into the outlet port of the filter-drier is important for a trouble free system operation. If too short, residues may obstruct the capillary, if too long the refrigerant flow is restricted. In case of doubt of filter size for replacement or assembly, it is better to use an oversized filter-drier. Figure 30 illustrates acceptable size.

Figure 30: Assembling example of inserting capillary tube into the filter-drier⁴¹



It must be ensured that the filter-drier has dry inner condition before being assembled to the refrigerant circuit. It is essential to make certain that the filter-driers sealing is intact to prevent moisture collection during storage with spare parts. Most commonly used desiccants are compatible with hydrocarbon refrigerants. Acceptable types are XH-5, XH-6 or equivalent.

Thermostat

Capillary tube thermostats are used to control the refrigerators or freezers compartment temperature. The capillary thermostat, depicted in Figure 31, consists of:

1. Thermostat body
2. Bellows element with capillary and gas filling, hermetic sealed (pressurised system)
3. Mechanical transmission system (levers, springs, adjusting stem)
4. Switchgear with contactor (snap-action switch)

For the temperature control of appliances using hydrocarbon refrigerants, thermostats must not present a potential source of ignition. For this reason, the location of the thermostat in the appliance should be selected such that a danger of ignition of a refrigerant leak can be eliminated or the device should be approved according to the standards for hazardous areas (such as Ex 'n').

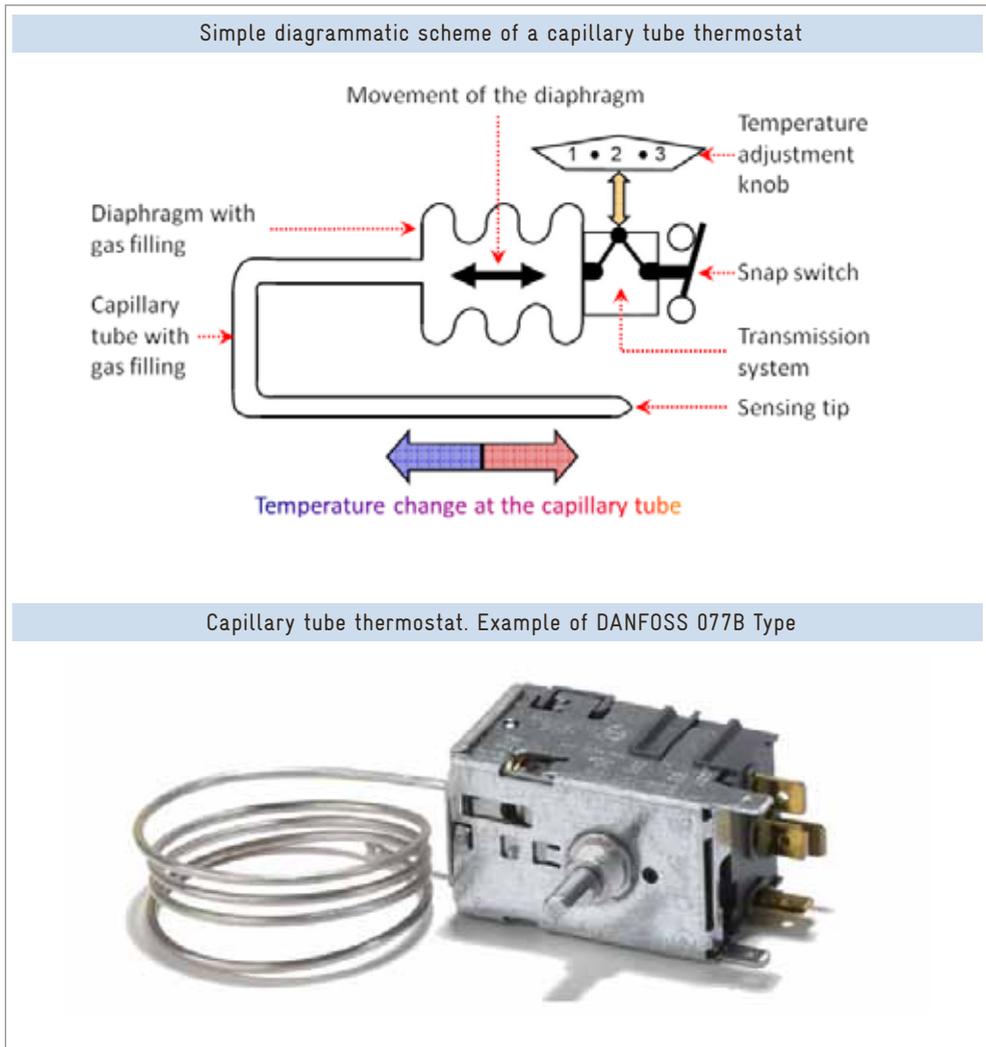
The pressurised part, which operates according to the principle of thermal expansion and contraction of a gas with a change of temperature, is the heart of a capillary thermostat. Following an increase in temperature within the capillary tube sensing tip, the gas expands and causes the bellows element to move. This movement activates a snap-action switch, causing opening or closing of snap-switch contacts. Using an adjustable counterforce applied to the bellows element, different temperature switching values are selectable in the form of temperature adjustment knob.

Electrical components within a refrigerated compartment

Lighting and the thermostat usually located in combination within a common housing must not present a potential source of ignition. With modern refrigerators, if these components are not placed at a location of the appliance where a formation of flammable concentration of refrigerant and air cannot be anticipated, the components are designed in sealed form. These components within the refrigerated compartment are as follows:

- Light bulb with bulb holder
- Light switch
- Electrical connections likely to be found on terminals, receptacles, connections, etc.
- Thermostat

Figure 31: Schematic view of a capillary thermostat⁴¹

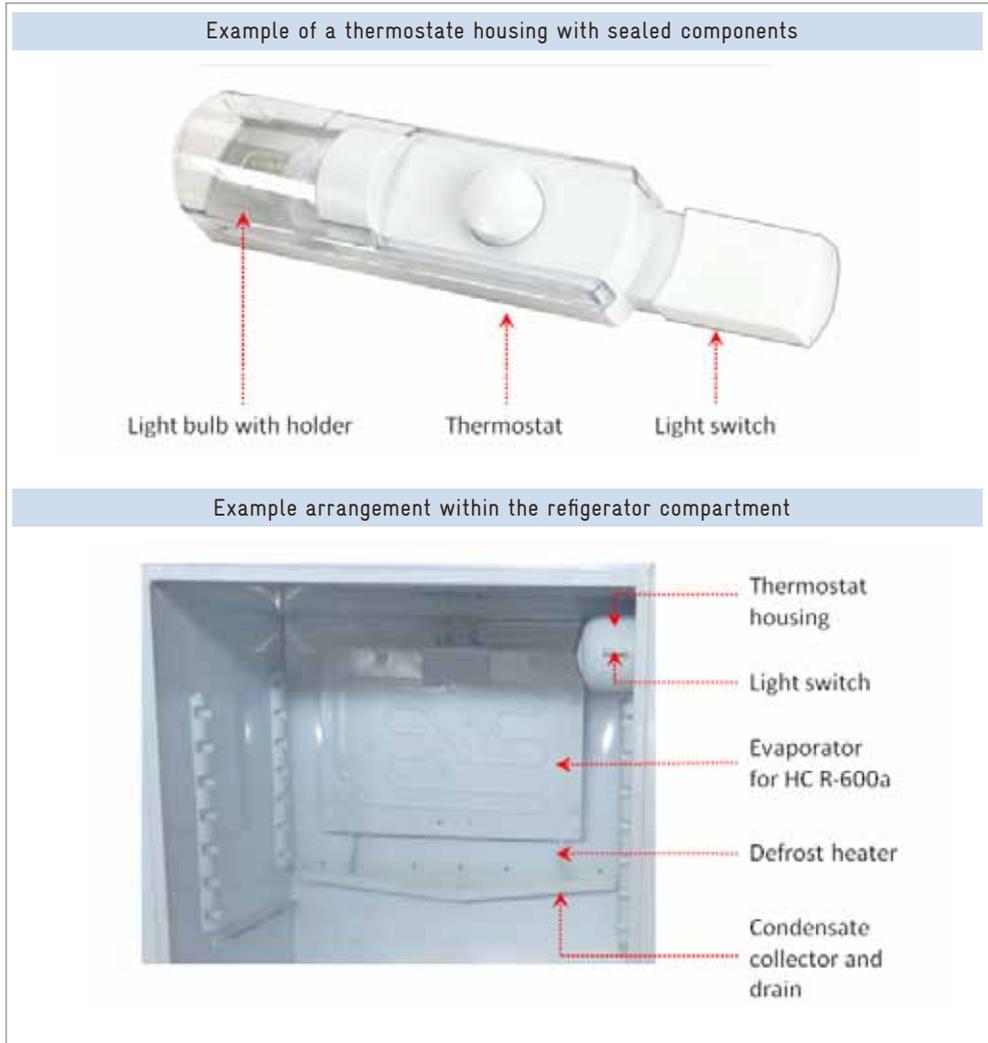


Other potential sources of ignition within the compartment, if installed, are:

- Defrost heater
- Defrost controller
- Defrost thermostat
- Fan motor blades

Figure 32 illustrates these components. The design features, and those mentioned in the preceding sections, are necessary to avoid the sparking components or hot surfaces coming into contact with leaking HC refrigerant into the refrigerated compartment and causing the ignition of the flammable mixture with the air. Modifications to the components or replacement with other non-approved parts are not permitted and should always be avoided.

Figure 32: Components within the refrigerator compartment and their placements⁴¹



3.4.2 Safety requirements

Users of this guideline are strongly recommended to refer to the GIZ Proklima publication “Guidelines for the safe use of hydrocarbon refrigerants – A handbook for engineers, technicians, trainers and policy-makers – For a climate-friendly cooling, 2010” for additional information relating to safety with flammable refrigerants.

Safety is of concern when applying any refrigerant, with respect to hazards arising from toxicity, asphyxiation, pressure explosions, mechanical injury, and so on. The use of HC refrigerants poses an additional flammability hazard. Quantities of flammable liquids or gases can be found in most workplaces, domiciles, and other environments; examples include petrol, paints, toiletries, heating fuels and alcohol. In all cases, these substances must be packaged, handled and used in an appropriate manner otherwise they can pose a serious hazard. Therefore certain safety principles are followed to ensure that an acceptably high level of safety is maintained. To use HC refrigerants safely, it is essential to understand flammability hazards and the corresponding means of achieving an appropriate level of safety.

There are three main aspects to consider when dealing with HC refrigerants:

- Ensuring the system is leak-tight, and sufficiently robust throughout its lifetime
- Ensuring the safety of equipment that uses or comes into contact with flammable atmospheres
- Protection of workers that may come into contact with flammable atmospheres in the workplace

The responsibility for the leak-tightness and the general safety of equipment normally lies with the manufacturer/producer and/or installer of the equipment. Equipment must be designed and constructed such that emissions and thus the creation of a flammable atmosphere are, as much as practicably possible, eliminated. This may be achieved through leak-tight design, ventilation and certain protective systems. Where it is possible for a flammable atmosphere to be created, those responsible for the positioning or installation of the equipment must ensure that ignition of that flammable atmosphere is not possible, for example, through elimination of potential sources of ignition.

The responsibility for protection of workers normally lies with employers and owners or operators of facilities where flammable atmospheres could occur. Therefore it is important for those people to be aware of the presence of flammable substances, put control measures in place to control the risk and reduce the occurrence of any incidents through the preparation of plans and procedures. This also includes

ensuring that employees and other workers are properly informed about and trained to control or deal with the risks accordingly and also identifying and classifying areas of the workplace where flammable atmospheres may occur and avoiding potential ignition sources in those areas.

Safety classification of HC refrigerants

The most widely used classification of substances is under the UN, where so-called dangerous goods receive a classification according to their main hazards. For the HCs commonly used as refrigerants, these are all classified as: UN Class: 2, gases, Division 2.1, flammable gas. However, within the RAC industry, a different classification scheme is applied. Most refrigerants are assigned a safety classification, which is a function of toxicity and flammability. The classification scheme is adopted by such standards as ISO 817 and EN 378. An overview of this scheme is shown in Table 5.

Table 5: Safety features for bulk tanks, cylinder enclosures and pump rooms¹⁷

Classification		Toxicity		
		Class A lower chronic toxicity	Class B higher chronic toxicity	
Flammability	Class 1	no flame propagation	A1	B1
	Class 2	lower flammability	A2	B2
	Class 3	higher flammability	A3	B3

By comparison, most common CFC, HCFC and HFC refrigerants, as well as R744 (carbon dioxide) have an A1 classification, although some HFCs have an A2 classification. A few HCFCs and HFCs have a B1 classification, whilst R717 (ammonia) has a B2 classification. There are no B3 refrigerants (although this may be possible with certain mixtures).

Typically, a “higher” classification – that is toxicity Class B instead of Class A, and flammability Class 3 instead of Class 1 – means that the refrigerating system has more onerous design requirements associated with it, in order to handle the higher risk presented by the refrigerant.

In addition, there is another measure for the application of refrigerants, termed the practical concentration limit (PL). This represents the highest concentrations level in

an occupied space, which will not result in any escape impairing (i.e. acute) effects. Thus, it is principally, the lowest “dangerous” concentration of a refrigerant, with a safety factor applied. The estimation of PL is based on the lowest of the following:

- Acute toxicity exposure limit (ATEL), based on mortality (in terms of LC50) and/or cardiac sensitisation, and/or anaesthetic or central nervous system (CNS) effects
- Oxygen deprivation limit (ODL)
- 20% of the lower flammability limit

Since, for HC refrigerants, 20% of the lower flammability limit represents the lowest concentration out of the above, this is the characteristic used to determine the PL. The PL is normally expressed in terms of mass per unit volume, and for the common HC refrigerants, it is approximated as 0.008 kg/m³, or 8 g/m³. For other refrigerants, such as most CFCs, HCFCs and HFCs, the PL is based on the ATEL and oxygen deprivation limit (ODL) values, and therefore tends to be higher than for the HCs. Consequently, the quantity of HC refrigerant permitted tend to be much less than most CFCs, HCFCs and HFCs. (However, the general principles here apply to all flammable refrigerants regardless of whether they are HCs or not.)

Basic approach for working with flammable refrigerants

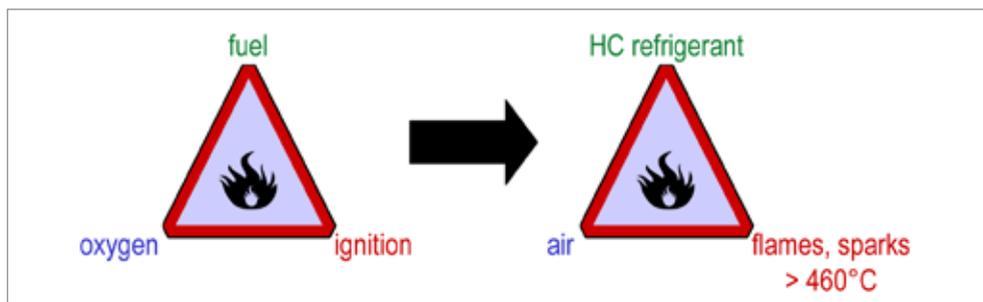
For anyone involved in the use of flammable substances, they should be mindful of the following:

- Know that there is a flammable substance being used and what its characteristics are
- Be aware of the practices for the safe handling and storage of flammable substances
- Introduce procedures and apply designs to prevent accidents arising from the flammable substances
- Find more detailed information when you need it

It is essential to understand the basic concept of flammability. Three ingredients are needed for a fire: a fuel at the right concentration, a supply of oxygen normally from air, and a source of ignition. The common way of illustrating this is by means of the fire triangle, in Figure 33. If you control these components, for example, by eliminating at least one, but preferably two of these, fire can be prevented. In order to achieve this, three general guidelines should be followed:

- containment of the substance,
- avoidance of ignition sources, and
- use of ventilation.

Figure 33: Fire triangle



Containment: The flammable substances must be kept within a suitably designed and constructed “container”, be it a cylinder or a refrigeration system. If the substance leaks, it should be prevented from spreading to other areas.

Ignition sources: Ensure that all the obvious and unobvious ignition sources have been removed from the equipment and handling areas. Ignition sources can vary greatly and these sources may include sparks from electrical equipment or welding and cutting tools, hot surfaces, open flames from heating equipment, smoking materials, etc.

Ventilation: There should be adequate airflow where flammable substances are stored and used. Good ventilation will mean that any vapour arising from a leak or a release will be rapidly dispersed. In addition to these, it is also important to consider the severity of the consequences of igniting the flammable substance. In some cases, the result of ignition could be minor, such as a momentary flame. Other situations may result in a serious explosion. Thus the quantity of flammable substance and the environment within which it is being held must be observed to understand the significance of an accident. In terms of the use of refrigerants, the entire lifetime of the equipment must be considered with respect to the guidance alone, both in terms of how the technicians handle the equipment, and how the equipment behaves when under normal use. Such considerations are necessary right from the conception of the equipment through to the design and installation stage since design features can affect the level of safety at a later stage. Here, both the groups of people who are at risk should be borne in mind: technicians and members of the public.

In order to address these in as comprehensive a manner as possible, a number of dimensions must be studied and understood by the personnel involved in the application of flammable refrigerants:

- Flammable characteristics of HC refrigerants, in order to appreciate what constitutes a flammable mixture
- Concepts of risk analysis, and an understanding of refrigerant leakage, gas dispersion, sources of ignition and consequences of ignition
- General requirements of regulations, safety standards and other industry guidance

The understanding obtained in these subjects can then be applied by the relevant parties to the stages of the lifetime of equipment under consideration, such as design, testing, production, distribution, installation, workshop activities, and servicing, and so on. This is equally useful when carrying out and interpreting the outputs for quality control of equipment, safety testing, third party inspections, labelling, etc.

Risk assessment

Whenever someone is working on a system that contains flammable refrigerants, all necessary precautions must be taken. The identification of those precautions is usually obtained through the process of risk assessment. In principle, an ignition event due to HC refrigerants can occur only when three essential preconditions exist simultaneously:

- First is the refrigerant release
- Second is the occurrence of a flammable mixture of HC and air
- Third is the presence of an active ignition source of a certain energy level or temperature at the same location and at the same time

The combination of these occurrences has to be prevented. An analysis of each working activity must be carried out. The risk assessment procedure therefore must consider the following:

1. The hazardous properties of individual substances and the hazardous properties of substances when used in combination and the circumstances of the work
2. The individuals who may be at risk
3. The likelihood that an explosive atmosphere will occur and its persistence
4. The likelihood that ignition sources will be present and become active and effective
5. The scale of the anticipated effects of a fire or an explosion

Based on these considerations, measures must be devised and applied, consistent with the risk assessment and appropriate to the nature of the activity or operation. The following, in order of priority, must be considered:

1. Reduce the quantity of dangerous substances to a minimum
2. Avoid or minimise the release of a flammable substance
3. Control the release of a dangerous substance at source
4. Prevent the formation of a flammable atmosphere, including the application of appropriate ventilation
5. Ensure that any release of a flammable substance which might give rise to risk is suitably rendered safe
6. Avoid ignition sources
7. Reduce to a minimum of the number of workers and eliminate the members of public that may be exposed
8. Avoid propagation of fire or explosion
9. Provide fire and explosion protection methods
10. Provide suitable personnel protective equipment

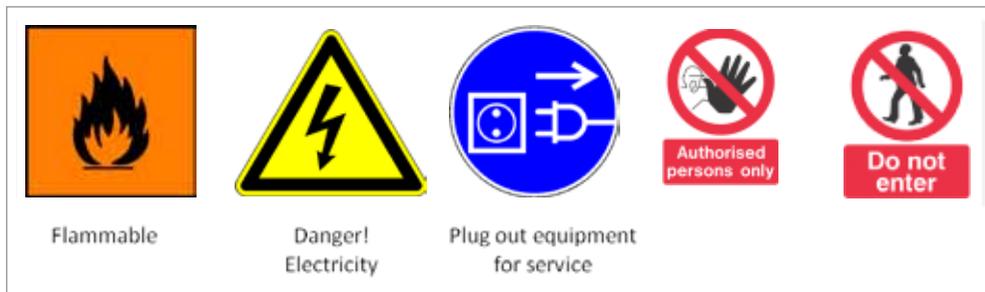
During installation, servicing and other activities that involve refrigerant handling, the tasks that lead to the greatest risk, especially for technicians who have not received training for flammable refrigerants or appropriate tools and equipment, are:

- Opening the system
- Removing refrigerant
- Charging
- Closing the system

Therefore, these aspects should have the greatest attention paid to them in terms of risk reduction. However, there is a considerable difference between the risk of servicing by well trained and equipped technicians and those that are untrained and not properly equipped. It is therefore essential that any technicians working on systems using flammables must be suitably trained. This also highlights the impor-

tance of clear marking of systems to enable technicians to make a decision on whether or not they should begin work on the system. Figure 34 illustrates further important signage around the work areas.

Figure 34: Examples of further appropriate signage¹⁷



Appropriate and necessary tools and equipment

Only work with the appropriate type of nitrogen: oxygen-free dry nitrogen (OFDN). The presence of oxygen can introduce a flammability risk. The presence of moisture can further be damaging to the reliability and operation of the refrigerating system. In some regions CO₂ may be more readily accessible to technicians than nitrogen.

The technician should always carefully read the installation and/or service manual that is provided by the manufacturer so that they are aware of any special particular requirements associated with the equipment under consideration. New or replacement components should be according to the manufacturers specifications. If in doubt consult the manufacturer's technical department for assistance. Figure 35 shows mandatory signs that should be in place for use on equipment and in working areas.

Some initial issues must also be addressed prior to working on a particular system or piece of equipment before carrying out any work. These are as follows:

1. It is essential that the technician is completely familiar with the equipment and all its detail
2. The technician must be familiar with the equipment's purpose and operation
3. The equipment should be, whenever possible, isolated from the electricity supply

4. Ensure that all refrigerant handling and mechanical handling equipment is available
5. All necessary personal protective equipment is available and being used correctly

Figure 35: Examples of mandatory signs for use on equipment and in working areas¹⁷



3.5 Training and after-sales servicing

Refrigeration systems, if not properly constructed, installed, operated or maintained, can be a danger to the health and safety of persons and detrimental to the environment. Any person who is involved with working on a refrigerant circuit should hold a valid certificate from an approved training organisation. This general approach is important for the use of any refrigerants.

The number of companies involved in installation, service and maintenance of refrigeration system is appreciable. In Article 5 countries most of these companies are small and operated by the company's owner and may include many technicians without formal training in refrigeration. In general these companies and technicians cannot usually afford to invest in training courses and reliable service equipment. Labour costs are much lower compared to the costs of equipment. To meet client's demands, appliances, system equipment and spare parts are in many cases provided by local second hand markets.

Existing refrigeration systems are kept running beyond their economic lifetime, resulting in increasing demand of servicing, repair and energy consumption. The intelligent, proper and safe use of HC refrigerants may facilitate the turnover in innovative refrigeration technologies to environmental savings, energy efficiency and affordable standards. However, national authorities must support related activities so that training and certification is accessible for workers in the field and all concerned parties. If training is well implemented it may lead to purposely economical competition on high level and with benefits for the country's infrastructure. The people that must be trained are those involved with HC appliances and systems – from their conception to destruction. They need to develop knowledge and skills to apply best

practices, including strategic risk assessment schemes for system conversion to HC refrigerants. This implies training activities in theory and practical matters.

The scope of training is related to the actual work responsibilities of employers, constructors, observers, manufacturing lines assemblers, installation companies or workshop owners and practical service engineers and technicians.

3.5.1 Importance of and approach to training

Users of this guideline are strongly recommended to refer to the GIZ Proklima publication “Guidelines for the safe use of hydrocarbon refrigerants – A handbook for engineers, technicians, trainers and policy-makers – For a climate-friendly cooling, 2010” for additional information relating training.

Recognising the importance of training:

The improvement of knowledge and skills is one practical manner in which the existing situation can be changed for the better. In some cases where vocational training for refrigeration exists and is structured, new or advanced technologies should be adopted. Lesson learned from previously conducted activities in Europe demonstrates that improved levels of training and work methods generally greatly reduce leakage rates and the number of failures in refrigeration systems. Multilateral Fund (MLF) evaluation of HCFC Phase-out Management Plans (HPMPs) notes that the introduction of better practices in refrigeration servicing has been the most important factor in reducing the ODS refrigerant consumption and emission in developing countries.

Training is generally driven by business needs and count more than ever if environmental challenges and burdens lead the industries to change. Rising awareness of these factors is one important driving instrument to force the related industries and companies to maintain specific training for involved personnel.

Identified below is a selection of some of the business needs:

- Need to meet the country’s (and the world’s community) obligation to protect the environment
- Need to provide a safe working environment and meet commitments to customers and society in handling refrigerants with due care
- Need to keep abreast of new technologies, new refrigerants and new legislation that are driving the change in the sector

- Need to improve refrigeration systems and appliances overall coefficient of performance
- Need to improve service levels in order to differentiate company's services from competitors, raise barriers to entry and improve charge out rates and margins
- Need to drive standards within the sector in order to prevent "cowboy technicians"
- Need to widen the employment base by providing alternative routes of entry to the sector for mature workers who are not prepared to take up an apprenticeship
- Need to reduce the time spent on manufacturing, installation, commissioning, maintenance and repair of plants and appliances in order to improve economical efficiencies
- Need to improve maintenance standards in order to reduce the cost of replacement parts and reduce the number of call outs on maintenance contracts
- Need to meet increasingly sophisticated requirements from retail, design, construction, manufacturing, installation, service and maintenance
- Need to reduce insurance costs by reducing exposure to liability claims under (a) health and safety legislation and (b) environmental legislation (c) product deterioration
- Need to compete with European competition where industry standards are higher and training provision more advanced.

Thus, training and networking events should be designed to meet these needs.

Approach to training and certification:

In general a country's legislation should prescribe certification at company level and for the active engineers and technician. The company needs to have the minimum required appropriate equipment for refrigerant handling and the engineers and technicians will have the knowledge and skills. Certificates should testify the competences so that equipment users will have the possibility to identify if company and personnel can perform the intended job.

Additional possibilities to support certification of companies and personnel at legislative level for A5 countries include:

- Only certified personnel may handle refrigerants (ODS, GHGs, HCs) and this may include a ban for selling refrigerants to non authorised persons
- Companies may have a minimum set of tools and equipment for refrigerant handling
- Only these certified companies should be able to buy refrigerants
- Governmental awareness campaigns promoting these certifications to private and commercial end-users and the equipment distribution chain (refrigeration wholesaler, industries, supermarkets, hospitals, governmental buildings operators, etc.)
- Mandatory record-keeping for equipment owners on information about refrigerant consumption and service needs for refrigeration equipment containing more than 3 kg of refrigerant
- Mandatory preventive maintenance and leak detection for refrigeration equipment containing more than 3 kg of refrigerant

Training courses in general and for HC technologies should be approved on national level by the responsible authority e.g. the Ministry of Education. Certification should be at the same level equal to new technician educated at vocational and educational training centre's (VETCs) or old technicians receiving this advanced HC education in form of evening courses or multiple day release courses. If appropriate, the courses can also be held with the same syllabus at training centre from trade organisations. Assessment test conducted to each training session should reflect the learning progress of the participants.

The authorisation scheme will gain the following benefits:

- Improving the standards of installation, service and maintenance for refrigeration equipment creating higher efficiency and lower energy consumption (emissions)
- The refrigeration equipment is reliable and its economic life is prolonged
- End-users are more satisfied because of lower costs and no need for additional repairs and/or early replacement
- There will be a market for educated technicians applying better service practices
- Receiving a register of competent companies and technicians and sustainable information about the consumed refrigerants

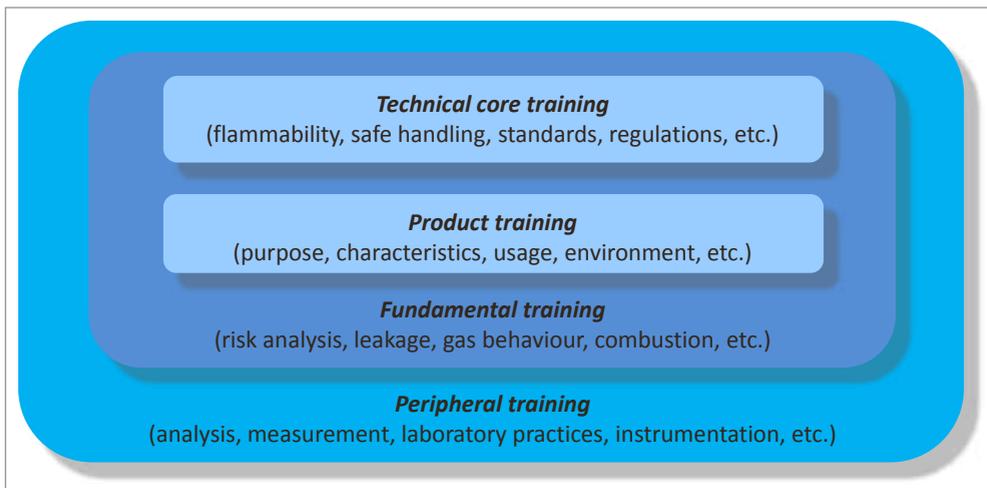
When offering training, the importance of manufactures production and engineers/ technicians business schedules should be recognised and accounted for to avoid disrupting them. This highlights the need to have, if possible, a range of approved training locations with specific training schedules and a jointly agreed and officially approved training programme.

3.5.2 Training for design and development

Persons involved with the design and development of systems using HC refrigerants require training. The training should cover a wide variety of topics since those designing the equipment need to be aware of and how to deal with different conditions under which the equipment will operate, and the possible failures and problems that may occur during the equipment lifetime. Whilst some of the training should cover conventional refrigerant handling aspects, it should also deal with more academic subjects for experimentation and analytical purposes.

Figure 36 provides an overview of the categories that should be considered for training of those involved in designing and development aspects. It should be noted that the inclusion and extent of training of certain topics will vary according to the role of the purpose of the work.

Figure 36: Overview of the training categories to be considered¹⁷



In general, four categories are identified, with two of them being the core subjects, and two further subjects being less critical.

Technical core training is based on the main components of the training that, for example, service and maintenance technicians might receive, such as safe refrigerant handling. However, with the important safety concepts, such as flammable properties, a deeper understanding should be gained. Of utmost importance is that the requirements of regulations and safety standards are covered. In particular, it is vital to understand the logic of the regulations and standards so that the boundaries can be worked within.

Product core training primarily focuses on the products or refrigeration appliances that are being worked upon. The training should provide an understanding of the systems and equipment under consideration, construction characteristics, how they are used, where they are installed, and the types of conditions they will be installed within, the usual service and maintenance practices, and so on. With this background the engineers can identify all the possible situations that the equipment may find itself in and the types of personnel that may be handling it so that they are able to anticipate the possible consequences and the conditions that could lead up to such consequences. To assist this, training should also be provided on typical and possible equipment and component failures, failure mechanisms, etc.

Fundamental training covers the fundamentals of safety-related issues. The subjects covered under this should include all those related to the safety of flammable substances so that the principles can be applied and taken into consideration when developing and designing refrigeration equipment. Furthermore, background knowledge on these topics will also help in the design and setting up of safety testing. The subjects should include mechanical component failure, especially leakage, processes and mechanisms, gas dispersion and mixing, combustion/fire and overpressure/explosion concepts.

Peripheral training covers subjects that should provide grounding for carrying out measurements and analysis. It may include approaches for setting up safety testing, applied methods for analysis of the results (that may differ from the methods normally used for refrigeration-related aspects), as well as familiarisation with the appropriate types of instrumentation and associated measurement equipment, its application and limitations. Further to this, there may also be coverage of the test standards and protocols for certain types of safety testing that isn't directly related to refrigeration equipment safety. The suggestions included here should act as guidance only, especially since some of the training for development and design stages should be more targeted for specific situations.

3.5.3 Training for production

Procedures for working within production area

Training and awareness-raising for workers will provide a more secure and healthy working environment, which are the key elements in a production area. In this quarter of work there is often a compromise between production output and procedures that could impede output. This is always a point of discussion. However, with the use of HC refrigerants and the need to regulate to a larger extent the procedures, it is often the case that an improvement in efficiency will be achieved due to the fact that individual operations are monitored in more detail. Nevertheless, it is important that managers handle any possible conflict carefully. The initial effort will require more time but the monitoring will provide valuable information and control of efficiency, thus providing significant benefits in safety, reliability and product quality.

Awareness-raising of manufacturing personnel

Within a production area there are many sections and installations that require special precautions and handling. Thus the personnel must be trained to consciously work with these. There also exist in this area a series of pipes, piping assemblies and electrical equipment with which the personnel must be comfortable with, and understand what to do in cases there are conflicts with their operations. Any new installation in general requires an awareness programme to be initiated in order that the production area and the personnel working there understand the implications of these new installations. The personnel have to be trained to consciously follow the rules, regulations and guidelines diligently. After awareness training and explanation of the procedures on how to handle the situations in which HCs are involved these will be considered soon as any other installation in the production area. This awareness programme by no means will be a one-off but a continuous process in order to keep the minds sharp in dealing with HCs or any other gases running in the production area. The supervisors of the facility must ensure that this is done.

Personnel to be trained

There are different levels of training with regards to the type of activities that is applicable to anyone entering the production area. Training should not be limited to regular staff in the production area but also to those from external agencies and companies. For anyone entering the area, they must have knowledge of basic industrial safety, proper understanding of the area and what to do in case of an emergency, specific knowledge of markings and warnings applied to installations (e.g. piping with HC) and understanding of the specific areas where HC are used. It is also strongly advised that procedures are setup to define that any activity in the production area are included in specific training and have approval of the safety manager.

This avoids, specifically in the early stages, poor habits being introduced and provides the opportunity to review and set up new procedures for the proper working in the production area.

Identification of areas

When a new process is introduced it is favourable to identify where this activity is performed in order that all the personnel involved in the production area on a daily basis is aware of the new process. This will also create a better understanding of the need for new procedures due to the changed production process. With the identification of the area, introducing the obligation to report any activities to the production line supervisor should also be included. In order that the principle of at least two persons are introduced whereby any repairs, changes to the production process, model changes etc, are monitored by the production line supervisors and safety managers. In this respect, with the change of shift the information can be transferred.

Changes to work situation

At the end of the production line a product will exit which contains HC. The whole process from the receipt of material until the filling with HC and packaging/shipment is involved in setting up the procedures. The output will already have an entire set of procedures for these activities in order to control the quality, product configuration and material, as well as production flow. What has to be introduced is the crosscheck at different production line areas. This is especially critical due to the fact that HCs are used. In mixed productions special care has to be taken to avoid the use of wrong components. In case of changes the production line has to be informed. The ideal case is that wrongly applied changes are detected the earliest possible. Before filling with HC it must be ensured that the product workmanship and configuration is correct. With or without mixed production what could be advisable is to use specific marking of HC suitable components, e.g. use of coloured baskets, racks and other storage items besides the traditional checking of the codes. In addition to procedures of information exchange when components or processes are changed at the start of each shift, increase the quality of the process.

Procedures review

The first step is to verify the existing product-specific procedures and review them in order to add the specific HC aspects to it. Secondly, run a production trial with dummy products and adjust the procedures for each individual step taking into account the full process. It is then also a good opportunity to setup a training programme tailored according to the functions performed in the production area and

a basic training for all. Additionally, the work-floor procedures have to be adjusted especially, among others, all which involve transport of materials, forklift movements, cranes, maintenance, repairs and machinery/equipment modifications. Special focus should be placed on sources of energy, mainly electrical but do not disregarding heat sources, including those that could be generated by friction. There are other aspects of the health and safety procedures that should also be included in the review. The procedures review plan is a continuous process with shorter review periods in the first year of production and when model changes are applied.

Staff training for distribution

Those involved or responsible for the storage, distribution and general handling of equipment containing flammable refrigerants should also receive some training. However, given that the equipment should be correctly designed, well-packaged and that generally only smaller (low charge) equipment is normally shipped pre-filled with refrigerant, the risk is considered minimal.

Nevertheless, the operator of the site should provide comprehensive training programmes for all levels of staff, from the most junior warehouse operator to the site director. It should be noted that majority of this training is good practice for most warehouses regardless of the products containing flammable refrigerants. All new employees should undergo induction training. The principal areas covered should include:

- Site safety and chemical safety
- Accident prevention
- Fire precautions and alarm procedures
- General background information
- Works facilities and amenities
- Company rules and procedures
- HC refrigerant's flammability aspects
- How this changes/impacts on their current practices (i.e. if using non-flammable refrigerants new to the site)
- Recognition of hazard warning signs used for packaging
- National regulations that relate to flammable and hazardous substances
- Basic fire fighting

Certain supervisory staff should receive more extensive safety training covering, flammability hazards, risks to individuals, checking for and dealing with leaks and evacuation in the event of a major emergency. There should also be a fire team that should train for 1-2 hours each week in order to ensure a permanent state or readiness and competency. There should be at least one full-scale fire drill and one

practise site evacuation annually. The first aiders on site should, from time to time, take part in simulated exercises with the site fire team, and practise recovery of “casualties” with specific injuries.

Those involved in distribution and shipping should, in addition, be aware of the use of UN Model Regulations for transportation of dangerous goods, particularly the transport requirements for equipment containing flammable refrigerants.

Those involved in warehousing, handling and (physical) transportation should additionally be aware of:

- General rules for storage of flammable materials
- Emergency procedures
- Checking packaging for leakage of equipment
- Correct manual handling practices
- Emergency procedures

Fork-lift truck drivers should pass a competence test set by an outside organisation before being allowed to drive fork lift trucks. Warehouse sites can train new drivers provided they have a qualified instructor. All drivers should undergo periodic refresher courses and competence tests:

- Simulated exercises
- Lecturers on fire and chemical hazards
- Videos
- Practical experience of wearing breathing apparatus
- Working with local fire brigade officers

Managers should receive two types of training, the first to improve their proficiency and enhance their management skills and the second to practise their emergency management roles. This second type of training is particularly important and should include an annual full- scale practise of major emergency lasting up to three hours. At these exercises, which ideally are organised by specialists, different managers should practise their roles.

3.5.4 Training for after-sales servicing

Training activities for after sales servicing includes the training of trainers, the training of technicians and the training of sales representatives on product knowledge. Depending on the country, there are specific training activities at Vocational Educational Training Centres (VETCs) covering the sector of domestic refrigeration as well. In many A5 countries the demand on service in the domestic sector is dominating and as a result, there are usually curricula available at the VETCs. In

fact, the quality of the conducted training in the various countries is very different and mostly lacks in resources. Private activities are also noticed, such as exemplary demonstration by the in-house training activities from Swaziland's Palfridge Company (See (4) case study).

With the first view, the service of a domestic appliance may seem simple but the demand on skills and knowledge for servicing activities is generally underestimated. The training of service technicians especially should include both theoretical and practical elements. The theory must comprise, among other topics, the knowledge about hydrocarbon refrigerant properties, steps to carry out an adequate risk assessment and how to design and maintain a sealed refrigeration system with minimised refrigerant charge and high efficiency. It is essential that all field works are performed securing a high level of overall quality to ensure the reliability of the optimised system with a minimum of emission.

Generally, the after sales servicing of domestic units is no difference to commercial refrigeration systems except the size. Technicians therefore have to develop skills and knowledge about thermodynamics, mechanics, electro techniques, material science and the regulatory standards and laws, which don't necessarily differ from those technicians working in the other sectors. The practical objectives of the training should reflect all activities of handling the alternative refrigerants in a safe way. Pipework and components installation with emphasis on modern brazing and reliable leak detection technologies are of high priority. Training should also comprise learning modules related to electrical components selection, installation and professional connection to the refrigeration system. At best possible the ratio between practical and theoretical content and time spent for the training should be split at around 70% practice and 30% theory. With the introduction of HC refrigerants, additional requirements have to be formulated to include the available state-of-the-art technologies into daily practice. This perhaps is the greater challenge to overcome.

In the past years European countries were confronted with a big discrepancy in education quality amongst refrigeration technicians of the member states. For this reason the European Leonardo project (EUR/02/C/F/NT- 84604 / EC Agreement N° 2002-4549/001-001LE2X) formulated minimum qualification of a "Refrigeration Craftsmen", which is indeed a good example for general core-training of technicians. The details of the contents for refrigeration training standard are listed in Appendix 4. Appendix 5 additionally provides an example of the assessment criteria for technicians.

Specific theoretical and practical updates for the use of flammable refrigerants are:

1. HC refrigerants and lubricants
2. Circuit components for the use with HCs
3. Tools and equipment for refrigerant handling
4. Risk assessment and general precautions for working
5. Accessing a refrigerant circuit
6. HC refrigerant recovery and venting
7. Repair of leaks
8. Leak checking (for tightness testing)
9. Strength (pressure) testing
10. System evacuation
11. HC charging
12. Repairs to electrical components
13. Routine system checks
14. Gas detection
15. Cylinder handling

4. CASE STUDY: PALFRIDGE LTD., SWAZILAND

A case study of Palfridge Ltd., the fridge company in Swaziland, is presented in this chapter to illustrate how the production line of refrigeration appliances can be successfully converted from the conventional use of fluorinated refrigerants to hydrocarbons. A pilot project was successfully implemented in Swaziland by the Proklima programme of the GIZ on behalf of the BMU, the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety.

The project was intended to assist the Government of Swaziland to phase out the use of ODSs in the refrigeration sector following their ratification of the Montreal Protocol in 1992. Two important areas that require special consideration when planning a factory conversion are: (1) the changes necessary for the design and installation of the production and associated areas, and (2) the required changes in the key components of the appliances to be produced. In the case of Palfridge these changes were implemented, providing the company an opportunity to redesign the factory layout, the production line routes and product testing, which led to a much faster manufacturing process and large energy and resource savings, as well as improved quality product and a significant cost reduction.

4.1 The factory

After 10 years of manufacturing domestic and commercial refrigerators and freezers the Palfridge factory gained comprehensive experience in the specific refrigeration sector and today claims the status of one of the leading fridge factories in the South African region and Africa in general.

Palfridge first started operations in 2001 and is located approximately 30km south-east from the capital Mbabane in Matsapha, the largest industrialised region of Swaziland in southern Africa (Figure 37). The main proportion of domestic refrigerator and freezer production is manufactured under the Kelvinator and Coolmaster labels. Other well-known brand names manufactured by the company are Aim, Farmers, Carriers, Cold Point, Fox Ware, Leonard, Sancon and Univa.

Figure 37: Location of Palfridge Company in Matsapha, Swaziland⁴²



The manufacturing facility is 15,000 m² on a plot that spans an area of 44,000 m². Its central location in Matsapha provides easy access to their outsourced functions, such as injection moulded components, wire harness, heater elements and packing material, as well as other locally produced raw materials.

There are two main production halls that are used, each with their own preassembly, cabinet and door foaming, assembly, evacuation, charging and leak and performance testing lines. HC and non-HC equipment are produced in the same assembly line and with access to both HC and HFC charging equipment. There are several separate halls for preassemblies of component groups, thermoforming, painting, coating of wire meshes and storages.

4.2 The production

In a 9-hour shift Palfridge manufactures a combination of 150 commercial and 350 domestic units with its present layout and equipment. This can be changed to accommodate additional volume if required. The current limitation of production is about 800 units in two 9-hour shift works. The factory is highly self-sufficient, manufacturing most of its own components such as condensing units, wire shelves and baskets, evaporator units and coils and heat exchangers. A number of vacuum formers, using ABS and styrene in various colours, are used to manufacture fridge and freezer door liners, plastic tanks and accessories for the commercial range.

The PUR insulation foam is delivered by road tanker and stored in 30 tonne bulk tanks. There are two separate foaming machines where the blowing agent is injected, providing flexibility to use different blowing agents 141B or upgrading to pentane. In effect, Palfridge is committed in doing so and will likely have completed this by 2012. The factory installation allows for CFC-free and environmentally friendly production. Cabinets are inert with nitrogen before foaming. A total of 14 production lines of different models are run simultaneously. Units are vacuumed to 0.08 Torr for 20 minutes before the refrigerant is injected. With the test line and final quality engineering, each unit is thoroughly tested and checked on the test line before being packaged. To cater for developing country needs the factory uses high quality proven compressors with a wide voltage range. Units suitable for tropical climates are also produced for high ambient applications.

To cater for the use of HC refrigerant the entire production line was changed, including new tightness testing equipment, evacuation lines, charging equipment and performance testing areas. The tank storage area required a complete reconstruction. Although much of these changes were not entirely necessary to implement HCs, it provided an opportunity for the company to radically redesign the factory layout, the production line routes and the product testing. This resulted in a much faster manufacturing process leading to large energy and resource savings, improved quality product and a significant cost reduction.

4.3 The products

Palfridge manufactures a range of stand-alone commercial refrigeration units, such as bottle coolers, freezers, storage cabinets and display cases as well as domestic refrigerators and freezers. The capacity of the cabinets ranges from small 50-litre models, to larger models of over 2000 litres. Most of the models have a HC charge size of less than 150 g although some exceed 300 g. Both R290 and R600a are used, depending on the type and size of cabinet and the operating temperature. Although

Palfridge uses HFCs for most of its commercial refrigeration units, the advent and successful conversion of the domestic production line for HC refrigerants has paved a way for switching to HCs for other production lines.

In general Palfridge products are exported. About 80% goes to southern and Central Africa and 20% to the countries of the sub-Sahara region. Only a few appliances are sold in Swaziland. Palfridge produces over 100,000 units annually. The full range of products is depicted in Table 6.

Table 6: Range of domestic and commercial refrigeration appliances produced by Palfridge Ltd.

Domestic appliances		Commercial appliances	
	All fridge		Beverage coolers
	Top freezer		Glass top freezers
	Bottom freezer		Commercial display
	Side-by-side		Commercial display under bar
	Chest freezers		

4.4 Development and design

The transition of the production line at Palfridge to cater for the use of HC refrigerant began in 2009. The main standard that was employed for the appliances is IEC 60335-2-89, however, where charge sizes exceed 150 g, the European standard EN 378 was used. The local testing laboratories do not have the appropriate testing equipment for the tests specified in IEC 60335-2-89, such as the leak simulation tests. Therefore, equipment was brought in, supplied by GIZ, especially for this purpose and modified accordingly to test the refrigerators at the Palfridge facilities under the supervision of an external laboratory. Conformity to the standards was through self-declaration and CE marking (See Appendix 3). The local test houses are using Palfridge staff to train them. Various other pieces of test equipment are being produced in-house.

4.5 Production and manufacturing

Nearly the entire production line was changed, including new tightness testing equipment, evacuation lines, charging equipment and performance testing areas. The bulk storage or tank storage area required complete re-construction. The entire installation was approved by the German Association for Electrical, Electronic and Information Technology (VDE – “Verband der Elektrotechnik, Elektronik und Informationstechnik”). Although much of the above was not entirely necessary to implement HCs, it provided the opportunity to radically redesign the factory layout, the production line routes and product testing. This has resulted in a much faster manufacturing process leading to large energy and resource savings, improved quality product and a significant cost reduction. Palfridge has also worked towards implementing ISO 9001, which is now in place since July 2010. ISO 14000 is scheduled to follow. The laboratory standard ISO 17025 has also been implemented since end of 2010. In addition, there is a new in-house computer aided Safety and Maintenance System that documents the total servicing, inspection and repair of the installation. It is important to highlight that in changing the models to use HCs, various structural changes were made. In fact, this afforded an opportunity to re-design the entire cabinet to better suit the new production process, improve performance and quality. As an example, for two of the models the reduction in energy consumption is between 30 to 40% compared to the conventional model, partly due to the HC and partly the re-design.

4.6 Training

Training of production line staff was carried out by the suppliers of the production line equipment. Design engineers and technicians were provided with general HC safety training, including training of a specific trainer to proliferate the HC safety training to field technicians. Another notable benefit of the conversion is the change in the culture of the factory. Previously, the factory was a typical “third-world” plant with dilapidated structures and machinery and untidy workplaces; the operators were scruffy and quality was comparable to the working conditions with very little pride and self esteem. After the installation of the new plant, the cleanliness and tidiness of the facility and the workers has dramatically improved, as well as the production process operating in a much more synchronised manner. The greatest change is that the workers themselves seem to be proud and dignified, helping to contribute to a much higher quality products and working environment.

Training materials availability:

The GIZ Publication “Best Practice in Refrigeration” is the only didactical training manual used for RAC-specific training activities. Each training participant received a printed copy of the publication at a cost of about about 400.00 Rand (40€). For a comprehensive training in domestic and commercial refrigeration technologies the use of this publication is helpful but insufficient. There is a dearth of other relevant training materials, such as:

- Other product specific training manuals are not available
- There are only some “spares manuals” as download available at the company’s homepage
- There are no repair guides for specific products and various topics available

Palfridge aspires to provide more specific client information on the internet. The company will appreciate additional support by providing specific training material in the form of:

1. Service manual for domestic and small commercial HC appliances
2. Booklet on “Basic Refrigeration”
3. Manual for installation and service of “Solar” and 12V DC equipment

Training commitment concerns:

There are efforts to strengthen the vocational and educational training (VET) in Swaziland but the visited training centre in Manzini which is acting for RAC business, is already a good start, with the potential to achieve and provide a higher

level of required training. Palfridge promises to support the four existing training centres in Swaziland with practical materials, such as providing refrigerators and freezers, etc. Additionally, there was a provision of tools and equipment for RAC, including HC equipment, under the UNDP activities. The operation of these Vocational and Educational Training Centres (VETC) do rely on high level of private commitment.

4.7 After-sales services

Service and maintenance is and will continue to be carried out using internal and external technicians. However, all technicians related to the enterprise will receive thorough HC safety training and certification. A similar training and certification scheme is being carried out across the region, particularly targeted at distributors, to ensure that any servicing is conducted by a competent technician. Palfridge has already identified all the field technicians, created a database and already begun preliminary training in the major centres. Palfridge staff has set up proper HC workshops in these centres, which include service equipment and ventilation systems. Technicians are trained by the factory engineers at these centres on both theoretical and practical aspects. The trainees themselves retrofit or change compressors and re-charge using HC. It is envisaged to supply the technicians with evacuating, charging and servicing equipment.

A second part of the workshop will contain a written exam and a practical testing, both designed by Palfridge. Successful candidates will be issued with a certificate of competence. This training will be held yearly and will also serve as an opportunity to pass down product information to the technicians. Palfridge has also begun training with a commercial training centre who would continue training other existing and aspiring technicians. Locally Palfridge also held multiple day workshops with students from the local universities and technical colleges.

After sales service arrangement (Liquitech Co. SA):

The general technical development of refrigerated devices, merchandising, spares pooling and after-sales service is centrally planned at the factory site in Swaziland. In Matsapha there are only a few service technicians located and the factory premises is not providing a “service centre” as such. For a comprehensive provision of after-sales services, Palfridge is linked with the specialised company Liquitech (see Table 7) and its 10 branches in South Africa. Most of the operational service technicians are self-employed and carry out the repair jobs under service contract with Liquitech Co. or Palfridge directly.

Table 7: Liquitech locations

CITY	ADDRESSES OF LIQUITECH BRANCHES
Durban	10 Imola Road, Westmead, Pinetown, Durban
Midrand	754a , 16th Road, Randjespark, Midrand, Gauteng
Cape Town	24 Nourse Avenue, Epping 2, Cape Town
East London	1 Wells Road, Woodbrook, East London
Port Elizabeth	19 Gates Street, North End, Port Elizabeth
Bloemfontein	No. 11C Mckenzie Street, Old East End, Bloemfontein
Nelspruit	Unit 1 B , Axis Industrial Park, Wilkens Street, Rockys Drift, Nelspruit
Pietersburg	5 Sapphire Street, Superbia, Polokwane
George	Unit 13, 80 Laing Street, George
Upington	No. 4 Progress Street, Industrial Area, Upington

Service, repair and warranty:

Palfridge in general provides a 12-month warranty for all appliances effective from the date of purchase. During this period in case of malfunction of the refrigeration system (except replacement of components with minor faults like thermostat, relays and switches) the appliance will be replaced. Direct interventions into the refrigerant cycle of the appliance are only carried out at the local service-station workshop.

After the warranty period, repairs are carried out in the same manner but in addition, by technicians or servicing companies that are not part of Palfridge’s service network. On the African continent, the repair of domestic and small commercial refrigeration appliances is of important economic status. Most of the companies, busy in the field of RAC, are involved in these kinds of repairs. The common workshop is small and operates by the owner himself with minimal staff of technicians or helping hands. The average skills of the independent service personnel are not well-trained and, in general, they gain the knowledge and skills for RAC services by taking “learning-by-doing” approach. There are about 100 independent service workshops in Swaziland and about 10 workshops in the city of Manzini.

4.8 Barriers

There were a few barriers. One was the time taken to analyse and redesign each cabinet model. Also, HC was not available locally and very few people have even heard of it. Palfridge first had to find a supplier to invest in importing HCs, which included the suppliers acquiring additional tanks with the US Department of Transport (DOT) rating.

With regards to the construction of the production facilities, there were very few local contractors that could execute work to the high level of safety requirements from the TÜV.

The other main barrier was changing the culture of the workforce to understand the safety issues and obeying the documented standards especially the maintenance team. However, directors of bigger companies are catching the global rise of green technologies and support Palfridge activities to extend the use of HC appliances. On-going efforts in the provision of training demonstrate an increasing level of overall service quality and product sales. Training activities includes the training of trainers, the training of technicians and the training of sales representatives on the product knowledge. The diffusion of gained skills and knowledge to field technicians and other sales-involved personnel is measurable but efforts have to be extended. Recycling of refrigerators and freezers is a big concern. For the end-of-life treatment there is no state-of-the-art refrigerator recycling provider in Swaziland. Recently there is one recycling services provider in the direct neighbour country in South Africa. The company “Air Products” is manufacturing cryogenic equipment to safely reclaim CFCs and cyclopentane propellants from insulation that are released during the recycling process of refrigerators. The unit uses liquid nitrogen in a patented low temperature heat exchanger to cool down and capture the ODS, which are released when the fridges and freezers are crushed.

ADDITIONAL NOTES AND RECOMMENDED REFERENCES

ADDITIONAL NOTE 1:

Appliances with a charge of less than 150 g of hydrocarbon refrigerant in each separate refrigerant circuit may be designed and assessed under the standard IEC 60335-2-89:2002+A2:2007 (or EN 60335-2-89:2002+A2:2007), “Household and similar electrical appliances – Safety – Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor”.

The specific requirements for systems using HC refrigerants are described in the following clauses:

- Clause 4: relating to information on “General requirements”, in particular NOTE 101
- Clause 5: relating to “General conditions for the tests”, in particular NOTE 5.101
- Clause 7: relating to “Marking and instructions”, in particular Clauses 7.1, 7.12, 7.15
- Clause 22: relating to “Construction, in particular Clauses 22.7, 22.105, 22.106, 22.107, 22.108, 22.109, 22.114

Appliances with a charge of more than 150 g of hydrocarbon refrigerant in each separate refrigerant circuit may be designed and assessed under the standard EN 378 “Refrigerating systems and heat pumps – Safety and environmental requirements”, Parts 1 and 2.

ADDITIONAL NOTE 2:

It is important to note that this guideline has referenced European regulations, directives and standards throughout, which have been done partly due to convenience but also because they are known to be effective and well-tested rules. In many countries where equivalent rules exist, they should be identified and applied accordingly. Where such rules may not exist, it would therefore be responsible to follow rules (such as those from Europe).

RECOMMENDED REFERENCES:

1. Charter, M. and Polonsky, M. J., 1999: Greener Marketing: A global perspective on green marketing practice. 2nd Ed. Greenleaf Publishing Limited, UK. 167p
2. Colbourne, D.; Hühren, R.; Schrempf, B., 2010: Guidelines for the safe use of hydrocarbon refrigerants – A handbook for engineers, technicians, trainers and policy-makers. GTZ Proklima publication, Germany. Hasse and Benton (Eds.). 315p
3. Croiset, I. C.; Lechtenböhmer, C.; Nassano, P., 2011: Guidelines for the safe use of flammable blowing agents in the production of extruded polystyrene boards (XPS). (In progress)
4. European Diisocyanate & Polyol Production Association, ISOPA.
URL: <http://www.isopa.org/isopa/>
5. GIZ Proklima, 2011: Guidelines for the Safe Use of Flammable Refrigerants in the Production of Room Air Conditioners. A handbook for engineers, technicians, trainers and policy-makers – For a climate-friendly cooling. (In progress)
6. Hühren, R., 2011: Training Manual: Servicing hermetically sealed systems using hydrocarbon refrigerant. (In progress)
7. Hühren, R., 2010: Good Practices in Refrigeration. GTZ Proklima publication, Germany. Hasse, V. (Eds.). 180p

APPENDICES

**APPENDIX 1: GWP AND ODP OF COMMON
REFRIGERANTS EXPLAINED**

**APPENDIX 2: APPROACH TO EMISSIONS
CALCULATIONS**

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APPENDIX 1: GWP AND ODP OF COMMON REFRIGERANTS EXPLAINED

Introduction

The GWP of a gas depends on the efficiency of the molecule as a GHG in trapping radiation and its atmospheric lifetime and is measured relative to the same mass of CO₂ and evaluated for a specific timescale. Thus, if a gas has a high radiative forcing but also a short lifetime, it will have a large GWP on a 20-year time scale but a small one on a 100-year scale due to its degradation in the atmosphere through chemical reactions⁴². Conversely, if a molecule has a longer atmospheric lifetime than CO₂ its GWP will increase with the timescale considered.

ODSs are chemical substances, such as halogens and fluorinated gases that contribute to the catalytic destruction of the Earth's stratosphere, or the ozone layer. The main source of these substances is the release of man-made halogenated refrigerants, such as CFCs, freons, halons. The ODP of these chemical compounds is the relative amount of degradation it can cause to the ozone layer in a given timescale. The ozone layer prevents the most harmful UVB wavelengths (280–315nm) of ultraviolet light (UV light) from passing through the Earth's atmosphere⁴³. Exposure to such light causes skin cancer, cataracts, damage to plants and reduction of plankton populations in the oceans photic zone.

Observed and projected decreases in ozone have generated worldwide concern leading to the adoption of the Montreal Protocol that bans the production of CFCs, halons, and other ozone-depleting chemicals. Table A1-1 illustrates the GWP and the ODP of commonly used refrigerants and blowing agents in domestic and commercial refrigeration from various literatures and calculations.

Table A1-1 GWP and ODP of various blowing agents and refrigerants

	Compo- sitions	Live time (years)	GWP [†] for a given time horizon			ODP ^{††}	Source
			20 years	100 years	500 years		
Blowing agents							
R-11	CFC-11	45	6 730	4 750	1 620	1	IPCC, 2007
HFC-245fa		8	3 380	1 030	314	0	IPCC, 2007
HFC-365mcf		9	2 520	794	241	0	IPCC, 2007
HCFC-141b	HCFC	9	2 250	725	220	0.11	
Cyclopentane		0.44		<25		0	IPCC/ TEAP, 2005
Methylal				<25		0	
Methyl Formate				<25		0	
HFO-1234ze	HFC			6		0	

† Global warming potential

†† Ozone depleting potential

Table A1-1 GWP and ODP of various blowing agents and refrigerants

	Compositions	Live time (years)	GWP ⁺ for a given time horizon			ODP	Source
			20 years	100 years	500 years		
Refrigerants							
R32	HFC	5	2 330	675	205	0	IPCC, 2007
R22	HCFC	12	5 160	1 810	549	0.055	IPCC, 2007
R12	CFC-12	100	11 000	10 900	5 200	1	USEPA, 2010
R134a	HFC	14	3 830	1 430	435	0	IPCC, 2007
R1234yf	Unsaturated HFCs			4		0	USEPA, 2010
R502	CFC-115: 51.2% HCFC-22: 48.8%		5 237	4 657	5 383	0.334	
R507a	HFC-125: 50% HFC-134a: 50%		5 090	2 465	767	0	
R404a	HFC mixture HFC-125: 44% HFC-134a: 4% HFC-143a: 52%		6 010	3 922	1 328	0	
R407a	HFC-32: 20% HFC-125: 40% HFC-134a: 40%		4 358	2 107	655	0	
R407c	HFC mixture HFC-32: 23% HFC-125: 25% HFC-134a: 52%		4 115	1 774	548	0	
R600a	Isobutane	negligible	negligible	3	0	0	IPCC/TEAP, 2005
R290	Propane	negligible	negligible	3.3	0	0	IPCC/TEAP, 2005
R1270	Propylene	negligible	negligible	1.8	0	0	IPCC/TEAP, 2005
R744	CO ₂	1	1	1	1	0	IPCC, 2007
R717	Ammonia	A few days	0	0	0	0	IPCC/TEAP, 2005

APPENDIX 2: APPROACH TO EMISSIONS CALCULATIONS

Introduction

There are various sources of emissions, either direct or indirect that occur during production, use and at the end of life of the appliances that need to be accounted for. This requires a systematic approach that is credible in its scientific accuracy, as well as practical and applicable in reality. This chapter focuses on how emissions can be calculated and energy efficiency demonstrated before any changes to the system occur.

‘Approach to emissions calculations’ provides a general methodology for quantifying baseline emissions (Section A2-1) and project activity emissions that occur during the course of the changes (Section A2-2). The calculation for reduction in emissions is presented in Section A2-3. To ensure that emission reductions are achieved and energy efficiency of the new system maintained, monitoring of relevant parameters is a vital step. However, there are parameters that need to be determined only once, at the onset of the project. These remain constant during the course of the conversion activity, while others need to be monitored and reported continuously on an annual basis. Section A2-4 outlines a general guide towards systematic monitoring of parameters applicable to emissions accounting.

There are two scenarios, baseline and project activity, each with six aspects – two each for production use and disposal – that are introduced. The baseline scenario assumes continued use of high GWP refrigerants for manufacturing cooling appliances, with energy consumption remaining unchanged. The project activity relates to the conversion process where climate-friendly hydrocarbon refrigerants are used that also has an impact on the energy consumption, particularly during the use of the appliances. Table A2-1 provides a summary of the scenarios that are described in detail in the sections that follow.

It should be noted that emissions from blowing agents are not included in the illustrated equations. However, this is important when accounting for total emissions and therefore should be included in the computation. References are made where applicable.

Table A2-1 Emissions scenario description[†]

Emissions sources		Baseline scenario	Project activity scenario
Production	Direct: physical leakage of refrigerants, losses during charging and emissions from repairs	A1a	B1a
	Indirect: energy consumption, assumed unchanging	A1b	B1b
Use	Direct: servicing and repair rate	A2a	B2a
	Indirect: energy consumption from the use of appliances	A2b	B2b
Disposal ^{**}	Direct: initial refrigerant and that filled during services released at end of life of appliance	A3a	B3a
	Indirect: energy consumption, assumed unaffected by the project activity	A3b	B3b

[†] There are two scenarios, baseline and project activity, each with six aspects, two each for production, use and demolition

^{**} Disposal may imply recycling, deconstructing or simply dumping. In fact, this should be part of the end-of-life emissions, which will depend on the residual refrigerant content at the end-of-life of the unit and the practises in the country.

2.1 Baseline emissions

Drafting a methodology for emissions accounting is a balance between scientific accuracy and practicability. Simplifications are inevitable to keep the procedure applicable in reality. The challenge is a realistic yet practicable determination of the baseline emissions. The major constraint is the limited availability of data concerning the baseline, as these data would have had to be collected in the past, before the project activity is even thought of.

The following simplifications have been made for this methodology: The baseline scenario is the state of the production technology and practices at the time of replacement and remains constant over the calculation period. This approach is different to a baseline determination within the framework of the Clean Development Mechanism (CDM), where the baseline scenario is dynamic and includes the most likely development without the project activity. This is to ensure additionality within the CDM. However, proving additionality in this strict sense is not required for the scope of emissions accounting during a change in production line, as no carbon credits for the offsetting market are earned with such an activity. This static approach simplifies the calculation and reduces the amount of required data without deviating too far in over- or under estimating the baseline.

The data to describe the baseline production is to be supplied by the producing company that might not have had a comprehensive monitoring system in place. Especially in developing countries, the data availability can be limited. It can therefore happen that data concerning the refrigerant loss during production or repair rates are determined based on “experience”. This is the reality and in order to calculate emissions reduction one has to use what is available. However, due care is to be exercised not to overestimate the emissions reduction.

As the main project activity is replacing HFC-containing appliances, the emissions reduction is calculated ex-post based on the actual produced and sold number of appliances. For the ex-ante calculation, the production data of the last available year can be used. The scope of this methodology covers the conversion of the production of domestic and commercial refrigeration appliances to refrigerants with low GWP. The calculation of the associated emission reductions, as explained in Section A2-3, will then include the GHG sources from refrigerant losses and power plant that services the grid for both the baseline and project activity scenarios.

The baseline emissions result from emitted refrigerant and electricity production needed to power the appliances. The amount of direct emissions from refrigerant and blowing agent is calculated from the losses during production, refills during servicing and finally the emission at the end of the product life, when the refrigerant contents are emitted during disposal or mechanical demolition.

In the course of adapting the technical design of the appliances to the new refrigerant, it is intended to improve the energy efficiency as well. The expected change of the energy consumption is the reason for including the energy consumption in the baseline calculation. The emissions are determined based on their time of occurrence, during production stage, usage and disposal.

The total baseline emissions are thus calculated using equation (1):

$$BE_{total} = BE_{ref,prod} + BE_{ref,use} + BE_{elec,use} + BE_{ref,disp} \quad (1)$$

where

BE_{total} represents the total baseline emissions
 $BE_{ref,prod}$ represents the baseline emissions from refrigerant during production
 $BE_{ref,use}$ represents the baseline emissions from refrigerant during use
 $BE_{elec,use}$ represents the baseline emissions from energy consumption during use
 $BE_{ref,disp}$ represents the baseline emissions from refrigerant at disposal

Scenario A1a: Direct baseline emissions during production

Refrigerant emissions:

Direct emissions during production arise from losses due to the following:

- Physical leakage of refrigerant from the distribution system of the factory;
- Losses at the charging head during charging process, and
- Refrigerant emissions from units that do not pass functionality test and need repair that involves venting of refrigerant.

It should be noted that emissions during refrigerant manufacture, its distribution, up until the receipt of the refrigerant at the factory are all important and should be included in the emissions accounting.

The emission due to baseline manufacture losses can either be calculated based on the emission factor (EF_{prod}) issued by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories⁴⁴ or determined based on historic production data.

OPTION 1

Use the default values for emission factors as presented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The lower value refers to developed countries, the upper value to developing countries:

Domestic refrigeration: $0.002 \leq EF_{prod} \leq 0.01$

Stand-alone commercial applications: $0.005 \leq EF_{prod} \leq 0.03$

The baseline refrigerant emissions during production are calculated separately for domestic and commercial appliances using equation (2):

$$BE_{ref,prod} = \sum_r EF_{prod} \times TIC_{ref,r} \times GWP_{ref,r} \quad (2)$$

where

$$TIC_{ref,r} = \sum_i \frac{N_i \times C_i}{1000}$$

and,

$BE_{ref, prod}$	represents the baseline emissions resulting from refrigerant losses during production [t CO ₂]
r	represents all refrigerant species used for production of the models
EF_{prod}	represents the emission factor of production
$TIC_{ref,r}$	represents the total initial charge of refrigerant per refrigerant <i>species</i> [t]
$GWP_{ref,r}$	represents global warming potential of refrigerant r [t CO ₂ e/t ref]
i	represents all produced models
N_i	represents the number of produced appliances of model i
C_i	represents the refrigerant content of model i [kg]

OPTION 2

Determine the refrigerant losses during production using factory specific data in a transparent way.

Scenario A1b: Indirect baseline emissions during production

Energy consumption:

The electrical energy consumption of the production line is assumed to be the same for the baseline and the project activity, thus can be excluded from the calculation.

Scenario A2a: Direct baseline emissions during use

Refrigerant:

Emissions from servicing arise from leakages and venting of the refrigerant circuit prior to repair, as well as during the repair activity. A lot of emissions in the latter case occur, for example if a compressor needs to be changed. Technicians will generally cut the pipe, release all the refrigerant, replace the compressor, recharge the system, find that they haven't sealed it properly, and release more gas. When transferring refrigerant to or from the system, there are often incidental emissions when connecting and disconnecting hoses. For smaller systems at least just as much gas is emitted during these activities as what leaks from systems.

The repair rate is the fraction of refrigeration appliances produced during one year that has been repaired with a recharge of refrigerant, and is based on empirical data covering the appliances repaired involving venting and recharging of refrigerant. In case sufficient empirical data is not available, emissions due to repair may be excluded from the calculation, as given in equation (3).

$$BE_{ref, use} = \sum_r FRR \times TIC_{ref,r} \times GWP_{ref,r} \quad (3)$$

where FRR refers to the repair rate, the annual fraction of repaired refrigeration appliances that are produced during one year.

Scenario A2b: Indirect baseline emissions during use

Energy consumption:

Indirect emissions during the use of appliances arise from their energy consumption. There are companies that sell their appliances in a number of different countries, some of which have significantly different emission factors. This should be taken into account. Thus, the yearly baseline emissions are calculated as the product of electricity consumption and the emission factor for electricity generation, as illustrated in equation (4):

$$BE_{elec,use} = \sum_j \left(\sum_i \frac{EC_i \times N_i}{1000} \right) EF_j \times CP_j \quad (4)$$

where

$BE_{elec,use}$	is the baseline emissions from electricity consumption during use [t CO ₂]
EC_i	is the average electricity consumption of model i per year [kWh]
N_i	is the number of produced appliances of model i
EF_j	is the emission factor for electricity for country j [t CO ₂ /MWh]
CP_j	is the proportion of appliances that are sold in country j

Determination of grid emission factors:

The grid emission factor is calculated according to the “Tool to calculate the emission factor for an electricity system⁴⁵”, Version 01.1 as issued by the CDM Executive Board.

Scenario A3a: Direct baseline emissions during disposal

In countries where no recycling infrastructure is in place, the gases contained in the cabinets are released to the atmosphere at the end of the product life. Even where recycling does take place, the processes are never 100% effective in recovering the entire refrigerant. In addition, it is found that there are often significant losses (between 10 - >50%) of emissions during collection and transport of appliances, even before they reach the recycling centres!

For simplification minor gradual losses during the product life may be neglected and the total initial charge assumed to be emitted at the end of life treatment that can involve the mechanical destruction of the cabinet in order to take out the metal parts, which can then be sold as scrap metal.

Refrigerant:

At disposal the amount of refrigerant that was initially filled into the cabinet, or refilled during servicing, is released to the atmosphere. Thus the refrigerant emissions at disposal can be determined using equation (5):

$$BE_{ref, disp} = TIC_{ref} \times GWP_{ref} \quad (5)$$

where

$$TIC_{ref} = \sum_i \frac{N_i \times C_i}{1000}$$

and

- $BE_{ref, disp}$ represents the baseline emissions from refrigerant at disposal
- GWP_{ref} is the global warming potential of refrigerant [t CO₂e/t ref]
- TIC_{ref} is the total initial charge of refrigerant [t]
- i represents all produced models
- N_i is the number of produced appliances of model i
- C_i represents the refrigerant content of model i [kg]

Scenario A3b: Indirect baseline emissions at disposal**Energy consumption:**

Indirect emissions at the time of disposal are not affected by the project activity and can therefore be neglected.

2.2 Project activity emissions

The emissions from the project activity or the conversion process mainly arise from the energy consumption during the use of the refrigerator cabinets. For completeness the emissions due to the refrigerant are included although its GWP is very low. The total emissions produced during the course of the project in t CO₂ are computed using equation (6):

$$PE_{total} = PE_{ref, prod} + PE_{ref, use} + PE_{elec, use} + PE_{ref, disp} \quad (6)$$

where

PE_{total}	represents the total emissions due to the project activities
$PE_{ref, prod}$	represents project activity emissions from refrigerant during production
$PE_{ref, use}$	represents project activity emissions from refrigerant during use
$PE_{elec, use}$	represents project activity emissions from energy consumption during use
$PE_{ref, disp}$	represents project activity emissions from refrigerant at disposal

It should be noted that emissions from blowing agents must also be included in the activity emissions.

Scenario B1a: Direct project activity emissions during production

Refrigerant emissions:

The procedure remains the same as applied in the baseline, as it is assumed that the production process does not change significantly due to the change of refrigerant. The emissions due to project manufacture losses (EF_{prod} in equation (2)) can be computed using two options: 1 – based on the emission factor issued by the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, or 2 – based on historic production data of the manufacturer.

OPTION 1

Option 1 uses the default values for emission factors as presented in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The lower value refers to developed countries, the upper value to developing countries:

Domestic refrigeration: $0.002 \leq EF_{prod} \leq 0.01$

Stand-alone commercial applications: $0.005 \leq EF_{prod} \leq 0.03$

The emissions during the project production activity are calculated separately for domestic and commercial appliances using equation (7).

$$PE_{ref, prod} = \sum_r EF_{prod} \times TIC_{ref, r} \times GWP_{ref, r} \quad (7)$$

with

$$TIC_{ref, r} = \sum_i \frac{N_i \times C_i}{1000}$$

and

$PE_{ref, prod}$	represents emissions resulting from refrigerant losses during production at the time of the project [t CO ₂]
r	represents all the refrigerant species used for producing various models
EF_{prod}	represents emissions factor of production
$TIC_{ref, r}$	represents the total initial charge of refrigerant per species [t]
$GWP_{ref, r}$	represents the global warming potential of refrigerant r [t CO ₂ e/t ref]
i	represents all the produced models of refrigerator
N_i	represents the refrigerant content of model i [kg]

OPTION 2

Determine the refrigerant losses during production using factory specific data in a transparent way.

Scenario B1b: Indirect project activity emissions during production

The electrical energy consumption of the production line may be assumed to be the same as that of the baseline and the project activity, and thus may be excluded from the calculation.

Scenario B2a: Direct project activity emissions during use – Direct emissions

Refrigerant:

The procedure remains the same as applied in the baseline, as it is assumed that the repair rates do not change significantly due to the change of refrigerant. Emissions from servicing arise from leakages and venting the refrigerant circuit prior to repair. The repair rate is the fraction of refrigeration appliances produced during one year and is based on empirical data. Direct refrigerant emissions from appliance use are computed using equation (8).

$$PE_{ref, use} = \sum_r FRR \times TIC_{ref, r} \times GWP_{ref, r} \quad (8)$$

where FRR is the repair rate, the fraction of repaired refrigeration appliances that are produced during one year.

Scenario B2b: Indirect project activity emissions during use

Energy consumption:

The yearly emissions due to the project activity are calculated as the product of electricity consumption and the emission factor for electricity generation, according to equation (9).

$$PE_{elec} = \sum_i \frac{EC_i \times N_i \times EF}{1000} \quad (9)$$

where PE_{elec} is the emissions due to the project activities [t CO₂]
 EF is the emission factor for electricity [t CO₂/MWh]
 EC_i is the average electricity consumption of model i during the project per year [kWh]
 N_i is the number of appliances of model i produced during the project

Scenario B3a: Direct project activity emissions at disposal

Refrigerant:

At disposal of the unit the amount of refrigerant that was initially filled into the cabinet, or refilled during servicing, is released to the atmosphere. This is calculated using equation (10):

$$PE_{ref, disp} = TIC_{ref} \times GWP_{ref} \quad (10)$$

where $PE_{ref, disp}$ is the project activity emissions of refrigerants at disposal
 GWP_{ref} is the global warming potential of refrigerant [t CO₂/t ref]

with

$$TIC_{ref} = \sum_i \frac{N_i \times C_i}{1000}$$

where TIC_{ref} is the total initial charge of refrigerant [t]
 i is all the produced models
 N_i is the number of produced appliances of model i
 C_i is the refrigerant content of model i [kg]

Scenario B3b: Indirect project activity emissions at disposal

Energy consumption:

There are no indirect emissions units are disposed of that are affected by the project activity.

2.3 Emissions reduction

The emissions reduction is calculated as the difference between baseline and project activity emissions using equation (11).

$$ER = BE_{total} - PE_{total} \quad (11)$$

where

ER is the total emissions reduction [t CO₂e]

BE_{total} is the total baseline emissions [t CO₂e]

PE_{total} is the total projected emissions [t CO₂e]

2.4 Parameter monitoring

In order to make sound estimates of emissions, monitoring of parameters is necessary. However, there are parameters that are determined only once, at the beginning of the project and remain constant during the project activity. These are stated in Table A2-2. Others, as stated in Table A2-3, must be monitored continuously and reports on their changes made annually.

Table A2-2 Parameters that remain constant

Parameter	Unit	Description	Source
GWP_{ref}	t CO ₂ e/t ref	Global warming potential for refrigerants	IPCC / TEAP SROC Report ⁷
EF_{prod}		Emission factor for losses during production	IPCC 2006
EF_{use}		Emission factor for losses during operation (leakages and servicing)	IPCC 2006

Table A2-2 Parameters that remain constant

Parameter	Unit	Description	Monitoring interval	Source
N_i		Number of produces cabinets monitored separately for each model	Annual	Factory report
$C_{ref, i}$	kg	Refrigerant content of model i	Determined once for each model	Factory report
EC_i	kWh/y	Average electricity consumption of model i per year	Determined once for each model	Test report
FRR	kgCO ₂ /kWh	Annual repair rate	Annual	Factory report
EF		Emission factor for electricity	Annual	Energy supplier or other reliable sources*

* For example, EIA or IPCC

APPENDIX 3 REQUIREMENTS FOR HAZARDOUS AREAS

Within Europe, there are two directives that specify the means of handling situations where there is a possibility of hazardous, or potentially explosive atmospheres. These two directives deal with (i) minimum requirements for improving the health and safety protection of workers potentially at risk from explosive atmospheres and (ii) concerning equipment and protective systems intended for use in potentially explosive atmospheres. These are collectively referred to as “ATEX” (from Atmosphères Explosives) directives. There are a number of European standards which are harmonised with the ATEX directives which deal with a variety of different requirements that relate to hazardous atmospheres, such as requirements for Ex-rating of equipment. Ex-rated equipment is symbolised using the sign EX, as depicted in Figure A3-1.

Figure A3-1: Symbol to indicate ATEX areas in a work place



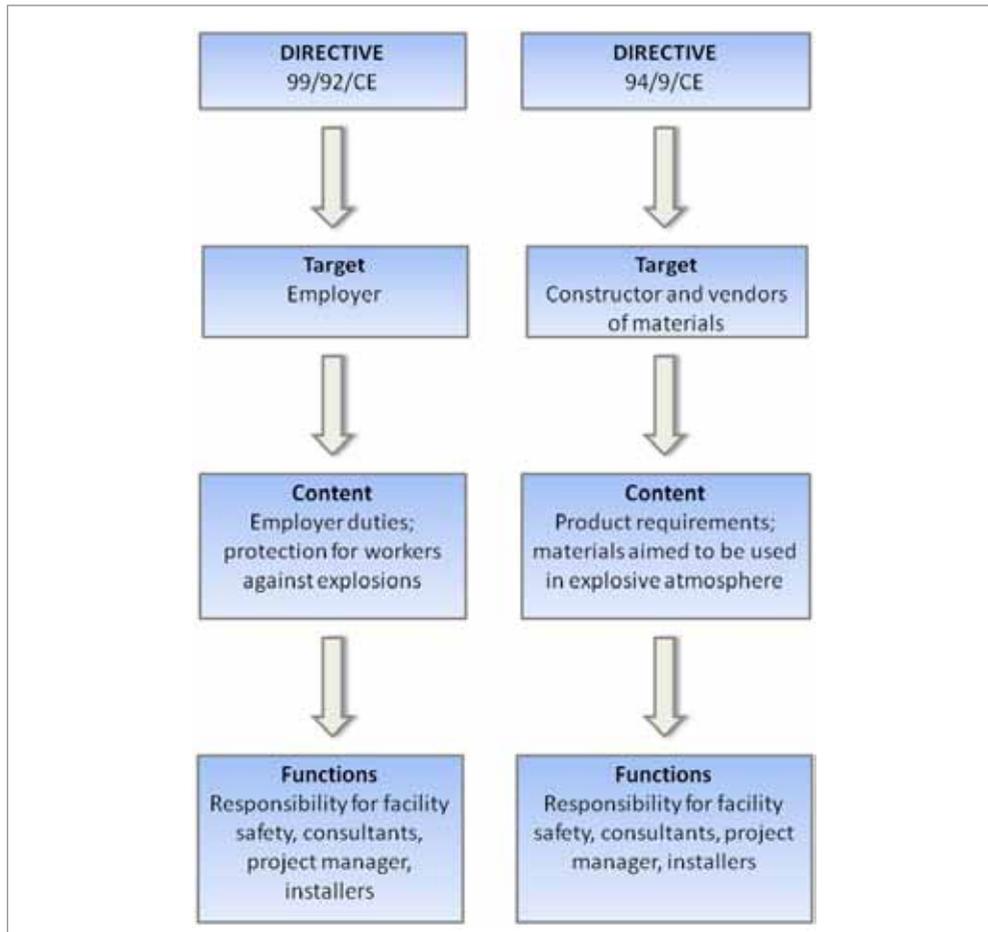
On a work site, either in the open or in a closed space, wherever flammable substances are present in large or small quantities, stored or manipulated, the environment and processes must be considered under the ATEX directives.

It is important to emphasise that ATEX directives do not necessarily regard the construction of equipment or specialised plants. Rather they are a way to understand if we find ourselves in a hazardous area and if it is necessary to apply appropriate behaviour and/or use designated equipment constructed according to the standards.

The directives, represented in the flowchart in Figure A3-2, applied to work sites with explosion risk are:

- 99/92/CE that sets the standards for the protection of the workers, and
- 94/9/CE that sets the standards for the materials and equipment designed for use in potentially explosive areas.

Figure A3-2: Directives applied to work sites with risk of explosive atmospheres



Conformity to Directive 99/92/CE

Identifying and understanding the problems arising from the use of flammable substances in a facility is paramount to the safety of all involved personnel. Directive 99/92/CE sets the considerations for the protection of the workers. Two broad steps can be taken: first, to identify the hazardous areas on the work site and classify the areas according to the standard zones; second, to evaluate the explosion risk, which involves considering and analysing all possible areas and situations prone to explosion, and taking actions or measures for prevention.

STEP 1: Identify hazardous areas

Once the choice of flammable substance for the production cycle is made, it is important as a first step to evaluate where, how and in which way hazardous areas will appear. This is done by applying Directive 99/92/CE in the following way:

1. Identify the flammable substances used in the process.
2. Apply the standard EN 60079-10-1 for explosive atmospheres in the form of gas, mist and vapours.
3. Issue a document in which the hazardous areas are indicated as function of the physical state of the substance and the frequency and duration of an explosive atmosphere.

The document consists of a report edited by an expert in the field accompanied by a lay-out of the facility indicating the areas defined as hazardous. The hazardous areas are classified by the type of flammable gas, vapour and/or mist present and are divided into three zone classes or areas, shown in Table A3-1.

Table A3-1 Hazardous zones

ZONES	RISK LEVEL	AREA DESCRIPTION
0	High	Presence of a consistent explosive atmosphere for long periods of time. In other words, the area which is frequently in a mixture of air and flammable substance in the form of gas, vapour or mist.
1	Medium	Area in which the formation of a consistent explosive atmosphere in a mixture of air and flammable substance in the form of gas, vapour or mist is likely to occur occasionally.
2	Low	Area in which during normal activity a formation of a consistent explosive atmosphere in a mixture of air and flammable substance in the form of gas, vapour or mist will not occur. If it occurs it would be due to malfunction or damage, and the duration will only be for a short period of time.

STEP 2: Evaluate explosion risk

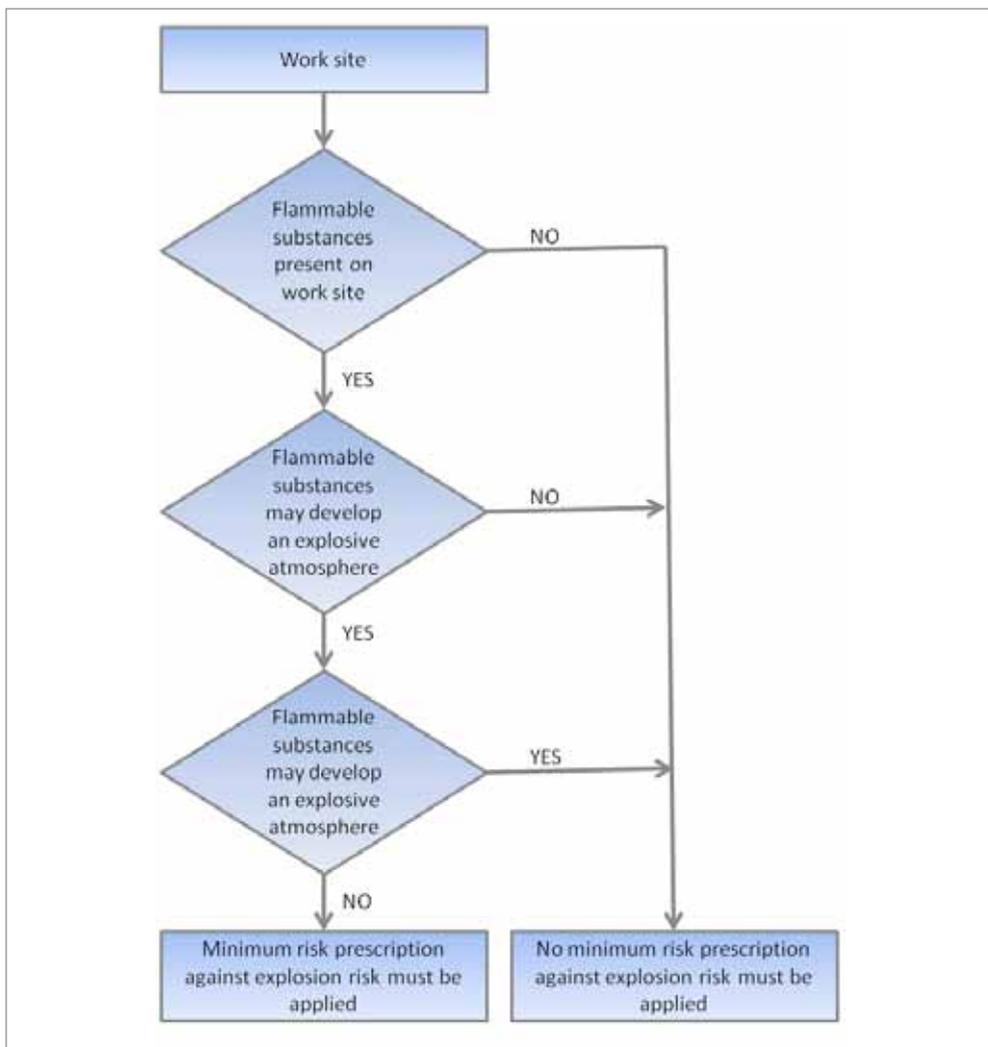
Once the hazardous areas have been identified, the explosion risk must be evaluated. It is important to note that the European standards regard only explosive atmosphere in air under normal conditions of pressure 0.8-1.1 bar and temperatures between -20 to +60°C, as this is the most common conditions.

Explosion risk can be excluded when:

- No flammable substances are present;
- Flammable substances are present but cannot develop an explosive atmosphere, e.g. if the temperature of the flammable substances remains constantly under flash-point, or if they are not in contact with air;
- Explosive atmosphere can develop but in reduced volume (zone negligible extent) that does not constitute any risk for the personnel present.

A flowchart, as depicted in Figure A3-3, can be used to apply minimum safety measures at work sites.

Figure A3-3: Minimum safety measure application flowchart.



It is of extreme importance that a specific analysis for explosion risk is carried out by an experienced certified expert. Measures have to be applied, for example in a case where a supplier indicates that a container of a substance does not pose any risk but the reality in the factory is that many more containers are used and that the sum DOES pose a risk.

The responsibility to verify whether or not the minimum prescription against explosion need to be applied lies solely in the hands of the user and NOT the raw material supplier!

The first thing to do when evaluating explosion risk is to exclude, if possible, the presence of explosive atmosphere. If this is not possible then proceed to the evaluation of explosion risk, in the different areas and under different conditions. Finally, appropriate measures and actions should be put in place to address the risks.

Figure A3-4 illustrates the evaluation procedure, areas and issues to consider and the actions to take when evaluating risks for explosion.

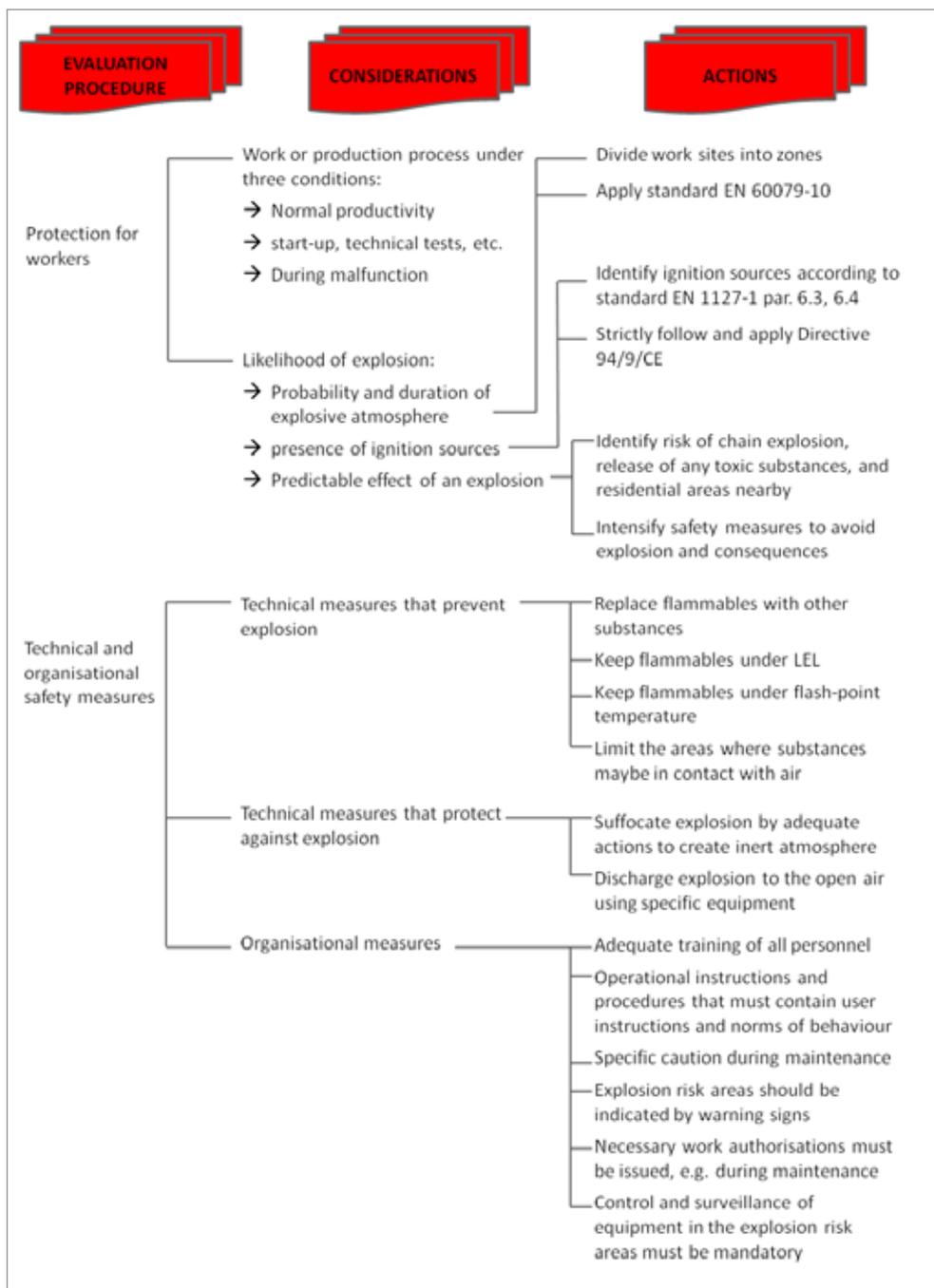
Conformity to Directive 94/9/CE

Directive 94/9/CE sets the standards for the materials and equipment designed for use in potentially explosive areas. It is important to understand that choosing equipment conforming to the standards guarantees that such products will not create efficient ignition sources, and if no special ambient conditions exist, there is no need to evaluate the reliability of the product, as this is already done by the manufacturer.

Understanding the conformity of a certain product means to understand if a product is appropriate for installation in a hazardous area. The appropriateness of the product, or equipment that includes safety devices for control and regulation and related components, is determined by the conformity evaluation of the equipment from the manufacturer.

Equipment to be installed in hazardous areas defined by ATEX bears a distinct marking: a number representing equipment category, followed by a letter (“G” for hazards arising from gas, vapour or mist, and “D” for hazards arising due to dust). Table A3-2 explains the equipment categories using the letter “G”. In domestic refrigeration the hazardous areas are mainly due to gas, vapour or mist.

Figure A3-4: Evaluation procedure, considerations and actions for explosion risk assessmentⁱⁱⁱ



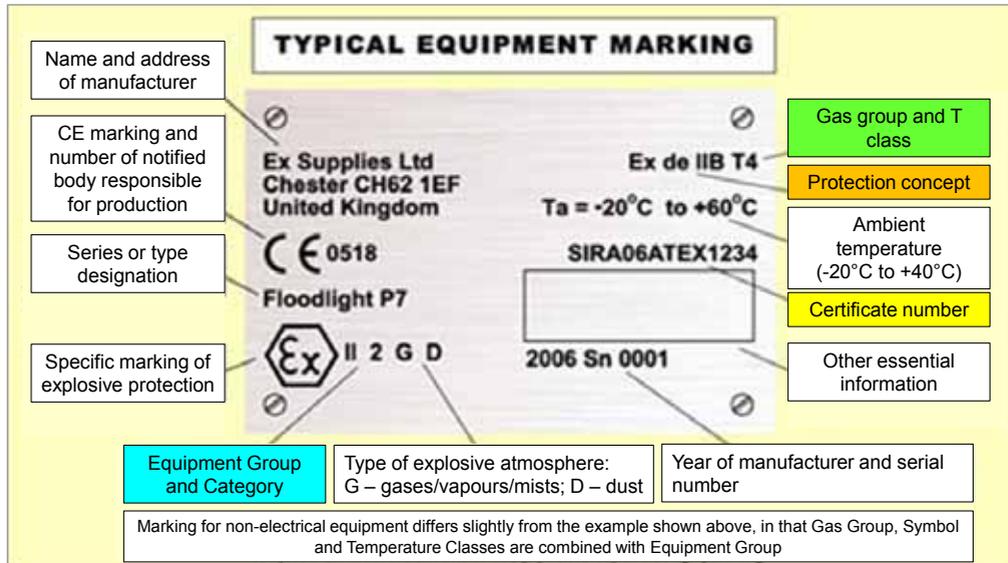
ⁱⁱⁱ Adapted from Croiset et al., 2011

Table A3-2 Equipment categories for installation in zoned areas due to gas

EQUIPMENT CATEGORY	REQUIREMENTS	SUITABLE ZONE	
1G	<ul style="list-style-type: none"> - equipment must have an EC-Type Certificate issued by an appropriate authority - manufacturer must use an approved quality system for the production - manufacturer must perform inspections following the national directives - manufacturer must be audited by the appropriate authority required by the Directive. 	0	
2G	1. Electrical equipment or combustion engines	<ul style="list-style-type: none"> - equipment must have an EC-Type Certificate issued by an appropriate authority - manufacturer must use an approved quality system approved by appropriate authorities - manufacturer must declare, under the control of appropriate authorities, that the product is in conformity with the approved prototype. 	1
	2. Non-electrical equipment	<ul style="list-style-type: none"> - not necessary for the equipment to go through the CE exam performed by appropriate authorities - it is sufficient that the manufacturer provides the technical documentation proving the conformity of the equipment, making sure to hand in the document to the appropriate authority. 	
3G	<ul style="list-style-type: none"> - No CE exam performed by appropriate authorities is required. It is sufficient that the manufacturer provides the technical documentation to the appropriate authority. 	2	

A typical CE marking plate is illustrated in Figure A3-5, and a sample CE Certificate provided in Figure A3-6.

Figure A3-5: A typical CE marking plate



Substances in use

Any flammable substances used in a facility require ATEX conformity verification, independent of the amounts used. The responsibility in all cases lies in the hands of the user of the products and not the producer of the flammable substance. Therefore it is highly recommended that the substance used and compositions are verified with great attention in order to also consider proper blends and flammable components.

Where mixtures of fluids are used, careful verification is strongly recommended due to the different boiling points at which these can separate. Although as a mixture the blends are not flammable, the single components may be and therefore all safety precautions must be followed.

Figure A3-6: A sample CE certificate

	CE CERTIFICATE
[1] TYPE EXAMINATION CERTIFICATE	
[2] Component destined for use with apparatus or protective systems intended for use in potentially explosive atmospheres	
Directive /9/CE	
[3] Number of Type Examination Certificate:	
[4] Component:	
[5] Manufacturer:	
[6] Address:	
[7] This component and its acceptable variations thereto are specified in the schedule to this certificate and the documents therein referred to.	
[8] (Name and reg. no. of appropriate authority)in accordance with Article 9 of 94/9/CE of the EU Council Directive of 23 March 1994, certifies that this component has been found to comply with the essential health and safety requirements relating to the design and construction of equipment and protective systems intended for use in potentially explosive atmospheres, as described in Annex II to the Directive.	
The examination and test results are recorded in the confidential Assessment and Test No	
[9] Compliance with the essential health and safety requirements is ensured by compliance with:	
EN 60079-0:2006	EN 61241-0:2006
EN 60079-11:2007	En 61241-1:2004
[10] The symbol "U" placed after the certificate number indicates that this certificate must not be considered as certificate for apparatus or protective systems. This partial certificate can be used as a base for certificate for apparatus or protective systems.	
[11] This CE Type Certificate relates only to the design and construction of the specified apparatus or protective system in accordance with Directive 94/9/CE. Further requirements of this Directive apply to the manufacture and supply of this component. These requirements are not covered by this certificate.	
[12] The marking of the component must include: II 2 GD Eex IIC IP 66/67 	
This certificate, attachment included, can only be reproduced in full and without variation.	
Date of Issue:	
Processed:	Approved:
(Name, Surname)	(Name, Surname)

Potentially explosive atmosphere:

For an explosion to occur three components must be present at the same time, mixed in proportions within the flammability limits:

- Presence of flammable substance within the correct concentrations
- Oxidator, the oxygen in the surrounding air, which is at around 21% oxygen
- Ignition source, e.g. electrostatic discharge, heat, etc. The standard EN 1127-1 identifies 13 different types of potential sources of ignition.

Gas, vapour and mist are considered flammable if, when they are mixed in the right proportions with oxygen and may cause an explosion. It is important to consider the difference between the gases apart from explosive substances. Explosive substances contain both the combustible substance and the comburant and therefore may explode in absence of oxygen. This gives the fire triangle, depicted in Figure A3-7.

Figure A3-7: Fire triangle



Explosion limits

Explosion limits or flammability limits of a gas or liquid vapour are limits identifying the range of concentration in which, if the mix air-vapour or flammable gas is ignited, such as by a spark, combustion of the mixture can take place. This combustion can result in an explosion or deflagration, depending on various factors, e.g. concentration of combustible, type of container, etc. The range of the event is limited by a minimum and a maximum percentage of combustible in the air, or less frequently, other combustible agents. These percentages are called Lower Explosive Limit (LEL) and Upper Explosive Limit (UEL).

For concentrations below LEL, there is not enough fuel for propagation of the flame.

For concentrations above UEL, the atmosphere is saturated with fuel (i.e. not enough air) and there is insufficient oxygen for the propagation of the reaction.

The situation of the concentrations over UEL is typical for a tank containing flammable liquid, such as solvent, pentane, petroleum, etc. stored at atmospheric pressure. The vapour developed by the flammable liquids makes the atmosphere constantly saturated and therefore above the UEL, but will nevertheless be considered as Zone 0. Unfortunately this can change during filling/emptying processes or during maintenance. In general the use of substances exceeding the UEL should be handled with special attention.

To control the concentration of flammable substances is one of the main problems in the field of safety when using hazardous substances. In some cases, to reduce the concentration of one gas that is explosive, inert gases like nitrogen can be used to replace air (the oxidator) to make the mixture less hazardous. This operation is called “inertisation”.

ATEX AREAS

The hazardous areas or zones within a facility consist of the departments where flammable substances are in use or stored. Inside the facility ATEX areas can be in the following places:

1. Refrigerant storage tank
2. Point where tank truck stops to load the refrigerant into the tank
3. On the pump/pumps feeding the high pressure pump
4. Inside the high pressure pump room
5. Inside the building where refrigerant is charged
6. Along the gas feeding line to the circuits
7. Inside the finished product storage

The safest and easiest way to classify the sites is to apply the standard EN 60079-10-1 – “Electrical apparatus for explosive gas atmospheres part 10 Classification of hazardous areas”.

To obtain a precise application of the standard so as to specify exactly where in the facility the hazardous areas can be found, it will be necessary to engage an expert in the field who will:

- Apply the EN 60079-10 standard
- Consider all conditions: chemical, climate, geometry and topography of the facility, etc.
- Edit a project

Other applicable regulations, laws and standards are as indicated in Table A3-3.

Table A3-3 Applicable laws, regulations and standards within ATEX areas

Regulations and standards	Contents	Directives
Declaration of conformity	EG machine directive	89/392/EWG, revised edition 91/368/EEC
Environmental protection of atmosphere, ground and water against contamination	Control of emissions from storage and distribution of petrol Landfills Urban wastewater treatment	94/63/EC; 1999/31/EC; 91/271/ EEC
Pressure vessel regulation	European pressure vessels	97/23/EC
Storage, filling and transport of flammable liquid	Equipment for the storage, filling, and transport of flammable liquids over land	12/13/96
Electromechanical standards	Type-tested low-voltage switchgear and control gear assembly, Electrical safety of machinery; Electrical safety of machinery and of applications in accordance with insulation resistance, earthing conductor resistance, functions; Electrical apparatus for the detection and measurement of combustible gas; General requirements and test methods	IEC 60073; IEC/EN 60439-1/A2; IEC/EN/UL/SABS; 60204-1; IEC 1310-2; EN 50054; EN 50054; EN 50054
Standards for flammable liquid tanks	Specification for design and manufacture of site-built, above-ground, vertical, cylindrical, and welded flat-bottomed, steel tanks for the storage of liquids at ambient temperature and above; Specification for tank vent flame arresters; Test apparatus and method of testing for maximum experimental safe gap; Flame Arresters for General Use	EN 14015; ASTM F1273-91; IEC 600079-1A; BS 7244
Non-electrical equipment	Non-electrical equipment intended for use in potentially explosive atmospheres – basic methods and requirements; Non-electrical equipment intended for use in potentially explosive atmospheres – protection by constructional safety; Flame arresters: performance requirements, test methods and limits for use	EN 13463-1 EN 13463-5 EN 12874
Fire protection	Fire protection	EN 2-3
Technical regulations for ventilators in ex-zones	Ex-proof / spark-proof for ventilators; Plastics and rubber machines, reaction moulding machines, safety requirements	VDMA 24169 Part 1, ADPE, EN 1612-2
Safety requirements	Safety requirements for automated manufacturing systems; Refrigerating systems and heat pumps, safety and environmental requirements; Industrial Thermo-Processing Equipment; Compressors and Vacuum Pumps	VDI 2854 EN 378 EN 746-2 EN 1012-2
Quality management standards	Potentially explosive atmospheres, application of quality management systems	EN 13980

APPENDIX 4 CONTENTS FOR REFRIGERATION TRAINING STANDARD

Introduction

This Appendix contains information relating to a set of competencies for technicians that work with any refrigerating system, to some extent. These were developed by the European Association of National Air-Conditioning and Refrigeration Contractor Associations (AREA). AREA is the European organisation of air conditioning, refrigeration and heat pumps contractors, and was established in 1988. AREA voices the interests of 23 national members from 20 European countries, representing more than 9,000 companies across Europe (mainly small to medium sized enterprises), employing some 125,000 people and with an annual turnover approaching €20 billion.

GENERAL JOB DESCRIPTION OF THE AREA Refrigeration Craftsman "ARC"

Work environment	<p>The AREA refrigeration craftsmen/craftswomen (ARC) work in different locations e.g. his company's workshop, construction sites, retail shops, factories, industrial areas, etc. The type of installation, the equipment he works with and the complexity of the design vary with his specific order.</p> <p>Most ARC work in small- (3-10 persons) and medium- (11-50 persons) size refrigeration contracting companies. These companies offer services in the fields of installation, sales, maintenance, repair, inspection and re-design of existing systems. The sub-sectors where they cover most activities primarily include commercial refrigeration, industrial refrigeration and comfort air-conditioning. Activities in transport refrigeration, refrigeration for process industries and mobile air-conditioning are also performed but not so often.</p> <p>Besides the refrigerating systems, the companies are involved in air treatment and electro-technical installations. They work generally country-wide but sometimes regionally or internationally. A substantial number of the refrigeration contracting companies are members of the national member associations of AREA.</p> <p>Typical customers are retailers, wholesalers, cold storages, food and pharmaceutical or medical industries, agro-businesses, manufacturing industries and office buildings constructors or operators.</p>
Work content	<p>With the help of work instructions, the ARC plans, prepares and performs the assembling of all parts of the refrigeration systems, which will be then commissioned and put into service. He also maintains, inspects, checks and repairs the refrigeration systems when there is a problem. He always controls his own work and records his tasks in the logbook linked to a specific installation. At all times he is respectful of the relevant requirements concerning the environment, quality, safety and energy efficiency. He is also involved at the end of life of the equipment.</p>
Responsibilities	<p>The ARC is responsible for the preparation and the execution of his own tasks, in accordance with the work instructions that he received. He is not responsible for others or other people's work, with the exception of his assistant(s).</p>
Professional attitude	<p>A certain amount of independence is expected from the ARC. He always gets his work instructions from his supervisor but most of the time he is alone on his way to a client and he performs his tasks independently of others. Also the ARC has to have a sense of responsibility. He needs to strive for high quality in his work, and he must permanently be conscious of the importance of meeting the environmental and safety requirements.</p> <p>Traditionally the ARC needs to have a service driven attitude, especially when he has to explain his work progress to the client or when he has to communicate with the client about the best possible work procedure in order not to interfere with the client's company operations.</p>

GENERAL JOB DESCRIPTION OF THE AREA Refrigeration Craftsman "ARC"

TRENDS

<p>Market changes</p>	<ul style="list-style-type: none"> - In order to avoid an increase of the charge of the refrigerating fluid in a refrigeration system, more cascade and indirect systems are used. The use of environmentally friendly refrigerants is researched. There are related safety issues. - The ARC will be even more service minded: there is a growing diversity services to customers, e.g. offering specific maintenance and lease contracts. Clients focus on their core business. - The industry is trying to bring solutions to a recurrent shortage of qualified personnel in most countries. - There are frequent mergers of refrigeration contracting companies. - Globalisation: see below European harmonization
<p>Regulations</p>	<ul style="list-style-type: none"> - There is a growing number of evolving rules about safety, health and consumer protection and environmental regulation, mainly European legislation; but also rules about quality, care and certification (e.g. PED, EN 378, and the F-gas regulations). Safety requirements concern refrigerants and installations. - Durability is now a well-established and sustained trend.
<p>Technical and technological developments</p>	<ul style="list-style-type: none"> - The use of Ammonia as a refrigerant is increasing versus the F-gases. This will lead to changes in environment and safety directions (e.g. certification and other requirements of the F-gas Regulations). - There are more indirect refrigeration installations: less refrigerant, distribution through secondary heat carrier and bigger pipeline systems. This affects design, assembling and maintenance operations. - More standardized units and prefabricated parts will somewhat simplify assembling activities. - Welding and connecting techniques are evolving, more TIG-welding. - Developments occur in the field of measurement and control technique: less electrical and pneumatic parts, more electronic and mechanical instrumentation. - Generally, we find better, larger and more sophisticated equipment, more precise instruments, faultfinding devices, digital logbooks and new communication means.
<p>Organisational & management changes</p>	<ul style="list-style-type: none"> - More regulations mean more administrative work and procedures. The ARC has more to report and in the office of the company; it brings more work to handle the procedures and to act on the results of the reports of the ARC.
<p>European harmonisation</p>	<ul style="list-style-type: none"> - The mutual recognition and the free movement of goods increase cross border activities. - The European legislation adapts itself to this situation to allow the Internal Market to be operational.

CORE ACTIVITIES OF THE AREA Refrigeration Craftsman

These are as follows:

1. PRE-ASSEMBLY OF THE REFRIGERATION SYSTEM
2. INSTALLATION OF THE REFRIGERATION SYSTEM
3. REPORTS, CHECKS AND TECHNICAL ADMINISTRATION
4. COMMISSIONING
5. MONITORING AND INSPECTION
6. FAULT FINDING AND REPAIR
7. DISMANTLING OF THE REFRIGERATION SYSTEM

CORE ACTIVITY 1: PRE-ASSEMBLY OF THE REFRIGERATION SYSTEM	
Process	The ARC collects the instructions, material lists and drawings for the part of the installation that he has to pre-assemble. He checks the materials, equipment and instrument needed for his work. He makes sure that no moisture or dirt can enter the pre-assembly.
Role & responsibilities	The ARC independently pre-assembles the refrigeration and electro-technical system following the work instructions received. Most often this work is performed in the workshop of his company or in a workshop, at the customer's location, under the supervision of a manager.
Complexity	While performing this key task, the ARC follows the work instructions applicable to various recurring activities like electrical wiring, brazing of pipeline systems.
Involved with	The ARC has to deal with supervisors, other colleagues and assistant(s).
Resources	To perform properly, the ARC needs tools and equipment like work bench, bending devices, brazing materials.
Quality of process & results	The ARC has to perform the task within the available time, according to the work instructions and following the legally prescribed procedures; he has to comply with the registration and administration documentation.
Choices & dilemmas	The ARC has to take into account that: <ul style="list-style-type: none">- he does not have an overview of the final place where the pre-fabricated part will be placed in the installation and how;- a colleague should at any time be able to take over his work;- a colleague should be able to place his pre-assembled part in the final installation.

CORE ACTIVITY 2: INSTALLATION OF THE REFRIGERATION SYSTEM

<p>Process</p>	<p>The ARC assembles refrigeration and/or air-conditioning installations in accordance with his company's directions, the project's work instructions and the relevant drawings and diagrams. These are specific refrigerating systems (compressor, condenser, expansion valve, one or two evaporators, and specific components). The materials are mentioned on a list that specifies the main components, copper pipes or other piping, electrical switches and wiring, instruments and flexible insulation materials.</p> <p>Part of the needed materials can be taken from his service van. He checks the quantity against the quantity of the materials in his van at the start of the project. He discusses with the client about the work that he is going to perform and the interference that it may have in the customer's company operations. Therefore the ARC should take into account the client's operations when planning his work.</p>
<p>Role & responsibilities</p>	<p>The ARC is responsible for:</p> <ul style="list-style-type: none"> - the good communication with the client - the quality of his work and of his assistant's work - performing the job within the given timeframe - the state-of-the-art installation of all parts in the refrigeration installation
<p>Complexity</p>	<p>The ARC has to take into account the interests of his own company, as well as the interests of the client's company. During his work, he has to comply with the safety and environmental aspects of the installation and the client's company. He has to adapt his work to the circumstances on the site.</p>
<p>Involved with</p>	<p>The ARC often works together with an assistant. He is also involved with the client organization, with personnel of subcontractors and personnel performing other tasks for the client.</p>
<p>Resources</p>	<p>The ARC uses the tools that are put at his disposal by his employer or that he has specially rented.</p>
<p>Quality of process & results</p>	<p>The ARC is expected to deliver the installation up and running as planned and designed for, and within the given timeframe. So the installation can contribute to the objectives of the client.</p>
<p>Choices & dilemmas</p>	<p>The ARC works on the client's premises, the circumstances can be different and unforeseen changes can occur. This can influence the quality and the expected delivery date and the ARC has to react properly. He has constantly to take into consideration the client's interests and his company's interests. When interests are conflicting, he has to inform the involved party without causing commercial harm.</p>

CORE ACTIVITY 3: REPORTS, CHECKS AND TECHNICAL ADMINISTRATION

Process	At all times the ARC should respect environmental, safety and health related legislation, especially after commissioning an installation. The installation has to be delivered as a safe, reliable and efficient product, following the EC marking requirements of the Machinery Directive. He works with different kinds of refrigerants and each has its own safety and environmental constraints, both nationally and internationally. The ARC is a key actor who has a great impact on the final result of the product or service supplied.
Role & responsibilities	The ARC is responsible for the correct assembling of the components, particularly the valves, according to the company's directions and the technical instructions of the equipment installed. He is responsible for his own work and for the work of his assistant(s). He has to pay special attention to the piping work and the pipe connections by hard soldering or brazing.
Complexity	As the ARC works on different sites, he should be able to perform his work under different and changing circumstances.
Involved with	The ARC often works together with an assistant. He is also involved with the client organization, with personnel of subcontractors and personnel performing other tasks for the client.
Resources	The ARC receives from his employer the handbook directions and the work instructions. The employer is responsible for the personal qualification and certification of the ARC.
Quality of process & results	The ARC is expected to know the content of the work instructions and directions and to have the knowledge corresponding to his personal certificates.
Choices & dilemmas	The ARC could run into conflicting situations between his own company's interests, the client's company's position and regulatory constraints.

CORE ACTIVITY 4: COMMISSIONING

<p>Process</p>	<p>The installation is commissioned at the client's site. During the building up of the installation, the Pressure Equipment Directive requirements have to be respected. The ARC checks the refrigerating system on the following items:</p> <ul style="list-style-type: none"> - electrical supply and electrical process control, - leakage control through a pressure test, - evacuating the system and vacuum testing so that there is no remaining moisture. <p>The ARC should work according to the relevant regulations and should register all the data into a protocol. The ARC fills the system with refrigerant. He does a second leakage check of the system. He puts the refrigeration system into operation in accordance with the design conditions. He registers all the data and figures in the logbook of the system. The ARC makes a report for the client and his company and writes the transfer protocol.</p>
<p>Role & responsibilities</p>	<p>The ARC is responsible for putting into service on site the refrigeration system in accordance with the design conditions. He makes sure that all legal and company procedures are followed in the starting process.</p>
<p>Complexity</p>	<p>The ARC takes into account that he works under the management of his company, but at the site of the client. The refrigeration system is sometimes a part of a whole production process of the client and he is only responsible for the refrigeration system so that he is depending on this production process.</p>
<p>Involved with</p>	<p>The ARC is has to work in cooperation with supervisors of other companies on the same site of the client.</p>
<p>Resources</p>	<p>The ARC has received his tools and equipment from his company to carry out his job.</p>
<p>Quality of process & results</p>	<p>The ARC is expected to deliver the installation in accordance with the design figures and at the right time, so that the installation can contribute to the goals of the client.</p>
<p>Choices & dilemmas</p>	<p>The ARC works on the client's premises, the circumstances can be different and unforeseen changes can occur. This can influence the quality and the expected delivery date. The ARC has constantly to take into consideration the client's interests and his company's interests. When interests are conflicting, he has to inform the party involved without causing commercial harm.</p>

CORE ACTIVITY 5: MONITORING AND INSPECTION

Process	The ARC is called by the client to check if the refrigerating system is working according to the design conditions. He has also to look if everything is respecting the safety and environmental regulations. The ARC has to write a report with his findings and conclusions and, if necessary, advise what the client has to do to bring the refrigeration system in good working conditions. A copy of his report goes to the installer company.
Role & responsibilities	The ARC is responsible for checking the refrigeration system according to the applicable directions and particularly for observing that there is no leakage. He is responsible for the content of his report and for coming to the right conclusions.
Complexity	The ARC has a direct contact with the client, he understands the contractual and commercial relationship between his company and the client and the consequences thereof, but he has to do his job independently and consider only the real figures and the factual observations.
Involved with	The ARC has to carry his task in good cooperation with the responsible person of the client organisation.
Resources	The ARC receives his tools and equipment from his company to carry out his job.
Quality of process & results	The ARC has to do his job while the installation is in operation without interrupting the working process of the client. The result must be to give to the client a reliable and good working refrigeration system for the future so that the installation can contribute to the goals of the client.
Choices & dilemmas	The ARC has to do his job during the time that the installation is in service without interruption of the working process of the client. But this is not always possible. The ARC has to negotiate his working conditions with the client to allow him to work professionally as planned. When the ARC identifies a problem, he has to negotiate about the best solution, bearing in mind the commercial relation between the client and his company.

CORE ACTIVITY 6: FAULT FINDING AND REPAIR

Process	The ARC is called by the client to research and find the fault and to repair parts or components of the refrigeration system because it is not working according to the design conditions or environmental and safety regulations. The ARC has to repair it as fast as possible and in a secured way. The ARC has to write a report explaining the results of his work and, if necessary, further advise what the client has to do to bring the refrigeration system in good condition for the future. A copy of his report goes to the installer company.
Role & responsibilities	The ARC is responsible for the results of his fault finding and repairing of the refrigeration system according to the information received and for checking that there is no leakage after his repair job, especially at the part/component repaired or replaced. He is responsible for the content of his report.
Complexity	The ARC has a direct contact with the client, and he could feel some pressure arising from the commercial relation between his company and the client but he has to do his job as soon as possible and following legal and regulatory directions.
Involved with	The ARC has to carry out his task with a good cooperating spirit and to negotiate with the responsible person of the client.
Resources	The ARC receives his tools and equipment from his company to carry out his job.
Quality of process & results	The ARC has to work normally during the time when the installation is in operation, without interruption of the working process of the client, but most of the time that is not possible so he has to negotiate so that a minimum of productive time is lost during his intervention. The result must be to give to the client a reliable and good working refrigeration system for the future, so that the installation can contribute to the goals of the client.
Choices & dilemmas	The difficulty is to work during the time when the installation is in operation. The ARC has to do his job professionally and quickly. When the ARC discovers that it is not feasible to keep the refrigeration system running, he has to negotiate about the best solution even if it is conflicting with the commercial relation between the client and his company.

CORE ACTIVITY 7: DISMANTLING OF THE REFRIGERATION SYSTEM

Process	Before dismantling, the ARC recovers the entire refrigerant and brings the refrigerant to a treatment plant in accordance with the applicable regulation. The ARC writes the necessary reports and gives a copy to his company so as they can register that the refrigeration system is out of operation and the recovered refrigerant has been taken care of.
Role & responsibilities	The ARC is responsible for the correct disassembling of the components and valves according to the company's directions and the instructions linked to the equipment. He is responsible for his own work and for the work of his assistant. The most important contribution is to bring all the refrigerant safely out of the refrigeration system.
Complexity	As the ARC works on different sites, he should be able to perform his work under different and changing circumstances, especially in this case where there is most of the time no commercial advantage and when the refrigeration system is generally in a poor condition.
Involved with	The ARC has to carry out his task with good cooperation and negotiate with the responsible person of the client, bearing in mind that there is no commercial interest.
Resources	The ARC receives his tools, equipment and recycling cylinders from his company to carry out his task.
Quality of process & results	The ARC is expected to know the content of the work instructions and directions and to have the knowledge corresponding to his personal certificates. The result has to be that there is no environmental pollution when he dismantles the refrigeration system.
Choices & dilemmas	The ARC could run into conflicting situations, being caught between his company, the client's company and the applicable legislation due to the absence of commercial interest and the difficulty of handling a system in bad condition.

Detailed ARC competence description

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below
		Pre-assembly	Installation	Technical Reports	Commissionsing	Monitoring	Fault Finding	Dismantling	
1.1 Basic Thermodynamics		1	2	3	4	5	6	7	
Description									
	The ARC is capable of giving a theoretical explanation about a basic compression refrigerating system			X	X	X	X		EN 13313
Success Criteria									
1.1.1	Know the basic ISO standard units as for temperature, pressure, mass, density, energy			X	X	X	X		EN 13313
1.1.2	Understand basic refrigeration terms as: Superheat, High Side, Heat of Compression, Enthalpy, Refrigeration Effect, Low Side, Sub-cooling, Vapor Quality, Saturated Suction			X	X	X	X		EN 13313
1.1.3	Describe the lines of a Log P/h chart of a refrigerant			X	X	X	X		EN 13313
1.1.4	Use the saturation tables of a refrigerant			X	X	X	X		EN 13313
1.1.5	Draw a scheme of a single compression refrigeration cycle used in a refrigeration system and function of the main components			X	X	X	X		EN 13313
1.1.6	Describe the operation and function of the following components expansion valve, evaporator	X	X	X	X	X	X		EN 13313
1.1.7	Describe the operation and function of the following components used in a refrigeration system:								
1.1.8	- Valves (ball valves, diaphragms, globe valves, relief valves)	X	X	X	X	X	X		EN 13313
1.1.9	- Temperature and Pressure Controls	X	X	X	X	X	X		EN 13313
1.1.10	- Sight Glasses and Moisture Indicators	X	X	X	X	X	X		EN 13313
1.1.11	- Defrost Controls	X	X	X	X	X	X		EN 13313
1.1.12	- System Protectors	X	X	X	X	X	X		EN 13313
1.1.13	- Measuring Devices as manifold thermometer		X	X	X	X	X		EN 13313
1.1.14	- Oil Control Systems	X	X	X	X	X	X		EN 13313
1.1.15	- Receivers	X	X	X					EN 13313
1.1.16	- Liquid and Oil Separators	X	X	X					EN 13313
Results									
	The ARC explains "how the refrigeration system works" to a client.								
	The ARC analyzes the operation of the refrigeration system and writes his conclusions in a report.								

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below
		Pre-assembly	Installation	Technical Reports	Commissioning	Monitoring	Fault Finding	Dismantling	
2.1 Component: Compressor									
Description	The ARC is capable of installing, putting into operation and carrying out the maintenance of reciprocating, screw and scroll compressors, single and two stage up to a power supply of 25 Kw.								
Success Criteria									
2.1.1	Explain the function of the compressor in the system	X	X	X	X	X	X	X	EN 13313
2.1.2	Explains the working of the compressor	X	X	X	X	X	X	X	EN 13313
2.1.3	Explain the lubricating system of the compressor		X	X	X	X	X	X	EN 13313
2.1.4	Explain the capacity control of the compressor		X	X	X	X	X	X	EN 13313
2.1.5	Install the above mentioned different kinds of compressors	X	X				X		prEN 378-2 art. 5.1
2.1.6	Connect the safety and control switches	X	X				X		prEN 378-2 art. 5.1
2.1.7	Install the suction and discharge valves	X	X				X		prEN 378-2 art. 5.1
2.1.8	Install the oil return system	X	X				X		prEN 378-2 art. 5.1
2.1.9	Start up and shut down these kinds of compressors		X	X	X	X	X	X	prEN 378-2 art. 6.3
2.1.10	Do measurements during operation of compressor		X	X	X	X	X	X	prEN 378-4 art. 5
2.1.11	Check the good working condition of the compressor		X	X	X	X	X	X	prEN 378-4 art. 5
2.1.12	Write a report about the condition of the compressor		X	X	X	X	X	X	prEN 378-4 art. 4.3
2.1.13	Take the decision to repair the compressor		X		X	X	X	X	prEN 378-4 art. 4.3
2.1.14	Take the decision to replace the compressor				X	X	X	X	prEN 378-4 art. 4.3
Results									
	A perfectly working compressor contributes to a low energy consumption and a reliable performance as planned for the client.								

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below
		Pre-assembly	Installation	Technical Reports	Commissioning	Monitoring	Fault Finding	Dismantling	
2.3 Component: Evaporator		1	2	3	4	5	6	7	
Description	The ARC is capable of installing, putting into operation and carrying out the maintenance of air cooled and liquid cooled evaporators.								
Success Criteria									
2.3.1	Explain the function of the evaporator in the system	X	X	X	X	X	X	X	EN 13313
2.3.2	Explain the working of the evaporator	X	X	X	X	X	X	X	EN 13313
2.3.3	Explain the several ways of defrosting the evaporator		X	X	X	X	X	X	EN 13313
2.3.4	Adjust an evaporating pressure control of the evaporator		X	X	X	X	X	X	prEN 378-2 art. 5.1
2.3.5	Install the above mentioned kinds of evaporators	X	X						prEN 378-2 art. 5.1
2.3.6	Connect the safety and control switches	X	X						prEN 378-2 art. 5.1
2.3.7	Install the liquid and suction pipelines in the correct position	X	X						prEN 378-2 art. 5.1
2.3.8	Install the hot gas defrost pipeline in the right position	X	X						prEN 378-2 art. 5.1
2.3.9	Install the hot gas pipeline to protect a watercooled evaporator against low evaporation pressure		X	X	X	X	X	X	prEN 378-2 art. 5.1
2.3.10	Start up and shut down all kinds of evaporators		X	X	X	X	X	X	prEN 378-2 art. 6.3
2.3.11	Do measurements during operation of the refrigeration system		X	X	X	X	X	X	prEN 378-4 art. 4
2.3.12	Check the good working condition of the evaporator		X	X	X	X	X	X	prEN 378-4 art. 4
2.3.13	Check the surface of the evaporator		X	X	X	X	X	X	prEN 378-4 art. 4
2.3.14	Write a report about the condition of the evaporator			X	X	X	X	X	prEN 378-4 art. 4.3
2.3.15	Take the decision to repair a part of the evaporator				X	X	X	X	prEN 378-4 art. 4.3
2.3.16	Take the decision to replace the evaporator				X	X	X	X	prEN 378-4 art. 4.3
Results									
A perfectly working evaporator contributes to a low energy consumption and a reliable performance as planned for the client.									

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below		
		Pre-assembly	Installation	Technical Reports	Commissioning	Monitoring	Fault Finding	Dismantling			
3.1 Piping Description The ARC is capable of building a leak tight copper piping system in a refrigeration installation. Success Criteria	Work with copper tubes from a diameter of 1/4" (6mm) till 7/8" (28mm) and from 35 mm till 54 mm.	X	X					X	X	prEN378-2 art. 6.2	
	In particular in the following ways:										
	- flared joints diameter of 1/4" (6mm) till 3/4" (18mm)	X	X						X	X	prEN378-2 art. 6.2
	- bends of copper tubes diameter of 1/4" (6mm) till 3/4" (18mm).	X	X						X	X	
	- fixed connections by hard soldering diameter 1/4" (6mm) till 7/8" (28mm) and from 35 mm till 54 mm.	X	X						X	X	EN 13133
	Make hard soldering joints for the following connections:										
	• copper-copper	X	X						X		EN 13133
	• copper-steel	X	X						X		EN 13133
	• copper-brass	X	X						X		EN 13133
	Install valves in the correct position	X	X								prEN 378-2 art. 5.1
	Install solenoid, control valves and other devices in pipelines	X	X								prEN 378-2 art. 5.0
	Install flexible insulation	X	X								prEN 378-2 art. 5.1
	Make pipe supports	X	X								prEN378-2 art. 6.3
	Perform a strength pressure test	X	X	X							prEN378-2 art. 6.3
	Perform a tightness test	X	X	X							prEN378-2 art. 6.3
	Perform a functional test	X	X	X							prEN378-2 art. 6.3
	Perform a conformity test of the complete installation		X	X							prEN378-2 art. 6.3
Results											
Safe and environmentally friendly refrigeration piping system without leakage by starting up											
Environmentally friendly refrigeration piping system without leakage during operation											

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below
		Pre-assembly	Installation	Technical Reports	Commissioning	Monitoring	Fault Finding	Dismantling	
4.1 Electricity Description The ARC is capable of installing the electrical cabling and wiring of a refrigeration system. Success Criteria	1	2	3	4	5	6	7		
	4.1.1	X	X				X	EN 50110 art.3.2.4	
	4.1.2	X	X				X	EN 50110 art.3.2.4	
	4.1.3	X	X				X	EN 50110 art.3.2.4	
	4.1.4		X		X	X	X	EN 50110 art.3.2.4	
	4.1.5		X				X	EN 50110 art.6.2	
	4.1.6	X	X				X	EN 50110 art.6.2	
	4.1.7	X	X		X		X	EN 50110 art.6.2	
	4.1.8		X		X		X	EN 60204-1	
	4.1.9		X		X		X	EN 50110 art.6.2	
	4.1.10	X	X		X		X	EN 50110 art.6.2	
	4.1.11				X	X	X	EN 50110 art.5.3	
	4.1.12				X	X	X	EN 50110 art.5.3	
	4.1.13		X		X	X	X	EN 50110 art.5.3	
	4.1.14				X		X	EN 50110 art.5.3	
	4.1.15				X		X	EN 50110 art.5.3	
	4.1.16				X		X	EN 50110 art.5.3	
	4.1.17			X		X	X	EN 13313	
	4.1.18			X		X	X	EN 13313	
4.1.19			X	X	X	X	EN 13313		
Results									
A safe environment for the client and his personnel									
A reliable electrical system									

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below
		Pre-assembly	Installation	Technical Reports	Commissioning	Monitoring	Fault Finding	Dismantling	
5.1 Measurements and Analysis									
Description									
The ARC is capable of measuring and analyzing physical data, and of making a correct diagnosis.									
Success Criteria									
5.1.1	Use a manometer set			X	X	X	X	X	EN 13313
5.1.2	Use a thermometer			X	X	X	X	X	EN 13313
5.1.3	Use a Torr gauge			X		X	X	X	EN 13313
5.1.4	Use scales to weight refrigerant		X			X	X	X	EN 13313
5.1.5	Use a airflowmeter			X	X	X	X	X	EN 13313
5.1.6	Use an acid test kit to check an oil sample			X	X	X	X	X	EN 13313
5.1.7	Use a recovery set			X	X	X	X	X	EN 13313
5.1.8	Handle a refrigerant cylinder			X	X	X	X	X	EN 13313
5.1.9	Drain oil out of a system			X	X	X	X	X	EN 13313
5.1.10	Use a multimeter for measuring Volt/Amp/Ohm			X	X	X	X	X	EN 13313
5.1.11	Use an electronic leak detection device			X	X	X	X	X	EN 13313
5.1.12	Use a vacuum pump			X	X	X	X	X	EN 13313
5.1.13	Place the data in a Log P/h diagram			X	X	X	X	X	EN 13313
5.1.14	Place the data in a h/x diagram			X	X	X	X	X	EN 13313
5.1.15	Use product information			X	X	X	X	X	EN 13313
5.1.16	Use a computer programme to control the system			X	X	X	X	X	EN 13313
5.1.17	Write a report based on the results of the measurements and draw the right conclusions			X	X	X	X	X	F-gases regulation
Results									
Correct information about the condition of the system at the time of measuring / analyzing, to be recorded to allow historical review and future use									

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below
		Pre-assembly	Installation	Technical Reports	Commissioning	Monitoring	Fault Finding	Dismantling	
6.1 Communication Description The ARC is capable of informing a client about the working procedures and the use of the refrigeration system. Success Criteria	1	2	3	4	5	6	7		
	6.1.1	X		X	X	X	X	X	F-gas regulation
	6.1.2	X			X	X	X	X	prEN 378-4 Art. 4.2
	6.1.3				X	X	X	X	F-gas regulation
	6.1.4				X	X	X		F-gas regulation
	6.1.5		X		X	X	X		F-gas regulation
	6.1.6		X		X	X	X	X	F-gas regulation
	6.1.7		X		X	X	X		prEN 378-4 Art. 4.2
	6.1.8				X	X	X		F-gas regulation
	6.1.9				X	X	X	X	F-gas regulation
	6.1.10					X	X		F-gas regulation
	6.1.11		X		X	X	X		F-gas regulation
	6.1.12		X	X	X	X	X		F-gas regulation
Results									
		The client has received the necessary information about the system installed, at different times of its life cycle, and understands the performance that he can expect in the future.							

Job Competence		Core Activities							The National Authorities to certify Qualification have to make sure that European and National Regulations, Directives and Norms are complied with particular as mentioned below
7.1 Environmental and safety regulations	Description The ARC is capable of handling the refrigeration system in a way that there is no loss of refrigerant and its working is safe.	Core Activities							
		Pre-assembly	Installation	Technical Reports	Commissioning	Monitoring	Fault Finding	Dismantling	
Success Criteria		1	2	3	4	5	6	7	
7.1.1	Be aware and know the environmental and safety regulations	X	X	X	X	X	X	X	prEN378-4 art. 4.1
7.1.2	Carry out a pressure test to check the strength of the system	X	X						prEN378-1 art. 6.3.3
7.1.3	Carry out a pressure test to check the tightness of the system		X		X		X		prEN378-1 art. 6.3.4
7.1.4	Evacuate the system to a level 270 Pa	X	X		X		X		prEN378-4 art. 5.3
7.1.5	Fill the system with refrigerant without loss of refrigerant		X		X		X		prEN378-4 art. 5.4
7.1.6	Control the charge of refrigerant				X		X	X	prEN378-4 art. 5.4
7.1.7	Do a visual inspection of the whole system especially the joints		X	X	X	X	X		prEN378-4 art. 5.1
7.1.8	Do a leak test of the system			X	X	X	X		prEN378-4 art. 5.1
7.1.9	Fill in the data in the logbook			X	X	X	X		prEN378-1 art. 6.4.2.5
7.1.10	Fill in the certificate of the pressure test			X	X		X		prEN 378-4 art. 4.3
7.1.11	Fill in the certificate of the evacuation test			X	X		X		prEN 378-4 art. 4.3
7.1.12	Fill in the certificate of the tightness/leak test			X	X	X	X		prEN 378-4 art. 4.3
7.1.13	Fill in a report with starting up figures			X	X		X		prEN 378-4 art. 4.3
7.1.14	Fill in a report with operational figures			X	X	X	X		prEN 378-4 art. 4.3
7.1.15	Fill in the report about the refrigerant used			X	X	X	X		prEN 378-4 art. 4.3
7.1.16	Fill in the document for removing dirty refrigerant			X			X	X	prEN 378-4 art. 4.3
7.1.17	Fill in the report about the refrigerant removed out of a system			X			X	X	prEN 378-4 art. 4.3
7.1.18	Fill in a report of dismantling of the system			X				X	F-gas regulation
Results									
Strict minimum emission of refrigerant									
The environmental auditors can monitor the history of the system.									

APPENDIX 5 EXAMPLE ASSESSMENT CRITERIA FOR TECHNICIANS

Learning outcome (The learner will...)	Assessment criteria (The learner can...)
(I) Understand the specific health and safety requirements which apply to the installation, servicing and maintaining and de-commissioning of HC RAC systems	<ul style="list-style-type: none"> • Identify the hazards associated with HC refrigerants: Flammability, low boiling point, asphyxiation (heavier than air), LFL, UFL, sources of ignition, practical limits, density • State and identify the commonly used refrigerant designations • State the requirements of HC specific risk assessments • Identify appropriate fire extinguishers for work on HC RAC systems
(II) Understand the legislative and organisational procedures for installation, servicing and maintaining and de-commissioning of HC RAC systems	<ul style="list-style-type: none"> • State the appropriate sources of health and safety information when installing, servicing and maintaining and de-commissioning of RAC systems • State the regulations, codes of practice, and industry recommendations appropriate to the installation, servicing and maintaining and de-commissioning of RAC systems, including working with refrigerants • State the occupancy classifications and charge size limitations for refrigeration systems • State charge size limitations for human comfort cooling and heating for air conditioning systems
(III) Understand the differences between Halocarbon and HC RAC systems	<ul style="list-style-type: none"> • Identify the specific system features and components which apply to HC systems: electrical devices, electrical enclosures, associated electrical devices (including halocarbon systems), compressors (including starter and associated electrics) • Identify the features and characteristics of: critical charge systems, oil compatibility, state the properties, advantages and disadvantages of HC refrigerants, including: <ul style="list-style-type: none"> - Leakage implications (direct and indirect) - Thermodynamic properties - Cooling capacity and energy efficiency - Density - Not stenching • Explain why HCs are not suitable for retro-filling into halocarbon systems • Identify typical applications of HC RAC systems: integral (plug in systems), fluid chillers, high stage CO₂ cascade systems, split AC systems, domestic fridge freezers (isobutane)

Learning outcome (The learner will...)	Assessment criteria (The learner can...)
(IV) Understand the procedures for planning and preparing for work on HC RAC systems	<ul style="list-style-type: none"> • State the requirements for completing a risk assessment for work on HC RAC systems • State the requirements for creating and maintaining a safe working area, including requirements for temporary zoning • Identify appropriate tools and equipment for work on HC RAC systems
(V) Be able to plan and prepare for work on HC RAC systems	<ul style="list-style-type: none"> • Complete a location specific risk assessment (using a dynamic risk assessment template) • Establish and maintain a safe working area • Select appropriate tools, equipment and PPE for work on HC RAC systems
(VI) Understand the specific requirements for installing and testing HC RAC systems	<ul style="list-style-type: none"> • Identify occupancy class • Identify the maximum refrigerant charge based on occupancy class • Calculate the maximum charge based on the practical limit Determine from calculations the system specific maximum charge • State the methods and procedures for: strength integrity testing, tightness testing, leak testing, evacuation and dehydration • State the procedures for charging HC refrigerants into systems • State the procedures for determining when charge is correct • State the records to be completed prior to handover • State the requirements for safely labelling HC RAC systems • Specify the information that should be provided to customers, including: operation of system and controls, using only appropriately trained servicing personnel, restrictions on the relocation of equipment
(VII) Understand the differences between halocarbon and HC service and maintenance procedures	<ul style="list-style-type: none"> • Identify appropriate 'like for like' replacement components for the following: electrical devices, electrical enclosures, associated electrical devices (including halocarbon systems), compressors (including starter and associated electrics) • State the importance of maintaining the integrity of sealed electrical enclosures • State appropriate methods for accessing and sealing HC systems • Specify the requirements for recovering HC refrigerants, including situations when it may be safe to vent refrigerant to atmosphere • State the requirements for the safe use of vacuum pumps when evacuating HC systems

Learning outcome (The learner will...)	Assessment criteria (The learner can...)
(VIII) Be able to service and maintain HC RAC systems	<ul style="list-style-type: none"> • Calculate the safe fill weight for the recovery cylinder (density difference between HFCs and HCs) • Connect equipment in preparation for recovery • Recover HC refrigerant to a prescribed pressure • Fill the system with nitrogen to a prescribed pressure and release to atmosphere • Un-braze specified component • Re-braze specified component while purging nitrogen through pipe-work • Pressure test joints (containment) • Evacuate to below 2000 microns • Re-charge with specified refrigerant weight • Run system and check operation • Remove charging equipment • Seal system and complete leak test with appropriate equipment • Complete service records as appropriate
(IX) Understand the decommissioning procedures for HC RAC systems	<ul style="list-style-type: none"> • Identify the safe procedures for handling potentially hazardous system materials, including: HC refrigerants • Identify work sequences for decommissioning and making safe a system in accordance with appropriate industry procedures systems

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This guideline aims to provide a general idea of the different steps when planning a conversion from an existing production system of domestic refrigerators to one that uses hydrocarbons, such as isobutane (R600a) or propane (R290), and the important aspects that small- to medium-size manufacturers need to consider. The holistic approach of this guideline makes it a good starting point of information, not only for directors and managers of enterprises responsible for technical aspects, product development, production line and training, but also for consultants, training institutions, teachers, lecturers and technicians.

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