PROKLIMA

Guidelines for the safe use of hydrocarbon refrigerants

A handbook for engineers, technicians, trainers and policy-makers - For a climate-friendly cooling

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

On behalf of

BMZ Federal Ministry for Economic Cooperation and Development

TÜV SÜD

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PREFACE

By Dr Volkmar Hasse, GTZ Proklima, Eschborn, May 2010

In 2007 the parties to the Montreal Protocol decided an accelerated phase-out of hydrochlorofluorocarbons (HCFCs), a group of ozone depleting substances (ODS) with high global warming potential (GWP). An important part of this decision was the agreement that assistance for developing countries from the Montreal Protocol's Multilateral Fund should prioritise alternative technologies to HCFCs which minimise climate and other environmental effects. To achieve this, the GWP of the alternative refrigerants must be as low as possible and the energy efficiency of the equipment must be as good as possible.

The most widely used HCFC is the refrigerant HCFC-22 in air conditioning. All conventional alternatives easily available to replace HCFC-22 are based on hydrofluorocarbons (HFC) gases with similarly high GWP.

All low GWP alternatives to HCFC-22 are flammable to various extents and therefore require appropriate precautions. Of these the least problematic choices are natural hydrocarbon (HC) refrigerants. They have a negligible GWP and should they ever catch fire will not produce any noxious fumes. In fact, the HC refrigerant HC-290 is highly refined propane, the same gas used worldwide for cooking.

The introduction of HC as replacement for HCFC-22 will be a significant element in avoiding emissions of extremely potent HFC greenhouse gases which are increasing steadily. This will be necessary to help avoid the climate catastrophes foreseen during this century, which will particularly severely affect developing countries. It is therefore the responsibility of our generation to make this transition possible and easy. The overall environmental benefits of this technology are paramount and can help to save literally millions of lives.

While avoiding climate change is the most important challenge of our days, it is still important to pay attention to the detail of how the conversions to environmentally friendly HC refrigerants are taking place to avoid unnecessary accidents due to ignorance and neglect.

There is currently a massive growth in the use of both HCFCs and HFCs in developing countries. This is alarming because it clearly cancels out worldwide efforts to curb other even less potent greenhouse gases. It is also economically wasteful as it can be foreseen that current international efforts aiming at a "phase-down" of HFCs will necessitate further expensive industrial conversions in the near future. Many developing countries have realised this situation and demand now a conversion to sustainable technologies not requiring yet another technology change. Developing countries repeatedly expressed their preferences for the introduction of technologies based on natural refrigerants with none or negligible GWP and superior energy efficiency.

As a reaction to this, the Executive Committee of the Multilateral Fund recently decided to provide additional 25% of funding to HCFC Phase-out Management Plans (HPMP) if low GWP alternatives are chosen.

With the phase-out of HCFC-22 it will be advantageous to introduce natural refrigerants. Once developing countries start to adopt the use of HC as refrigerants, authorities and enterprises as well as individual technicians and engineers will find some barriers to their implementation. Many of these are related to a lack of information and misperceptions about the flammability issue leading to fear and reluctance.

Despite this, we observe an increasingly rapid uptake of HCs in developing countries, unfortunately often with little know-how resulting in rather dangerous equipment operating conditions. While we cannot assume responsibility for any individual conversion, we consider it essential to contribute the best available safety information in an easily understandable way, to ensure a safe and sustainable shift to natural refrigerants. While everyone is already using HC gas in everyday life, e.g. in the kitchen as cooking gas and in refrigerators, in vehicles as an environmentally friendly fuel replacing gasoline, as propellant gas in hygiene products such as deodorants and hairsprays, we do acknowledge that HC refrigerants must be used safely in all applications including air conditioners.

With this handbook we want to go the extra mile to safety by providing sound and reliable information on precautions that can be taken to prevent any untoward accidents. It is targeted at an audience concerned with the introduction of HC refrigerants at all levels from national policies to equipment design and manufacturing, installation, maintenance, servicing and end-of-life disposal. Advice is given to:

- Help policy-makers to encourage a nation-wide introduction of HC technology emphasising safety and state-of-the-art technologies
- Enable manufacturers and installers of HCFC and HFC equipment to reliably assess the suitability of HC options and subsequently implement them
- Enable a transition from HCFC to natural refrigerants directly and bypassing the introduction of high GWP transitional HFCs

To provide an even better service to our partner countries, GTZ Proklima formed an alliance with TÜV SÜD, a well known authority on safety and quality systems.

GTZ Proklima has first-hand experience with the introduction of HC refrigerants in developing countries at government as well as industrial and servicing levels. This experience has been accumulated continuously since 1995 in about 40 developing countries, starting with the introduction of the “Greenfreeze” HC technology for refrigerators in China and India, and through extensive training programmes for refrigeration and air conditioning technicians, addressing many complex issues facing the servicing sector. GTZ Proklima also implements several natural refrigerant projects around the world including air conditioning, industrial and commercial refrigeration.

To complement this, TÜV SÜD is providing experience with assessing the safety of refrigeration systems throughout the world, including certifying and accrediting newly developed equipment. The contributions of TÜV SÜD range from setting up a quality control infrastructure and undertaking inspections, to training and certification.

Today is an appropriate time to widely introduce sustainable and economical natural refrigerants in developing countries to provide environmentally friendly cooling for comfort and productivity. A change from the ozone depleting HCFCs directly to HC refrigerants will contribute to a greener growth of developing economies. This will prevent a truly huge amount of greenhouse gas emissions thereby helping to preserve our planet for our children.

By Mr Bernhard Schrempf, TÜV SÜD, Munich, May 2010

The application of natural refrigerants in the refrigeration and air conditioning industry is increasing, and this is largely due to their favourable environmental characteristics. For over a century, ammonia (R717) has been used predominantly in larger refrigerating systems (typically with capacities of over 100 kW), and its track record has been highly successful. However, for smaller capacities, the use of ammonia (R717) is less effective for various technical and cost reasons. Therefore the application of other natural refrigerants, such as the HCs – propane (R290), propene (R1270) and iso-butane (R600a) – may be widely used. These refrigerants are of course highly flammable and explosive, so that whilst their application as refrigerants may present excellent environmental benefits, their handling with the necessary expertise is essential.

Subject to compliance with certain safety principles, the application of flammable HC refrigerants can be done as safely as with any other type of refrigerant. This handbook is intended to inform about the best practices for applying, handling and otherwise working with flammable refrigerants in order that the systems and operations can be carried out securely. In addition to general safety information, it describes quality-assurance measures associated with the design and construction of components and systems, and desirable handling practices that should accompany their use.

In addition, one of the most important aspects facing the refrigeration industry today is that of refrigerant leakage. This issue is not only relevant to one group of refrigerants, but to all; flammable and non-flammable, alike. Permanently sealed systems provide not only a high level of safety, but also preserve the system's efficiency. Thus, the issue of system tightness is also addressed in detail within this handbook.

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GTZ and TÜV SÜD do not assume liability for any statements made in this book or any actions taken by its readers or users, which may cause unintended damage or injury as a result of any recommendations or inferences made within this handbook. Although all statements and information contained herein are believed to be accurate and reliable, they are presented without guarantee or warranty of any kind, expressed or implied. Information provided herein does not relieve reader or user from their responsibility of carrying out its own evaluation and analysis of the situation, and reader or user assumes all risks and liability for use of the information, actions and events obtained. Reader or user should not assume that all safety data, measures and guidance are indicated herein or that other measures may not be required. This handbook makes only general recommendations on the use of HCs as refrigerants which do not compensate for individual guidance and instructions. National laws and guidelines must be consulted and adhered to under all circumstances. The handling of flammable refrigerants and its associated systems and equipment is to be done by qualified and trained technicians only.

PART 1: SAFETY INFRASTRUCTURE

1.1 GENERAL INTRODUCTION

1.1.1 Background

Interest in and application of hydrocarbon (HC) refrigerants is growing, especially now that the global warming impact of refrigerants is becoming an increasingly important aspect for the refrigeration and air conditioning industry.

The accelerated phase-out of HCFCs under the Montreal Protocol in September 2007 and a foreseen regulation of fluorinated gas emissions under a future climate change agreement – within the Montreal and Kyoto area – heighten the need to substitute widely used fluorinated substances in favour of climate-friendly refrigerants.

Hydrofluorocarbon (HFC) refrigerants with their typically high GWP as well as environmentally friendly natural refrigerants (such as HCs, ammonia and carbon dioxide) are all available as mature technologies for most applications, both in industrialised and developing countries. If HFCs continue to replace HCFCs in a substantial manner, the climate benefits of the Montreal Protocol may be lost within a short period of time. Despite their superior properties, natural refrigerants continue to remain in the shadows, largely because of exaggerated safety concerns which are rarely properly addressed.

It is widely known that HCs are excellent refrigerants in terms of performance and because of their negligible environmental impact aspects. However it is generally acknowledged that their main hindrance is related to their flammability.

To date, extensive and reliable information on the safety issues of natural refrigerants is fairly disparate, and with the continual evolution of safety standards, much of the existing published information is increasingly outdated. Ensuring a good level of safety requires that all stages within the equipment life – from conception to destruction – are considered. Most of the publications currently available only address the discrete elements of a system's life, for example, refrigerant handling, maintenance activities, design guidelines, etc In addition, some publications are rather basic or incomplete, whilst others (such as safety standards) often seem complex and require specialised knowledge in order to make them comprehensible.

Therefore, the purpose of this publication is not only to collate much of the existing information and guidance related to the safe use of HC refrigerants, but also to present the information in a comprehensive manner such that all of the stages in the system's life are covered in an interlinked way.

This handbook will function as a guidebook for policy-makers involved in designing nation-wide policies to support the use of natural refrigerants (i.e. regulatory aspects, standards, etc) and also for private companies who are deciding upon the introduction of HC refrigerants and who require knowledge about all the technical, economic, environmentally relevant and regulatory aspects on the safe use of HCs.

It has also been recognised that simply describing technical requirements is not always sufficient in itself to ensure that a high level of safety is achieved; introducing a robust infrastructure is equally important.

For example, how government or industry bodies may set up schemes for certification of technician training, or how manufacturers, distributors or contracting companies may organise their quality management systems to help with the ongoing improvement of safety levels, etc, are all important considerations.

1.1.2 Using the handbook

This handbook covers a wide range of aspects such as organisational, regulatory and technical aspects. Accordingly, it is divided into several sections, with each being aimed at particular groups of users. The parts are as follows:

- Part 1: Safety infrastructure
- Part 2: Quality systems for safety
- Part 3: Training
- Part 4: Production and manufacturing facilities
- Part 5: Equipment design and development
- Part 6: Working on systems and equipment
- Part 7: Case studies

In order to provide some guidance as to which groups of users may benefit most from reading certain sections, a brief summary and suggested target groups are listed in Table 1. Of course, the target groups are not exhaustive, but may be used to provide an indication as to the type of knowledge that may be gained by reviewing the relevant elements of a given part of this handbook. It is also noted that often, certain text within one part refers to text from another part, and in this way, each part cannot always be self-contained. For example, for those who are working on systems, the material within Part 6 is most relevant, although a technician may also need some knowledge of the rules that specify refrigerant charge limits, which are covered in detail in Part 5, since such issues are primarily a design matter. Part 7 provides some case studies and does not include requirements for using HCs but provide a little insight into the experiences of enterprises that have been through the process.

Table 1: Overview of the various parts of the handbook and the target groups

Part	Description	Target groups	Linked to
Part 1: Safety infrastructure	An overview of the implications of HCs to all stages of equipment lifetime and the background to managing safety issues	Directors and managers responsible for: technical aspects, product development, production line, training; policy-makers and national authorities; trade associations, technical institutes	Part 2, Part 3, Part 4, Part 5, Part 6
Part 2: Quality systems for safety	Considerations for setting up and operating a safety management system with a focus on handling HC refrigerants	Managers and engineers responsible for: equipment production, projects; policy-makers, national authorities	Part 3, Part 4, Part 5, Part 6
Part 3: Training	The approach for training different groups of people on different subjects and the formats for transfer of information	Policy-makers, national ozone units, training institutions/trainers, teachers, lecturers	Part 4, Part 5, Part 6
Part 4: Production and manufacturing facilities	General aspects covering the setup behind production lines and in-house construction of systems and equipment using HCs, as well as workshop servicing of equipment	Managers and engineers involved with: production of equipment, in-house servicing and repairs	Part 2, Part 6
Part 5: Equipment design and development	Compilation of the rules and peripheral information relating to the design and construction of systems using HCs, and risk assessment concepts to help evaluate the safety of equipment	Engineers and technicians involved with: development of systems, design, commissioning and servicing; trade associations, technical institutes	Part 2
Part 6: Working on systems and equipment	General guidelines for the practical handling of HC refrigerants and equipment during installation, servicing, maintenance and related activities	All field engineers and technicians involved with: servicing, repair, maintenance, disposal, refrigerant handling; technicians' associations	Part 3, Part 5
Part 7: Case studies	Examples of how enterprises have adopted the use of HC refrigerants	Manufacturers of systems, end users and operators	All Parts

In addition, there is supplementary information for reference purposes within the Appendices providing information on the following:

- *Non-safety related technical aspects*; this contains some general information about the application of HC refrigerants in terms of their behaviour in systems compared to conventional refrigerants, and also an overview of the types of systems and applications HCs are normally used within
- *Example conversion procedures*; to provide pictorial guidance to engineers and technicians about how systems may be converted to use HC refrigerants safely
- *Cooperation partners*; this includes a selection of different types of partners which may be of interest depending upon which country or region is under consideration
- *Flammable characteristics of HCs*; here a few characteristics of flammability are described, in order to help provide insight into the implications of flammable substances
- *Calculations for refrigerant concentrations*; this includes some information relating to the estimation of the refrigerant concentration arising from releases of refrigerant that may be applied to a variety of different circumstances within enclosed spaces, for assisting with safety assessments
- *Equipment for technicians*; a fairly exhaustive list of tools and equipment that would normally be required when working with or conducting practical training workshops for the use of HCs
- *Material for refrigeration training modules*; this is information detailing the criteria for minimum requirements for skills and competences for refrigeration technicians
- *Record sheet for refrigerant use*; an example of a data-sheet that resides with a system so that its system servicing and maintenance history can be logged
- *Vapour pressure-temperature and liquid density tables*; these can be used for estimating maximum operating pressures of the different refrigerants, and also used in calculations for estimating charge sizes of systems

The handbook is also complimented with a glossary and a comprehensive bibliography, including safety standards and codes of practice related to refrigeration issues as well as for hazardous areas and various other sources for further reading.

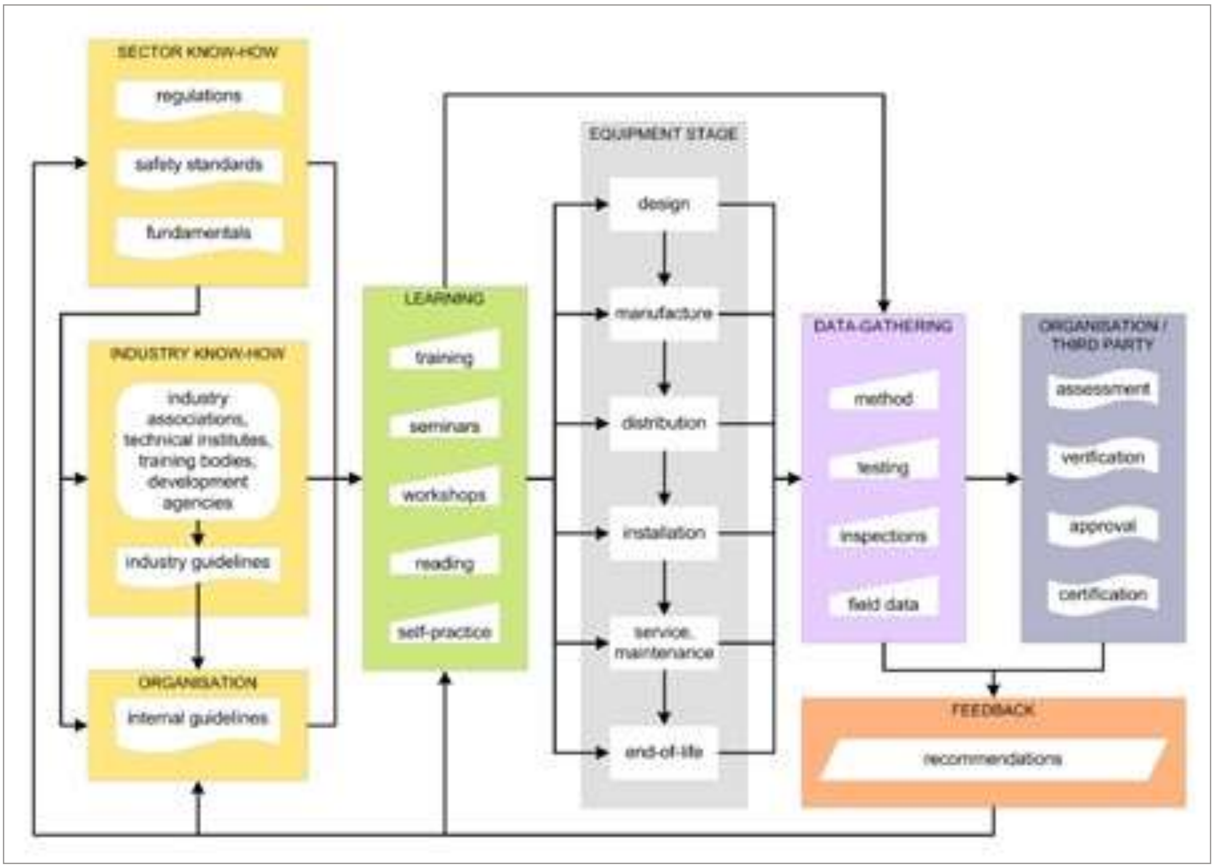
Lastly, it is reiterated here that the safety of such systems and equipment requires many other aspects to be addressed such as pressure, mechanical, toxicity and electrical safety, and for these, guidelines on general safety and refrigeration safety should be sought.

1.1.3 Approach of the handbook

To assist the reader with utilising this handbook, an overview of how it is compiled is presented. A conceptual overview of the important elements that contribute to addressing the safety of refrigeration and air conditioning (RAC) equipment throughout its lifetime are illustrated in Figure 1. The general conceptual stages that the equipment goes through during its lifetime are indicated in the centre of Figure 1, starting with its design and ending with its disposal at end of life. Each of these stages normally requires slightly different information due to the specific demands for that stage.

The information is largely sourced from the "sector", typically in the form of regulations, safety standards and also fundamental technical information. Such information may then be transposed into more useable formats. Typically this is carried out by the "industry"; specific bodies associated with the RAC industry, such as trade associations, technical institutes, colleges, universities and development agencies (particularly in the case of A5 countries) may compile the information from the sector sources to produce industry guidelines, codes of practice or other such material. Similarly, particular organisations, such as manufacturers, contracting companies or even training companies may also produce their own internal guidelines. For this, the information may be sourced from the regulations, standards, etc, and also, if available, from the industry guidelines. Often the guidelines, whether industry-wide or internal to a particular organisation, will be broadly applicable to one or two of the equipment stages (for example, design stage or installation and servicing stage).

Figure 1: General overview of the approach covered in the handbook



How this information is transferred to the individuals who are directly involved with the equipment at each of the stages of its life is of utmost importance. Thus, ensuring a comprehensive approach to learning is essential; this may be in the form of technical training, attendance of seminars and practical workshops, reading of relevant literature and actually putting the information that has been learned into practice. Topics relevant to the individual's intended involvement with the equipment should be targeted as well as providing a general overview of many of the issues.

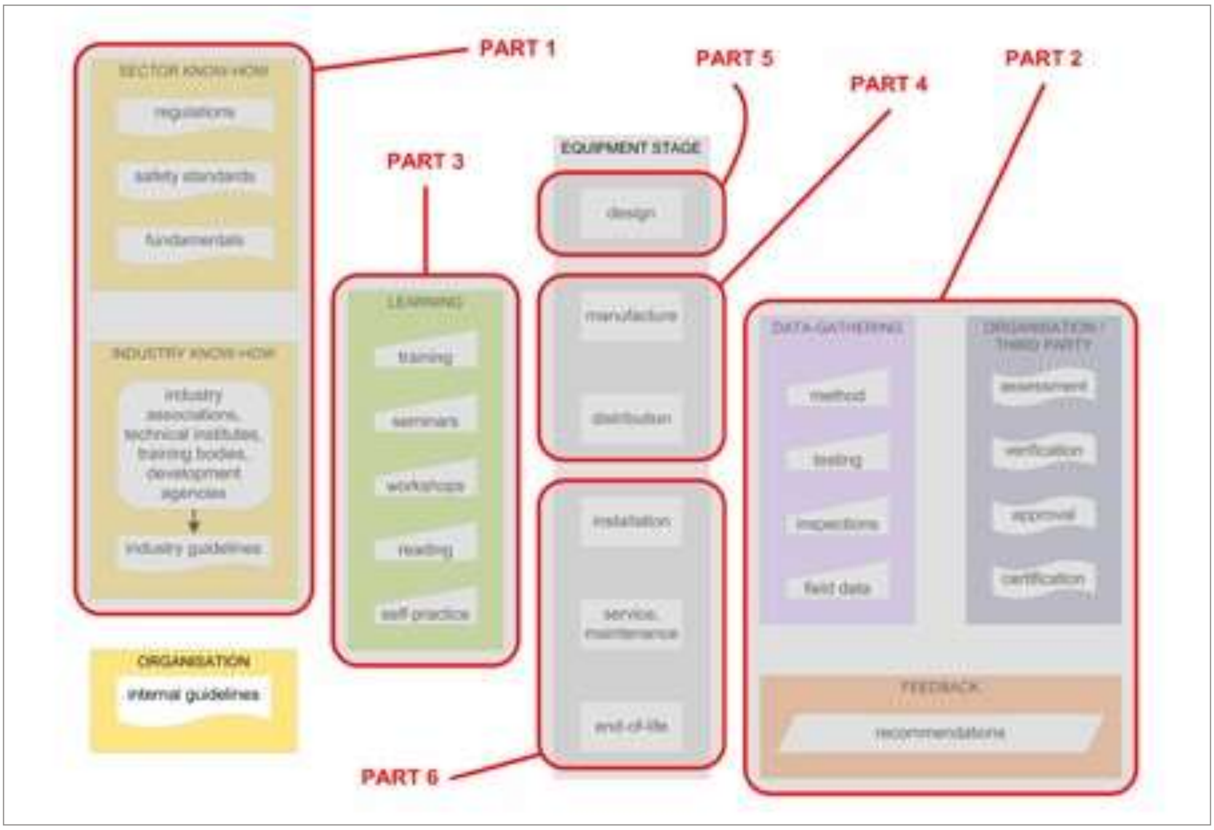
In order to ensure that the designs, practices, operation and other activities are as intended, a process of data-gathering should be carried out, and this may be voluntary or mandatory according to certain stipulations. Such data-gathering may be in the form of recording working methods or procedures, carrying out on-site or laboratory testing, inspections or gathering and compiling field data.

This data may then be utilised in a number of different ways, either in-house by certain individuals within the organisation, or by a third party. The data may be used to assess the reliability of components, processes or operations. It may also be used to verify that certain designated criteria are being met, and in certain cases, approval and certification of designs, testing, procedures and so on. In addition, the same data-gathering and assessment and certification procedures may be used for ensuring that the necessary learning processes are being conducted properly.

One of the most useful outputs from both data-gathering and third-party activities, are the provision of feedback in terms of recommendations, guidance and other advice. This may be related to the success or viability of the initial guidance material for design, manufacture, servicing, or indeed, in case there are any problems with the sector know-how such as parts of safety standards.

Figure 2 provides an indication of which parts of this handbook are applicable to the different elements for addressing the safety of RAC equipment. However, it must be noted that there is cross-over amongst most of the topics that are covered, so the indication in Figure 2 is only approximate. (Note that Part 7 isn't included since it doesn't provide direct guidance.)

Figure 2: Indication of the relevance of each part of the handbook



Overall, the different parts of the handbook are broadly arranged with the most general aspects dealt with first (Part 1, 2 and 3), and then the more specific issues related to the particular stages within the equipment lifetime dealt with in the latter parts (Parts 4, 5 and 6).

As a final remark, it should be noted that each situation, especially from an individual country respect, should be considered with discretion. In many cases, practices that may be suitable or appropriate within one country may not be in another. In particular, legal systems and existing safety infrastructures vary by country and often by region to some degree. Therefore the guidelines within this handbook may have to be morphed to suit the individual geographical and political regions, as well as particular types of enterprises and products.

1.14 Considerations for policy-makers

There are a number of important issues that should be considered by policy-makers. Based on the current trends, it is widely accepted that HC refrigerants will be occupying a notable portion of the refrigerant usage in the near to medium future. This of course will present significant energy efficiency, environmental and in many cases cost benefits, as well as avoiding or even bypassing reliance on costly synthetic alternative refrigerants. However, it is essential that authorities handle the situation strategically, not only with planning future eventualities, but also to exploit the situation. For instance, in carrying out the necessary training, further incentives should be introduced to help raise the standards of technician qualifications – to include a deeper understanding of energy efficiency, environmental aspects as well as reliability – so as to prepare the entire sector for a long future and sustainable technology.

In terms of general considerations for the introduction of HC refrigerants, the following items may be pertinent:

- *Awareness raising*. It is important that not only RAC technicians are aware of the refrigerant (as well as efficiency and environmental) issues, but other stakeholders that are at the periphery of the industry. In particular, awareness-raising campaigns should be developed for both the RAC industry and for the wider sectors, such as for architects, construction people, building operators, facilities managers, end-users, etc.
- *Focus on training*. Ensuring a high level of safety is essential and one of the key way and means of doing this is through the training of technicians, but also other engineers within the sector. Not only does this target safety, but it also helps uplift the entire servicing sector in terms of improvements in knowledge and know-how, quality of work, awareness, and so on. Supporting this should be a focus on registration and licensing schemes for technicians and engineers. Within this, it may be appropriate to set levels of qualifications and allocation of corresponding levels of permission to work on particular types of systems.
- *Culture shift*. In many locations, the importance of a "safety culture" is not as embedded within the industry as in other countries. Measures should be introduced to help shift the industry culture to taking the issue of safety (as well as related topics such as leakage avoidance, efficiency, etc) much more seriously. Again, this may be done through legislation, awareness raising and incentives.
- *Steady and surely*. Approach the instruction of HCs in a controlled and steady manner, so that working practices and behaviour can be changed in a measured and controlled way. One approach may be to consider a phased introduction of HC according to sectors, for example, start with simple/easy systems and build-up to more complex installations over time. Another option is to integrate with existing or new technician registration schemes, where only the more highly trained or more qualified technicians are permitted to use HCs, and the use of accreditation systems. Or a combination of the two.
- *"National experts"*. Possibly establish a central point within the country or region, where safety or other technical issues may be resolved. For this, authorities could encourage selected individuals from the field to become "national experts" who can dedicate themselves to information gathering and who can work with and coach enterprises to introduce HCs properly and safely and with minimum problems. In addition it may be an option to give authority to organisations or expert individuals to carry out checks and inspections to ensure that the relevant rules are being followed and the necessary level of safety is being achieved.
- *Develop incentives*. Whilst the environmental benefits are widely known, incentives may be provided to help encourage industry to overcome the additional implications of using HCs. Examples include tax allowances or other financial benefits that favour the use of low-GWP refrigerants, deliberation of import tariffs, or conversely other means to disincentivise the use of high GWP alternatives. In any case, these should be linked to ensuring or guaranteeing the responsible use of HCs.
- *Regulations and standards*. Authorities may wish to consider introducing legal and other instruments such as safety standards to help direct the use and application of HC refrigerants – or indeed all refrigerants. Alternatively if such rules currently exist, authorities can identify means for modifying existing regulations and standards to enable the wider and safer use of HCs. However, in doing this, it is important to make sure that regulations and standards are not overly prescriptive, but employ a framework to enable safe and innovative use of HCs without unnecessarily prohibiting its use. Thus, it is sensible to use national and international experts to review and guide new or modified regulations and standards.

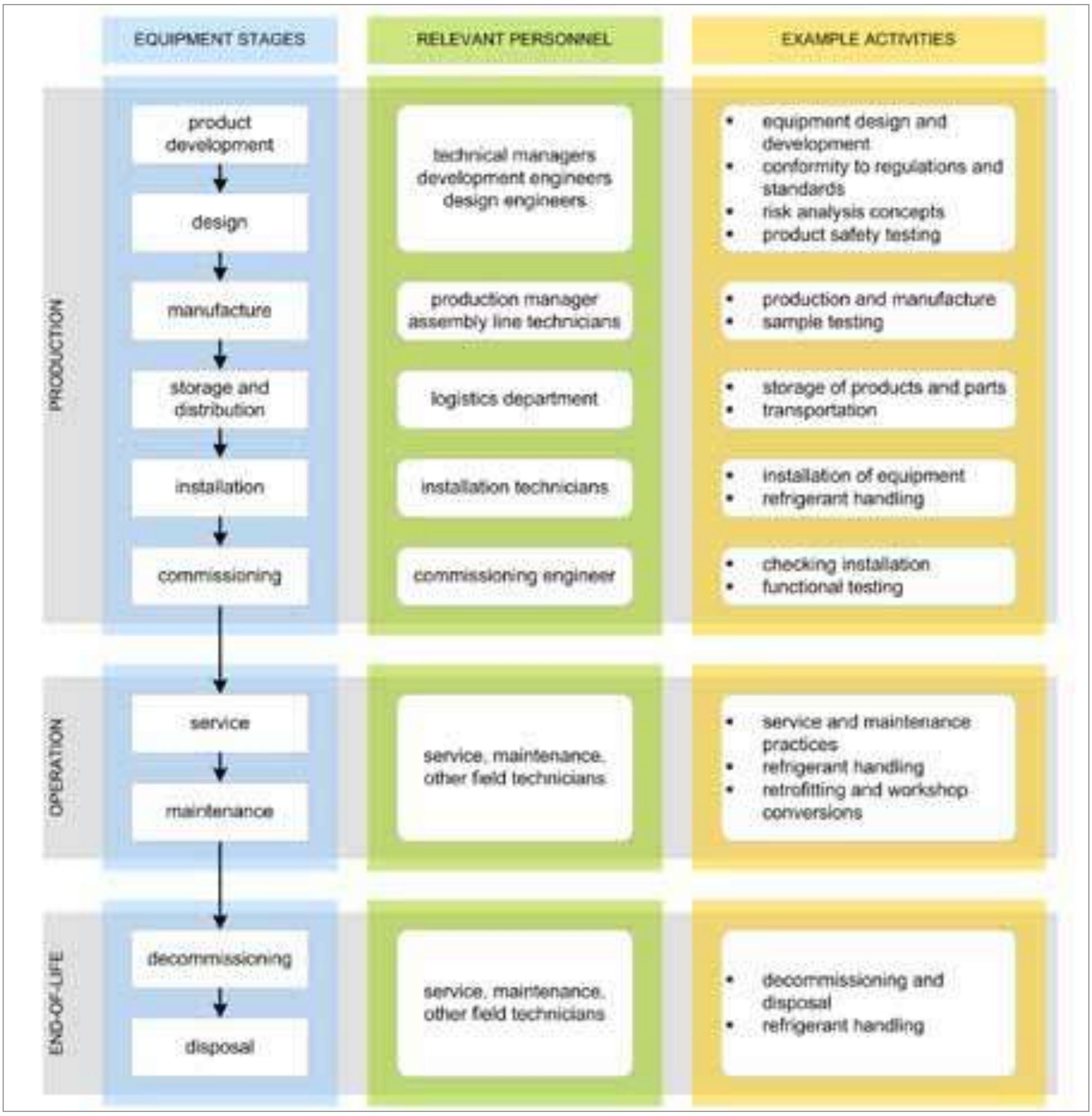
For many of the considerations discussed above, it is important to involve the RAC industry. In doing this, it is preferable to empower industry bodies that encompass all stakeholders, including those on the periphery, including development agencies and environmental NGOs. At the same time, it can also be prudent to avoid too-strong a representation of any one body or group of interests, since – as has been seen many times before – a strong bias is likely to emerge, and thus stifles development of new technologies. The industry-wide involvement may be in the form of establishing regular forums for technical exchanges, sharing experiences, informing of the latest developments and collating such technical information for widespread dissemination. This may also include developing and setting minimum standards for training organisations, producing technical guidelines on best practices and working through strategies and policies.

1.1.5 Key stages during equipment lifetime

In order to ensure that products and installations using HC refrigerants are safe throughout their entire lifetime – both to members of the public and those that work on them, it is essential to address every single stage in the equipment lifetime. Here, the stages in the equipment lifetime from Figure 1 are elaborated on, as shown in Figure 3.

To the left of Figure 3 are the key stages in the equipment lifetime, from conception of the product to the disposal of the equipment. In the centre column are examples of the personnel that are primarily concerned with working on those stages. To the right are examples of the types of activities those personnel are required to be competent at, in order to maintain a high level of safety. All the personnel involved need to be aware of their responsibilities, and those in charge must make sure that the workers are informed and aware of those responsibilities. Furthermore, it is clear that the actions taken by personnel at any stage in the equipment life usually have consequences at the latter equipment stages.

Figure 3: Overview of the stages within the equipment lifetime, the key personnel and the subject groups that may be needed to execute the work



There are common activities within many of the stages, meaning that many of the people involved in such stages need to be familiar with the technical details from various sections. For example, people working in production, installation, servicing, maintenance and decommissioning all need to be aware of good refrigerant handling practices. Also, people involved with the design, commissioning, servicing and maintenance all need to be familiar with the requirements of the safety standards. Thus, many of the issues are interrelated throughout all the stages of the equipment life.

In general, whilst an organisation is preparing material for and working on each of the stages within the equipment lifetime, the following issues should be kept in mind:

- In order to assist those working at the various stages, it would be useful to provide staff with concise, easy to use manuals, guidance notes, etc, focussed on each part or for each key activity they are expected to carry out. Ensure that it is comprehensible and peer reviewed.

- Provide proper and thorough training to those involved, both theoretical and practical.

- Check other literature; manuals, handbooks, industry guidelines, manufacturers documentation, refrigerant suppliers information, etc, and the original regulations and safety standards to ensure that the correct information is used.

- Develop a system for obtaining feedback from other stages and set up a scheme for information sharing. Using such feedback, for example, from field data, technicians, etc, on aspects such as leakage, equipment and component failures, problems with repairs, actual minor or major accidents, and so on. Utilising this information will greatly enhance the level of safety for the future.

Lastly, producing guidelines can never anticipate all the situations that may be encountered, or all the peculiarities of different types of equipment. Therefore it is important that individuals understand the logic behind the rules of the requirements, and in this way they can be adapted to new or unforeseen equipment and situations.

1.2 BASIC SAFETY WITH FLAMMABLE REFRIGERANTS

1.2.1 Introduction

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 is, 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. These matters are mainly addressed in Part 4 and Part 5 of this handbook.

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. These matters are mainly addressed in Part 3 and Part 6 of this handbook.

1.2.2 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 2.

The toxicity classification is based on whether toxicity has or has not been identified at concentrations of less than 400 ppm by volume, based on data used to determine the threshold limit value – time weighted average (TLV-TWA) or consistent indices. There are two toxicity classes:

- Class A refrigerants are those where no toxicity has been observed below 400 ppm
- Class B refrigerants are those where toxicity has been observed below 400 ppm

The flammability classification depends upon whether or not the substances can be ignited in standardised tests, and if so, what the lower flammability limit (LFL) and the heat of combustion are. There are three flammability classes:[1]

- Class 1 refrigerants are those that do not show flame propagation when tested in air at 60°C and standard atmospheric pressure
- Class 2 refrigerants are those that exhibit flame propagation when tested at 60°C and atmospheric pressure, but have a LFL higher than 3.5% by volume, and have a heat of combustion of less than 19,000 kJ/kg
- Class 3 refrigerants are also those that exhibit flame propagation when tested at 60°C and atmospheric pressure, but have an LFL at or less than 3.5% by volume, or have a heat of combustion that is equal to or greater than 19,000 kJ/kg

Since the common HC refrigerants (R290, R600a, R1270) have a TLV-TWA of 1,000 ppm or higher (depending upon the source of the information), they have a Class A toxicity classification. However, these refrigerants do exhibit flame propagation under standard atmospheric conditions, and the LFL is typically around 2% with the heat of combustion around 50,000 kJ/kg. Thus the flammability classification is Class 3. Overall, this renders them with an A3 safety classification according to the relevant standards.

1 Currently there are attempts to introduce a new "lower" lower flammability class ("Class 2L") into certain safety standards, which are intended to advantage certain flammable HFC refrigerants. However, this proposed classification does not impact on the use of HC refrigerants.

Table 2: Refrigerant safety classification scheme

Classification			Toxicity	
			Class A	Class B
			lower chronic toxicity	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. The guidance included in Parts 5 and 6 of this handbook address these issues.

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 LFL 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/m^3, or 8 g/m^3. For other refrigerants, such as most CFCs, HCFCs and HFCs, the PL is based on the ATEL and 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.)

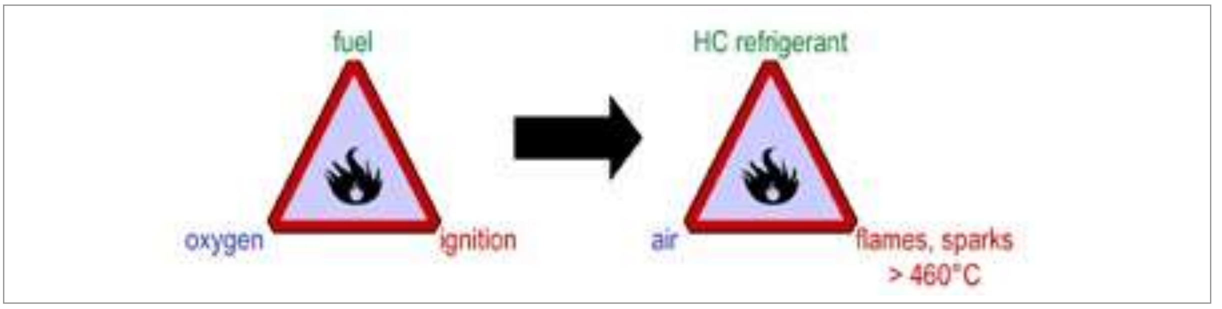
1.2.3 Basic approach for working with flammable refrigerants

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 4. 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, use of ventilation.

Figure 4: The 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.

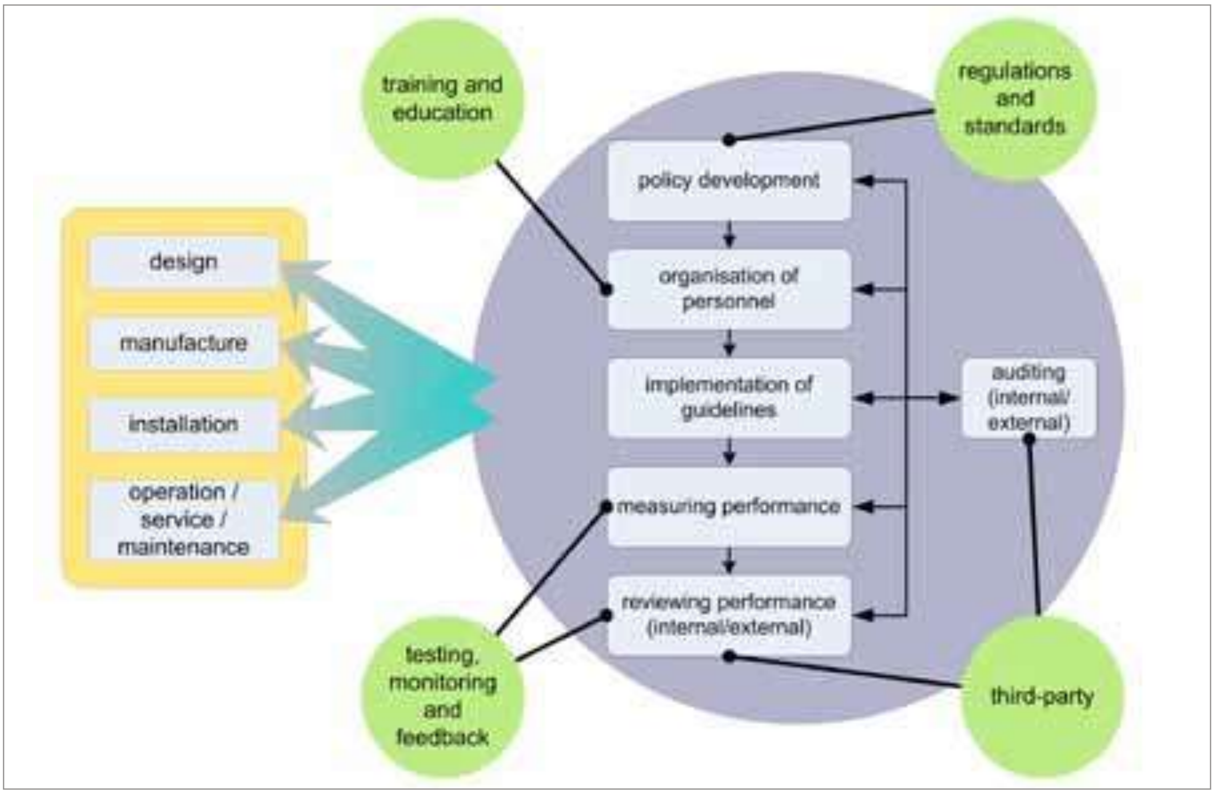
1.3 DEVELOPMENT OF SAFETY MANAGEMENT SYSTEMS

1.3.1 Introduction

It is essential to utilise all the tools that are available to ensure as high a level of safety as possible, stretching from the conception of the product or equipment to disposal at the end of life of the equipment. Such tools may be perceived as different layers of protection, applied to minimise the risk posed by the flammable refrigerant. These primarily address: safety planning, investigation of elements at various stages and auditing and assessment of the findings. These concepts are primarily aimed at directors and managers, but also supervisors and engineers, since it is the senior individuals that normally have the responsibility to implement such systems.

The components of a robust safety management system are illustrated in Figure 5. There are five stages that are crucial to a safety management system, starting with development of the safety policy within the organisation, handling of personnel, development and implementation of guidelines, introducing means to gather data and measure performance, and then reviewing that performance. Linked to all of these is an auditing process, to check that all is operating as intended. This entire system should be applied to the product or equipment at one or more of its stages, depending upon the level of involvement or responsibility that the organisation has over the product or equipment. There are also external elements that feed into the safety system. For example, the use of regulation and safety standards used to develop internal policy and guidelines; training and other educational schemes for the instruction of personnel; testing, monitoring and feedback procedures for measuring and reviewing performance, which third parties may also participate in.

Figure 5: Overview of key elements of safety management system



1.3.2 Development of a policy

In principle, it is the intention to avoid safety-related problems in whatever stage of the equipment lifetime is under consideration. Such problems may include cessation of production process, endemic fault within a specific design, injury to staff, injury to members of the public and damage to own or others' property. Thus, it is important to devise controls to avoid such forms of accidental loss. The general approach for doing this is: identification of hazards g assessment of risks g decision regarding precautions needed g implementation of guidelines g verifying that they are used. This thought process defines the groundwork for a safety policy, and such policies should cover all activities that the organisation is involved in. This may include the selection of personnel for particular jobs, equipment and materials, design of equipment and products, the way work is carried out, how services are provided, and so on.

A written statement of policy and the organisation and arrangements for implementing and monitoring it demonstrates to staff, and anyone else, that hazards have been identified and risks assessed, eliminated or controlled. Thus, for all of the stages throughout the equipment lifetime, there must be a clearly documented safety policy.

Key elements of a policy should guarantee the following:

- Lessons are learned from mistakes and successes
- Safety audits are carried out
- Action is taken according to the findings of audits and it is documented
- Audits involve personnel at all levels as well as external contractors
- Reviews of safety policy and guidelines are carried out frequently

1.3.3 Organising personnel

To make the safety policy effective it is essential to organise all personnel related to the safety systems, and moreover, they should be involved and committed. Of primary importance is to ensure that the personnel are competent, through proper recruitment, training and advisory support, specifically:

- Assess the skills needed to carry out all tasks safely, whether it is managerial or practical work
- Provide the means to ensure that all personnel are adequately instructed and trained
- Ensure that people doing especially hazardous work have the necessary training, experience and other qualities to carry out the work safely
- Arrange for access to sound advice and help, such as training, technical updates and so on
- Carry out restructuring or reorganisation to ensure the competence of those having safety-critical responsibilities

In order to make sure personnel are engaged with the policy, formulate a robust control system, for example, by allocating responsibilities, securing commitment, instruction and supervision. In addition:

- Demonstrate a commitment and provide clear direction and ensure everyone knows the importance of safety issues
- Identify people responsible for particular activities, especially where special expertise is called for, e.g. carrying out risk assessments, handling refrigerant, designing systems, etc
- Ensure that managers, supervisors, engineers and technicians understand their responsibilities and have the time and resources to carry them out
- Ensure everyone knows what they must do and how they will be held accountable

Since the safety system normally relies upon coordination of various parties, there must be genuine cooperation between individuals and groups. This may be achieved by:

- Setting up dedicated safety committees and consulting all personnel that may be involved.
- Involving personnel at all levels (such as from technician to technical manager) in planning and reviewing safety-related activities, writing procedures and identifying and solving problems
- Co-ordinating and co-operating with personnel from other organisations that are working on the same project or similar issues

All policies and subsequent actions must be well communicated, whether verbally or in written form, and always properly disseminated. Such information should include information about hazards, risks and preventive measures to personnel and any others working on the premises or on the equipment externally. Forums should also be set up to discuss safety matters on a regular basis. In general, it is important to ensure that:

- Responsibilities for specific safety matters have been allocated to the appropriate people
- Personnel are clear on what they have to do and that they will be held accountable
- Everyone involved in the relevant processes are properly consulted
- Personnel have sufficient information about the safety issues and risks
- All individuals have the minimum levels of expertise and they are properly trained
- If and when specialist advice from outside is needed, it is arranged

Specifically in the case of refrigerating systems, it is essential that all personnel dealing with systems – from their conception to destruction – are competent to carry out special activity or activities. The development of safe refrigeration systems thus requires education in several fields, particularly pressure safety for the refrigerant system, tightness of the refrigerant system, electrical safety for the equipment and avoidance of flammable atmospheres. Furthermore, in most refrigeration systems there are pressure vessels and pipes under pressure, so it is necessary that personnel are competent in these different fields. Continuing education over time is also necessary, for which there exist a variety of courses directed at technicians, engineers and electricians covering practical aspects of refrigeration plant operation, servicing and general maintenance.

1.3.4 Planning and setting guidelines

Planning involves setting objectives, identifying hazards, assessing risks, implementing performance criteria and developing a positive culture. Practical steps that need to be taken include:

- Identifying hazards and assessing risks, and deciding how they can be eliminated or controlled
- Complying with the safety legislation that apply to the organisation as a whole and the process or equipment in particular
- Developing and agreeing targets with relevant personnel
- Forming a robust purchasing and supply policy for safety-related components or services
- Designing tasks, processes, equipment, products and services and safe systems of work
- Establishing procedures to deal with serious and imminent danger
- Co-operating with other organisations, subcontractors, etc
- Setting performance criteria against which the effectiveness of the safety measures can be verified

Guidelines should describe what personnel must do to deliver the safety policy and to control risk. They must identify who does what, when and with what result, and in order to validate this they must be: measurable and achievable. For example, statements such as “staff must be trained” are difficult to measure if it is not specified what “trained” exactly means and who has the responsibility to do the work.

FAILING WELL!

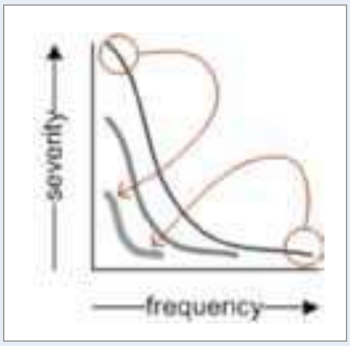
Enterprises and other organisations should be encouraged to develop a "fail-well" culture. Within any area of business failures and mistakes should be analysed in order to gain an improvement, and the same applies to the field of safety. It is widely seen that the most successful organisations within safety-critical fields embrace this type of culture.

Often, if an engineer, technician, etc, makes a mistake or a minor accident occurs, they will keep the occurrence to themselves, and are unlikely to report it. Such a failure may be considered shameful and will be kept a secret and "hopefully" forgotten. This occurs because of the fear of getting into trouble, being disciplined, punished and ridiculed by others – such a mentality is present in many organisations.

However, such a culture is not only counter-productive but also destructive, both to the individual, their peers and the organisation as a whole. Since improvements are made through learning from mistakes, trial and error, analysis of undesirable outcomes, and so on, hiding or ignoring of mistakes, problems and accidents will inhibit positive development. For this reason, it is necessary to makes changes within the organisation to create a "fail well" culture.

The management within the organisation must promote this shift in thinking, by raising awareness, developing policy and also demonstrating to the staff through their own participation. Within the organisation accept that mistakes are not avoidable, objective, single events, remove any stigma associated with admitting and reporting mistakes and moreover, reward individuals for their honesty and for highlighting their mistakes that could or did lead to accidents. Through analysing the reported mistakes and accidents and developing subsequent improvements in working procedures, operation of equipment and so on, the benefits can be demonstrated to the staff.

Systems should be put in place to process the feedback – work with the individual to understand why they made the decision they took based on the information they had, analyse these decisions based on what they knew at the time, identify systemic errors that occurred in under- or overestimating difficulties, complexities, abilities, availability of equipment, and so on. All staff should be fully engaged in the development of the process and rewarded and championed for their contribution to improvement the levels of safety. Perhaps the most significant benefit of adopting this culture is that it helps mitigate catastrophic accidents; if there are many smaller mistakes, or "near misses", the possibility of a major accident increases. Therefore if these less severe events are avoided, prevention of major accidents will follow.



In general, it is important to ensure that:

- A safety plan is in place
- That safety matters are always considered before any new product, project or activity is started
- All hazards are identified and risks assessed with respect to personnel, members of the public, and property
- There are guidelines that address the relevant aspects, such as behaviour within premises, operation of plant, control of substances, operating procedures, and so on
- Plans are in place to deal with serious or imminent danger, such as major releases of gas, fires, process deviations, etc

1.3.5 Measuring performance

It is essential to measure the performance of aspects related to safety matters. This provides an indication of how successful the approach which has been taken is. Active monitoring, before things go wrong, involves regular inspection and checking to ensure that your guidelines are being implemented and management controls are working. Reactive monitoring, after things go wrong, involves learning from mistakes, whether they have resulted in equipment failures, incidents, property damage, injuries or near misses.

There are two key components of monitoring systems:

- Active monitoring; before things go wrong – this checks whether the objectives set out in the guidelines are being met and are effective
- Reactive monitoring; after things go wrong – this enables the learning of mistakes and subsequent optimisation of procedures, guidelines, etc, as a result of investigations into components failures, incidents, damage and injuries

Information from both active and reactive monitoring should be used to identify situations that create risks, and do something about them. Priority should be given where risks are greatest. Look closely at serious events and those with potential for serious harm. Both require an understanding of the immediate and the underlying causes of events. In the case of reactive monitoring, investigate and record what happened, and find out why. Refer such information to the personnel with authority to take remedial action, which may including change of suppliers, improving test methods, or even organisational and policy changes.

In general, it is important to ensure that:

- Whether the organisation is meeting the objectives and guidelines for safety aspects
- The controls for risks are sufficient
- The organisation is complying with the safety legislation that affects the processes, products, and so on
- The investigations get to all the underlying causes of a problem
- Investigations do not just stop when it has found the first person that has made a mistake
- There are accurate records of all faults, problems, errors, and so on that may lead to incidents, injuries, and accidental loss

1.3.6 Auditing and reviewing

Monitoring provides the information to enable reviews to be carried out on components, assemblies and activities and helps identify how to improve guidelines and thus, performance. Audits, either by personnel within the organisation or by third parties from outside the organisation, complement the monitoring activities. Auditing may be used to check the suitability or accuracy of the monitoring process, test within a different environment, or check to see if the policy, guidelines, organisation and internal mechanisms are actually achieving the intended results. In short, it helps inform about the reliability and effectiveness of the safety systems.

It is constructive to combine the results from measuring performance with information from the audits to help improve the approach for the safety management. This is done in conjunction with reviewing the effectiveness of the safety policy, whilst paying particular attention to:

- The degree of compliance with safety performance and guidelines, including legislation
- Areas where guidelines are absent or inadequate
- Achievement of the objectives and performance criteria
- Failure and incident data, including analyses of immediate and underlying causes, trends and common features

These indicators will show you where you need to improve.

14 IDENTIFICATION OF COOPERATION PARTNERS

14.1 Introduction

When a company initiates the introduction of HC refrigerants in their equipment, either for manufacturing, installing, servicing, or some other activity, and there is an absence of knowledge or experience, the company should seek out support from cooperation partners. Some refrigeration institutions / organisations worldwide such as associations, universities, laboratories, national ministries or governmental departments offer companies support and consulting referring how to deal with refrigeration systems.

There are several types of organisations that may be approached for support:

- Industry associations
- Technical institutes and associations
- Development agencies and international funds
- National authorities
- Standardisation bodies
- Accreditation bodies

It should also be noted that in certain cases, some organisations may not be sympathetic to the uptake of HCs or other alternative refrigerants. Therefore, it is important to choose cooperation partners wisely. Several such organisations are listed in the Appendix 3.

14.2 Industry associations

Industry associations vary widely. Within the RAC sector they tend to represent groups of commercial organisations, for example, end users of RAC equipment, contractors/installers, component manufacturers, appliance producers, and so on. Their primary objective tends to be supporting the collective interests of their member companies. Their activities may include setting up trade events, exchanging market developments, producing industry guidance, and defending their members' activities within commercial, environmental or political arenas. Most industry associations operate on a membership scheme, where a company may join, for a certain fee, which may be as a function of the size of the company.

Obviously, if the large majority of an industry association's membership comprises companies that have no interest, or even technologies compete against HC refrigerants, then it is unlikely that cooperation will be forthcoming. On the other hand, industry associations do exist that are dedicated to HC refrigerants, or natural refrigerants, or related technology, in which case there could be benefits to be gained. In this case, the types of cooperation possible may include:

- Sourcing of technical information
- Developing technical or other types of guidance
- Identification of market areas
- Introductions to other partners
- Legislative or policy support

Normally, information on industry associations can be found on the internet, within trade journals or at exhibitions.

1.4.3 Technical institutes and associations

Here, the term 'technical institutes' covers a range of different bodies, although in particular, it refers to non-commercial organisations whose primary interest is of technological or scientific nature. The main examples include universities and polytechnics (with departments involved with RAC and related subjects), private and public research organisations, and societies dedicated to the dissemination of technical information. Thus, the types of activities that these organisations may be involved in could be public research and development projects, private research work, organisation of conferences, development of technical literature, and so on.

Some such organisations have individual membership schemes or consortia schemes whilst others may only carry out work specifically upon request and probably payment. Since technical institutes are largely technology-neutral, in that they don't tend to have commercial biases, they can be very useful for obtaining independent information, in this respect. Also the reliability of technical information can be of a higher quality and go into more depth, than from certain other sources. Typically, technical institutes can be useful for:

- Evaluation of products
- Carrying out independent test work
- Development and evaluation of a particular technology
- Producing specific technical guidance
- Solving particular technical problems

However, it is important to ensure that if paying for their assistance, be sure to identify ones that have expertise in the particular topic under consideration, so as to increase the potential for obtaining values for money.

Normally, information on technical institutes can be found on the internet, or from checking associations of technical reports or other technical publications.

1.4.4 Development agencies

Development agencies include UN organisations, bilateral partners and international funds. Under the Montreal Protocol on Substances that Deplete the Ozone Layer, the United Nations development agencies (and a few bilateral partners) operate as implementing agencies and provide assistance to developing countries (A5 countries under the Montreal Protocol) to phase-out ODS, such as the fluorinated refrigerants, i.e. CFC, HCFC (and possibly in the future also for HFC).

The agencies provide partner countries with both policy advice and assistance with implementation of phase-out measures of ODS, e.g. technology transfer and capacity building for the introduction of alternative environment-friendly technologies. Partner countries receive financial/technical help with the submission of project proposals to the Multilateral Fund's Executive Committee.[2] The application for funding goes through national governments and their respective national ozone officers.

2 More information about implementing agencies to the Multilateral Fund is available on the Multilateral Fund internet site (www.multilateralfund.org/implementing_agencies.htm)

In addition, other funding sources from bilateral or multilateral partners may be available for the implementation of projects to introduce HC refrigerants as climate-friendly alternative to fluorinated greenhouse gases. One example is the International Climate Initiative funded by the German Federal Ministry for Environment, Nature Conservation and Nuclear Safety. The International Climate Initiative supports climate protection projects in developing and newly industrialising countries and in transition countries in Central and Eastern Europe.[3]

1.4.5 National authorities

National authorities, such as Environmental Ministries and Health and Safety Departments are involved in formulation of policies and legislation relevant to HC refrigerants. The legislation may affect the workplace and so to ensure the safety of the people working with HCs, it may prescribe regulatory controls as it is often classified as a hazardous gas (e.g. for transport etc) and detail precautionary measures on how to prevent ignition. Certain laws may prescribe certification of the design, manufacture, supply, operation, and repair of pressure equipment used in workplaces.

Most national authorities manage valuable information and data sources and may give guidance on proper set-up of safety infrastructure for the application of HCs for different settings and conditions. For example, inquiries related to proper fire protection in buildings may be addressed to safety and fire protection institutes/authorities. Information on technical backgrounds such as safety tests and regular safety checks may be obtained from research institutes for engineering and safety.

As the involvement of national authorities varies widely from country to country and even between districts on the sub-national level it is not possible to make any general statements on their form of involvement. The following paragraphs highlights some main authorities and their possible functions in the very first steps of introducing legislation on HCs – where there is no policy in place yet, as is currently the case in many developing countries.

In the course of formulating a national phase-out plan for the HCFC phase-out, national authorities have taken the opportunity to create a framework enabling a wide application of HCs. The introduction of HCs is also regarded as a contribution to climate policy.[4]

National Ozone Units/Environmental Ministries

The National Ozone Units (NOUs) are national focal points for the implementation of the Montreal Protocol, and are key to any decisions and actions related to the implementation of the phase-out plans for HCFCs in their countries. NOUs are often subordinated departments in environmental ministries.[5] The respective departments in environmental ministries decide upon the acceptance of the HCFC phase-out management plans or any other environmental policies which may affect the application of HCs.

3 Amongst others, two projects to introduce HC refrigerants are funded since 2008, one with an air-conditioner manufacturing company in China and the second with a manufacturer of commercial refrigeration equipment in Swaziland. GTZ is implementing these projects on behalf of the Ministry and advising the corporations on technical issues related to the factory conversion and safety issues. More details about these projects are available on the internet site of the International Climate Initiative www.bmu-klimaschutzinitiative.de/en/home, or from GTZ, www.gtz.de/proklima.

4 One example is a project funded by the German Environment Ministry in China and implemented from 2008 to 2010. The purpose of this project was to assist China's Ministry of Environmental Protection in developing a climate-compatible policy for the refrigeration and foam sector and to formulate appropriate standards and regulatory provisions to support the use of natural refrigerants. More information about this project is available at http://www.bmu-klimaschutzinitiative.de/en/projects?p=1&d=212.

5 Contact details are available at www.unep.fr/ozonaction/information/contacts.htm

The preparation of the national HCFC phase-out management plans may involve the following activities which will then be coordinated by the national environmental ministry and the NOU, for example:

- Organisation of consultation meetings for stakeholders (establishment of regular meetings with government agencies for policy review and meetings with industry representatives for sector-level approaches)
- Setting-up information dissemination tools for industry interaction and organising sector-level work-shops
- Drafting of plans based on input by stakeholders and data collected in all relevant sectors

Industry representatives can address the NOU for information about ongoing developments under the HCFC phase-out; how different sectors will be affected by the commitments taken on the international level; how to receive support for introducing alternative technologies and which cooperation partners are available internationally and/or nationally. Additionally, the NOU is able to provide guidance and information on the current status of national legislation/standards for the introduction of HC refrigerants.

Health and safety departments[6]

National institutions for occupational health and safety often provide data sources on workplace health and safety. These departments develop standards and legislation for the protection of people in contact with dangerous substances. Since dealing with HC refrigerants is subject to safety and health provisions, certain requirements for workplace design and precautionary measures and in some cases documents may be issued by health and safety departments. National fire protection institutes provide guidance on safety measures in buildings.

1.4.6 Standardisation bodies

Standards are developed on a national, European and international level, amongst a variety of different organisations. An overview of these organisations (with some randomly selected national organisations for illustrative purposes) is shown in Figure 6.

There are a large number of international standardisation organisations, but the main two that are directly involved with standardisation for refrigeration system safety is International Standardisation Organisation (ISO) and International Electro-technical Commission (IEC). Both of these bodies are essentially independent of governments, industry associations and private enterprises. Similarly, they are also independent of each other. However, there is now a formal agreement between the two organisations to collaborate and compliments each others' standards. This also helps prevent overlap, contradiction and repetition of development work and requirements within the standards.

At a European level, there are also two main bodies that are involved with standards for refrigeration safety, Comité Européen de Normalisation (CEN) and Comité Européen de Normalisation Electrotech-nique (CENELEC). Again, these are also independent of governments, European institution such as the Commission and European Parliament, and are also independent of each other. However, as with ISO and IEC, there is also a formal agreement of cooperation between the two bodies. Similarly, there is also a legal responsibility of both CEN and CENELEC to develop "harmonised" standards in response to the publication of European directives; this enables the essential requirements of EU directives to be met by confirming with harmonised standards.

6 An example is the UK Health and Safety Executive (HSE), which provides extensive information on safety matters, including flammable gases (www.hse.gov.uk)

At a country level, most countries have national standardisation bodes, and some have more than one.[7] National standardisation bodies either produce their own standards or review and adopt international (and if within Europe, European) standards. In addition, certain countries have trade associations or technical institutes that produce their own (internal) standards, which may be adopted as national standards. Some national standards bodies are independent, whilst some are directly or indirectly linked to government.

Figure 6: Overview of links between international, European and national standardisation organisations (national bodies are shown as examples)

Generally, countries that have membership to ISO or IEC may adopt an ISO or IEC standard as a national standard, which may be a direct copy, or with modifications to suit the national situation. National standardisation bodies within Europe that are members of CEN and/or CENELEC (this applies at least to all EU members states) have an obligation to adopt their standards. Normally the same national body liaises with both ISO and IEC (and CEN and CENELEC if within Europe), whereas in certain countries there may be separate national bodes dealing with ISO (and CEN) and IEC (and CENELEC) If the country has a conflicting national standard, this must be withdrawn. Sometimes, CEN adopts ISO standards and vice-versa, and similarly, CENELEC may adopt IEC standards and vice versa.

7 The contact details for virtually every national standardisation body may be found may be found in at least one of the following: www.iso.org/iso/about/iso_members.htm; www.iec.ch/dyn/www/f?p=102:5:0; www.cen.eu/cen/Members/Pages/default.aspx; www.cenelec.eu/Cenelec/About+CENELEC/Our+organization/CENELEC+Members/Default.htm

1.4.7 Accreditation bodies

Accreditation bodies are used for ensuring that the application of national or internationally agreed standards by organisations that provide certification, testing, inspection and calibration services are correctly achieved.[8]

1.5 FRAMEWORK OF REGULATIONS AND STANDARDS

1.5.1 Introduction

The rules that impact on the safe application of HC refrigerants may be categorised into regulations, standards and industry guidelines. Each of these serve a particular purpose, and it is important to understand what these are and how to identify the appropriate documentation to use for a particular situation. There are a extensive number of regulations, standards and industry guidelines that directly or indirectly impact on the use of HC refrigerants, at the following stages

- Design of systems and equipment
- Manufacture of components, systems and equipment
- Installation and positioning of systems and equipment
- Service, maintenance and dismantling of systems and equipment

The different types of rules have varying priority, and the hierarchy of regulation, standards and guidelines is shown in Figure 1. Generally, national regulations have overall priority and their requirements are legally binding. National and to a lesser extent, international standards, are a technical interpretation of what is considered to be "safe", and lastly, industry guidelines tend to be non-binding and informative only.

Figure 7: Hierarchy of regulations, standards and guidelines

This section will provide an overview of regulations and industry guidelines, but will focus on the concept of standards and where and how they should be applied.

8 A listing of most accreditation bodies can be found at the internet site of the International Accreditation Forum (www.iaf.nu), at http://www.compad.com.au/cms/iaf/public/5

1.5.2 National health and safety rules

In most countries, there are other important national rules which have to be considered. Typically, this includes generic legislation (as one or several acts) relating to industrial safety and health of workers. Such rules will specify among other things, the provision and use of work equipment by employees at work, whilst the obligation for the requirements are directed to employers. Such rules are considered the central document to use when assessing the hazard potential of work equipment. Often, the authorities will produce regulations, standards or codes to help facilitate the practical application of the laws in companies. To support the general health and safety legislation, there will normally be complimentary rules that apply to the inspection of work equipment and installations subject to monitoring by an approved body or authorised "competent person".

1.5.3 Regulations

National regulations are normally the overriding rules that apply, but have a tendency to simply state "it must be safe", rather than actually describing what "safe" is. Regulations are typically specific to individual countries (except in some cases within the European Union where certain regulations apply throughout member states). Because regulations are generally country-specific, it is not practical to provide a detailed overview of their requirements. However, since there are very few, if any, regulations that deals specifically with the safety of HC refrigerants, providing descriptions of them serves little purpose. Normally, a number of different types of regulations should be applied to the context of the use of flammable refrigerants within refrigeration system. Such regulations include the following:

- Machinery safety
- Pressure vessel and pressure system safety
- Electrical safety
- Flammability of gases and liquids
- Hazardous area safety[9]
- Waste substances and waste equipment
- Building construction safety

Thus, normally within a country, the consideration of such regulations will provide an indication of how flammable refrigerants should be handled and any special aspects to address.

1.5.4 Standards

A standard is principally an agreed, repeatable way of doing something. It is a published document that contains a technical specification or other precise criteria designed to be used consistently as a rule, guideline, or definition. Standards are developed by committees comprising interested parties such as the producers, sellers, buyers, users and regulators of a particular product, process or service. The developed standards are designed for voluntary use and do not impose any regulations. However, laws and regulations may refer to certain standards and make compliance with them compulsory.

Although standards are designed for voluntary use and do not impose any regulations, by law many governments, industry bodies and trade associations require products, services, etc, to conform to a standard or a regulation before they can be offered for sale, or placed on the market. This is to ensure that countries and companies can compete on equal terms, that a certain quality is attained, and to ensure that a certain level of safety has been achieved.

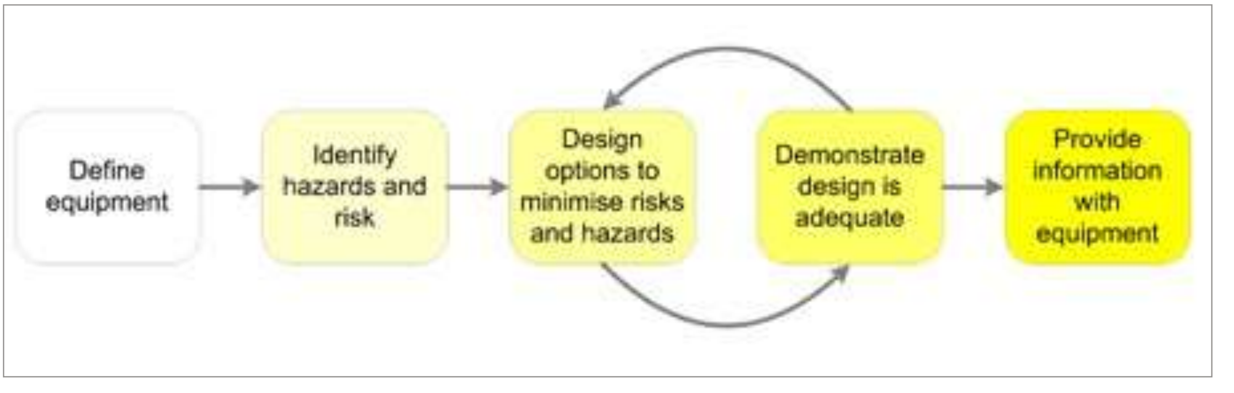
9 Reference is made to the two so-called "ATEX" European directives: the ATEX 95 equipment directive 94/9/EC, "Equipment and protective systems intended for use in potentially explosive atmospheres", and the ATEX 137 workplace directive 99/92/EC, "Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres"; these help provide a broadly logical approach to handling flammable substances for any situation.

Safety standards approach

There are a variety of different safety standards, covering an extensive range of materials, products, processes and services. For components and assemblies typical of those used for RAC situations, there is a fairly common approach, as detailed in Figure 8.

Firstly, the thing that is under consideration is defined, and then risks and hazards associated with it are identified. One or more design options may be offered so that the risks and hazards would be reduced to an acceptable level. However, the validity of the chosen approach must then be demonstrated somehow, and this may be through inspections, certification and/or testing. Depending upon whether the criteria is met or not, alternative approaches may need to be considered and implemented. Lastly, there is normally a requirement to make a provision of information, which may include marking, instructions and/or other documentation.

Figure 8: Typical approach for safety standard



Within the context of a refrigeration system, there is a large number of related standards. Figure 9 provides a map of the different aspects related to refrigeration systems and the safety-related issues that are normally addressed within standards. The map in Figure 9 identifies six main categories:

- The entire environment within which the system operates
- The entire refrigeration system
- The components that comprise the system
- Instrumentation and controls associated with the system
- Fluids used within the system
- Associated equipment used with the system, e.g., during servicing

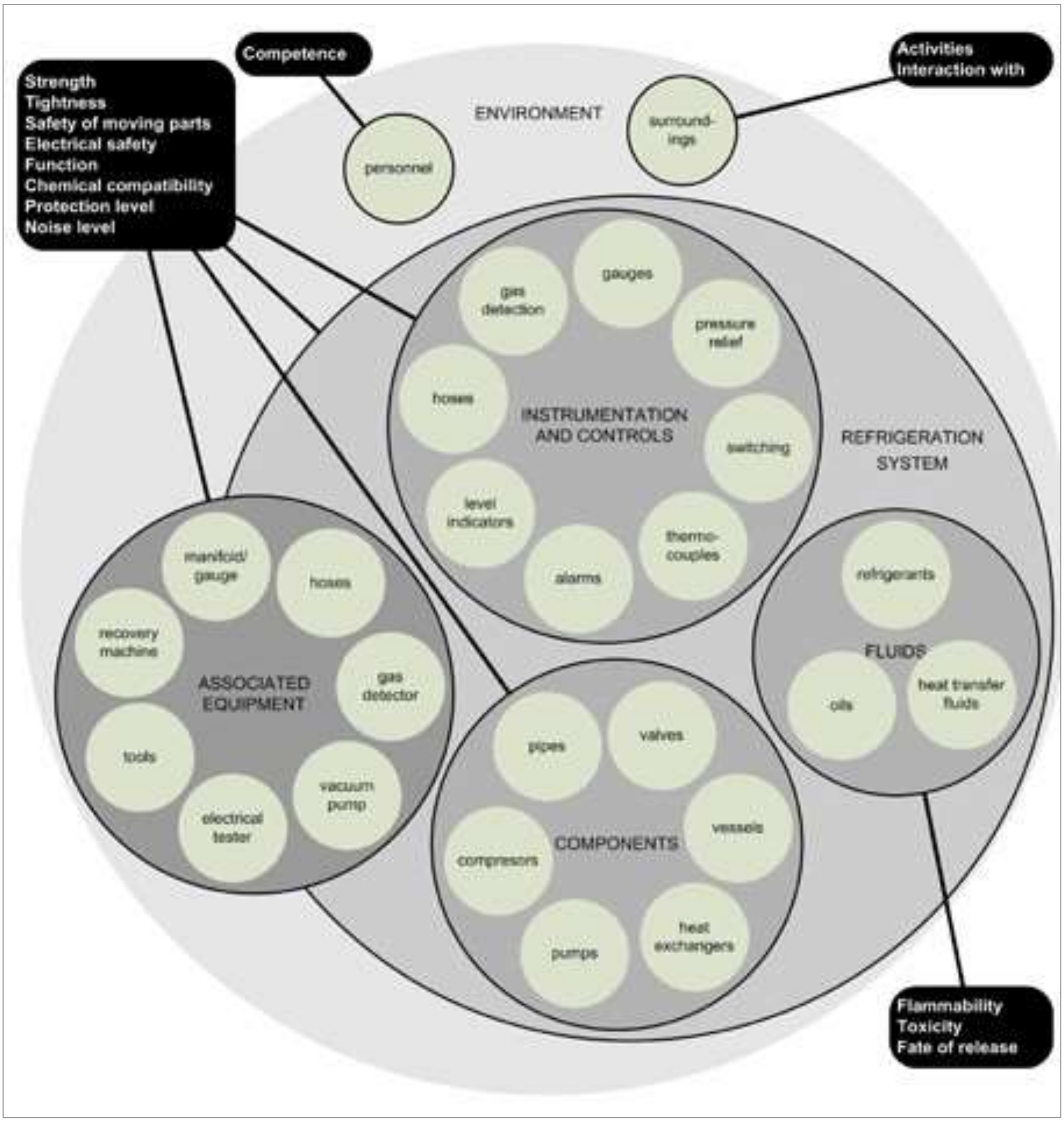
For all of these categories and the elements within them, there are a series of considerations that may be applied in order to evaluate the level of safety. For the components, instruments, controls and associated equipment, as well as the entire system, aspects such as strength, tightness and electrical safety should be evaluated. For the fluids, toxicity, flammability and fate of released fluids should be addressed. In addition, personnel need their competence ensured and the surroundings need to be considered with respect to various form of interaction with the system and its parts.

For a large proportion of these categories and elements, safety standards exists that describe the safety considerations for each and the types of testing and evaluation required to meet the desired level of safety. Amongst these standards are included:

- General standards, which are conceptual or that cover components, etc, for a wide range of applications (not just for RAC)
- Standards that deal specifically for with RAC applications, but are not refrigerant-related
- Standards that address RAC components, systems and equipment, but which specifically account for refrigerants including HC refrigerants

It is the latter type of standard that will be addressed further.

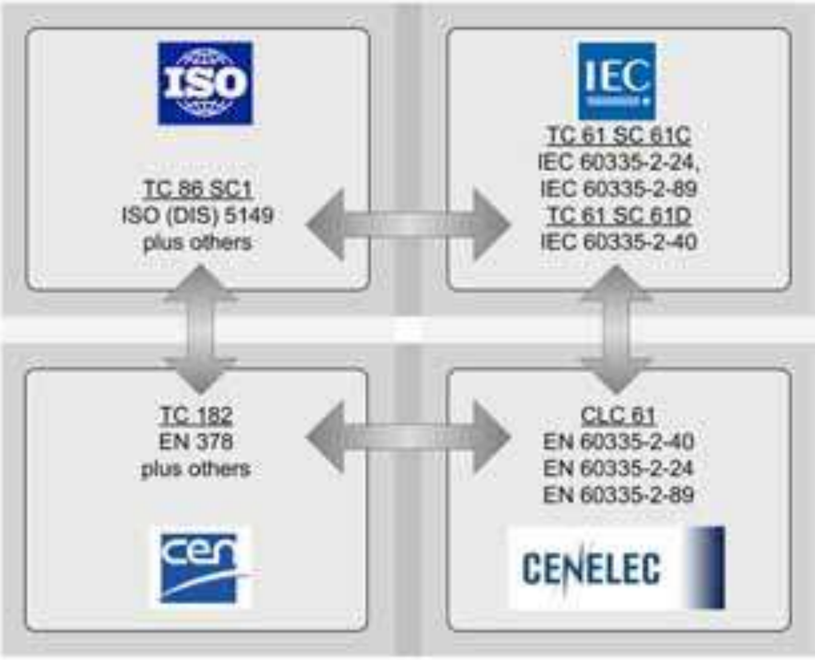
Figure 9: Aspects of a refrigeration system implicated by safety standards



Safety standards concerning HC refrigerants

There are several European and international standards that address RAC equipment, and which specifically include requirements for HC refrigerants. Typically, these standards are applicable to entire assemblies and components, rather than individual elements in isolation. These key European and international standards are shown in Figure 10, along with the technical committee that is responsible.

Figure 10: Key international and European standards that address HC refrigerants, associated committees and inter-linkages



At international level, there are currently four standards, one from ISO and three from IEC. The ISO standard, ISO 5149 is a general standard that in theory applies to any RAC system. The three IEC standards, IEC 60335-2-24, IEC 60335-2-40, and IEC 60335-2-89, apply to domestic refrigeration, air-conditioners and heat pumps, and commercial refrigeration, respectively. Similarly, at a European level there are also currently four standards: a CEN standard, EN 378 which is a general standard that in theory applies to any RAC system, and for three CENELEC standards, EN 60335-2-24, EN 60335-2-40, and EN 60335-2-89. A summary of their scope is included in Table 3.

Some important remarks can be made in relation to these standards:

- ISO 5149: the current version of this standard is from 1993, and it is somewhat out of date, and does not include any useful requirements with regards to the use of HC refrigerants. Since before 1998 it has been under revision, and the current version (DIS ISO 5149: 2009) is based on the published version of EN 378. However, significant modifications are proceeding, and as a result the final requirements may be considerably different from the current draft.
- IEC 60335-2-24, IEC 60335-2-40, IEC 60335-2-89: these "appliance" standards are part of a group of over 100 other parts that cover a wide variety of other (non-RAC) appliances and equipment. They are all based on a common standard, IEC 60335-1, which is for general safety requirements for household and similar electrical appliances. This provides the basis for the other standards, which in turn list a series of additions and modifications necessary to make the particular part applicable to the appliance under consideration.

- EN 378: The current version is 2008 and its requirements cover the use of HC refrigerants for a range of applications.
- EN 60335-2-24, EN 60335-2-40, EN 60335-2-89: these are virtually the same as the IEC versions, except for certain modifications for conforming to the European situation.

The main requirements of these standards are used for a large portion of the guidelines within this handbook. However, it should be recognised that this material is not a substitute for conforming to relevant standards (and regulations). It is also noted that some elements of the safety standards are not ideal and may in fact sometimes be inappropriate (if this is the case, a thorough justification should be provided for how an equivalent level of safety is being achieved through alternative measures). Furthermore, standards are continually updated, revised and amended, so the contents of this section/manual is not a substitute for the standard itself However, in order to conform to a safety standard, the safety standard should be used – this is only guidance. Nevertheless, in absence of requirements within a national standard, these could be used in addition.

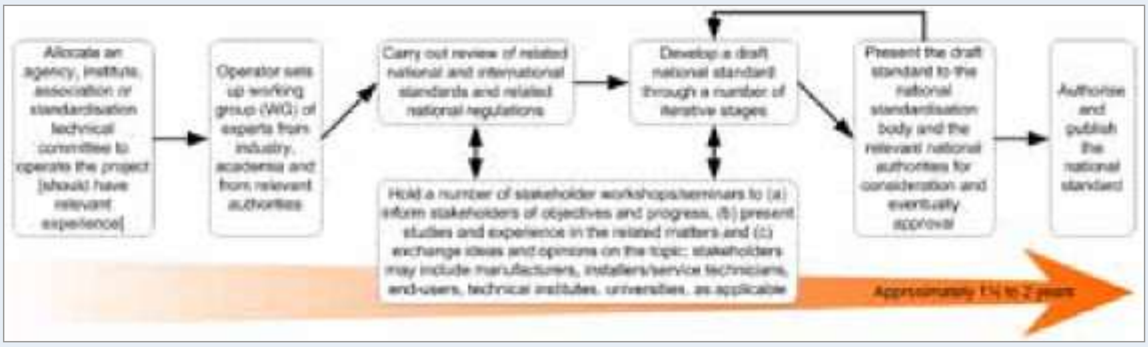
Table 3: Summary of the relevant safety standards

Standard	Title	Application	HC charge size limits
IEC and EN 60335-2-24	Particular requirements for refrigerating appliances, ice-cream appliances and ice-makers	Domestic refrigeration	Up to 150 g
IEC and EN 60335-2-40	Particular requirements for electrical heat pumps air-conditioners, and dehumidifiers	Any air conditioning and heat pump appliances	Up to ~ 1kg and ~ 5 kg, depending upon application
IEC and EN 60335-2-89	Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor	Any refrigeration appliances used for commercial situations	Up to 150 g
EN 378	Refrigeration systems and heat pumps –safety and environmental requirements	All refrigeration, air conditioning and heat pumps; domestic, commercial, industrial	Variable, depending upon application
ISO (DIS) 5149	Mechanical refrigerating systems used for cooling and heating – safety requirements	All refrigeration, air conditioning and heat pumps; domestic, commercial, industrial	Variable, depending upon application

DEVELOPING A STANDARD

It may be useful for an A5 country to develop its own version of a standard. When doing this, in one respect it is advisable to follow an equivalent international standard, or a widely acknowledged national or regional (e.g., European) standard. On the other hand, such standards are often overly complex and riddled with restrictive requirements as a result of commercial interests during the standards development process. Therefore, it is advised that an as simplistic approach as possible is developed, whilst ensuring a good level of safety but not prohibiting technology, but also ensuring that it is sufficiently comprehensible for most technicians and engineers to easily follow.

The standards development process differs amongst countries, and according to the type of standard. The following process illustrates the process carried out within one Asian country to develop a national standard for HC appliances.



Checks should be introduce in various points to ensure that the process is not being used to prohibit, rather than to produce a robust and safe standard

Electrical standards

There are many national and regional electrical standards applicable globally. The main European standard is EN 50110: 2004 “Operation of electrical installations” (including National Annexes). The standard consists of two parts. The first part, EN 50110-1 contains minimum requirements applicable for all CENELEC member countries and some additional informative annexes dealing with safe working. The second part, EN 50110-2 consists of a set of normative annexes which specify either the present safety requirements or give the national supplements to these minimum requirements at the time when this standard was prepared. In addition to this, there are also a variety of electrical standards specific to electrical appliances and other equipment. The generic standard for appliances is EN / IEC 60335-1.

Hazardous area standards

There are a large number of standards that are applicable to “hazardous atmospheres”, which typically apply to situations where flammable gases (or dusts) may be present. Most of these standards have been developed for situations where large quantities of flammable substances are present, such as oil rigs, refineries and other petro-chemical facilities. Nevertheless, the same principles apply where flammable refrigerants are used, and therefore such standards are also of interest. Further, within Europe and certain other countries, legislation on hazardous atmospheres generally invokes certain assessment methodologies described in hazardous atmosphere standards, and therefore should be given some consideration. In fact, these standards are also applicable in other aspects of the equipment lifetime, such as during testing, manufacture and disposal. However, it is also noted that these standards are often unlike standards used within the RAC industry and can seem onerous, so they must be read and applied with careful consideration.

1.5.5 Other publications

Other publications, including codes of practice guidelines are also useful sources of information. These may be produced by industry or trade associations, technical institutes, development agencies, and so on. These tend to be specific to certain countries and/or specific to certain applications to equipment. In this respect they may be useful. However, they rarely tend to carry any level of authority and are tended to be used as guidance for understanding and interpreting regulations and standards. A list of selected publications which may be of use is provided within the bibliography. Lastly, there are a variety of technical and scientific publications that are directly applicable to many types of systems and equipment using flammable refrigerants, and these can be also be particularly useful when situations are being investigated in depth.

PART 2: QUALITY SYSTEMS FOR SAFETY

2.1 INTRODUCTION

2.1.1 General overview

The concept of quality as we think of it now first emerged out of the Industrial Revolution. From here on, quality systems were established in companies for good quality of production and rectifying of errors. As mentioned previously, to ensure a high level of safety for a product and/or service not only requires conforming to a set of rules.

The International Organisation of Standardisation's ISO 9001: 2008 series describes standards for a quality management system (QMS) addressing the principles and processes surrounding the design, development and delivery of a general product or service. Organisations can participate in a continuing certification process to ISO 9001: 2000 to demonstrate their compliance with the standard, which includes requirements for continual improvement of the quality system. Also manufacturers must establish and follow quality systems to help that their products consistently meet applicable requirements and specifications.

The essential elements that a quality system shall embody for design, production and distribution include:

- Personnel training
- Controlling the product design
- Controlling documentation
- Controlling purchasing
- Product identification and traceability at all stages of production
- Controlling and defining production and process
- Defining and controlling inspection, measuring and test equipment
- Validating processes
- Product acceptance
- Controlling non-conforming products
- Instituting corrective and preventive action when errors occur
- Labelling and packing
- Controls
- Records
- Servicing
- Statistical techniques

This type of approach is common for a variety of reasons; in addition to safety, it may also be needed for product reliability, maintaining efficiency, continued development and improvement, customer satisfaction, environmental impact, and so on. Whilst the concept described here is generally applicable, the focus is on handling of HC refrigerants.

Figure 11 illustrates an overall generic approach of the quality system for safety. The approach is centred on the activities under consideration. This may range from a small company that only designs one specific component or self-employed technician carrying out service work, up to a large manufacturer of components and factory-assembled appliances or a contractor carrying out design, installation, commissioning and maintenance of very large refrigeration systems. Thus the activity under question may be singular and fairly isolated, or it may include a number of interconnected activities. However, for a project that involves several organisations, the system should be set up to handle the entire set of activities in an interconnected manner. Similar, for a given product or appliance, such a system should encompass what happens to it for the duration of its lifetime, far beyond the point of leaving the factory. Of course, all of the components that are indicated in Figure 11 may not be directly applicable to all conceivable activities, and conversely, there could be other peripheral processes that should be adopted that are not shown.

In general, a given activity requires a supply, for example, raw materials, components, external services, supporting equipment, designs, etc. These inputs are then utilised to carry out the activity. During or after the activity, various forms of routine testing may be carried out to check that the output is as intended, for example, the system is leak tight, all the sources of ignition are sealed, checking against safety specifications, etc. However, in order to get a deeper insight into how reliable the activity is, a selected number of items or services may be subjected to more rigorous evaluations, or type-testing. This is sometimes carried out by independent laboratories, or independently witnessed. The results of the routine tests and/or the type testing are checked against a set of criteria. If the test regime indicates a negative result then corrective action must be taken (since it may indicate that the product, installation or service does not meet the desired safety requirements). This may include improving the supply of the input material or services, optimising the activities carried out, but also checking that the testing is being done correctly. Sometimes, a third-party may be engaged at this stage to double-check for errors, or to provide additional expertise. If the test result criteria are met, then the output is considered to be positive. In this case, the necessary documentation can be prepared, for example, test reports, commissioning sheets, etc. Finally, the relevant literature is presented (where relevant) and finally some form of approval can be supplied, certification and/or quality marking if required. The latter may range from a simple process, such as a facilities manager signing off a technician's work, to getting official certification from a notified body for completion of a large refrigeration facility or a specific appliance to be sold within a particular region.

In order to ensure that each of the internal processes is being carried out according to the best practice, a scheme of inspections should be set up. For instance, with the activity inputs the purchase of materials, parts or services should be observed and checked to ensure that their specifications meet what is needed by the main activity, that the quantity of the supply is consistent, etc. Similarly, the inspections should also observe how the prescribed working procedures are being carried out for the activity under consideration, and that both the routine testing and type testing are also following the established protocols. Further, the actual scheme that has been set up to carry out the various inspections may also be subject to inspections and checks itself so that global errors can be identified. Whilst the process inspections may be carried out internally, the overall inspection is often conducted by a third party to ensure that critical issues are not being overlooked.

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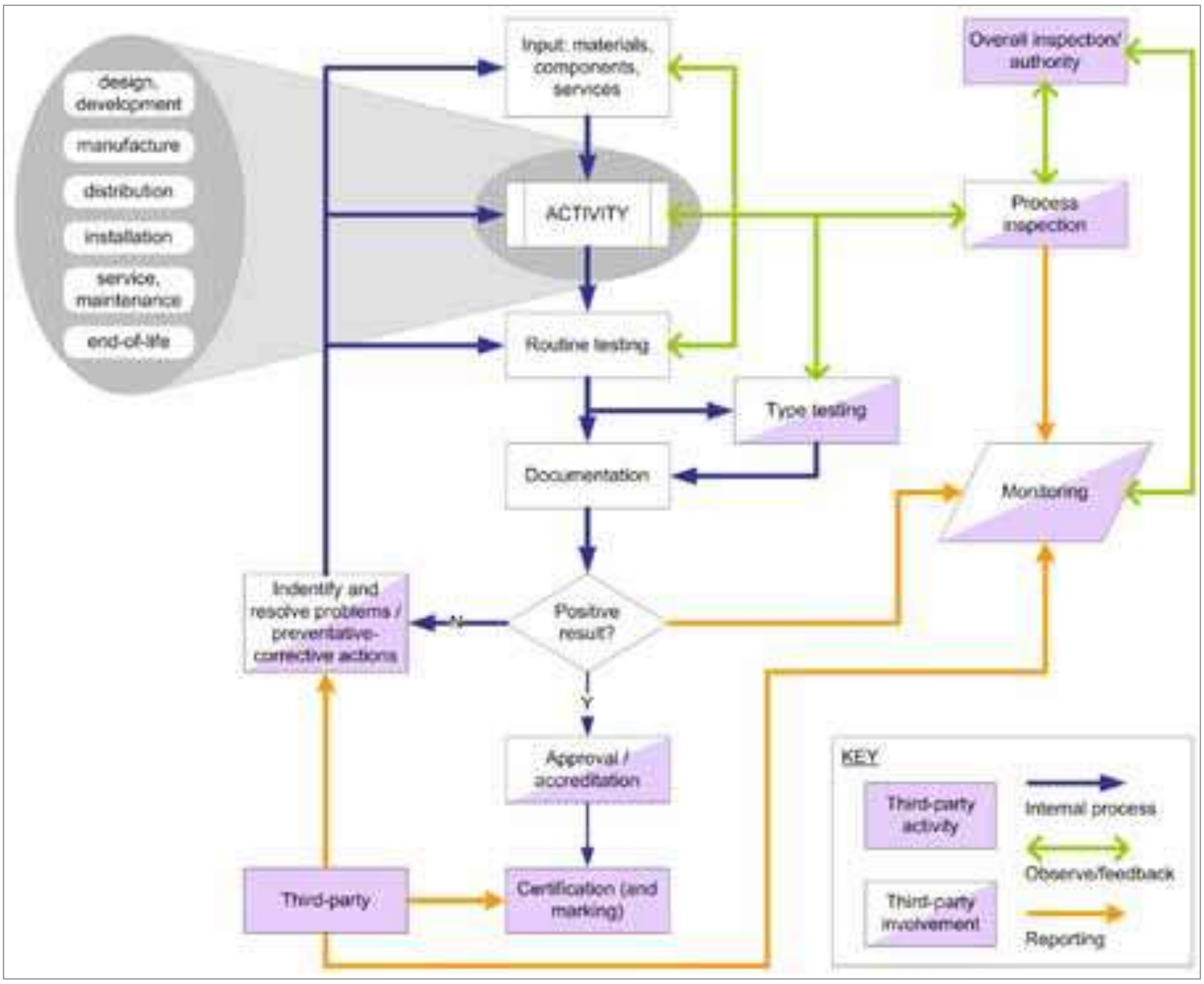
To build up a picture of the activity as a whole, a scheme for monitoring should be established. This acts as a database for recording the reliability (or unreliability) of all the processes, and therefore enables the organisation to identify where problems have originated, or to highlight trends that could eventually lead to a significant hazard. In particular, the monitoring should be extended throughout the lifetime of the equipment or product, since feedback on longer-term problems enables the relevant parts of the activity to be optimised to attain better reliability for future products. For example, it may help to identify a particular valve that frequently leaks after one year of use, or a particular technician that fails to replace proper electrical parts, and so on. Again, the involvement of a third-party can also add value at this stage to assist with providing independent interpretations to the observations, and to feed in experience from other sources.

Figure 11: Overview of a general quality system to address safety matters



2.1.2 Quality control systems

Quality control (QC) is a procedure or set of procedures intended to ensure that a manufactured or installed product, service or some other process adheres to a defined set of quality criteria or meets certain requirements. It may encompass safety testing, third party inspections and quality marking.

Advantages of QC are typically improved reliability, maintainability and safety. In fact, it is necessary to have a QC system for good and safe quality in design, development, production, construction, installation operation and during a servicing. The process uses resources to transform requirements (inputs) into characteristics or specifications (outputs) for the refrigeration systems. Refrigeration systems and their components will be thoroughly inspected and tested ensuring conformance to engineering specifications such as pressure equipment rules in certain countries. A certified quality management system is mandatory when organisations are dealing with products with strong health and safety requirements. For example, in Europe, the establishment and certification of QM systems is a condition for achieving CE[10] marking of equipment and components. One of the most widely known quality control systems is ISO 9001. Alternatively, the QM system may be developed internally or selected specifically to suit the nature of the business.

There is also external QC which checks the products and services at necessary intervals throughout a year, often without prior notice. In the case of products, items may be taken from the storage place to check them in an external laboratory and similarly all documentation associated with the product and that related to the internal quality control may be checked as well. In the case of some service, this may be observed (maybe on a random basis) directly as it is being carried out, and possibly an inspection of the work following completion.

In order to implement an effective QC programme, the organisation must first decide which specific standards, guidelines or some other set of rules that the product or service must meet. Then the extent of QC actions must be determined (for example, the percentage of units to be tested from each lot). Next, real-world data must be collected (for example, the percentage of units that fail) and the results reported to management personnel. After this, corrective action must be decided upon and taken (for example, defective units must be repaired or rejected and poor service resolved at no charge until the manufacturer is satisfied). If too many units failure or too many instances of poor service occur, a plan must be devised to improve the production or service process and then that plan must be put into action. Finally, the QC process must be ongoing to ensure that remedial efforts, if required, have produced satisfactory results and to immediately detect recurrences or new instances of trouble.

WORKING WITH A THIRD PARTY

Many manufacturers work together with third parties. An inspection contract will be agreed between such an institution and the manufacturer which is the basis for the inspections during the year and which is a confirmation for the customer that the products / equipment respect all relevant norms and standards. Third parties offer an integrated service to help local and regional manufacturers solve production problems, carry out failure analysis, support quality control or development testing, improving productivity and product quality and safety to provide a greater competitive advantage. Many notified bodies operate worldwide in compliance with local and international laws, regulations and the required safety standards from other countries.

10 Communautés Européennes; CE-certified means that the CE marking is a mandatory conformity mark on many products placed on the single market in the European Economic Area (EEA)

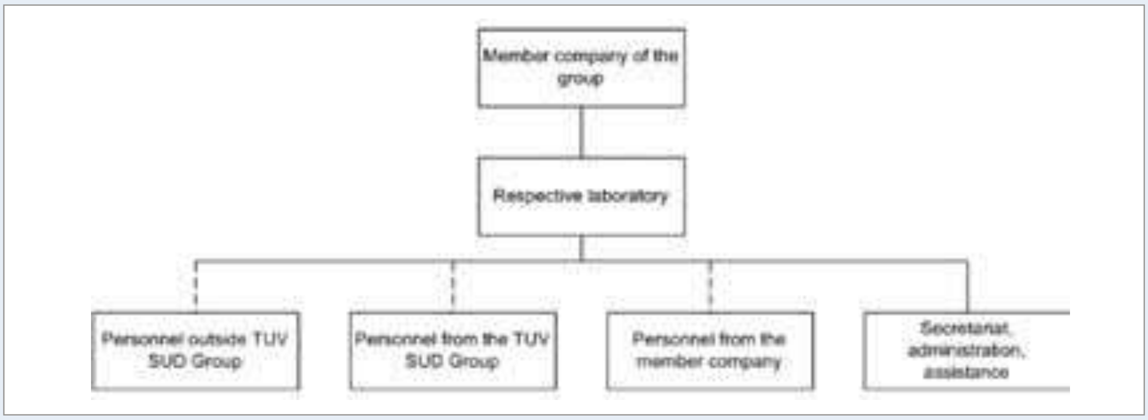
If a company decides to implement a QC programme, they would need to consider certain aspects to ensure its success. There are three steps to be followed in order:

- Step 1 – establish management support
- Step 2 – measure the process
- Step 3 – deal with activity

These steps are a useful guideline with respect to the manufacturer, installing or servicing of refrigeration systems.

CALIBRATION LABORATORIES

Services provided by third-party test and calibration laboratories must be of a high level of quality, of recognised competence and independence. These laboratories must adhere to the international standard ISO/IEC 17025, and must also conform to a mutual recognition and acceptance of test and calibration results by different companies and countries. This applies, in particular, to laboratories accredited by organisations that are parties to mutual recognition agreements. The quality system of the laboratories satisfies the requirements set forth in ISO/IEC 17025, ISO/IEC Guide 2 and ISO 9001. Compliance with quality-system procedures and processes, with which all laboratory staff conducting tests and calibrations must familiarise themselves, ensures that the high quality of testing and calibration activities is continuously maintained and improved. All customers can use the services of the laboratories without discrimination in terms of their accreditations/approvals, competencies and capacities. The figure below shows the organisational structure of the member companies and their affiliated laboratories.



The latest edition of ISO 9001 (2008) specifies requirements for a QM system where an organisation must demonstrate its ability to consistently provide a product that meets customer demands and applicable regulatory requirements. All requirements of this standard are generic and are intended to be applicable to all organisations, regardless of type, size and product provided. Where any requirements of this standard cannot be applied due to the nature of an organisation and its product, this can be considered for exclusion.

Ultimately, the entire QC system is controlled through interaction with industrial partners, and normally there is no direct governmental involvement.

EN 13980

Enterprises, regulatory authorities or other organisations may find the material within the European Standard, EN 13980 – "Potentially explosive atmospheres. Application of quality systems" useful when considering the application of flammable refrigerants. This standard contains requirements and information for establishing and maintaining quality systems related to equipment or workers that may come into contact with flammable atmospheres. It can be used to guide enterprises and authorities in developing and checking the quality systems put in place. It is complementary to the other quality system standards, such as ISO 9000 and ISO 9001 and addresses the general issues of quality management systems, management responsibilities, resource management, product realisation and measurement, analysis and improvement, all specifically applicable to products and environments that involve flammable materials.

2.2 FEED-IN ELEMENTS (INPUTS)

In order to carry out some form of activity, certain elements will be sourced to contribute towards carrying out the activity. This may include, for example:

- Rules and regulations; for correct preparation and execution of activities
- External consultant advice; for checking or guiding an activity raw materials; for the construction of components
- Components; for making up parts of a system
- Parts of assemblies; for connecting to a larger construction
- Tools and equipment; for assembling, installing or working on systems
- Technical literature; for assisting with design work and calculations
- Procedures; for implementing components or carrying out critical actions

Whatever the element under consideration, it is appropriate to clearly identify all of the input streams and also to designate responsibility to specific individuals. Ultimately, taking this type of approach assists with maintaining a good level of quality for the input streams, which translate to a better level of safety, but also to help to trace and resolve problems that may manifest at a later stage.

In general, ensure that all the input streams are systematically identified and documented. For each, specifications or some other performance criteria must be set up, along with mechanisms, such as audit schemes, to check whether criteria are met and if not, how to handle such problems or errors.

Frequently review requirements related to each of the input streams, in case the needs of the activity have changed or in case there are modifications to the activity. This may include checks to purchasing procedures, introducing the necessity for suppliers to have certified quality systems or being audited by the organisation, introducing checking procedures for critical actions, or alternative means of assessing incoming documentation.

Lastly, for any input streams, there should be scheme put in place to ensure their traceability, for example covering its history, application, and forwarding location. The traceability should provide complete information about every step that that each input goes through in latter stages.

23 TESTING

Testing covers a wide range of disciplines, and may include testing of:

- Designs, developmental concepts, methodologies, etc
- Manufacturing or production equipment, processes or emergency systems, etc
- Materials, components, appliances, sub- or entire assemblies or installations, etc
- Maintenance procedures, completed repairs, etc

The common standard applicable to most cases is EN 378 "Refrigerating systems and heat pumps. Safety and environmental requirements. Design, construction, testing, marking and documentation".

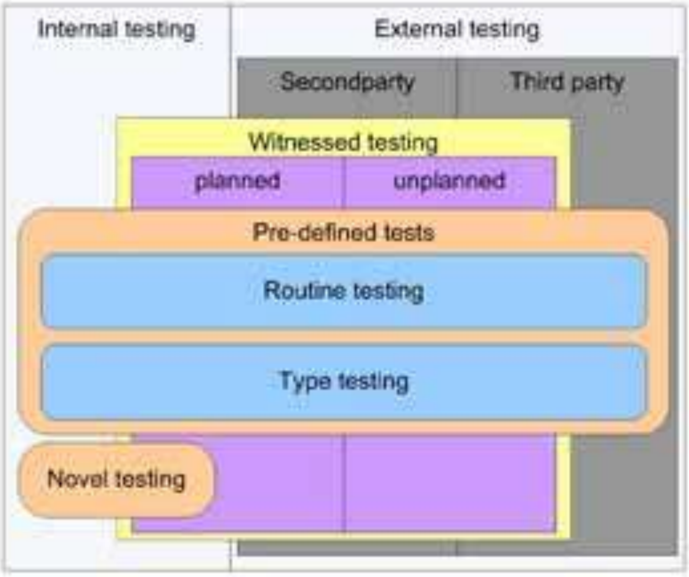
The test itself may be physical testing in the case of components or equipment, or in fact it may be conceptual or paper-based testing in the case of procedures or operations. In all cases, it is essential to clearly identify what is to be tested, the method of test and the criteria for passing (or failing) the test. Any test requirements must be systematically documented and carried out precisely based on the documentation, that is a formal test plan is always needed.

Figure 12 indicates common types of tests and locations. In this respect, there may be three types: those that are carried out internally within the organisation, those that are carried out at some location, but are witnessed by interested parties, or those that are carried out external to the organisation. The external tests may be second-party tests (that is, by a separate organisation with some interest, such as a customer) or third-party tests (that is, but a completely independent and normally contracted organisation).

The most frequently used tests or routine tests, normally carried out by the organisation as part of a production, installation or servicing process. Whilst this is usually carried out by the organisation internally, it is sometimes witnessed to ensure that the practice has not deviated from the intended. For example, this may be leak testing, pressure testing, and functional safety testing, and so on. Type-testing is also a commonly carried out internally, but may also be witnessed or done externally. This is often a more rigorous test that is applied to something that this normally tested routinely, in order to check that an assumed higher level of safety is still inherent in the design or process. Examples include high pressure destructive testing or observing the behaviour of an item within a fire situation. Lastly, where some unusual issue has to be addressed and no specific test procedures exist within standards or other guidelines which must otherwise be followed; novel test methods need be devised. Example of this may arise during the development of a new type of safety device or where a hitherto unanticipated set of circumstances has arisen. In case of non-standardised methods procedures shall be appropriate and fully documented. Instructions, standards, written procedures, work sheets, check lists and reference data shall be maintained up-to date and readily available.

Component testing is important, but also the test of the complete system/appliance. For the safe service of appliances it is not only important that the components fulfil the safety standards. Infrastructure for testing of products (components) is an integral part of any refrigeration product and service. Infrastructure is based upon numerous structural elements like machinery, workforce, quality managers/inspectors, technical engineers, and others.

Figure 12: Common types and locations of testing



Whenever a test regime is put in place, it must be comprehensively documented. This should include:

- Instructions for planning tests
- Relevant standards
- Sampling scheme
- Location of tests
- Set up of test facilities
- Operating procedures
- Approved personnel
- Presence of witnesses, if applicable
- Data-acquisition and data storage
- Technique(s) for analysis of results
- Reporting format
- Distribution channels for test report

An important point concerning safety testing is the competence of the person carrying out the inspection of the system. The system operators must satisfy themselves that the technicians designing or working on the system meet the necessary levels of competence applicable for the work activities under consideration.

The most common tests for RAC systems and equipment include routine tests on components and assemblies, typically:

- Strength (pressure) test for components and assemblies
- Tightness (leakage) test for components and assemblies
- Vacuum test for components and assemblies
- Functional tests on assemblies, for example, for pressure protection of function of emergency ventilation systems
- Leak simulation tests on assemblies to identify accumulation of refrigeration

Proper descriptions of these are generally found in the relevant safety standards that cover RAC components, systems and associated equipment.

CERTIFICATION OF TEST HOUSES

The Standard ISO/IEC 17025: 2005 is the main standard used by testing and calibration laboratories. This standard specifies the general requirements for the competence to carry out tests and/or calibrations, including sampling. It covers testing and calibration performed using standard methods, non-standard methods, and laboratory-developed methods. It is applicable to all organisations performing tests and/or calibrations. These include, for example, first-, second- and third party laboratories, and laboratories where testing and/or calibration forms part of inspection and product certification. ISO/IEC 17025 is applicable to all laboratories regardless of the number of personnel or the extent of the scope of testing and/or calibration activities. When a laboratory does not undertake one or more of the activities covered by ISO/IEC 17025, such as sampling and the design/development of new methods, the requirements of those clauses do not apply. ISO/IEC 17025 is for use by laboratories in developing their management system for quality, administrative and technical operations. Laboratory customers, regulatory authorities and accreditation bodies may also use it in confirming or recognising the competence of laboratories. ISO/IEC 17025 is not intended to be used as the basis for certification of laboratories. Compliance with regulatory and safety requirements on the operation of laboratories is not covered by ISO/IEC 17025.

2.4 INSPECTIONS

2.4.1 Introduction

Inspection refers to a physical process of observations and recording the state of a particular product, assembly, installation, service activity or some other process. Inspections may apply to nearly any activity or item, such as:

- Design department procedures
- Specific design concepts
- Working or evaluation methodologies
- Manufacturing, storage or workshop facilities
- Components, appliances, completed assemblies or installations
- Installation or other site working processes by technicians
- The ability of specific personnel

Again, the standard commonly applied to most cases is EN 378, whilst the standard specific to personnel is EN 13313 "Refrigerating systems and heat pumps – Competence of personnel – Complementary element".

Usually it requires an individual checking something against an existing specification or set of requirements or, on the basis of professional judgement, against general requirements. It may be required for conformity to a standard or regulation, to support certification, for internal purposes or for a customer.

The inspections may be carried out by staff within the organisation, so-called second parties (i.e., organisation with a vested interest in the operations, such as a customer), or some third party. Particularly with larger-scale operations, it can be beneficial to ensure that inspections occur from the initialisation of a project to avoid costly problems from the start. If third-party inspections are being used, it is important to use certified firms with the training and equipment to ensure a good standard of service, and support services may range from planning to operation to reporting. Depending upon the application, inspections may be one-off or initial inspections or periodical inspections whose periods may vary from a half year to twelve years.

2.4.2 Use of third-parties for inspections

Particularly when new technologies, such as HC refrigerants are adopted, it is useful to employ third parties for inspections, which may offer companies a range of relevant services and expertise. Independent inspections of such organisations assist the manufacturer, installer or handler of refrigeration systems in assuring a desired level of quality and safety. Thus, the involvement of a third party enables such companies to carry out design, testing, production, installation and field work test to do so whilst conforming to relevant rules and standards, as well as making sure that they meet the characteristics and specifications demanded by the costumer, without being influenced by internal or other commercial pressures. Independent guidance may also be provided in terms of selection of materials, refrigerants, equipment, meeting deadlines and obtaining transparency for each step with the applicable activity.

What a company needs to know when it develops a new appliance/model or makes a site-built installation is from country to country different. Every country has different requirements and needs. The companies may need to get it approved to check that it follows the appropriate standards and/or regulations properly. Third parties offer their expertise and knowledge of all appliances/units for the RAC industry. The inspections include tests when the refrigeration system with HC refrigerant is in use – so called monitoring or supervision of start-up. These tests are carried out concerning conformity to rules and standards, as well as making sure that the companies meet the characteristics and specifications demanded by the customer. According to the national laws in the corresponding country a third party involvement may be necessary. The third party will also determine what exactly the producer of a new appliance/model needs to prepare according to the national or regional regulations.

Whatever the inspection body is doing, it is important that they follow to ISO/IEC 17020, which is the international standard for general criteria for the operation of various types of bodies performing inspections.

2.4.3 Function of an inspection body

The inspection body is the organisation whose staff are responsible for carrying out the inspection. In order to maintain independence, this body must not be the designer, manufacturer, supplier, installer, purchaser, owner, user or maintainer of the items which they inspect, nor the authorised representative of any of these parties. Similarly, the inspection body and its staff must not engage in any activities that may conflict with their independence of judgement and integrity in relation to their inspection activities. In particular they cannot become directly involved in the design, manufacture, supply, installation, user or maintenance of the items inspected, or similar competitive items.

Normally, any interested parties will have access to the services of an inspection body. The procedures under which the body operates must be administered in a non-discriminatory manner, whereby there is a clear separation of the responsibilities of the inspection personnel from those of the personnel employed in other functions (which are established by organisational identification and the reporting methods of the inspection body with the parent organisation). Similarly, the inspection body shall provide safeguards within the organisation to ensure adequate segregation of responsibilities and accountabilities in the provision of inspection services by organisation and/or documented procedures.

Lastly, an inspection body is expected to participate in an exchange of experience with other inspection bodies and in the standardisation processes as appropriate. Technical requirements differ from country to country, safety philosophy is not the same in all countries and thoroughness of inspection is not always the same, so it is important for organisations to employ the appropriate approach for any given region.

2.4.4 Practical aspects of inspections

In terms of the use of HCs in RAC systems, it is important that an inspection covers checks of all the safety-critical aspects to ensure the safe operation of the equipment and protection of the workers. Such checks shall be made to ensure that everything complies with the appropriate safety standards and regulations. Similarly, it is necessary to check that the correct procedures have been followed, for example, for testing procedures, acceptance procedures, marking, supplying of test certificates, operating manuals, plant plans, and availability and location of maintenance records. The inspection of any equipment or installation must include the following checks, which must be considered by the competent person:

- Documentation referring to pressure and hazardous area equipment
- Safety devices and equipment
- Record of the tightness, strength and any other relevant tests
- Visual inspection
- Checking the marking
- Documentation of the components
- Fill in all the legal required documents and certificates

A more comprehensive list of HC-specific checks is listed in later Parts of the handbook.

Some communication measures must also be taken:

- Identification of key personnel and applicable responsibilities
- Arranging appointments with the relevant parties
- Properly inform relevant personnel about the method of operation of the equipment
- Write a report about the condition of components, assemblies or parts of equipment
- Decision-making with regards to repair or replacement of one or more parts
- Discuss and advise the relevant parties about applicable safety issues, maintenance planning and environmental issues
- Process any concerns, disagreements and complaints
- Discuss and advise the relevant parties about the work procedures
- Explain to the relevant parties about the content of any reports

All inspections must be documented, and no systems or equipment can be put into operation unless it is documented.

2.5 MONITORING

Monitoring is essentially the recording of data from various processes, such as the quality of the input streams, test results, information from inspections, observations from the field, external reporting, and so on. The accumulated data undergoes continual assessment in order to identify problems, otherwise unseen errors, particular trends, etc, which are then used to develop corrective and/or preventative measures as appropriate.

In general, any activity may be monitored, such as the construction, assembly and installation of a system, service or maintenance activities and the carrying out of all relevant tests and inspections. An organisation may also be carrying out performance, type and safety testing of refrigeration components, failure analyses, risk assessment, prototype and product testing (of course, such organisations may also offer other non-safety related services).

The type of information that should be integrated into a monitoring system may include that associated with personnel, equipment and processes:

- Identification of necessary skills and experience for carrying out given activities
- Collation of personnel involved with a particular activity and their specific roles
- Qualification of those carrying out specific activities, e.g. education, training records, job descriptions, skills and experience
- Regular and top-up awareness training
- Lists of equipment and components supplied, selection criteria and occurrences when purchase requirements were not met
- Receipt of faulty or incorrect components or equipment and subsequent actions
- Working procedures required for a particular activity and when they were (or were not) followed
- Outcome of testing and inspections
- How recommendations and problems were handled
- Documentation of conformance with the relevant criteria
- Deviation in processes or procedures, reasons and alternative actions

Accordingly, there is a need to develop suitable means to do this, such as standardised reporting sheets, electronic data collection, etc.

In terms of monitoring the reliability of suppliers and their components, if suppliers do not have certified components in the programme, it is necessary that the buyer carries out regularly audits with the manufacturer and examines the specifications provided by him. In any kind it is necessary that manufacturers agree an approval procedure for the refrigeration components and appliances. Documents should be provided together with the required number of sample products for assessment and testing. If required, a “worse case” analysis of the product range together with a draft test plan can be prepared. This analysis is assessed in a “worst case review”. Where the product is a single product this meeting may simply be a document exchange. Where a number of products are derived from a basic design they are assessed to identify a worst case version for testing in order to limit the amount of test work to be carried out. A documented worst case assessment is produced for the approval body as a record of the agreement. The test plan is finalised and testing is carried out on the sample product(s) witnessing the test work as necessary.

26 FEEDBACK AND PREVENTATIVE/CORRECTIVE ACTION

This is the process of transferring findings and other related information from monitoring and analysis of that data to the relevant processes. Corrective action is one necessary to eliminate the cause of a detected non-conformity or other undesirable situation, whereas preventive action is an action to eliminate the cause of a potential non-conformity. For example, a change in a specification for a valve, an improved leak testing method, a better brazing procedure or an improvement in on-site maintenance of electrical components. It is also important to consider monitoring and feedback of equipment placed into use, usually in terms of safety testing, quality testing for marking/labelling, etc.

Examples of the type of information used for feedback may include a number of different aspects, as discussed below, and also the types of corrective actions that may be considered.

(i) Components and sub-assembles that are unreliable, for example, as indicated by:

- Frequent failures during routine or type testing
- Repeated maintenance calls for replacement of parts
- Occurrence of higher leakage rates
- Need for re-calibration of gas detection systems

In these cases, remedial actions may include entering into discussion with the suppliers, checking installation and fitting guidelines, sourcing alternative suppliers, or revising purchase specifications.

(ii) Particular designs that perform inadequately, for example, as indicated by:

- Tendency to fail within a short period of time
- Nuisance tripping of safety devices
- Intermittent releases from pressure relief devices
- Problematic functional testing

In these cases, remedial actions may include revising system designs, checking reliability of electro-mechanical devices, checking component specification to ensure compatibility with adjacent parts, or introducing more rigorous test schemes.

(iii) Technicians that carry out poor quality work, for example, as indicated by

- Reliability of serviced equipment
- Observed quality based on subsequent field inspections
- Frequency repeated service visits to re-repair leaks
- Electrical components left in inappropriate condition

In these cases, remedial actions may include checking the competence of the technicians, providing additional training, revision of working instructions or the provision of better quality service tools.

(iv) Procedures that result in unsatisfactory outputs, for example, as indicated by:

- Inconsistent test results
- Equipment or installations supplied without appropriate marking or manuals
- Repeated calls from recipients regarding basic or routine matters
- Complaints from certain parties regarding the absence of response to safety-critical matters

In these cases, remedial actions may include a revision of test procedures, addressing the final product checklist procedures, improvements to internal communication channels or the assignment of definite responsibilities to particular individuals. Conversely, it is also recommended to record and feedback the positive information. This type of feedback is also beneficial since it may contribute to identification of further means of improving processes or equipment.

To ensure that the benefits of the feedback are maximised, distinct communication routes must be established. This requires each action or sub-activity to be identified and the data or documentation received by the monitoring exercise is channelled back to the relevant departments or personnel that can act on that information. Where possible, formalised structures should be developed, where regular reviews are set up to analyse the information and decide upon correction or preventative measures as and when appropriate.

2.7 ACCREDITATION AND CERTIFICATION

Accreditation is the procedure by which an authoritative body gives formal recognition that an organisation or person is competent to carry out specific tasks. It is essentially a formal recognition of technical competence, as well as compliance to a quality management system. Central to accreditation are two features: the principle of external review, with regular external audits carried out by an independent body; and to fulfil the requirements of standards, such as ISO 17025 (for general requirements for the competence of testing and calibration laboratories). Subsequently, certification is the procedure by which a third party gives written assurance that a product, process or service conforms to the specific requirements.

Accreditation and certification may be applied to anything that has had to meet a specific set of requirements, for example, components, assemblies, installations, procedures or personnel, for example:

- For equipment like components, assemblies and installations, it is normally carried out against requirements of regulations and standards, although it may also be against internal specifications
- For procedures, it may be carried out against the achievement of meeting certain criteria set out in standards, regulations or some other adopted guidelines
- For personnel, it may be carried out in a number of ways, such as based on the outcome of a practical and/or theory-based assessment, or also according to historical experience and background

Often accreditation and certification requires a third party to carry out verification procedures, where confirmation is attained, through the provision of objective evidence, that specified requirements have been fulfilled. This verification may be through direct inspections of production processes and testing, or through auditing of procedures used for the production processes and tests. In such cases, auditors of the accreditation bodies may participate in witness audits on the business premises of the company or its subcontractor, if relevant. Additionally, a third party body may carry out tests either in their own test laboratory or externally.

If a product is manufactured at several manufacturing sites with different qualifications (for example, servicing components from different locations), the qualification level of the respective manufacturing site may only be used if different designations are given to the models. Otherwise only the level of qualification which applies to all manufacturing sites may be used for advertising.

Once certification has been provided to an individual or organisation of particular product, holders of certification marks must constantly monitor the processes or procedures or individuals that have been awarded the mark to ensure continued conformance to the requirements. This includes carrying out the specified tests and inspections, document any complaints in connection with certified products and the correction of non-conformances. Often the certification body must be immediately notified of any changes made to the products after certification. If the certificate concerned is to be maintained, the certification body may request the manufacturer to prove observance of codes of practice or may require an additional test or inspection to be carried out. In order to ensure maintenance of the product characteristics on which a certificate has been based, the certification body may regularly inspect manufacturing and testing facilities as well as quality assurance measures. In these cases, the holder must ensure that the certification body can inspect the manufacturing and business premises and warehouses listed on the certificate.

Certification is often manifested by means of product marking. If the third-party determines that the requirements are being met, then the organisation may apply the applicable marking to the product.[11] In some cases the manufacturer is allowed to use this mark on their own responsibility. Notified bodies will issue approval certificates for each unit and may perform manufacturing and quality system audits to verify compliance with all the necessary standard requirements. Then the manufacturer is authorised to apply the marking (with the number of the notified body).

The certification process often requires the certification body to evaluate the documents submitted by the testers or auditors. Based on this, it decides whether or not a certificate may be issued. If there are disagreements concerning certification it can be resolved via established complaints procedures. Generally, certificates, certificates of conformity, test certificates, etc, are based on the version of the relevant regulation, directive or standard valid on the date of issue of the certificate. Such certificates do not entitle the holder to use a certification mark of the notified body. Any marking that may prove necessary falls under the responsibility of the persons indicated in the relevant regulation, directive or standard.

CE-MARKING IN EUROPE

In Europe, for example, the refrigeration systems and components that are placed on the market have to be CE signed by manufacturers. The CE-marking shows that a product has met EU consumer safety, health or environmental requirements. A notified body may be involved by vessels and tubes in the design phase, the production phase, or both, and the CE-marking shall only be followed by the identification number of the notified body †. The CE-mark is a visible declaration by the manufacturer (or his representative, importer, etc) that the equipment complies with all the requirements of all the applicable directives. This mark allows manufacturers and exporters to circulate products freely within the 15 European Union (EU) members. Having ensured that the equipment does indeed meet all these requirements (including all the administrative requirements involved in being able to demonstrate compliance), the CE-mark may then be affixed and the product released. The letters, “CE”, indicate that the manufacturer has undertaken all assessment procedures required for the product. The CE-mark is not a quality mark, it indicates conformity to the legal requirements of the EU Directives and their nominated standards.

† For example, the reference number 36 (CE-36) for TÜV SÜD

11 If the product is being placed on the European Union market, this marking may be the CE-Mark, whilst in other regions, other forms of marking may be applicable.

PART 3: TRAINING

3.1 INTRODUCTION TO TRAINING

3.1.1 Significance of training

In general RAC 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. Whilst HC refrigerants are very good refrigerants, every technical operation requires considerations of workers and users' safety, including responsible proper disposal of contaminants and waste products. Safety practices and recommendations are provided and detailed explained within this Part, but additionally equipment manufacturers' guidance must be followed. Any person who is involved with working on or breaking into a refrigerant circuit should hold a valid certificate from an approved training organisation. This general approach is important for the use of HCs but should also cover any refrigerants used.

The number of companies involved in installation, service and maintenance of refrigeration and air conditioning 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 and air conditioning. In general these companies and technicians in addition, cannot usually afford to investment 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. Until recently, in Europe scrapped or discarded refrigerated appliances and system components would find its way to A5 countries. Some larger and more professional companies and local wholesalers have access to international manufacturer's equipment. Existing refrigeration systems, appliances and air-conditioners 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 RAC technologies to environmental savings, energy efficient 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 in with HC appliances and systems – from their conception to destruction – 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.

3.1.2 Recognising the importance of training

The improvement of knowledge and skills is the practical way to change the existing situation in a better way. In some cases where vocational training for RAC 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 RAC systems. Multilateral Fund (MLF) evaluation of HCFC Phase-out Management Plans (HPMPs) notes that the introduction of better practices in RAC servicing has been the most important factor in reducing the ODS refrigerant consumption and emission in developing countries.

In general, it can be said that to be well trained is a competitive predicate.

End-users soon will know where to get high quality and system/appliance reliability under reasonable conditions. Knowing these facts we realise the situation that training generally is driven by business needs. This counts more than ever if environmental challenges and burdens lead the industries to change. Rising awareness of these factors is one important driving instrument to get the related industries and companies forced to maintain specific training for involved personnel.

Below is a selection of some of the business needs possibilities identified:

- Need to meet the countries (and the worlds community) obligation to protect the environment
- Need to provide a safe working environment and meet commitments to customers and society to handle refrigerants with due care to people and equipment
- Need to keep abreast of new technologies, new refrigerants and new legislation that are driving change in the sector
- Need to improve RAC systems and appliances overall coefficient of performance (COP)
- 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 aren't 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 is more advanced

Training and networking events should be designed to meet these needs.

VOCATIONAL EDUCATION AND FURTHER CRAFTS TRAINING IN GERMANY

The skilled crafts sector is number 1 in Germany when it comes to providing training. Its dual training system is based on enterprise / VETC level. It combines practical work and learning in the enterprise with theoretical education (and practical unifying sessions) in a vocational school during training. The training concludes with the skilled worker's examination after about 3 years under authority of the trade unions. Every skilled worker can take further training and sit the master craftsman's examination. The master craftsman's examination is the top specialist skilled crafts qualification and authorises the person to manage an RAC enterprise and to train apprentices.

3.1.3 Approach for 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:

a) Only certified personnel may handle refrigerants (ODS, GHGs, HCs) and this may include a ban for selling refrigerants to not authorised persons
b) Companies may have a minimum set of tools and equipment for refrigerant handling
c) Only these certified companies should be able to by refrigerants
d) Governmental awareness campaigns promoting these certifications to private and commercial end-users and the equipment distribution chain (RAC wholesaler, industries, supermarkets, hospitals, governmental buildings operators, etc)
e) Mandatory record keeping for equipment owners on information about refrigerant consumption and service needs for RAC equipment containing more than 3 kg of refrigerant
f)) Mandatory preventive maintenance and leak detection for RAC 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 RAC equipment creating higher efficiency and lower energy consumption (emissions)
- The RAC equipment is reliable and its economic live 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.

RESPONSIBILITIES IN THE FIELD OF VOCATIONAL TRAINING IN GERMANY

In Germany, the state's functions are shared out between the Federal Government and the 16 counties. Fulfilment of these functions is a matter for the individual counties, provided that the basic law does not provide or permit otherwise. The individual counties are also responsible for public-sector schools and education, and hence for vocational schools, the majority of which come under the responsibility of the country and a local authority. All legislation on schools, including that on vocational schools, is individual country legislation. The Standing Conference of Ministers for Education and Cultural Affairs (KMK) is an important institution working to harmonise education policies in the 16 countries. An overview of the general structure of responsibilities in the field of vocational training in Germany is shown in the figure below.

3.1.4 Training for field service technicians

The training of service technicians should include both theoretical and practical elements. The theory should include (but is not limited to) the knowledge about the HC refrigerant properties, steps to carry out an adequate risk assessment and how to design and maintain a sealed RAC 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.

The main focus however should be on the technical skills. The practical objectives 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 from high priority. Training should also comprise learning modules related to electrical components selection, installation and professional connection to the RAC system. At best possible the ratio between practical and theoretical content and time spend for the training should be split at around 70% practice and 30% theory.

3.2 TRAINING FACILITIES

3.2.1 Introduction

The training facility should show and demonstrate exactly how to build and provide an effective learning, training and certification environment. If possible the training location should be embedded in national local VETCs where other trades like electricians, plumbers and metal workers are based. This will create additional synergy effects in fact of trainer's competence (brazing, welding, electro technique etc) and limits equipment and tools investments to the RAC trade specific scopes. Theoretical classrooms and practical work-sites can be jointly used. In many cases infrastructure as previously explained, may already exist at national VETCs for the RAC sector and HCs training will build an upgrade to the currently approved syllabus.

If the national training content is once approved, the VETC/college should develop the best training programmes possible, following the countries policy and the required technical standards, with respect to the available clientele. If necessary these institutions may link with other agencies or among each other to exchange knowledge and experience and deliver recommendations for the authorities and develop tailored training programmes for companies and personnel that require more than one training source or specific training content as per example a company in-house training.

Possible training facilities are:

- Colleges
- Vocational educational training centres (VETCs)
- Trade unions training centres (associations)
- Private training schools (companies)
- Manufactures training centres

Finally a RAC technology steering board should exist. Members may come from the previously mentioned facilities. Internal board regulations used to be setup and common exchange of views may formulate the country specific needs and focus on trends for the future.

3.2.2 Ideal set-up of training workshop site

The training site for about 20 participants should be equipped with didactic material in order to emphasis and provide the means for a practical training. Additionally the training field should have access to a classroom for theoretical training. A list of work-sections and spaces are provided in Table 4.

Table 4: Relevant areas for HC training facilities

	Scope	Minimum required	Ideal
1	Ventilated practical work area with bench and vice for each participant, general purpose. Chalkboard or whiteboard, sockets	✓	
2	Brazing installation (propane / oxygen) at every work bench		✓
3	Installation rack for RAC system assembling close to work bench	✓	
4	Isolated chamber or box in arrangement with 1+3		✓
5	Domestic refrigeration demonstration units		✓
6	Commercial refrigeration demonstration units		✓
7	Split AC demonstration units		✓
8	Mobile AC demonstration unit		✓
9	Components and material storage	✓	
10	Teacher office with furniture	✓	
11	Theoretical classroom for about 20 places. Chalkboard or whiteboard.	✓	
12	Refrigeration laboratory		✓
13	Electro workshop		✓
14	EDP software classroom		✓
15	Welding and metal cutting workshop		✓
16	Toilet F+M		✓
17	Recreation area (partly outside)	✓	

3.2.3 Tools and equipment

The RAC sector deals with design, manufacturing, installation, service and maintenance of appliances and systems. The sector maintains technical training and mechanical engineering course work, with certifications, associate degrees up to bachelor degrees. They perform their work with a lot of different tools, both basic and specific to working with the industries produced equipment.

Basic hand tools

RAC specialists use many basic hand tools in the course of manufacturing, installation, maintenance and repair of equipment. They use everyday tools like hammers, pliers and screwdrivers, as well as basic hand tools like folding rules, flashlights, telescoping and retractable inspection mirrors, drillers, wrenches and levels.

Flare nut wrenches and nut drivers

RAC specialists deal with hex head screws and tubing and need the tools to work with them. Nut drivers remove and replace hex head screws in metal panels, cabinets and framework, and flare nut wrenches are used with metal tubing without breaking it.

Specialised tools for tubing

RAC equipment is outfitted with tubing that specialists install, maintain, remove, replace, connect and disconnect. They use specialised tools such as tube benders and cutters, flaring and swaging tools, inner-outer reamers, piercing and pinch-off tools to handle and work with tubing.

Specialised measurement tools AC clamp-on ammeters

Ammeters, resistance, voltage, temperature and air velocity measuring instruments are used in RAC to measure electrical values and air flow. Ammeters and AC clamp-on ammeters measure electrical current without interrupting the circuit. Air velocity measuring instruments are available as meters, multifunction instruments and kits to check fans and blowers and measure air pressure. Thermometers (electronic and analogue) are used to measure the temperature of any kind of medium (e.g. air, refrigerant, water) and contact temperatures of system and appliances spots. All these devices used secure the efficient RAC cycle operation. Sound meter provide information about the sound level of an operating RAC system and are used to determine if the sound level is at an agreeable level.

Service and installation equipment

RAC specialists use specialised equipment to install, repair and maintain refrigeration and air conditioning systems. Programmable charging scales help technicians precisely charge refrigerant by the proper weight (very important for HC technologies). Refrigerant leak detectors help with fast and accurate leak assessment. Electronic thermistor vacuum gages and U-tube mercury manometers display vacuum levels while evacuating non-condensable gases (NCGs) and humidity from systems. Vacuum pumps remove NCGs, humidity and remaining content of HCs from systems. Hygrometers are used for precise measuring of humidity. The use of oxygen-free and dry nitrogen (OFDN) plays a key role in professional RAC exertions practices. Therefore nitrogen storage cylinder and pressure regulators are a “must have” for every specialist.

Refrigerant handling and identifying/analysing equipment

First of all there is the manifold gauge set equipped with refrigerant transfer hoses and RAC system connection adapters. Gauges are used to analyse the RAC systems operational pressure/temperature of refrigerant in the different system sections and components. Refrigerant recovery units maintain safe refrigerant transfer from RAC systems into refrigerant storage containers without emission of substances to the atmosphere. Recycling or reclaim units clean recovered refrigerants up to virgin refrigerant product standard. Refrigerant analyser/identifiers allow the identification and classification of refrigerants and determine if the refrigerants are contaminated (mixed) and appropriate for recycling/reclamation and further reuse.

Recommended tools and equipment

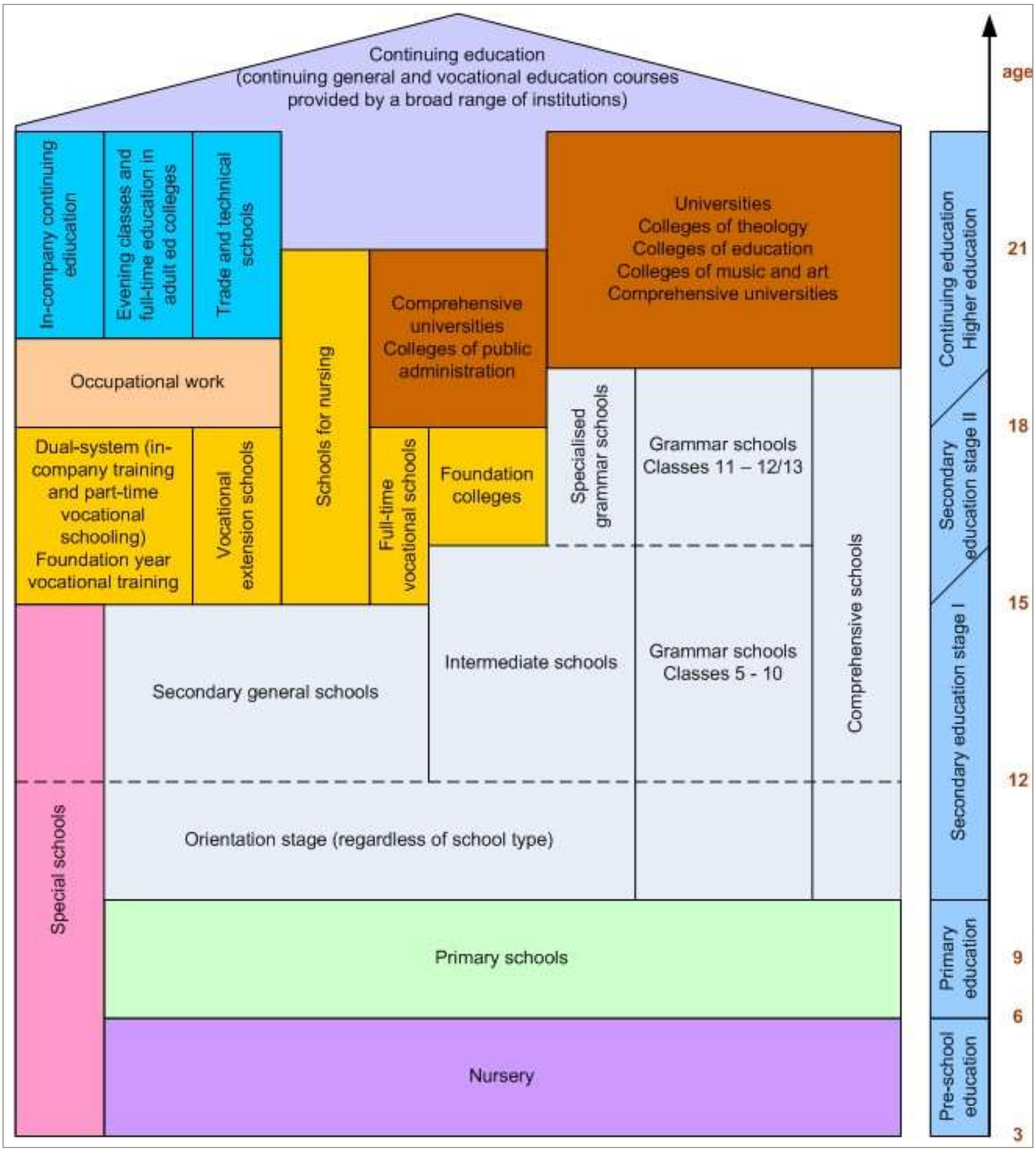
The equipment needed for the RAC training site in general (including HC technologies) is calculated for about 20 participants. A list of suggested tooling, and associated descriptions are detailed in Appendix 6.

3.2.4 Implications of location situation

The situation and organisation of vocational educational training (VET) varies worldwide from country to country, for example, in Figure 13, which illustrates the set-up in Germany. Qualified training is mandatory for a functional economy, but A5 countries may have less capability compared with industrialised countries to force the existing structure with emphasis on actual demand and challenges for the future.

Globalisation of the economy, environmental policies, increasing international competition, changes in demographic development and in the labour market are giving rise to a need for new strategies on education and training policy. In many countries reforms in the education and training system have tended to concentrate on expanding general education and academic pathways while VET often receives comparatively little attention in the ongoing process of structural adjustment. Moreover in many countries VET is part of secondary education organised and delivered by colleges or schools, an approach which only inadequately prepares graduates to meet the demands of real-world work.

Figure 13: Exemplary diagrammatic representation of the typical structure of the education (including VET) system in Germany



Assessments in A5 countries have shown that employers are often not satisfied with the quality of VET. In particular, they complain of the low quality of training schemes, lack of practical skills of trainees as well as inappropriate training contents. However economic development depends to great deal on adapting VET systems to meet social, environmental and economic demands.

For this reason many countries stress the need to place a greater emphasis on VET and highlight the importance of:

- Providing attractive, qualified training programmes and continuing training opportunities in order to enhance employability and occupational mobility
- Designing VET to conform more closely with the field of practice which is highly stipulated for the refrigeration and air conditioning industry facing the deterioration potential of ODS and refrigerants with GWP
- Orienting VET closer to the requirements of the employment system and the corresponding labour market needs
- Preparing young people for degrees which comply with high standards while opening up forward-looking employment prospects

Particular importance is to be assigned at the same time to cross-border cooperation in order to obtain expertise and support in promoting the development and strengthening of VET. This support can be found in bilateral projects between A5 countries and industrialised countries in Europe, USA and Asia, but also support can be given from international development agencies in form of development of training programmes and delivery of required equipment, tools and components.

Some A5 countries do not have the structure that appropriate equipment and tools are available for the RAC servicing sector in general. If equipment from required quality has to be imported, usually it is from high price and loaded with taxes. This fact can lead to the situation that RAC companies and technician hardly can afford the required material. The government should provide alleviations and incentives to enable the provision of materials under competitive conditions for the RAC servicing sector. Within the framework of existing possibilities, international development agencies should consider not only to supply requested RAC tools and refrigerant handling equipment, but also special and safe components and functional parts for HC conversion technologies which cannot be found in most cases on the local market.

It is very important to recognise the interconnection (based on national policies and regulations) between well maintained and efficient HC based RAC systems and appliances, specialists competence / company certification and the local availability of components, functional parts and refrigeration grade HC refrigerants.

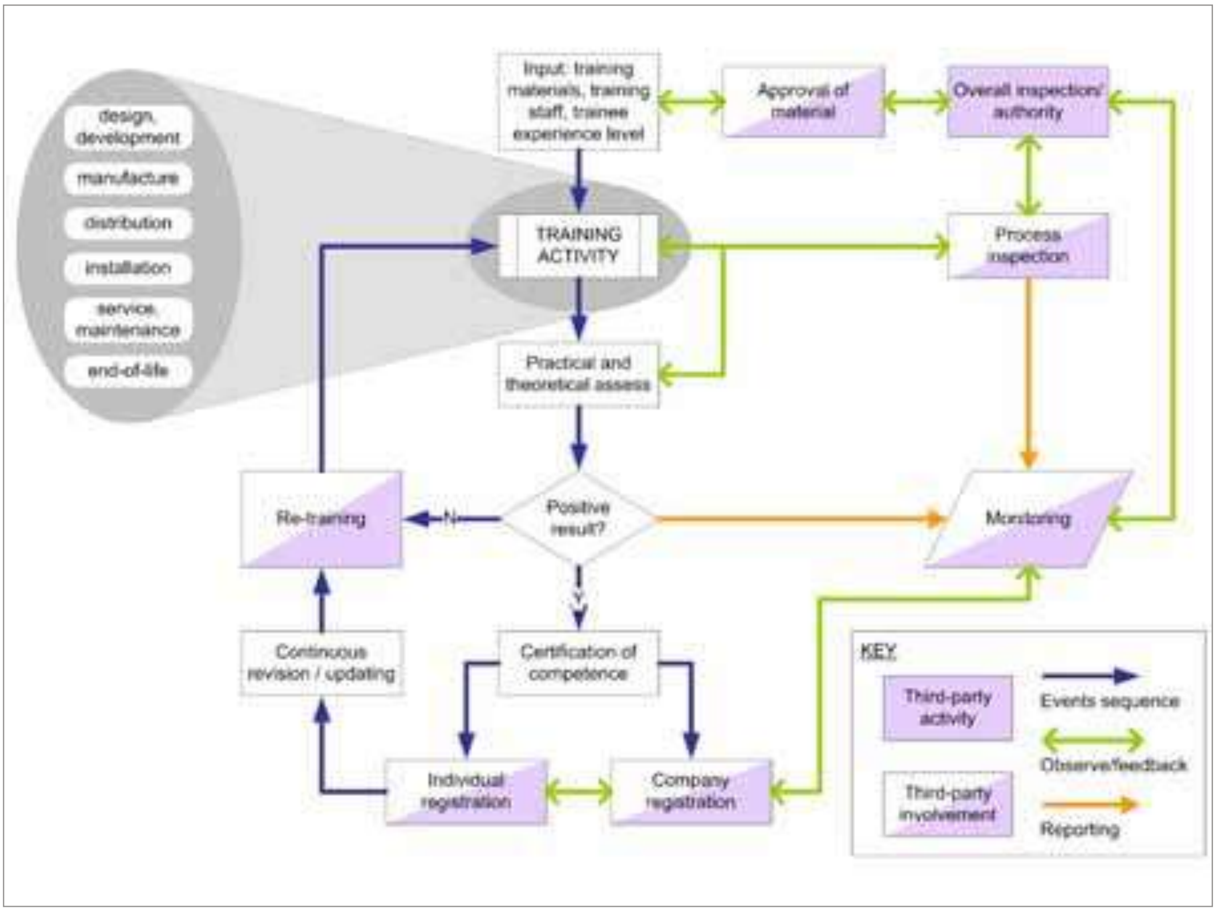
3.3 MANAGEMENT SYSTEM

3.3.1 Introduction

The quality management approach detailed in Part 2 can also be applied specifically to the training, certification and registration of engineers and technicians, and a variation is illustrated in Figure 14. This approach should apply to all individuals, whether they are dealing with the design and development of systems, manufacturing and production, assembly and installation of systems or refrigerant handling during service, maintenance or end-of-life.

Regarding the inputs, these are essentially the training materials, training staff, and also the personal experience of the individual. Thus, in order to proceed with a particular type of training, these inputs must meet certain levels or standards; a poor quality trainer can contribute to a poorer level of learning, or if the individual has no existing knowledge of the subject, they may get negligible benefit from a certain course. Therefore, it is important to set criteria for the various inputs to meet.

Figure 14: Overview of a general quality system applied to technician training, certification and registration



Depending upon what field the training is for, both theoretical and practical assessments should be carried out. If the individual fails the assessment, then further training is required. Again, the assessment should be of sufficiently high level, and set amongst external parties to ensure that qualifications are interchangeable. Assuming the trainee passes, then they could receive a certificate of competence and depending upon the responsibilities, be entered into a registration scheme. The adoption of such a registration scheme can be extremely useful. For example, it is easy to require that the individual goes through periodic re-training in order to obtain revisions in information and technical updates, if that registration is to be maintained. Similarly, the company that the individual is employed by can also be entered into a registration scheme; however, a condition of this is that the company also meets a set of minimum requirements (such as the availability of tools and equipment).

Usually external bodies will be used to provide inspections of the training activities, as well as the input materials and quality of assessment. This may then be part of an overall inspection scheme set up by some national authority; maybe an industry or governmental body addressing the RAC industry training as a whole, with the governmental authority approving the bulk of the input materials. The monitoring component is critical, since it will gather information on the general quality of the training process and the success of the trainees themselves. However, it must also be linked to the activities of those trainees working within the field, for several reasons, including gathering feedback on the correspondence between the course material and the actual work being carried out, and more importantly whether any systematic problems arise in practical situations that need to be addressed more deeply within training courses to minimise the potential for accidents and so on. Throughout the process, the involvement of a third party may be through direct governmental intervention, or indirectly through a nominated trade association.

3.3.2 Input requirements

The input requirements for training normally comprise three main categories:

i) Training material for the specific syllabus
ii) Training staff
iii) Existing level of trainee competence

Training material broadly covers the information that may be required by the trainee to pass the assessment, according to the particular syllabus. However, the lecture notes should cover a broad range of topics related to the subject under consideration, and must not cover only what is required by the assessment. This helps to give the trainee wider knowledge and understanding of the issues they are likely to encounter elsewhere. In addition, the training material should be supplemented by recommended textbooks and other technical guidance, for example, from institutes, trade organisations and development bodies, as well as exemplary technical literature from companies.

The competence of the trainer, both working in the field and as a teacher, is important. In order to have the proper personal qualifications, training instructors in general must have the necessary first-hand vocational and pedagogical qualifications with the majority of the topics they are teaching about – theoretical and practical – as well as peripheral matters that may be broadly related to the topic. Instructors are normally considered occupationally (vocationally) qualified if they are at least 24 years old and have passed the final examination in a relevant occupation requiring formal training.

Alternatively, other examinations can be recognised if candidates can show suitable perennial practical experience. Vocational and pedagogical qualifications include the ability to plan, carry out and monitor training independently, with an orientation to creative, construction action.

It is also essential for the trainee to have already achieved a certain level of knowledge, experience, competence and skills in the general subject area that is being taught. Since the handling of HC refrigerants is effectively an “add-on” subject for refrigeration technology, the trainee should have some existing background knowledge on, for example, general refrigerant characteristics and safe handling, basic electrics, brazing, refrigeration theory, appreciation of system components and system types, and so on; depending upon the type of training they are embarking on.

Provided that the inputs to the training are comprehensive and meet the guidance above, this should provide a robust framework for inputs to the training.

The best possible way to gain inputs (syllabus) for training in general is to have (establish) a VET committee at national level where members (experts) of the different training organisations (VETC, Union, Association) may formulate content and recommendations of training content for RAC technologies including information from the field, upgrades and “add-ons” to the overall inspection authority. Participants from important national or international manufactures may be invited to give additional inputs if requested. Additional, development organisations and governments from industrialised countries may support syllabus formulation activities if needed. Trainers and instructors from vocational training bodies can be invited to obtain an industrial training from international manufacturers or VETCs, located in Europe or elsewhere, to receive the necessary knowledge and skills (including existing syllabus) required for the A5 countries need. In fact these are well implemented procedures known from Europe, Asia (Japan, Korea) and USA.

3.3.3 Assessment

Two forms of assessments should be carried out, pre- and post-training.

Pre-training assessment

Pre-training assessment is used to establish the baseline for knowledge and/or skills and should be carried out before the training workshop starts. In order to cover the widest possible spectrum it is recommended that multi-choice items are used. Pre-tests should be analysed in order to detect weaknesses in the current provision and state of knowledge and to identify the scale of the task on training.

Post training assessment

Post-training assessment can be used for two purposes. The first is to simply enable an analysis of progress made and this can be used to encourage students to greater efforts. The second purpose is to enable certification of successful trainees as part of a national certification scheme, which in turn can be a competitive advantage for certified technicians and servicing workshops.

While pre-training assessment is often best carried out using multiple choice items as described, only knowledge can be properly assessed this way. Any post-training certification assessment should include a rigorous practical assessment reinforced by practical sample work assessment and additional question and answer sessions.

3.3.4 Guidelines for certification of persons

It is important to ensure that organisations involved with certifying technicians follow the appropriate procedures. National legislation may restrict the access to refrigerants to certified technicians and servicing workshops following a pre-defined process and schedule. The overall inspection authority will assess whether it is more appropriate to use a certification programme devised by national VET committee (including and probably reflecting existing structure) and with certificates either awarded by a National Awarding Body or the VETC directly.

Alternatively it is possible to “participate” in internationally recognised certification schemes developed by refrigeration association or training institutions in other countries. Such international certificates can be “localised” as necessary and provide the benefit of harmonising standards in those countries that use them.

Furthermore the standard ISO/IEC 17024 (on general requirements for bodies operating certification of persons) can be used as a baseline, as it provides a benchmark for certification bodies offering certification of persons in any occupation and facilitates accreditation by national bodies. It is for organisations and entities wishing to attain international recognition for the certification of the competence of individuals.

The intention of ISO/IEC 17024 is to provide a framework for accreditation and certification programmes for individuals and a standard against which a third party can validate the management system for certification of persons. The standard itself is not enough to certify a person, but it is designed to be used in conjunction with a “scheme standard”. It requires that competence is demonstrated which includes education, knowledge, skills and experience requirements that a certified person needs and would be expected to meet. In addition, ISO/IEC 17024 provides the general requirements for a management system, where it describes conditions for application, examinations, surveillance and re-certification of individuals. It specifies the requisites eluding conflict of interest including certification, confidentiality of information, competence of staff and contractors, and the need for stakeholder input into certification schemes. This standard specifies requirements for a body certifying persons against specific requirements, including the development and maintenance of a certification scheme for personnel.

Staged and targeted introduction for training and certification

It would be sensible to deal with the introduction of HC refrigerant and systems using a staged approach. It is preferable to start with equipment that would pose least risk, and move forwards to more vulnerable equipment types as experience, knowledge and familiarity increases. Equipment considered having the least risk have the following characteristics:

- Smaller refrigerant charges – smaller charge size, particularly with respect to the room size are much safer and the danger of not properly estimating the minimum room size is less pronounced.
- Fewer numbers of potential sources of ignition (SOI) – there is less chance of the technician incorrectly identifying them or making errors in sealing or removing them.
- Similar equipment characteristics across the installed base – if most of the equipment within a particular category is similar, it would be easier for a technician to know how to handle it and therefore minimise the possibility of errors.
- Refrigerant-containing parts outside – the more parts of the system that are positioned outside minimises the risk of leakage to the inside, and also the technician is more likely to carry out refrigerant handling outside.
- No additional modifications to make to the system – situations that do not include the necessity to fit other items such as gas detection, mechanical ventilation systems, etc, which requires a high level of knowledge of the technology.

Based on these characteristics, the system categories may be allocated an overall risk level, where level 1 indicates systems posing the least risk, and level 4 indicates systems with the greatest risk, as shown in Table 5. (In fact, according to Table 5, most of the system categories that correspond to an overall risk level of 4, probably should not be using HC refrigerants at all due to the demands of safety standards.)

As mentioned, it is recommended that the introduction of HC refrigerants is staged according to the risk level associated with a given system category. Figure 15 provides a suggestion as to the timescale for doing this, where there is a one year increment between each level in order to enable a gradual development of experience, knowledge and familiarity with the technology. A slightly longer interval between level 3 and level 4 is proposed due to the additional complications likely to be encountered.

Figure 15: Suggested timescale for the staged introduction of HC refrigerants according to risk level

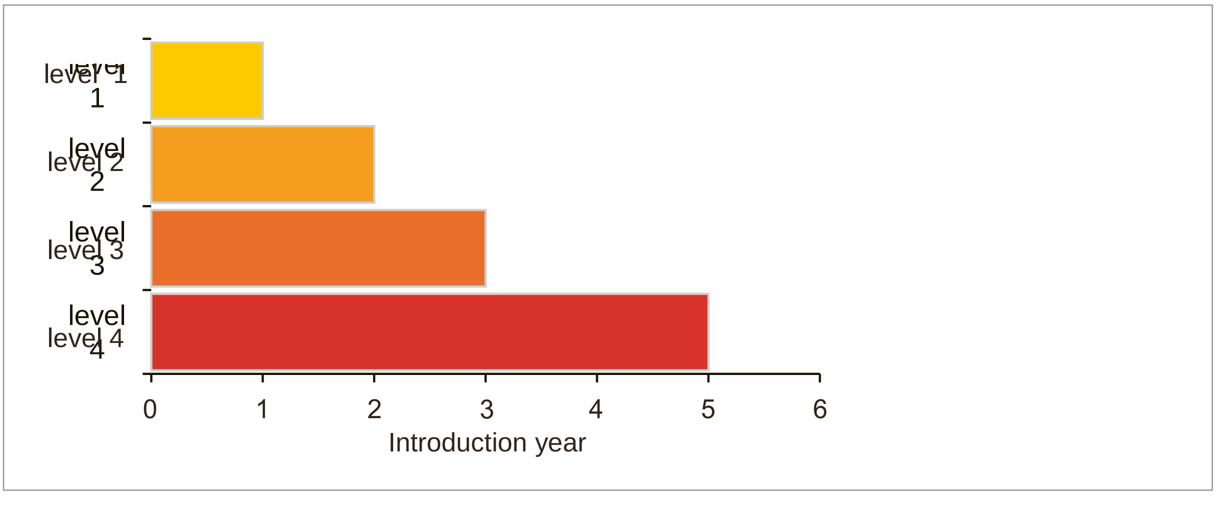


Table 5: Overall risk levels associated with the application of HCs to system categories

System categories	Risk rating (Low, Medium, High)					Overall risk level
	charge Size	number of SOIs	Similarity	external	other items	
Domestic refrigeration	L	H	L	H	L	level 2
Retail refrigeration						
• Integral (stand-alone)	L	M	M	H	L	level 2
• Split (condensing unit)	M	M	H	M	H	level 4
• [Central direct expansion]	H	H	H	M	H	[level 4]
• Central indirect	M	L	L	L	M	level 2
Air conditioning						
• Integral (window/portable)	L	L	L	H	L	level 1
• Split	L	L	L	M	L	level 1
• Close control	M	H	M	M	M	level 3
• Rooftop unit	M	M	M	M	M	level 3
• [Ducted direct expansion]	H	H	H	M	H	[level 4]
• [Multi-split]	H	M	H	M	H	[level 4]
• Chiller	H	L	L	L	M	level 2
Transport						
• Car air conditioning	L	L	L	L	L	level 1
• Transport a/c	M	M	H	M	L	level 3
• Truck refrigeration	M	M	M	L	M	level 2
• Fishing vessels	M	M	H	M	M	level 3
Food processing, bespoke	H	M	H	M	H	level 4

It is also noted that the system categories within Table 5 within square parentheses '[…]' should not be considered for use with HC refrigerants. Consequently, the only types of systems that HC refrigerants could be applied to (where applicable) are retail refrigeration split systems, food processing and other bespoke systems that would require case-by-case evaluation.

Setting up of a body to issue certificates

Many countries already have a certification body to issue and hand over certificates to persons after VET process in the different occupations. Where these structures exist it is to analyse if adaptations for the RAC industries are necessary. In any case these bodies should be independent and not bounded by instructions. Responsibilities should only relate to the Overall Inspection Authority. Best possible way for implementation of a certification body (where they do not exist) is to establish a VET committee at national level, where members (experts) of the different training organisations (VETC, union, association) take part.

3.3.5 Technician and company registration (licensing)

Registration requirements are the most effective way to ensure that assigned RAC and HC professionals and companies will change their current work practices. It is an effective way to prevent technicians who have the necessary training and are applying the formulated Code of Practice from losing business to those who ignore the regulations and continue "business as usual".

A good example is found in the UK, a voluntary registration scheme of well trained "Safe Refrigerant Handlers" which is maintained by the Air Conditioning and Refrigeration Industry Board (ACRIB). However it is considerable that this registration is executed by RAC trade unions or the VET committee, whatever is applicable. A further step will be the discussion with the Overall Inspection Authority (Government) about the possibility of making the scheme mandatory. Whether authorised and enforced by a government body and under general supervision it is important that the supervision focuses on issues of real importance and enforcement of the prescribed Code of Good and Safe Practices, rather than on legal formalities.

For certified technicians or companies, a registration card should be issued which should allow identification of the certified person or company as well as the expiry date. In order to extend the validity of the certification, the Overall Inspection Authority and its stakeholder partners and executive bodies will decide if there is need for a further assessment of skills and knowledge after expiry or not. If not, the technician or company simply renews the registration card. Otherwise, the technicians have to be re-assessed or if necessary first re-trained and then re-assessed. This opportunity for re-training and re-assessment thus occurs periodically after the expiry of the certification and allows the technicians to remain updated concerning newest technology developments. It also allows ensuring that the skills and knowledge of the technicians are appropriate and to control and monitor the supply and use of refrigerant.

3.3.6 Inspection of operations and monitoring

As discussed under Part 3.3.2 the inspection of general training and licensing system operation is to have (establish) a VET committee at national level where members of the different training organisations (VETC, union, association) take part. Assigned experts (e.g. committee chairman or deputy) should inspect stepwise the overall functional operation and if compliance with implemented regulations is secured.

i) Quality and enforcement of training to ensure equal standards throughout the sector
ii) Compliance with code of practices and regulations during various training
iii) Assessment of training participants
iv) Certification of participants
v) Registration of participants
vi) Certification and registration of enterprises
vii) Compliance with the code of practices and regulations as exercised in the field
viii) Monitoring
ix) Reporting to the overall inspection authority

Members (experts) of the different training organisations (VETC, union, association) may formulate content and recommendations of training content for RAC technologies including information from the field, upgrades and "add-ons" to the overall inspection authority. Participants from important national or international manufacturers may be invited to give additional inputs if requested to gain information on new technologies and standards.

3.4 CONTENT FOR STANDARD REFRIGERATION TRAINING

3.4.1 Introduction

Part 3.4 refers to the European "Leonardo da Vinci Project" EUR/02/C/F/NT- 84604 / EC Agreement N° 2002-4549/001-001LE2X. Responsible and in charge is the "Air conditioning and Refrigeration European Association" (AREA).[12] AREA is the European Association of National AC&R Contractor Associations, set up to serve the air conditioning and refrigeration contractors at the European level and formulated a uniform educational level for training and qualification throughout Europe. Standards are given to enable the various European countries to compare, check and adapt (if necessary) their educational and training programmes. Content of this standards are provided in this section to exemplary demonstrate necessary minimum content of syllabus topics for vocational and educational air conditioning and refrigeration training and may enable especially A5 countries to find specific guidance in developing national training standards, where not already exist, or if there is a need for modification.

The following European standards and regulations take part in the formulation of core activities and to define the AREA Refrigeration Craftsman/Craftswomen (ARC):

- EN 13313, Refrigerating systems and heat pumps – competence of personnel
- EN 378, Refrigerating systems and heat pumps, safety and environmental requirements
  - Part 1: Basic requirements, definitions, classification and selection criteria
  - Part 2: Design, construction, testing, marking and documentation
  - Part 3: Installation site and personal protection
  - Part 4: Operation, maintenance, repair and recovery
- EN 50110, Operation of electrical installations
- European "F-Gas Regulation"

12 For further information please visit the AREA internet site, www.area-eur.be

3.4.2 Categorisation of ARC topics and ARC competence description

A thorough description of ARC topics and the ARC competencies has been developed, and this has been included in Appendix 7.

3.4.3 Additional syllabus for HC refrigerants

The skills and competences for each of the subject areas in Appendix 7 can be supplemented by the material within this handbook, wherever relevant.

3.4.4 Example of assessment criteria

Some suggested criteria and topics for assessment of technicians specifically for handling HC refrigerants are included in Appendix 8.

3.5 TRAINING FOR DESIGN AND DEVELOPMENT

3.5.1 Introduction

Persons involved with the design and development of systems using HC refrigerants also 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 all of the 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 16 provides an overview of the categories that should be considered for training of those people involvement with design and development aspects. Obviously the inclusion and extent of training of certain topics varies according to the role of the purpose of the work.

Figure 16: Overview of the categories of training to be considered

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

3.5.2 Technical core training

This 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.

3.5.3 Product core training

This is primarily focussed on the RAC products 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 more 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.

3.5.4 Fundamental training

For the fundamentals of the safety-related subjects, the subjects 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 to 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.

3.5.5 Peripheral training

The 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 RAC 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.

3.6 TRAINING FOR PRODUCTION

3.6.1 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 the production area there is often a compromise between production output and procedures which 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.

3.6.2 Awareness-raising of manufacturing personnel

In a production area there are many areas and installations that require special precautions and handling. Thus the personnel must be trained to consciously work with these. In the production area there also exist 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 an awareness training and explanation of the procedures how to handle the situations in which HCs are involved these will be considered soon as any other installation in the production area. Of course this awareness programme will not 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 this is done.

3.6.3 Personnel to be trained

There are different levels of training with regard 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 any procedures are setup that 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 setup new procedures for the proper working in the production area.

3.6.4 Identification of areas

When a new process is introduced it is favourable to identify where this activity is performed in order that in the production area all the personnel involved on a daily basis is aware of the new process. This will also create a better understanding of the need of new procedures due to the changed production process. With the identification of the area also the introduction of the obligation to report any activities to the production line supervisor should be introduced. 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.

3.6.5 Changes to work situation

At the end of the production line a product will exit which contains HC and 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, material as well as production flow. What has to be introduced is the crosscheck at different production line areas due to the fact that HCs are used. In mixed productions special care has to be taken in order to avoid the use of wrong components and in case of changes the production line has to be informed. The ideal case is that wrong applied changes are detected the earliest possible and before filling with HC 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.

3.6.6 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 to 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 disregard heat sources also the ones who could be generated by friction. There are of course other aspects of the health and safety procedures which should also be included in the review. The procedures review plan is a continuous process with shorter review periods the first year of production and when model changes are applied.

3.6.7 Staff training for distribution

Those who are 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.[13] 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 in 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 a and dealing with leaks and evacuation in the event of a major emergency. There should also be a fire team which 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, and particularly the transport requirements for equipment containing flammable refrigerants.

13 It is noted that the majority of this training is good practice for most warehouses, whether the products contain flammable refrigerants or not.

Those involved in warehousing, handling and (physical) transportation should in addition 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 major emergency lasting up to 3 hours. At these exercises, which ideally are organised by specialists, different managers should practise their roles.

PART 4: PRODUCTION AND MANUFACTURING FACILITIES

4.1 INTRODUCTION

Where systems are manufactured which require charging of HC refrigerant, special consideration is necessary for the design and installation of the production and associated areas. Thus the areas that store and transfer the refrigerant and where the refrigerant-filled appliances are worked upon must be addressed. They key areas are:

i) Refrigerant storage (cylinders or bulk tank)
ii) Refrigerant pumping and control of supply
iii) Refrigerant charging areas
iv) Appliance repair and refrigerant recovery area
v) Refrigerant supply distribution pipework
vi) Other work area (leak checking, electrical safety testing, operation/performance testing, final assembly, packaging areas)

These are listed in an approximate order of risk, with item (i) posing the greatest risk and item (vi) the lowest risk. This provides an indication as to the level of consideration, the extent of the safety features and the degree of control necessary to apply to that part in order to ensuring safe operation of the facility.

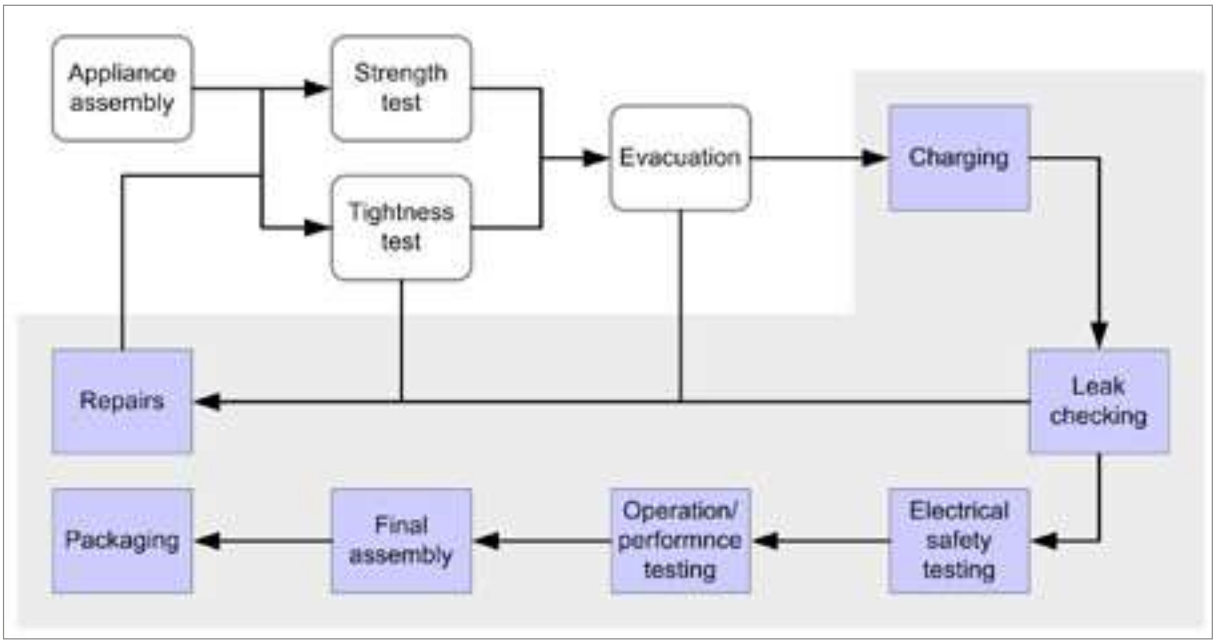
In terms of the actual production or assembly line, there are a number of positions where there is a risk of a release of flammable refrigerant, and these are indicated in Figure 17. Thus, from charging through to the packaging stage, there is a potential for emission of refrigerant. In the event that an appliance is found to be faulty, it may be sent to a repair area for removal of refrigerant and remedial action to be subsequently taken.

In order to ensure safe operation of the production line and associated areas, a safety system must be introduced. The main features of such a safety system may include: a gas detection system, a ventilation system, associated control system, warning alarms, marking and signs and relevant instructions and procedures. In addition to the hardware, it is essential to provide specialist training of staff, which should include:

- Workers
- Supervisors
- Maintenance staff
- Building/facility managers
- Operations managers

In order to ensure that the installation is carried out appropriately, it is advisable to get the entire installation and procedures approved by a relevant notified body, such as TÜV (see Part 2). A major challenge is integrating these elements of the safety system into the various parts of the entire facility. The following sections provide an overview as to how this can be achieved.

Figure 17: Typical manufacturing process, identifying positions where refrigerant releases should be considered



4.2 REFRIGERANT SUPPLY

4.2.1 Refrigerant storage

Refrigerant storage may be in the form of bulk tanks or cylinders, which may be located externally to the production area or within charging machines. Depending upon the country, the area that the tanks or cylinders are located should be a zoned area (according to hazardous area guidelines), and the associated rules that are applicable should be conformed to.

Bulk tanks are normally supplied as 1 tonne or 2 tonne vessels and are positioned outside. There may be one or more vessels depending upon the demand. The siting and positioning of the vessels is normally subject to national and local regulations and codes. Typically, these require the features included in Table 6. In addition, the operators must ensure there are adequate arrangements for inspection and maintenance of the tank and the associated equipment. This is normally arranged by the HC refrigerant supplier.

Cylinders may be used in one of two ways: either located external to the factory or positioned inside a charging machine. If located externally, they are normally positioned within a cylinder cage or an independently constructed cylinder room. If positioned within the charging machine, unused full, or used empty cylinder must be stored within a cylinder cage or a cylinder room which is located outside at some distance from the factory. The siting and positioning of the cylinders within a cage or a special room are normally subject to national and local regulations and codes. Typically, the installation of a cylinder cage or a cylinder room requires the features included in the corresponding columns in Table 6. In addition, the operators must ensure there are adequate arrangements for inspection and maintenance of the cylinder cage or room and the associated equipment.

Table 6: Safety features for bulk tanks, cylinder enclosures and pump rooms

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

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

4.2.2 Refrigerant pumping and control of supply

In order to transfer the refrigerant from the tanks or cylinders to the charging area, special equipment is required. This primarily includes 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, pressure gauges, and so on. Normally such equipment is housed in a special pump room, which is also classified as a hazardous area. This area should be equipped with the following features included in Table 6. Additional requirements may be necessary, as dictated by equipment suppliers and national regulations.

4.2.3 Refrigerant supply distribution pipework

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. Preferably welded stainless steel pipe should be used, that is treated as necessary to make it resistant to corrosion. Furthermore, it should be protected against mechanical damage and impacts; this typically applies to pipework close to the ground level in the working areas. The pipework may be fitted with pressure sensors so that the necessary alarm system can warn of an increase in internal pressure or in case of a rapid loss in system pressure, although this would be ineffective for smaller leaks. Another option is to monitor the pressure of the refrigerant transfer pump in case the pressure of the refrigerant has dropped, in which an alarm can be provided to the changing area. Also, a pressure relief device should be fitted where necessary and vented to the outside in case of excessive pressure build-up. 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. Flammable gas warning signs must be applied at regular internals 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.

4.3 APPLIANCE PRODUCTION

4.3.1 Refrigerant charging areas

Refrigerant charging is normally carried out using specially designed charging machines, and it is highly recommended that only those intended for use with flammable refrigerants are employed. There are three categories of charging machines:

- Those that are fed with refrigerant from a remote location
- Those that are fed from a cylinder held in the immediate locality
- Those that are fed from a cylinder held internally

In all cases, the charging machine should include a gas detector used to initiate internal exhaust ventilation in case of an inadvertent release. The ventilation rate will depend upon the quantity of refrigerant held in the charging machine, but also the associated safety features incorporated to prevent further refrigerant being fed into the charging machine from the supply line; thus a larger contained quantity and no emergency shut-off valves in the line will necessitate a greater ventilation rate. For a setup where the refrigerant cylinder is remote from the charging machine but positioned in the immediate area, an enclosed area or bund wall should be used, which contains additional gas detectors and floor-level ventilation system.

The charging of the appliance should be carried out using proper connectors so as to minimise the quantity of refrigerant released upon disconnection (as well as the quantity of air ingress into the system). All charging should take place over an inverted ventilated hood such that it catches any refrigerant that gets released. There should be ventilation inlet both within the inverted hood and at floor level in case of a wider spill. Gas detection should be fitted within the charging area at a position where any significant release will be sensed, so that in the event that an abnormally high concentration is detected, the supply of refrigerant to the charging machine can be terminated and the ventilation rate can be stepped-up. There should always be at least a bund wall surrounding the charging area to hold in any accidental release, and in some cases, the entire charging process may be carried out within a special charging room within which the conveyor passes through.

4.3.2 Appliance repair and refrigerant recovery area

In the event that a system has failed a test at some point along the production line, it may be required to carry out repairs. If the system has been charged with refrigerant, it is usually necessary to remove the refrigerant before carrying out the work. This can be done by either:

- Recover the refrigerant using a refrigerant recovery machine, flush with nitrogen, then evacuate using a vacuum pump (which may be a conventional type or one specially for hazardous areas depending upon the conditions)
- Vent the refrigerant into the exhaust ventilation duct, flush with nitrogen, then evacuate using a conventional vacuum pump
- Employ a specially designed product that recovers, evacuation and exhausts without worker intervention
- Use a combined venting and evacuation device (for example, that uses compressed air driven venturi pump)

Whichever method is employed, the area where the operation is carried out must be setup appropriately, and the equipment used must be fit for the purpose. For example, the recovery machines should not have any potential sources of ignition associated with them, and if the vacuum pump is not one especially for use with flammable refrigerants, then it should be used only in a special area and the system well flushed with nitrogen before use. In any case, to improve the safe handling of the appliance when opening it, the evacuated system should first be flushed with nitrogen in order to render the residual HC inert. All work involving refrigerant handling should be carried out over an inverted hood with associated gas detectors and a ventilation system. If activities such as brazing, electrical testing, etc, are to be carried out, they should be done in a special area. Handheld gas detectors should also be available. (For additional requirements, refer to Part 4.5 and Part 6.1 on workshop areas and repairs.)

4.3.3 Other work areas

There are several other work areas that handle the appliances that contain HC refrigerants. Within each of these there is a possibility of an emission of refrigerant, for example:

- Leak checking area; small release previously undetected may be occurring
- Electrical safety testing area; small release previously undetected may be occurring
- Operation/performance testing area; small release previously undetected may be occurring, or temporary release may occur when dummy condensing unit or evaporator unit are connected to or disconnected from the manufactured appliance using quick connector
- Final assembly area, where the building of the appliance is completed; small release previously undetected may be occurring
- Packaging area, where appliance is wrapped and boxed; small release previously undetected may be occurring

Since, the appliances are also transferred from one area to the next either by mechanical conveyor or manually, there is a possibility for a leak to develop at any of these stages. Therefore, appropriate safety features should be considered and installed where deemed necessary, including:

- Inverted hood and associated ventilation system
- Gas detection
- Emergency stop buttons
- Audible and visual alarm signal
- Warning signs
- Associated emergency management control system

Each stage should be assessed for the risk of leakage, the quantity of leakage and the likelihood of ignition based on the activities being carried out at that position. In some cases, all of these features may be necessary, whereas in others few may be needed.

4.4 FACTORY SAFETY SET-UP

4.4.1 Introduction

Any production facility should always have a safety system incorporated into the production and/or workshop area. Within the present context, a "safety system" is a combination of equipment and controls that are interconnected and which enable the installation to operate in a safe manner and to automatically deal with hazardous situations without undue risk to the workers. The main features of a safety system may include:

- Gas detection system
- Ventilation system
- Warning alarms
- Control system
- Marking and signs
- Instructions and procedures

4.4.2 Gas detection

Gas detection requires a number of sensors to be located at appropriate positions to ensure that any release of refrigerant will be identified. The number and positioning of the sensors requires careful consideration of all the potential release points and the likely distribution of those releases. There are a variety of different types of gas sensors; it is important to use ones which are applicable to hazardous areas, that are not susceptible to contamination and which retain their accuracy well. Probably the most suitable are infra-red types, and secondly, good quality catalytic types, although cost implications and the presence of other substances (that may give false readings) can affect the choice. In order to maintain operation of the safety system, it is sensible to have spare sensors available and to re-calibrate regularly. The gas detection system should be constantly active.

4.4.3 Ventilation system

A well designed ventilation system is used to exhaust emitted refrigerant to the outside, comprising hoods, inlet grilles, ductwork and fans. For working areas, inverted hoods should be used to "collect" released refrigerant, both from working position and inlet grilles at floor level to remove further spillages. The discharge should be positioned out of the building in a way that any exhausted refrigerant cannot travel back into any buildings or occupied spaces. The fans are normally dual speed so that two flow rate settings can be used: a low level flow rate for normal operation and a high level flow rate for emergency operation. Fans motors and fan blades must be rated for use in hazardous areas. It is also advisable to install a second back-up fan in case of a failure of the main fan motor or blades. The ventilation flow rate is calculated according to the position of the duct inlet and the maximum possible emission of gas likely from the source. As with gas sensors, the ventilation system should be operating both during working periods and absent periods, and it may only be switched off if entire installation has been decommissioned. Lastly, pressure sensors (differential pressure switches) must be employed to ensure that ventilation is always working; in the event that the ventilation fails, then the supply of refrigerant must be terminated.

4.4.4 Warning alarms

A set of warning signals are required to be distributed about the production and other areas, such that in an emergency situation, both workers and responsible managers are made aware. Both visual (coloured lamps) and audible alarms should be employed. Different levels of alarm should be used to indicate the level of risk. For example, a green lamp to indicate it is safe to work, an amber lamp to indicate that a low concentration of refrigerant has been detected, and a red lamp to warn that a major release or some other system failure has occurred. The warnings should be able to be seen by all workers and personnel, whether in the production area or the designated offices.

4.4.5 Control system

A control system is necessary to act as a central point for receipt of signals from gas detectors, ventilation pressure sensors, gas vessel or pipe pressure sensors, manual emergency buttons, etc. Similarly, the control system sends the desired activation signals to visual and audible alarms, terminates pumps and/ or operation of charging machines, activates shut-off valves, etc, as necessary according to the input signals. The entire system (controls, ventilation system, gas detection, etc) should be provided with uninterruptible power supply (UPS) that will maintain operation for a minimum period of time (e.g., one hour). Further, the control system should be designed in such a way that it is fail-safe, i.e., if something happens that may result in a signal not activating a safety feature (e.g., a failure in electrical supply, pneumatic air pressure, a part of ventilation system, a gas detector signal, etc), all refrigerant supplies must be closed off and electrical supplies terminated (e.g., by using normally-closed valves, contactors, etc). The use of pneumatic controls rather than electric should also be considered in order to minimise the potential for sources of ignition. During normal operation, the different levels of alarms, ventilation, etc, may be activated according to different gas concentrations measured (for example, 15% of the LFL, 30% of LFL, etc).

4.4.6 Marking and signs

Relevant marking and signage is required at all critical positions, in order to ensure that personnel are aware of the nature of the equipment, and to minimise the likelihood of interference with the safety equipment. Signs and warnings may include: "flammable gas", "read the instructions before using", "hazardous area", "authorised personnel access only" and similar (see Figure 18).

Figure 18: Examples of appropriate signage

4.4.7 Instructions and procedures

An essential aspect of the safety system is the development and use of proper instructions and working procedures. These should be written in a comprehensible manner and relayed to all relevant personnel. Such material should cover, but not be limited to:

- Correct operation of all production equipment
- Correct operation of all safety-related equipment
- Mechanics and logic of safety system
- What to do in an emergency
- Reporting structures and procedures
- General safe handling of flammable gases
- Correct/safe working procedures
- Maintenance procedures
- Exhaustive list of prohibited actions (such as unauthorised modifications or other work carried out on any of the safety system)

The applicable instructions and procedures should be included for approvals process by the certification body.

4.5 CONSIDERATIONS FOR WORKSHOP/REPAIR AREAS

4.5.1 Introduction

Workshop and repair areas within small-scale production areas and service/maintenance departments require careful consideration of their layout in order to ensure a safe working environment. A comprehensive risk assessment should be conducted prior to setting up and installation of the area. Documents relating to the areas detailed above can be obtained from guidelines dealing with hazardous areas.

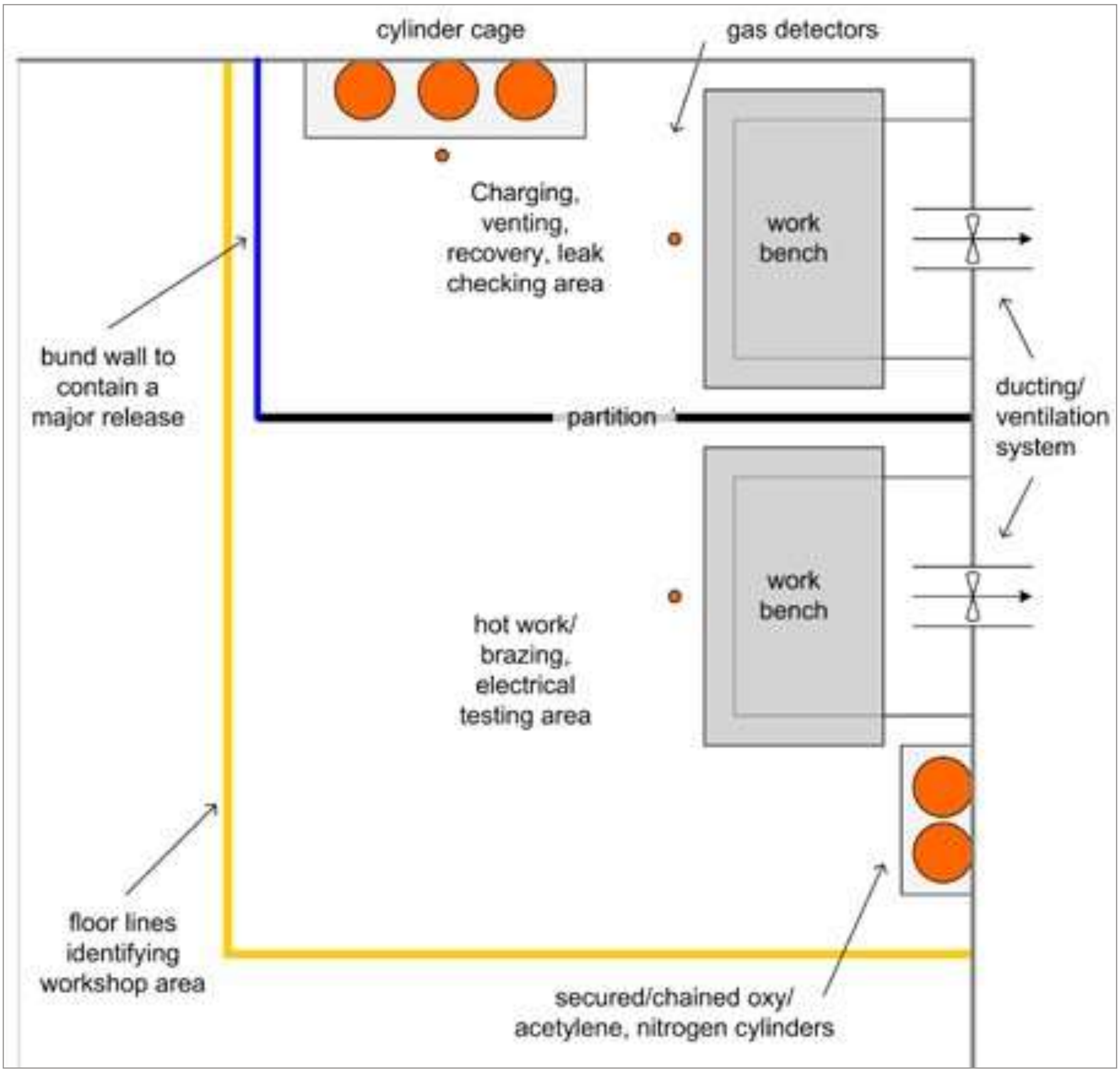
A Workshop/repair area is normally set up for appliance servicing/reconditioning, and not for appliance manufacture. Other processes such as refrigerant recovery, appliance leak testing and appliance performance testing may also take place in this area.

The following sets out general requirements for avoiding electrical and flammability hazards for charging equipment and appliances and are also applicable to all other machinery and processes used for other operations carried out in the charging area.
All personnel working in charging areas should be suitably trained, both in the use of flammable refrigerants and the use of fire extinguishers for tackling HC refrigerant fires. No unauthorised access should be allowed to the charging area. All work carried out should be in accordance with procedures suitable for use with flammable refrigerants, for example, those within Part 6 of this handbook.

4.5.2 Area layout

A suggested layout for the workshop area is provided in Figure 19. It is divided into two discrete areas, one for refrigerant handling and the other for hot and electrical work. Some parts of the workshop area where refrigerant handling will take place should be classified as hazardous areas. Electrical equipment and other equipment that may otherwise be a potential source of ignition should be subject to the requirements for, say, zone 2 areas. The area should be adequately identified on all sides, and particularly at entrances, with notices indicating the presence of HC refrigerant. It is preferable to have a gated bund wall surrounding the charging area – approximately 0.5 – 1.0 m high – in case of a major release. Also the entire working area should be identified on the floor with visible yellow lines.

Figure 19: Suggested layout for workshop/repair area



In addition, notices shall be present, indicating:

- A warning notice – "Highly flammable"
- A warning notice – "Authorised personnel only"
- A warning symbol – Flammable gas
- A prohibition sign – No smoking or naked flames

Within both areas, there must be a dry powder fire extinguisher provided. Refrigerant cylinders should preferably be stored outside, and refrigerant cylinders being used should be kept in a dedicated flammable gas cage.

4.5.3 Workshop safety system

The safety system for the workshop area primarily comprises gas detection and ventilation equipment.

Permanent HC gas detectors should be used in the area to detect releases of HC refrigerant. Upon detection of gas at concentrations up to 20% of the LFL (i.e., less than 0.4% by volume), audible and visible (flashing light) alarms, automatic shut-off devices and extra mechanical ventilation should be activated. The HC gas detectors should be located at ground level and at either side of refrigerant handling equipment and places where a release may possibly occur. They should be placed down wind of natural and forced ventilation drafts to ensure their effectiveness. A single sensor at ground level will normally cover an area of no more than 30m², although a higher density is preferable. Gas detectors should be calibrated at regular intervals, as recommended by the manufacturer. As far as practicable, detector sensors should be protected from ingress of foreign material and substances that may "poison" a catalytic sensor, and be protected again mechanical damage.

The mechanical ventilation system should be installed in all areas where HC refrigerants are being used. Normally, two stages of ventilation are required, in order to satisfy the following:

- To maintain the refrigerant/air concentrations less than 1000 ppm for HC refrigerants
- To remove dangerously high concentrations of refrigerant as quickly as possible to reduce the risk of fire or explosion

Inverted hoods should be positioned below work surfaces that are allocated for working on the system and that would necessitate refrigerant handling. At least 50% of the ventilation inlet flow should be taken from ground level and low points around areas of greatest leak potential. The airflow must be exhausted to the outside, specifically to a safe place away from sources of ignition, doors and windows, ventilation system inlets and occupied areas. Ventilation flow (i.e., pressure) detectors should be used in the ventilation ducting to monitor flow rates. The volume flow rate of the ventilation is calculated according to the quantity of refrigerant being used, and the quantity that could be released over a certain time.

There should be emergency buttons positioned in convenient locations to allow operators to shut electrical equipment and initiate ventilation if necessary.

4.5.4 Working practices

Most incidents occur from human error, and therefore a set of safe working procedures must be developed. The focus of such procedures is to help avoid releases and ignition of HC refrigerants. All personnel that have access to the workshop area must have a thorough knowledge of these procedures.
The general rules for workers in the workshop/repair areas are the same as those detailed within Part 6 for service and maintenance activities. The focus of these rules is that on no account should naked flames (e.g. from welding torches) be used in the charging area.

4.5.5 Equipment for workshop area

The following provides a non-exhaustive list of service equipment, protective equipment and documentation normally used in workshop/repair areas.

Service equipment

- Electronic leak detector (suitable for HCs)
- Soapy water (or leak detection spray cans)
- Refrigerant cylinders (R290, R600a, etc,)
- Refrigerant recovery cylinder
- Nitrogen (oxygen-free, dry nitrogen) cylinder
- Vacuum pump and vacuum gauge
- Refrigerant recovery machine (suitable for use with HCs)
- Venting hose
- Scales/electronic balance
- Gauge manifolds and hoses
- Hand tools including adjustable spanners, pliers, valve keys, etc

Documentation

- Flammable gas stickers
- R290, R600a, etc, refrigerant stickers
- Flammable gas signs
- "Do not enter" or equivalent signs
- Comparators for R290, R600a, etc

Protective equipment

- Fire extinguisher
- Gloves
- Goggles

4.6 CARRIAGE OF SYSTEMS

4.6.1 Introduction

Adherence to national and international regulations is necessary if refrigeration equipment containing a charge of HC refrigerant is to be transported. Particular requirements are generally determined by the equipment charge size. In general, the applicable regulations require adequate packaging and marking. Transport companies should also be consulted when transporting equipment containing HC refrigerants. HC refrigerants have United Nations number designation UN 1965, and refrigerating systems containing flammable refrigerants have United Nations number designation UN 3358. The following summarises various transportation regulations for equipment containing flammable gas. (It is noted that in line with other requirements, the refrigerant charge is applicable per refrigerant circuit.)

4.6.2 Transport by road

Transport by road and rail within Europe is covered by the Articles Dangereuses par Routier, 2009 (ADR)[14]. Equipment containing less than 12 kg of flammable refrigerant is exempt from regulations for carriage provided it is protected by design (i.e. conforms to the appropriate safety standards). Where the charge is above 12 kg, the equipment is subject to the provisions for any receptacle containing flammable gases.

The United Nations Model Regulations for Transport of Dangerous Goods, 2007 (TDGR)[15] generally applies to transport by road and rail outside Europe. Equipment containing less than 12 kg is exempt from the regulations provided it is protected by design. For equipment containing over 12 kg, it must be subject to a pressure type-test of at least three times the maximum working pressure and comply with the packaging requirements detailed in these regulations.
The requirements for ADR and UN Model Regulations are virtually the same.

4.6.3 Transport by sea

The International Maritime Dangerous Goods Code, 2008 (IMDG)[16] prescribes requirements for transport of equipment by sea. Refrigerating machines containing less that 100 g of flammable refrigerant are not subject to the regulations. Otherwise packaging requires special marking. Refrigerating machines may be carried unpacked in crates or other appropriate over-packs, provided that the equipment has been pressure tested and designed so as to prevent the release of refrigerant during transport conditions. However, if the charge is less that 12 kg then these requirements do not apply.

14 http://www.unece.org/trans/danger/publi/adr/adr2009/09ContentsE.html
15 http://www.unece.org/trans/danger/publi/unrec/rev15/15files_e.html
16 http://www.imo.org/Safety/mainframe.asp?topic_id=158

4.6.4 Transport by air

The International Civil Aviation Organisation/International Air Transport Association, 2009 (IATA)[17] prescribes the regulations for transport by air. This forbids transport of equipment containing more than 0.1 kg in either passenger or cargo planes. If transport by air is necessary, the regulations do permit up to 150 kg of flammable refrigerant to be carried by cylinder, so systems can be charged on-site.

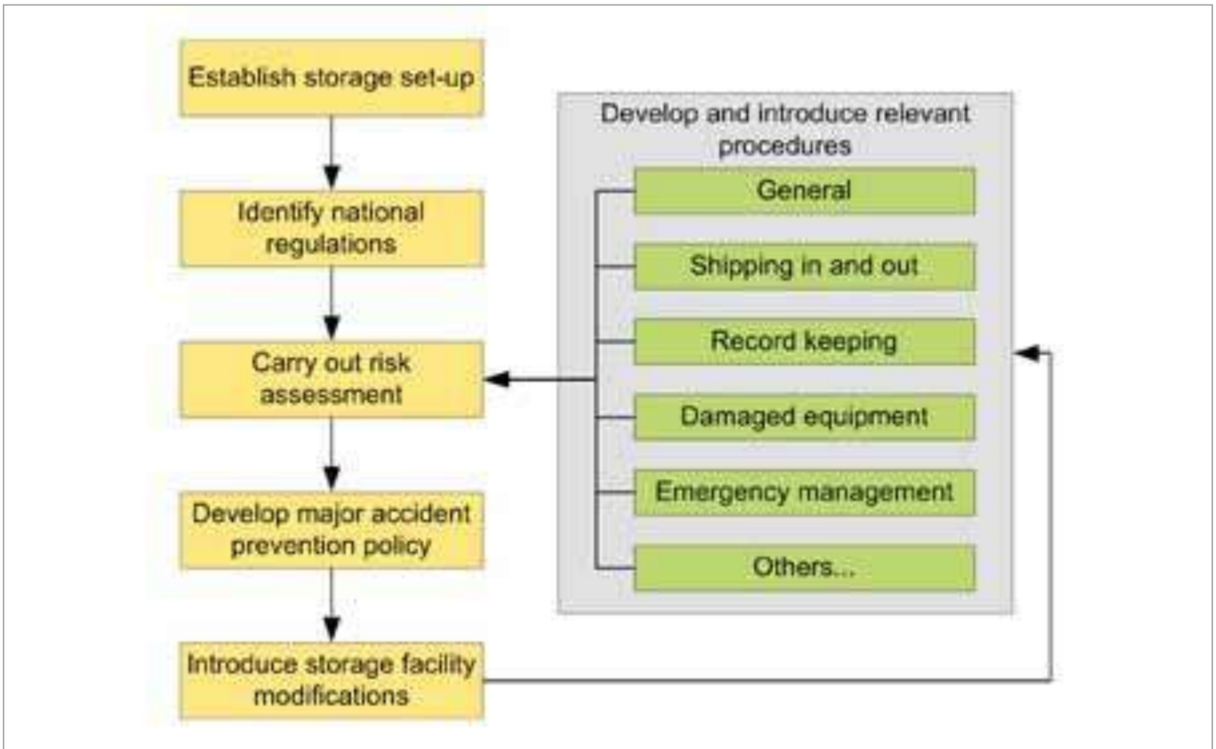
4.7 STORAGE OF SYSTEMS

4.7.1 Introduction

RAC safety standards do not normally apply to storage of relevant products and equipment in warehouses and similar facilities. Therefore national regulations normally have to be applied. Generally these will indicate that a risk assessment should be carried out to help draw up requirements for the warehouse and also to check the planned set-up. Note that where companies contract out storage and warehousing facilities, they should also ensure that these companies also follow the appropriate requirements.

The following Part provides a general indication as to the types of issues that should be addressed. In general, the approach illustrated in Figure 20 should be followed.

Figure 20: General approach to be followed for warehousing and storage of systems



Normally warehouses and storage facilities will contain a variety of materials that are hazardous, so appropriate measures should already be in place. However, in the case of handling RAC systems that use flammable refrigerants, additional considerations may be required. In particular, the following issues must be addressed, for which employer of the workers within the facility has ultimate responsibility for:

- Identify the current set-up (or proposed set-up in the case of new installations)
- Identify and become familiar with national regulations
- Carry out risk assessment
- Establish a major accident prevention policy

17 http://www.iata.org/ps/publications/dangerous-goods-regulations-dgr.htm

- Introduce design changes and modifications to the facilities
- Develop and impose new procedures, related to general practice, shipping (in/out), record keeping, for damaged equipment and emergencies
- Re-consider and revise the risk assessment

Note that there must be periodic revisions of the risk assessment to ensure that any changes in equipment, practices, and experience are accounted for.

In terms of national regulations if the total quantity of flammable material stored exceeds a certain quantity, local authorities may have to be informed, and similarly, the local authorities may have the be directly involved in the evaluation of risk assessments and development of procedures.

4.7.2 Risk assessment

The set up and operation of the storage and warehousing facilities should be based largely on the findings and outcome of a risk assessment; since such facilities may differ widely amongst companies and locations, as well as variations in location regulations, it is not possible to provide specific sets of guidelines.

The risk assessment should be produced with respect to the hazards under consideration, that is:

- Thermal radiation from a warehouse fire
- Explosion hazards

These hazards should be described in detail, bearing in mind that it is difficult to separate out the individual hazards posed from individual substances within a warehouse, therefore considering the combined effect. It is also important to ensure that the quantities of flammable material involved are also suitably determined. In this case, assessment should be based on the quantities of flammable material held on the site, being the greater of:

(a) The maximum quantity stored for a short period, even if that is less than one day, over a year taking account of seasonal demands and fluctuations in business activity
(b) The maximum quantity that is liable to be stored in the near future (1 year)

The risk assessment should be based largely on the various characteristics of the site and the equipment, such as:

- Site location
- Nature of the warehousing operation
- Nature and location of materials stored
- Areas set aside for segregated storage of flammable substances
- Drainage systems
- Presence of neighbours with hazard potential
- A description of nearby centres of population, such as residential areas and places of work
- The maximum number of persons on site and their likely locations.
- Total quantity of hazardous substances and the maximum individual quantities
- Type and characteristics of the packaging

This list is not exhaustive, and the more specific items listed in subsequent sections may also be considered. The methods for integrated safety and risk assessment detailed in Part 5 may be used to assist with such risk assessments, although specific guidance for this particular situation should also be sought.

Based on the outcome of the risk assessment, the employers and owners and operators of the site must provide the appropriate general safety measures to eliminate or control the risk of fire and explosion, to workers and other occupants. Such measures may include means of preventing the build-up of potentially flammable atmospheres, avoidance of potential SOIs, introduction of particular training, and emergency procedures. If after implementing such measures it is found that there is still a high risk, then the relevant requirements for hazardous areas may need to be considered.

4.7.3 Major accident prevention policy

Employers must ensure that the owners and operators of the storage facilities (be it themselves or another party) develop a comprehensive major accident prevention policy. This must be comprehensively documented, usually in coordination with local authorities. It must also be fully implemented and systems put in place to ensure that it is fully implemented.

Emergency management must be based on well thought out and practised emergency procedures for all eventualities. Plans must cover all the possible major hazards, and be developed to include the following:

- Sites should be fitted with break-glass fire alarms in strategic locations
- An alarm system that can be heard by all employees
- There must be at least two emergency evacuation assembly areas
- Evacuation procedures must be well rehearsed
- All grades of staff should be instructed not to hesitate to raise an alarm if a fire has broken out and it looks as if it might get out of control
- Immediately the alarm sounds the on-site fire fighting team should attempt to bring the fire under control
- If the fire is in a warehouse, the local fire service should be called immediately and the site fire alarm sounded
- There must be a designated well equipped first aid room

It is also mandatory to have pertinent information available for the fire services. This includes layout of premises, type and quantity of hazardous materials, location and type of fire fighting equipment and whom to contact in the case of an emergency.

4.7.4 Set-up of warehouses

The warehouse should be designed, constructed and fitted to a standard sufficient to store dangerous substances. Also the organisation should develop guidelines for the storage of the products or equipment under consideration. These should describe the conditions under which all hazardous substances are stored. The following list includes a number of aspects for consideration:

Safe design and construction of the building

- Constructed at a safe location
- Safe secure construction, considering layout and supporting equipment
- Appropriately sized fire compartments formed by block walls, constructed of essentially non-combustible materials (profiled metal/brick/block walls)
- Fire resistant doors
- No storage within basements or cellars and no direct access to below ground
- At least one emergency entrance point to the site
- Impervious floor to each warehouse
- High quality electrical installation
- Adequate level of natural or artificial lighting
- Security precautions, such as a secure perimeter fence, intruder alarms

- Bunding and drainage
- Site flood lighting/perimeter lighting
- Formation of zoned areas where applicable (ventilated and no sources of ignition)

Emergency systems
- Adequate means of emergency escape from all buildings
- Clear exit routes, no locking of exit doors
- Fire precautions, detection and foam/water sprinkler systems, relevant alarm signals, smoke alarms
- Adequate fire fighting facilities
- Venting systems, consideration of additional emergency ventilation with gas detection
- Fitted with in-rack sprinkler system
- Availability and access to personal protective equipment, and first aid, eye wash bottles, etc
- An emergency generator

Storage
- Packaging types
- Height of storage
- The storage process
- Segregation and separation procedures – minimum separation distances (e.g., 2 m)
- Fork-lift trucks used

Training to occupants
- Proper informing and training of all occupants and operators
- Permit to work on any part of the facility or its equipment
- Shipping-in and out procedures

Documentation and signage
- Hazardous substance data sheets
- Marking and safety signage

Operations
- Night time patrols/guards
- A gate office that is manned 24 hours/day
- Arrangements to accompany visitors all the time they are on site
- No smoking policy

4.7.5 General procedures

Procedures must be developed in general, but also for activities involving shipping in and out, record keeping, for damaged equipment and for emergencies. The general procedures are necessary to ensure that the operation of the storage facilities is well maintained and that the general safety measures are not compromised in any way. General procedures should include the following:

- Maintaining good standards of housekeeping
- Weekly inspections and tests of fire sprinklers and other fire safety systems
- Good condition of pallets, racking and shelving
- Maintained fire exits, emergency routes, and lighting
- Presence of fire extinguishers
- Daily inspections of fork lift trucks and other transportation equipment
- Maintenance of personal protective and emergency equipment (showers, eyewash, etc)
- Appearance and presence of signs and marking
- Scheme for routine leak checking within packaging

- Training update for workers
- Record keeping (computer database)

Other aspects will be applicable.

4.7.6 Shipping-in/-out procedures

For the handling of equipment as it leaves or arrives at the warehouse, consideration should be given to the following:

- Safe loading and unloading instructions
- The manner by which vehicles and fork-lift trucks are operated
- Dealing with damaged or deteriorated goods
- Labelling of goods
- Methods for shrink/stretch wrapping; ensuring the avoidance of static electricity
- Stock inspection
- Screening of packaging of leakage
- Presence and availability of handheld gas detectors
- Ensuring the vehicle driver has the relevant safety data or transport emergency cards
- Good signage, especially if multi-lingual workers may be present

It is sensible to analyse the actual practices and ensure that the developed procedures reflect the actual practice and do not inadvertently cause hindrances.

4.7.7 Record keeping procedures

A comprehensive record-keeping scheme should be introduced, with regards to the equipment being handled. The information on stock should include:

- Chemical names and brand names where applicable
- Hazard category
- Location
- Owner details
- Storage details
- Personnel/manning details
- Fire fighting equipment
- First aid equipment
- Sprinkler data
- List of other relevant equipment in the warehouse
- Details of electrical installations
- Drainage details
- Potential hazards to fire fighters
- On site risks/hazards to buildings, plant, equipment etc in the event of fire
- Off-site risks/hazards to people and the built and natural environment

The above information should be designed to assist fire fighting operations in the event of a major fire, enhance accident management and facilitate mitigation of its consequences, to staff, the public and the environment

4.7.8 Damaged equipment procedures

It is possible that systems will be damaged at some point, whether it is from within the storage facility or occurring prior to receipt into the facility. In either case, it is essential to have proper procedures in place to deal with leaking systems. In order to support this, companies must hold the appropriate equipment for dealing with it. The written procedures for dealing with releases should include for:

- Recovery of refrigerant
- Storage of recovered refrigerant
- Details of arrangements for work areas
- Special control of sources of ignition within the relevant areas

Workers who deal with such leakage should have access to:

- Comprehensive data on the hazards
- Appropriate personal protective equipment (safety goggles, etc)
- Fire extinguishers
- HC gas detectors

Damaged or leaking equipment should be stored in a designated area/building well away from the main warehouse that is well ventilated, equipped with appropriate security features and has segregated areas to ensure compliance with the segregation rules for hazardous substances (the relevant section in Part 4.5.3 and Part 6 should be referred to).

PART 5: EQUIPMENT DESIGN AND DEVELOPMENT

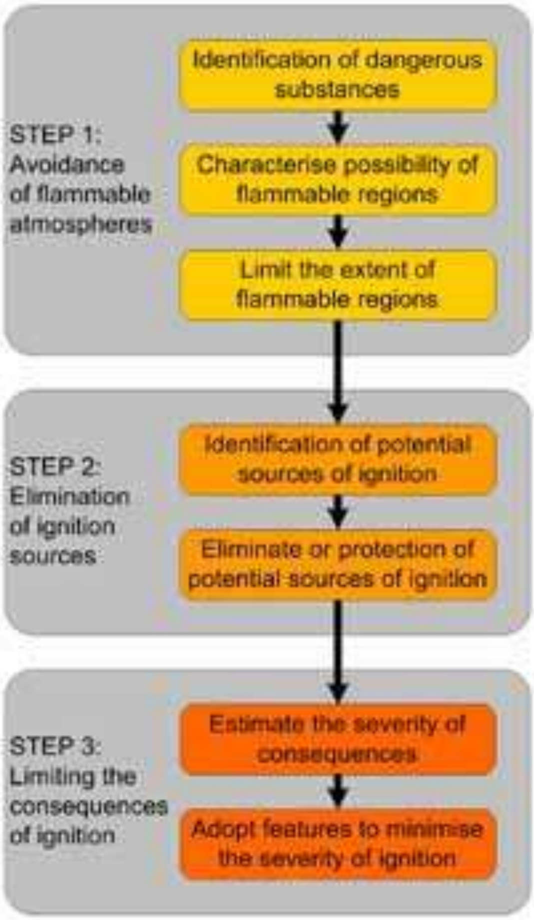
5.1 INTRODUCTION TO SAFE DESIGN FOR HC REFRIGERANTS

5.1.1 Integrated safety

Careful consideration of the design and construction of systems and installations is essential for achieving a high level of safety for systems. Whether the system is a stand-alone appliance or a large installed centralised system, the principle of integrated safety should be applied, regardless. Through this, the flammability hazard is dealt with using a mixture of ignition prevention measures and, if the ignition risk cannot entirely be avoided, techniques for protection against the consequences of ignition.

When a flammability hazard has been identified, a systematic approach must be taken to minimise the risk. This comprises three main steps: firstly, if possible, prevent the formation of flammable atmospheres; secondly, prevent the ignition of any flammable atmospheres that might occur; and finally, limiting the range of flames and pressures to a minimum were ignition to occur. This approach must be integrated into the design and operation of any RAC equipment using HC refrigerants, based around the procedure in Figure 21.

Figure 21: Flow chart indicating the design steps to integrate flammable substances safely



According to Figure 21, the first step is to avoid as practicably as possible, the occurrence of a flammable atmosphere:

- It is known that an HC refrigerant is being used, and therefore the flammable characteristics are needed to understand its behaviour in the event of a release.
- Since a flammable atmosphere can occur, it is necessary to identify the parts of the equipment or the installation where a flammable region may be present in the event of a release. It is a common approach to estimate the likelihood that a particular region may experience a flammable mixture. Each region should be characterised according to the probability or frequency of the presence of a flammable mixture and the extent and persistence of that flammable mixture.
- The extent of any flammable regions should be eliminated entirely if at all possible; otherwise the amount present should be kept to the minimum practicable. This includes the flammable material being, suitably contained, prevent a release from spreading, ensuring that the contents of containers and pipes are clearly identifiable and adopting other practical measures, such as detection of potentially flammable atmospheres, alarm procedures and appropriate ventilation.

The second step is the elimination of potential sources of ignition:

- Ignition can be caused by high energy sources such as electrical discharges and hot surfaces. Therefore it is important to identify when and where potential sources of ignition could occur and to analyse the area. Particular attention should be given to electrical or mechanical equipment, although there are many other potential ignition sources to which consideration must be given.
- Once the ignition potential of the flammable gas and the likelihood of flammable regions are known, the appropriate protection can be applied to the electrical and mechanical equipment.

The third step is limiting the severity of consequences of an ignition event:

- If there is a residual risk of ignition, the maximum pressure development and the extent of any flames and radiated heat should be evaluated, which may necessitate using numerical or experimental methods.
- Adopt one or more of the possible methods of protection against overpressure and flame spread, such as venting, suppression, containment and isolation.

These fundamental concepts can be directly applied to the case of HCs in RAC systems and equipment:

- Step 1: consider the possibility of refrigerant leakage and how to avoid or minimise it, reduce the charge size of the system, and/or the amount that may be released into a particular area, use ventilation, gas detection and associated controls
- Step 2: identify all the potential sources of ignition and remove or ensure they are protected against ingress of refrigerant in the event of a leak
- Step 3: ensure that all housings or enclosures have venting or otherwise eliminate the possibility of refrigerant entering them, and use marking and instructions to raise the awareness of those who may come into contact with the system and refrigerant

Furthermore, equipment must be designed and manufactured after due analysis of possible operating faults in order to preclude dangerous situations as far as possible, and any misuse which can reasonably be anticipated must be taken into account. When equipment is subject to special checking and maintenance conditions must be designed and constructed with such conditions in mind and must be so designed and constructed as to be capable of coping with actual or foreseeable surrounding area conditions. Wherever possible, if there is a possibility of a release of flammable gas, enclosed structures may be employed so that a release will not give rise to a flammable atmospheres outside the equipment. If equipment is within a housing or a locked container, it must be possible to open such housing or container only with a special tool or by means of appropriate protection measures.

APPLICATION OF ATEX EQUIPMENT DIRECTIVE

For products being sold within Europe, the EU ATEX "equipment" directive (94/9/EC concerning equipment and protective systems intended for use in potentially explosive atmospheres) must be considered for all equipment which are capable of causing an explosion through their own potential sources of ignition. (However, equipment intended for use in domestic and non-commercial environments is broadly exempt.) The means of conformity depends upon the type of equipment and the manner of its application and use.

Most RAC equipment may correspond to equipment Group II, Category 3, i.e., designed to be capable of functioning in conformity with the operating parameters established by the manufacturer and ensuring a "normal" level of protection, where it is intended for use in areas in which explosive atmospheres are unlikely to occur or, if they do occur, are likely to do so only infrequently and for a short period only and therefore must ensure the requisite level of protection during normal operation.

Equipment in this category must comply with the relevant Essential Safety Requirements (ESRs). This means that the equipment must be so designed and constructed as to prevent foreseeable ignition sources which can occur during normal operation, including taking account of the following:

- Principles of integrated explosion safety
- Any misuse which can reasonably be anticipated must be taken into account.
- Special checking and maintenance conditions
- Surrounding area conditions
- Marking and instructions
- Selection of materials
- Design and construction (enclosed structures and prevention of leaks, additional means of protection, safe opening, overloading of equipment)
- Potential ignition sources
- Hazards arising from external effects

If the equipment does fall under ATEX then compliance with the ESRs is needed, the process for which is summarised in the Figure below. This is achieved through conformity to either one of the modules:

- Internal control of production (self-certification; see info box in this Part), or
- Unit verification (i.e., using a notified body)

Alternatively, any other module that specifies stricter requirements may be used, most of which require third-party involvement.

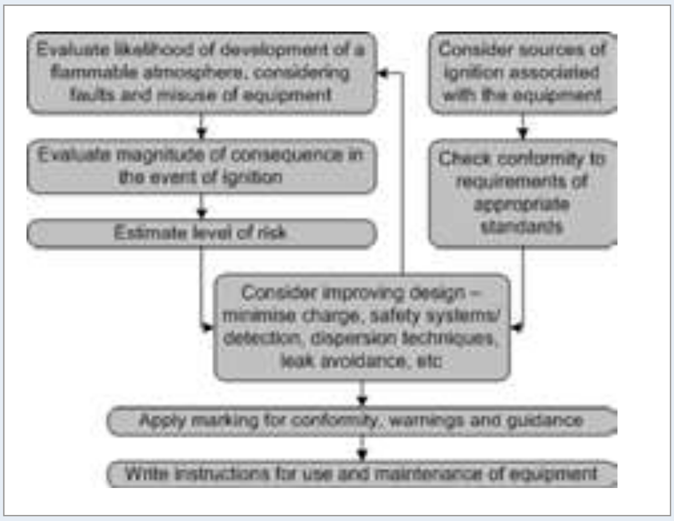


Figure indicating the means to meet the essential safety requirements

The following sections address these aspects in detail. Much of the direction is taken from the relevant safety standards, but these following sections in addition attempt to provide further insight to the rules and give additional safety measures.

INTERNAL CONTROL OF PRODUCTION

Any manufacturer/producer of equipment must document the development and production process so they may demonstrate the level of safety that has been achieved; in some countries, this is mandatory by law. This procedure is where the manufacturer/producer ensures and declares that the equipment satisfies the necessary safety requirements applicable to it, that is a written declaration of conformity. Supporting this declaration, the manufacturer/producer must establish the technical documentation (as detailed below) and must keep it at the disposal of the relevant authorities for inspection purposes (typically for a period ending at least 10 years after the last piece of equipment was manufactured). The technical documentation will enable the conformity of the equipment with the relevant requirements of the rules to be assessed. It must cover the design, manufacture and operation of the product, as follows:

- A general description of the equipment
- Conceptual design and manufacturing drawings and schemes of components, sub-assemblies, circuits, etc
- Descriptions and explanations necessary for the understanding of said drawings and schemes and the operation of the equipment
- A list of the standards applied in full or in part, and descriptions of the solutions adopted to meet the safety aspects of the safety requirements where the standards have not been applied
- Results of design calculations made, examinations carried out, etc
- Test reports

The manufacturer/producer must keep a copy of the declaration of conformity with the technical documentation. In particular, the manufacturer/supplier must take all measures necessary to ensure that the manufacturing process guarantees compliance of the manufactured equipment with the technical documentation referred to above and with the relevant safety requirements applicable to such equipment.

5.1.2 Other safety considerations

It should be noted that whilst the information provided is largely specific to the use of HC refrigerants, it is important to recognise that there are many other aspects that the system designer must consider with respect to general refrigeration safety. Although not necessarily covered within this handbook, the following aspects should also take a high priority in the consideration of the design of any RAC system and associated installation:

- General electrical safety
- Electromagnetic compatibility
- Protection against moving parts
- Protection against excessive noise
- Safety in coldrooms and other areas with controlled atmospheres
- The design, testing, selection and installation of heat exchangers, pressure vessels, compressors, pumps, valves and other ancillary components
- The design, testing, sizing and installation of pipework and pipe-to-pipe joints and pipe-to-component connections, layout, use of supports and general protection
- Arrangement and setting of pressure relief and pressure limiting devices
- Provision of marking signage and documentation

In order to address these properly, the relevant safety regulations, standards and codes must be referred to. Standards such as IEC 61160 on design review can provide guidance in terms of ensuring that all the important aspects are taken into account.

5.2 AVOIDANCE OF LEAKAGE

5.2.1 Introduction

It is essential to avoid refrigerant leakage for both safety and environmental reasons. In terms of safety if the likelihood of a refrigerant release can be minimised, then the flammability risk is reduced accordingly. With regards to environmental impact, although HCs have zero ODP and negligible GWP, the loss of refrigerant from a system will lead to a reduction in system efficiency and cooling capacity, thus increasing energy consumption in two respects. Depending upon the type of system, a deficit of a few grammes of refrigerant charge can increase energy consumption by several percent. In addition, design temperatures of the cooling system may no longer be achievable, and there are further financial implications associated with the replacement of the lost refrigerant and the repair work.

Avoidance of refrigerant leakage can be achieved by addressing various stages of system handling:

- Appropriate system design and selection of appropriate components and layout
- Suitable installation and tightness testing/leak checking practices
- Regular maintenance and system checks
- Servicing by competent technicians, using proper equipment

Different types of systems tend to have different leak rates; leak rates being usually defined as the quantity of the leaked refrigerant as a proportion of a systems total charge per year (for example, a system that leaks 1 kg of its 10 kg charge in 1 year is said to have a 10% leak rate). Some typical values taken from various studies that monitored leak rates from a population of actual systems, are provided in Table 7. The variation in the leak rates is mainly a function of the design of system and the manner by which they are looked after. It is important to be aware that it is possible – if designed and maintained well – for a system to have a leak rate of zero. On the other hand, it is often the case that systems have leak rates of over 100%. Nevertheless, it is worth noting the types of systems that exhibit higher leak rates, which indicates when and where greater attention should be paid to leak minimisation.

Table 7: Typical range of average empirical refrigerant leakage for different types of systems

Type of equipment	Typical annual leakage rate (% of charge)[18]
Domestic refrigeration	0.5 – 2.5%
Retail refrigeration; integral/stand-alone	1 – 5%
Retail refrigeration; split/condensing unit systems	8 – 20%
Retail refrigeration; direct expansion central systems	8 – 35%
Air conditioning; integral/portable units	0.5 – 2.5%
Air conditioning; single split systems	5 – 15%
Air conditioning; multi-split systems	5 – 20%
Air conditioning; chillers	3 – 15%

18 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 2006 Assessment, UNEP Nairobi, Ozone Secretariat, 2007; IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Climate System, Switzerland, 2005.

Some recent European legislation on fluorinated gases[19] pays attention to the reduction of leakage from systems. Although this regulation does not cover HC refrigerants, it may be useful to consider some of its requirements in terms of reducing leakage regardless of the refrigerant type. The important parts of the regulation stipulate the following:

- Leak checking must be carried out with the frequency dependent upon the size of the system
- Keeping records on all systems (above a certain size), including charge size, date of leak checking, any remedial work, the quantities of refrigerant added and removed and the identity of the technician
- Labelling of the system with the type and quantity of refrigerant inside
- Refrigerant must be recovered during plant servicing and maintenance and at end of life.
- Any technician working on a system must be properly training and certified with the appropriate qualifications
- Company certification is required for all companies employing personnel to undertake work on equipment containing or designed to contain fluorinated refrigerants

The equipment operators are under obligation to ensure that all these requirements are adhered to.

5.2.2 General system design

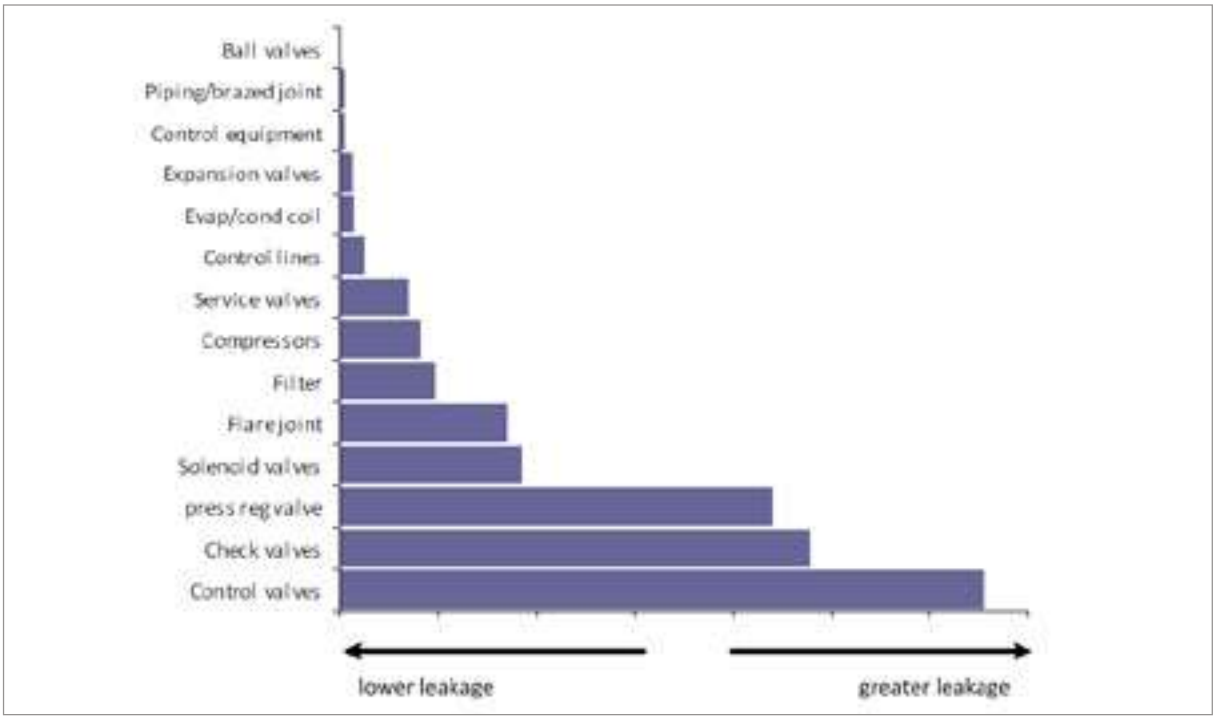
Some general principles may be applied to the design of a system:

- Consider the use of more than one independent refrigerant circuit, so that in the event of a major leak, the loss of the refrigerant would be less; this can have cost and space implication which require consideration
- Generally, with large systems, the use of automatic shut-off valves can be considered, which can be used to isolate parts of the refrigeration circuit (e.g., receiver, condenser, etc) when a leak is detected
- When designing pipework and selecting components, it is preferable to have as few pipe joints and seals (for example in valves, etc) as possible
- Ensure that all the materials that are to be used within the refrigeration system (particularly valve seals, o-rings, etc), are fully compatible with the HC refrigerant to be used. It is important to be aware that the compatibility of refrigerants with elastomers is different when different types of oils are involved
- Be aware that unsaturated HCs (e.g., R1270) are incompatible with certain materials that saturated HCs (e.g., R290) are compatible with
- Consider the full range of operating temperatures and pressures that the materials will be subjected to, as this can also affect the compatibility
- Try to minimise the use of components and joints that are known to result in high levels of leakage;

A thorough overview and additional practical tools for aiding the reduction of emissions of (any) refrigerant is provided by the Real Zero project[20] of the Institute of Refrigeration, and further guidance can be found within the Code of Practice on Minimisation of Refrigerant Emissions[21]. In addition, there is a draft standard EN 15834:2009 on the qualification of tightness of components and joints (applicable to components and the entire assembly), which should be used. Of particular interest is that the standard is intended to characterise the tightness of the parts considering the stresses met during their operations, following the fitting procedure specified by the manufacturer, and also specifies the minimal information to be provided by the supplier of a component to the person in charge of carrying out the fitting procedure.

19 Regulation (EC) No 842/2006 on certain fluorinated greenhouse gases
20 See www.realzero.org.uk
21 See www.ior.org.uk/ior_publication.php?pubid=E6EM1WETAB

Figure 22: An indication of the tendency of different individual components to leak



5.2.3 Considerations for piping

When designing and installing pipework, a number of important considerations should be adhered to:

- Pipework and components must be protected against impact, weathering, external corrosion, and electrolytic corrosion at the junction of dissimilar metals
- Care must be taken to ensure that all joints are brazed correctly
- Piping should not be installed in such a way that bends or joints are stressed
- Where insulation is used, care must be taken to ensure that water does not collect at the interface of the tube and insulation
- Steel piping has superior properties to copper piping in respect of mechanical strength and lack of susceptibility to vibration and work hardening, however, steel piping is subject to external corrosion and must be adequately protected against it
- Pipes must be adequately supported, according to tube diameter, number of joints, weight and spacing distance
- Piping should not be routed where it is likely to be walked on, or used as lifting beams, where this is impossible, protective covers and warning labels should be provided
- Pipe runs must be designed to allow for expansion and contraction
- Piping must be designed to minimise the effects of vibration
- The need to prevent liquid hammer should be taken into account in the design of pipe routing and the selection of valve types
- Where the decision is taken to use quick-acting valves in long lines and means of suppressing pulsation must be provided
- The use of mechanical joints must be minimised; welding or brazing are the preferred jointing methods. In particular, flare joints must be avoided as they are one of the most common sources of leakage
- Wherever possible compressor connections should be made using continuous piping without the use of vibration eliminators or flexible connectors, providing that excessive vibration or stresses will not be transmitted to the rest of the system
- Where vibration eliminators or flexible connectors are required, they must be installed in strict accordance to manufacturers instructions, to ensure that they do not cause catastrophic leakage

5.2.4 Considerations for major system components

When designing and installing other system components, a number of important considerations should be adhered to:

- Heat exchangers must be protected against possible mechanical damage
- Heat exchangers containing water must be protected against freezing.
- Access must be provided for leak testing of compressors, evaporators, condensers and associated components
- Where there is a risk of refrigerant leakage into water or other heat sink fluid, a means of drawing off and sampling that fluid must be provided
- Lower temperature air coolers and drip trays should be completely defrosted during every defrost cycle
- Defrost controls should be designed and adjusted to avoid any unnecessary defrost operations, to minimise thermal stresses
- Heat exchangers containing water must be protected against freezing
- Compressors should be installed on anti-vibration mountings

5.2.5 Considerations for valves

The following should be considered when selecting and choosing valves:

- Sufficient valves must be provided to ensure that servicing and maintenance can be carried out without causing significant loss of refrigerant
- Care is required to avoid unsafe pressures in isolated circuit sections containing liquid refrigerant.
- Where reasonably practicable, valves which have a bellows or a diaphragm instead of a spindle seal should be used
- Valves which have O-ring spindle seals should be used in preference to valves with spindle packing glands provided that the O-ring material is suitable for the temperatures and fluids involved
- Where suitable elastomeric material is not available, packed glands may be used
- Seal caps should always be fitted to all valves
- Whenever possible, the safety valve or other device which protects the high pressure side of the refrigeration circuit should be vented to the low pressure side and not directly to atmosphere, but maintenance access to the device must be possible without the use of intervening stop valves
- The low pressure side of the system should be vented to atmosphere
- The high pressure side of the system must not be protected by a bursting disc venting to atmosphere
- Dual relief valves should be encouraged to facilitate rapid change over at mandatory service intervals and to sustain plant operation
- An indicating device should be fitted to the outlets of valves so that a check can be made, during maintenance, whether the valves has discharged to atmosphere

5.2.6 Leak detection

Leakage cannot be prevented by refrigerant detection methods, but it generally helps ensuring that smaller leaks do not evolve into larger leaks. A number of options are available for detection. Refer to Part 6.1.

ALTERNATIVE JOINING METHODS

It is well-know that conventional flare connections can easily develop leaks. Whilst it is preferable to use brazed joints, it is sometimes necessary or appropriate to make mechanical connections, or maybe to avoid the use of a brazing torch under certain circumstances. In these cases, certain other options may be considered.

Press joints ("Lok-ring")

Where brazing is not possible, this 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 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.

"Euro-flare"

The so-called "Euro-flare" – also known as "solder nut" and "brazing stud" – is also a possible option, especially whenever screwed connections are necessary (for example, for an air conditioner outdoor/indoor unit suction/ liquid line). These are flare fittings consisting of a brazing adapter (tube fitting), nut and copper seal. In case of repair only the copper seal has to be changed. They come with a variety of different fittings.

Ferrule compression joints ("Swagelock")

Ferrule compression fittings are permanent mechanical joints. They work on the basis of compressing and hardening metallic materials within the nut onto the pipe, which provides a gas-tight seal and resistance against vibration. These are normally applied to very high pressure systems and are considered highly reliable.

5.3 REFRIGERANT CHARGE SIZE LIMITS

5.3.1 Introduction

Refrigerant charge size limits are prescribed in a number of different standards, and since the requirements amongst these standards vary, this section intends to provide a compilation of those requirements:

- EN 378
- EN / IEC 60335-2-24
- EN / IEC 60335-2-40
- EN / IEC 60335-2-89

In general, the mass of HC refrigerant within a single refrigerant circuit is limited, according to the type of system, the type of location and the size of the space, particularly in respect to occupied areas.[22] For installations within human occupied spaces, a minimum room size is to be specified for a given refrigerant circuit charge size.

Two restrictions apply to refrigerant charge sizes:

- The first is a "maximum" charge size (M_{max}), which is a function of the type of location and its occupancy (or not)
- The second is an "allowable" charge size (M_{al}), which is a function of size of the (occupied) area that the refrigerant could leak into

The allowable charge sizes are typically based on the assumption that under the worse case, the entire refrigerant charge from a circuit will leak into a space almost instantaneously, and since the vapour is denser than air, it will partially stratify – thus the allowable charge normally accounts for this by adopting a 20% safety margin. (In certain cases, this safety margin is extended to factors approaching less than 5%.) On the other hand, the values for maximum charge size have been chosen on a broadly arbitrary basis, having little or no technical basis, although it can be seen that there is a general correspondence between lower charge sizes and the number and vulnerability of the occupants. In the case of systems located below ground level, a common value is applied throughout on the basis that it is difficult for a denser-than-air vapour to disperse upwards.

A summary of these maximum and allowable charge sizes is provided in Table 10.

In general, HC refrigerants should be used only in sealed systems with restricted charge or otherwise in occupancy categories where only competent members of staff are present. In any case, the refrigerant charge in a system with any refrigerant-containing part situated below ground level is restricted to no more than 1.0 kg. Sealed systems with refrigerant charge of 4 × LFL (for example, 4 × 0.038 = 0.15 kg for R290) or less may be sited in any location or category of occupancy provided there are no sources of ignition associated with the refrigerating system (LFL values are provided in Table 8 for selected common HC refrigerants).

The following sections provide a description of refrigerant charge size restrictions, according to the occupancy category, A, B or C, and also according to the positioning of the system and its parts:

22 Within EN 378, refrigerant charge limits are also identified according to the type of system – be it direct expansion or indirect (where a non-hazardous secondary heat transferring fluid is used). In this publication, this variable is accounted for by means of the presence of any refrigerant-containing part of the system.

- Entire system within human occupied space which is not a machinery room
- Compressor and liquid receiver in an unoccupied machinery room or in the open air
- All refrigerant containing parts in an unoccupied machinery room or in the open air
- Entire system within a specially constructed ventilated enclosure

Figure 23 is a flow chart that may be used for determining the appropriate refrigerant charge size and/or minimum room size for HC refrigerants.

Table 8: Flammable limits and Practical Limits of several HC refrigerants

Value		R600a	R290	R1270	R290/ R600a †	R290/ R170 ‡
Lower Flammability Limit	(kg/m^3)	0.043	0.038	0.043	0.040	0.038
	(%)	1.80	2.10	2.50	1.95	2.15
Practical limit (kg/m^3)		0.008	0.008	0.008	0.008	0.008
Density of vapour (kg/m^3)*		2.48	1.86	1.77	2.17	1.82

† Based on 50% R290 and 50% R600a molar composition
‡ Based on 94% R290 and 6% R170 molar composition
* At standard atmospheric pressure (101.325 kPa) and 21°C

5.3.2 Occupancy categories

The identification of the type of occupancy is critical to the determination of maximum refrigerant charge size. This is because in some locations, occupants may be unaware of the emergency exits or may find it difficult to exit the building in the event of an emergency, and in other locations, the occupants may be well aware of the emergency procedures. Considerations of safety in refrigerating systems take into account the site, the number of people occupying the site and the categories of occupancy. The maximum quantity of refrigerant permitted (per refrigerant circuit) is a function of these conditions.

Thus, refrigerant charge size restrictions described are limited according to the occupancy category, A, B or C:

- Category A: general occupancy not restricted at all – dwellings and public places where people are unlikely to be aware of the refrigerant hazards
- Category B: supervised occupancy – restricted to a certain number of people, some of whom are aware that the system is charged with a HC
- Category C: occupancy with authorised access only – where trained personnel operate who should be competent in handling refrigerant or at least aware of emergency procedures

Table 9: Types of occupancies and examples

Occupancy	Description	Examples
Category A	Rooms, parts of buildings, or another location where people may sleep, where people are restricted in their movement or where the number of people present is not controlled or to which any person has access without being personally acquainted with the personal safety precautions	Hospitals, prisons, nursing homes, theatres, super-markets, transport termini, hotels, lecture halls, dwellings, restaurants, ice rinks, passenger vehicles, etc
Category B	Rooms, parts of buildings or buildings, where only a limited number of people may be assembled, some of them being necessarily acquainted with the general safety precautions	Office buildings, laboratories, places of work, places for general manufacturing, etc
Category C	Rooms, parts of buildings, buildings where only authorised persons are granted access and which is not open to the public and; authorised persons shall be acquainted with general safety precautions of the establishment	Non public areas in supermar-kets, cold stores, manufacturing facilities, refineries, manufac-turing facilities e.g. for chemi-cals, food, ice and ice cream

If there is the possibility of more than one category of occupancy, the more stringent requirements apply, i.e., category A is chosen in favour of category B, or category A in favour of category C. However, if occupancies are isolated, e.g. by sealed partitions, floors and ceilings, then the requirements of the individual category of occupancy apply.

5.3.3 Category A o ccupancies (general occupancy)

General occupancy is defined in EN 378-1: 2008 as "a location where people may sleep or where the number of people present is not controlled or to which any person has access without being personally acquainted with the personal safety precautions". A sudden loss of refrigerant should not be able to raise the concentration of refrigerant within the room to or above the Practical Limit (given in Table 8) in a human-occupied space and there shall be no sources of ignition associated with the refrigerating system or located in an area where the refrigerant could gather in the event of an leak.

In all system and occupancy types below, the maximum refrigerant charge per circuit is limited to M_{max} = 1.0 kg, if any refrigerant-containing part is situated below ground level.

Entire system in human occupied space

Where (a) the entire system is located in a human occupied space, or (b) where the compressor and receiver part of the system is located in an unoccupied machinery room or in the open air, but part of the system is located in a human occupied space, then HC refrigerants shall be permitted only in systems with refrigerant containing part in a general occupancy with a refrigerant charge:

- Up to the allowable refrigerant charge (M_{al}) detailed below (see Part 5.3.5), but not exceeding the maximum charge of M_{max} = 1.5 kg

System in ventilated enclosure

Where the entire system is located within a mechanically ventilated enclosure (see Part 5.6.5), HC refrigerants shall be permitted only in systems with refrigerant containing part in a general occupancy with a refrigerant charge:

- Up to the maximum charge of M_{max} = 130 × LFL (kg)

System in open air

Where the entire system located in the open air, HC refrigerants shall be permitted only in systems with refrigerant containing part in a general occupancy with a refrigerant charge:

- Up to the maximum charge of M_{max} = 5.0 kg

5.3.4 Category B occupancies (supervised occupancy)

Supervised occupancy is defined in EN 378-1: 2008 as "rooms, parts of buildings or buildings, where only a limited number of people may be assembled, some of them being necessarily acquainted with the general safety precautions." A sudden loss of refrigerant should not be able to raise the concentration of refrigerant within the room to or above the Practical Limit (given in Table 8) in a human-occupied space and there shall be no sources of ignition associated with the refrigerating system or located in an area where the refrigerant could gather in the event of an leak.

In all system and occupancy types below, the maximum refrigerant charge per circuit is limited to M_{max} = 1.0 kg, if any refrigerant-containing part is situated below ground level.

Entire system in human occupied space

Where (a) the entire system is located in a human occupied space, or (b) where the compressor and receiver part of the system is located in an unoccupied machinery room or in the open air, but part of the system is located in a human occupied space, then HC refrigerants shall be permitted only in systems with refrigerant containing part in a general occupancy with a refrigerant charge:

- Up to the allowable refrigerant charge (M_{al}) detailed below (see Part 5.3.5), but not exceeding the maximum charge of M_{max} = 2.5 kg

System in ventilated enclosure

Where the entire system is located within a mechanically ventilated enclosure (see Part 5.6.5), HC refrigerants shall be permitted only in systems with refrigerant containing part in a supervised occupancy with a refrigerant charge:

- Up to the maximum charge of M_{max} = 130 × LFL (kg)

System in open air

Where the entire system is located in the open air, HC refrigerants shall be permitted only in systems with refrigerant containing part in a supervised occupancy with a refrigerant charge:

- Up to the maximum charge of M_{max} = 10.0 kg

5.3.5 Category C occupancies (authorised occupancy)

Authorised occupancy is defined in EN 378-1: 2008 as "An occupancy which is not open to public and where only authorised persons are granted access. Authorised persons shall be acquainted with general safety precautions of the establishment." A sudden loss of refrigerant should not be able to raise the concentration of refrigerant within the room to or above the Practical Limit given (given in Table 8) in a human-occupied space and there shall be no sources of ignition associated with the refrigerating system or located in an area where the refrigerant could gather in the event of an leak.

In all system and occupancy types below, the maximum refrigerant charge per circuit is limited to M_{max} = 1.0 kg, if any refrigerant-containing part is situated below ground level.

Entire system in human occupied space

Where the entire system is located in a human occupied space, HC refrigerants shall be permitted only in systems with refrigerant containing part in an authorised occupancy with a refrigerant charge:

- Up to the allowable refrigerant charge (M_{al}) detailed below (see Part 5.3.5), but not exceeding the maximum charge of M_{max} = 10.0 kg

Part of system in human occupied space

Where the compressor and receiver part of the system is located in an unoccupied machinery room, or in the open air, HC refrigerants shall be permitted only in systems with refrigerant containing part in an authorised occupancy with a refrigerant charge:

- Up to the allowable refrigerant charge (M_{al}) detailed below (see Part 5.3.5), but not exceeding the maximum charge of M_{max} = 25kg

System in ventilated enclosure

Where the entire system is located within a mechanically ventilated enclosure (see Part 5.6.5), HC refrigerants are permitted in systems with refrigerant containing part in an authorised occupancy without restriction of the refrigerant charge.

System in open air or special machinery room[23]

Where the entire system is located in the open air or a special machinery room, HC refrigerants are permitted in systems with refrigerant containing part in an authorised occupancy without restriction of the refrigerant charge.

5.3.6 Calculation of allowable charge sizes (M_{al})

For systems that are located in occupied spaces, but are not used for cooling or heating for human comfort, the allowable refrigerant charge per independent circuit is determined from:

$$M_{al} = V_{Rm} \times PL \quad (1)$$

where

M_{al} = allowable mass per circuit (kg)
V_{Rm} = room volume (m^3)
PL = practical limit (kg/m^3); see Table 8

Conversely, for a given circuit charge size, the minimum room size can be determined from:

$$V_{Rm} = \frac{M_{al}}{PL} \quad (2)$$

PL

23 Within the standard EN 378: 2008, when describing occupancies, it states "machinery rooms are regarded as unoccupied", whilst in the definition of machinery rooms it states that they are "only accessible to authorised persons". Given the ambiguity, machinery rooms can be considered as occupancy C.

For systems that are located in occupied spaces, and are to be used for cooling or heating for human comfort, the allowable refrigerant charge per independent circuit is determined from:

$$M_{al} = 2.5 \times LFL^{1.25} \times h \times \sqrt{A_{Rm}} \tag{3}$$

where
LFL = lower flammability limit (kg/m³)
A_{Rm} = room floor area (m²)
h = some nominal height (m), according to the position of the equipment:

- h = 0.6 m for floor mounted
- h = 1.0 m for window mounted
- h = 1.8 m for wall mounted
- h = 2.2 m for ceiling mounted

Conversely, for a given circuit charge size, the minimum room floor size can be determined from:

$$A_{Rm} = \left(\frac{M}{2.5 \times LFL^{1.25} \times h} \right)^2 \tag{4}$$

For a particular sub-category of equipment, non-fixed (portable) factory sealed single package air conditioners or heat pumps, the allowable refrigerant charge per independent circuit is determined from:

$$M_{al} = 0.55 \times LFL \times A_{Rm} \tag{5}$$

This is provided that the charge size of no greater than 8 m³ × LFL (approximately 300 g for HC refrigerants). There are additional requirements applied to this type of equipment, such as when the appliance is switched on, a fan must operate continuously supplying a minimum airflow as under normal steady state conditions, even when the compressor is switched off by the thermostat.

5.3.7 Equipment airflow[24]

In order to reduce the risk of ignition of leaked refrigerant – especially within an enclosed area – the fan associated with the equipment (for example, the air handler or condenser fans) located in the enclosed area should have a minimum airflow rate, corresponding to:

$$\dot{V}_{af} = \frac{0.004 \times M}{LFL} \tag{6}$$

where
$\dot{V}_{af}$ = volume airflow of fan(s) (m3/s)
M = refrigerant charge (kg)
LFL = lower flammability limit (kg/m3); from Table 8

This is a generalised approximate formula which is based on measurements over a range of conditions, and therefore may not be accurate for all situations. It is also noted that the effectiveness of mixing is

24 Note that this is not a requirement of any standard, but is considered to add additional means of improving safety levels

ADDRESSING CHARGE SIZE LIMITS

It is known that some of the calculations for charge size limits within the safety standards, as detailed here, can be very restrictive, sometimes with good reason, sometimes without. If there is a certain need for higher charge sizes, then consider certain approaches:

- Use two independent refrigerant circuits rather than one
- Use indirect refrigerant circuits so that the refrigerant charge may be kept in a location away from the occupied space
- Use a safety system, where if there is a leak, a limited quantity of refrigerant may be released into the occupied space, whilst retaining the remaining refrigerant within an external (outside or occupancy C) part of the system. If this type of approach is being used, ensure that the mechanism is tested and its reliability proved, and carrying out a thorough risk assessment to confirm that under no circumstances will a failure lead to a flammable atmosphere being created in a location that hasn't already been designed to handle it.

On the whole, standards are not regulations, and therefore they do not necessarily impose legal requirements (unless stated by a legally-binding contract). Furthermore, standards tend to lag technological developments (rather than lead them) so they can often be oblivious of new technologies, methods or techniques that could be employed to achieve a similar or greater level of safety. In such cases, it may be necessary to develop risk assessments and approvals from third-parties to enable the adoption of approaches that deviate from the standards. Since the drafting of standards is often dominated by enterprises that favour specific technology options in preference to others, standards may reflect these preferences whilst inhibiting others. In these cases, the new or alternative technologies, methods or techniques should be fed into the standards making process to enable them to become more inclusive.

Table 10: Summary of maximum and allowable refrigerant charge sizes according to EN 378, and EN / IEC 60335-2-24, -89 and -40

Location of refrigerant containing parts	System type	Refrigerant mass †	Occupancy type				
			Category A (general occupancy)		Category B (supervised occupancy)		Category C (occupancy with authorised access only)
			RHPAC	Comfort HPAC	RHPAC	Comfort HPAC	RHPAC and Comfort HPAC
Human occupied space which is not a machinery room	Direct	Allowable (M_{al})	$PL \times V_{Rm}$	$2.5LFL^{1.25}h\ A_{Rm}$ or $0.5A_{Rm}LFL$	$PL \times V_{Rm}$	$2.5LFL^{1.25}h\ A_{Rm}$ or $0.5A_{Rm}LFL$	$PL \times V_{Rm}$
		Maximum (M_{max})	1.5 kg, or 1 kg BG	26 × *LFL*, or 1 kg BG	2.5 kg, or 1 kg BG	26 v *LFL*, or 1 kg BG	10 kg (or 25 kg*), or 1 kg BG
In an unoccupied machinery room or in the open air or a special ventilated enclosure	Indirect	Allowable (M_{al})	5 kg, or 1 kg BG	130 × *LFL*, or 1 kg BG	10 kg, or 1 kg BG	130 × *LFL*, or 1 kg BG	No limit, or 1 kg BG
		Maximum (M_{max})	5 kg, or 1 kg BG	130 × *LFL*, or 1 kg BG	10 kg, or 1 kg BG	130 × *LFL*, or 1 kg BG	No limit, or 1 kg BG

Notes:

RHPAC = Refrigeration, heat pumps and air conditioning

Comfort HPAC = heat pumps and air conditioning (specifically for human comfort)

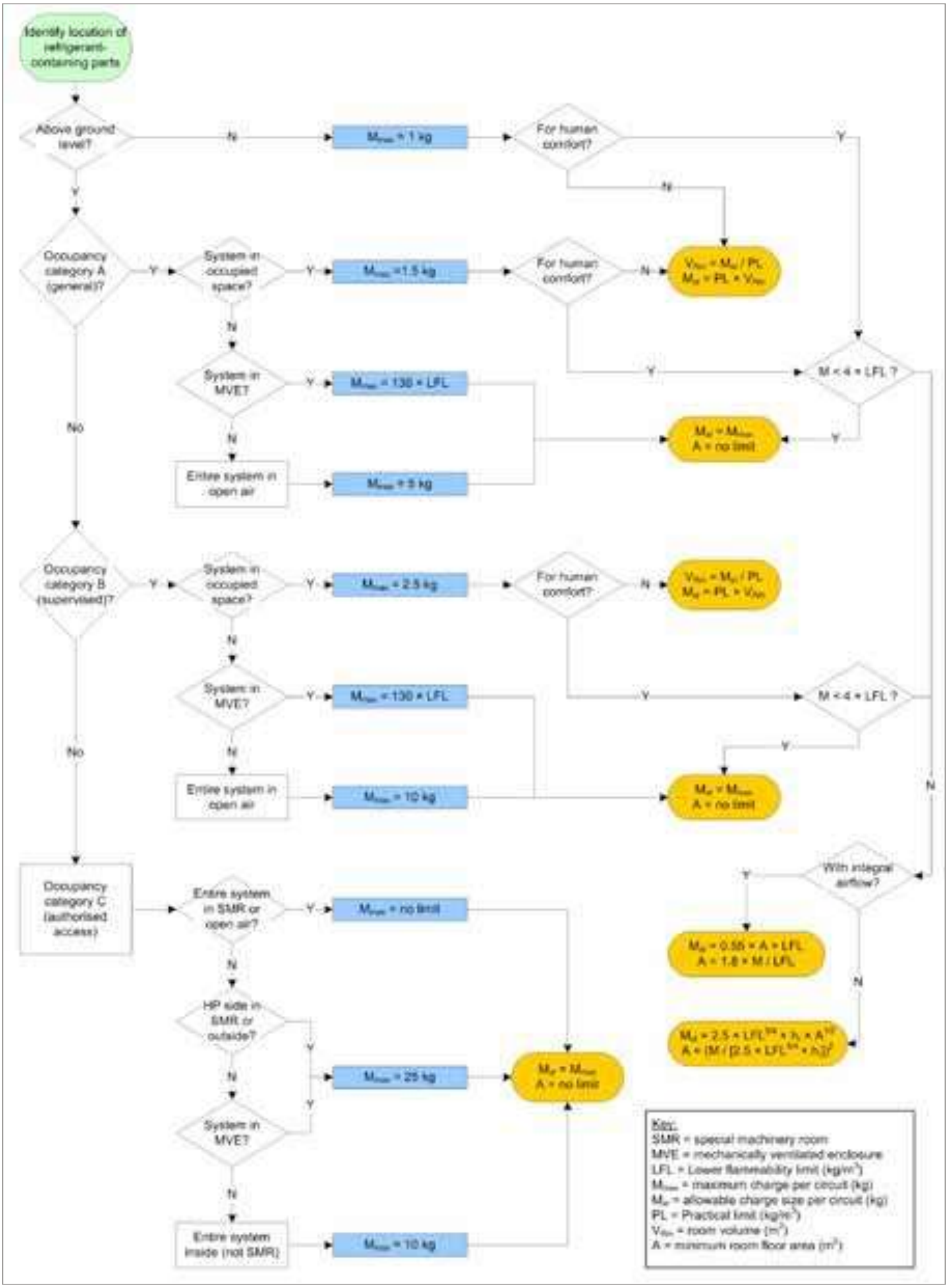
Allowable and maximum refrigerant charge sizes in kg

BG = below ground; note that refrigerant charges above 1 kg are not permitted below ground, including interconnecting pipework or other refrigerant-containing parts

* 25 kg if compressor and liquid receiver are in an unoccupied machinery room or in the open air

† Circuits containing ≤ 0.15 kg do not apply and can be sited in any locations

Figure 23: Determination of maximum charge amount and room size for HC refrigerants



5.4 CHARGE SIZE REDUCTION

5.4.1 Introduction

The reduction of refrigerant charge mass is a very important consideration in the design and construction of systems using HC refrigerants. Assuming that all other factors are the same, a greater charge size results in a higher risk of ignition, and therefore a reduced refrigerant charge will achieve a higher level of safety for a system. There are additional benefits to be gained from smaller charge sizes, such as from a cost perspective; not only because less quantity of refrigerant is required, but a smaller internal volume normally corresponds to less construction material (i.e., metal). Furthermore, smaller charges can improve system efficiency by reducing cycling losses due to less mass of refrigerant to be redistributed and to achieve thermal equilibrium. Conversely, the main disadvantage of reducing charge size is that the performance of systems tends to be more sensitive to leakage, i.e., efficiency and capacity can degrade sooner as refrigerant is leaked out. Sometimes the stability of the system can be reduced, for example, when controlling evaporator superheat. It is important to carry out charge reduction commensurate with system performance optimisation, such that dual benefits are obtained, and one isn't achieved at detriment of the other.

Until recently, the approach of charge size reduction was not normally carried out in RAC industries, since there was no motivation to do it. This is a fairly new concept, and it is likely to become more of a focus as environmental and safety issues progress.[25]

5.4.2 General approach

The general approach to reducing the refrigerant charge can be addressed through three levels:

- Considering the application; that is external considerations that, for example, reduce heat load on the system or shorten pipe lengths
- Considering the system architecture; that is the system type, for example, the use of a direct expansion instead of a flooded system or an indirect system instead of a direct expansion system
- Considering the system component; that is the selection and design of, for example, heat exchangers, pipework and so on

For air conditioning systems, reduction of heat load is difficult to address, as this is often an independent issue. However, for refrigeration equipment, issues such as insulation thickness, electrical component efficiency and other such design aspects should be considered. In terms of system architecture, there are a variety of implications that may be relevant to the system charge size: whether it is direct, flooded or indirect system; single or multi-evaporator; single-stage, multi-stage or cascade system; integral or split type system. Depending upon the type and purpose of the system, other concepts should be considered. For example, to adopt an indirect system instead of a direct expansion or flooded type system can reduce the charge size by up to a factor of 10, whilst in some cases the use of an indirect circuit may not be practical, it may introduce significant additional costs or it may result in a reduction in system efficiency.

A common way of assessing the refrigerant charge within a system is through the "specific charge", which is the ratio of charged mass to the nominal cooling capacity. Generally, the specific charge – for a particular system design – varies according to nominal cooling capacity, and the application temperature (Figure 24). For an increase in cooling capacity the specific charge will lessen, due to the disproportionate change in internal volume for refrigerant-containing parts. For a given system (with a fixed charge), a lower evaporating temperature will coincide with a reduction in cooling capacity, thus the specific charge will be greater. In addition, systems that rely on longer pipe runs and that employ receivers will also have higher specific charges.

25 The reader is directed towards publications under the International Institute of Refrigeration, where several technical conferences specifically address the theme of minimisation of refrigerant charge (www.iifiir.org)

Figure 24: Illustration of how specific refrigerant charge may vary according to system cooling capacity and application temperature range

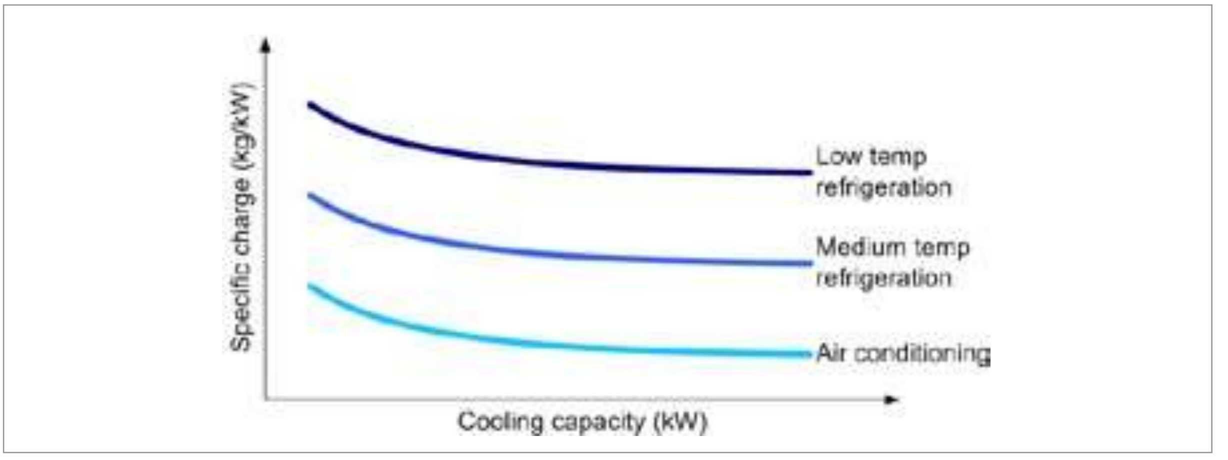
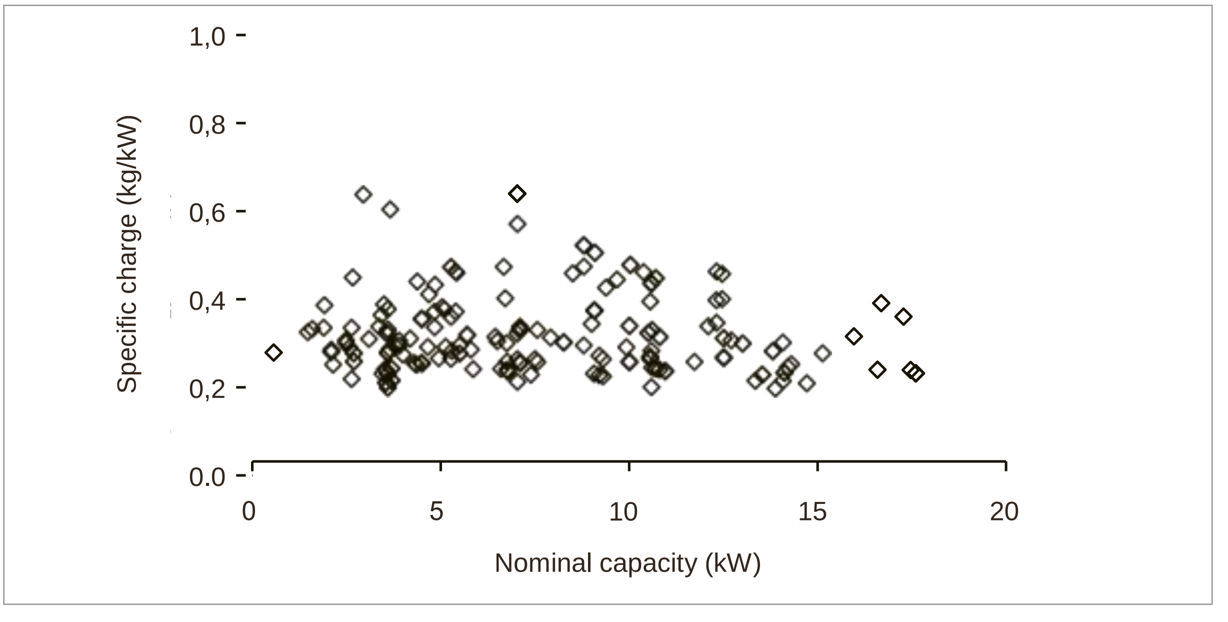


Figure 25 provides some data for split type air conditioners, using R22. This data set represents around 250 models from nine different manufacturers. It can be seen that for a given cooling capacity, some models use over three times as much refrigerant as some others. This example is useful for highlighting the potential for charge size reduction in such equipment.

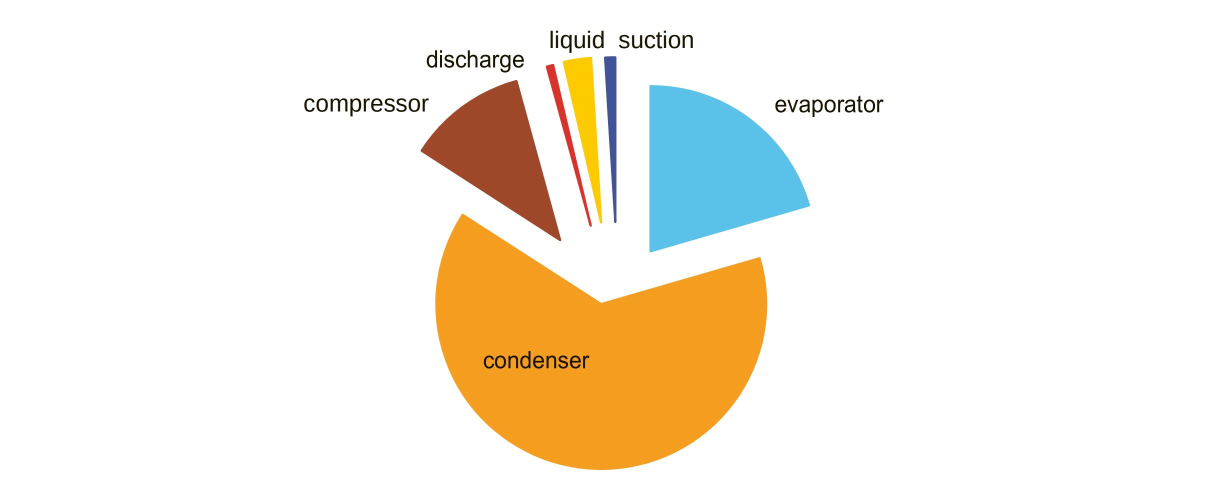
Figure 25: Variation in specific refrigerant charge for approximately 250 split air conditioners using R22, from nine different manufacturers



5.4.3 Consideration of individual components

It is useful to understand the typical distribution of refrigerant within systems, as it helps to identify the areas where charge minimisation work should be focussed. Figures 3 show a breakdown of refrigerant distribution amongst components for a split type air conditioner, although this is similar to, for example, window air conditioner, a small air conditioning chiller, commercial integral display cabinet and a commercial freezer cabinet. In general, it can be seen that the majority of the refrigerant is held within the condenser, compressor, evaporator and liquid line. In terms of component design the greatest potential for charge reduction is within the heat exchangers, and this should be the main focus.

Figure 26: Example distribution for refrigerant charge within a split air-conditioner



In carrying out the charge minimisation work, certain criteria should be adhered to: in particular, maintain the design cooling (or heating) capacity, and maintaining – or exceeding – the existing efficiency. Furthermore, it is important to consider the effect of charge variation on both cooling (or heating) capacity and system efficiency. This is a particular concern when dealing with systems that use capillary tubes, short-tube restrictors, and to a lesser extent, thermostatic expansion valves.

Compressors

Different types of compressors have a range of internal volumes, thus the quantity of refrigerant contained within the compressor will vary widely accordingly. For example, rotary, scroll and hermetic reciprocating types often have smaller internal volumes than, say open and semi-hermetic reciprocating and screw compressors. Typically, the refrigerant mainly occupies two regions within a compressor, being in low pressure vapour within the suction chamber and absorbed in the oil within the sump. Thus, in order to reduce refrigerant charge within the compressor, three options exist:

- Select a compressor with as small an internal volume as possible
- Reduce the in internal volume of the suction chamber
- Use a oil with low refrigerant solubility

In terms of selecting a compressor with a small internal volume, data can normally be supplied by compressor manufacturers. Reducing the internal volume of the compressor is obviously an activity for the compressor manufacturer rather than system designer. It should also be noted that if the internal volume is very small, there can be high pressure losses along the compressor flow path which would therefore be detrimental to performance, and may also negatively affect oil distribution within the crankcase. The oil can be a significant sink for refrigerant, so using an oil with a low solubility (with the refrigerant used) will absorb minimal quantities of refrigerant during operation. In particular, many mineral oils and polyol ester (POE) oils tend to hold more refrigerant than polyalkyl glycol (PAG) oils. Alkyl benzene (AB) and polyalpha olefins (PAO) oils have moderate solubilities. However, several oil producers provide lubricants optimised for HCs, which tend to have lower solubility. Ultimately, the choice of oil is typically more strongly dependent upon performance criteria, rather than for the purpose of charge reduction, and it is usually the choice of the compressor manufacturer as to which lubricant is used within a specific compressor.

Evaporators and condensers

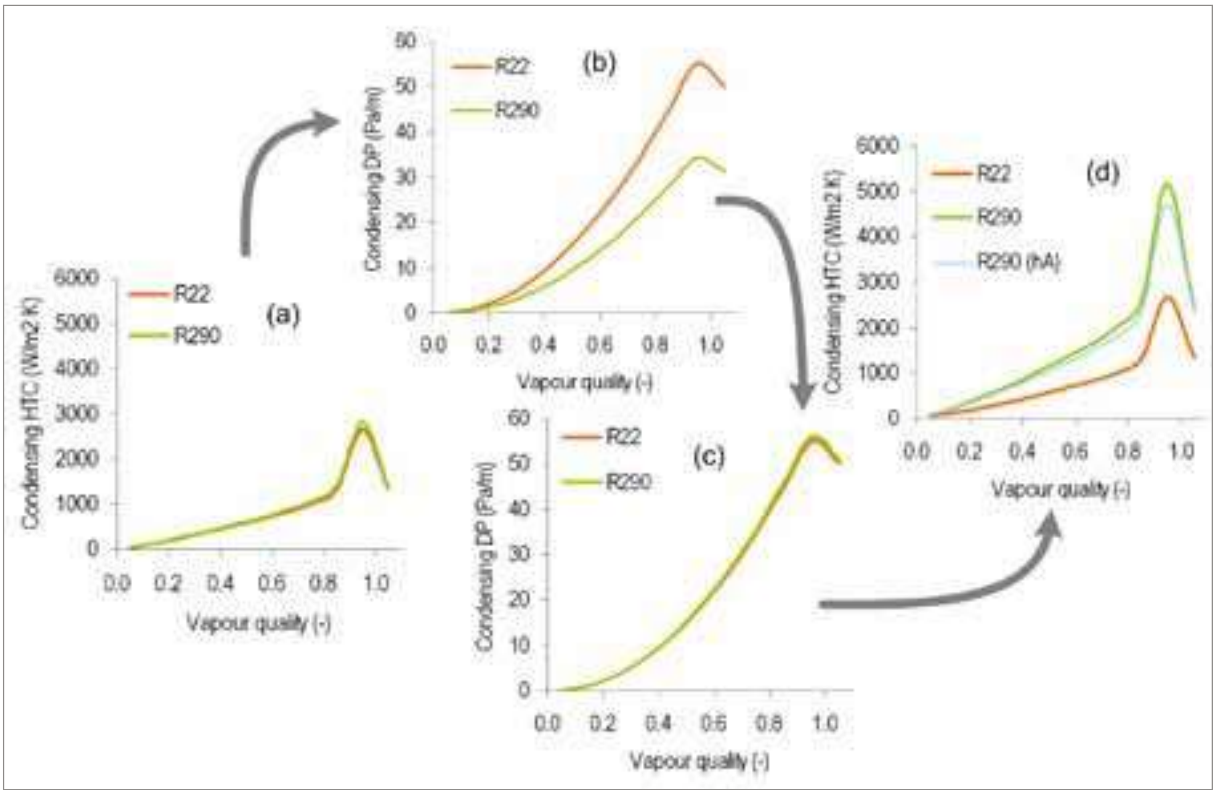
The choice of evaporator type and condenser has a major influence on the contained mass of refrigerant. Whilst the choice of exchanger type is limited because of the application (i.e., refrigerant-to-water, refrigerant-to-air, etc) it is still possible to address sub-types of heat exchanger and specific designs.

In the case of refrigerant-to-air heat exchangers, there is a choice of finned-tube type exchangers or micro-channel exchangers (where the small bore tubes are essentially within the fins). The latter can be more costly, although their use can dramatically reduce the charge, and also the total volume for the exchanger (for the same capacity and temperature difference) can be notably smaller. Halving the pipe diameter but doubling the length (to maintain surface area) will approximately halve the charge, thus, in general, a higher mass velocity will result in lower charge.

Conventional finned-tube coils can therefore be redesigned by reducing pipe diameter and increasing the number of circuits. Since the viscosity of HCs tends to be lower than that of the common HCFCs and HFCs, an incremental drop in the pipe diameter will often result in the same pressure loss; further reduction in diameter normally necessitate an increase in the number of circuits. Typically for the evaporator, only a moderate reduction in charge size may be achieved. However, adjusting the condenser design in this way can provide significant reductions in charge.

An illustration of such an approach is provided in Figure 27. Initially, the condensing heat transfer coefficient for R22 and R290 is shown for the same condenser coil (a). However, when comparing the pressure drop (b), it is seen that R290 is much lower. Therefore the pipe diameter of the pressure drop of the R290 coil matches that of the original R22 coil (c). Finally, comparing the subsequent heat transfer (d), it is seen that the value for R290 is about double that of R22. However, key benefit is that the refrigerant volume of the condenser has been halved and correspondingly the refrigerant mass.

Figure 27: Illustration of effect of advantageous reduction of tube diameter for R290 condenser



It is also appropriate to design the circuitry of the condenser so that the entire subcooling region is included within a single tube, to further enhance heat transfer in this single-phase region. Also with finned tubes, if it is possible the outside surface area should be increased, e.g., by more fins per unit length, as this allows for a smaller internal volume (or tube length), thus reducing charge. However, as with many other aspects, other factors pose limitations as to how closely fins can be spaced (for example, avoidance of excessive frosting or avoiding accumulation of debris within dusty environments).

A number of potential problems exist with lower charge finned tube and micro-channel exchangers, and it is worthwhile paying particular attention to these aspects:

- With micro-channels, the shorter circuits tend to inhibit condensate drainage, especially with single pass exchangers with common headers
- Frosting and defrosting is major problem because of the close proximity of the fins and tubes
- A large portion of the refrigerant can exist within the bends, tees and manifolds, thus a significant reduction in pipe diameter may not be as pronounced in the charge reduction of the overall heat exchanger
- The likelihood of internal fouling and mal-distribution of refrigerant are greater, similarly, problems with icing of moisture can also occur in evaporators
- When carrying out studies, and in particular modelling exercises to investigate the possibilities of smaller tubes, it is important to recognise that the pressure drop and heat transfer correlations usually employed for normal sized tube diameters, may not be applicable to very small tubes so more appropriate ones should be sought as well as experimental validation
- Within evaporators, there is a greater occurrence of boiling instability with smaller diameter tubes, resulting in intermittent variations in heat transfer coefficient, thus necessitating a larger than expected internal surface area to account for this phenomenon

For refrigerant-to-water heat exchangers, there is again a choice of different types: shell-and-tube, tube-and-shell, coaxial tube and plate heat exchanger types. Generally shell-and-tube exchangers (which have the refrigerant on the outside of the tubes) require very large quantities of refrigerant and are normally used for specific types of large systems. Tube-and-shell (where the refrigerant is inside the tubes) require smaller quantities of refrigerant. Wherever possible, it is preferable to employ plate type evaporators and condensers since these contain relatively small quantities of refrigerant, and in addition tend to be much lower cost. Different manufacturers offer plate exchangers of various designs, some of which require less charge than others. It is advisable to carry out a comparison of different products to identify the lower charge based on a given capacity.

It is also worthwhile considering the use of internally treated surfaces (such as the use of roughened surfaces, geometric enhancements, turbulators, etc) as these may also enable smaller tube bores whilst maintaining the desired heat transfer coefficients.

Lastly, it is always important to consider the implications of using "bought" heat exchangers and specially designed heat exchangers. Generally, a heat exchanger supplier may only be able to provide a limited number of designs, for example, in terms of the number of different pipe diameters, tube spacing, etc. This obviously limits the potential opportunities. However, if a company can offer to build any design required, this offers a greater scope for charge size reduction and associated optimisation.

Liquid, delivery, suction and discharge lines

The refrigerant mass contained within interconnecting pipework can vary widely between systems due to particular geometry and system layouts. It is reported that well selected piping can reduce charge by 15 – 40%, depending upon the particular system design. When using HC refrigerants, there are particular advantages compared to many other fluorinated refrigerants, such as R22, since the viscosity of HCs is lower. Thus for the same sized pipe, smaller pressure drops occur. This can be exploited by employing slightly smaller pipe diameters, which if done correctly, will reduce charge mass whilst not adversely affecting performance. Consideration of the liquid line can offer particular advantages. Since the volumetric flow within the liquid line is small (compared to vapour phase piping), smaller diameters can be used to significantly reduce the refrigerant mass. However, it is important that pressure drops are not allowed to increase too much, otherwise "flashing" of the liquid refrigerant can occur which is detrimental to system operation particularly in fittings. However, such problems can be overcome through the use of liquid pumps (usually applied to larger systems) or liquid-suction heat exchangers. If the system employs a reasonably long (two-phase) delivery line into the evaporator, similar benefits can be obtained with smaller diameters. In fact, it is possible to adopt this concept for liquid lines, i.e., to use “pre-expansion” where liquid exiting condenser is slightly expended, so that both liquid and vapour pass through liquid line, so that the vapour displaces what would normally be occupied by liquid. Lastly, it should be noted that – particularly for smaller systems – the course increments of standard refrigeration piping may not necessarily allow reductions in pipe sizes without increasing overall pressure drop.

Liquid receivers and suction accumulators

Liquid receivers may be located on the high pressure side, low pressure side or at intermediate pressure in a multi-stage system. They usually demand high additional quantities of refrigerant (often almost doubling the refrigerant charge), and therefore they can be avoided if possible. However, they are normally used for a specific reason, for example, where maintaining efficiency over a wide range of operating conditions or for pump-down cycles, in which case their use may be difficult to neglect. Alternatively a carefully designed larger condenser may be used as an alterative to the receiver, so that greater refrigerant charge can be avoided. If the receiver is absolutely necessary, it should be sized so that it can accommodate as necessary the maximum and minimum variation in liquid level, only. Furthermore, it is preferable to use vertically mounted (instead of horizontal) as these can be more precisely sized to accommodate the tolerances.

Suction accumulators are also generally used when a wide range of operating conditions is anticipated and capillary tube or short-tube restrictor is used in the system, to avoid liquid flooding to compressor. Although the accumulators may be fairly voluminous, because they contain superheated vapour the occupied charge mass is not as significant as a liquid receiver. However, notable reductions in charge size can be obtained by optimising the accumulator geometry; that is as small a volume as possible, whilst reducing velocity sufficiently to deposit liquid droplets.

5.5 SOURCES OF IGNITION AND METHODS OF AVOIDING IGNITION

5.5.1 Introduction

If refrigerant leaks from the system, there must be no potential sources of ignition (SOI) associated with the equipment that could ignite it. Potential SOI include:[26]

- A spark with energy > 20 mJ
- An open flame
- A hot surface > 450°C

Therefore precautions should be taken to avoid the possibility of direct sources of ignition such as excessively hot surfaces, electrical switches and exposed electrical contacts or coming into contact with any release of refrigerant within the system. This may be addressed in a number of different ways.

5.5.2 Hot surfaces

All parts of the equipment should be checked to ensure that the temperatures of any surfaces that may be exposed to leaked refrigerant do not exceed the auto-ignition temperature of the refrigerant, reduced by 100 K (see Table 24 in Appendix 4); this equates to about 350°C for most HCs. Unless the maximum surface temperature of a device (under uncontrolled conditions) is stated by the manufacturer, the temperature should be checked by testing. Such tests are specified in EN 60335-1, EN 60335-2-24, EN 60335-2-34, EN 60335-2-40, EN 60335-2-89 and EN 60204-1. In all of these standards, the tests follow the criteria:

26 A more extensive list of potential SOI to consider are: flames, hot gases, hot particles; mechanically generated sparks; electrical apparatus (electric circuits are opened and closed, loose connections, stray currents); static electricity; lightning; radio frequency electromagnetic waves (from 104 Hz to 3 x 1012 Hz); other Electromagnetic waves (from 3 x 1011 Hz to 3 x 1015 Hz); ionizing radiation; ultrasonics; adiabatic compression, shock waves; exothermic reactions, including self-ignition of dusts

- Temperature is measured continuously by thermocouples fixed on the exposed surface of the device
- Protective devices other than self-resetting thermal motor-protectors for motor-compressors must not operate, except those which are terminated by a non-self resetting protective device or by an intentionally weak part becoming permanently open-circuited
- When steady conditions are established, thermal motor protectors for motor-compressors must not operate
- If a control device is used which stops the defrosting at a given temperature or pressure, the defrosting period is automatically terminated when the control operates
- During the test sealing compound must not flow out

5.5.3 Electrical sources of ignition

Electrical components should be selected and/or positioned carefully. The RAC equipment must be constructed so that any leaked refrigerant will not flow or stagnate where electrical components, which could be a source of ignition (and which could function under normal conditions or in the event of a leak) are fitted. According to the relevant safety standards (EN 378, EN 60335-2-24, EN 60335-2-40, EN 60335-2-89) all electrical components that could act as a source of ignition under these conditions must comply with one of the following:[27]

- The component is constructed according to EN 60079-15 or IEC 60079-15 (for group IIA gases) complying to clauses 9 to 26
- The component is constructed according to EN 60079-15 or IEC 60079-15 (for group IIA gases) complying to
  - clauses 3 and 4
  - clauses 17 to 30
  - clause 31 for restricted dressing enclosures
  - clause 33.5.3.2 (here the test may also be used for enclosures larger than 100 cm^3)
- The component is located in an enclosure which complies with the requirements of EN 60079-15 for enclosures (suitable for use with group IIA gases)
- Any electrical components suitable for use in zone 2, 1 or 0 area as defined by IEC 60079-14
- The component is not located in an area where a potentially flammable mixture of refrigerant and air could accumulate; this is demonstrated by the leak simulation test described later

In addition, care should be taken to ensure that electrical terminals, including capacitor terminals are adequately tightened and secured against loosening and that adequate insulation is provided to avoid live parts shorting together. Similarly, electric motors must be of brushless design.

Whilst it is standard practice to earth all parts of an assembly (including housing and ancillary parts), it is critical to ensure that this is carried out comprehensively for equipment using flammable refrigerants.

5.5.4 Fan assemblies

For the case of fan assemblies, it may be possible for sparks to be created between the fan blades and the housing. Whilst the likelihood of sparks occurring is unlikely, it is ultimately the responsibility of the system designer to consider this issue. In general, the possibility of sparking due to mechanical impact is essentially negated provided that certain materials are avoided, and further the likelihood of impact is reduced by ensuring a minimum clearance distance between the parts. For general guidance, the following should be followed:

- The fan construction must be of rigid design, considering casings, supporting structures, guards, protective devices and other external parts, particularly if the deformation resulting from an impact is such that the moving parts do not come into contact with the casing

27 Refer to the specific standard for precise details

- Consideration should be given to the pairing of materials for the casing and fan blades, which if come into contact during operation may result in heat generated from friction or sparks arising from impact; in general
  - plastic materials for both pair is normally acceptable
  - plastic materials and any metal pair is normally acceptable
  - aluminium and aluminium or other metallic pairs are normally acceptable
  - stainless steel pairs must not be used
  - steel alloy and brass pairs must not be used
- If (non-aluminium) metallic pairs are used, chrome content should be less than 15% (to avoid sparking), rotational speed should be less than 40 m/s, and additional considerations are necessary is the shaft power is greater than 5.5 kW
- Paint containing aluminium or iron oxides must not be used because of the risk of sparks
- The fan must be fitted so as to avoid excessive vibration
- All metallic parts must be earthed
- The most important criterion is the clearance distance between the fan blades and the casing, which shall be at least 1% of the diameter and no less than 2 mm

When selecting a fan, its purpose should also be considered, and the level of protection chosen accordingly. For example, if the fan is used solely for circulating air, then the level of protection may not necessarily be very high, whereas if the purpose of the fan is specifically to exhaust a flammable concentration arising from a release of refrigerant, then the requirements must be appropriate for and meet the rules for use in hazardous atmospheres.

EXAMPLES OF POTENTIAL SOURCES OF IGNITION

The following electrical items should receive particular attention since they may provide direct electrical sources of ignition:

- manual switches
- liquid level switch
- condensate pump
- thermostats
- flow switches
- fan speed controllers
- pressure switches
- start relays
- programmable controllers
- potential relays
- defrost switches
- contactors, isolator switches
- universal relays
- time switches
- mini-circuit breakers
- oil differential switches
- thermal overloads
- fan delay switches

Providing such items only comprise solid state parts or have casings which are solid encapsulated or otherwise sealed to at least IP67 or are located externally to the casing of the refrigerant containing parts then the criteria of the test below are normally achieved.

5.5.5 Further considerations

Depending upon the approach used for avoiding sources of ignition, its integrity over the lifetime of the equipment must be considered. In particular:

- Sealed or enclosed components. A damaged component could be replaced by one of insufficient tightness, or after repairing a component in-place, the method of sealing may accidentally be spoiled. In addition, general wearing of a component, such as through weathering or corrosion may also render it unsafe according to the requirements of safety standards.
- Solid state components. Whilst such devices do not normally produce sparks, in the event of overloading or manufacturing defects, excessive temperatures may occur, arcing or even a naked flame.
- Specially positioned components. Employing the approach that uses testing to identify the positioning of potential sources of ignition in locations that will not experience flammable concentrations in the event of leakage are advisable since it avoids the potential complications highlighted above. However, it is important, firstly to ensure that the tests are conducted and analysed thoroughly since it is easy to make errors whilst carrying out this approach, and secondly that it is not possible for the same or similar component to be repositioned (to a more vulnerable location).
- Components inside confined spaces. Whilst certain safety standards permit the use of potential SOI inside confined spaces – such as refrigerated cabinets or chiller housing – provided that certain criteria are met, it is strongly recommended that this approach is avoided. Even if a number of features are put in place, and tests carried out, to prevent the refrigerant from entering a confined space and reaching a potential SOI, the consequence of ignition in such a location are much more severe than ignition occurring outside a confined space (see Part 5.8.7). Given the effects of ageing of components or the possibility of untrained technicians making unexpected modifications to equipment, it is highly advisable to eliminate all potential SOI from enclosed or confined spaces.

In addition to the above, it is also worth evaluating the potential for parts that are not normally considered, to be sources of ignition under failure scenarios. This may include electrical connections and terminals that may work loose and re-wirable fuses.

Whilst plugs and sockets for connecting equipment to mains supply may not necessarily be SOIs, there is a potential for them to be, especially if they are inadvertently separated. Whilst for smaller systems that have a relatively small charge size, this issue may not be of concern, for systems that use larger charge sizes and that may be serviced on site, it can be worth considering having the plus and sockets to conform to the following:

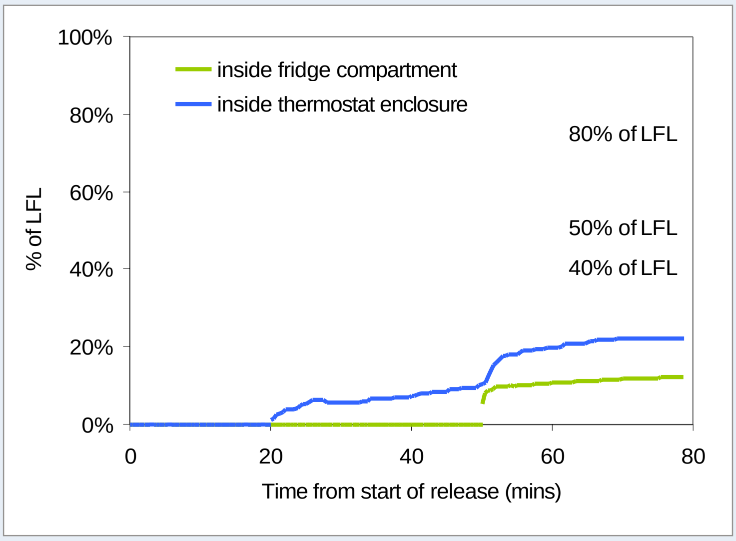
- Interlocked mechanically or electrically, or otherwise designed so that they cannot be separated when the contacts are energized and the contacts cannot be energized when plug and socket are separated.
- If they are allocated and connected to only one apparatus, they can be secured mechanically to prevent unintentional separation and the apparatus shall be marked with the warning – "WARNING – do not remove or replace fuse when energised", or "WARNING – do not separate when energised"

Similarly, plugs and sockets and similar connectors for internal connections require a minimum separating force of (at least 15 N) or they are prevented by mechanical means from loosening or separating.

It is also worth remarking on the presence of electrical arcs inside the refrigerating machine, particularly the compressor: it is known that for hermetic and semi-hermetic compressors, arcing will at times occur, however, the concentration of the refrigerant is (or should be) 100%, i.e., absent of air, or oxygen. Therefore, any arcing inside the system will not result in combustion. It should be noted that even in the event that there is an inward leak at the suction side of the compressor due to a sub-atmospheric evaporating pressure, a normal system will be unable to operate with even 5% air, let alone 90% (as would be required for ignition).

EXAMPLE OF LEAK SIMULATION TEST

The figure below shows the results of a leak simulation test on a thermostat enclosure within a refrigerated compartment. The method was as described in this Part: From an electronic balance-mounted cylinder within a water bath at 32°C, the R600a was injected at a "critical points" into the cabinet in the foamed area via a capillary tube. Sampling points connected to an infra-red gas analyser were positioned within the thermostat enclosure and another in the middle of the fridge compartment. 30 grams (being 80% of the nominal charge) of R600a was injected at each critical joint. According to the conditions, the release time was approximately seven minutes. During the first test from the first "critical point", a negligible amount of gas entered the compartment (data not shown as concentration <0.1% of LFL). The second test from the second "critical point" showed that there was a notable rise in gas concentration. However, it can be seen there is a delay between the time of the release and the build up of the gas – this is due to the gradual migration of the refrigerant through the foam within the wall of the cabinet. However, neither the concentration within the compartment, nor importantly, the concentration within the enclosure approached any of the minimum concentrations within the test criteria (i.e., 40%, 50% or 75% of the LFL). Thus, in this example, the thermostat enclosure is considered not be a potential source of ignition.



5.5.6 Leak simulation tests for potential sources of ignition

When HC refrigerants are employed, it may be necessary to carry out a test to determine whether electrical components are a potential source of ignition, which is applied to one sample of each refrigeration system. This type of test is described in most of the relevant standards, although there are some variations, depending upon what type of equipment the standard covers. The tests included in EN 378, EN 60335-2-24, EN 60335-2-40 and EN 60335-2-89 are detailed below. There is some deviation between the tests detailed in some of the standards, partly due to the characteristics of the equipment, and partly due to the disconnectedness in drafting the requirements. The general methodology is provided that applies to all tests, and the variations according to equipment type are identified within the Table 11. In general, there are two categories of equipment: refrigeration equipment for storage (e.g., domestic and commercial refrigerators, freezer, etc), and all other equipment. Although the test requirements for the former come from the standards that apply to domestic and commercial refrigeration appliances using up to 150 g of HC refrigerant, the test methods, from say EN 378 that apply to all other equipment, are not as suitable for refrigeration equipment for storage that uses larger charge sizes.

However, these tests are also sensitive to the design of the equipment (at the time of testing) and of course to the approach taken by those carrying out the work. Therefore, additional options are also provided below which will enable a more robust series of tests to be carried out.

When carrying out these tests, the test area should be constructed according to the requirements of, for example, the EU ATEX Directive and/or the requirements indicated by hazardous area standards, such as the IEC 60079 series. The installation should be approved by a competent body.

General test methodology

A refrigerant leak is simulated at a number of positions around the circuit that are considered to be "critical", i.e., points that a leakage is most probable, as discussed below. Throughout the test, the concentration of refrigerant is measured continuously at positions surrounding each potential source of ignition. The concentration of leaked refrigerant is measured at least every 30 s from the beginning of the test until completion, as close as possible to electrical components which, during normal operation or abnormal operation, produce sparks or arcs.

The existing protection – in whatever form – is considered to provide an acceptable level of resistance to the ingress of flammable refrigerant if the measurements demonstrate the following criteria are met:

- The concentration does not exceed 75% of the refrigerant LFL at any time[28]
- The concentration does not exceed 50% of the refrigerant LFL for more than 5 minutes, or the duration of the test if less than 5 minutes during and after the release quantity has been injected
- The measured refrigerant concentration surrounding a component that will not function during the pre-purge period may exceed the 75% of the LFL during this time[29]

The test is performed twice and is repeated a third time if one of the first tests gives more than 40% of the LFL.

PAY ATTENTION TO REFRIGERATED COMPARTMENTS

It is of highest importance to consider the use of electrical items and other potential sources of ignition within refrigerated compartments. This is because, if there is a leak into the compartment, it is very difficult for it to be dispersed, unlike if the leak is to the outside of the appliance where the refrigerant will normally disperse quickly. If refrigerant finds its way into the compartment it is likely to form a flammable concentration that could last for hours, days, or even weeks, and in the event of a failure of an electrical component, then the consequences can be severe. Therefore, follow certain rules:

- If at all possible, make sure no potential sources of ignition, even if they are protected, are not located within the compartment
- Make sure there is absolutely no way that refrigerant can migrate from the position of a leak hole in the refrigerant-containing parts, through the insulation, along the outside or within electrical cables, through "sealed" panels, and so on; carry out thorough testing to address all eventualities.
- Make sure that any form of sealing (for example, around cable entries, etc) is extremely reliable, such that it cannot be removed, it will not dissolve, carbonise or degrade in any other way over time; consider the extended lifetime of the equipment, i.e., 20 years or more.

28 It is recommended that 50% of the LFL is used throughout (instead of 75% specified within the standard) in order to be consistent with the requirements of EN/IEC 60079-15

29 It is also recommended that 50% of the LFL also be used here

The generally applicable conditions for the release are as follows:

- A critical point may be, but not limited to:
  - a joint in the refrigerant system tubing
  - a bend of more than 90°
  - some other position in the circuit that is considered to be weak due to the thickness of the metal,
  - exposure to damage, sharpness of a bend or the manufacturing process
  - aluminium to copper joints or other bi-metallic connections
  - gaskets or seals of compressors, valves or other components
- The release is made in vapour phase, injected through a suitable capillary tube, and care should be taken to ensure that the installation of the capillary tube does not notably influence the test results, for example, by foam or other substances entering the capillary tube
- The mass flow rate through the capillary tube is dependent upon the type of equipment being tested and that particular part under consideration
- During a test in which the appliance is operated, gas injection is started at the same time as the appliance is first switched on
- The release rate should be controlled and the released mass confirmed by measurement (preferably by weighing the cylinder); ensure that there is liquid remaining in the cylinder upon completion of the test
- Whenever tests are carried out with the equipment running under normal operation, this is done at the rated voltage
- The location must be draught-free, unless the draft is produced by the appliance
- The positioning of the refrigerating system and the refrigerant sampling equipment must not notably influence the test results
- If a blend refrigerant is used that can fractionate, the test results are evaluated considering the blend component that has the lowest LFL
- The equipment for measuring the refrigerant concentration should have a sufficiently rapid response to changes in concentration, typically 2 to 3 seconds
- If the measuring method is one that removes gas samples, then it must do so at a rate less than 4 ml per minute

Particular test conditions apply according to the type of equipment under consideration, as detailed Table 11. For equipment that has potential SOI both within an enclosed space and outside or on the shell of the equipment or in positions some distance from refrigerant containing parts, two or more sets of tests will need to be conducted depending upon each individual situation.

For refrigerated storage equipment, there are two categories: those with protected cooling systems and those with unprotected cooling systems.

Appliances with a protected cooling system are those:

- Without any part of the cooling system inside a food storage compartment
- Where any part of the cooling system which is located inside a storage compartment is constructed so that the refrigerant is contained within an enclosure with at least two layers of metallic materials separating the refrigerant from the storage compartment, each layer having a thickness of at least 0.1 mm, the enclosure has no joints other than the bonded seams of the evaporator where the bonded seam has a width of at least 6 mm
- Where any part of the cooling system which is located inside a storage compartment has the refrigerant contained in an enclosure which itself is contained within a separate protective enclosure, if leakage from the containing enclosure occurs, the leaked refrigerant is contained within the protective enclosure and the appliance will not function as in normal use
- The protective enclosure must also withstand a scratch test (as described in the relevant standards)

AWARENESS OF OWNERS AND OPERATORS

Depending upon the type and number of systems being installed, as well as the local circumstances, it may be necessary for the equipment owners and operators to be fully aware of the use of flammable refrigerants (for example, building and facilities managers). Sometimes the installation is such that additional work may be carried out that is somehow linked to or impacts on the refrigerating or air conditioning system that could compromise the intended level of safety. This particularly applies to situations where other parties unrelated to the cooling equipment are required to do work that necessitate tampering with the existing installation. If these contractors are unaware of the presence or implications of flammable refrigerants, then subsequent hazardous situations may arise. Therefore owners and operators need to be aware of any work that is to be carried out that falls into this category, and enlist assistance and advice from the relevant personnel who are competent with regard to the cooling systems. Situations that may pose a risk primarily include installation or modification to electrical equipment and electrical supplies that are linked to, or even located nearby, the refrigeration system, but even structural modifications to buildings, housings, etc. It is essential that where systems currently conform to safety requirements, the activities of other parties do not result in non-compliance.

Appliances with an unprotected cooling system are those:

- Where at least one part of the cooling system is placed inside a food storage compartment or those which do not comply with the requirements for protected cooling systems

Equipment may also be designed to employ a pre-purge system, where a fan is used to purge a particular space where potential SOIs may be present, but before they are energised. If such an approach is employed, then the design of the circuits must be fail-safe, that is, if the airflow cannot be proved, then the electrical circuit cannot be energised.

Table 11: Overview of the various test requirements for different types of equipment

Criterion	Refrigerated/freezer cabinets: Protected cooling system	Refrigerated/freezer cabinets: Unprotected cooling system	All other systems
Leak quantity	50% of the charge ±1.5 g		Total release amount is total nominal charge or the maximum quantity that leaks based on testing
☒ For components inside space	80% of the nominal refrigerant charge ± 1.5 g or the maximum that can be injected in 1 hour, whichever is the smaller	80% of the nominal charge of the refrigerant ± 1.5 g	
Leak rate	Constant rate over one hour		*Air conditioners, heat pumps, etc (up to 5 kg)*: Total release amount ±5% in four minutes *Other systems*: The total release amount at 0.0017 kg/s (100 g/min) per 1 m3 of internal volume of the equipment enclosure
☒ For components inside space	According to the release amount made through a capillary tube of diameter 0.7 mm ± 0.05 mm and a length of between 2 m and 3 m	Total release amount in time not exceeding 10 minutes	
Location of release	At the point of closest approach of critical points in the external parts of the cooling circuit		In the most unfavourable direction
☒ For components inside space	In the most unfavourable direction	Close as possible to the centre of the back wall of compartment, one-third of the height down	
Operating mode	Appliance switched off or operated under normal operation, whichever gives the least favourable result		Appliance switched off or operated under normal operation, whichever gives the least favourable result (unless a pre-purge is activated prior to energising any loads, in which case test is conducted whilst appliance is operating
☒For components inside space	Appliance is tested with doors and lids closed, and is switched off or operated under normal operation, whichever gives the more unfavourable result. During a test in which the appliance is operated, gas injection is started at the same time as the appliance is first switched on.	Two tests are carried out: (a) where 30 minutes after the injection is completed, the door or lid is opened at a uniform rate in a time between 2 s and 4 s, to an angle of 90° or to the maximum, whichever is less; (b) as with (a), except from the start the door or lid is subjected to an open/ close sequence at uniform rate of between 2 s and 4 s. For more than one door or lid, the less favourable sequence or combination of opening lids or doors is used. If fitted with fan motors the test is performed with the less favourable combination of motor operation	
Refrigerant cylinder temp	32 °C ± 2 K for leakage simulation on low-side pressure circuits, or 70 °C ± 2 K for leakage simulation on high-side pressure circuits		20 – 25°C
Test room size	Not specified		Volume ≥ 4 × M / LFL, height ≥ 2.2 m
Duration of test	Until the concentrations start to go down		Not stated (until the concentrations start to go down)
☒For components inside space	At least 1 h after injection of the gas has stopped	Until the concentrations start to go down	

Additional options

The test methods specified within the standards are based on the assumption that the condition of the equipment will remain as new, but this is obviously not the case. Activities such as transportation, poor quality service and maintenance, unanticipated component failures, unauthorised modification, re-installation and basic ageing processes can result in a loss of integrity of the original design and construction. Therefore, it is pertinent to increase the severity of the leak simulation tests in order to address these unknown possibilities.

Aspects to consider regarding the refrigerant release include:

- Assume that a leak could occur from any refrigerant-containing part, not only the "critical" points
- Simulate a leak occurring from a wide pipe diameter to represent a catastrophic pipe fracture
- Consider leaks emanating from ends and joins in pipe insulate where the refrigerant may travel to if the rupture is originally from an insulated part of the pipework
- Simulate liquid (or two-phase) leaks in addition to vapour leaks as these could also occur from a system
- Test release masses greater than that of the nominal charge, to simulate the case of an over-charged system, or where there is a release originating from refrigerant transfer hoses connected to a refrigerant cylinder
- Identify possible channels, ducts and cable sheathing that the refrigerant could possible pass through

Aspects to consider regarding the test room conditions:

- The rest room should be completely sealed so that the high concentration within the test space is not gradually diluted
- If the equipment may be installed inside and the possibility of it being located in a small space, then "soak" the entire piece of RAC equipment within a high concentration of refrigerant to simulate extreme conditions; this can be done over a long period of time (for at least one hour), both under still conditions and with a constant airflow within the room (average airspeed of around 0.2 m/s) to encourage ingress into parts of the equipment
- For confined compartments, such as completely or partially enclosed housings, storage spaces, etc, totally fill the volume with refrigerant; gaps and small openings can be covered with paper or film to simulate a severe situation
- Measure the gas concentration at more frequent intervals, such as at least every 10 s, since under turbulent airflow conditions, the gas concentration can vary erratically over very short intervals

Aspects to consider regarding the potential SOI:

- Measure the concentration of gas surrounding a component enclosure, rather than inside it, to account for it accidentally being replaced with a non-sealed enclosure
- Loosen or damage seals, openings or covers of enclosures to simulate the situation where the technician has not left the component in its original condition, or it has been subject to aggressive ageing
- Measure the concentration around solid state components in case of faults
- Remove seals around cable entries and grommets
- Measure concentration around other non-sparking components such as electrical connections and terminals that may work loose, or fuses that may blow

Other options to increase the severity of the test conditions should be sought, and in particular, they should be relevant to the particular characteristics of the equipment under consideration.

5.6 DESIGN OF SYSTEM INSTALLATION

5.6.1 Introduction

This section specifically addresses technical requirements for installing systems and equipment. It is focussed on the design and construction of the equipment, rather than installation practices of technicians.

The material represents a compilation of the requirements from several different standards, mainly EN 378, DIS ISO 5149, IEC 60225-2-24, IEC 60225-2-40, and IEC 60225-2-89. However, this only represents guidance and provides some explanation. In order to conform to a safety standard, the safety standard should be used. However, in absence of requirements within a national standard, the material here could be used in addition.

This section covers:

- Installation of systems inside (normally occupied spaces)
- Installations outside (both occupied and unoccupied locations)
- Machinery rooms
- Piping in general (for any location)
- Safety valves
- Gas detection
- Additional system safety concepts

5.6.2 General requirements for installation of systems inside

The main considerations for systems that are installed inside where non-competent persons may be present (i.e., occupancy categories A and B) relate to the size of the refrigerant charge. In particular, it must be ensured that the refrigerant charge of the individual circuits of the system do not exceed the charge size limits, as described in Part 5.3. The use of these charge size limits assumes that no additional requirements are necessary for the occupied spaces.

Nevertheless, for the installation and siting of equipment, consideration should also be given to the local environment, whereby obviously dangerous situations must be avoided. In this way, attention should be paid to the routing of pipework, location of exposed refrigerant-containing parts and major potential sources of ignition (such as open fires).

5.6.3 General requirements for installations outside

There are two situations to consider for outdoor installations to ensure against damage to the system and in the event of releases, undesirable consequences:

- where the equipment is located in an area accessible by members of the public, and
- where the equipment is located in a restricted area, with access to authorised persons only

In general, the installation should meet the following guidelines:

- All refrigerant-containing and other critical parts of the equipment must be protected from mechanical damage
- Equipment housing should be designed and constructed to be robust resistant to weathering and other forms of damage

- The equipment should be positioned at a certain distance away from items that may be negatively affected by a release of refrigerant, although this is done with consideration to the size of the refrigerant charge
- The equipment should be positioned so that there is always good free ventilation around all sides of the equipment, and it will not be inhibited by any permanent or temporary blockages
- The area should be free of combustible materials
- Consideration should be given to the presence of drains, etc, in case escaped refrigerants could pass into them
- Consideration should be given to the positioning of the equipment with regards to opening to other buildings, duct inlets, vents, etc

In particular, for equipment located in an area accessible by members of the public:

- The charge of individual refrigerant circuits should not exceed the values specified in Part 5.3
- The equipment housing should be designed to prevent or inhibit interference from others, possibly by including special access tools, locks or similar approach
- Consideration should be given to the positioning of the equipment with regards to areas where people may congregate

In particular, for equipment located in an area accessible only by authorised personnel:

- Access to the area should be controlled by the means of a fence or similar, which is locked
- The fencing or similar should provide good access to workers, and should preferably be at a radius of between 2 m to 5 m away from the equipment, depending upon the charge size and the design of the equipment

It is appropriate to designate some "safe" distance from refrigeration systems located outside, in order to minimise the possibility of flammable concentrations entering human occupied places (for example, through windows, ventilation openings, where people may be congregating outdoors, etc). In general, it is difficult to predict the maximum distance that a release of gas will remain above its LFL for an outdoors situation, particularly with small quantities (for example, below 100 kg)[30]. One approximation is to consider the maximum volume that may result following a catastrophic release of refrigerant. However, outside wind speeds tend to be fairly high (compared to indoor environments) even when the air seems "still", so the extent of the flammable mixture should also be adjusted to account for further dispersion provided by the surrounding air.

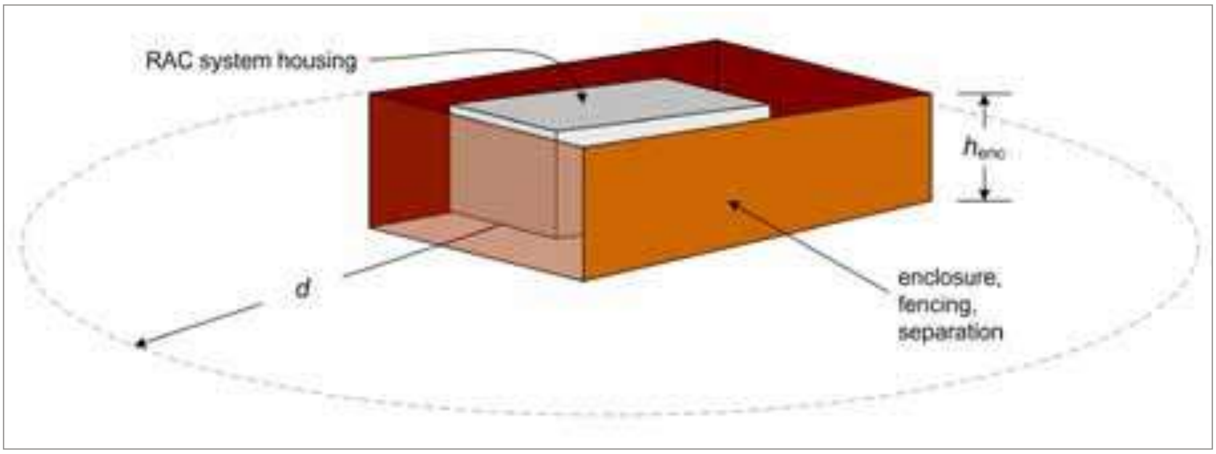
Using this approach, the minimum "safe" distance, d (m) may be approximated from equation (7), according to the situation illustrated in Figure 28.

$$d = c_w \times \sqrt{\frac{M_r}{\pi \, h_{enc} (LFL)}} \qquad (7)$$

where M is the refrigerant charge per individual circuit (kg) and h_{enc} is the height (m) of the enclosure or fence surrounding the system. Note that the distance of the fence from the unit is not particularly relevant (provided it is within the "safe" distance), and in the case that no fencing is present, the height of the unit housing may be used for the calculation. The constant C_W is a function of the local airflow conditions. For example, if the equipment is located in an area which is fairly sheltered, such as besides or between buildings, $C_W \approx 0.5$, whereas if the system is located in an exposed location, such as on a roof, $C_W \approx 0.25$. However, it is always necessary to assess the specific situation on a case-by-case basis.

30 Whilst gas dispersion models are widely available to study such situations, they are predominantly applicable to industrial-scale releases, and cannot be used for the situation under consideration here.

Figure 28: Indication of the "safe" distance from a refrigeration system



In addition, especially for equipment with large refrigerant charge sizes (say, above 25 kg per circuit), national regulations for the storage of flammable gases should be considered.

5.6.4 Machinery rooms

For systems, or parts of systems that are located within machinery rooms, certain rules apply. In general the machinery room must be located in accordance with local and national regulations, and must also conform to the general requirements of safety standards that apply to machinery rooms using any type of refrigerant.

When systems using HC refrigerants are located within machinery room, additional requirements must be addressed. These largely relate to the fact that a flammable concentration can be present and therefore all possible measures must be taken to avoid its ignition. In general:

- Where the risk of explosion may occur because it is possible for the concentration of refrigerant to reach the lower flammability limit, the installation should comply with the requirements for hazardous areas (for example, Ex-rated components and construction)
- There must be no source of ignition inside the machinery rooms (see Part 5.5)
- Combustion equipment must not be installed in the same machinery room as that containing an HC refrigerating system (for example, no boilers, etc) since these are SOIs
- All piping and ducting passing through walls, ceilings and floors must be tightly sealed so that leaked refrigerant cannot pass through into other enclosed or occupied areas
- Air intakes for any equipment must not be taken from within the machinery room
- Precautions must be taken so as to prevent leaked refrigerant that is denser than air entering into drainage systems
- Voids in the machinery room floor should be avoided, or designed so that heavier than air refrigerant could not accumulate in these spaces in the event of a leak

Consider that it may be possible to design the machinery room such that any release of flammable refrigerant is detected and a sequence of measures such as alarms, shutting down electrical supplies and use of extract ventilation, so as to avoid excessive use of explosion-proof components.

The machinery room should be designed and built specifically with consideration of the use of HC refrigerants. In particular:

- There must be direct access (doors) to the outside machinery rooms is the refrigerant charge in the equipment could result in a concentration higher than 20% of the LFL

- If the door does not open directly to the outside air then it should be through a dedicated vestibule equipped with self-closing, tight-fitting doors
- Have as large an open wall area as possible; ideally at least 50% of the area of one of the walls should be open, and preferably close to 100%, since this both encourages good dispersion the event of a release but also minimises the severity of the consequences in the event of ignition
- The open area may be fencing, grilles, etc, but should not pose any resistance to the free-flow of air
- If there is any less than 25% of the total (four walls plus ceiling) area that is not open, then some explosion relief must be provided if it is possible for the concentration of refrigerant to reach the LFL, so that if ignition does occur, only a particular part of the construction will fail or lift, and will do so in a "controlled" or intended manner, rather than uncontrolled damage to the building
- This explosion relief may be in the form of a frangible wall or roof, which should have very low mass and weak fixings, and should require a force of less than around 20 kPa to open

It is important to have open wall spaces in the machinery room for two purposes. First, free airflow to the outside will enable the dilution and removal of refrigerant in the event of a leak. Secondly, if a flammable concentration does occur, and it is ignited, then a large open area will reduce the possibility of a large overpressure developing and thus more likely to avoid severe consequences such as damage to people and property.

The access to the machinery room should be permitted for suitably trained, authorised persons only. Thus, the door should be locked and appropriate signage provided (although movement through the exit of the room must not be restricted).

Ideally, the area around the machinery room should meet the requirements for installations of equipment outside (see Part 5.6.3).

There must be an audible and visual alarm positioned inside and at least a visual alarm positioned outside the machinery room, close to its entrance. The alarm is be used to warn technicians inside the machinery room and those who may enter it from the outside.

In addition, the emergency exhaust ventilation must be used and should meet the following:

- The outlet from the exhaust ventilation must be in accordance with national regulations
- Emergency exhaust ventilation fan must be either (a) with the motor outside the airflow, or (b) rated for hazardous areas, since its purpose is to handle flammable atmospheres
- The fan must be located to avoid pressurisation of the exhaust ductwork in the machinery room, that is, it should "suck" and not "push"
- Fan motors and fan blades must not cause sparks to occur if it contacts the duct material (see Part 5.5.4)
- The outlet must not be restricted but means of keeping rubbish, leaves and birds from entering should be employed
- The bottom of any rising ductwork open to the outside must have a drain with a trap for rainwater and with access for inspection
- Discharge ducting must be positioned so that there is no risk of vented refrigerant entering other buildings in the area nearby, or re-entering the machinery room itself
- The exhaust duct discharge is best positioned at as high a position as possible, and pointed in several different directions so as to encourage better dispersion of the vented refrigerant
- The exhaust duct suction inlet points should be well positioned so as to ensure that good flow will occur over all the refrigerant-containing parts of the system and that no regions for stagnation could occur (see Figure 29)
- The inlet ducts or louvers should be balanced to ensure and even flow throughout

The ventilation rate is dependent upon the operating scheme, such that:

- If the machinery room contains absolutely no potential sources of ignition according to hazardous area standards, then the ventilation rate should be at least the greater of equation (8) and (9)

$$\dot{V}_{air} = 0.003 \times V_{Rm} \quad (8)$$

$$\dot{V}_{air} = 0.014 \times M^{2/3} \quad (9)$$

- If there are potential sources of ignition, which will be terminated in the event of a leak, then the ventilation rate must be at least according to equation (10) to ensure that even in the case of a major catastrophic leak, the refrigerant concentration within the machinery room should not exceed the LFL

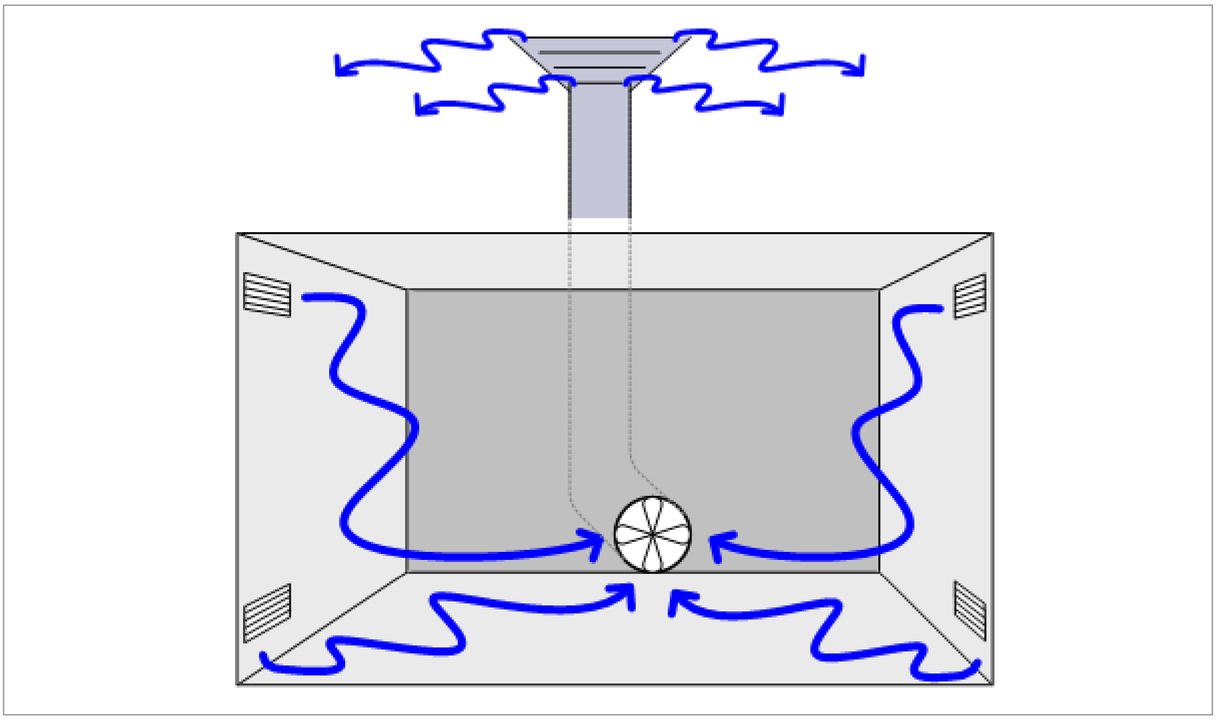
$$\dot{V}_{air} = \frac{0.004 \times M}{LFL} \quad (10)$$

- Under all circumstances, there should be a background ventilation rate of at least 4 air changes per hour available whenever the machinery room is occupied by technicians or other personnel, i.e., on constantly or initiated by (fail-safe) sensors

Again, where ventilation fans are used to ensure the discharge of a flammable atmosphere, the fan assembly should be suitable for hazardous areas. An emergency stop button (or buttons) must be provided in the machinery room (except for emergency mechanical ventilation), the action of which is to stop all refrigerating machinery. A remote switch must be provided outside and near to the machinery room door for isolating all electrical equipment not protected for use with HC refrigerants and for stopping all machinery.

Fire extinguishers are to be installed in accordance with local fire authority requirements and notices describing their correct usage be posted.

Figure 29: Suggestion for mechanical ventilation inlets and outlet for a machinery room



5.6.5 Ventilated enclosures

As mentioned in Part 5.3, the use of a ventilation enclosure may be employed so that larger refrigerant charges can be safely applied to occupied spaces. In general, the type of system must be either a fully indirect system, where all refrigerant containing parts are within the enclosure, or a partially indirect system, where refrigerant containing parts are ducted directly to the outside, as illustrated in Figure 30. In addition, the following applies:

- There must be absolutely no potential SOIs located within the enclosure or within the ventilation duct, specifically, they should be of a type that cannot be modified or accidentally exposed
- Ideally, as many electrical items as practicable, should be positioned on the outside of the enclosure
- The room within which the ventilation enclosure is installed should be at least ten times the volume of the enclosure; this is a largely arbitrary value, but the general idea is to avoid a flammable concentration developing within the room in the event that a leak occurs during servicing of the equipment, and to sufficiently relieve any overpressure that may develop in the event of ignition within the enclosure
- The room must also have sufficient air inlets to enable the make up of exhausted air, i.e., it must not be completely air tight
- The appliance must be designed so that it does not operate unless all of the access panels are securely fitted, such that refrigerant cannot enter the room
- The refrigerant-containing parts have to be isolated from the occupied space by the enclosure, such that in the event of a catastrophic release of refrigerant, none can migrate from the enclosure into the room
- The appliance enclosure must have a ventilation system that produces airflow from the appliance interior to the outside space, through sealed ducting, such that there is always a negative pressure within the enclosure
- The ventilation duct must also remain open so that if there is a leak of refrigerant and the fan is not operating (for some reason), then the majority of the refrigerant can migrate through the duct, in preference to any gaps in the enclosure walls

This negative pressure – which must be checked by measurement in the interior of the appliance enclosure – shall be 20 Pa or more and the flow rate to the exterior shall be at least 2 m³/h or greater, according to that specified by equation 11.

$$\dot{V}_{min} = 15 \times s \left(\frac{M_r}{\rho_r} \right) \tag{11}$$

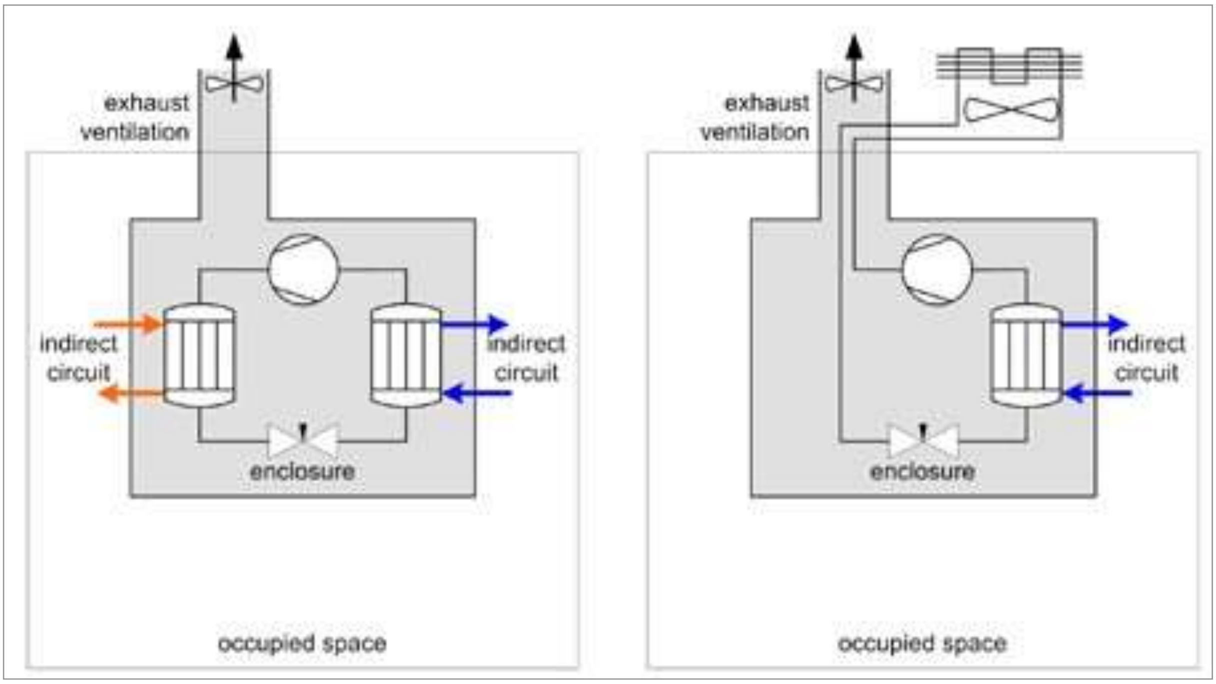
where V_{min} is the volume flow of the ventilation (m³/h), is a safety factor = 4, is the refrigerant charge mass (kg), and ρ_r is density of the refrigerant at atmospheric pressure at 25 °C (kg/m³) (see Table 8)

The ventilation system is to be operated as follows:

- The ventilation fan is operated permanently and the fan speed or air flow is monitored, and in case of failure the appliance or the compressor is switched off within 10 s, or
- The ventilation fan is switched on by a refrigerant detector at a value above 25 % of the LFL, and the detector has to be located at a suitable point according to the density of the refrigerant

This function must be tested to ensure it performs as intended. Further, it is essential that the detector, ventilation and differential pressure sensor function are checked at regular intervals, and any failure must be indicated and the system be switched in a safe mode. The manufacturer's instructions must contain these instructions, as well as a specification for the maximum length and size of the ventilation duct and the number of bends, so that the intended pressure drop is not exceeded.

Figure 30: Schematic diagram of options for ventilated enclosures



DEVELOPMENT OF A R290 ENCLOSURE FOR SUPERMARKET SYSTEMS

Various options may be considered for a supermarket refrigerating system, and one such approach is to adopt a special ventilated enclosure comprising the entire refrigerating system, which provides cooling to a secondary heat transfer circuit, which is fed into the sales area.†

The principle design approach for the refrigeration plant is for a self-contained system located within a gas-tight enclosure. By positioning the refrigerant-containing parts outside the property (e.g., on the roof top), many of the essential elements of the relevant regulations (i.e, the ATEX Directive) can be satisfied. Thus, particular attention is paid to the design of the enclosure so that when considering the rules for hazardous area, it is possible to use components which are not Ex-rated, thus being more cost efficient. In summary:

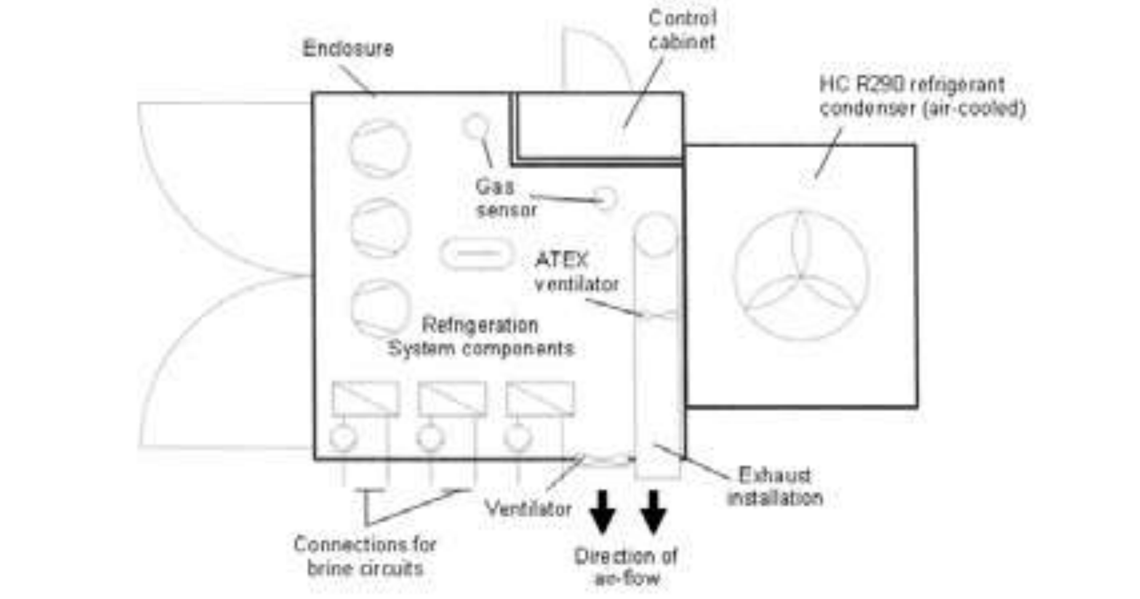
- All pipework, as connections between different circuit components, such as the heat exchanger, valves, pressure switch, control units, compressor, pumps, etc, are produced with brazed connections, thereby almost entirely excluding the possibility of leakage. All components and connecting lines are located within the enclosure.
- Since R290 is denser than air, it will collect at the bottom of the enclosure in case of leakage therefore the base is constructed as a leak-proof pan so that any releases will be held within the enclosure.
- Within the gas-tight enclosure, at least one gas sensor is positioned, where upon exceeding a pre-set concentration the gas sensor isolates the electricity supply from all electric components.
- There is an additional fan in the wall of the enclosure which also does not have to be Ex-rated; this fan ventilates the otherwise gas-proof enclosure to the ambient, primarily for the purpose of dissipating the heat arising from the system components (e.g., compressors).
- In the event of a release of refrigerant, the electricity supply to this additional fan is terminated, before the Ex-rated fan is initiated to exhaust any released refrigerant
- In addition, the electrical control cabinet within the enclosure that feeds the circuit components, is totally separated (by open ground) from the refrigeration plant – this total separation is necessary because in the case of an emergency, the control cabinet stays in operation.
- This remote cabinet also control the Ex-rated fan and other components in the area outside the enclosure, such as those associated with the secondary circuit.

A further advantage of this approach is that the machinery for the secondary circuit such as pumps, etc) are also mounted within the enclosure, which provides convenience in terms of versatile positioning and mounting of the entire assembly, only requiring coupling to the main lines of the secondary circuit following its installation. Also, since the entire refrigerating system is factory-sealed, there is no need for strength testing, tightness testing and charging on-site, thereby improving overall quality control and minimising the potential for errors.

† Lidl Germany has implemented the system; refer to the case study in Part 7 for further information

DEVELOPMENT OF A R290 ENCLOSURE FOR SUPERMARKET SYSTEMS

This figure shows the top-view of the enclosure of the refrigeration system in connection with control cabinet and air-cooled condenser.



5.6.6 Installation of pipework

When systems are installed inside, outside or in machinery rooms, there may be some additional pipework necessary, which is addressed by this section and applies equally to all situations. Also, the requirements for site-installed pipework are virtually identical to those for pipework in packaged equipment.

There are a number of general requirements for pipework used for any type of refrigerant, for which the relevant publications should be referred. Here, guidelines are provided specifically for piping for HC refrigerants:

- The installed piping must not present a hazard for persons and free passage in escape and access routes must not be restricted
- No valves and detachable joints must be located in areas accessible to the general public
- Inside occupied spaces, non-permanent joints are not allowed except in the case of split units where site made joints directly connecting the indoor unit to piping may be permitted
- Any brazed, welded, or mechanical connections must be completed before opening the valves to permit refrigerant to flow between the refrigerating system parts
- An access valve must be provided in the system to evacuate the interconnecting pipe and/or any uncharged refrigerating system part, if at least one part of the system is pre-charged and should whenever possible be located outside
- Flared connections should not be used, but where absolutely necessary flared joints should be restricted to use with annealed piping and to pipe sizes not exceeding 19 mm and not less than 9 mm outside diameter, and to locations where the joints remain exposed for visual inspection
- Refrigerant tubing and flexible connectors must be protected or enclosed to avoid mechanical damage
- Low temperature solder alloys, such as lead/tin alloys, are not acceptable for pipe connections
- If piping passes through service ducts, walkways and crawl spaces, they must be vented to a safe place to prevent a dangerous accumulation, that is, if the concentration could exceed the LFL

- Channels or ducts should contain no electrical wiring or potential ignition sources
- Where piping passes through occupied spaces, the maximum permissible charge of refrigerant must not exceed the allowable refrigerant charge (see Part 5.3), or if the charge size of the system exceeds 1.5 kg of refrigerant, the system pipework must not pass through occupied spaces
- It is possible to pass pipework through ventilated conduit so that if there is a leak of refrigerant, then it will pass along the conduit into the outside; in this case the conduit must be rigid, tightly sealed, continuous, fire resistant and sufficiently protected from external mechanical damage from disconnection and it must not be possible for others to alter or affect it in any other way
- Refrigerant piping must not be located in lift wells, public lobbies, hallways, stairways, stairway landings, entrances or exits, apart from the following exceptions, unless the piping has no mechanical joints, valves, or controls therein and are protected and accidental damage
- Marking should be applied to pipework or insulation to indicate the presence of flammable gas

Specifically in terms of piping from pressure relief devices or piping that contains refrigerant charging points:

- Piping from pressure relief devices must be discharged to a safe place
- If the discharge is to atmosphere, refrigerant must be vented via a correctly sized pipe (as required in the relevant standards), and at sufficient height to prevent local hazards, including the possibility of ignition of the discharge vapour; the use of equation (7) (see Part 5.6.3) may be used to estimate the safe distance
- Marking to indicate the presence of flammable gas must be placed on relief vent outlets
- Where reasonably practicable, charging points for refrigeration systems containing more than 1.5 kg of HC refrigerant shall be in the open air
- Marking to warn of the presence of flammable refrigerant should also be applied to charging points

Care has to be taken to exclude HC refrigerants where any welding or brazing is to be undertaken. This can be achieved by recovering refrigerant and purging the pipe section with oxygen-free dry nitrogen (OFDN). Further guidance for technicians installing pipework and components for HC systems can be found in Part 6.

5.6.7 Indirect or secondary systems

When HC refrigerants are used within indirect circuits, release of the refrigerant into the areas served by the secondary heat transfer fluid (due to leakage through the evaporator or condenser wall into the secondary circuit) must be prevented. This may be achieved by implementing at least one of the following options:

- Use an automatic air/refrigerant separator, within the secondary circuit on the outlet pipe from the evaporator or the condenser and must be at a higher level relative to the heat exchanger; the air/ refrigerant separator must have a flow rating and be rated to discharge the refrigerant that can be released through the heat exchanger, and it must discharge refrigerant into the vented unit housing, specially constructed machinery room, or outside air, or
- Use a double wall heat exchanger, between the primary and the secondary circuit, in order to avoid refrigerant leakage into the secondary circuit, or
- Use a design that ensures that the pressure of the secondary circuit is always greater than the pressure of the primary circuit in the area of contact (such as a high-pressure HTF), or
- Use a double indirect system

In general, where the quantity of refrigerant exceeds 25 kg, measures should be taken to detect the presence of refrigerant in any associated circuit containing a heat transferring fluid, for example, by means of a gas detector.

5.6.8 Use of pressure safety devices

Certain devices are sometimes required to control the pressure within the system in the event of a failure. The handling of pressure in this respect is the same for HCs as with any other refrigerant, and therefore dedicated guidelines on these matters should be referred to. However, the requirements for HCs tend to be slightly different and more restrictive than for non-flammable refrigerants, so a summary is provided here.

In general, the need for safety devices – such as pressure relief valve (PRV) and pressure limiting switches – is a function of the size of the system and the upper pressures it may possibly develop, as well as other mechanical features of the equipment.

Determining appropriate means of protection
As mentioned for PRVs and pressure limiting devices, Figure 31 should be used to determine the minimum means of protection against excessive pressure. This requires up to three parameters to be identified:

- Maximum allowable pressure (PS)
- Pressure equipment category (PE)
- Results of an intrinsic safety test

A summary of the required procedures is detailed below.

Maximum allowable pressure

The design pressures for refrigerating system components and the assembly shall not be less than the maximum allowable pressure (PS) for the system. The PS shall not be less than the saturation pressures of the refrigerant corresponding to specific designated temperatures, which are normally based on a design ambient temperature (particular to the local climate), the part of the system and the type of condenser. For example:

- The high pressure side of a system with air cooled condenser, PS should correspond to around 13 K above the design ambient temperature
- The high pressure side of a system with a water cooled condenser or hot water heat pump, PS should correspond to the maximum leaving water temperature plus 8 K
- The high pressure side of a system with an evaporative condenser, PS should correspond to around 11 K above the design ambient temperature
- The low pressure side of a system, PS should correspond to the design ambient temperature
- The low pressure side of a system with a heat exchanger exposed to indoor ambient temperature only, PS should correspond to the indoor design temperature

Pressure equipment category [31]

The pressure equipment (PE) category requires a category to be obtained for each of the components within the system and the highest provides the PE category for the entire assembly. The basic methodology is as follows:

- For each component, identify whether it is a vessel (such as an accumulator, a compressors, a received, etc) or piping (a pipe, a valve, etc)
- If the component is a vessel, find the volume (in litres), or if it is piping, the nominal diameter (DN, in mm)
- Find the PS, which should normally be based on the PS value of the entire assembly
- If the component is a vessel, calculate the product of PS × volume, or if it is piping, the product of PS × DN
- Use Table 12 to determine the PE category

31 This is the approach defined within the European Pressure Equipment Directive (PED) (97/23/EC)

The highest PE category for any one component is normally the PE category allocated to the entire assembly.

Table 12: Identification of PE Category for HC systems using small sized vessels and piping

Type	PS (bar)	Vessel	Piping	Vessel	Piping	PE Category
		V (litres)	DN (mm)	PS × V	PS × DN	
if	and	and	and	and	and	then
Vessel	>0.5 & ≤ 200	≤1	-	-	-	< I
		>1	-	≤25	-	< I
				>25 & ≤50	-	I
				>50 & ≤200	-	II
Piping	>0.5	-	≤25	-	-	< I
			>25 & ≤100	-	≤250	I
			>100 & ≤250	-	>100 & ≤3500	II

Requirements for intrinsic safety test

This test is only applicable for equipment as indicated in Figure 31. It is primarily used for determination of the maximum pressure during abnormal operation, and both the high pressure side and the low pressure side are evaluated.

For determination of the pressure at the high pressure side, the heat exchanger at the high pressure side of the refrigeration system is subjected to following test:

- The system is installed taking into account the instructions of the manufacturer
- The system is operated at an ambient temperature of 23°C ± 5 K
- When steady conditions are attained, the flow of the heat transfer medium (e.g., air, water) to the high pressure side heat exchanger is restricted or shut off, whichever is the most unfavourable without the refrigeration system being non-operative (and if the refrigeration system is equipped with external heaters, they must be activated)

The highest pressure that occurred during this test is recorded.

For determination of the pressure at the low pressure side, the heat exchanger at the high pressure side of the refrigeration system is subjected to following test:

- The system is installed taking into account the instructions of the manufacturer
- The refrigeration system is not operated in order to simulate standstill conditions
- The temperature of the heat transfer medium (e.g., air, water, etc) to the low pressure side heat exchanger is maintained at the maximum temperature specified by the manufacturer for 30 min (if the medium is a liquid) or 60 min (if the medium is air)

The highest pressure that occurred during this test is recorded.

A hydrostatic strength pressure test is then carried out on 3 samples of each component and joints, or on the assembly as a total, at a pressure of 3 times the recorded pressure for the respective parts of the system. Alternatively other equivalent tests (such as burst test) may be used. The acceptance criterion is that the component or assembly under test shall not rupture.

Pressure relief valves

PRV are needed in the event of abnormal operation or an external fire to prevent the build-up of excessive pressure and subsequent pressure blast. The situation that necessitates a pressure limiting device for systems can be determined from Figure 31. Standard literature should be referred to for the selection and sizing of PRV, as well as the discharge line sizing as the same rules apply to all refrigerants. When used, the settings for the PRV must be according to:

- Pressure relief device setting: 1.0 × PS
- Pressure relief device that achieves the flow at 1.1 × PS: ≤ 1.1 × PS

Discharge from pressure relief devices can only take place so that persons and property are not endangered by the released refrigerant. An indication device is required to check during maintenance whether the relief valves have discharged to atmosphere.

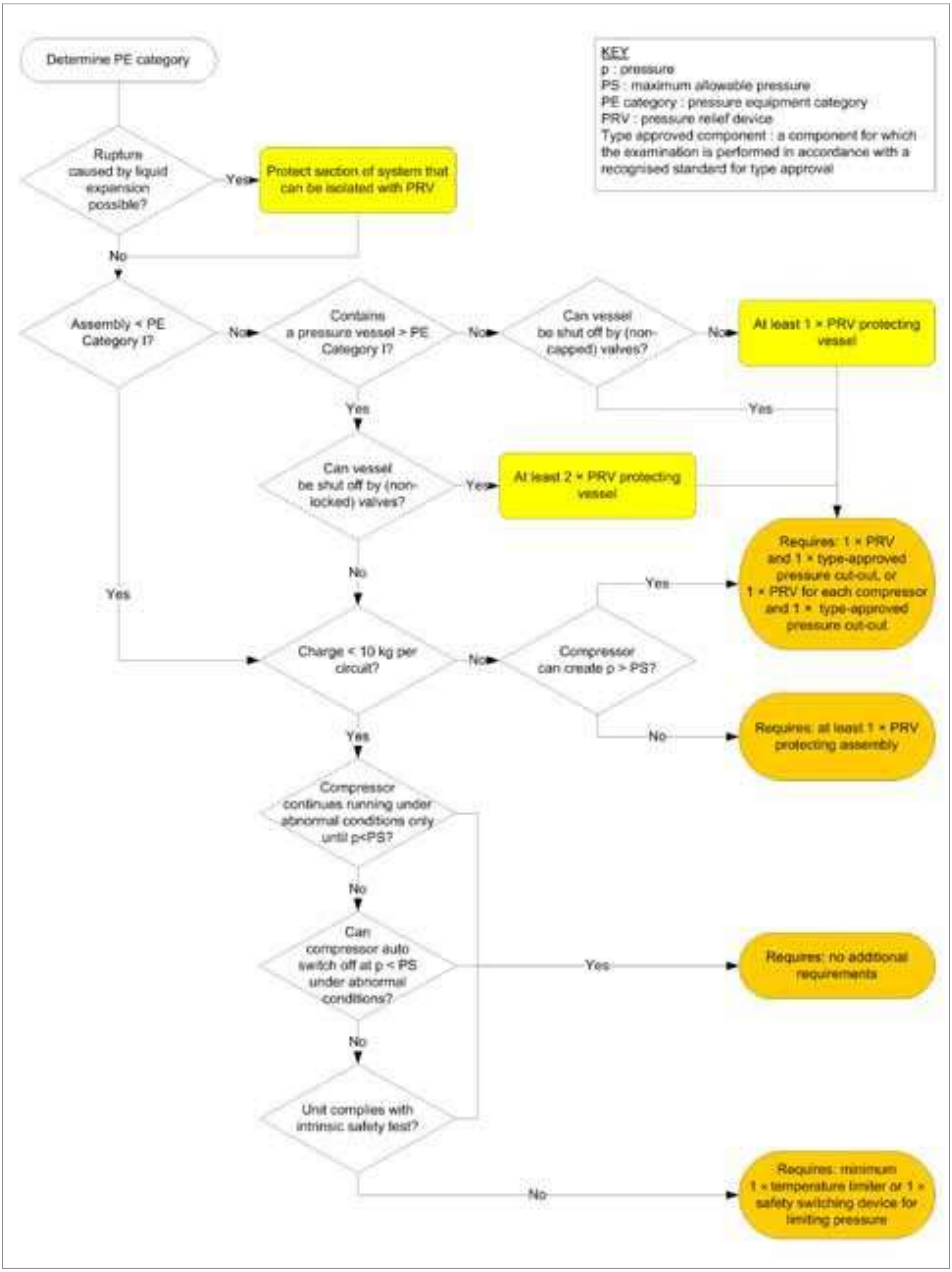
Pressure limiting devices

Larger systems are normally provided with a pressure limiting device (high pressure cut-out switch), although the situation that necessitates their use is indicated in Figure 31. The high pressure cut-out shall be of the manual reset type, set to operate at the following pressures:

- Safety switching device for limiting the pressure for systems with relief device: ≤ 0.9 × PS
- Safety switching device for limiting the pressure for systems without relief device: ≤ 1.0 × PS

If used for protection of the refrigerating system against excessive pressure, they must not be used for control purposes; if a high-pressure switch is used for control purposes, a separate device must be fitted in addition, and the relevant marking applied.

Figure 31: Flow chart for determining the appropriate means of protection against excessive pressure



Temperature limiting device

Under certain circumstances a temperature limiting device may be used; this is a safety switching device which is approved and designed to fail-safe so that in the event of a defect or malfunction of the device, the power will be interrupted.

Fusible plugs and busting/rupture discs

In isolation, fusible plugs or bursting/rupture discs must not be used with HC refrigerants since once they melt, they will release the entire refrigerant charge, which is not desirable. However, they may be used in series with pressure relief valves. This has two benefits – first it helps to prevent leakage through the PRV seal, and second, it provides an indication that the PRV has lifted which helps to bring attention to the fact that the system may have a problem.

Arrangement of pressure indicators

For systems containing more than 1.0 kg of refrigerant, connections for pressure indicators must be provided (the fitting of permanent pressure indicators is optional). Where the refrigerant charge exceeds 2.5 kg refrigerant, the system should be equipped with pressure indicators on each pressure side of the system (including intermediate pressure stages). It should be noted that although this is specified within safety standards, the logic for doing this is not evident. For example, most systems do not indicate a loss of refrigerant via pressure unless they are extremely low in charge, and furthermore, the addition of more fittings increases the possibility of leakage.

Level indicators on refrigerant receivers

Refrigerant receivers in systems containing more than 2.5 kg of refrigerant and which can be isolated should be provided with a liquid level indicator to show at least the maximum liquid level. On occasions where liquid receivers are used, an indicator can be useful anyway to alert of a loss of refrigerant.

5.6.9 Fixed refrigerant detection[32]

Usually, machinery rooms must be installed with an appropriate safety system that comprises gas detection, ventilation equipment and alarms. In addition to machinery rooms, there may be other situations where permanent refrigerant detection may be employed. In general, the detectors should meet the following:[33]

- Permanently installed, and preferably multi-point sensing detectors must be fitted to satisfy safety requirement and alert the user or operator to the presence of leaked refrigerant
- The detector(s) should be reliable (less than 5% drift per year) and accurate (within ±3% of LFL) and should not be affected by other substances present in the machinery room or elsewhere
- They should have a rapid response time, for example, < 5 s at 25% of LFL
- Whilst some electronic detectors can be 'tuned' so that they react only to a single substance, others cannot discriminate between refrigerant and volatile compounds such as cleaning fluids or solvents; some electronic detectors can give false readings if they are contaminated with certain chemicals.
- They should be installed strategically so that they cannot be inadvertently damaged, and should be easy to maintain
- Detectors may be used to initiate the isolation of electrical equipment that does not conform to the relevant requirements (see Part 5.4) before the refrigerant reaches the Practical Limit
- The detector(s) have to function at a level not exceeding 20% of the LFL, and then automatically activate an alarm, start mechanical ventilation and stop the refrigerating system when it triggers
- The detector(s) must continue to function at higher concentrations, and may be used to activate further alarms and increase the flow rate of exhaust ventilation upon detection of higher concentrations

32 Note that fixed refrigerant or gas detection systems are not "leak detection", they simply observe the presence of a gas at a particular location, and must not be assumed to provide any indication that a leak has not occurred.

33 See http://www.hse.gov.uk/pubns/gasdetector.pdf for further guidance on selecting gas detectors

- Detector sampling points should be located so that they provide rapid signals in the event of a leak, and that the effect of air movement does not inhibit their effectiveness; where the refrigerant is heavier than air (as is the case with most HC refrigerants), sampling points must be located at floor level
- A single detector sampling point can normally cover an area of about 30 m² provided it is mounted at floor level
- Detectors must be calibrated for the specific refrigerant they are intended to detect; be aware that certain types of detectors (such as corona discharge) may not necessarily be suitable for flammable gases if the head has not be designed correctly, so ensure that the correct types is selected

Detectors with as fast a response time as possible should be used. Nevertheless, it should be noted that it could take many seconds or even minutes for a high concentration of refrigerant to be transmitted by a gas detector. Thus, it cannot be assumed that a gas detector will instantaneously initiate emergency ventilation – this needs to be taken into consideration when designing safety response mechanisms.

Where gas detection is used, robust maintenance and calibration schemes must be put in place. All types of gas detection are known to drift and can become contaminated over time and therefore become ineffective after moderate periods of time. The effectiveness of a detection and emergency system is only as good as the maintenance regime.

In addition to conventional gas detection methods, other means should be employed where appropriate to assist with the identification of a leak. The following may be considered:

- Charge level indication, which is a means of determining whether the system is correctly charged with refrigerant
- Whilst factory charged systems which have few breakable joints may not require visual indicators, any system which is likely to need occasional service access to circuit components should be fitted with a liquid line sight glass
- For larger systems which would otherwise use gauge glasses, seal-less level indicators using magnetic or inductive or capacitive sensors should be preferred

5.6.10 Integration of system safety concepts

In principle, the initial approach to improving the level of safety of the equipment should be to optimise the design so as to minimise the concentration in the event of a catastrophic release. This can be achieved through a number of different design considerations, such as reducing refrigerant charge size as much as possible, positioning refrigerant-containing parts as a high a level as possible, and adjusting the design so as to increase air speed to help disperse a release. (These aspects are addressed in more detail in Parts 5.4, 5.8.5 and 5.8.6.) Appropriate correlations can be employed to identify which parameters can be used to reduce the concentrations for a particular construction.

Depending upon the type of system and the environment within which it is installed, it may be possible to incorporate additional safety concepts in order to reduce the quantity of refrigerant released, or to disperse the refrigerant so as to ensure a lower concentration. There are normally two aspects to this approach: first a sensing method to identify a potential problem, and second, an action to try to mitigate the problem. In practical terms these correspond to a means of recognising the release of refrigerant, and then an action to reduce the quantity of refrigerant that could be leaked out, or to prevent the accumulation of a flammable cloud. Table 13 includes a number of example combinations.

Table 13: Example sensing methods and preventative actions and indication of effectiveness

Action	Sensing method			
	Gas detection	Pressure switch	Parameter algorithm	Liquid level sensor
Initiate extract ventilation	✓✓✓	✓	✓✓✓	✓
Initiate/continue unit airflow	✓✓	✓	✓✓	✓
Redirect dampers (ducted system)	✓✓	✓	✓✓	✓
Shut down electrical feed	✓	✓	✓	✓
Close solenoid shut-off valves	✓✓✓	✓	✓✓✓	✓
Activate by-pass valve	✓✓	✓	✓✓	✓
Terminate compressor	✓✓	✓	✓✓	✓

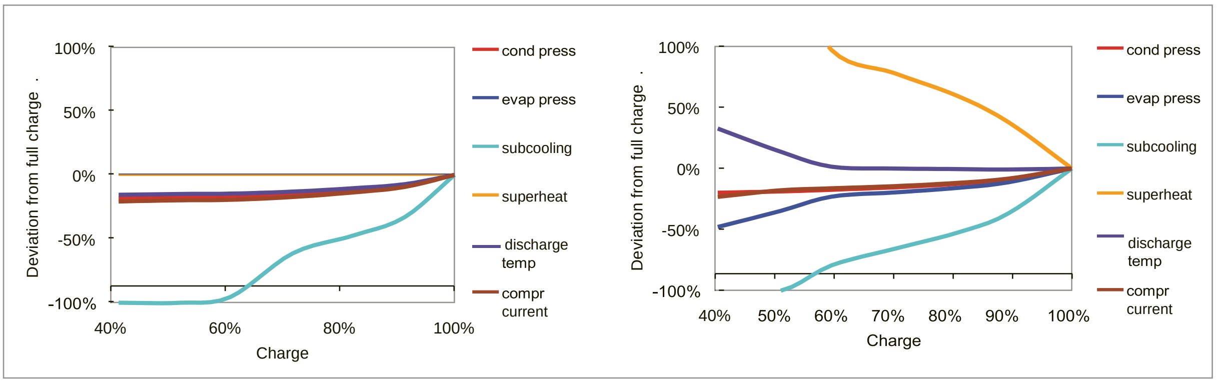
Sensing methods

The main sensing methods are described as follows:

- Gas detection: a gas detector is used to recognise a release of refrigerant. However, this type of approach must be used with care, since, particularly in certain occupancies, the detector may get damaged if not protected well or may be subject to nuisance signals arising from other sources that are present in the space. Similarly, it is important that the sensor is positioned in the optimum location in order to have the highest likelihood of sensing the highest concentration within as short a time period as possible. Furthermore, most types of gas detectors require recalibration over time, which may not be practical in certain situations.
- Pressure switch: a pressure switch may be used to provide an indication of a possible loss of refrigerant. However, the effectiveness is dependent upon the type of system, and is also sensitive to other conditions, such as the outside temperature or indoor set-point, system pull-down, and so on. This is not normally a particularly reliable method, so testing of the mechanism over the anticipated ranges of operating and environmental conditions is necessary.
- System parameter algorithm: it is possible to characterise the performance of the system – through parameters such as saturation pressures and temperatures and compressor current – to identify the deficit of charge, irrespective of environmental or other operating conditions. For example, the change in condensing pressure and compressor current for a given outside temperature. This can be fairly reliable, provided that the effects of ageing on the performance of the system are taken into account, and that the response time is rapid with respect to the time scale for a catastrophic refrigerant leak. Figure 32 shows how selected system parameters vary with a reduced charge, for a system using a thermostatic expansion valve and for a system using a capillary tube.
- Liquid level sensor: For systems with receivers, there will be no variation in most system performance parameters as the refrigerant until sufficient refrigerant has been leaked out to empty the receiver; depending upon the size of the received and the initial charge level, this could account for a large portion of the charge size. For these types of systems, use of devices such as liquid level sensors within a receiver may be used to identify a reduction in refrigerant quantity, although the change in receiver level will also vary with operating conditions which must be taken into account.

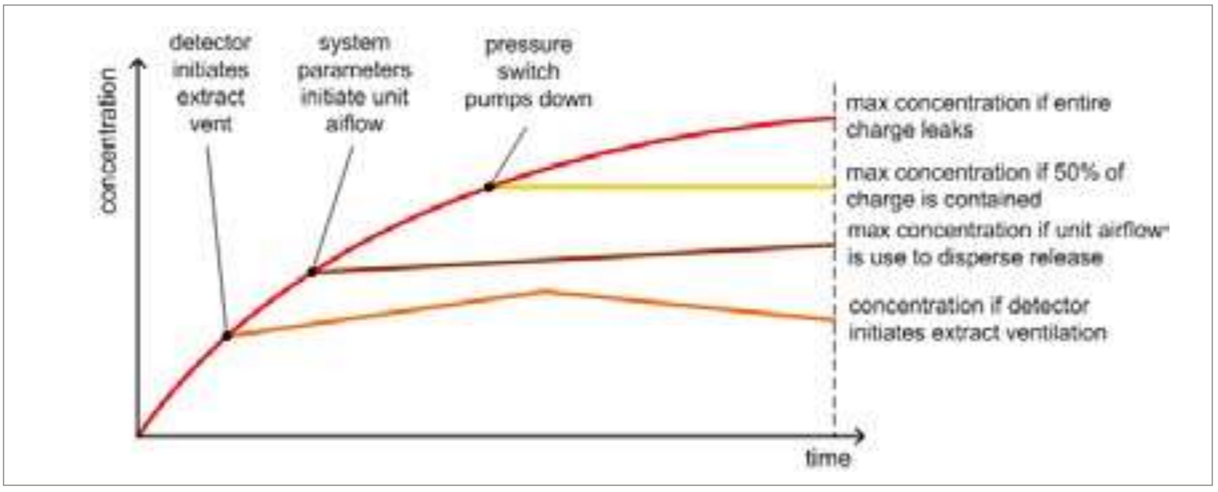
In addition, there are certain other means of indicating a loss of refrigerant, such as flow meter type devices used to identify the presence of bubbles in the liquid line.[34]

Figure 32: Effect of reduction in refrigerant charge on selected system parameters, for a system with a thermostatic expansion device (left) and a system with a capillary tube (right) based on 35°C outside temperature



The sensing method should be used to produce an action that helps to minimise the amount of refrigerant released, or reduce the concentration of the released refrigerant or both. Figure 33 illustrates the effects of certain combinations. In the first case, if a leak occurs with no further action, a high concentration of refrigerant may develop within the room over the duration of the release. With the use of one set of measures, the concentration may be limited by using a pressure switch to pump the refrigerant into the outside unit, thus preventing any further build-up of refrigerant. In another case, the system parameters algorithm may be used to imitate the airflow of the unit within the room, so that the refrigerant is rapidly dispersed and the concentration build-up is minor. In the last case, a gas detector within the room is used to initiate extract ventilation which then reduces refrigerant from the space.

Figure 33: Change in room floor concentration with initiation and termination of airflow (note that this illustration does not indicate that one option is any more effective than another; the differences are only for purposes of clarity of the diagram)



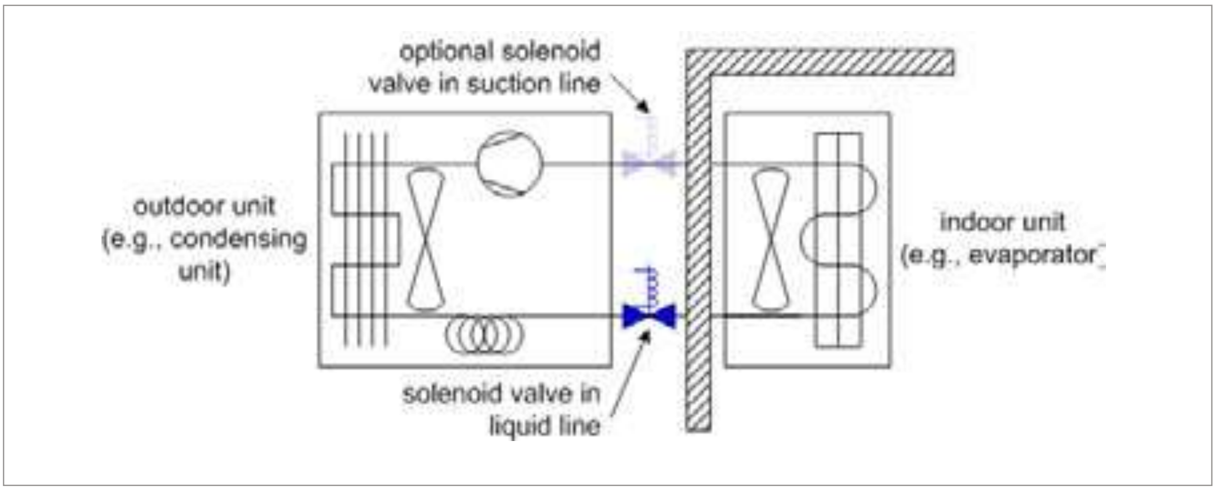
34 Over recent years, there have been developments on sensors that fit into a system's liquid line that is used to directly indicate the absence of refrigerant from the system (i.e., through the presence of flash-gas). Is it not known whether these have been commercialised to date, but such a device would present a very interesting sensing device for a safety control system.

Actions

There are a number of actions that may be considered, although their suitability will depend upon the type of system being used and the cost implications, as discussed:

- Initiate extract ventilation: this is essentially what should be used for machinery rooms (see Parts 5.6.4 and 5.6.5)
- Initiate/continue unit airflow: airflow from an indoor air handler or condensing unit can be very effective in reducing the concentration of leaked refrigerant, especially if the discharge velocity of the air is high
- Redirect dampers: for a ducted system, dampers within the air stream that may be carrying leaked refrigerant from the evaporator may be redirected to vent any refrigerant to the outside
- Shut down electrical feed: this is often used in machinery rooms, but may also be used in other situations, where it is possible for a high concentration to develop nearby electrical components (even if they are protected); obviously ensuring that the switching itself does not create a source of ignition
- Close solenoid shut-off valves: if part of the system is outside, a pump-down cycle can be activated by using a solenoid valve in the liquid line, which will prevent refrigerant being passed to the inside space (see Figure 34); it is necessary to use a normally closed solenoid valve in case of failure of the electrical supply (under certain circumstances a valve may also be placed in the suction line but this is probably unnecessary since the compressor normally only leak back a small amount of refrigerant especially as it may encourage leakage)
- Activate by-pass valve: similar to the use of a shut-off valve, but the refrigerant is bypassed away from the indoor components
- Terminate compressor: compressor operation is terminated to as to prevent refrigerant being pumped into the inside space, and in the event that the high-pressure parts are inside, the reduction in pressure may help to reduce the leak rate

Figure 34: Use of a normally-closed solenoid valve in a remote or split type system



The effectiveness of these methods will be a function of the type of system and the design of the control strategy, so it is important to ensure that whatever approach is used, is well tested and checked under a variety of different failure conditions.

5.7 MARKING AND INSTRUCTIONS

5.7.1 Introduction

It is important to provide warning signs, marking, and detailed information to all personnel that may be directly affected by the safety risks of equipment and substances. The necessity to have signage and instructions applies to most activities and equipment. For example:

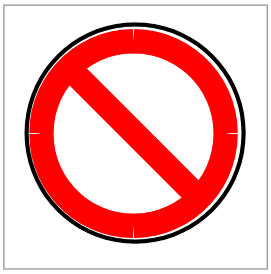
- Warning of hazardous substances within systems, cylinders, working areas
- Requiring workers and other personnel of activities that they should do
- Making workers and other personnel aware of what they must not do
- Informing workers of the correct procedures and processes that should be carried out in relation to particular equipment

The use of signage, marking and instructions is normally a requirement of safety standards and regulations.

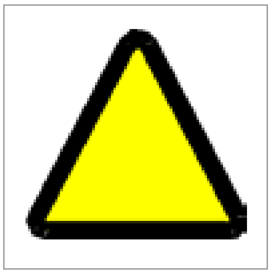
5.7.2 Marking and signage

There are five main categories of safety signs; each has a different shape and colour. These are summarised as follows:

Prohibition
- Description: a red circular band with a diagonal cross-bar on a white background
- This implies: "You must not", "Do not do", "Stop", etc
- Normally there is a black symbol within the circle which denotes that a certain activity or behaviour is prohibited

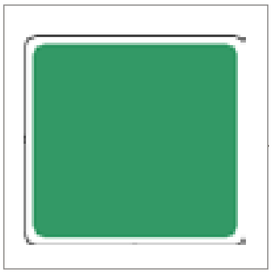


Warning
- Description: a yellow triangle with a black border
- This implies: "Caution", "Risk of danger", "Hazard ahead", etc
- Normally there is a black symbol within the triangle which denotes a warning against that specific type of hazard

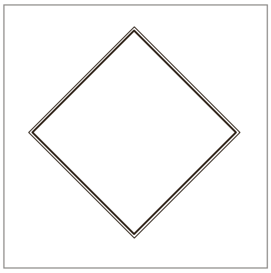


Mandatory
- Description: a blue solid circle
- This implies: "You must do", "Carry out the action", "obey instruction", etc
- Normally there is a white symbol within the circle which denotes the action that must be followed

Safe condition
- Description: green solid square or rectangle
- This implies: "The safe way", "Where to go in an emergency", etc
- Normally there is a white symbol or white text within the rectangle square which provides information about the safe thing to do the or the safe direction to go in



Hazardous labelling



- Description: a diamond shape, of varying colours
- This implies that the package contains a particular hazardous substance
- Normally there is a symbol in the top half of the diamond, beneath which there is corresponding text which provides the primary hazard warning, and a hazard class number is at the base of the diamond. The colour of the diamond is also dependent upon the substance

Specific to the situation under consideration:

- There are a number of prohibition signs that are likely to be used, particularly in the case where technicians and other workers are involved with refrigerant handling and associated equipment. Figure 35 includes a selection of possible symbols that may be adopted.

Figure 35: Some prohibition signs that may be used during refrigerant handling and other activities

"do not enter" "authorised persons only" "no smoking" "no naked flames"

- Warning signs may be applied to both the equipment and to working areas. In terms of the equipment, the flame warning symbol should be applied to the equipment nameplate, on remote pipework, and on the repair manual and must be always visible when accessing parts for maintenance. Figure 36 provides some examples of such signage.

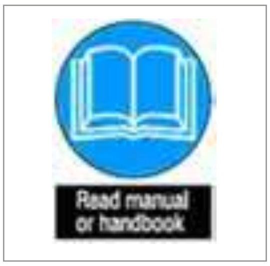
Figure 36: Some warning signs that may be applied to equipment and working areas

"flammable gas" "extremely flammable" "danger hazard area"

- Mandatory symbols may be applied to both the equipment, manuals and working areas. For example, a symbol for reading the user manual, the repair manual and the installation manual should be visible on equipment. It is also required that a statement requirement that the appliance must be installed, operated and stored in a room with a floor area larger than "X" m² be applied to portable appliance.

  Figure 37 provides some examples.

Figure 37: Some mandatory signs for use on equipment



"read manual or handbook" "warning –"

- Safe conditions symbols may be used in technician working areas and in permanent installations such as production lines and workshop areas, for example to indicate safe exit passages and locations of emergency stop buttons. Figure 38 provides some examples.

Figure 38: Some mandatory signs for use in working areas

"emergency exit" "emergency stop"

- Hazardous substance labelling, such as that in Figure 39 for flammable gases, is normally applied to refrigerant containers and refrigerant storage areas.

Figure 39: "flammable gas" hazard label

The official symbols described here can be found within ISO 3864, ISO 7000 and IEC 60417.[35]

35 see http://www.graphical-symbols.info/

5.7.3 Manuals and other instructions

Sets of instructions, in the form of manuals, guidance notes, data-sheets, etc, should be provided for both training and a source of reference for nearly all stages in the equipment life. In particular, manuals and other guidance should be provided for:

- Design of equipment and installations
- Manufacturing, operation of production line equipment and assembly
- Operation and working of the production area safety system
- Storage and distribution of equipment
- Installation of the systems and/or equipment
- Service, maintenance, dismantling and disposal of the systems and/or equipment
- Operation of the systems and/or equipment for the user

Specifically for equipment using flammable refrigerants, it must be accompanied by further instructions, including at least the following:

- The information with which the equipment is marked, together with any appropriate additional information to facilitate maintenance (e.g. address of the importer, repairer, etc)
- Instructions for safety: putting into service, use, assembling and dismantling, maintenance (servicing and emergency repair), installation, adjustment, an indication of the danger areas in front of pressure-relief devices (when used)
- Where necessary, training instructions
- Details which allow a decision to be taken beyond any doubt as to whether an item of equipment in a specific category or a protective system can be used safely in the intended area under the expected operating conditions
- Electrical and pressure parameters, maximum surface temperatures and other limit values
- Where necessary, special conditions of use, including particulars of possible misuse which experience has shown might occur
- Where necessary, the essential characteristics of tools which may be fitted to the equipment or protective system.

On being put into service, all equipment must be accompanied by a translation of the instructions in the language or languages of the country in which the equipment is to be used (and by the instructions in the original language). Instructions must contain the drawings and diagrams necessary for the putting into service, maintenance, inspection, checking of correct operation and, where appropriate, repair of the equipment, together with all useful instructions, in particular with regard to safety. Ensure that literature describing the equipment must not contradict the instructions with regard to safety aspects.

Depending upon the size of the enterprise that is producing the equipment, the type of systems and equipment, and other factors, the manuals may be separate for each stage (or sub-stage), or the manuals for certain stages may be combined. In any case, the information must be complete and include all the relevant instructions and data for the equipment to be used correctly and safely. Of utmost importance is that any such instructions should be written clearly and concisely so that everyone can comprehend it correctly; ensure that any reader will understand exactly what the manual intends.

Table 14 provides an overview of the type of information the manuals applicable for each general stage. The relevant information on safety is mostly available within the relevant sections of this publication. However, this only applies to safety and flammability aspects; there is of course other material that should be included in all cases.

Table 14: Overview of the general information required for manuals

Stage (and target groups)	Relevant Part of this handbook	Design (design/ development engineers)	Manufacture (production workers, supervisors, maintenance staff)	Storage and distribution (warehouse staff, supervisors, delivery staff)	Installation (installation technicians)	Service and maintenance (service/ maintenance technicians)	Operation (appliance/ system users or operators)
Basic flammability safety	1.2.1						
Refrigerant safety classification	1.2.2						
Basic working with HCs	1.2.3						
Regulations	1.5.2, 1.5.3						
Principles RAC safety standards	1.5.4						
Technician tools and equipment	3.2.3						
Production site refrigerant supply	4.2						
Equipment for appliances production	4.3						
Safe operation of production line	4.4						
Workshop and repair areas	4.5						
Principles safe design	5.1						
Design for avoiding leakage	5.2						
Refrigerant charge size limits	5.3						
Avoiding sources of ignition	5.5						
Outdoor installation requirements	5.6.1, 5.6.3						
Machinery rooms	5.6.4, 5.6.5						
Component installation and selection	5.6.6, 5.6.7						
Fixed gas detection	5.6.8						
Marking	5.7.2						
Risk analysis	5.8						
Refrigerant handling procedures	6.1, 6.3, 6.5						
Commissioning of systems	6.3						
Retrofitting, retro-filling systems	6.4						
Pressure-temperature data	A.1						
Flammability characteristics	A.3						
Refrigerant use sheet	A.8						
Refrigerant safety data sheet	[supplier]						

Whilst Table 14 refers to particular sections within the handbook, the actual material within the manuals or other documentation does not need to be exactly reproduced, but the relevant material may be used to assist with building up the documentation. Depending upon the set up of the facility under consideration or the type of systems and equipment being referred to, differing material will be required. Similarly, the depth of the information provided within the documentation will vary according to the type of activity under consideration and also the complexity of the systems and equipment.

In order to check that the instruction manuals are of sufficient quality, they should be "tested" by having trials of less-competent persons try to follow the relevant instructions, and to assess the adequacy of the subsequent work and obtain their feedback.

5.8 RISK ANALYSIS

5.8.1 Introduction

Risk analysis, typically in the form of a quantitative risk assessment (QRA) and other techniques, should be carried out on systems and equipment that uses flammable refrigerants. The main reasons for carrying out a risk analysis are:

- To ensure that a detailed safety evaluation has been carried out, since safety standards are only on qualitative assumptions about risk, made by working groups, committees, etc, and thus are not always robust for all situations

- To enable the identification of ways and means to improve the level of safety of the systems and equipment, by way of detailed investigations of all of the factors that affect the risk

In particular, the use of risk analysis helps to avoid emotive descriptions such as "safe" or "unsafe". Furthermore, because the approach is intended to represent a real life case, the use of "safety factors" and "worse case" assumptions are not applied. It also provides a useful medium for achieving a rational understanding of flammability risks associated with the use of HC refrigerants. In general, if there is little knowledge and understanding of the risks and the components of the risk associated with the use of a particular technology, the safe design, use and operation of equipment will have many uncertainties associated with it. This leads to a more risky situation. However, if those involved attain a greater knowledge and understanding of the issues, then a much higher level of certainty in the safe design, use and operation will be achieved. This ultimately leads to a reduced level of risk.

5.8.2 General risk assessment techniques

Determining the risk of something is to estimate the likelihood of harm that a particular hazard, or set of hazards, may cause to people or property. The risk itself is a product of the likelihood of an undesirable event happening, and the severity of that undesirable event. Thus to carry out a risk assessment it is necessary to identify and analyse the hazards, estimate the risks, and using this output determine possible risk-reducing measures.

There are four common techniques for carrying out a risk assessment: hazard and operability study (HazOp), failure modes and effect analysis (FMEA), event tree analysis (ETA), and fault tree analysis (FTA). These may be used individually or together.

To carry out such activities, it is important to obtain qualitative and quantitative data based on past experience; on occasions when this is not possible, experiments and calculation may be used as a means to obtain the appropriate information on the hazards and contributing events and processes. When analysing events and processes related to equipment and installations, it is essential to ask open questions, such as "how…?", rather than "what…?", so that a wider understanding is gained (i.e., "how does this event occur?", not "what event occurs?"). Furthermore, the risk analysis should be carried out by a team covering the necessary expertise. At least, it should include:

- Specialist(s) on the design, construction and operation of the system/equipment/installation under consideration
- Specialist(s) on the physical and chemical mechanisms that result in the hazards under consideration
- Reviewer(s) to check the reasonableness of the overall assessment

In addition, there are a number of standards that may be directly or broadly applicable to risk assessment of the situation or equipment under consideration, and these should be sought.[36]

36 See for example, EN 15198 – Methodology for the risk assessment of non-electrical equipment and components for intended use in potentially explosive atmospheres; EN 1127 – Explosive atmospheres. Explosion prevention and protection; EN 15233 – Methodology for functional safety assessment of protective systems for potentially explosive atmospheres

The output of any such study should include identification of any items, locations, set of conditions, activities that lead to the greatest risk, and present approaches to target these, which should be ranked in order of priority.

Failure modes and effect analysis (FMEA)[37]

FMEA primarily addresses the effects of failures or malfunctions of individual components (or process actions) within a system, with the objective of identifying which components are the most critical and thus, which require greatest consideration. The overall approach requires each component to be listed and a thorough series of questions asked (such as those in Figure 40 regarding the manner of its failure and the possible outcomes in the event of it failing.

Figure 40: Questions to be asked for each component within a system as part of an FMEA

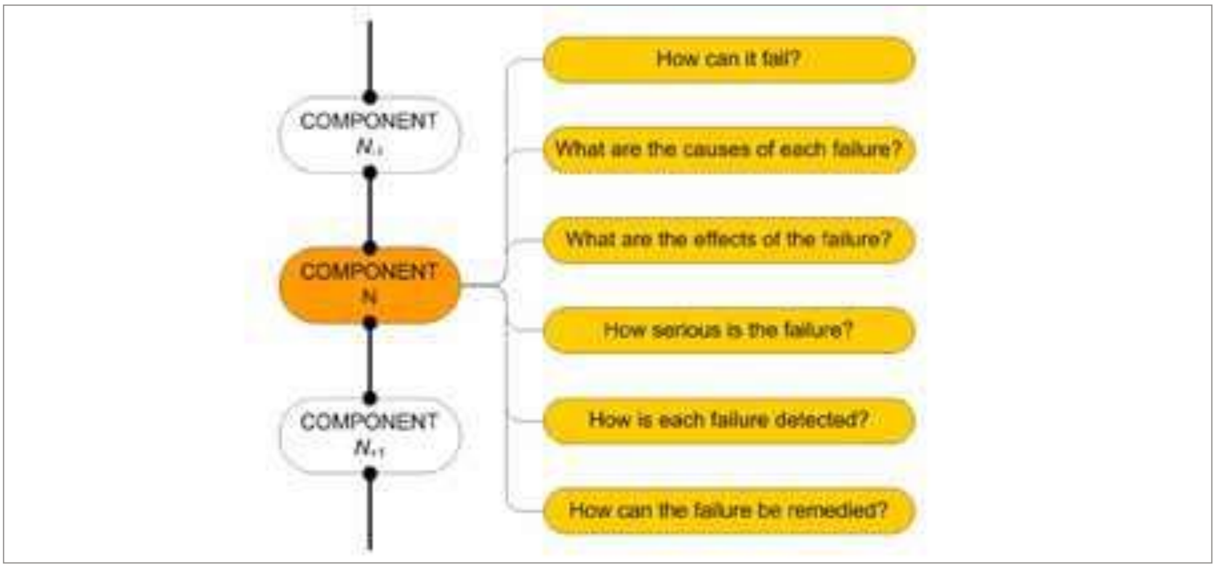


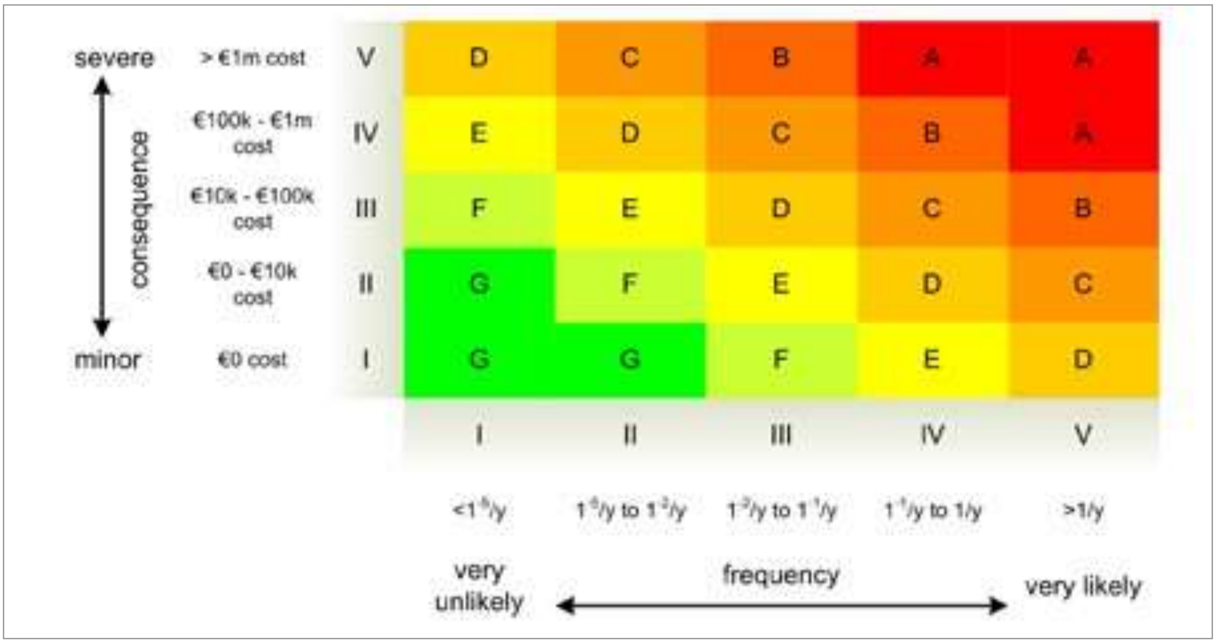
Table 15: Example of some FMEA questions for fixed flammable gas detection sensor

How fail?	Causes of?	Effects of?	How serious?	How detected?	How remedied?
No signal	Faulty connection	No alarm or venting	High	Regular test signal	Manual repair
No signal	Contaminated sensor	No alarm or venting	High	Regular test sample	Manual replacement
No signal	Covered sensor	No alarm or venting	High	Regular test sample	Manual action
False signal	Contaminant in air	Other gas leak	Low	Alternate detector	Alarm signal
...	...	...	...	...	...

37 Guidance can be found in IEC 60812 – Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)

Finally, for a system or overall installation, a summary sheet should be prepared which presents the failure modes in a prioritised sequence, making it obvious which elements require most attention. This should be complimented with corrective actions or measures, which could be design changes, new or changed procedures or processes, servicing or maintenance plans, organisational changes, and so on.

Figure 41: Example of determination of risk on the basis of the frequency of an undesirable event occurring and the cost-severity of the damage cause by the consequence of the event; "A" is unacceptable, "G" is acceptable



An example of how such an analysis may be carried out is provided in Table 15.
For each failure the level if risk should be identified. This is carried out by:

(i) Estimating the severity of each failure, which may be categorised from negligible or minor to catastrophic, and
(ii) Estimating the probability of each failure – typically from experience and/or calculation – which may range from improbable to frequent.

From the product of severity × probability, the risk of each failure can be determined. Thus a failure that has minor severity and is very improbable does not present a problem. However, a failure that is likely to occur very frequently and has a catastrophic severity must be addressed further. Figure 41 illustrates this concept, by means of quantifying different levels of frequency of an event, and severity of the consequences (in terms of cost). The most desirable situation falls under "G", whereas the least favourable is "A". Note also that if a component is linked to others (as it nearly always the case) either mechanically or procedurally, then the ultimate consequence may be significantly more (or less) severe than initially indicated; it either case it must be accounted for.

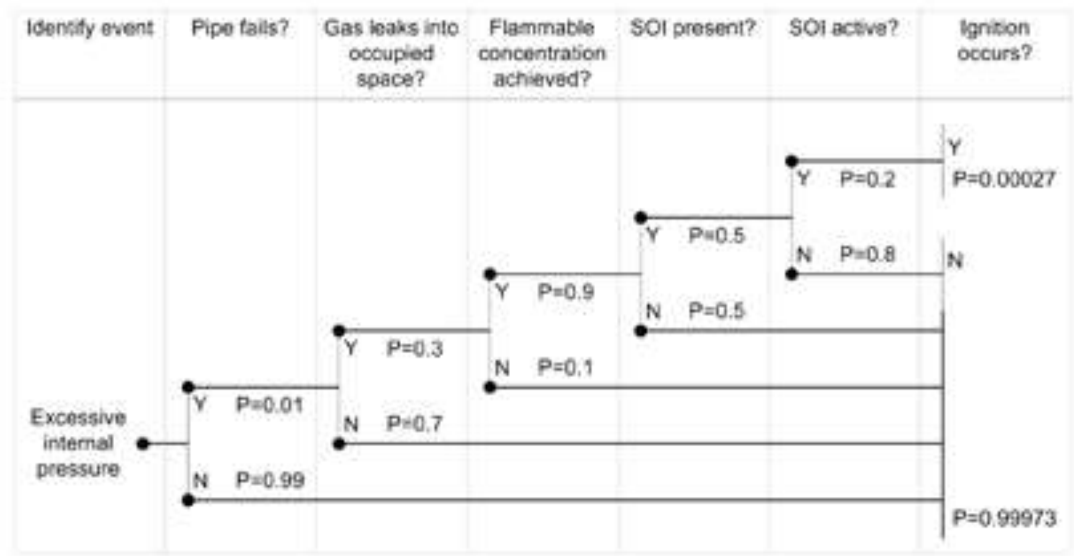
Event tree analysis (ETA)[38]

ETA is a logic-based technique, characterising the likelihood of hazards occurring according to contributing events not occurring or occurring. This approach is commonly used to analyse situations involving releases of flammable or toxic gases.

Essentially, each possible event leading up to one or more end consequences, starting with one or initiating event, must be listed, and a probability assigned to each of these events. The initiating event may be a component failure, a change in condition, a human action or some other occurrence, whilst the end consequence may be an ignition event, overpressure, fatality, property damage, and so on. Starting from the initiating event, a sequence of paths are plotted in order to identify the consequences of each possible event. The occurrence of each event (and non-occurrence of the event) has a probability assigned, from which the overall probability of the end consequence is determined.

An example of an event tree for a release of flammable gas from a pipe, leading to possible ignition, is presented in Figure 42.

Figure 42: Example of event tree for a flammable gas release from a pipe



Fault tree analysis (FTA)[39]

FTA is another technique that combines a graphical approach and estimated probabilities to determine the likelihood of undesirable outcomes. It helps to systematically develop an overview of the possible events leading to one or more consequences.

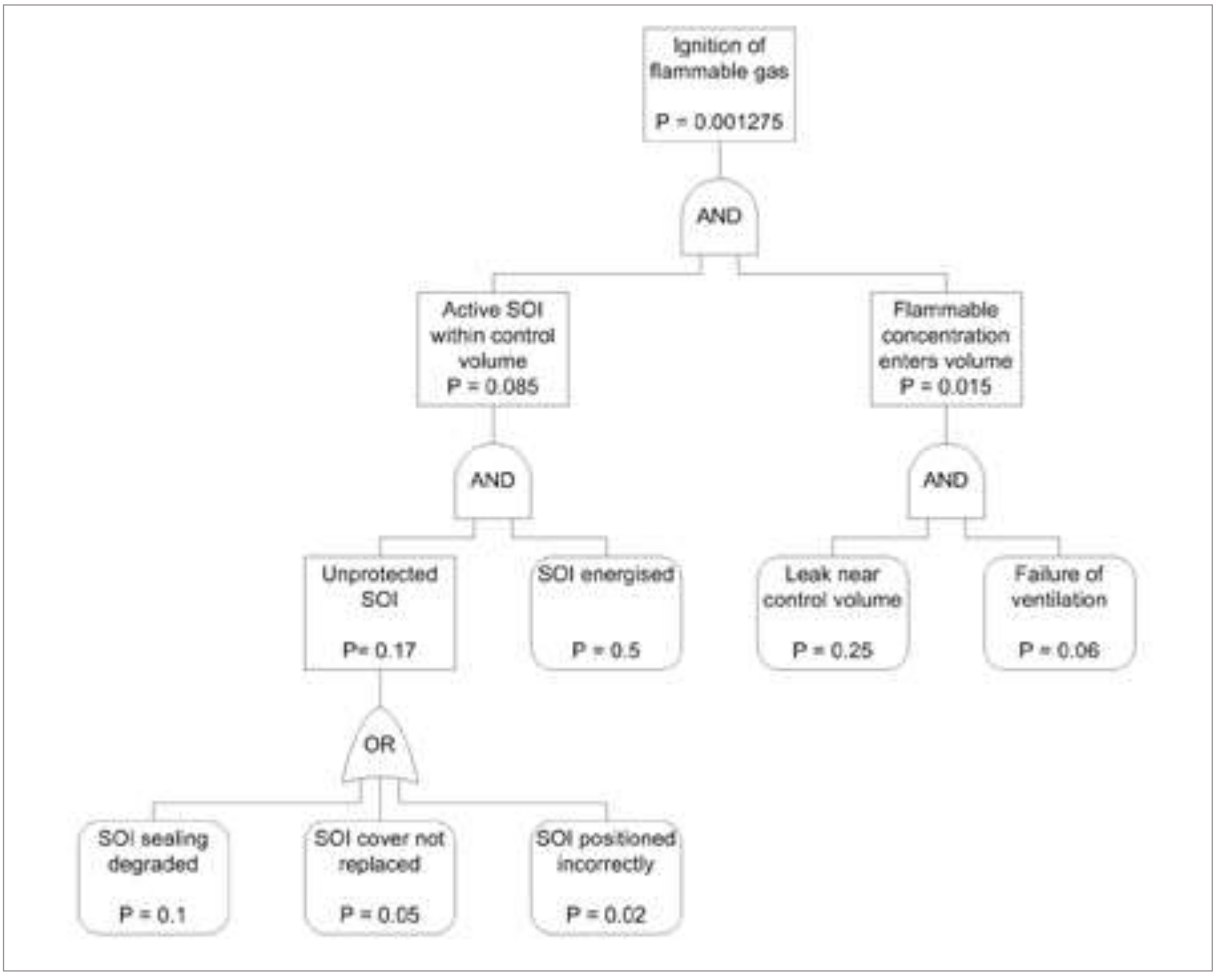
It is carried out by first identifying the most serious consequence, or 'top event'. From that, the fault tree is constructed in a manner that relates the sequence of events that ultimately lead to the occurrence of the top event. Usually, it is produced using a series of the logical 'AND' and 'OR' gates, which represent the combination of conditions required to satisfy the subsequent event. For each event, a probability should be assigned. Where two or more events are necessary for the subsequent event to occur, then an AND gate is used and the probabilities multiplied. Whereas if the prior event may act independently to result in the subsequent event, an OR gate is used and the probabilities summed.

Figure 43 is a basic illustration of a fault tree, showing the failure of the protection of a SOI events and a release of flammable gas events, leading to the top ignition event.

38 Guidance can be found in IEC 60812 – Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)

39 Guidance can be found in IEC 62502 – Analysis techniques for dependability – Event tree analysis

Figure 43: Example of a fault tree leading to a top event of ignition of flammable gas by an unprotected SOI



Hazard and operability study (HazOp)[40]

A HazOp is not actually a risk assessment technique (by definition), but it provides a useful means of gaining insight to the possible hazards posed by systems and installations, which can then be quantified by other means. Broadly, to carry out a HazOp requires a series of "what if?" questions to be asked about a particular process, system or workings of an installation. It is used to systematically examine the manufacturing, design, construction, installation, operation and service and maintenance activities of systems or equipment.

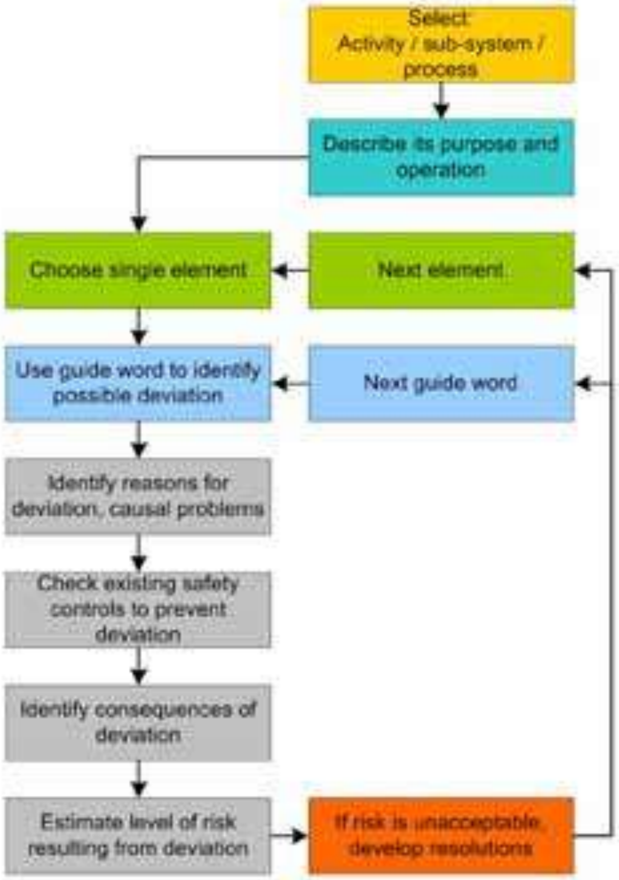
Figure 44 is a flow chart with the typical HazOp procedure. Initially the boundaries of the system, equipment, activities, etc, need to be established, which then needs to be broken down into individual elements for examination. For each element, certain guide words should be used to examine the possible "deviations" (i.e., problems, faults, mistakes, etc) in operation. These guide words are generally:

- "no" or "none" g the negation of the intention
- "more" g a quantitative increase
- "less" g a quantitative decrease
- "as well as" g in addition to
- "part of" g a qualitative decrease
- "reverse" g the opposite of the intention
- "other than" g a complete substitution

40 Guidance can be found in the standard IEC 61882 – Hazard and operability studies (HAZOP studies) – Application guide

For each of the deviations identified, the causes should be then sought, since these may be used to help prevent the deviations. Similarly, the existing design and associated controls should be checked in order to determine if or how they prevent the deviation. Next, the consequences of the deviations must be identified, and subsequently, and estimation of the risk arising from the deviation, possibly using the same approach detailed in Figure 41. If the risk is unacceptably high, then alternative means of handling the deviation need to be developed. The entire process should be carried out for all elements within the chosen boundary.

Figure 44: Typical work flow diagram for carrying out a HazOp analysis



To illustrate the approach, an example is given of a technician charging HC refrigerant into a system. A number of possible deviations are listed based on the guide words:

- "no" or "none" g e.g., no electronic balance, hose connection loosens
- "more" g e.g., overcharged refrigerant, pressure too high
- "less" g e.g., insufficient refrigerant in cylinder, lack of ventilation
- "as well as" g e.g., SOI present nearby, air in the system
- "part of" g e.g., no gas detector present, valve cap not replaced
- "reverse" g e.g., backflow from system, back-seat instead of front-seat manifold valve
- "other than" g e.g., untrained technician, wrong hose connection

A selection of these is included in Table 16 as examples.

Table 16: Example application of HazOp to HC refrigerant system charging during servicing

Deviation	Cause of deviation	Consequence	Existing controls	Possible actions
Hose connection loosens	Insufficient tightening	Release of gas	Manual stop valve	Use gas detector, activate emer-gency airflow
Overcharged refrigerant	Poor manual control	Pressure relief activates, system part ruptures	Manual weight check	Recover refriger-ant, activate emergency airflow
SOI present nearby	Technician not checked area	Ignition of release	None	Reminder alarm, have checklist
Valve cap not replaced	Technician forgot	Slow release of gas	Instructions, signs	Valve-to-cap connecting string

5.8.3 Specific methodology

This section presents a methodology for quantitative risk assessment (QRA) of flammable refrigerants in RAC systems. It is intended to provide a general approach to quantifying the main individual events – in terms of probabilities – that lead to a given consequence and the evaluation of that consequence.

Figure 45: Basic sequence of events causing a hazard from flammable refrigerants

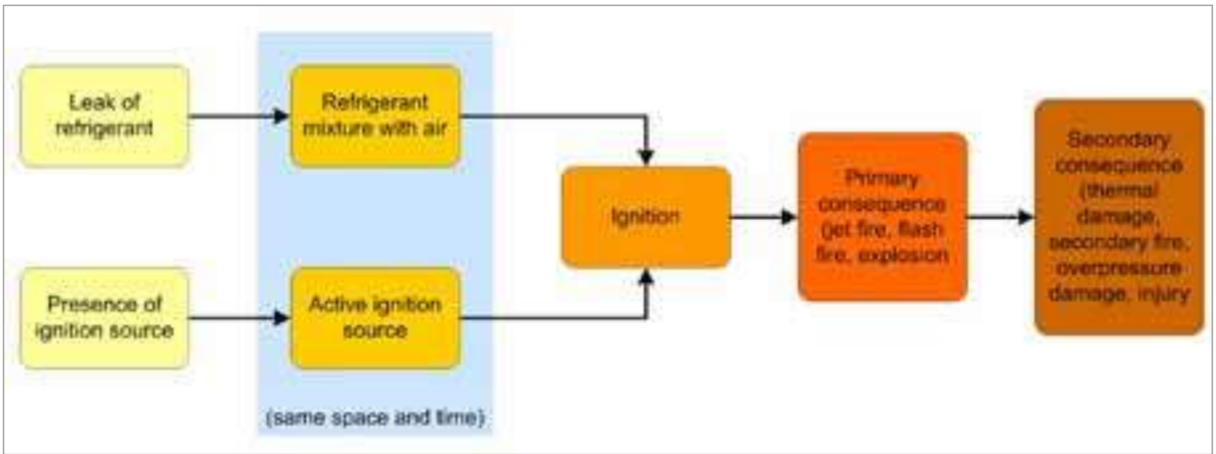


Figure 45 provides a basic overview of the sequence of events that lead to undesirable consequence and hazards: RAC component failure leading to a refrigerant leak g creation of a flammable mixture g ignition of the mixture g consequence event g damage. The first output of interest from a QRA is the frequency of ignition – expressed as the number of occurrence of an event per unit time, for a specific RAC equipment design, within a particular environment. The second output is the severity of the consequences caused by that ignition event.

Whilst the use of QRA should be applied to many of the stages during the lifetime of the equipment, the phases that are focussed on here are those during the in-use stages. In particular:

- In-use operation of the systems
- During service and maintenance (refrigerant handling)
- During storage (if applicable)

The two groups of persons at risk during these activities should also be considered:

- Member of the public
- Workers (technicians)

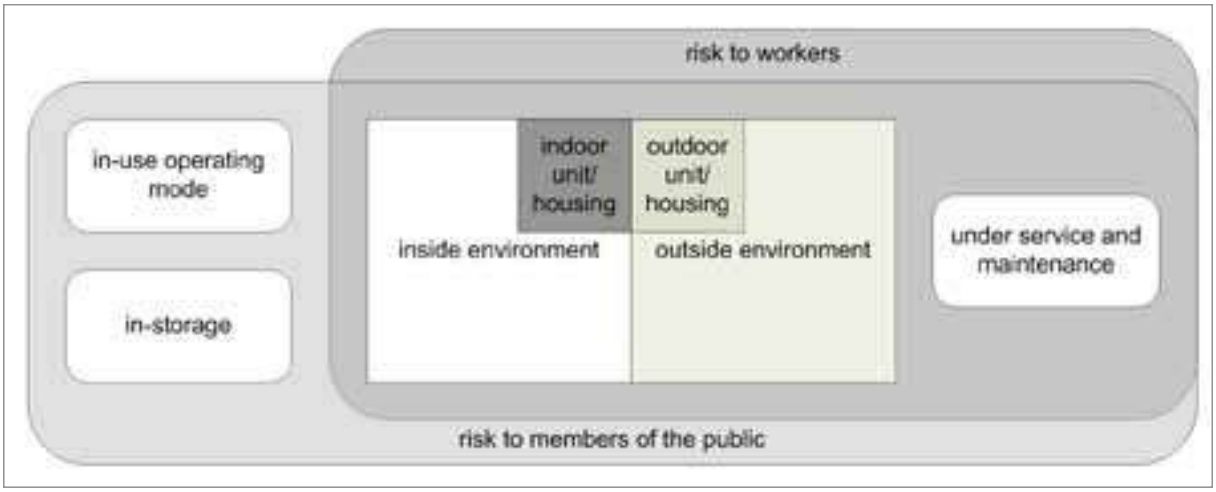
Lastly, the locations under consideration must also be addressed, which relate to the presence of the refrigerant-containing parts, typically:

- Ignition of flammable mixture within a room (occupied space or machinery room)
- Ignition of flammable mixture within the equipment's indoor enclosure or housing
- Ignition of flammable mixture outside (in the open air)
- Ignition of flammable mixture within equipment's outdoor enclosure or housing

A map of these concepts is provided in Figure 46.

In general, the risk of ignition for an outside location is normally much smaller than for an indoor situation, due to the large area and high rates of ventilation. Similarly, due to the wide variety of conditions and the very small quantities of gas anticipated to be released, the calculation of the risk can be rather uncertain. Although the discussion hereafter therefore relates more so to releases inside occupied or enclosed spaces, consideration must also be given to outside areas.

Figure 46: Map of modes, locations and target groups to consider in risk analysis



When evaluating the risk, a wide number of conditions should be accounted for

- Use mode: normal operation, storage, servicing, maintenance
- Operating mode: compressor on or off
- Unit airflow condition: off or on, different flow rates
- Mechanical ventilation: off or on, different flow rates
- Presence of thermal sources

• Infiltration and natural ventilation: different rates according to environmental conditions
• Presence of SOIs: different positions, different types
• Leak size: ranging from very small to very large
• Controls: failure of control circuits, detectors, fans, valves, etc

In order to properly evaluate the probabilities described above, it is useful to have an understanding of the physical processes that lead to them. Therefore a discussion of such aspects as refrigerant flammability characteristics, refrigerant leakage, dispersion of refrigerant leaks and overpressure and thermal dose is presented later.

Frequency of ignition

An ignition event is coincidence of three fundamental events:

• Occurrence of a leak,
• Development of a flammable-refrigerant/air mixture at a specific location, and
• Co-existence of a source of ignition being "active" within the flammable mixture.

These events have their individual probabilities or frequencies, and the frequency of ignition (f^*) is essentially the product of these. The ignition frequency of a single leak under a particular set of conditions (f^*) is calculated from equation (12).

$$f_i^* = f_{leak,i} \sum_{i=1} P_i^{F*} \quad (12)$$

where $f_{leak,i}$ and P_i^{F*} are leak frequency and probability of ignition of a flammable mixture by an active SOI, respectively. $f_{leak,i}$ refers to a specific leak size in terms of duration, under a set of conditions and is largely related to the construction/installation of the system and compressor operating mode (on- or off-cycle), and is normally based on empirical (and anecdotal) data. i represents each individual set of operating and environmental conditions. P_i^{F*} may be evaluated with respect to a vertical element/region within the room so that sources of ignition (SOI) are linked to local formation of a flammable mixture (in light of the relative buoyancy of the gas).

To account for the dynamic nature of equipment operation and/or associated environment, f_i^* is normally evaluated for each set of conditions, such as compressor operating mode and the presence of alternate or multiple airflow types. Consequently, the overall ignition frequency (f^*) is the sum of the individual ignition frequencies for all leak sizes, weighted with the corresponding time fraction for each combination of conditions – compressor operating mode and each airflow type – that is present (equation 13).

$$f^* = \sum_{j=1} f_j^* \varphi_j \quad (13)$$

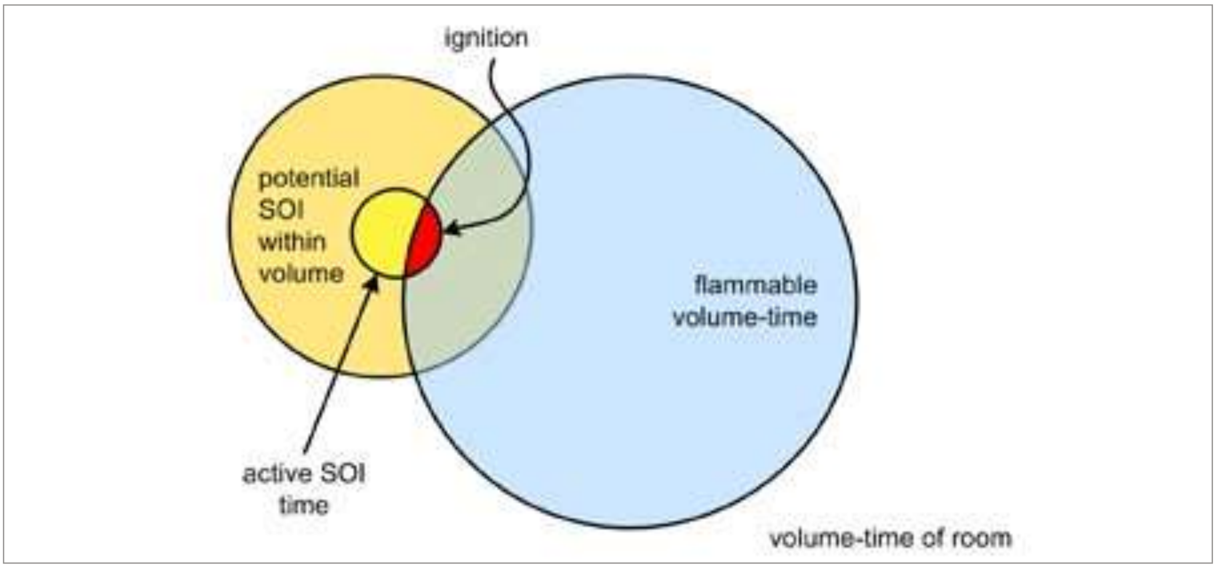
with each φ_j referring to different operating modes, infiltration rate, presence of thermal currents, mechanical ventilation, and so on.

For determining the probability of ignition (P_i^{F*}) for an active source of ignition (SOI) surrounded by a mixture at a flammable concentration (C^F) within an enclosed space, the characteristics of each individual SOI should be accounted for. For a given space-time, ignition could potentially occur when an active SOI is present at the same time and spatial position as C^F, as illustrated in Figure 47. The coincidence of these leads to ignition, as indicated by the blackened area. To determine P^{F*}, it is evident that two component probabilities are needed: probability of an active SOI at the same time as C^{F}, and probability of C^{F} at the same spatial position as the potential SOI. P_i^{F*} is determined from equation (14).

$$P_i^{F*} = \sum_{N=1}^{N_{soi}} \left\{ 1 - \left[(1 - P_{V,i}^{F}) + P_{V,i}^{F}(1 - P_{soi,i}) \right]^{N_E} \right\}_{N_{soi}} \tag{14}$$

where P_V^F is the probability of a flammable volume, P_{soi} is the probability of an active source of ignition, N_{soi} is the number of SOI, and N_E is the number of active events of each SOI. P_V^{F}, and therefore P^{F*}, is a function of the size and duration of a flammable mixture, influenced by many parameters, including charge size, leak duration and airflow conditions, arising from infiltration, convection by thermal sources, evaporator and/or condenser fans, and various forms of mechanical ventilation, and requires modelling of a release to determine relevant characteristics.

Figure 47: Venn diagram indicating occurrences necessary for ignition



Occurrence of SOI events

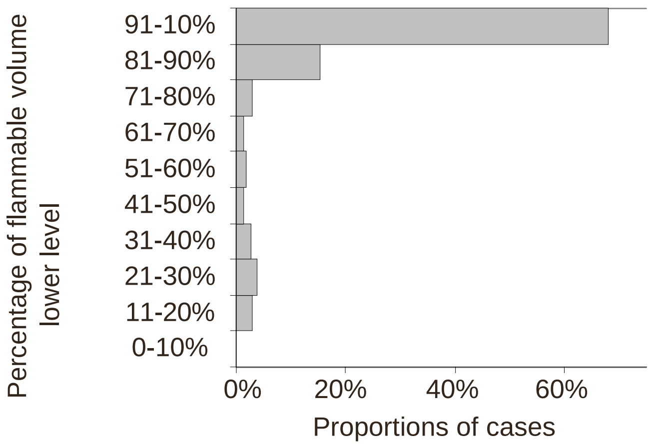
Within a given space, an active SOI may be present on the RAC equipment or elsewhere within the room, and on tools used for servicing activities. For a single active SOI event assumed to occur for some duration randomly within a reference period, the probability of its occurrence can be given by the ratio of the duration of the SOI to the duration of that reference period. Similarly, if a flammable volume event occurs randomly over a given duration within the same reference period, the probability of the flammable concentration being present is the ratio of the duration of that flammable concentration to the reference period. As the SOI event and the flammable volume event are independent, the probability of them occurring simultaneously within the same reference period is the sum of both probabilities. Therefore, the probability of the SOI event being present at the same time as the flammable concentration can be written as equation (15), showing the probability of an active SOI within a flammable volume within a given reference volume under a given set of conditions resulting from a certain leak size (in terms of duration).

$$P_{soi,i}^{F} = P_{avail} \frac{(t_{soi} + t_i^{F})}{t'}, \quad P_{soi}^{F} \leq 1 \tag{15}$$

where P_{avail} is included to account for the availability of the SOI (e.g., if electrics are protected against ingress of refrigerant, $P_{avail} = 0$, or the integrity of protection may fail, $0 < P_{avail} < 1$; otherwise, for permanent SOI, $P_{avail} = 1$.)

The significance of the positioning of the sources of ignition should also be considered, since the probability calculations require the room be divided into three levels of equal volume to account for the locality of SOI. If there is a major proportion of the flammable concentration occurring consistently within the upper levels of the room, then all SOI should be addressed, however, if the majority remains within the lower level, then it may be possible to account only for the SOI around the floor level. Values of the ratio of flammable volume-time existing within the lower level of a room (below 1 m) to total flammable volume-time for a variety of different situations are shown in Figure 48 as a percentage of cases that have a proportion the flammable volume-time below the height of 1 m within the room, relative to the total arising from a given release. It is seen that some 70% of the cases have at least 90% of their flammable volume-time existing in the lower level, and 85% of cases with at least 80% of the flammable volume-time within the lower layer. It is therefore considered acceptable to only account for the SOI at floor level.

Figure 48: Proportions of flammable volume-time being present within the lower level for a variety of different situations



Occurrence of flammable volume events

The probability of having a flammable volume ($P_V{}^F$) is based on the coincidence of the active SOI being present in the same spatial location as the flammable concentration. For this, it is assumed the SOI are located randomly within the same reference volume that the flammable concentration may exist, thus the need for P_V^F. Thus there are two possible outcomes: a flammable concentration event occurs within a given location representing a flammable volume, or the concentration < LFL. This probability is the ratio of the number of flammable volume events to the total possible events for the flammable volume to occupy, where the number of events is interpreted as total volumetric elements, so the probability of the flammable volume is given by (equation 16).

$$P^F_{V,i} = \frac{\bar{V}^F_h}{V'_h} P_{sys} P_{perc} \tag{16}$$

where the reference volume V' corresponds to the horizontal levels chosen for grouping local SOI ($V'_h = A_{Rm} h_{Rm} / N_h$), and $\bar{V}^F_h$ is the mean flammable volume existing within that reference volume. P_{sys} is the probability of a system to release its charge, also interpreted as "annual leak rate" or the ratio of total mass leaked from a given population of systems to the refrigerant bank. P_{perc} is percolation probability which is failure to ignite a C^F due to small pockets of unmixed gas or air within a cloud.

Flammable volumes

In carrying out a quantitative risk assessment (QRA) on the likelihood of ignition, it is important to be able to accurately estimate the size and duration of a flammable region that has arisen due to a leak of refrigerant for any set of conditions. There are a variety of different approaches that may be used for this purpose. These may include:

- Computational fluid dynamics (CFD)
- 2-D or 3-D zonal decay models
- Gaussian models
- Simplistic methods

The choice of approach for estimating the flammable volume and flammable time will be dependant upon the resources available, the necessary accuracy, the availability of validation data, and so on. In any case, it is useful to consider the three distinct processes that may arise from a refrigerant release:

- Descending plume: When a leak develops within the refrigerant circuit, it produces a high velocity jet, which may impinge on a surface or flow directly into an open space in any direction, but eventually gives way to buoyancy forces and a relatively low velocity plume is formed that falls towards the floor, whilst increasingly entraining more air from the surroundings causing it to dilute.

- Spreading plume: If the descending plume approaches the floor with a concentration at or above the LFL, the plume is considered to spreads across the floor. As this happens, the flow entrains air from above and subsequently dilutes further. As the descending plume continues to the floor, the new denser front displaces the existing diluted mixture thereby creating an upper layer, and each successive layer entrains material from the layer above it.

- Cloud decay: At the end of the release, if any of the mixture is at or above LFL then a cloud is considered to be present. The concentration within the cloud tends to decay in a similar manner to that for the spreading plume in terms of entrainment of the more dilute mixture from above. However, there is negligible horizontal flow across the floor (due to cessation of the descending and spreading plume) so whilst a velocity gradient between the layers still exists due to the air movement within the room the rate of entrainment is at a slower rate.

In carrying out calculations to evaluate these processes, it is also essential to account for the various sources of airflow, including unit airflow, mechanical ventilation, infiltration, and thermal convection.

Consequences

The ignition event can result in one or more "primary" consequences, which depend upon the local conditions: a jet fire, a flash fire, and/or an explosion (which is characterised by the development of sufficient overpressure from the expansion of the gases). The interaction of these primary consequences with the surroundings, lead to possible "secondary" consequences: thermal damage from radiated heat, a secondary fire perhaps due to flame impingement or sufficient overpressure to cause damage to property and/or people. To account for these, intensity of thermal radiation and overpressure (within the room) were used to evaluate consequence, from where the individual risk of fatality (associated to the installation) is estimated. Frequency of fatality (f_{fatal}) is the sum of individual fatality frequencies resulting from each f_i* (equation 17).

$$f_{fatal} = \sum_{i=1} \left(f_i^* P_{fatal} \{ f_i^* \} \right) \varphi_{occ,i} N_{occ,i} \qquad (17)$$

where $N_{occ,i}$ and $\varphi_{occ,i}$ are the number of occupants and their residence time fraction, respectively. $P_{fatal}\{f_i^*\}$ is the probability of fatality due to thermal intensity applied to an occupant (I_{occ}) and/or room overpressure ($\Delta p°_{Rm}$) corresponding to the conditions for f_i*.

The probability of fatality associated with a dose of thermal radiation can be calculated, for example from equation (18), when $0 < P_{fatal} < 1$.

$$P_{fatal}(I_{occ}) = a + b \ln I_{occ} \quad (18)$$

where a = - 3.79 and b = 0.54.

The probability of fatality due to overpressures can be calculated, for example from equation (19), when $0 < P_{fatal} < 1$.

$$P_{fatal}(\Delta p^o_{Rm}) = a + b \ln \Delta p^o_{Rm} \quad (19)$$

where a = - 3.62 and b = 0.76.

Overall risk

In order to represent the overall risk impact posed by an installation, the use of integrated thermal intensity-frequency (equation 20) and integrated overpressure-frequency (equation 21) may be used. They represent the time- and severity-weighted consequence of ignition.

$$X_{Iocc} = \sum_{i=1} \left(\sum_{j=1}^{Nleak} f_{i,j}^* \, I_{occ,I,j} \right) \quad (20)$$

$$X_{\Delta po} = \sum_{i=1} \left(\sum_{j=1}^{Nleak} f_{i,j}^* \, \Delta p^o_{Rm,I,j} \right) \quad (21)$$

Alternatively, for a single set of conditions, the discreet risk can be found from the product or for the risk due to thermal intensity or overpressure, respectively.

Acceptability of risk

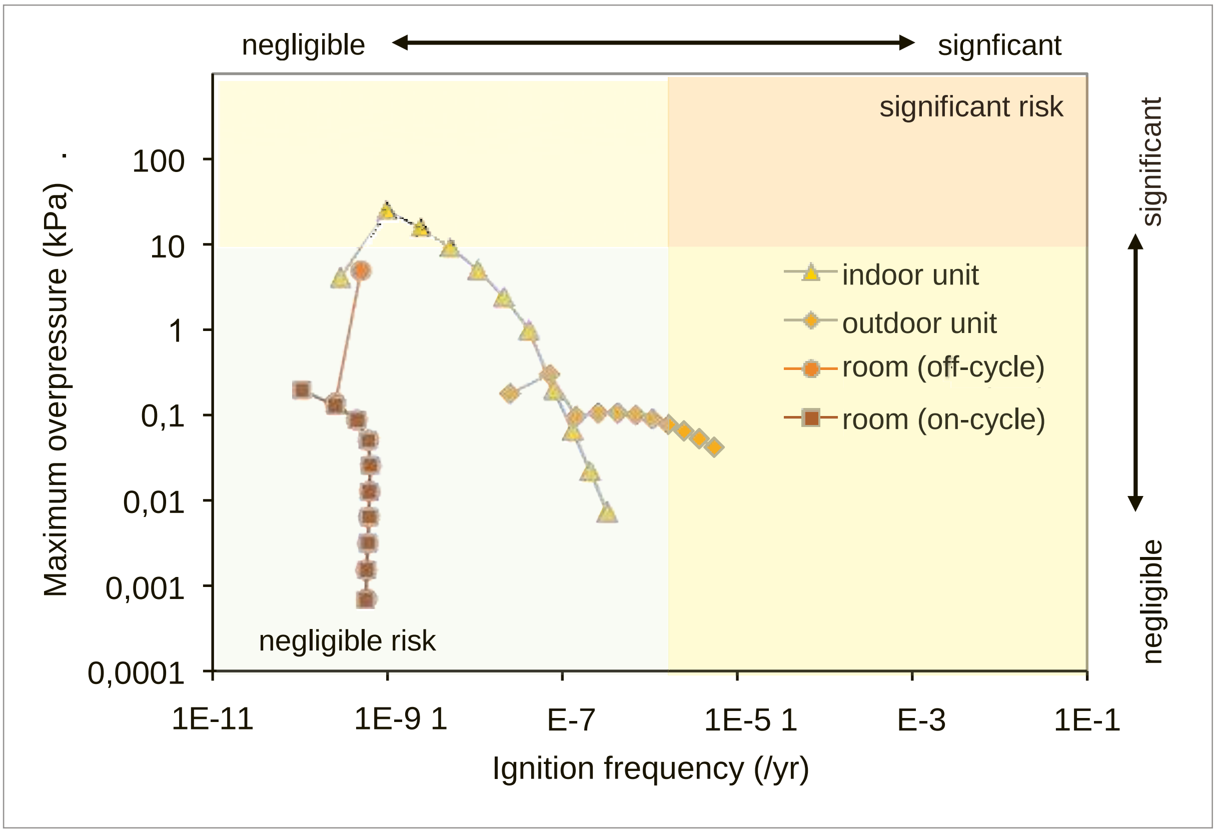
It is necessary to put the calculated risks into context if equipment is to be judged as “safe” or “unsafe”. This was achieved by establishing certain limits to compare against the outcome of the QRA, indicating an acceptable or unacceptable risk considering: frequency of ignition and frequency of fatality. Ignition risk may be interpreted as fire risk, since ignition may lead to a secondary fire. In this respect, it is useful to compare the risk of RAC equipment against risks from, say, domestic refrigerators (non-HC), which have a value of 1.1×10-5 y-1, which is evidently considered “acceptable” by society. For fatality risk, the UK Health and Safety Executive recommend values for “negligible” risk to an individual: member of the public $f_{fatal} = 1\times10^{-6} y^{-1}$, and service industry worker $f_{fatal} = 1\times10\ 10^{-5} y^{-1}$. Thus calculated f_{fatal} should be lower than these. A summary of the suggested acceptable risk criteria is given in Table 17.

Table 17: Suggested maximum acceptable risk criteria

Criteria	Limits	
	To members of public	To members of public
Frequency of ignition (fire) (f^*)	< 1×10^{-5} y^{-1}	< 1×10^{-5} y^{-1}
Thermal intensity (I_{occ})	< 1050 s (kW $m^{-2})^{4/3}$	< 1050 s (kW m-2)4/3
Overpressure (Δp^{o}_{Rm})	< 250 kPa	< 250 kPa
Frequency of fatality (f_{fatal})	< 1×10^{-5} y^{-1}	< 1×10^{-6} y^{-1}

Often the output of a QRA can be considered by plotting a frequency-consequence curve, for example, such as that in Figure 49. This example is for the ignition of a flammable refrigerant that has leaked into the indoor unit, outdoor unit and into the room, when the airflow is either on or off. Using this approach is a useful tool for observing the overall risk, and in particular, helping to identify the situations that could be potentially high-risk. The figure is divided into four sections, where the upper right quadrant represents the region of "significant risk" (i.e., severe consequence occurring with high frequency), and the lower left quadrant representing the region of "negligible risk" (i.e., negligible consequence occurring with low frequency). Where risk values land within the regions of high risk, consideration can be given to design or procedural changes so that the risk can be reduced.

Figure 49: Example of a frequency-consequence curve for ignition of flammable refrigerant from different sized leaks into the indoor unit, outdoor unit and occupied space for an air conditioner



5.8.4 Flammability characteristics

The flammable characteristics of a substance also affect the risk in various ways, so it is important to consider these characteristics in light of the environment within which they will be used. The following provides a brief introduction to the aspects to be considered.

Lower and upper flammable limits – The flammability limits, and in particular, the LFL are used to relate the size of refrigerant charge to the dimensions of the spaces that the equipment may be located in. In addition, it is required for determining air flow rates for extract ventilation. They are also critical for the operation of refrigerant detectors in terms of set values.

Minimum ignition energy and auto-ignition temperature

These characteristics are primarily related to the consideration of sources of ignition. Both on the RAC equipment, and in certain cases, in the surrounding area, it is important to avoid potential sources of ignition. Ensuring that any potentially hot surfaces have a sufficiently low temperature, or devices that could produce an electro-static charge above the minimum ignition energy helps reduce the hazard. Similarly, service and maintenance technicians can consider the use of their tool and how they work on equipment with respect to these characteristics.

Heat of combustion, adiabatic flame temperature and laminar flame speed

These characteristics are of primary use when carrying out risk assessments. In particular these help understand the severity of the consequences of an ignition event. For example, the amount of thermal radiation emitted and the strength of a pressure wave caused by an explosion.

Refer to Appendix 4 for a detailed explanation of the flammability characteristics.

5.8.5 Refrigerant leakage

In carrying out risk assessments, it is essential to ensure that the leakage characteristics are well known, so that they can be represented precisely. Thus gathering empirical data on leakage is a vital exercise. In particular, the following information should be sought:

- Positions of the system where leaks arise from, and the locations
- Reasons for the leakage (corrosion, mechanical connections, broken seals, etc)
- Release rate

Such information should be drawn from as large a population of equipment as possible in order to achieve a sufficiently representative data-set. Furthermore, additional details should be recorded such as the age of installation, local environmental conditions, etc. It is also beneficial to request service and technician staff to record how much refrigerant they added to a system in order to get an impression of the size of the leaks.

Taking a systematic approach to leak analysis can yield benefits in terms of reliable quantitative data on leakage and appropriate means of mitigation. Table 18 provides some examples of possible causes of leaks.

For each cause of leakage, it is important to understand the conditions and mechanisms that lead to such a leak occurring, what the likelihood of them occurring with the system and anticipated conditions under consideration. A useful tool to carry out such an analysis is FTA (see Part 5.8.2). Latterly, what measures can be put in place to prevent those mechanisms and thus the leak from developing. Note that different types of failure apply to some piping materials (such as steel) and rarely to others (such as copper).

Table 18: Examples of causes of leaks, development rate and prevention

Type of leak	Cause	Development	Prevention
Forced rupture damage	mechanical impact from external object	Immediate	protect equipment against external impact, drop test
Pitting corrosion, crevice corrosion, galvanic corrosion	Presence of chloride, dissimilar metals	Slow, gradual	Avoid combinations, contaminants
microbiologically-induced corrosion	Presence of certain microorganisms	Slow, gradual	Prevent occurrence of stagnant moisture, protection of surfaces
Erosion-corrosion	High velocity flow, containing particulates	Slow, gradual	Reduce velocities and particulates
Stress-corrosion cracking	Strain and tensile stresses within pipe, pressure/temperature transients, ammonia and water presence	Gradual g immediate	Prevent combination of conditions
Fatigue cracking	Excessive fork harden-ing from due to vibration rate	Gradual g immediate	Good pipe design, vibration testing
Thermal fatigue	Thermal stratification, cycling, stripping	Gradual g immediate	Good pipe design, vibration testing
Pressure rupture, burst	Excessive internal pressure	Gradual g immediate	Good piping design, selection of pipe material, consideration of temperature fluctuations
Loosening of fitting	Vibration, poorly made connection	Immediate	Pressure limiting devices, proper design pressure
Softening of elastomeric seal	Chemical reaction with materials, high absorp-tivity	Slow, gradual to medium rate	No mechanical joints or well made mechanical joints, no screw fittings
Fretting	Repetitive rubbing of surface	Slow, gradual	Proper material compatibility checks
Liquid hammer	Pressure wave from instantaneous valve closing	Slow, gradual	Avoid contact between hard surfaces

All of the data can be collated in order to develop a distribution of different leak sizes for a particular set of equipment. Thus, for each nominal incremental leak size, the frequency and consequence may be evaluated. An example of such a data-set is provided in Figure 50.

Figure 50: Example of a leak size distribution for a set of systems, where large leaks are very infrequent and small leaks are much more frequent

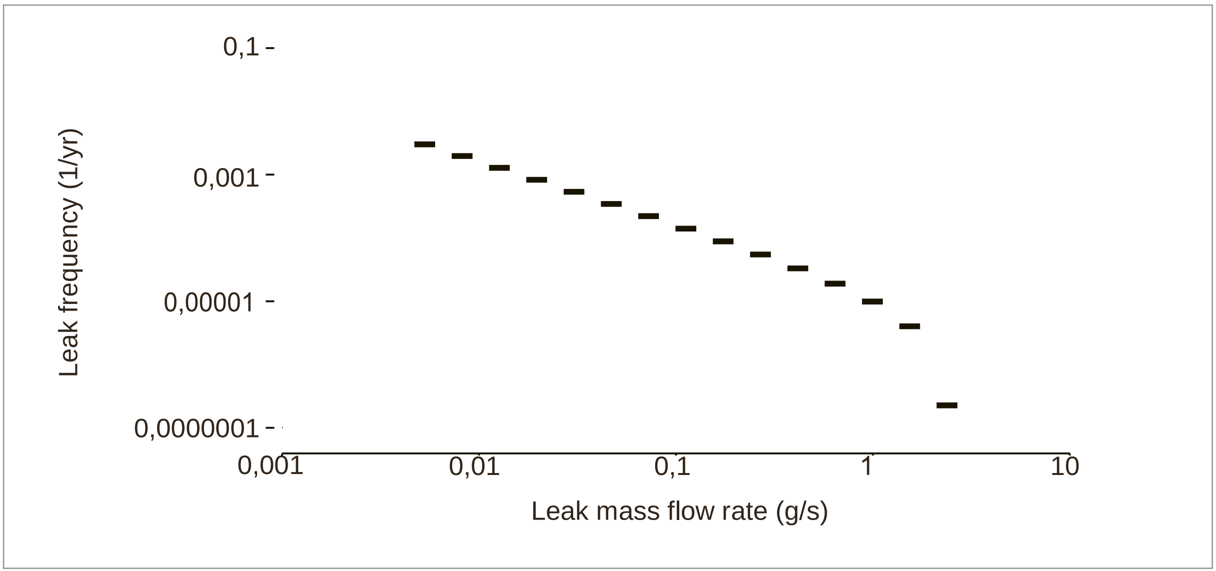
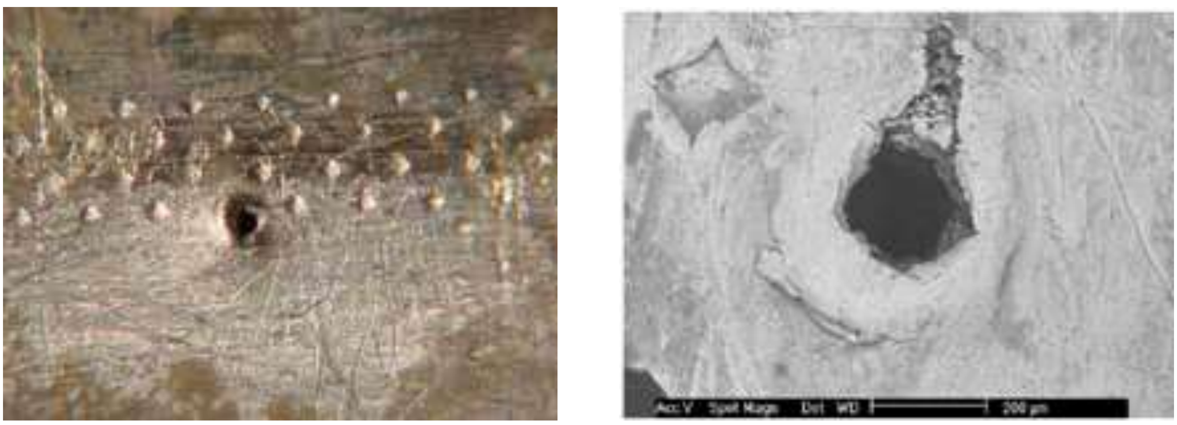
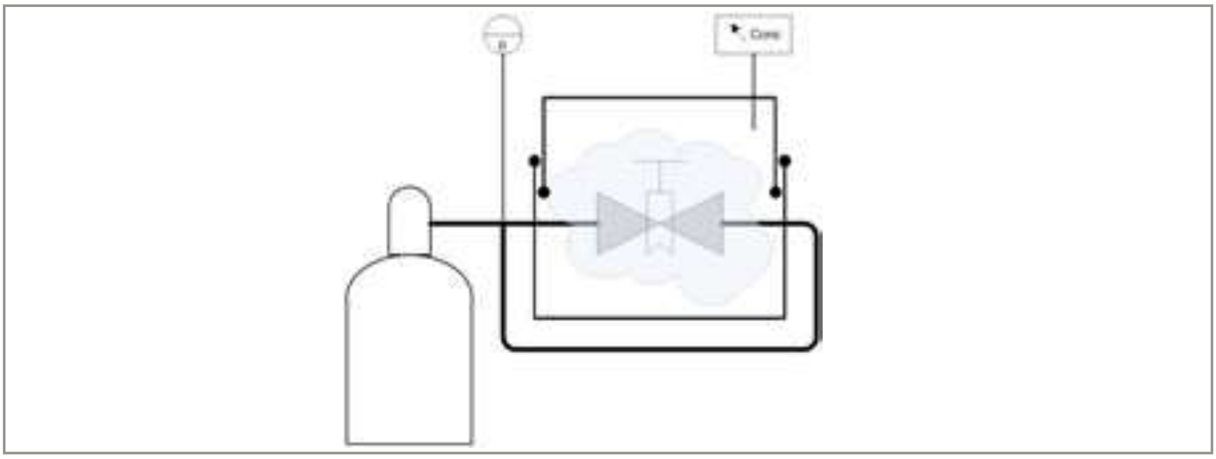


Figure 51: Example of refrigerant leak holes due to corrosion



Another means of evaluating the size of a leak is to enclose the leaking component within an air-tight container. Into the leaking component is fed a supply of gas, and then the gas concentration within the container can be measured and the additional mass of the vessel after a certain period of time. By using a mass balance, the leak rate for a given pressure differential (and particular gas) can be estimated. An example of the type of set-up that may be used is illustrated in Figure 52.

Figure 52: Option for measuring release rate from a leaking component, joint or other element



Also as a part of the leak evaluation process, it is useful to assess exactly how much refrigerant remains in the system after a leak has ceased, i.e., how much refrigerant will actually leak out, rather than the quantity that is charged into the system. Some refrigerant usually remains in the system, sometimes absorbed within the compressor oil, and also how much is retained in the internal volume of the system under atmospheric pressure. This may be done experimentally, by weighing the system before and after a leak, or estimated by calculation from the internal volume and the mass and solubility of the refrigerant within the compressor oil.

The quantity of refrigerant retained can typically vary from 5% to 50%, depending upon the size and geometry of the system, the operating mode and operating conditions, type of oil, and so on.

5.8.6 Dispersion of refrigerant releases

Once a leak has occurred, the risk becomes a function of the behaviour of the gas with respect to the local environment. In particular, the release may originate from a refrigerant containing part located external to the confines of the refrigerating equipment, or from a part located within the housing. If the release occurs within the housing, then it may be rapidly transferred out of the equipment, or it may accumulate within. For example, if the conditions are such that the refrigerant exiting the leak hole is immediately mixed with the surrounding air within a very large space, then the amount of flammable material will be small, and unlikely to come into contact with a source of ignition. Conversely, if the refrigerant leak enters a relatively small space with minimal air movement, then due to its density being greater than that of air, it may accumulate and exist for a longer period of time within its flammable limits. The larger this “cloud” and the longer it exists for, then the greater the likelihood that it may come into contact with an active source of ignition.

Figure 53 and Figure 54 illustrate this concept of the formation of a flammable region for a release into a room, and into equipment housing (or even machinery room), respectively; the flammable region is the volume of the gas/air mixture that is in a concentration between the LFL and UFL.

Figure 53: Illustration of the flammable region following a refrigerant leak from an evaporator into a room

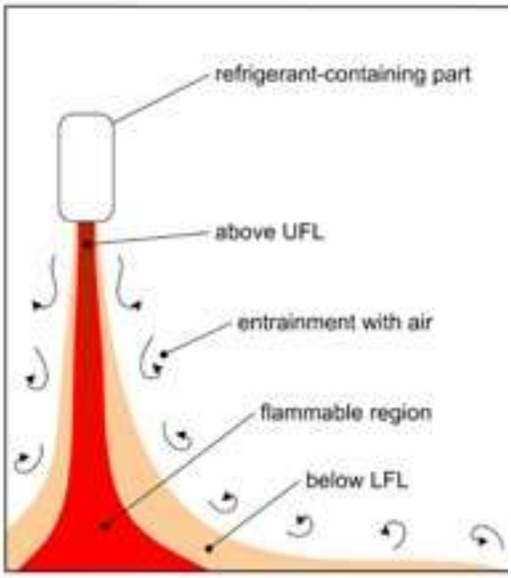
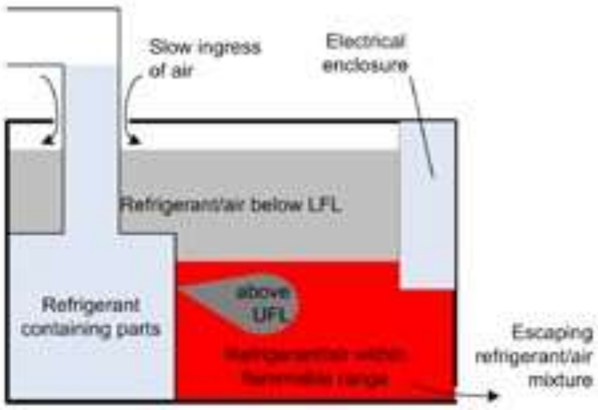


Figure 54: Illustration of the flammable region following a refrigerant leak within equipment housing and gradual escape of mixture



In order to estimate the amount and concentrations of released refrigerant that exists within its flammable range, it is important to be able to characterise how the release disperses. One means of evaluating the complex dispersion process is by observing the development of floor concentrations. Understanding the various physical parameters that affect the dispersion of a release is important for both carrying out a risk analysis and also for developing design features of the RAC equipment. Thus, the following elaborates on some selected aspects affecting dispersion of a release. (Appendix 5 contains a set of correlations for calculating average floor concentrations under a range of conditions.)

Release rate

Normally, that that a higher release flow rate produces higher concentrations, since a greater quantity is dumped in a shorter time, giving it less time to disperse before the region is flushed with more gas. For a finite charge, the mass flow rate of the refrigerant (assumed to be constant) dictates the release time, which implies that the shortest time for the total charge to be leaked will produce higher concentrations.

The minimum release time assumes a complete shearing of a refrigerant pipe, such that the compressor pumps out al the refrigerant within a matter of minutes. The actual time for this to occur depends of course upon the charge size, compressor displacement, component dimensions and so on. However, under real conditions a loss of refrigerant is likely to stop the compressor, thus slowing release rate, combined with dissolution from compressor oil, reduction of internal pressure due to rapid vaporisation of refrigerant, internal restrictions such as expansion devices and other valves, and so on. Experiments reveal that for smaller systems the fastest possible leak time is around three or so minutes, and longer for larger systems. In reality, leaks occur over a wide range of durations, from minutes to days to weeks and longer.

Figure 55 shows the maximum floor concentration for a release of R290 for the complete charge of refrigerant to be released over a range of different durations. In general it is seen that the longer the release time (or lower the mass flow rate) the lower the maximum floor concentration will be. Of course, most causes of leaks, a release with a high mass flow is unlikely to occur immediately; most leaks start small and evolve into larger ones.

Release velocity

Typically, a higher leak velocity improves the mixing of the released refrigerant within a space. Generally, a leak from a refrigeration circuit will be at very high velocity due to the large pressure difference. However, in some cases the leak may impinge on the inside surface of an enclosure causing the release into the room itself to have negligible momentum. Examples of this include releases inside a refrigerated compartment or within AHU casing.

Releases may be in vapour phase or mixed phase (once it expands into the atmospheric pressure and temperature). Vapour-phase releases are considered to be the worse case since two-phase releases are expected to produce more favourable mixing since the liquid rapidly flashes off to create a large amount of mixing within the room.

Release direction, height and location

The orientation of a release strongly influences floor concentrations. A downward direction leads to higher floor concentrations, whilst upward directed releases produce much lower concentrations. In the case of very low velocity releases though, the effect of orientation becomes minor since the momentum of the plume is small compared to buoyancy forces.

The mean concentration within a plume of released gas also reduces with distance from the source, which is reflected by floor concentrations. Figure 56 shows how sensitive maximum floor concentrations are to the release height. Given that refrigerant-containing parts of RAC equipment vary widely in their height, it is important to consider the effect of leaks from a variety of heights.

Figure 55: The maximum floor concentration following the release of a given quantity of R290 into a 25 m^2 room over different release times

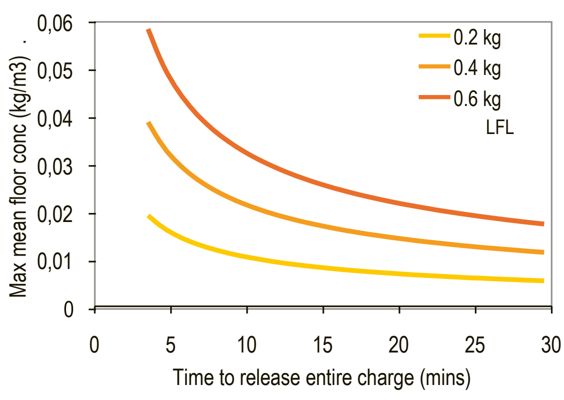
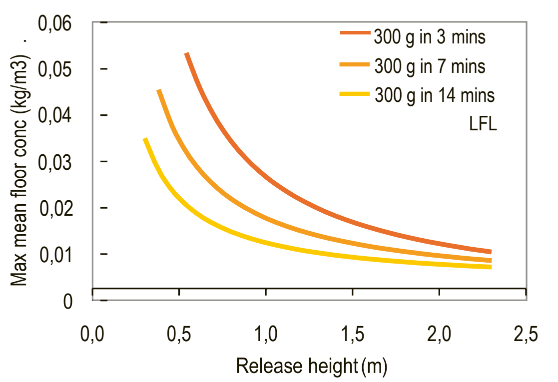


Figure 56: The maximum floor concentration following the release of a 300 g into a 25 m^2 room for a range of release heights for different release times



Room size

Generally the size of the room area and its volume will affect the concentrations arising from a release. As would be expected, for a given release mass, the floor concentrations will reduce as the room size gets larger, as shown in Figure 57. However, if a mass that is proportional to the room volume is released (for example, based on a fixed mass per m^3 of room volume) then the maximum floor concentration can be higher, as shown in Figure 58. This is because of the additional time it required for the refrigerant to move across the room. It is also noted that if there is some airflow within the room, the rate of increase in floor concentration with larger room size because diminished. In terms of room geometry, several studies have found that room shape and ceiling height had negligible influence on floor concentrations particularly in a still environment.

Figure 57: Maximum floor concentration for a 0.5 kg release into a room within 7 minutes under still conditions

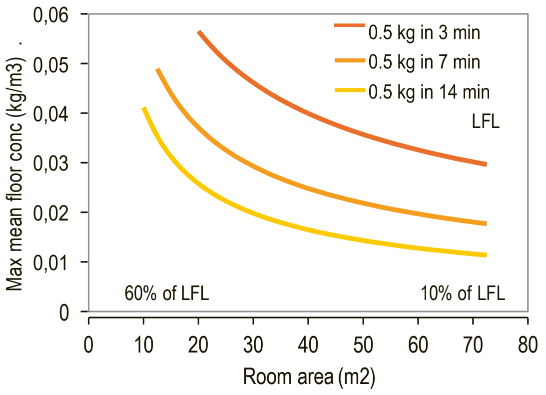
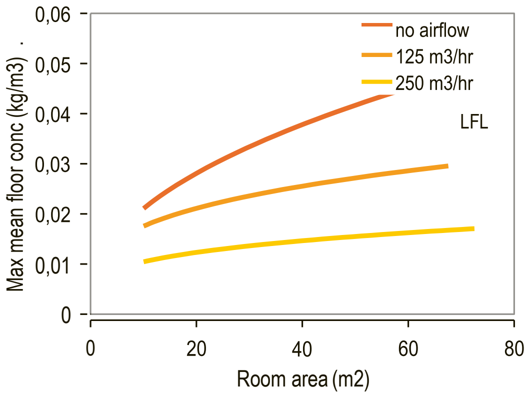


Figure 58: Maximum floor concentration for a release mass corresponding to 8 g/m³ into a room within 7 minutes, with and without airflow



Floor surface and obstacles

Normally, a courser floor texture will result in poorer mixing and thus higher concentrations because of the greater frictional resistance to the gas cloud moving across the surface. Thus thick carpets tend to be more hazardous than smooth tiles, for example. In terms of obstacles within the room, it is known that obstacles do not generally inhibit mixing, except in certain occasions where channels are created or when there is a barrier at floor level.

Air movement

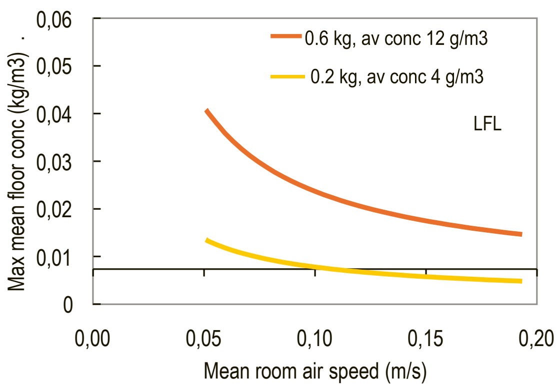
Air movement has a major influence on dispersion of a release. Firstly, movement of air is generated by the falling of the gas within the room, and may also be produced by infiltration, forced airflow and thermal sources. Since RAC equipment often utilises an integral fan to discharge air from the evaporator or condenser into the room, it is important to consider its effect on dispersion, as well as exhaust or other ventilation sources.

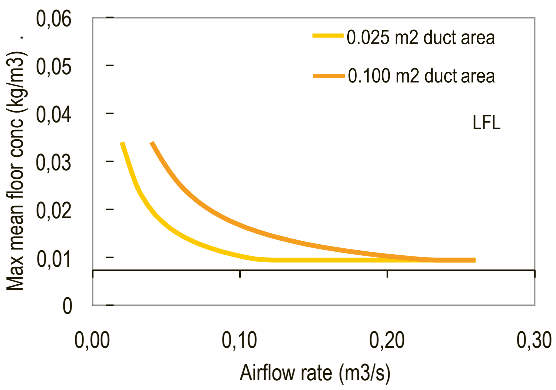
Infiltration rates within rooms are known to vary widely depending upon the construction of the building and the external weather conditions, typically varying from as low as 0.5 h^{-1} air changes to over 10 h^{-1} air changes. Measurements have shown that even the smaller infiltration rates of less than 0.5 h^{-1} influence floor concentrations. Thermally induced convection from warm surfaces can produce significant air mixing, thus lowering floor concentrations. Such thermal sources may include heat transfer through walls, generation of heat from human (or animal) occupants, from radiators or similar heaters and electrical appliances.

The air speed in the room has a strong influence on the mixing of a release in a room. Generally, the higher the airspeed the lower the concentrations (assuming all other parameters are constant). Also, it is known that once some critical air speed is achieved, then essentially homogenous mixing will occur, that is no stratification of the refrigerant release will be present. This is illustrated in Figure 59 for two different release quantities. In terms of airflow from RAC units, the discharge velocity of the air duct influences the room air speed. Figure 60 shows how a smaller duct area produces better mixing, despite the same airflow rate.

Figure 59: Effect of mean room air speed, of a release into a 25 m^2 room; at a sufficiently high air speed, the maximum concentration is the same as the mean room concentration

Figure 60: Effect of air outlet duct area on floor concentration of a 0.5 kg release in 7 min into a 25 m^2 room; the smaller duct area produces a higher velocity the creates better mixing





The positioning of the source of airflow discharge source, such as the fan or the duct, can also influence the mixing of the refrigerant. Further, the height of the ventilation inlet and outlet are critical to mixing, particularly with respect to the position of the release source. Since on RAC equipment, the fan height can vary widely with equipment type, it is considered an important variable. Figure 61 illustrates the influence of height variation of floor concentration – when there is no airflow, the closer the release to the floor, the higher the concentration. However, if there is airflow, and the duct discharge is at about the same position at the release, the height has little influence on the concentration. If the duct height is fixed at a high level, the presence of airflow causes the floor concentration to be reduced, but it continues to increase as the release position approaches the floor.

Similar trends apply to the direction of the airflow discharge; whilst most condensing units discharge air in a single direction, many duct outlets have a multi-directional discharge vent. As with the height of the discharge, the airflow direction relative to the direction of the release is a significant factor in the amount of mixing.

Refrigerant type

Several HCs are likely to be used in refrigeration and air conditioning systems: R290, R600a and R1270, and mixtures thereof. Each has a slightly different density and therefore they will exhibit slightly different dispersion characteristics. Figure 62 compares the floor concentrations for these three refrigerants over a range of airflow rates. It is seen that whilst R290 and R1270 behave similarly, R600a tends to give notably higher concentrations. The density of R600a vapour at atmospheric pressure and temperature is about 40% higher than R290 and R1270, and therefore has a tendency to sink towards the ground faster and is less susceptible to the effects of surrounding air movement.

Releases into small enclosures

A slightly different situation is that illustrated in Figure 54, where a leak occurs within the housing of the refrigerating equipment. Due to the level of confinement, only a relatively small quantity of refrigerant can escape from the enclosure and a flammable concentration rapidly develops, and thereon remains for a long duration. The small volume of the enclosure encourages homogenous mixing of the refrigerant and air mixture into a high concentration, thus with the continual ingress of air, it is possible that a flammable concentration could always be present. With this type of situation it is important to ensure that there is as free a flow of air through the enclosure as possible, which may of course require mechanical ventilation. In fact, this situation is also comparable to the case of a machinery room, where rather large quantitative of refrigerants (in relation to the size of the room) may be released into the space.

Figure 61: Effect of release height in relation to air discharge height, when the duct is at the same height as the release, and when the duct height is fixed

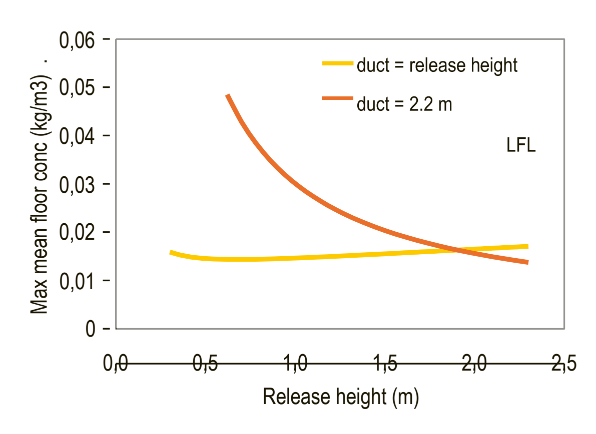
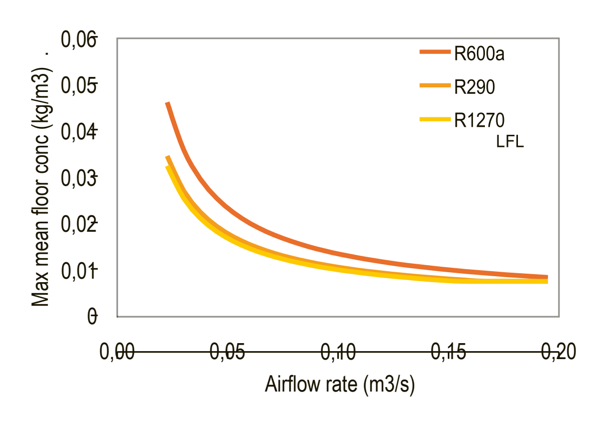


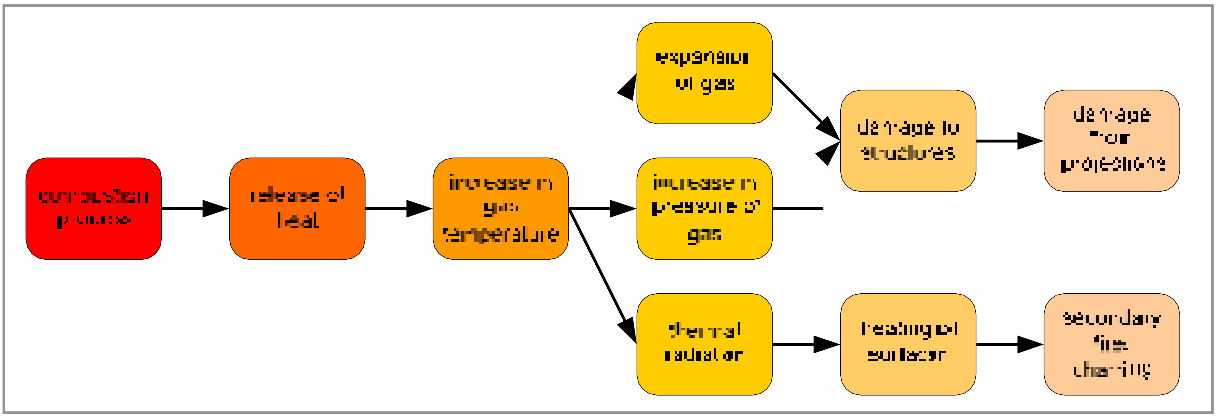
Figure 62: Variation in floor concentration for different HC refrigerants, over a range of air flow rates



5.8.7 Consequences of ignition

Once the refrigerant has leaked from the system and has formed a flammable mixture, it is important to understand the possible consequences if it is ignited. The consequence may be perceived as a change in the distribution of the energy that is released after the combustion process. The flow chart in Figure 63 illustrates the types of processes that are undergone to result in a consequence.

Figure 63: Combustion process leading to consequences



Consequences of ignition have two categories: a primary consequence which describes the events that occur as a direct result of ignition (e.g., pressure rise and thermal radiation) and a secondary consequence, which are the events that are caused by the primary consequence (e.g., damage to buildings and secondary fires).

The severity of the consequences is partly related to the initial quantity of heat released in the combustion process, but it is also affected by the environment under which the combustion process occurs. For example, in the case of R290, ignition of a stoichiometric mixture will result in a flame temperature of around 2000°C (i.e., approaching the adiabatic flame temperature, Table 24). If this occurs inside and the nearby surroundings are fairly combustible a secondary fire could occur, whereas if this occurs outside on non-combustive materials, the secondary consequence could be minimal.

The two forms of consequences that should be addressed are thermal intensity (I), which can be used to quantify degrees of burns to people (or likelihood of secondary fire), and overpressure ($\Delta p°$) that causes damage to building structure and injury to people. An outcome of large and/or $\Delta p°$ includes damage to buildings, their contents, injury to people and fatalities. (With regards to an ignited jet or plume, its velocity is generally greater than flame speed and so burning is unlikely to be sustained.)

The necessary I for flashover (that is, leading to a secondary fire) varies considerably with construction and furniture materials. Data showed flashover to occur over a range of I = 125 – 4100 s (kW m^{-2})$^{4/3}$, including different foam insulation, wood and gypsum based materials. Other easily combustible materials such as loose paper or hair may ignite at even lower I.

Thermal radiation

When a flammable substance burns, the heat energy is partially given off as thermal radiation. A "dose" of thermal radiation may be sufficient to cause burns to individuals nearby. The severity of burns is a function of heat flux and its duration, and this dose is termed thermal intensity, and it is a function of the heat flux from the combustion and the duration that the heat source is present (say, the burning time). The heat flux radiated onto an occupant (q_{occ}, in kW m-2) is a function of the total heat released (the product of the mass of flammable material and its heat of combustion), the burning time, and an incidence ratio which is influenced by the size and shape of the flammable volume.

At around I_{occ}= 115 s (kW m^{-2})$^{4/3}$ pain will be felt on exposed skin, becoming more severe with higher I_{occ}. Above I_{occ} = 1050 s (kW m-$^{-2}$)$^{4/3}$ fatalities are expected and death is almost guaranteed at 6500 s (kW m^{-2})$^{4/3}$.

Overpressure

When a flammable mixture is ignited, the exothermic reaction raises the temperature of the combustion products, translating to an increase in pressure and/or volume. Under ideal conditions, where ignition is at the centre of a spherical stoichiometric mixture, the maximum pressure or volume can be reliably determined from the gas law. Based on the initial (ambient) temperature of the flammable volume, and the maximum adiabatic flame temperature, the maximum pressure that can be reached is approximately seven times the atmospheric pressure, assuming a confined (fixed) volume that is completely filled with the mixture. Conversely, if the flammable mixture were in an unconfined volume (i.e., constant pressure) its volume after combustion would be approximately seven times the initial volume of the flammable mixture. For most situations under consideration, the flammable material is within a partially confined space and only occupies part of that space. This implies both a pressure rise, and a volumetric change of the burning mixture within the room. As a result the overpressure within the room ($\Delta p°_{Rm}$) will be less than seven times atmospheric pressure.

The pressure and/or volume of a flammable mixture increase exponentially following ignition until a maximum pressure (p_{max}) is reached, and that development of Δp at time (t) after ignition follows the "cube-law". The rate of the burning front under ideal conditions is at a speed that corresponds to the laminar burning speed (about 0.4 m/s for HCs, see Table 24). However, the influence of room geometry, obstacles and air movement creates turbulence which further accelerates the flame front. Based on experiments in fairly empty rooms, this corresponds to an increase of about three times the laminar burning speed.

Most rooms and enclosures are not completely sealed, and most occupied spaces have paths in the room fabric through which developed pressure will escape. As $\Delta p°_{Rm}$ rises, material may be vented from the room, and this occurs in two stages. Initially, any openings such as gaps in the room fabric, ventilation ducts, etc, allows the higher pressure gas to escape from the room. Secondly, certain barriers that comprise the room construction may eventually give way at a given $\Delta\rho^{\circ}_{Rm}$, thereby enlarging the venting area. In both cases, the exhausted material results in a lower rate of pressure rise. The overpressure at which panels, windows and other items are blown out, is a function of their mass (inertia), size and the strength of fixings.

Four examples of $\Delta\rho^{\circ}_{Rm}$ development over time are given in Figure 64, which were based on a flammable R290 mixture in a 40 $m^2 \times 3$ m room. By far the greatest $\Delta\rho^{\circ}_{Rm}$ is for a fully confined room that is entirely filled (120 m^3) with a stoichiometric mixture. By introducing a vent panel (equivalent to 5% or the total wall area), there is a major reduction in $\Delta\rho^{\circ}_{Rm}$ as the excess pressure is rapidly exhausted (noting also that the burn time is reduced because some of the flammable material was vented before it was burned). A more realistic situation is where the room contains a flammable layer of 0.5 m deep (or 24 m^3 at a concentration between LFL and stoichiometric), and when ignited produces $\Delta\rho^{\circ}_{Rm}$ proportionally lower than the completely flammable room. Again, by introducing a vent, $\Delta\rho^{\circ}_{Rm}$ is further reduced.

Figure 65 provides examples of the overpressure evolving from different design features of equipment housing. It is assumed that refrigerant has leaked into a rigid metal enclosure that is half filled with a stoichiometric gas/air mixture (this may also be analogous to a machinery room). Simulations for four situations are presented:

- Housing with 0.5% of the enclosure wall area open
- Housing with 10% of the enclosure wall area open
- Housing with a steel panel covering 15% of the wall area
- Housing with a plastic panel covering 15% of the wall area

Figure 64: Examples of room overpressure development under different situations

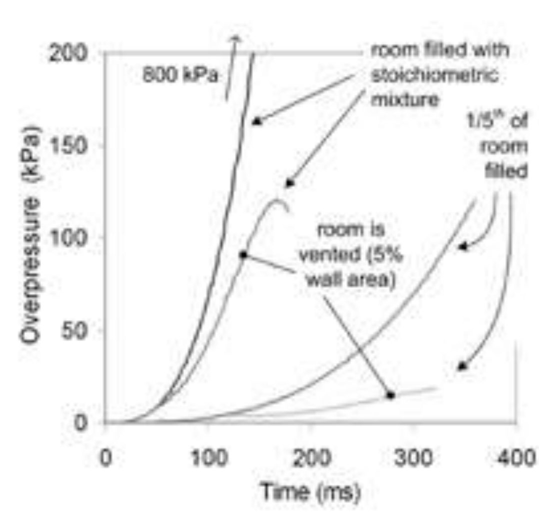
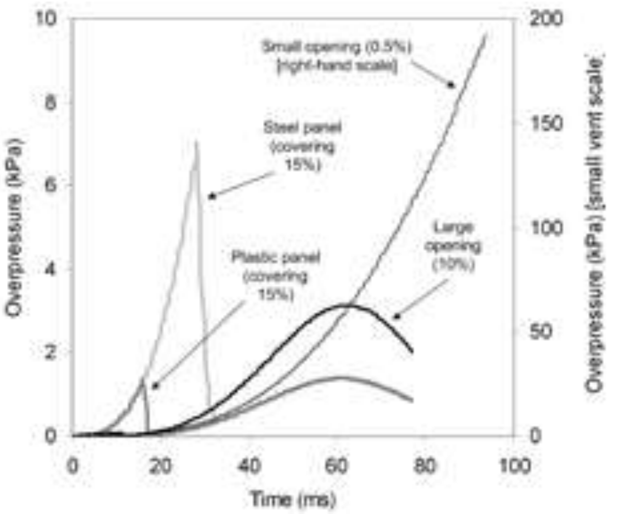


Figure 65: Examples of compartment overpressure development with different designs



It can be seen that with a very small opening, the effects of ignition could result in a significant overpressure (nearly 200 kPa), with the possibility of the resulting shockwave causing notable damage to property. However, if the opening is significantly larger (say 10% of the enclosure surface area, in this case) then the rising pressure is rapidly vented, and the resulting overpressure is some 100 times lower than in the previous case. The use of detachable panels has a similar effect, although there tends to be an initial peak that represents the blowing-off from its fixings. Nevertheless, the resulting overpressure is massively reduced compared to the small vent opening, and it would be highly unlikely to result in secondary

damage. This example emphasises the importance of appropriate design of equipment housing.
If there is overpressure within an enclosure that escapes, a shock-wave will travel outwards. The pressure wave will have an exponential decay away from source, and the rate of decay is mainly a function of source overpressure only. However, within enclosed spaces, shockwave will be reflected (but dampened), but nevertheless, it may still damage building structure.

To interpret the severity, any $\Delta\rho^{\circ}_{Rm}$ below about 3 kPa is unlikely to cause any physical damage to persons or property. Persons exposed to overpressure (alone) above about 250 kPa would be begin to suffer fatalities. As $\Delta\rho^{\circ}_{Rm}$ approaches 450 kPa, death is almost guaranteed.

PART 6: WORKING ON SYSTEMS AND EQUIPMENT

6.1 TECHNICIAN ACTIVITIES AND REFRIGERANT HANDLING

6.1.1 Introduction

This section mainly deals with the issues faced by technicians that are working on systems and equipment that use HC refrigerants. Primarily this involves refrigerant handling aspects, but also checking that the area and the equipment are safe to use HCs and that refrigerant containers are handled properly.

Studies on flammable refrigerants have demonstrated that the risk of fire or explosions is higher when systems are being worked on, compared to when they are operating normally. Due the fact that the possibility of a release of refrigerant and the presence of potential sources of ignition is greater, the risk of ignition is typically 100 – 1,000 times greater than when the equipment is not subject to human interference. This highlights the importance of having only competent technicians working on such systems, and that it is essential to follow proper safe working procedures.

The main stages of the RAC equipment life that require handling of refrigerants include the following:

- Assembly and installation of systems and equipment
- Carrying out routine maintenance on systems and equipment
- Carrying out servicing and repair activities to systems and equipment
- Decommissioning, dismantling and disposal of systems and equipment

During these stages, a variety of specific activities are normally carried out that involve either refrigerant handling directly, or the possibility of contact with an emission of refrigerant. These include, for example, refrigerant recovery or venting, evacuation, leak checking and gas detection, charging and general handling of cylinders. On the other hand, there are also certain activities that do not relate directly to the refrigerant, but are equally important since they also contribute to the safety of the system in the event of an accidental release or provision of warnings to others, such as proper sealing of systems, repairs to electrical components and marking of systems.

Whilst the requirements detailed forthwith may seem considerably more onerous than when non-HC refrigerants are used, in actual fact, the majority of the requirements are identical for both flammable and non-flammable refrigerants. However, it is the importance of following the rules precisely for safety purposes that is the primary difference. Therefore, in addition to having specific knowledge related to HC refrigerants, technicians must also be knowledgeable in RAC systems technology in general and should be fully competent in the safe handling of non-flammable refrigerants.

Whatever the type of refrigerant, some common hazards apply to all refrigerants, such as:

- Gases and liquid under pressure, when released under atmospheric conditions can cause freeze burn (similar to frost bite) if it comes into contact with skin. Therefore, proper personal protection (such as goggles, gloves and full body clothing) must be worn. If the skin does come into contact with refrigerant under these conditions, treat the affected area by bathing the area with cold water as the first aid followed by consultation with a medical professional.

- Released refrigerant will displace air in the lower part of the room, therefore posing the threat of asphyxiation and causing suffocation to occupants or other toxic effects. Therefore, ventilation is required and the technician must be aware of the necessary actions to take in this event. In case of such accidents, the person must be removed to an uncontaminated area and kept warm and still, and if required, given artificial respiration or oxygen and seek medical help if needed.

Furthermore, it is difficult to anticipate all possibilities and situations, so it is essential to be aware that the requirements here are not exhaustive, and are intended as a general guide only. Additional precautions may be appropriate dependent upon the particular equipment and conditions.

Whilst it is the technicians that will be carrying out the work on the system, and handling the refrigerant, the employer and the owner and operator of the facilities have the overriding responsibilities. In most countries, this is a legal responsibility. In particular, the employer/owner/operator must be responsible for the following:

- Ensuring that all equipment and materials for use by the technician are fit for purpose and are in an acceptable condition
- Ensuring satisfactory working conditions and, in particular, adequate lighting, good accessibility, etc
- Ensuring that working procedures/instructions are available for each process to be undertaken by the technician
- Ensuring that the person sent to carry out a particular activity is component to do so, and if not, then a supervisor of the required level of competence is always present
- Ensuring that a general strategy is in place so that correct working practices are employed

Lastly, all parties – technicians as well as the employer, facilities owner and operators – must put in place a system to record all the actions that have taken place, and in particular record any accidents, incidents and near misses that have occurred during the working activities. In the event that some such event does occur, it should be investigated and measures put in place to prevent it from reoccurring (see Part 1.3 and Part 2). In the case that there is a problem with the RAC equipment, the fault or problem must be reported to the supplier or manufacturer so that the problems can be rectified accordingly. All activities associated with handling the equipment should be logged on data-sheets (see Appendix 9 for an example).

6.1.2 Risk assessment

Whenever someone is working on a system that contains flammable refrigerants, the 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 simultaneously occur:

- 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 the above three occurrences has to be prevented. An analysis of each working activity must be carried out.

The employer and/or facilities owner and/or operator (or its representative, which may be authority delegated to a sufficiently competent technician) has to make a suitable and sufficient assessment of the risks to employees arising from the flammable substance and to eliminate or reduce the risk, as far as is reasonably practicable. This is achieved by adopting a process which either eliminates or reduces the risk. The risk assessment procedure must consider:

- The hazardous properties of individual substances and the hazardous properties of substances when used in combination and the circumstances of the work
- The individuals that may be at risk of harm
- The likelihood that an explosive atmosphere will occur and its persistence
- The likelihood that ignition sources will be present and become active and effective
- 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, to the following (in order of priority):

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

The risk assessment must be regularly reviewed and make any revisions that are found to be necessary. Before a workplace containing places where a flammable mixture could occur can be used for the first time, the employer and/or facilities owner and/or operator has to ensure that its overall fire and explosion safety is verified by a competent person. All risk assessments must be documented.

SAFE WORKING CARDS

Companies should provide their employees with laminated cards to assist their working safety on site. These laminated cards should include a site safety check list and a basic risk assessment procedure. They should be hard-wearing and be easy and convenient for the technicians to use, comprising the most important aspects to remember. If the technicians are likely to encounter a range of different types of equipment, it may be pertinent to develop such cards for each specific type of system or environment.

Figure 66: Identification of activities that may involve and emission of refrigerant

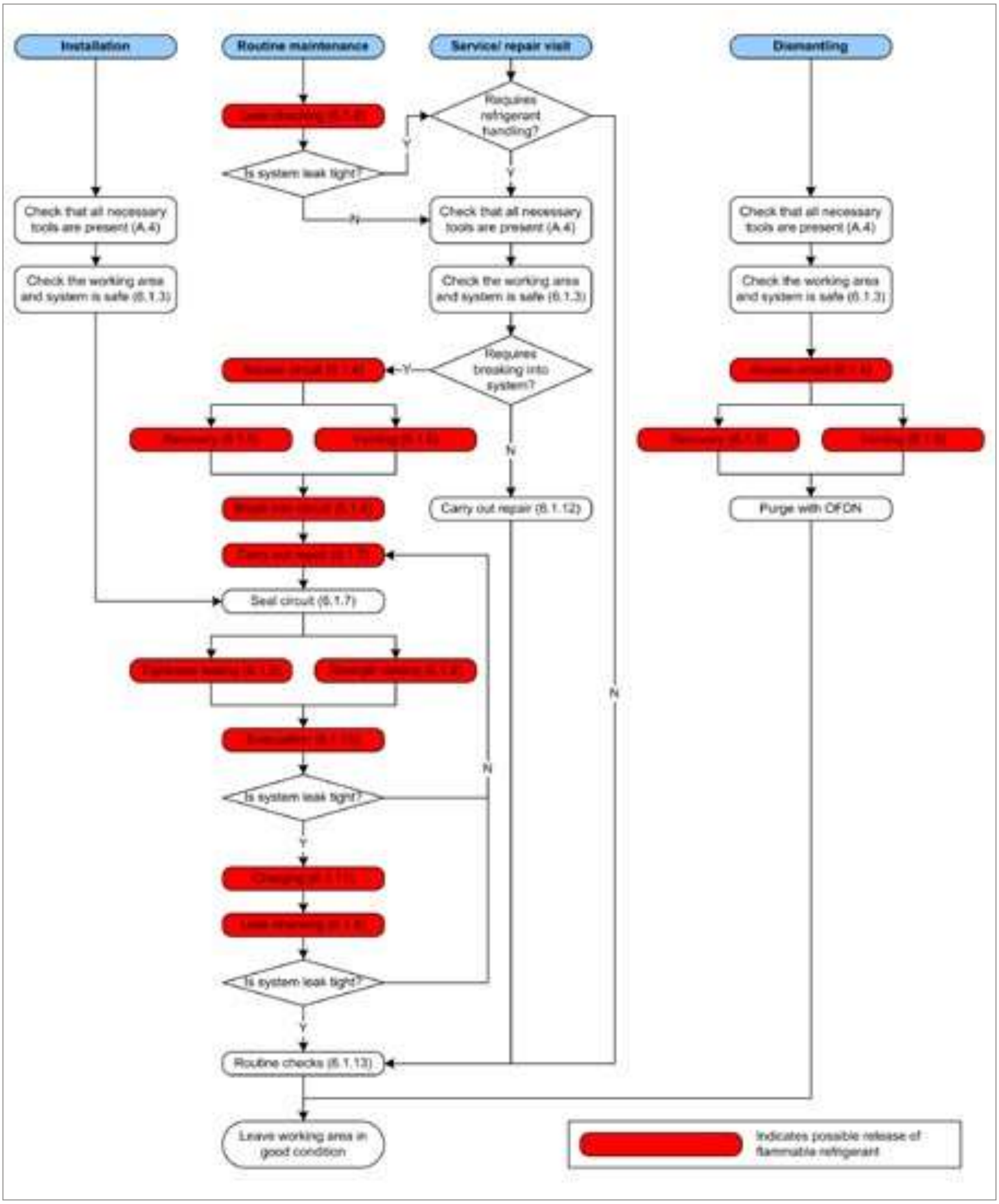


Figure 66 shows typical sequence of activities that technicians may carry out when working on a system for the purposes of installation, maintenance, servicing and dismantling. During any of these activities, the technicians may have to carry out refrigerant handling activities, or may come into contact with an emission of refrigerant for some reason. The majority of such situations are identified within Figure 66; but of course, many other circumstances arise that also demand additional considerations.

The following sections therefore provide some guidance of the important considerations for these activities in particular, so that appropriate risk assessment and subsequent working instructions can be developed. In addition, guidance is also provided for the other activities, i.e., where the presence of flammable refrigerant is not anticipated, but which must be addressed since they also contribute to the overall safety of the site-work and to the longer-term safety of the equipment when technicians are not present.

WORKING AREA GAS DETECTION

Whilst technicians are working on systems, it can be advisable to make use of a portable gas detector. Such a detector can be clipped to clothing or placed on the floor within the working area. It should be switched on for the duration of the work, and set to alarm at 15% of the LFL, to warn that flammable concentration may be nearby. In this way, technicians can be alerted whenever an inadvertent release of flammable refrigerant occurs, and can immediately act upon the relevant emergency procedures.

6.1.3 General precautions for working

Before carrying out any work on a refrigerating system or associated equipment, it is essential to ensure that the immediate area is suitable for working safely, and the appropriate precautions are in place. In particular, prior to beginning work on systems containing HC refrigerants, safety checks are necessary to ensure that the risk of ignition is minimised.
The following precautions should be taken before working on the refrigerant circuit:

- All staff and others working in the local area must be instructed on the nature of the work being carried out
- The area around the workspace must be sectioned off
- Obtain permit for hot work (if required)
- Working within confined spaces should be avoided
- No flammable materials are stored in the work area
- No ignition sources are present anywhere in the work area
- Suitable fire extinguishing equipment (CO_2 or dry-powder type) is available within the immediate area
- The work area is properly ventilated before working on the refrigerant circuit or before brazing or handling electrics

- Ventilation should safely disperse any released refrigerant and preferably expel it externally to the outside
- Suitable flammable gas detectors are present and operating to warn workers of a dangerous concentration of refrigerants and that the gas detection equipment being used is non-sparking, adequately sealed or intrinsically safe
- All maintenance staff have been instructed
- Erect appropriate signage, including "no smoking" and "do not enter the area" signs
- All appropriate and necessary tools and equipment are available

Only work with the appropriate type of nitrogen: oxygen-free dry nitrogen (OFDN). The presence of oxygen can introduce a flammability risk (and the presence of moisture can be damaging to the reliability and operation of the refrigerating system). In some countries, carbon dioxide (CO_2) may be more readily accessible to technicians than nitrogen; this is an acceptable alternative, provided that it meets the same requirements in terms of no oxygen and no moisture, i.e., oxygen-free dry carbon dioxide.

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.

Other activities required to be carried out on the system or equipment that require the assistance of other skilled personnel, should only be carried out under the supervision of the person competent in the use of flammable refrigerants.

If the installation permits, it is recommended that the equipment is removed from its existing position to a controlled workshop environment where work can usually be conducted in a more controlled and thus safer manner.
Some initial issues must also be addressed prior to working on a particular system or piece of equipment before carrying out any work:

- It is essential that the technician is completely familiar with the equipment and all its detail
- The technician must be familiar with the equipments purpose and operation
- The equipment should, whenever possible, be isolated from the electricity supply
- Ensure that all refrigerant handling and mechanical handling equipment is available
- All necessary personal protective equipment is available and being used correctly

TEMPORARY FLAMMABLE ZONES

When working on systems using flammable refrigerants, the technician should consider certain locations as "temporary flammable zones". These are normally regions where at least some emission of refrigerant is anticipated to occur during the normal working procedures, such as recovery, charging, and so on; typically where hoses may be connected or disconnected. In anticipation of the maximum quantity of refrigerant that may be released during such a procedure (such as disconnecting a hose whilst it is full of liquid refrigerant), the minimum distance from this point that should be considered as a temporary flammable zone, is around half a metre in all directions.

6.1.4 Accessing a refrigerant circuit

Ideally when accessing a system, either to add refrigerant or remove it, service valves should be employed. If service valves are not present, then a shraeder type valve should be selected. For smaller systems there may not be any direct means of accessing the system, in which case two options are available:

- Application of a piercing tap valve
- Use of piercing pliers

If either of these methods is applied, then it is essential to select the correct diameter fitting for the pipe, otherwise it is highly likely that the refrigerant will not be contained and a large release will occur. It is also important to note that neither of these methods is considered to be a permanent access point to the system. Therefore, after all the refrigerant has been removed and the system flushed with OFDN, the pliers or piercing valve must be removed, and replaced with a permanent connection.

Regardless of the means of accessing the system, any method will result in some emission of refrigerant and therefore the appropriate precautions should be put in place to minimise the size of the emissions and eliminate any potential sources of ignition.

Under no circumstances must the system be broken into it contains any flammable refrigerant or any other gas under pressure, by means of cutting or breaking pipework.

A number of other aspects must be considered when gaining access to a system:

- If it is necessary to break into a system, especially to change parts or to carry out brazing, all of the refrigerant must be recovered from the system, using the appropriate procedures detailed below
- Although it may be possible to pump-down a system and isolate refrigerant within parts of the system that is not being worked on, it is generally preferable to remove the entire refrigerant charge in case of unexpected failures
- If refrigerant has been removed, the system must be flushed with OFDN; although there will always be some residual HC within the system, the concentration in OFDN must be sufficiently low to render it non-flammable (thus, this process may need to be repeated several times)
- Flushing is achieved by breaking the vacuum in the system with OFDN and continuing to fill until the working pressure is achieved, then venting to atmosphere, and finally pulling down to a vacuum
- Before carrying out any further work, the area should be checked with an appropriate refrigerant detector prior to and during any hot work to make the technician aware of a potentially flammable atmosphere
- OFDN is then be purged through the system both before and during the brazing process; this operation is absolutely vital if brazing operations on the pipework are to take place
- Compressed air or oxygen must not be used for flushing or filling the system under any circumstances whatsoever

In all cases, only refrigerant handling and other service equipment designed for use with flammable refrigerants should be employed when working with HC refrigerants.

6.1.5 Refrigerant recovery

Prior to working on a system, it is necessary to remove the refrigerant from the system. Under most circumstances it is recommended to recover the refrigerant, as opposed to venting it. Conventional recovery procedures, as used for any other refrigerant, are equally applicable when dealing with HC refrigerants. However, special attention should be paid to certain aspects:

- The recovery machine used must be suitable for use with flammable refrigerants, and in particular, it should not have any potential sources of ignition (the requirements are the same as those for a refrigerating system)
- The recovery cylinder must be suitable for the refrigerant used (specifically, in terms of the pressure rating and the compatibility of valve seals, etc)

When connecting hoses between the refrigeration system, manifold gauges, recovery machine, and recovery cylinder, ensure that the connections are secure and there are no potential sources of ignition nearby. Since it is good practice to purge the hoses, manifold and recovery machine prior to recovery to avoid the ingress of refrigerant, this should be done to minimise the emission of refrigerant but also whilst making sure that there is sufficient ventilation to dilute the release.

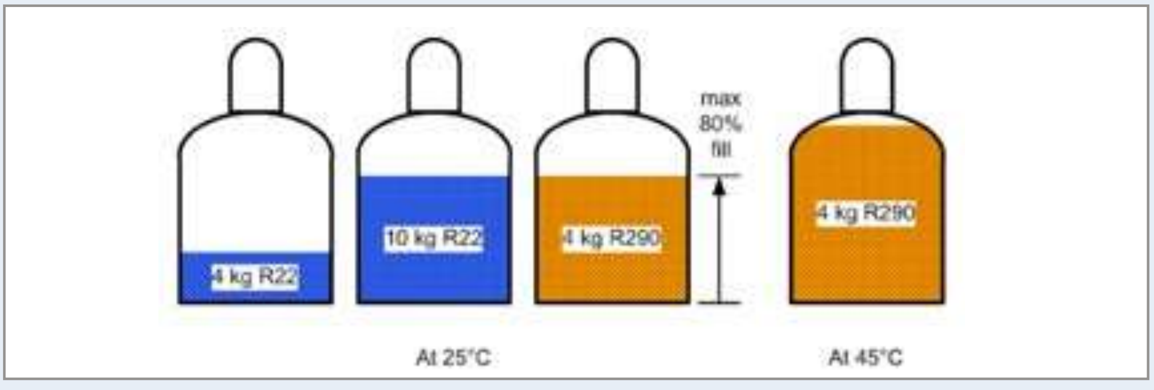
Filling of the recovery cylinder should be done carefully by monitoring the mass of refrigerant added into the cylinder, thus the cylinder should be kept preferably on electronic balance throughout the entire procedure. Ensure that the cylinder does not overfill, that means the cylinder is not filled to more than 80% of its volume with liquid refrigerant. Similarly, the discharge pressure should also be monitored to ensure that the maximum allowable pressure of the recovery cylinder is never exceeded. After recovery has been completed, the recovery cylinder should be labelled with the type and mass of refrigerant it now contains.

RECOVERY CYLINDERS – BE CAREFUL!

When using a refrigerant recovery cylinder with HC refrigerants, it is essential to use it properly. Liquid HCs have less than half the density of fluorinated refrigerants, and therefore they take up more than twice the volume within a cylinder. If this is not considered when adding refrigerant to a recovery cylinder, there is a possibility of the recovery cylinder bursting – the consequences are severe! Any recovery cylinder should be filled to a maximum of 80% of its volume. If the refrigerant is R22, it must only be filled to 80%; if the refrigerant is R290, is must only be filled to 80%. However, in the case of R22, the mass may be 10 kg, whereas with R290 the mass may only be 4 kg. The figure below illustrates this concept. The essential thing to remember is that when the cylinder gets warmer (as it may do whilst standing outside in the direct sunlight, or sitting in a van being transported) the liquid expands and takes up more volume – this is also shown in the figure below. If the liquid expands too much, then the cylinder will be unable to withstand the pressure and will subsequently burst, certainly causing damage and injury. The maximum fill capacity of the cylinder can be estimated from:

Max fill of HC (kg) = 0.4 × max fill of HFC or HCFC (kg)

For a more accurate calculation, the conversion factors in Table 20 can be used instead of 0.4.



The recovery machine should be operated until the system pressure reaches a value of 0.3 bar, absolute (-0.7 bar gauge) or lower. Since HC refrigerants tends to be soluble in many types of oil, there may be a subsequent rise in pressure because of the slow desorption of refrigerant from the compressor oil. Thus, a second or third run of the recovery machine may be necessary. Once the refrigerant has been recovered to the appropriate system pressure, the system should be flushed with OFDN, to render the contents non-flammable.

General guidance on safe recovery procedures can be found in other publications.

6.1.6 Refrigerant venting

Venting may be carried out as an alternative to recovering the refrigerant. Because HC refrigerants have no ODP and negligible GWP, under certain circumstances it may be considered acceptable to vent the refrigerant. However, if this is to be considered, it should be done in accordance with the relevant national rules or regulations, if they permit. In particular, before venting a system, it would be necessary to:

- Ensure that legislation relating to waste material has been considered[42]
- Ensure that environmental legislation has been considered
- Ensure that legislation addressing safety of hazardous substances is satisfied

Normally, venting is only carried out with systems that contain a small quantity of refrigerant, typically less than 150 g; larger quantities should be recovered.

If venting is to be carried out, a set of special procedures is required to ensure that it is done safely, by following the general safety procedures discussed within this section, and through appropriate use of a suitable hose:

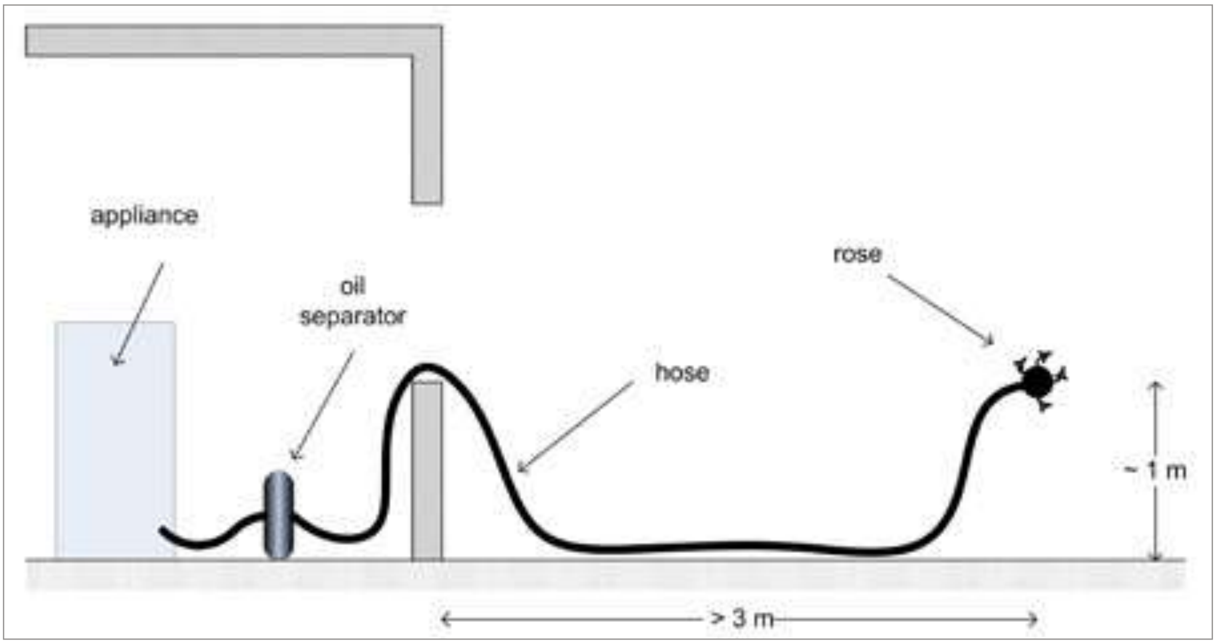
- Venting to inside a building is not permissible under any circumstances
- Venting must not be to a public area, or where people are unaware of the procedure taking place
- The hose must be of sufficient length such that it will extend to at least 3 m beyond the outside of the building
- The venting should only take place on the certainty that the refrigerant will not get blown back into any adjacent buildings, and that it will not migrate to a location below ground level
- The hose it made of material that is compatible for use with HC refrigerants and oil
- A device is used to raise the hose discharge at least 1 m above ground level and so that the discharge is pointed in an upwards direction (to assist with dilution)
- Ideally, there should be a type of rose on the end of the hose so that the vented refrigerant can discharge in different directions, with fairly small outlet orifices (so as to assist dilution)
- Close to the inlet of the hose, an oil separating device is fitted to present the emission of refrigeration oil, so that it may be collected and disposed of properly following the venting procedure (a recovery cylinder may be used for this)
- There must be no sources of ignition near the hose discharge
- A flammable gas warning sign must be positioned close to the hose discharge
- The hose should be regularly checked to ensure that there are no holes or kinks in it, that could lead to leakage or blocking of the passage of flow

When carrying out the venting, the flow of refrigerant should be metered using manifold gauges to a low flow rate, so as to ensure the refrigerant is well diluted. Once the refrigerant has ceased flowing, the system must be flushed out with OFDN; if not, then the system should be pressurised with OFDN and the venting procedure carried out two or more times, to ensure that there is minimal HC refrigerant remaining inside the system.

42 Within the EU for example, there are conflicting views as to whether venting of such certain refrigerants is permissible.

A schematic diagram illustrating the vent hose is provided in Figure 67.

Figure 67: A diagram illustrating the positioning and design of the vent hose



6.1.7 Repair of leaks

It is of utmost importance to properly repair refrigerant leaks, as soon as they are discovered. If they cannot be repaired immediately, the refrigerant charge should be removed from the system until the point at which the leak can be properly repaired. A number of considerations are relevant when attempting to repair a leak:

- Repair the leak properly – this means, removing the refrigerant, examining the leak source, determin- ing the reason for the leak and carrying out the proper course of action (it does not mean simply try to tighten the connection, or some other "quick-fix")
- From examining the leak and subsequently determining the cause, try to identify and action relevant means to ensure that the leak will not reoccur
- If the leak has occurred from a flared connection, if possible try to replace it with a brazed or similarly effective joint
- Before embarking on the repair, ensure that the refrigerant had been removed and the system flushed with OFDN, especially if brazing is to take place

If system has been accessed using means such as piecing plies or line tap valves (due to there being an absence of appropriate screwed fittings for manifold gauge hoses), it is absolutely not acceptable to leave these devices attached to the system – they are highly prone to leakage and are easily mishandled. Instead, there exist various options for re-sealing a system, including fittings using brazing, press connections (e.g., "lok-ring"), Euro-flare connections and ferrule compression joints (e.g., "swagelok") (see Part 5.2). Whichever method is used, the pipe where the line tap valve or piercing pliers had been used must be replaced, and a proper charging point, such as Schrader valve or some other service port be fitted. Remember that whether a service prot of a Schrader valve is used, the cap must always be fitted.

In general, the guidance on leak prevention should be followed when repairing a leak (see Part 5.2).

6.1.8 Leak checking (for tightness testing)

Leak detection is an important activity to carry out when working on refrigeration systems, and an essential one for systems that use HC refrigerants. It is also vital to recognise that leak detection is not gas detection; gas detection is merely an aid to detecting leaks. It is noted that some methods used for leak detection do not necessarily rely on the detection of gas.

During manufacturing or factory assembly of the system, the preferred method of leak detection is to pressurise the system with helium and use a highly sensitive helium gas detector to search for leaks. There is specific equipment available for carrying out these procedures. However, using pressurised helium detection is not convenient for site work. Therefore a number of other means for leak detection may be considered during on-site work:

- Bubble test: the system is pressurised to the nominal working pressure with OFDN (or the refrigerant, after charging for final leak testing), and every single joint, connection and component is and checked for bubbles using soapy water or other such fluids. This is the most commonly used method and is considered to be one of the most reliable.

- Holding pressure test: the system is pressurised to the nominal working pressure with OFDN, and the pressure is monitored over a period of time (at least 10 minutes) in order to check for a fall in pressure. This should be carried out within a constant temperature environment. However, this method is less accurate, it may not pick up very small leaks and the change in pressure may be a result in other factors such as internal pressure equalisation of mixing with oil.

- Gas detection: the system is charged with OFDN and a whiff of refrigerant to the nominal working pressure and refrigerant gas detectors are used to check every single joint, connection and component for the presence of refrigerant. (When using gas detection, see Part 6.1.4.) Often, this method is used alongside the bubble test to pinpoint the exact position of the leak.

- Fluorescent dye: this requires that a particular dye be added to the system, which normally mixes with the oil. Thus, when leak occurs, the location of a leak can be traced, with the assistance of an ultra-violet lamp. Again, depending upon the size and location of the leak, this method often requires further identification of the exact leak position using the bubble test method.

- Ultrasonic sensor: the system is pressurised to as high a pressure as permissible (according to the system maximum operating pressure) with OFDN, and the sensing device is used to convert and amplify the sound of the leak such that the operator can detect it audibly. The effectiveness of this method is sensitive to the amount of noise in the surrounding area, and again requires the use of a bubble test to determine the precise position of the leak hole.

Upon identification of the leak, the appropriate procedures should be used to repair it. It is essential to be aware that systems may have more than one leak, so the system should be repeatedly checked, including positions of recently repaired leaks, to ensure that all the leaks have been found.

In general, frequent inspection of charge level and gas detection should be carried out, especially on larger systems. Whenever there is any indication that leakage has occurred, actions should be taken immediately to find and repair the leaks.

6.1.9 Strength (pressure) testing

Testing of the strength of the system using pressure is normally required after changes have been made to the system, including re-connecting parts of the system using brazing or mechanical joints, exchang- ing one or more components or making an addition to the assembly. The strength (pressure) test should be conducted in the same manner as with any other refrigerant. In summary:

- Ensure all personnel are at a safe distance from any refrigerant containing parts
- Charge the system with an inert gas typically OFDN
- Gradually pressurise the system to 1.1 × allowable working pressure of the system, as prescribed on the system data plate
- Hold the pressure for several minutes and then gradually depressurise the system
- Check all parts of the system for deformation

If no deformation of the system parts is found, then the test result is positive.

If the maximum working pressure is not displayed on the system, then it may be estimated based on the saturation pressure of the refrigerant at 55°C, although it does depend upon the local climate conditions; if the maximum ambient is expected to be higher, then the test pressure should also be increased. (Please also refer to Part 5.6.7.)

6.1.10 System evacuation

After the system has been sealed, leak checked and strength pressure tested, it is necessary to evacuate it in order to remove air, moisture and unwanted residual refrigerant. (Note that evacuation will not remove particulate matter.) If this directly follows refrigerant recovery or venting, it is necessary to flush the system with OFDN. If flushing it not possible because of the system configuration then some OFDN should be added to the system after recovery before evacuation takes place. This is necessary to prevent flammable mixtures occurring.

When connecting the hoses between the system, gauge manifolds, and vacuum pump, ensure that the connections are secure and there are no potential sources of ignition nearby. Furthermore, ensure that the pump discharge is in an area free of potential sources of ignition. It is also necessary to ensure that a proper vacuum gauge is used since conventional manifold gauges will not provide a proper reading, and in fact often leads to the technician assuming that a good vacuum has been achieved when it may certainly not be the case.

The system should be evacuated to the desired pressure (typically 500 microns or less), and then left to stand for about 15 minutes to ensure that all of the refrigerant has been removed from the oil and any residual moisture has evaporated. If the pressure continues to rise, then this could be due to evaporating moisture or an (in-flowing) leak. If it continues after two or more evacuation procedures, then this suggests the presence of a leak, since there will be a finite quantity of moisture to remove. If the system is to be worked on (for example, breaking into it, brazing, etc), then the vacuum must be broken with OFDN.

Ensure that the vacuum pump is of good quality and of appropriate capacity for the system, and that the oil level is correct.

Along with other service machinery, the vacuum pump should be free of potential sources of ignition. This typically requires that the on/off switch be sealed or of a non-sparking type, alternatively it may be switched remotely at the plug socket provided this is located away from the refrigerant containing parts.

6.1.11 Charging

Charging of refrigerant may be carried out in a number of possible ways, as with any other refrigerant, depending upon the location, type of system, available equipment and the desired accuracy:

- Electronic mass-flow controlled charging machines
- Volumetric charging by graduated cylinder
- Mass charging by (electronic) balance
- Charging to sight glass
- Charging according to system performance

Typically, charging machines are limited to manufacturing facilities, so the remaining four options are possible for on-site charging. Out of these, mass charging using a balance is the preferred method, since it is the most precise, and the charge amount is normally included in terms of mass on the equipment dataplate. Nevertheless, virtually the same charging procedures are used with HC refrigerants as with any other types of refrigerant, except that certain considerations are particularly important:

- Prior to charging, ensure the system has been strength pressure tested with OFDN
- Prior to charging, ensure the system has been tightness tested (leak checked)
- When connecting hoses between the refrigeration system, manifold gauges and refrigerant cylinder, ensure that the connections are secure and there are no potential sources of ignition nearby
- Ensure that contamination of different refrigerants does not occur when using charging equipment
- It is good practice to purge the hoses and manifold prior to charging to avoid contamination of the refrigerant; this should be done to minimise the emission of refrigerant but also whilst making sure that there is sufficient ventilation to dilute the release
- Hoses or lines should be as short as possible to minimise the amount of refrigerant contained in them
- Ensure that the refrigeration system is earthed prior to charging the system with refrigerant, to avoid the potential for static build-up
- Extreme care must be taken not to overfill the refrigeration system
- Upon completion of charging, a further leak check must be carried out prior to leaving the site
- After charging, carefully disconnect the hoses, attempting to minimise the quantity of refrigerant emitted
- Label the system when charging is complete (if not already)
- The mass of refrigerant charged into the system should be noted in a log-book and marked on a nameplate

With any type of mass charging, the method should be more accurate than with most other refrigerants because HCs have a lower density than CFCs, HCFCs and HFCs. Typically, a balance should have an accuracy of at least ±3% full-scale, especially when working on critically-charged systems.
When charging the system the technician must be aware that HC refrigerant have a lower density than most other refrigerants, so typically 40 – 50% of the charge expected with, say R22, is used. This is an important consideration since over-charging a system is likely to result in extremely high pressures and subsequent catastrophic rupture of the system and massive discharge of the refrigerant.

6.1.12 Repairs to electrical components

Before starting work on electrical components, the relevant power feed should be switched off before the sealed components are opened. If it is necessary not to switch off the relevant electrical components for repair work, the concentration in the atmosphere in the area concerned should be monitored continuously in order to warn people about a potentially dangerous situation should it arise. If a fault exists that could compromise safety, then no electrical supply can be connected to the circuit until it is satisfactorily dealt with.

All electrical devices must not be potential sources of ignition, and this is normally achieved through a number of ways, typically:

- Using components that do not produce arcs, sparks, etc
- Using components that are sufficiently sealed such that they do not allow the ingress of flammable refrigerant
- Using components that are positioned in a locations where leaked refrigerant cannot and will not reach in the event of a leak

Full details are provided elsewhere (see Part 5.5).

Thus, when working on such electrical components, it is essential to ensure that:

- Faulty components that are intended not to spark, are not replaced by components that do spark
- Faulty components that are intended not to spark, are not modified in a way such that they do spark
- If replacing sealed components, it is done so using the same components or with components that have at least the same level of sealing
- After opening and/or working on sealed components, they are afterwards sealed as initially intended
- If working on or replacing specially positioned components, they are left fixed in their original positions
- Electrical cabling is and will not be subject to wear, corrosion, excessive pressure, vibration, sharp edges or any other adverse environmental effects
- All electrical apparatus is mounted securely

In many cases, a combination of special component positioning and component sealing is used to prevent a release of flammable refrigerant from reaching a potential source of ignition. Therefore it is essential that no alternations are made to the construction of the equipment as this could influence the desired level of protection, in a way that is not obvious to the technician.

Furthermore, the technician should be aware that the construction of parts of an appliance, for example, positioning of barriers, walls, locations of pipe runs, etc, may indirectly affect the level of safety achieved with electrical components (or other potential sources of ignition). For example, if a pipe is repositioned next to an unprotected electrical component then a refrigerant leak may have a greater chance of entering it, or if a cable entry through an internal partition is not adequately sealed there may be a chance that refrigerant leaked on one side may migrate to an exposed electrical component on the other side.

When working on systems and equipment in general, it is important to check all electrical components to ensure that the intended level of protection (as intended during the protection of the equipment) has not been compromised through, for example, unauthorised modifications to the equipment, or from the effects of ageing, wear or mechanical stresses.
In addition to checking potential sources of ignition, other electrical parts should also be checked. For example:

- Terminal connections are tightly affixed and not loose, which could result in unintended arcing
- Protective conductor connections should be checked each time a repair is made
- Wiring and cabling should also be checked to make sure they are not damaged

If a defect is found, which puts the reliable operation of the refrigerating systems at risk, the installation should not be started up again.

Intrinsically safe components are the only type that can be worked on whilst live in the presence of a flammable atmosphere, although this is not normally used with RAC appliances or system. Test apparatus should also be of an appropriate rating. In all cases, in order to confirm that intrinsically safe components and test equipment are used, the “Ex-i” marking should be observed.

6.1.13 Routine system checks

When dealing with systems that use flammable refrigerants, there should be an emphasis on ensuring that the level of safety of the equipment and associated installation is maintained at a high level. This primarily involves checking, and if necessary making the required adjustments, so that the entire installation meets the requirements of the relevant safety codes, standards and regulations.

After completing any installation work, repair work or as a part of regular maintenance, such checks may include:

- Ensuring the function of safety devices, including refrigerant detectors and mechanical ventilation systems
- That the minimum required airflow, if used, is being achieved
- Ventilation ducting and fans are free from debris and restrictions
- No piping has been installed in unacceptable positions
- Pipework and components are in good condition and not leaking or likely to leak
- Piping is fully protected from physical damage
- Mechanical connections are only located where permitted
- The system isn't installed in a room that is smaller than the minimum size as permitted by the standards
- Ensure that any missing or illegible labels on components, devices or housing are replaced
- The appropriate manuals, handbooks, etc, are present where necessary
- Refrigerant cylinders are not being stored in the area
- Check that there is continuity of earth bonding for all equipment
- Ensure that the system and component mountings are secure

It is good practice to develop a check list to cover these items and for the technicians to note down that the relevant checks have been carried out.

6.1.14 Gas detection

Refrigerant detection is an essential requirement for technicians working on systems that use flammable refrigerants. Before, for the duration and after work has been completed, the area must be checked with an appropriate refrigerant detector to ensure the technician is aware of potentially flammable atmospheres.

Ensure that the gas detection equipment being used is suitable for use with flammable refrigerants, as determined by the detector manufacturer or supplier. Under no circumstances can potential sources of ignition be used in the searching for or detection of refrigerant. In particular, a halide torch (or any other detector using a naked flame) must not be used.
Electronic gas detectors can be used to detect flammable refrigerants. However, the documentation or manufacturer should be consulted in order to check that it is suitable for HC refrigerants. In some cases, the detector may require re-calibration (which should be done in a refrigerant-free area). Gas detection equipment is to be set at a percentage of the LFL of the refrigerant and must be calibrated to the refrigerant employed and the appropriate percentage of gas (maximum 25 % of LFL) is confirmed.

If the presence of flammable refrigerant is suspected, all naked flames and other potential sources of ignition must be removed and/or extinguished.

6.1.15 Cylinder handling

HC refrigerants are available in a range of cylinder sizes, both refillable and non-refillable, depending upon the producer. Most refillable cylinders are equipped with pressure relief valves, and some cylinders employ special (unique) cylinder connections in order to differentiate them from other refrigerant cylinders, thereby reducing the possibility of muddling cylinder types. Some cylinders also employ an automatic excess flow valve within the liquid valve, which will close the valve if the refrigerant flow out of the cylinder is too fast (for example, if the refrigerant hose becomes disconnected).

Many of the requirements associated with handling flammable gas cylinders are dictated by national regulations, and these should be checked for individual national situations. Otherwise, the following include general refrigerant cylinder safe handling guidelines:

- Do not remove or obscure official labelling on a cylinder
- Always refit the valve cap when the cylinder is not in use
- Check the condition of the thread and ensure it is clean and not damaged

- Do not expose cylinders to direct sources of heat such as steam or electric radiators
- Do not repair or modify cylinders or cylinder valves
- Always use a proper trolley for moving cylinders even for a short distance – never roll cylinders long the ground
- Take precautions to avoid oil, water and foreign matter entering the cylinder
- If it is necessary to warm the cylinder, use only warm water or air, not naked flames or radiant heaters, the temperature of the water or air must not exceed 40°C
- Always weigh the cylinder to check if it is empty – its pressure is not an accurate indication of the amount of refrigerant that remains in the cylinder
- Use only dedicated recovery cylinders for the recovery of HC refrigerant
- Always check that the cylinder is not beyond its mandatory safety check or pressure test date
- Ensure that the cylinder is not being used for a refrigerant that it is not intended to be used for

The storage of HC refrigerant cylinders is also normally controlled by national regulations; however, the following provides typical guidance:

- Cylinders should be stored in specific dedicated areas or cages, preferably outside, but in a dry, well-ventilated area remote from fire risk
- Access to storage areas restricted to 'authorised persons only', and such places must be marked with notices prohibiting smoking and the use of naked flames
- They should be stored at ground level, never in cellars or basements
- Access to cylinders should be readily accessible
- Never store cylinders in residential premises
- Use and store cylinders in an upright position
- The total quantity stored is usually be restricted to no more than a certain limit (for example, 70 kg in the UK)
- Static electricity build-up should be avoided

The transportation of cylinders is also normally controlled by countries' specific national regulations. The requirements for HC refrigerant cylinders are typically the same as those for LPG, propane and butane used for fuel, etc. The following provides an indicative list of rules that may be broadly applicable in many countries:

- Carry written information giving the details of the substances carried (such as material safety data sheets or similar); this information must be available in an emergency so it should be located in a position where it is visible and accessible, and is often applicable to vehicles that are carrying a quantity of flammable gas above a certain quantity
- Know and understand the hazards and emergency procedures for handling these substances
- Carry a dry powder fire extinguisher of at least 2 kg capacity; it is recommended that the driver of the vehicle is trained in the practical use of fire extinguishers
- Cylinders must be located in an upright position with their valve uppermost and be properly secured
- Ensure adequate ventilation in the vehicle; this may require modifications to a closed van
- Display flammable gas hazard warning signs on the rear of the vehicle
- No naked flames or smoking allowed inside the vehicle
- Never leave cylinders in a closed vehicle unsupervised for longer than necessary

It is recommended that the refrigerant supplier is consulted in order to obtain the specific rules for a given country.

6.2 INSTALLATION OF EQUIPMENT

6.2.1 Introduction

The installation covers a range of activities from a site survey to ensuring that the appropriate manuals are in place. The entire installation process is critical in ensuring the long-term safety of the equipment, for example, by ensuring that the safety features included within the design are correctly setup within the plant. The general procedure – with respect to safety matters – for the installation process is provided in Figure 68.

Figure 68: General procedure for installation of systems and equipment

Depending upon the type of equipment to be installed (for example, stand-alone appliance, appliance with pipework connection, remote system with pipework, or fully assembled system) the actual procedure may be abbreviated accordingly.

6.2.2 Preparation

Preparatory stages are important as they influence the safety of the actual installation activities, as well as helping to identify any fundamental incompatibilities between the equipment to be installed and the installation site.

Initially, it is important for the responsible person, who is overseeing the entire project, to study the specification of plant design (or instructions in the case of an appliance installation), and to understand fully the purpose, operation and peripheral requirements of the equipment and associated components. Similarly, a site survey is required in order to be familiar with the installation location to identify any potential mismatch with the equipment to be installed. Always carry out a risk assessment to decide whether it is appropriate for the use of HC for the application under consideration.

6.2.3 Conformity to safety guidelines

Once the general requirements of the project are understood, it is necessary to carry out a check to ensure that the intended installation will meet with the requirements of the chosen technical guidelines, such as safety standards and regulations. A summary of the key aspects to consider are mentioned below. Further details may be found in Part 5.

Charge sizes

In general, the mass of HC refrigerant within systems is limited, and this is normally done according to the type of system, the location and the size of the space, particularly in respect to occupied areas. In the case of systems within occupied spaces, a maximum charge size is specified for a given room size, or alternatively, a minimum room size for a given charge size. The approach requires consideration of two characteristics:

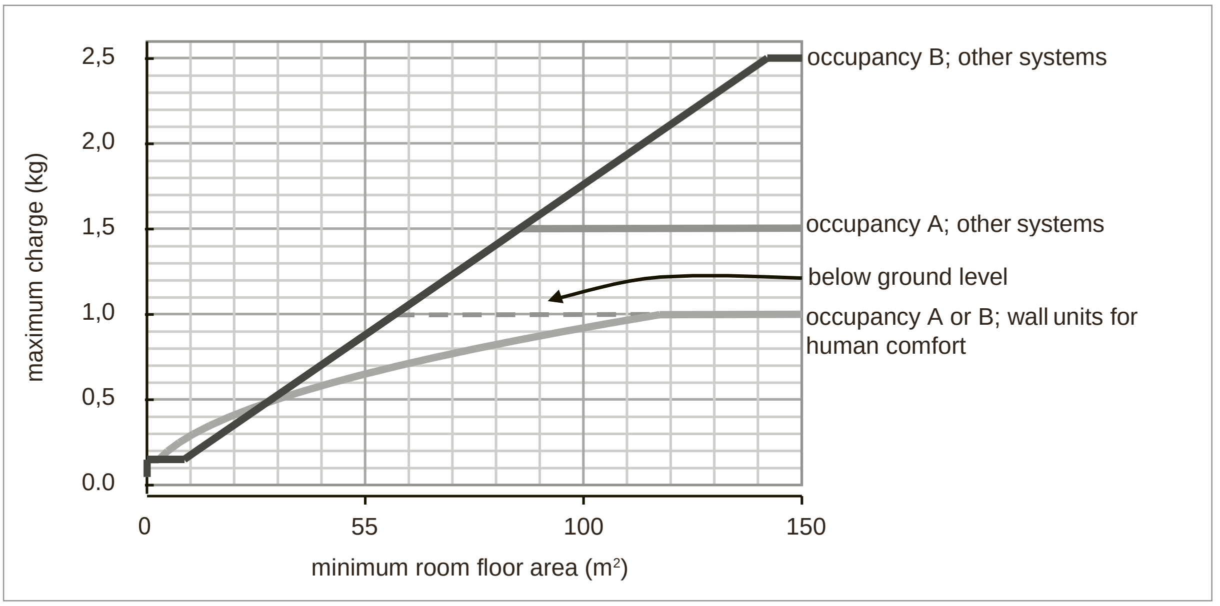
- The first is an upper charge size limit, which is a function of the type of location and its occupancy
- The second is an allowable charge size, which is a function of size of the room that the refrigerant could leak into

Approximate values for public (A) and private (B) occupancies are summarised in Figure 69. Additional to this, other limits apply, such as:

- Entire systems located within a specially constructed ventilated enclosure for occupied spaces can have up to 5 kg of refrigerant
- For any system below ground level the upper limit is 1.0 kg regardless of occupancy type
- If all refrigerant containing parts are within a machinery room or in the open air then the charge size is not limited
- If the charge size is less than 150 g there is no limit

Note that these limits apply to individual system circuits, thus is as system has two independent refrigerant circuits, the charge size limit is applied to each separately. Refer to Part 5.3 for detailed requirements.

Figure 69: Summary of HC charge size limits for single refrigerant circuit within an occupied space, dependent upon type of system



Minimising leakage

Systems must be designed to minimise the possibility of leakage. This includes avoiding mechanical joints, not using fusible plugs, applying proper protection against corrosion and mechanical damage, etc. General system design, piping and valves and component selection are discussed in Part 5.2.

Positioning of equipment and pipework

There are a variety of general rules that should be applied to the positioning of refrigerant containing parts. This includes restrictions for running pipework through other spaces (that are not being served by the RAC system) and ducting or service shafts, the location of pressure relief devices and outlets, the locating of condensers and other parts of the system outside, in case of a refrigerant release entering other parts of the building. Further details are provided in Part 5.6.

Sources of ignition

All systems must have no sources of ignition (SOI) associated with it, such as sparking electrical components or hot surfaces. All parts of the equipment should be checked to ensure that the electrical and other components conform to the requirements, as laid out in Part 5.3. In summary, this means:

- Comply with the designated parts of IEC 60079, or an equivalent standard that makes electrical components suitable for use in an area in which an explosive atmosphere can occur, or
- Not be located in an area where a potentially flammable gas mixture will accumulate, as proved by testing

Typically for larger systems where, in the event of a catastrophic leak where the concentration of refrigerant exceeds the LFL, the electrical equipment should be selected according to the requirements for explosive atmospheres.

Electrical components should be selected and/or positioned carefully. Also, care should be taken to ensure that electrical terminals, including capacitor terminals are adequately tightened and secured against loosening and that adequate insulation is provided to avoid live parts shorting together.

Depending upon the approach used for avoiding sources of ignition, its integrity over the lifetime of the equipment must be considered. Wearing of a component, such as through weathering or corrosion may also render it unsafe. Similarly, components that could be interfered with in the future should be installed such that it is not possible for it to be repositioned or affected in such a way that it becomes unsafe.

Machinery rooms or enclosures

If in a machinery room a special enclosure is employed, it must meet with the rules, as detailed in Part 5.6.4. In general, these address the following:

- Avoidance of potential SOIs
- Use of minimum flow rate for normal and emergency ventilation
- Suitable means of initiating ventilation such as air pressure switches or gas detectors
- Minimum open areas of walls to assist with natural ventilation
- Explosion protection

Safety controls

A number of components and associated control systems may be used to enhance the level of safety of the plant, such as:

- Pressure switches
- Pressure relief devices
- Flow switches
- Liquid level indicating devices
- Pressure indicators
- Gas detectors

It should be ensured that these are in place as and when necessary.

6.2.4 Site work

This involves the actual practical activities carried out by the installation technicians and engineers. Before starting work, the equipment and working areas must be checked to ensure they are safe. Examples include:

- Ensure that those who will be working on site are familiar with the implications of flammable refrigerants and all technicians handling HC refrigerants are competent to do so, and that there is adequate supervision
- Ensure all necessary equipment and facilities are available to carry out the work, such as calibrated handheld gas detectors, oxygen free dry nitrogen, proper charging equipment, and so on
- Components, pipes and fittings and materials conform to specifications and standards
- Ensure that all flammable substances (refrigerant and otherwise) are stored correctly
- All staff working in the area should be instructed about HC system being installed and to take extra precautions like "no smoking"
- Dry powder or CO_2 fire extinguisher should be kept adjacent to the installation area for any emergencies

In general, always carry out a risk assessment to decide whether it is appropriate to handle HC refrigerants on the site. Further details are provided in Part 6.1.2.

6.2.5 Testing

Following the completion of the construction of the equipment, the necessary tests must be carried out on the system. In particular, this includes:

- Tightness ("leak") test (see Part 6.1.8)
- Strength ("pressure") test (see Part 6.1.9)
- Functional test of safety devices, such as pressure switches, das detectors and emergency ventilation, etc

In addition, all electrical components must be checked to ensure they are not potential sources of ignition.

6.2.6 Marking and documentation

All the necessary marking and documentation must be in place, such that after the installation is complete, all the necessary instruction is available to ensure that anyone approaching the plant will be made fully aware of the risks and the appropriate conduct:

- Signs on equipment housing and components, including "flammable gas" warnings, "read the instructions", "do not remove", "no sources of ignition", "authorised access only", and so on
- Operating and handling instruction manuals, safety data sheets, maintenance sheets, safe working guidelines, and so on

Further details can be found in Part 5.7.

6.3 COMMISSIONING OF SYSTEMS AND INSTALLATIONS

6.3.1 Introduction

Commissioning is the advancement of an installation from the state of static completion to full working order, according to the specified requirements, which includes the setting-to-work of an installation and the regulation of the system. The general approach will be outlined here, but the focus will be paid only to the aspects that are implicated by the use of flammable refrigerants.

Any complete installation including the complete refrigeration system should be commissioned, in terms of checking it against appropriate drawings and operational specifications, before the system is put into service. Particular attention must be paid to the safety features employed for the purposes of using flammable refrigerants.

The commissioning can only be carried out by a competent person and the results documented before the system can be put into operation. A single competent individual must have overall authority over the commissioning process. It should only be carried out according to a commissioning specification, which prescribes the detailed requirements with which the various commissioning services have to comply.

The proper commissioning of refrigeration equipment is crucial to ensure the correct operation of the safety features and to minimise the risk of the refrigeration system itself operating abnormally in a manner that could compromise safety. A poorly commissioned refrigeration system may have the potential to compromise the safety of building occupants and maintenance personnel. Often, the commissioning procedure is shortened due to pressure from the end user and/or other parties that want to have the plant operative, especially if there have been delays during the installation phase. Unfortunately, a restricted commissioning programme will nearly always result in the plant not working at its best and can greatly compromise the level of safety.

The responsibility for carrying out the commissioning is usually a contractual matter and that parties involved in any activities must comply with the relevant contract requirements. In any case, the operation of the system and safety features is often a matter for specialists and for this reason the design, installation and, particularly, the commissioning of a system will generally be required to be carried out by a competent person for the refrigeration equipment manufacturer and/or consultant and/or contractor. A number of different skills will be involved and strict attention to formal co-ordination between those involved is defined in the contract documentation.

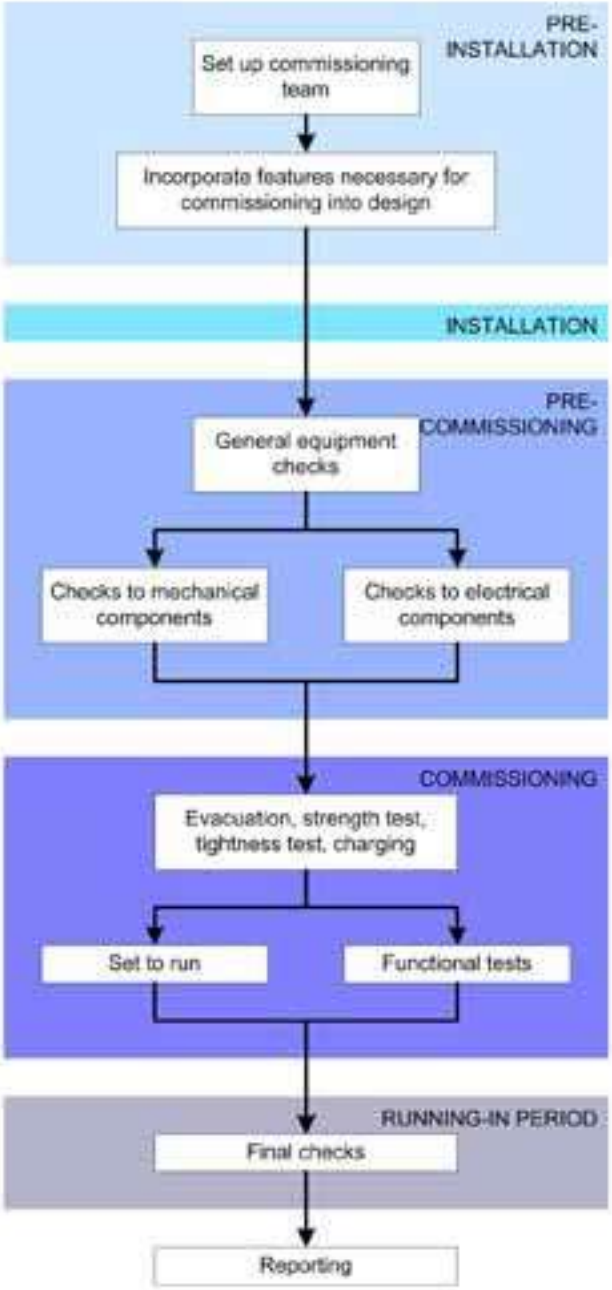
Normally the requirements for more comprehensive commissioning procedures increase with the size and complexity of the installation. For the larger projects, a commissioning management team should be formed to co-ordinate and oversee the commissioning process. Figure 70 provides an overview of the commissioning procedure for larger installations; smaller projects or appliances may omit certain stages.

6.3.2 Commissioning requirements

The following summarises the main requirements for a successful commissioning process:

- The equipment must be inherently commissionable, which must be specified at the outset of the design of the equipment
- All parties must allow sufficient time for the complete commissioning process and integrated into the overall programme
- Formation of a commissioning management team
- Ensure that all personnel involved need to be suitably competent
- Maximise off-site pre-commissioning activities, where applicable
- Implement post-occupancy checks to confirm the performance of controls and refrigerant leak checking.

Figure 70: Overview and sequence of the key stages involved in commissioning



It is essential that the results of all checks and measurements are recorded in writing by the commissioning engineer together with any commentary, as appropriate. Breaks in the continuity of commissioning operations are likely and proper records will show the state of progress at any particular stage. Usually, the provision of commissioning records is an important part of the hand-over information for the building user.

6.3.3 Preliminary design aspects

To ensure proper commissioning, information must be provided by the designer. It should be given either on drawings or in the design specification. The latter should always include a clear description of how it is intended the system should operate and the design parameters. The success and feasibility of the commissioning procedures will be influenced by the facilities provided in the design.

The refrigerating system and equipment should be designed and installed with all the necessary components and facilities and with adequate access to permit the required commissioning procedures to be properly carried out. It is essential to provide adequate safety controls and interlocks to protect the equipment during operation and throughout the commissioning process.

Details relating to the following should be included in the refrigeration specification:

- Description of the division of responsibility between the various parties
- Off-site and on-site pre-commissioning procedures
- On-site commissioning procedures
- Arrangements for management of delays
- Phased completion requirements
- Involvement in any complete system and sub-system performance testing
- System documentation
- Operator training requirements before and during the commissioning period (there may also be a requirement for post handover operator training)
- Post occupancy checks

6.3.4 Specification

In order to commission a refrigeration system the commissioning team must be provided with comprehensive details relating to the design/specification of the system. Details concerning the refrigeration plant and/or system to be commissioned must be supplied to the commissioning engineer. This specification information should include the following:

- Full details of the refrigerant, R-number, its safety classification, number of circuits, charge size of each, and whether the system is supplied fully charged, or with a holding charge
- A full description of the equipment and the operation of the refrigerating system, explaining the control system and logic
- Full details and comprehensive instructions regarding safety both for normal functioning of the refrigerating system and for occurrences which may arise as a result of a fault or accident
- Complete schematics of the refrigerating system prepared using industry recognised graphics and symbols, especially so that the location of refrigerant containing parts can be identified in relation to the different types of occupancies
- Reference to the safety codes, standards and other guidance to which the system was designed

Information must be provided in relation to refrigerant piping and accessories, identifying that which was made up during manufacturing and that which was installed on site. Where there is refrigerant pipe installed on site, the schematic drawing should include:

- Details of any refrigerant distribution pipework, the location of valves, mechanical joints, instrumentation, safety devices and fittings.
- Details of any refrigerant leakage detection system arrangements, together with numbers of sensors and alarm sounders or indicators, exhaust fans, ductwork and descriptions of their locations.
- Details of any systems or arrangements associated with the refrigerating system, such as pressure relief devices and associated pipework
- Manufacturer's setting-to-work, operating and maintenance instructions for refrigerating equipment.
- The manufacturer's specified settings for all safety devices
- Design temperatures, pressures and flow rates at stated operating conditions for all fluids at defined indication and measuring points
- Other environmental considerations that may be of relevance

Information relating to the electrical components (and other potential sources of ignition) must also be provided, such as:

- A list of all electrical components, identifying which are specially selected or positioned so as to not be a potential source of ignition
- The type of protection for each electrical component, where applicable
- Details of electrical protection devices for the compressor and other motors
- The design settings for starter overloads and any adjustable thermal cut-outs

6.3.5 Pre-commissioning

In order to minimise the on-site commissioning time and help negate the adverse effects of reduced commissioning timescales, as much pre-commissioning as possible should be performed off-site. The purpose of the pre-commissioning is to check that the equipment and system are in a satisfactory and safe condition for setting to work. It is desirable that the appointed commissioning specialist be a member of the team overseeing this work and that the work be part of the commissioning contract. These checks should be carried out shortly before the initial running of the plant:

- General site around installation to be cleared of rubbish and debris
- Ensure equipment, pipework, electric cabling is correctly labelled
- Packaged equipment delivered to site has any transportation points removed

A match between the actual installation and the requirements of safety rules must be established. Thus, it is important that the set of rules – whether a particular safety standard, interpretations of safety regulations, industry codes of practice or internally developed guidelines – are communicated to those carrying out the commissioning. In particular, the following aspects must be checked:

- Avoidance of flare or other mechanical connections where specified
- Pipework only passes through permitted areas, or if through ducts, conforms to the relevant rules
- Adequate protection against external damage, corrosion or tampering is ensured
- The charged mass of refrigerant is within the permitted refrigerant charge size limits, especially considering equipment positioned below ground level
- Refrigerant-containing parts are positioned only in locations that they are permitted
- The inclusion of all pressure safety devices, pressure indicators, level indicator, etc, are included as necessary
- The rules for potential sources of ignition are adhered to
- Special consideration is given to systems that are located outside and where leaked refrigerant could flow to, and similarly where emergency exhaust ventilation is directed
- Any machinery rooms or equipment enclosures are constructed as necessary
- All relevant markings and signage are applied as necessary, such as “flammable gas” and “authorised access only” warning stickers
- All relevant instructions and manuals are in place, and that they contain the necessary information and guidance

The following checks are to be carried out after the installation of the refrigeration plant:

- Pipework is complete and secured
- Valves are provided as specified and fitted with sealed caps that are tight
- All flanged connections are correctly aligned, with the correct gaskets in place
- Capillary tubes must be free from damage and distortion
- Purging, charging and pump-down connections are provided

- Safety devices are fitted, e.g. a low pressure cut-out, high pressure cut-out, oil pressure differential switch (where fitted) and, chilled water low-temperature thermostat, low water flow rate switch and liquid line solenoid valves for start-up protection
- Automatic control arrangements are provided, solenoid valves fitted with coils in place
- Sight glass and liquid level indicators
- Suction, discharge and oil pressure gauges, or digital read out on solid state equipment, is fitted, or provision made for external connection of pressure reading
- Relief valves are correctly sized and vented to a safe location
- Flexible refrigerant connections are checked for tension and chaffing

The following checks to the electrical equipment must be carried out after the installation of the refrigeration plant. Note that for all equipment forming an integral part of the refrigeration plant these checks would initially be the responsibility of the manufacturer.

With all electrical supplies isolated, carry out the following:

- All electrical terminals are secure and tight
- The control panel to see that it is free from foreign materials (wire, metal chips etc) and clean if required
- Check that the main incoming power cables are properly connected
- Verify that all sources of electrical supply to the refrigeration plant are taken from a point of isolation
- Verify that the refrigeration plant earth terminal is properly connected to a suitable earthing point, and ensure that all internal earth connections are tight
- Check wiring from all hard wired safety devices, such as the high pressure cut out
- Ensure that remote overload trips are set correctly for compressor and oil pump motors
- Set the current load limiting device (where provided) to allow operation at 100% load without tripping
- Check that mechanical interlocks have not been tampered with during the set up period
- All sealing to electrical components is in place un-damaged

With electrical supplies energised, carry out the following:

- Check that the declared voltage is available on all supply phases
- Where appropriate check that safety cut-outs de-energise the system
- Where motor power is substantial or reduced voltage starting or complex interlocks are involved, the control circuit logic and the starter operation should be tested before the motor is rotated (e.g. set any time delays associated with motor starter)
- In addition to the compressor starter operation, ensure satisfactory operation of any associated electrical controls, e.g. a liquid line solenoid valve, electrical heater on the oil failure control
- Check for clean operation of all contactors, relays and interlocks

Certain operational checks must be carried out, as follows:

- For safety devices and automatic controls, check the settings and simulate the actuation of all safety devices and automatic controls for ancillary plant serving refrigeration systems to ensure correct functioning
- Operation of fans and that they are achieving minimum flow rate along ductwork
- Gas detection systems, automatic activation of alarms, shut-down procedures and initiation of exhaust ventilation, and so on

6.3.6 Refrigerant handling

Refrigerating plant may be of the factory assembled and packaged type or may be built up into a complete system on-site. In either case, certain checks will be required at some stage prior to operating the plant.

For factory-assembled systems:

- Observe pressure readings; where readings are lower than those specified by the manufacturer's data and the ambient temperature, leak testing of the system will need to be repeated and where pressures in parts of the system are nominally atmospheric, evacuation and charging must also be carried out again
- Where pressures are consistent with the manufacturer's data for the system and the ambient temperature, then further pressure testing and evacuation should not be necessary and where the system has a holding charge only, additional charging will be necessary
- In any case a leak test on all joints is recommended prior to applying a complete charge

Procedure for systems assembled on-site:

Before putting into service any refrigeration system, all the components or the whole system must undergo the following tests, where needed:

- Strength pressure test
- Leakage check (tightness test)
- Evacuation carried out (see Part 6.1.10)
- Refrigerant charging carried out (see Part 6.1.11)
- Functional test of safety devices

Finally, test of the complete installation must be complete before putting it into operation.

6.3.7 Setting to work and adjustments

Before operating the compressor for the first time (the compressor may have been operated briefly during the charging operation) a further visual check should be carried out on the complete system and, in particular, all refrigeration safety devices should be subjected to their complete cycle of operation.
Carry out the following:

- Set the refrigerant pressure controls in accordance with the manufacturer's instructions or ensure that factory settings have not been disturbed
- Adjust the high pressure switch to the manufacturer" specified settings
- Ensure that if automatic reset is used, then short-cycling does not occur, or, if provided the time delay device is set correctly
- Check all pilot lights, the timer (to limit the number of starts per hour of the compressor) and the motor winding high temperature cut-out

Immediately prior to commencing a continuous test run on the refrigeration system check that:

- All refrigerant circuit shut-off valves are in the open position, except for the bypass valves, in particular ensure that the condenser liquid line valve is open
- Compressor suction and discharge valves are open
- Oil suction and discharge pressure gauge valves are open
- Solenoid stop valves of the evaporator are operational on the magnetic coil control
- Refrigerant pressure controls are reset, as well as the oil pressure control, the freeze protection thermostat and/or freeze protection pressure switch

6.3.8 Start-up, shut-down and running-in

Start the system as prescribed by the manufacturer or according to the plant designer. After running the machine for about 10 minutes, note the motor starting current and pressure gauge readings. Re-check the function of the pressure cut-outs and ensure that these de-energise the machine. Record the operative settings. The refrigerating system should now be in full operational order.

Carry out the full functional checks for any additional safety controls. Where applicable:

- Use calibrated gas mixture to apply to gas detectors, and follow the relevant sequence, such as pump-down cycle, electrical shut-down, initiation of mechanical ventilation and audible and/or visual alarms, etc
- Similar a less of refrigerant from the systems, and follow the relevant sequence

Follow through the manufacturer's instructions, or the correct sequence as detailed in the design description to shut-down the complete plant, observing that any automatic or safety features operate satisfactorily. Throughout the above, note and record any irregularities in the shut-down cycle (e.g. noise, vibration, or unexpected pressure variation). Establish the cause, and where appropriate, rectify.

When all procedures above have been satisfactorily completed, the entire system should be set to operate and allowed to run for a continuous period of at least 72 hours under normal automatic control. It is recommended that the installation should be continuously supervised by a competent person for at least half of the run-in period.

After this period, carry out the following:

- Test the system for refrigerant leaks; this should be done at least twice during the running-in period
- Check the operation and calibration of automatic control and protection devices, including the satisfactory operation of the liquid line solenoid valve, automatic pump-down, low and high pressure cut-out, etc
- Check all mechanical equipment for excess heat, noise and vibration

6.3.9 Handover and documentation

On completion of commissioning, it is important that the end user or a representative be consulted to ensure that they are satisfied the system is working to the agreed design specification. The plant should not be handed over until both the end user and the installer are satisfied with its operation. A final submission should be made to the designed party (according to the contract). This should include:

- A full set of the details for the system design, drawings, equipment technical data, and safety mechanisms
- Full description of commissioning procedures
- Any problems identified, and what if any actions taken to resolve them
- Operating parameters including pressure, temperatures, flow rates, concentrations, etc, under which conditions
- Operating, servicing and maintenance instructions and control settings for any major items of equipment included in the installation
- A list of recommended spare parts for critical equipment;
- Declaration of conformity relevant to the installed items of equipment as required by legislation
- Other information as required by the controlling authority to complete the health and safety file
- Other pertinent information (for example, the data-sheet in Appendix 9)

6.4 ON-SITE AND WORKSHOP CONVERSIONS

6.4.1 Basic principles and warnings

Under certain circumstances, there may be a desire to convert a RAC system from a non-flammable refrigerant to use HCs. This approach may be considered for a number of reasons, such as:

- A desire to improve the efficiency of a system
- To minimise the environmental impact
- Because it may be more cost-effective than using other refrigerant options
- If there are no other refrigerant replacements available

However, note that if existing refrigeration system is working correctly then there is normally no need to convert the system to use any alternative refrigerant.

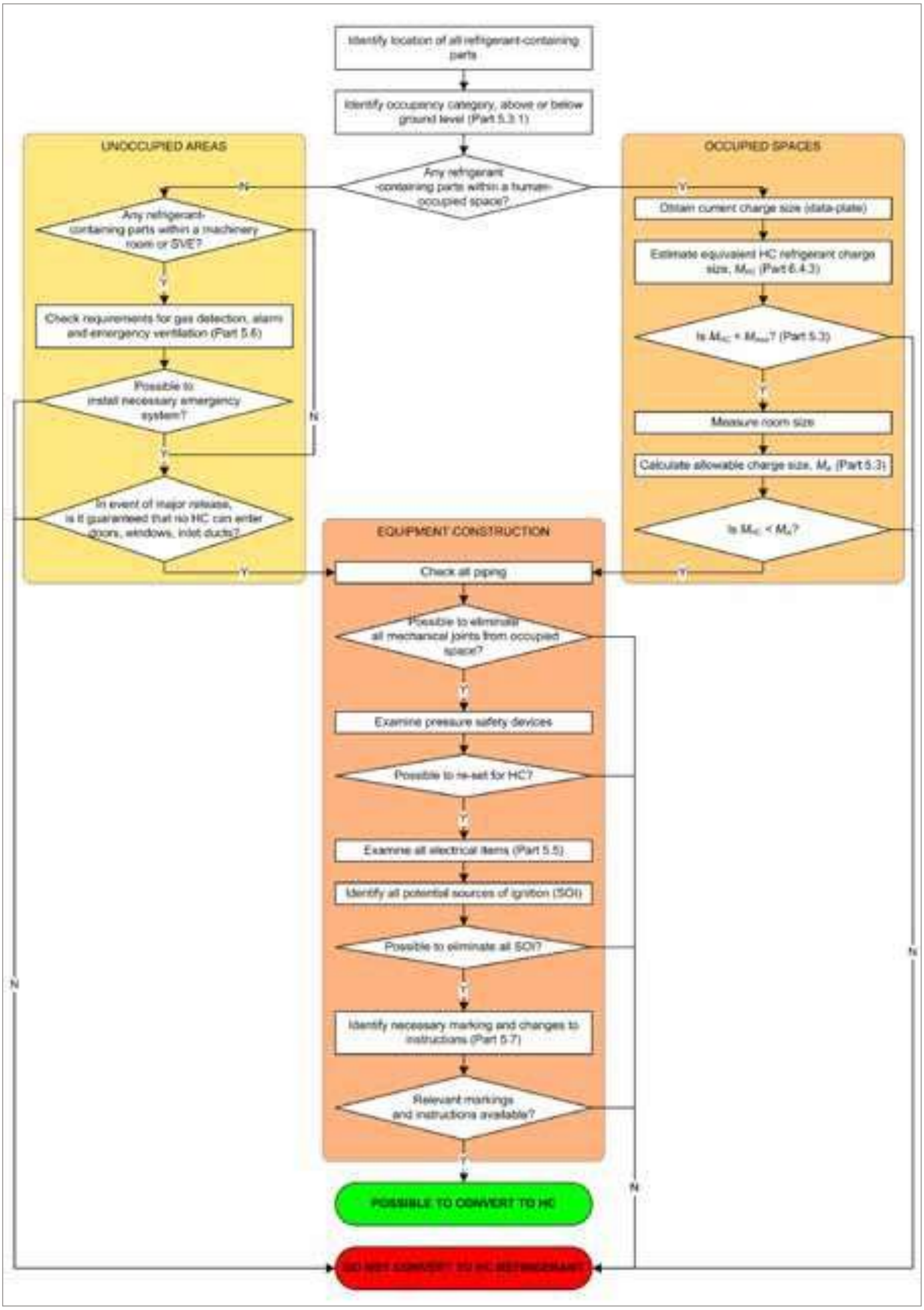
Note that in this case, the term “conversion” is used. This is important as it distinguishes from other phrases such as “re-fill”, “drop-in” and “retrofit”. The reason for this is that when a non-flammable refrigerant (say R12) is replaced by another non-flammable refrigerant (say R134a), if any changes are required to the system, then they relate to performance (e.g., change of capillary tube length) or compatibility (e.g., change in oil type). However, when changing from a non-flammable refrigerant (say R22) to a HC refrigerant (say R290), additional considerations must be taken into account. These include identifying whether or not the HC can be applied given the particular circumstances, and if so, carrying out the required changes to the equipment that are related to mitigating the flammability risk. A switch from a non-flammable to a flammable refrigerant should be considered in terms of an entire conversion of the equipment, not just a change of refrigerant.

For these reasons, it must be emphasised that carrying out a system conversion to use flammable refrigerant necessitates careful consideration of the implications and it is essential to weigh up the risks and benefits. If a conversion is to take place, then it should be done comprehensively, with care and with attention to detail.

Given that a conversion to a flammable refrigerant represents a significant change in the purpose of the system, it must be understood that the conversion can only take place provided that the final product meets the requirements of the relevant safety standards and national regulations.

In order to help explain the correct procedure more vividly, some examples of conversions are included in Appendix 2.

Figure 71: Decision chart for determining whether it is possible to convert a system to use HC refrigerant (in order to conform to the relevant standards)



6.4.2 Considerations affecting conversions

When approaching the choice of converting a particular system, it is important to follow a logical sequence of safety-related considerations to help make the correct decision. Such considerations include the following issues:

- The type and complexity of the equipment to be modified
- The environment and location within which the equipment is installed
- The quantities of refrigerant involved (in relation to the system location)
- The necessity to introduce additional emergency systems
- The ease or possibility of modifying parts of the system
- The ease or possibility of handling the potential sources of ignition

A decision chart to assist with evaluating the suitability of the equipment (predominantly with respect to the requirements of the safety standards) is provided in Figure 71. This may be used to provide a good indication as to whether a system can be converted to use an HC refrigerant, although other specific aspects may need to be considered in addition; i.e., the requirements elsewhere within this handbook (for now systems) and the relevant safety standards.

Since the refrigerant charge and the location of the refrigerant-containing parts of the system have such a strong influence of whether or not a conversion is viable, the suitability can be approximated according to typical system types. Table 19 provides an indicative overview of the types of systems that have been found to be acceptable for conversion. The viability is indicated as follows:

- ✔✔ – often suitable
- ✔ – sometimes suitable
- ✖ – normally unsuitable
- ✖✖ – always unsuitable

As previously explained, each situation is unique in terms of the combination of system design and installation location and therefore each must therefore be evaluated independently.
Two other issues should be considered with respect to the suitability of carrying out a conversion.

Firstly, it is strongly recommended that companies set up special conversion workshops at their facilities (see Part 4.5). Thereby, systems can be removed form the site to the dedicated workshop in order to carry out conversions. There are significant advantages to this:

- Access to proper tooling and equipment is more likely
- The working area can be set up to handle the use of flammable refrigerants
- Expert technicians that specialise on HCs are more likely to be present
- There will be better and more immediate access to the required parts and components

Whilst it is understood that certain types of equipment may not be portable, this approach should be taken is possible.

Secondly, companies involved in frequent conversions of a particular type of system should prepare dedicated “conversion kits” for their technicians, where each kit is dedicated to a particular type of RAC system.

Table 19: Application areas for natural refrigerants – Refrigeration

Sector	Equipment type	System type	Viability
Domestic refrigeration	Chiller cabinets	Integral	✓✓
	Freezer cabinets	Integral	✓✓
Retail refrigeration	Water coolers	Integral	✓✓
	Chiller cabinets	Integral	✓✓
	Chiller cabinets	Remote	✖
	Chiller cabinets	Distributed	✖✖
	Chiller cabinets	Indirect	✓✓
	Freezer cabinets	Integral	✓✓
	Freezer cabinets	Remote	✖
	Freezer cabinets	Distributed	✖✖
	Freezer cabinets	Indirect	✓✓
Cold storage and food processing	Storage cabinets	Integral	✓✓
	Coldstores	Remote	✖
	Coldstores	Distributed	✖✖
	Coldstores	Indirect	✓✓
	Process cooling/freezing	Remote	✖
	Process cooling/freezing	Distributed	✖✖
	Process cooling/freezing	Indirect	✓✓
Transport refrigeration	Road transport trucks	Integral	✓✓
	Refrigerated railcars	Integral	✖
	Reefer containers	Integral	✖
	Marine refrigeration	Integral	✖
Domestic air conditioners, dehumidifiers and heat pumps	Portable units	Integral	✓✓
	Window units	Integral	✓✓
	Through-wall units	Integral	✓
	Split units	Remote	✓✓
	Hot water heating	Integral	✓
	Central heating	Integral/indirect	✓
Commercial air conditioning and heat pumps	Split units	Remote	✓✓
	Multi-split/VRV	Distributed	✖✖
	Packaged ducted	Remote	✖
	Central packaged	Remote	✖✖
	Positive displace chillers	Integral/Indirect	✓✓
	Centrifugal chillers	Integral/Indirect	✖✖
	Hot water heating	Integral	✓
	Central heating	Integral/indirect	✓
Transport air conditioning	Cars	Remote	✓✓
	Buses	Remote	✖
	Trains	Remote	✖
	Aeroplanes	Remote	✖✖

6.4.3 Conducting conversions

If a conversion is to be carried out, the correct sequence of activities must be carried out in such a way that both the safety of the workplace is maintained as well as ensuring the inherent safety of the equipment. A suggested process is provided in Figure 72. In fact, most of the activities related to refrigerant handling during installation, maintenance, servicing and dismantling are also applicable here.

The following steps describe the process in Figure 72.

Estimate the HC refrigerant charge size

This can be done using the existing refrigerant charge. Therefore, obtain the current refrigerant charge size from the equipment data-plate (M_{dp}). Then, using the correction factors (C_f1) in Table 20, estimate the equivalent mass for the chosen HC refrigerant (equation 22).

$$M_{HC} = M_{dp} \times Cf \qquad (22)$$

The correction factor in Table 20 thus represents the percentage of mass of HC refrigerant required. For refrigerants not included in Table 20, the correction factor can be estimated as the ratio of HC liquid density to the existing refrigerant liquid density, at a temperature of around 50 – 55°C.

Table 20: Conversion factors ( ) to estimate equivalent HC charge size

Fluorinated refrigerant	HC refrigerant				
	R600a	R600a/R290 (50%/50%)	R290	R290/R170 (94%/6%)	R1270
CFC-12	(0.43) †	0.40	n/a	n/a	n/a
HFC-134a	(0.47) †	0.45	n/a	n/a	n/a
HFC-1234yf	(0.53) †	0.50	n/a	n/a	n/a
HCFC-22	n/a	n/a	0.42	0.41	0.42
HFC-407C	n/a	n/a	0.45	0.44	0.45
HFC-404A	n/a	n/a	0.51	0.50	0.52
HFC-507A	n/a	n/a	0.51	0.50	0.52
HFC-410A	n/a	n/a	(0.51) †	(0.50) †	(0.52) †

† Would require change in compressor displacement
n/a: HC refrigerant not applicable to system using existing fluorinated refrigerant

Check all necessary tools present

Prior to carrying out any work, it is essential to ensure all the tools and equipment and also spare parts required for the work are to hand. (A check list for tools and equipment may be developed from Appendix 6.)

Check the working area and system

Before handling HCs or any other refrigerant, it is necessary to ensure both the working area and the system are safe and that the technician gains familiarity with the system. The applicable guidelines are provided in Part 6.1.3.

Gain access to refrigerant circuit

Whether for HCs or any other refrigerant, the same rules apply for accessing the refrigerant system, as detailed in Part 6.1.4.

Recovery

Any remaining refrigerant within the system must be recovered, particularly since the refrigerant with be CFC, HCFC or HFC and therefore if released will be harmful to the environment. Furthermore, there are also safety implications associated with releasing non-flammable refrigerants as well. Therefore a recovery machine should be used to recover the existing refrigerant, and stored in a cylinder approved for that refrigerant. The guidance in this handbook (see Part 6.1.5) can also be used in this case, particularly with regards to prevention of refrigerant mixing, avoidance of overfilling, and marking the cylinder appropriately after use. (The guidance for handling cylinders in Part 6.1.15 should also be followed regardless of whether the refrigerant is flammable or not.)

Repairs

If it is necessary to carry out repairs to the system, then the system must usually be broken into. The approach detailed in this handbook (see Part 6.1.4) may also be used at this step. Subsequently the necessary repairs can be carried out (for which some of the guidance in Part 6.1.7 may be useful). At this point, it may also be beneficial to take the opportunity to conduct other, less critical repairs, such as oil changes, replacing filter driers, internal cleaning of the circuits, replacing damaged parts, and so on.

Design changes

The design changes that are made to the RAC system are critical to ensure that the safety requirements are met. It is essential that, based on the type of system, the location, occupancy and the HC refrigerant charge size, the appropriate safety features are integrated into the equipment. Failure to do this properly may result in a serious flammability hazard. (Part 5 of this handbook should be checked in this regards.) The major considerations are usually:

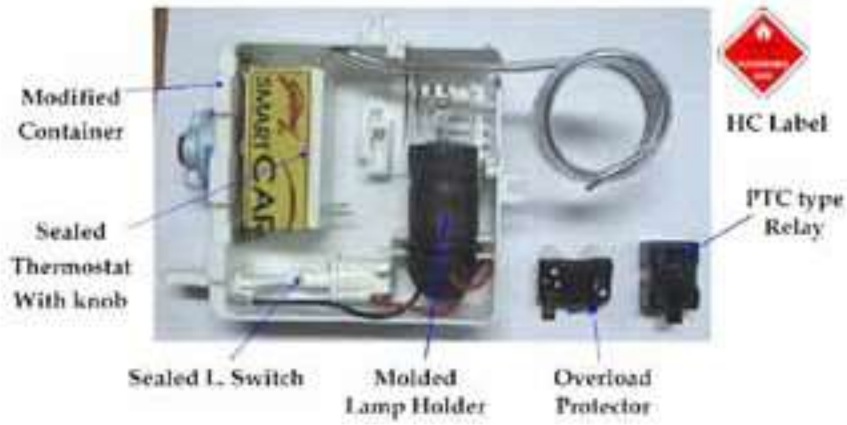
- Elimination of all mechanical joints from occupied space and minimisation of the possibility for leakage (see Part 5.2)
- Re-setting of pressure safety devices (see Part 5.6)
- Elimination of all potential sources of ignition (see Part 5.5)
- Setting up of emergency detection/ventilation/alarm system (see Part 5.6)
- Application of relevant markings and modifications to instructions (see Part 5.7)

It is re-emphasised that particular attention must be paid to addressing the potential sources of ignition. In all cases the following assessment must be carried out:

- Inspect the system and associated equipment, and note down all electrical components
- Determine which of the components could act as a potential source of ignition
- Decide how each of those potential sources of ignition will be handled, for example, by replacing with sealed components, using solid state devices or types, or placing within a fully sealed enclosure
- Consider also that electrical terminals must be adequately secured and sufficient insulation is provided to avoid shorting of parts
- Carry out the modifications accordingly

CONVERSION KITS

If enterprises are involved with carrying out conversions of existing systems, it is recommended that "conversion kits" are used. The reason for this is that it is too "convenient" for technicians – once at a site and already working on a system – to use short-cut methods for the conversion to HC refrigerant. Given the safety risk, this approach should be avoided. One way of helping to achieve this is to issue technicians with a comprehensive conversion kit that contains all the necessary bits and pieces. For example, such kits may contain data sheets (with conversion factors, room size/charge size estimations, etc), risk assessment forms, working instructions, sealed and solid-state electrical components, flammable gas stickers, valves, special fittings, and so on. If enterprises typically deal with a range of different systems, then it is sensible to have conversion kits that are better suited to each different type of system.



The marking of all equipment that contains HC refrigerant is also re-emphasised here. The appropriate "flammable gas" stickers must be placed on equipment housing entries and refrigerant access points, as well as on exposed piping.

Sealing the system

Upon completion of the work to the system, the circuit must be sealed according to the guidelines (see Part 6.1.7).

Testing the integrity of the system

Since the refrigerant circuit has been broken into, it is necessary to carry out leak tightness tests and strength pressure tests (see Parts 6.1.8 and 6.1.9, respectively).

Evacuation

The system must be evacuated (see Part 6.1.10).

Refrigerant charging

Provided that the system is provided to be leak free, then it may be charged with the appropriate HC refrigerant, according to the quantity determined in above (based on Table 20). (General guidance for safe charging with HC refrigerants is in Part 6.1.11.) Ensure that the charged quantity is recorded on the equipment data-plate.

Final checks

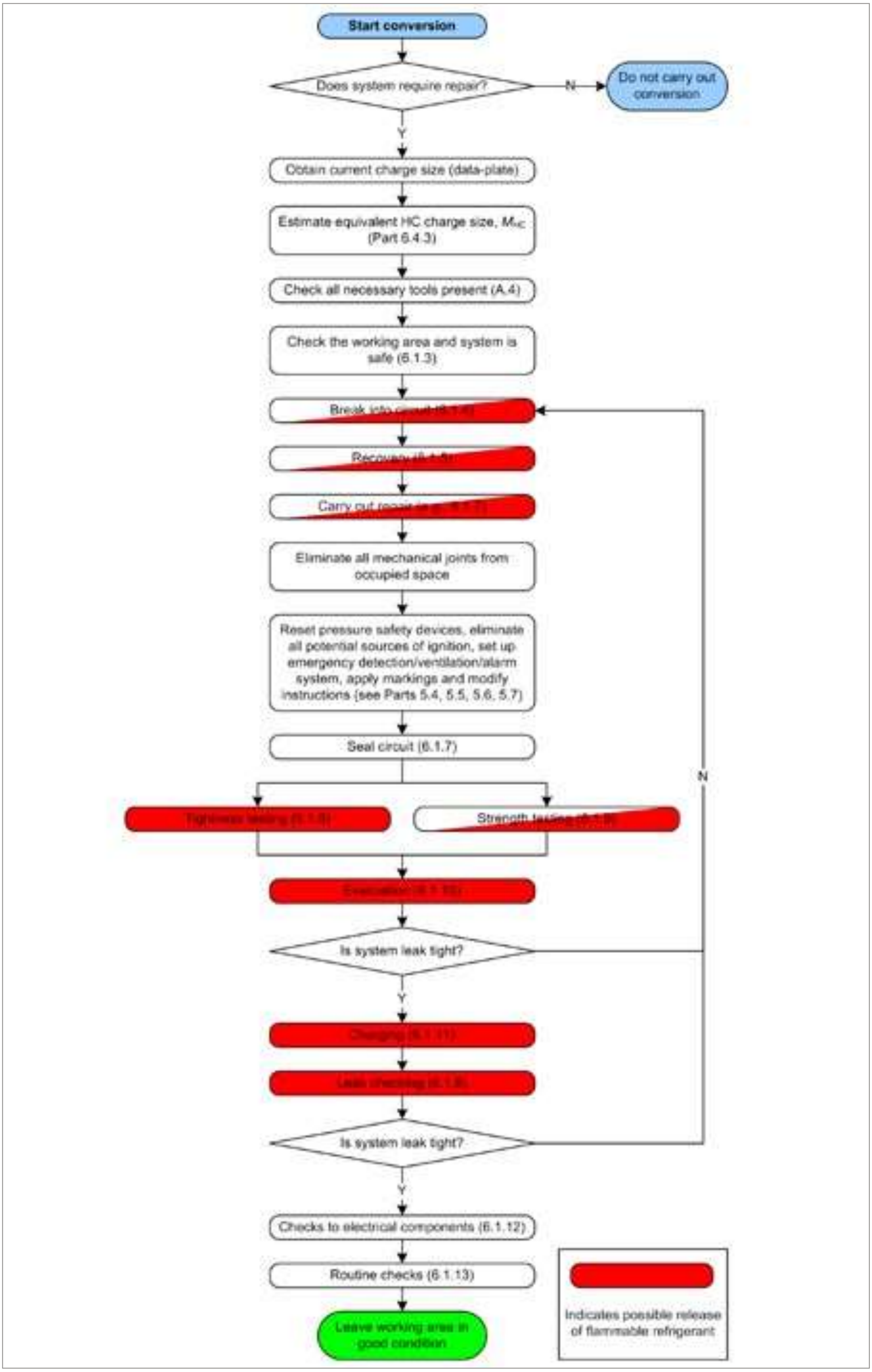
After charging is complete, it is important to carry out a series of final checks to ensure a safety and reliability of the system. These final checks include:

- Repeat leak checking (see Part 6.1.8)
- Repeat checks to electrical components (see Part 6.1.12)
- Carry out the routine checks (see Part 6.1.13) where relevant

If considerable modifications have been made to the system, a commissioning procedure based on the recommendations in Part 6.3 should be carried out.

Finally, initiate the operation of the refrigeration machine and run for a period of about 15 – 30 minutes to ensure it is working correctly.

Figure 72: Flow chart indicating the sequence of activities for converting a system to use HC refrigerant



6.5 DISMANTLING

Decommissioning and disposal occurs at the end of a systems' life, when it is to be taken out of service. The majority of the activities involved in this stage are broadly applicable regardless of the refrigerant used. In general, the following actions are necessary:

- Removal of refrigerant
- Removal of oil
- Dismantling of refrigeration system and associated equipment
- Delivery of refrigerant, oil and hardware to the appropriate collection stations

In particular, attention should be paid to the following aspects in relation to the handling of flammable refrigerant:

- Recovery of refrigerant
- Evacuating the system
- Flushing and leaving a holding charge of OFDN within the system
- Allowing ample time for the refrigerant to dissolve from the refrigeration oil
- Removing the refrigeration oil and storing in a container with a blanket of OFDN
- Marking of all the refrigerant cylinders, oil containers and system materials to show what they are and what the intended destination is
- Delivery of the recovered refrigerant to a refrigerant collection station for recycling and re-use if possible
- Delivery of the recovered oil to a collection station for recycling or destruction
- Delivery of the metals, plastics and other materials from the system construction to appropriate recycling centres

In the case of complete pieces of equipment, it must be labelled stating that it has been de-commissioned and emptied of refrigerant. The label is to be dated and signed. Ensure that there are labels on the equipment stating the equipment contains flammable refrigerant.

PART 7: CASE STUDIES

7.1 Introduction

This part of the handbook is intended to help provide an illustration of how enterprises have integrated some of the concepts described within this handbook into the development of HC refrigeration and air conditioning systems. A number of case studies are presented here. It is hoped that other enterprises that will also begin to adopt the use of HC refrigerants within their products can learn from these examples.

These case studies provide a mix of different perspectives, including both manufacturers and end users, both small systems and large systems.

- Benson Air Conditioning – a producer of split and larger air conditioning products; the examples here are split type systems
- Carter Retail Equipment (CRE) – a producer of retail refrigeration systems; the example here is integral water-cooled display cabinets
- De'Longhi – a producer of small room air conditioners as well as many other types of appliances; the example here is a portable room air conditioner
- Hindustan Unilever – a producer of a wide variety of food products; the example here is of HC ice-cream freezers of Hindustan Unilever within India
- Johnson Controls International (JCI) – a manufacturer of many type of RAC systems and components; and example here of a range of chillers
- Lidl – a supermarket chain; the example here is the generic design of new supermarkets
- Palfridge – a producer of domestic and commercial refrigeration appliances; the example here is a range of commercial stand-alone commercial cabinets
- Victorian Transport Refrigeration – a producer of refrigerated transport and vehicle air conditioning systems
- Waitrose – a supermarket chain; the example here is the generic design of new supermarkets

In addition, there are many other companies within Europe, Australia and increasingly within Asia and South and Central America, which produce refrigeration and air conditioning systems using HC refrigerants. The interested parties are recommended to search the internet for such products.

7.2 Benson Air Conditioning (Australia)

Product information

Non-ducted and ducted split air conditioners, including cooling only, and reverse cycle and heat recovery products are produced. The capacity of the wall splits range from 2.4 kW to 12.5 kW, whilst the ducted split model range from 3.5 kW to 100 kW. All units use R290 and the charge sizes of the wall splits are from 0.2 kg to around 1 kg. Products are made in Thailand and China. Over the past four years, many thousands of products have been sold primarily to the Austral-Asian markets, but also in certain other regions.

Development and design

All models are designed to the Australian safety standards AS1677-1 and AS1677-2 as a minimum, but various additional measures are introduced in order to exceed these requirements. Third-party approval of the design and construction of the units was obtained from the relevant authority within the Australian Government. Further, the air conditioners were optimised especially for the characteristics of R290, rather than being based on conventional HCFC or HFC design strategy.

Production and manufacturing

The production line for the air conditioners was specially modified for the R290 products. This was partly to account for the different components needed for the construction of the units, but also to introduce more thorough and rigorous tightness (leak) testing regime. The products are not charged during production, so the layout of the production line did not need to be modified for hazardous areas. However, quality management systems were used to improve leak tightness, as well as re-training of workers in this respect. Charging is carried out on-site or at the distribution centre, depending upon the type of products. For this, strict procedures are put in place.

After sales

All technicians that work on the systems in any way must have undergone the appropriate specialised training and be certified under the scheme operated by the Australian Government (TAFE) and the Benson internal training programme. Equipment owners and operators are requested to only accept service contracts with Benson, or with other companies whose technicians are suitably certified only. At end of life, a complete recovery and recycling service scheme is in place.

Barriers

The main barriers were associated with overcoming some state government legislation within Australia, as well as compliance to EU standards and achieving CE certification (particularly PED certification) for products for the European market.

Cooperation partners

There was no working with any cooperation partners.

Contacts

Steve Smith (bensonac@bigpond.net.au)

Benson split air conditioner

7.3 Carter Retail Equipment (UK)

Product information

Integral display cases utilising R1270 with a water-cooled condenser. The case design had to fulfil traditional retail specifications and be multiplexed in a conventional way.

Development and design

The standards employed were EN 378 Parts 1 – 4: 2008/9, IoR Code of Practice for A2/A3 refrigerants, EN 60335-2-24: 2003, and Dangerous Substances Explosive Atmospheres Regulations 2002 (DSEAR) and European ATEX Directive 95. The design was completed in line with the above standards and regulations to develop a water cooled (condenser) integral display case for use in a class A occupancy, with a charge not exceeding 1.5 kg, whilst maintaining a high level of safety, reliability, energy saving and client specific system integration. The design focused heavily on the above ensuring that components selected were already approved or tested for use with HC refrigerants. A large amount of simulation leak testing was carried out in house to ensure compliance with EN 378 standards and that sources of ignition were moved or components replaced where appropriate. The design and build were externally validated for compliance and further testing was carried out. All design and manufacture is in line with CRE ISO 9001 accreditation.

Production and manufacturing

The business invested in an HC production line with a dedicated HC charging machine, comprising automatic evacuation, leak test and HC charging facilities. This line also has fixed leak detection and operational and emergency ventilation in line with DSEAR and ATEX regulations. Training on the safe handling of HCs was also provided for shop floor operatives.

After sales

Product specific training (including safe handling of HCs) was provided at CRE for service providers responsible for maintaining the sites post installation. CRE has also provided any technical assistance required on site and developed safe systems of work (SSOW) for service technicians.

Barriers

The main issues with the development of the HC water cooled integrals were: -

- Little “official” data on HCs for the application. CRE worked with equipment OEMs on validating Hitachi scroll compressors to operate on R1270 with warranty
- A large financial commitment was made by the business
- Nervousness of other end users to adopt the concept mainly due to lack of understanding on HC refrigerants

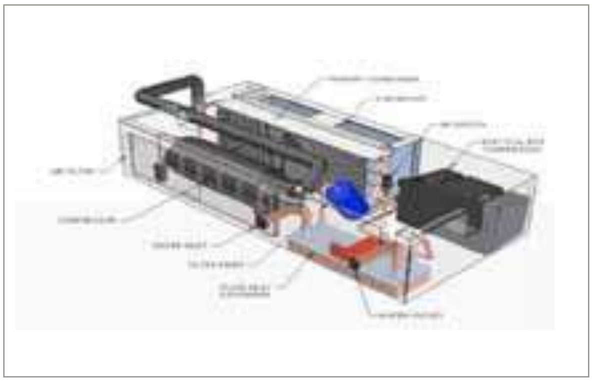
Cooperation partners

The main cooperation partner was Cool Concerns Ltd (UK) for external verification of design and applicable standards.

Contacts

Ian Garvey, Engineering Director (ian.garvey@cre-ltd.co.uk)

Diagram of Carter display case (left) with positioning and construction of condensing unit (right)



7.4 De'Longhi (Italy)

Product information

The products are portable air conditioners (single duct), using R290. They are currently manufactured in their factory in China and sold in Europe and Australia. De'Longhi started to manufacture them in 1998, and since then several hundreds of thousand units are in use.

Development and design

The reference safety standard is EN/IEC 60335-2-40 with Amendment A1, and no additional design features above the standard requirement were applied. As for all De'Longhi products they got the certification of the product from third-party test house like IMQ or TÜV.

Production and manufacturing

The production area was modified in the way that a leak detection system was added in the production line. The safety management systems follow ISO 9001 and are certified accordingly. The members of staff were trained by their Italian colleagues, which has long experience in the application of R290.

After sales

Service and maintenance in the after-sales sector is carried out by their own technicians. The technicians attend regular training courses in the De'Longhi headquarters. To ensure that only competent people work on the equipment only their own technicians are allowed to repair the units. To handle end-of-life aspects they follow the European WEEE Directive and De'Longhi is member of a consortium for the treatment of electrical waste.

Barriers

Initially the safety standard did not consider the application of flammable refrigerants and this was the main problem. When the EN standard was not available we used a draft standard (IEC 61D/53/CD). As second problem was the lack of specific components (mainly compressors).

Cooperation partners

De'Longhi is not working with any cooperation partners

Contacts

Alberto Aloisi, Technical Manager (alberto.aloisi@delonghi.it)

Examples of De'Longhi room air conditioners

7.5 JCI (Denmark)

Product information

Two types of HC equipment are produced: air cooled and liquid cooled chillers – for many different applications – with a capacity range from 60 kW to 500 kW. The largest charge is about 25 kg per circuit with two circuits per chiller unit. The latest design of the larger chillers use screw compressors and are equipped with inverters and run from 30 Hz to 70Hz. To date, well over 1,000 units are currently in operation. The production began in 1996, and the main markets have been Denmark, Sweden, United Kingdom and Germany.

Development and design

The standard EN378 and the European Pressure Equipment Directive (PED) were applied, where PED is the most challenging part. The European ATEX Directive is not relevant, so therefore additional design features were necessary to be applied. (This was evaluated by TÜV who concluded that ATEX was not relevant for the chillers). The approval and certification of the design and its serial production of the product as required by the PED were achieved.

Production and manufacturing

There was no need to modify the production area. However it was important to regularly consider the safety of the control panels and components, particularly with regards to their positioning. The compressors and the main parts are monitored by pressure in order to detect leakage. Staff training was carried out both within the workshop and in the field on an individual basis.

After sales

All persons that work on the systems must be trained in safe refrigerant handling, so it is ensured only competent persons work on the equipment. In some cases servicing and maintenance is carried out by external contractors in which case the training would then have also be done externally. In either case the duration is two days of training. End-of life aspects are handled as any other refrigeration system.

Barriers

The main barriers are in the mindsets of any parties involved.

Cooperation partners

They worked with notified body to achieve the PED approvals through and they have communicated a bit with TÜV, and also worked with a training provider.

Contacts

Alex Cohr Pachai, Technical Manager (Alexander.C.Pachai@jci.com)

A new JCI air cooled R290 chiller

7.6 Hindustan Unilever / Kwality Walls Ice Cream (India)

Company information

Hindustan Unilever Limited (HUL), a subsidiary of Unilever, is India's largest FMCG company. When reaching the point-of-sale (e.g., retail shop) the ice cream products are stored in freezer cabinets. For the sales of ice cream to the consumer, the business relies on over 2 million ice cream cabinets placed worldwide at the points of sale.

Product information

In 2000, Unilever committed to stop buying HFC cabinets by 2005, replacing new cabinets using R290. By early 2010 Unilever had around 500,000 HC cabinets in use around the world. The size of the equipment varies between 150 and 400 litres storage volume and the refrigeration capacity varies from 100 and 300 W. The rollout in India started in 2007 for HUL and by early 2010, there were 7,000 cabinets using R290; the plan is to double this figure by 2015.

Development and design

The standard IEC 60335-2-89 is followed, but also taking into consideration national regulations apply, they take precedence. In addition, Unilever has commissioned quantitative risk assessments (QRA) by independent establishments and recommendations from these have been included in functional specifications prepared for the cabinet suppliers. Although the manufacturers have responsibility for the correct design of their equipment, Unilever cannot ignore the importance of design on the safe operation of the cabinets and therefore to ensure that cabinet manufacturers pay attention to important design aspects, Unilever issues them with functional specifications. It is then up to the manufacturer to demonstrate to Unilever that they have considered each point in the specifications. Unilever has undertaken initial field trials of HC cabinets in various countries during 2000 to 2004, with no reported problems in performance or safety. For the Indian market, additional trials in special climate simulation tests ascertained that the cabinets performed reliably under extreme tropical conditions, and withstood tough handling during transportation. Also field trials in India have been undertaken successfully. All trials confirmed that HC cabinets are at least as safe and reliable as their HFC containing equivalents, and also have on average a 10 % less electricity consumption. Unilever developed a detailed Rollout Summary Document, and a Safe Servicing Training Package. This package acts as the basis for a local rollout implementation strategy in a specific country or region.

Production and manufacturing

India does not have a commercial refrigeration equipment manufacturer with capabilities to manufacture ice cream cabinets with HC refrigerants. Cabinets have been imported from other Asian countries, where several Asian suppliers collaborate with European manufacturers. The cabinet manufacturers are responsible for necessary production area modifications, safety management systems and manufacturing staff training.

After sales

Transporters are trained to handle the cabinets carefully. Each outlet is inspected before the cabinets are being installed and post-installation checks are carried out to ensure that the placement of the asset is according to requirements.

Every cabinet has to go through a pre-dispatch inspection before being deployed in the market. Hindustan Unilever use own service stations with 3rd party service providers- Service stations have been made HC safety-compliant. Safety measures such as fire extinguishers, improved electrical infrastructure, signboards, first aid kits, personal protective equipment, were installed. Exhaust fans were installed to ensure rapid dispersion of refrigerant in case of leakage.

Training is done in-house and covers technical and safety aspects. The training sessions include classroom as well as practical training. To ensure that only competent personnel work on the equipment, written evaluation tests are undertaken, and it is mandatory to pass the tests to get the formal license to service HC cabinets.

Regarding end-of-life, the mother company Unilever has a global "cabinet disposal policy" which ensures that an environmentally benign way of disposal is applied locally.

Barriers

The main barriers were found to be:

- A lack of Indian manufacturers of HC cabinets and HC components (i.e. compressors); the short term option is to import from other countries
- A lack of skilled technical manpower, and this has been overcome by developing and applying in-house training concepts
- Since there were no suppliers for dedicated HC spare parts in India, these have to be imported from other countries in the region
- Availability of HC refrigerant in India; even importing is very complicated, as all imported cylinders do not have the approval of the Indian Commissioner of Explosives – it took ten months to find a supplier who had the required licenses and permissions to import cylinders and refrigerant (from Italy)
- There is a lack of clarity, particularly but not exclusively in India, with regards to the legislative framework for use of HC as refrigerant in commercial appliances, on safe storage of HC cabinets and HC refrigerant, on service technician skills requirements, and on service station safety compliance – joining forces with all stakeholders would be the way forward to overcome this

Cooperation partners

In the initial phase of HC cabinet development, Unilever cooperated with several partners on the assessment of potential risks of this technology. In particular:

- Development and design of HC cabinet technology has been done in close cooperation with some key cabinet manufacturers
- Together with specialist consultants, Unilever developed standard training material for service technicians, used as the basis for dedicated local training concepts, as described here in the Indian rollout case

Contacts

Baasit Shukri, National Cold Chain Manager, Hindustan Unilever (Baasit.Shukri@Unilever.com)
Berty Jacob, Group Leader Business Systems Technology (Berty.Jacob@Unilever.com)
Rene van Gerwen, Global Lead Engineer Refrigeration & HVAC (Rene-van.Gerwen@Unilever.com)

Kwality Wall's ice cream cabinets with HC refrigerant located at point-of-sales in India

7.7 Lidl (Germany)

Product information

Supermarket systems consisting of a compact plant for outdoor installation with indirect cooling (medium temperature and air conditioning) and a heating system, using R290 in the primary circuit and potassium formate brine in the secondary circuit. An additional low temperature stage is uses R744 direct expansion or also with a secondary circuit with brine. The low temperature stage is built in as cascade in the medium temperature stage. The system designed for Lidl supermarkets has the following capacity data:

- Medium temp.: 55 kW cooling capacity
- Air conditioning: 40 kW cooling capacity
- Heat pump: 60 kW heating capacity (without waste heat)

Using the standard housing a cooling capacity up to 200 kW is possible. The charge size depends on the overall refrigerant quantity of the plant lies between 40 and 80 kg of R290. Currently there are four plants in operation in Germany. In May 2010, the roll-out for all newly built Lidl stores in Germany will start. In total there will be approximately 200 plants in operation by mid-2012. At the same time, the first plants in Denmark and in Switzerland will also come into operation. The first integral plant has been produced in 2008.

Development and design

The following standards and regulations were applied: GPSG, 11. GPSGV, RL 94/9/EG (ATEX 95), TRBS 2152, BGR 104, BGR 500, RL 2006/42/EG (MRL), RL 97/23/EG (DGRL), EN 378 1-4. TÜV SÜD; Drees & Sommer Advanced Building Technologies; Fa. Effektivplan; DGNB (German Sustainable Building Council); DENA (German Energy Agency) were involved in approving design and certifying the products.

Production and manufacturing

The production area was modified in a way that the final assembly hall of Futron (the machinery supplier) was completely reconstructed to better comply with the requirements of serial production. As a final control, a test plant for the simultaneous testing of up to three plants was built. The whole production area is equipped with gas sensors and a ventilation system according to EU ATEX Directive, corresponding to the integral plant concept itself. In the case of an accident, the whole building area will be switched off from energy supply. Safety management systems put in place included the whole production area being furnished with instructions and procedures for the safe use of flammable refrigerants exist.

After sales

There was no need for training, because Futron GmbH is specialised on the use of natural and flammable refrigerants since many years. Futron has only trained expert staff. Operation and maintenance can also be conducted by external expert staff. A precondition for this is a certificate of specialist knowledge and extensive training from Futron. In addition the Plant is 100% recyclable.

Barriers

The main barriers were the outdated and untenable prejudices against flammable refrigerants and some difficulty in the availability of components (due to low market demand) delayed the immediate implementation. An economically reasonable realisation of the concept was possible by adhering to the following design features:

- Creating a compact device for outdoor installation
- Avoiding the application of ATEX Directive
- Using a secondary circulation for cold transmission

After intensive talks with several component manufacturers and by highlighting the commitment of the project from Lidl as a large end-user, the necessary accreditation and approval was given. In the meantime, there exists a good availability and a normal competition situation for the necessary components.

Cooperation partners

The first integral-plant is a cooperation project between Lidl and Futron. Lidl (as an important end-user) took part in all phases of the project. Therefore it was possible to design the plant optimised for this kind of application. All integral-plant-series designed by Futron will be customized in accordance with the requirements of the End customer.

Contacts:

Andreas Schwarz, Area manager (Andreas.schwarz@lidl.de)

A Futron integral plant at Lidl supermarket

7.8 Palfridge (Swaziland)

Product information

The Palfridge factory is in Swaziland, southern Africa. The products are sold throughout the region of southern and Central Africa, but also into the Middle East and in the future to Europe. They manufacture a range of stand-alone commercial refrigeration units, such as bottle coolers, freezers, storage cabinets and display cases. The capacity of the cabinets range from small (around 50 litres) to larger models (over 2,000 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 upon the type and size of cabinet and the operating temperature. Over 100,000 units are produced annually, and the entire production is being shifted from HFCs to HCs over a 12 month transition period. The transition began in 2009 is expected to be completed in 2010.

Development and design

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 bought in specially (supplied by GTZ) and modified accordingly to tested the refrigerators at the Palfridge facilities under the supervision of an external laboratory. Conformity to the standards will be through self-declaration and CE marking. (The local test houses are using Palfridge staff to train them!) We have made various other pieces of test equipment in house.

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 VDE. 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 is currently working towards implementing ISO 9001, which will be in place by July 2010. ISO 14000 is scheduled to follow. The laboratory standard ISO 17025 is also being implemented and expected to be completed by end 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 it afforded an opportunity to re-design the entire cabinet to better suit the new production process, improve performance improvement 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.

Training to 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, but in addition, the production process now operates in a much more synchronised manner, whilst the greatest change is that the workers themselves seem to be proud and dignified, helping to contribute to much higher quality products and working environment.

After sales

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 and 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.

Barriers
There were a few barriers. One was the time taken to analyze and redesign each cabinet model. Also, HC were 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 them acquiring additional tanks with 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 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.

Cooperation partners
GTZ Proklima

Contacts
Roy Singh, Technical Director (roys@palfridge.com)

Charging area of production line (left) and example of some HC cabinets (right)

7.9 Victorian Transport Refrigeration – Refrigerated transport and vehicle AC (Australia)

Product information
Victorian Transport Refrigeration (VTR) developed a range of refrigerated transport systems from small 1 tonne capacity vans through to 5 tonne truck systems. Depending on the capacity and temperature level, these systems use a R290/R170 blend, R290 and also a blend of R290/R600a. These transport system are purpose built, but are also tailored to the particular needs of the customer. Although the units have originated from the HCFC product range, the systems have been carefully optimised specifically for the HCs and also to minimise the refrigerant charge quantity such that all HC models contain significantly less charge than conventional systems. Several hundred systems have been supplied since production began a couple of years ago.

Development and design

No international or national (Australian) safety standards or guidelines exist specifically for transport refrigeration systems although a draft safety standard AS 1677 Part 3 (unpublished) applies to the use of HC for motor vehicle air conditioning systems. Therefore in absence of a formal standard, VTR designs and constructs the systems according to the requirements of AS 1677 Part 2 (for static systems), and also observes the provisions of the Australian and New Zealand "Refrigerant handling code of practice 2007" Parts 1 and 2 and the "The Australian automotive code of practice for the control of refrigerant gases during manufacture, installation, servicing or de-commissioning of motor vehicle air conditioners 2008" (which apply to the handling of fluorinated refrigerants). Although these documents do not explicitly cover the use of HC refrigerants, they nevertheless serve as a point of reference to inform the design and maintenance of the systems.

Production and manufacturing

Systems are assembled from commercially available components within the production facilities, where they are also fitted to the vehicles. Apart from a slightly different production route to ensure the correct components are used and that potential sources of ignition are avoided there are no significant differences. However, a checking process is necessary to ensure that the vehicle or trailer within which the refrigerating parts are to be installed does not include any potential sources of ignition. Since the systems are charged after installation, the production area does not need to address the requirements for hazardous areas. However, for charging and servicing of systems, a dedicate area is used. The facilities employ internal quality procedures to ensure that the necessary precautions have been put in place at each stage in the process.

After sales

After-sales service and maintenance is carried out by VTR technicians who provide on-site service and regular maintenance programmes. Careful records of systems in the field are kept, and preventative maintenance schedules are applied to ensure reliability, and to avoid the risk of client exposure to expensive system failures. All staff are qualified refrigeration mechanics through the technical "TAFE" colleges and hold Certificate 3 qualifications combined with the standard four year apprenticeships. Specialised training is not provided for transport refrigeration by the TAFE system, so this is provided in house, with technical support and advice from the refrigerant suppliers.

Barriers

One major barrier is, as identified above, the lack of appropriate safety standards. Whilst it has been possible to develop internal guidelines to enable the development of HC products, the availability of an industry code of practice or national or other standard would of course help to resolve acceptance issues. However, the main barrier that was faced have not been technical or commercial, but were instead due to peer pressure from industry peers and competitors who alleged it was not feasible to use HCs, and that the refrigerant wouldn't work or would damage equipment. Despite such significant resistance, VTR persevered with the product development and commercialisation. As a result there is growing positive feedback from customers and users based on the evidence and practical experience.

Cooperation partners

The main cooperation partner was their refrigerant supplier (Hychill Australia) who worked closely with VTR to provide technical advice and to offer guidance on system design and maintenance issues.

Contacts

Rohan Cox (scms01@bigpond.com)
Ross Bradshaw (ross@hychill.com.au)

Installed refrigeration system inside a truck/mobile cold rooms

7.10 Waitrose / John Lewis Partnership (UK)

Product information

Supermarkets using R290 and R1270; up to 70 integral items including cabinets and cold stores, all of which are interconnected by water piping. The average charge of a single system is around 700 g, and with the total quantity of refrigerant approximately 75 kg.

Development and design

The reference safety standards used were: EN 378 Parts 1 – 4: 2008/9, IoR Code of Practice (A2 A3 Refrigerants), EN 60335-2-40: 2003, EN 60079-0: 2009, EN 60079-10-1: 2009, EN 60079-14: 2008, EN 60079-15: 2005. The design was completed by several OEM's providing individual pieces of equipment including cabinet manufacturers and chiller manufacturers. The overall design consisted in simple terms of water cooled integral direct expansion HC cabinets, a chilled water circuit (between shop floor and chillers) and roof mounted HC water chillers. Cold air retrieval from the shop floor is used to comfort cool the shop floor and back of house areas of the supermarket, a small amount of the heat is rejected from the cabinets directly to the shop floor by way of a de super heater coil in the compressor discharge prior to the water cooled plate condenser. The site also incorporates other integral cabinets and appliances that are air cooled HC systems i.e. icemakers and service cabinets. Small HC split AC systems are used to cool small offices and staff dinning room during times of warm ambient conditions.

Production and manufacturing

The production of the HC equipment was carried out by approximately 10 OEM's and the equipment shipped to site pre-commissioned and ready to run. Several of the OEM's were already producing HC variants of their standard HFC product range, others began from scratch. Generically OEM's have modified their manufacturing facilities to comply with relevant standards including DSEAR / ATEX and have purchased automatic HC charging equipment, especially for smaller cabinet charge sizes <800 g.

After sales

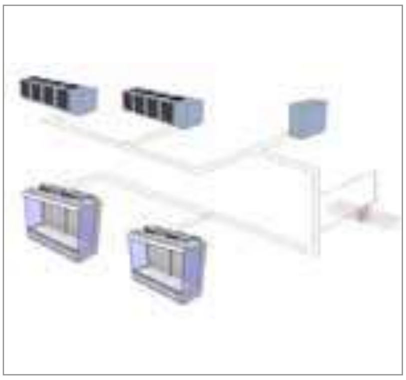
The sites are maintained by contractors who have all undergone HC refrigerant handling training as specified by Waitrose. There are currently (May 2010) over 5,000 HC trained service personnel operating across the UK and this number is increasing weekly.

Barriers
There are still several ambiguities and contradictions in standards that where primarily written to include HC systems with very small charge sizes. Many of the refrigeration specific standards can in places contradict/ overlap with DSEAR / ATEX and this continues to be debated.

Cooperation partners
Waitrose worked with over 10 suppliers to develop and deliver the HFC free supermarket this included a consultant specialising in HC refrigerants and involved verification of all the OEM's equipment design and manufacture to ensure compliance with the relevant standards.

Contacts
Les King, Refrigeration Manager (les_King@waitrose.co.uk)

HC chiller (left), system layout (centre) and example of display case (right) in Waitrose store



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ABBREVIATIONS

AB	Alkyl benzene
AC	Air conditioning
ACRIB	Air Conditioning and Refrigeration Industry Board
ADR	"Articles dangereuses par routier"
AHU	Air handling unit
ARC	AREA refrigeration craftsman/ craftswomen
AREA	Air Conditioning and Refrigeration European Association
ATEL	Acute toxicity exposure limit
ATEX	"**AT**mosphère **EX**plosible" (synonym for the European ATEX-directive)
BMZ	German Federal Ministry for Economic Cooperation and Development
BRA	British Refrigeration Association
CE	"Conformité européenne"
CEN	"Comité européen de normalization"
CENELEC	"Comité européen de normalisation electrotechnique"
CF	Conversion factor
CFC	Chlorofluorocarbon
CFD	Computational fluid dynamics
CNS	Central nervous system
COP	Coefficient of performance
CPD	Committee for the Prevention of Disasters
CRE	Carter Retail Equipment
DENA	German Energy Agency
DGNB	German Sustainable Building Council
DN	Diameter nominal
DOT	(US) Department of Transportation
DSEAR	Dangerous substances explosive atmospheres regulations
EC	European Commission
EN	European norm
ESR	Essential safety requirements
ETA	Event tree analysis
EU	European Union
FMCG	Fast moving consumer goods
FMEA	Failure modes and effect analysis
FTA	Fault tree analysis
GHG	Greenhouse gas
GTZ	"Gesellschaft für technische Zusammenarbeit" (German technical cooperation agency)
GWP	Global warming potential
HazOp	Hazard and operability study
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HPMP	HCFC phase-out management plan
HTF	Heat transfer fluid
HUL	Hindustan Unilever Limited
HVAC	Heating, ventilating and air conditioning
IATA	International Air Transport Association
IEC	International Electro-technical Commission
IMDG	International maritime code for dangerous goods
IMQ	"Instituto italiano del marchio di qualita"
ISO	International Standardisation Organisation
JCI	Johnson Controls International
LFL	Lower flammability limit
LPG	Liquid petroleum gas
LPGA	Liquid Petroleum Gas Association
MLF	Multilateral Fund
NCG	Non-condensable gases
NOU	National ozone unit
ODL	Oxygen deprivation limit
ODS	Ozone depleting substances
OEM	Original equipment manufacturer
OFDN	Oxygen-free and dry nitrogen
PAG	Polyalkyl glycol
PAO	Polyalpha olefins
PE	Pressure equipment
PED	Pressure equipment directive
PL	Practical concentration limit
POE	Polyol ester
ppm	Parts per million
PRV	Pressure relief valve
PS	Pressure
QC	Quality control
QRA	Quantitative risk assessment
QMS	Quality management system
RAC	Refrigeration and air conditioning
SOI	Sources of ignition
TDGR	Transport of dangerous goods regulation
TLV-TWA	Threshold limit value – time weighted average
TÜV	"Technischer Überwachungsverein"
UFL	Upper flammability limit
UN	United Nations
UPS	Uninterruptible power supply
V	Volume
VDE	„Verband der Elektrotechnik, Elektronik und Informationstechnik"
VET	Vocational and educational training
VETC	Vocational and educational training centres
VTR	Victorian transport refrigeration
WEEE	Waste electrical and electronic equipment

GLOSSARY

A5 Countries: Countries that are Party to the Montreal Protocol, listed under Article 5. These countries are permitted a ten-year grace period in the phase-out schedule in the Montreal Protocol compared with developed countries.

Accreditation body (quality control): A body that conducts and administers a laboratory accreditation system and grants accreditation. An accreditation body may wish to delegate fully or partially the assessment of a testing laboratory to another competent body (assessment agency). Whilst it is recognised that this may be a practical solution to extending recognition of testing laboratories, it is essential that such assessment be equivalent to that applied by the accreditation body and that the accreditation body take full responsibility for such extended accreditation.

Accredited laboratory (quality control): A laboratory is then accredited when it was accredited through a national recognised accreditation body for accreditation of test laboratories according to ISO/ IEC Guide or a national equivalent.

ADR (Articles Dangereuses par Routier): A regulation introduced in 2009 that should be referred to when transporting refrigerating machines by road and rail within Europe.
Allowable charge size: The amount of refrigerant that is permitted to be used in a refrigerant circuit of a direct expansion system, usually based on the room size, so that a flammable concentration will be avoided in the event of a catastrophic leak.

Approvals body (quality control): A company specialising in testing and certification of engineers, test/quality engineers, design/development engineers, manufacturing/production engineers, engineering executive management and marketers.

Approved training organisation/awarding body (training): Organisation which is recognised on national level to assess competence and to award certificates (a proof of competence) recognising the health, safety, technical, environmental and energy conservation competence of persons working on refrigerating systems and heat pumps

Assessment (training): Process by which the evidence generated, gathered and provided about a person is judged to determine competence

ATEL (Acute-toxicity exposure limit): Describes the adverse effects of a substance which result either from a single exposure or from multiple exposures in a short space of time (usually less than 24 hours). To be described as acute toxicity, the adverse effects should occur within 14 days of the administration of the substance.

Brazing: A joining process whereby a filler metal or alloy is heated to a melting temperature above 450°C and distributed between two or more close-fitting parts by capillary action.

Bulk tanks: A permanent or fixed location container for holding large quantities of refrigerant (or other fluid), typically of a volume of 2,000 litres, 4,000 litres or greater.

Bund wall: A low-level wall usually surrounding containers with a flammable or otherwise dangerous fluid so that in the event of a spillage the release is better contained within a controlled area.

CE-certificate: A mark that certifies that a product has met EU consumer safety, health or environmental requirements. A notified body may be involved in the design phase, the production phase, or both, and the CE-marking shall only be followed by the identification number of the notified body. The

CE-mark is a visible declaration by the manufacturer (or his representative, importer, etc) that the equipment complies with all the requirements of all the applicable directives.

CEN (Comité Européen de Normalisation): A major provider of European Standards and technical specifications. It is the only recognized European organization according to Directive 98/34/EC for the planning, drafting and adoption of European Standards in all areas of economic activity with the exception of electrotechnology (CENELEC) and telecommunication (ETSI).

CENELEC (Comité Européen de Normalisation Electrotechnique): A non-profit technical organization set up under Belgian law and composed of the National Electrotechnical Committees of 31 European countries.

Certificate (training): Document issued under the rules of the assessment system indicating that the named person is competent to deal with applicable technologies, health, safety, environmental protection and energy conservation requirements for RAC system operating wit HC refrigerants.

Certification (training): Procedure used to demonstrate the qualification of personnel at a certain level and leading to the issue of a certificate.

Certification body (quality control): A body that conducts certification conformity. A certification body may operate its own testing and inspection activities.

CFC (chlorofluorocarbons): Halocarbons containing only chlorine, fluorine and carbon atoms; these are both ozone-depleting substances (ODSs) and greenhouse gases.

Charge: The term normally used to refer to the quantity or mass of refrigerant used in a circuit of a refrigerating system.

Competence (training): Ability to perform safely and satisfactorily the activities within an occupation and with reference to this handbook to be competent means to have the knowledge and/or skill to perform the task(s) under consideration, so that a best possible level is achieved and simultaneously to possess the necessary insight into the relevant problems to understand why the task should be carried out in such a way. A person shall be deemed competent if it can be demonstrated that he is capable of carrying out the required activities.

COP (coefficient of performance): A measure of the energy efficiency of a refrigerating system, which is defined as the ratio between the refrigerating capacity and the power consumed by the system and primarily dependant on the working cycle and the temperature levels (evaporating/condensing temperature) as well as on the properties of the refrigerant, system design and size. (The comparable term "EER" or "energy efficiency ratio" is also used.)

Direct expansion system: A refrigerating system with one degree of separation from the occupied space, for example, an evaporator or condenser of the refrigerating system in contact with the air or the substance to be cooled or heated.

Emergency ventilation: A ventilation system (fans and ducting) used for extracting any build-up of flammable refrigerant within a room, enclosure or area in order to help mitigate the possibility of ignition; it is normally initiated by gas detection equipment.

ETA (event tree analysis): A logic-based technique, characterising the likelihood of hazards occurring according to contributing events not occurring or occurring.

First-party (quality control): First-party activities are carried out by manufacturers and suppliers. First-party testing is a large sector. It is for example used as an internal quality control measure that the products, materials, items and services are up the requirements expressed in legislation, standards, technical specifications and contracts with the clients. The manufacturers' declaration of conformity expressed by different ways of marking the product is often based also on the outcome of these tests. In the fulfilment of conformity assessment requirements, for example those of the European directives, manufacturers must take all means necessary to ensure that the manufacturing process assures compliance with the prototype, to affix the CE marking to the product and to establish a technical documentation. For the purpose of complying with the related modules the manufacturer shall ensure that a quality system is implemented according to pertinent standards.

Flooded system: A refrigerating system that relies on a pool of boiling refrigerant to remove the heat from the heat transfer medium; this type of system usually requires significantly greater refrigerant than a so-called dry expansion type system, where the boiling refrigerant passes through the exchanger.

FMEA (failure modes and effect analysis): A method to primarily address the effects of failures or malfunctions of individual components within a system, with the objective of identifying which components are the most critical and thus, which require greatest consideration.

FTA (fault tree analysis): a technique that combines a graphical approach and estimated probabilities to determine the likelihood of undesirable outcomes. It helps to systematically develop an overview of the possible events leading to one or more consequences.

Functional testing: Testing the operation of a device or mechanism to check whether it operates as intended.

GHG (greenhouse gas): The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation within the spectrum of the thermal infrared radiation that is emitted by the Earth's surface, by the atmosphere and by clouds. This property causes the greenhouse effect.

GWP (global warming potential): An index comparing the climate impact of an emission of a greenhouse gas relative to that of emitting the same amount of carbon dioxide. GWPs are determined as the ratio of the time integrated radiative forcing arising from a pulse emission of 1 kg of a substance relative to that of 1 kg of carbon dioxide, over a fixed time horizon.

HazOp (hazard and operability study): Similar to a risk assessment technique in that it provides a useful means of gaining insight to the possible hazards posed by systems and installations, which can then be quantified by other means.

HC (hydrocarbon): Chemical compounds consisting of one or more carbon atoms surrounded only by hydrogen atoms.

HCFC (hydrochlorofluorocarbons): Halocarbons containing only hydrogen, chlorine, fluorine and carbon atoms. Because HCFCs contain chlorine, they contribute to ozone depletion and they are also greenhouse gases.

HFCs (hydrofluorocarbons): Halocarbons containing only carbon, hydrogen and fluorine atoms. Because HFCs contain no chlorine, bromine or iodine, they do not deplete the ozone layer, but like other halocarbons they are potent greenhouse gases.

HPMP (HCFC phase-out management plan): A scheme comprising policy and technical elements that enable a country to phase out the consumption of HCFCs within the schedules prescribed within the relevant amendment to the Montreal Protocol.

IATA (International Air Transport Association): An organisation which prescribes the Regulations for transport by air.

IEC (International Electrotechnical Commission): the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies — collectively known as "electrotechnology".

IMDG (International Maritime Dangerous Goods Code): A regulation introduced in 2008 which should be referred to when transporting refrigerating machines by sea.

Indirect system: A refrigerating system with more than one degree of separation from the occupied space, for example, where an evaporator cools or condenser heats the secondary heat transfer fluid (such as water or brine) which passes through closed circuit containing heat exchangers, that are in direct contact with the substance to be treated (such as air inside the occupied space).

ISO (International Organisation of Standardisations): the world's largest developer and publisher of International Standards.

Kyoto Protocol: The Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted at the Third Session of the Conference of the Parties (COP) to the UNFCCC in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol agreed to reduce their anthropogenic greenhouse-gas emissions (specifically carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) by at least 5% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol entered into force on 16 February 2005.

LFL (Lower flammability limit): The lower end of the concentration range of a flammable solvent at a given temperature and pressure for which air/vapour mixtures can ignite. The flammability range is delineated by the upper and lower flammability limit. Outside this range of air/vapour mixtures, the mixture will not ignite (unless heated).

LPG (liquefied petroleum gas): A mixture of various hydrocarbons – typically propane and/or butane – which is normally used as a fuel gas for heating and cooking. The composition of LPG normally incidentally includes moisture, sulphur and other substances not normally suitable for use in refrigerating systems.

Machinery room: An enclosed room or space, vented by mechanical ventilation, sealed from public areas and not accessible to the public, which is intended to contain components of the refrigerating system.

Maximum charge size: The upper limit of the quantity of refrigerant than can be used in a particular type of system and occupancy.

MLF (Multilateral Fund): A fund established in 1991 to assist A5 countries in meeting their Montreal Protocol commitments, through financing activities including industrial conversion, technical assistance, training and capacity building.

MSDS (materials safety data sheet): A safety advisory bulletin prepared by chemical producers or suppliers for a specific refrigerant or compound.

Montreal Protocol on Substances that Deplete the Ozone Layer: Adopted in Montreal in 1987 and subsequently adjusted and amended in London (1990), Copenhagen (1992), Vienna (1995), Montreal (1997) and Beijing (1999). It controls the consumption and production of chlorine- and bromine-containing chemicals, known as ozone depleting substances (ODSs) that destroy the stratospheric ozone layer. NCGs (non-condensable gases): Gaseous contaminants sometimes found inside a refrigerating system, often nitrogen and oxygen due to migration from the air, which collect within the high side a system and impedes its performance.

Notified body (quality control): A Notified Body is an organisation that has been nominated by a member of Government and notified by the European Commission (as sample). A Notified Body will be nominated based on designated requirements, such as knowledge, experience, independence and resources to conduct the conformity assessments. The primary role of a Notified Body is to provide services for conformity assessment on the conditions set out in the New Approach Directives in support of CE Marking. This normally means assessing the manufacturers conformity to the essential requirements listed in each directive. Conformity assessment can be inspection, quality assurance, type examination or design examination, or a combination of these.

Novel testing: Where some unusual issue has to be addressed and no specific test procedures exist within standards or other guidelines which must otherwise be followed. Example of this may arise during the development of a new type of safety device or where a hitherto unanticipated set of circumstances has arisen.

Occupancy category: The type of category that is occupied by persons, necessary for the determination of safety design requirements for the refrigerating system; either A (e.g., public), B (e.g., private) or C (e.g., authorised personnel).

Occupied space: Space bounded by walls, floors and ceilings in buildings which are occupied for a significant period by persons.

ODL (oxygen deprivation limit): Concentration of a refrigerant or other gas that results in insufficient oxygen causing the onset of abnormal.

ODP (ozone depletion potential): A relative index indicating the extent to which a chemical product may cause ozone depletion compared with the depletion caused by CFC-11. Specifically, the ODP of an ozone depleting substance (ODS) is defined as the integrated change in total ozone per unit mass emission of that substance relative to the integrated change in total ozone per unit mass emission of CFC-11.

ODS (ozone depleting substance): Substances known to deplete the stratospheric ozone layer. The ODSs controlled under the Montreal Protocol and its Amendments are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), halons, methyl bromide, carbon tetrachloride, methyl chloroform, hydrobromofluorocarbons and bromochloromethane.

OFDN (oxygen free dry nitrogen): Refrigeration-grade nitrogen used for working on refrigeration systems, that minimises the potential for contamination of the inside of the system with air, moisture or other contaminants.

PL (practical concentration limit): Another measure for the application of refrigerants. 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.

QC (quality control): A procedure or set of procedures intended to ensure that a manufactured or installed product, service or some other process adheres to a defined set of quality criteria or meets certain requirements. Examples of this include safety testing, third party inspections and quality marking.

QMS (quality management system): A system used to assess the principles and processes surrounding the design, development and delivery of a general product or service.

QRA (quantitative risk assessment): A method used to numerically evaluate the probability of a particular hazard occurring, such as the likelihood of an occurrence of ignition of a flammable gas and the severity of the consequences, normally drawing on statistical and empirical data of the contributing events.

Qualification (training): The evidence of a certain level of professional competence. Any involved person shall demonstrate a level of predefined competence of theoretical and/or practical ability as necessary for the activity in question.

Refrigerant: A fluid used for heat transfer in a refrigerating system, which absorbs heat at a low temperature and a low pressure of the fluid and rejects it at a higher temperature and a higher pressure of the fluid usually involving changes of the phase of the fluid.

Refrigerating system: A combination of interconnected refrigerant-containing parts constituting one closed circuit in which the refrigerant is circulated for the purpose of extracting and rejecting heat (i.e., heating and cooling).

Sealed system: Refrigerating system in which all refrigerant containing parts are made tight by welding, brazing or a similar permanent connection (this may include capped valves and/or capped service valves).

Second-party (quality control): Second-party activities are performed by buyers, users or consumers. Second-party testing is performed by the receiver of the products, materials, items and services mainly in order to ensure that agreed requirements and specifications are fulfilled. For ordinary consumers, testing can be performed by consumer interest organisations or buyer organisations of products. Because of its often very individual nature this type of testing is not considered in detail here.

SOI (source of ignition): An electrical or other device that is capable of igniting a mixture of flammable refrigerants and air, within its flammable limits.

TDGR (United Nations Model Regulations for Transport of Dangerous Goods): A regulation introduced in 2007 that should be referred to when transporting refrigerating machines by road and rail outside Europe. Equipment containing less than 12 kg is exempt from the regulations provided it is protected by design. For equipment containing over 12 kg, it must be subject to a pressure type-test of at least three times the maximum working pressure and comply with the packaging requirements detailed in these regulations.

Third-party (quality control): Third-party activities done by organisations independent of the above mentioned parties. A third-party is a person or body that is recognised as being independent of the parties involved, as concerns the issue in question. Third-party testing is especially required, preferred or used if the results have a considerable influence or effect on public or societal issues, in particular related to health, environment, safety and large economic values. It is also applied when taking measures to eliminate the possibility of cheating and considerable misconduct or when crucial risks and consequences of wrong or manipulated results exist. Third-party testing is expected to provide a non-biased view and thus a better confidence in the test results.

TLV-TWA (threshold limit value – time weighted average): average exposure on the basis of an 8 hour per day, 40 hour per week work schedule.

Type-testing: Rigorous test that is applied to something that this normally tested routinely, in order to check that an assumed higher level of safety is still inherent in the design or process. Examples include high pressure destructive testing or observing the behaviour of an item within a fire situation.
VETC (vocational and educational training centres): An educational establishment that prepares trainees for jobs that are based on manual or practical activities, traditionally non-academic, and totally related to a specific trade, occupation, or vocation.

APPENDICES

APPENDIX 1: NON-SAFETY RELATED TECHNICAL ASPECTS

Introduction

There are several HCs that may be used as refrigerants. R600a (iso-butane) and R290 (propane) are the most widely used in non-industrial applications. In addition to these, R1270 (propylene), and two sets of blends are also used. There are several mixtures of R600a and R290 and another is a mixture of R290 and R170, although the compositions for these vary by producer. There are also mixtures of R290 and R1270. For industrial applications, a variety of other HCs are used, including R50 (methane), R170 (ethane), R601 (pentane), R601a (isopentane) and R1150 (ethylene). Table 21 provides a list of HC refrigerants and some basic properties.

Table 21: HC refrigerants and basic properties

Refrigerant number	Chemical or composition*	Molecular mass (kmol/kg)	Critical temperature (°C)	Normal boiling point (°C)	Vapour pressure at 30°C (kPa)
R170	ethane (C_2H_6)	30.1	32.2	-88.6	4704
R290	propane (C_3H_8)	44.1	96.7	-42.1	1092
R433A	R1270/R290 (30%/70%)	43.5	94.2	-44.5	1178
R433B	R1270/R290 (5%/95%)	44.0	96.3	-42.6	1108
R433C	R1270/R290 (25%/75%)	43.6	94.6	-44.2	1165
R436A	R290/R600a (56%/44%)	49.3	115.9	-34.3	768
R436B	R290/R600a (52%/48%)	49.9	117.4	-33.4	741
	R290/R600a (50%/50%)	51.1	120.7	-31.0	814
	R290/R170 (94%/6%)	43.3	94.2	-49.0	1393
R50	methane (CH_4)	16.0	-82.6	-161.5	[super critical]
R600	butane (C_4H_{10})	58.1	152	-0.5	288
R600a	isobutane (C_4H_{10})	58.1	134.7	-11.7	410
R601	pentane (C_5H_{12})	72.2	196.6	36.1	83
R601a	isopentane (C_5H_{12})	72.2	187.2	27.8	111
R1150	ethylene (C_2H_4)	28.1	9.2	-103.8	[super critical]
R1270	propylene (C_3H_6)	42.1	91.1	-47.6	1321

*Compositions in molar percent

Refrigerant purity

Refrigerant grade product should be used for all RAC systems. Commercial grade HCs (e.g. liquefied petroleum gas, short cut LPG) contains significant quantities of sulphur, water, and other impurities and could contribute to oil degradation, shorten compressor life and invalidate warranties. The composition of commercial LPG is variable so the thermodynamic properties of the fluid may vary significantly from cylinder to cylinder. Also, unlike commercial LPG, HC refrigerants are not odorised.

Material compatibility

It is important to consider the compatibility of the refrigerant and the compressor oils with system materials such as plastics, elastomers, metals, etc. Virtually all common elastomer and plastic materials used as 'O' rings, valve seats, seals and gaskets are compatible with HC refrigerants. Materials that are not compatible and should not be used in HC systems include EPDM, natural rubbers and silicone rubbers. It should be noted that, chloroprene (neoprene) products are specifically incompatible with unsaturated HCs (i.e., R1270, R1150). Whilst testing has been conducted on a number of selected materials with refrigerant and oil combinations it should be noted that there are numerous different grades available in the market and for this reason compatibility should be checked with the manufacturer or supplier of the component. Normally component suppliers will be available to confirm whether or not the used materials pose a compatibility problem.

Lubricants

Most common refrigeration oils are also compatible with HCs, although there is often high solubility with certain mineral and POE oils. However, various lubricant manufacturers provide refrigeration oils specifically for HC refrigerants. An overview of the suitability of HCs with various lubricants is provided in Table 22.

Table 22: Compatibility and solubility of different oils with HCs

Oil type	Compatibility	Solubility
Mineral Oil (MO)	Good	High
Alkyl benzene (AB)	Good	Medium
Polyol Ester (POE)	Good	High
Poly alpha oelfin (PAO)	Good	High
Poly alkyl glycol (PAG)	Good	Medium

Thermo-physical characteristics and transfer process

Thermodynamic and transport properties of refrigerants affect the design and performance of the refrigerating system. The most important properties are vapour pressure as this is a common factor used in selecting a particular refrigerant for a given type of system and application. HCs have a much lower molecular mass than the commonly used CFCs, HCFCs and HFCs, and these result in some differences in their thermophysical properties and therefore their operating characteristics.

Vapour pressure

The group of HCs cover a broad range of vapour pressures, suitable for most RAC applications. Certain HCs are blended in order to achieve certain other vapour pressures. Over the range of vapour pressures offered by common CFC, HCFC and HFC refrigerants, there is a comparable set of HC refrigerants, as indicated in Table 23. A particular characteristic of HC refrigerants is that the slope of the vapour pressure curve with respect to temperature tends to be 'flatter' than with the CFCs, HCFCs and HFCs, and this results in a lower compression ratio (for the same operating saturation temperatures).

Table 23: Comparable HC refrigerants for replacing ODS and HFC refrigerants*

ODS refrigerant	HFC refrigerant	HC refrigerant
		R600a
R12	R134a	R436A, R436B, R290/R600a
R502	R404A, R507A	R290, R1270, R433A, R433B, R433C, R290/R170
R22	R407C	R290, R1270, R433A, R433B, R433C, R290/R170
	R410A	
R13, R503	R23	R170
R11, R123	R236ea, R236fa, R245fa	R601, R601a
*Comparable in terms of operating pressure/temperatures and cooling capacity		

Volumetric refrigerating effect

The volumetric refrigerating effect of the HCs whose vapour pressure corresponds to that of CFCs, HCFCs and HFCs also tend to provide similar volumetric refrigerating effects (also implicit in Table 3). Although the latent heat of HCs is approximately double that of the CFCs, HCFCs and HFCs, the vapour density is about half, thus resulting in similar refrigerating effect.

Discharge temperature

HCs have a fairly high specific heat capacity and therefore the compressor discharge temperature tends to be lower than for most CFCs, HCFCs and HFCs, based on a similar set of operating conditions.

Pressure loss

HCs have a fairly low density and low viscosity, which results in a smaller frictional pressure loss than may be experienced with common CFCs, HCFCs and HFCs (for a given refrigerating capacity). This is relevant to both single phase liquid and vapour flows, and two-phase flow.

Heat transfer

HCs have a fairly high thermal conducted and low viscosity, which results in a higher convective heat transfer coefficient than may be achieved with most common CFCs, HCFCs and HFCs (for a given refrigerating capacity). This trend is applicable for single phase liquid and vapour flows, as well and two-phase flow. However, for pool boiling HCs have no significant benefit over other refrigerants.

Charge size

The density of HCs is around half that of CFCs, HCFCs and HFC, therefore the corresponding charged refrigerant mass is normally less than 50% of that required for other refrigerants.

Equipment cost implications

For given refrigerating system, the main cost implication is the requirement for no sources of ignition, which generally translates as the avoidance of sparking electrical components. Under certain conditions, this can be achieved by repositioning the vulnerable components, thus resulting in no cost variation.

For other circumstances, existing electrical components may need to be replaced with, for instance, low current/low voltage components or sealed/encapsulated devices. In these cases, the level of additional cost is sensitive to the type of equipment and the number and types of electrical devices associated with it, and a cost evaluation can only be carried out on a case-by-case basis. With larger systems that necessitate the use of a flammable gas detector and associated emergency ventilation, the add-on cost can be somewhat higher. With respect to non-safety aspects, it is often the case that smaller interconnecting pipework, evaporator and especially condenser tubes can be used whilst maintaining the same system cooling capacity and efficiency, means that less copper is required to construct the system, leading to a cost reduction. Manufacturers have found that when a thorough technical analysis is carried out, product cost can be less than with HCFC and HFC models.

Common applications

Other than industrial refrigeration, there has been refrigeration, air conditioning and heat pump equipment produced using HCs in a wide variety of equipment, including:

- Domestic refrigeration
- Small commercial refrigeration appliances
- Supermarket systems (using indirect circuit to the occupied areas)
- Small portable and single split air conditioners
- Water-to-water heat pumps
- Air conditioning and refrigeration chillers
- Refrigerated trucks

By far the most extensive application is domestic refrigeration, although small commercial refrigeration systems are also expanding rapidly, and water-to-water heat pumps previously had a large market share. There are a number of reasons for the limited application in other types of systems, of which there are two general cases. The first is the insufficient political (legislative) drivers to force manufacturers and contractors to overcome the inertia caused by the additional issues to deal with then adopting a flammable refrigerant. The second is the reluctance of many compressor manufacturers to permit their compressors to be used with flammable refrigerants (for example now in the case of water-to-water heat pumps), and other similar commercial influencing factors.

There is a large and realistic potential for HCs to replace HCFCs and HFCs in a variety of targeted system types. The categories that are applicable are those listed above (except domestic refrigeration), where experience has already been gained. Taking into consideration the aspects highlighted above, there is potential for HCs to be used, or used more widely in a number of situations.

Domestic refrigeration

Approximately one third to one half of domestic refrigerators is currently manufactured using HCs, primarily R600a, and its use is continuing to increase, for example, in South America. The reason for the remaining portion still using HFC-134a is mainly due to the manufacturers not seeing the need to shift production from one technology to another, whilst in certain regions (e.g. North America) the potential for legal implications of using a flammable refrigerant are considered too risky to offset the environmental and/or marketing arguments. There are no technical reasons why HCs cannot be used for the large majority of the sector; with certain models, it may be necessary to use specific components suitable for flammable atmospheres, which can increase the cost of the product.

Commercial refrigeration

In terms of the types of systems used within the commercial refrigeration sector, integral (stand-along), remote (condensing units) and centralised systems must be considered separately. In terms of integral systems, the issues are similar for domestic refrigerators; there is a continued growth in the use of R600a and R290 in a variety of different appliances, for vending machines, bottle coolers, freezers, kitchen storage cabinets, etc. For the majority of products, HCs can be widely applied, particularly given that there are international safety standards that permit their application. For the larger systems that require larger refrigerant charge sizes, the use of HCs is restricted to regions where safety standards are currently in place (for example, but not exclusively, Europe, Australia/New Zealand, Indonesia).The widespread adoption of these standards would enable to use of HCs in larger systems across a greater extent, in a large proportion of equipment. For remote systems, charge sizes are often large and typically extend to various parts of a building. Thus, whilst the application of HCs is technically possible, and may be possible within the scope of safety standards, it is complicated and must be handled on an individual basis. For this reason, the use of HCs in remote systems is minimal, and is unlikely to be a technology of choice. For the same reasons as with remote systems, HCs cannot be used in conventional centralised pack/rack type systems. Instead, many central systems in Europe and elsewhere use HCs within a central chiller (located in a machinery room or outside) to cool a secondary refrigerant (brine, glycol, carbon dioxide), which is circulated to display cases and coldstores. As supermarkets shift to alternative systems, the use of central HC chillers is a viable option and has the potential to be used in the large majority of systems.

Industrial refrigeration

Industrial refrigeration covers a wide range of applications, including food processing, cold storage, process refrigeration, liquefaction of gases, and industrial heat pumps and heat recovery. HCs are not often used in many of these sub-sectors, although they are fairly wisely applied in process refrigeration; specifically chemical and petro-chemical processes. Since the majority of these systems are bespoke construction, it is difficult to provide general rules in terms of technical, cost, safety or legislative implications of applying HCs.

Transport refrigeration

Transport refrigeration can be broadly divided into reefer ships, intermodal refrigerated containers, refrigerated railcars and refrigerated trailers/trucks. Of these, HCs have been applied within refrigerated trucks and trailers. There are no technical reasons for why they cannot be applied widely in road transport systems, and the additional safety measures are not prohibitive (for example, use of a gas detector and warning alarm). The primary restriction is the possible legislation in certain countries that may prevent flammable refrigerants being used widely. The use of HCs is not considered for use in reefer ships or intermodal containers and railcars. However, due to the unusual nature of the applications, it is difficult to make broad statements without further consideration.

Air conditioners and heat pumps

Air conditioners can be divided into window, portable, single split, ducted and multi-split units. R290 has been applied in portable units and single split systems for at least 10 years, in Europe, Australasia and more recently are being produced in China. Due to charge size limitations ducted and multi-split air conditioners are not suitable for use with HCs. Whilst there are no technical or legislative reasons for why HC cannot be more widely applied to window, portable and single split air conditioners, recent changes to safety standards have introduced more restrictive limits on charge sizes, meaning that special attention has to be paid to redesigning existing models for much lower refrigerant charges. However, in certain situations, this can actually lead to a reduction in equipment cost. Overall, for the smaller sized air conditioning sector, a large portion could easily adopt HCs.

Water-heating heat pumps

Water heating heat pumps are typically small and medium sized appliances used in dwellings and commercial buildings for providing hot water and central heating. For small domestic water heating heat pumps, R290 has been widely used within Europe. Since 2002, its use has declined due to the introduction of the Pressure Equipment Directive (PED), which necessitated the approval of the preferred types of compressors for use with HC refrigerants. Since most of the compressor manufacturers had a policy against use of HCs in larger systems, approvals were not forthcoming and the use of R290 in these types of systems became limited. Apart from this legislatively-orientated hindrance, there are no technical reasons why R290 cannot be applied widely across this sector, particularly since they are self-contained systems and can be easily designed to meet safety requirements.

Air conditioning chillers

Air conditioning chillers may be divided into positive displacement and centrifugal machines, and cover a wide range of capacity sizes. They may be located within building basements, in machinery rooms, in enclosures outside buildings or on building roofs. Currently, there are no (non-industrial) centrifugal chillers using HCs, although several companies within Europe and other regions are producing small and medium sized scroll, reciprocating and screw chillers using R290 and R1270. These are typically positioned outside (besides the building or on the roof) and also within machinery rooms, although this can invoke additional costs because of the extra safety measures. HC chillers cannot be located below ground, which limits their widespread application. Otherwise, there are no technical problems with their application, and generally the cost impact of adopting HCs is minimal (except for economies of scale). It is possible that HCs could be used in over 80% of small and medium sized chiller applications.

Vehicle air conditioning

Vehicle air conditioning includes car, bus, rail, truck and air transport air conditioning. Presently, HCs are not applied in new systems for any of these uses, and in fact their use in aviation air conditioning is not viable because of safety issues. Whilst HCs have been used to a limited extent as a retrofit refrigerant in bus air conditioning, it is unsuitable due to the high refrigerant charge sizes. Similar issues probably apply to rail car and truck air conditioning. Despite the extensive application of HCs as retrofit refrigerants in car air conditioning in certain regions, their application in new systems is unlikely to materialise due to the current focus on the other candidate options, such as R744 (carbon dioxide) and unsaturated HFCs.

APPENDIX 2: EXAMPLE CONVERSION PROCEDURES

Introduction

This Appendix is intended to complement the information provided within Part 6.4 of the handbook. There are too many occasions where systems are found to have been converted from HCFCs or HFCs straight to HCs without proper care and attention and consideration given to ensuring that the system is left in the correct state where it conforms to the appropriate safety standards. These situations are dangerous and not acceptable.

It is acknowledged that conversions of equipment will take place, and whilst there are disagreements as to this taking place, it was considered important to provide detailed information on the correct manner by which a conversion should be carried out, including some pictorial, step-by-step example. If a conversion is considered, then the situation must be analysed, and if it is decided to take place it must be carried out to include all the relevant stages as described in Part 6.4 and as illustrated below.

Conversion of split air conditioner

Identify problem with air conditioner

1) Obtain current charge size
g 1.3 kg of R22

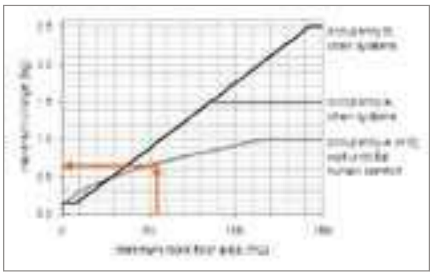
2) Estimate equivalent HC charge
g Assuming conversion to R290, 1.3 × 0.42 = 0.54 kg of R290

Conversion factors (C_f) to estimate equivalent HC charge size

Fluorinated refrigerant	HC refrigerant				
	R600a	R600a/R290 (50%/50%)	R290	R290/R170 (94%/6%)	R1270
CFC-12	(0.43) †	0.40	n/a	n/a	n/a
HFC-134a	(0.47) †	0.45	n/a	n/a	n/a
HFC-1234yf	(0.53) †	0.50	n/a	n/a	n/a
HCFC-22	n/a	n/a	0.42	0.41	0.42
HFC-407C	n/a	n/a	0.45	0.44	0.45
HFC-404A	n/a	n/a	0.51	0.50	0.52
HFC-507A	n/a	n/a	0.51	0.50	0.52
HFC-410A	n/a	n/a	(0.51) †	(0.50) †	(0.52) †

3) Identify occupancies
g Outdoor unit is in well ventilated area, authorised access only (category C)
g Indoor unit within office (category B)

4) Check charge size limits
g Charge size is below maximum limit (0.54 kg < 1 kg)
g Room size is 6 m × 9 m = 54 m^2, so below allowable charge (0.54 kg < 0.56 kg)



5) Check all necessary tools are present and the working area is safe
g Okay

Conversion of split air conditioner	
Identify problem with air conditioner	
6) Eliminate all mechanical joints from occupied space g Okay	 
7) Reset pressure device g none	
8) Eliminate all potential sources of ignition g Inside unit: transformer, display/ LED, swing motors, fan motor, connection block, PCB (relays, micro switch) – all non-SOIs g Outdoor unit: – fan motor, capacitors, connection block, compressor terminals (internal overload) – all non-SOIs, although mains contactor must be fitted into sealed enclosure	
9) Set-up emergency ventilation/detection and alarm system g Not applicable	
10) Carry out relevant repairs g Okay	
11) Apply relevant documentation and system markings	
12) Final leak checking g Okay	

Conversion of commercial cabinet

Identify problem with cabinet

1) Obtain current charge size
g 0.285 kg of R12

2) Estimate equivalent HC charge
g Assuming conversion to R600a/R290 blend, 0.285 × 0.40 = 0.114 kg of R290

Conversion factors (C_f) to estimate equivalent HC charge size

Fluorinated refrigerant	HC refrigerant				
	R600a	R600a/R290 (50%/50%)	R290	R290/R170 (94%/6%)	R1270
CFC-12	(0.43) †	0.40	n/a	n/a	n/a
HFC-134a	(0.47) †	0.45	n/a	n/a	n/a
HFC-1234yf	(0.53) †	0.50	n/a	n/a	n/a
HCFC-22	n/a	n/a	0.42	0.41	0.42
HFC-407C	n/a	n/a	0.45	0.44	0.45
HFC-404A	n/a	n/a	0.51	0.50	0.52
HFC-507A	n/a	n/a	0.51	0.50	0.52
HFC-410A	n/a	n/a	(0.51) †	(0.50) †	(0.52) †

3) Identify occupancies
g Cabinet positioned within retail area (category A)

4) Check charge size limits
g Charge size is below maximum limit (0.11 kg < 1.5 kg)
g Charge size is below 0.15 kg, so no need to consider allowable charge or room size

5) Check all necessary tools are present and the working area is safe
g Okay

6) Eliminate all mechanical joints from occupied space
g None present

7) Reset pressure devices
g None

Conversion of commercial cabinet	
Identify problem with cabinet	
8) Eliminate all potential sources of ignition g Front of unit: fan motor, lamp – all non-SOIs; light switch, thermostat, lamp starter – all outside cabinet away from refrig-erant-containing parts so a leak cannot reach them g Rear of unit: – fan motor, capacitors, connection block, compressor terminals (internal overload) – all non-SOIs; over-load/relay must be swapped with solid-state type	     
9) Set-up emergency ventilation/detection and alarm system g Not applicable	
10) Carry out relevant repairs g Okay	
11) Apply relevant documentation and system markings	 
12) Final leak checking g Okay	

Disclaimer

Whilst GTZ and TÜV SÜD do not condone the conversion of existing equipment using non-flammable refrigerant to use flammable refrigerants that they were not initially intended for, they do recognise that such conversion do and will continue to take place, regardless of recommendations to the contrary. Therefore, in order to try to help that it is done in the safest manner, some examples are provided in the Appendix. However, in doing this, GTZ and TÜV SÜD do not assume liability for any statements or any actions taken by its readers or users, which may cause unintended damage or injury as a result of any recommendations or inferences made within this handbook. Although all statements and information contained herein are believed to be accurate and reliable, they are presented without guarantee or warranty of any kind, expressed or implied. Information provided herein does not relieve reader or user from their responsibility of carrying out its own evaluation and analysis of the situation, and reader or user assumes all risks and liability for use of the information, actions and events obtained. Reader or user should not assume that all safety data, measures and guidance are indicated herein or that other measures may not be required. Here only general recommendations are made, which do not compensate for individual guidance and instructions. National laws and guidelines must be consulted and adhered to under all circumstances. The handling of flammable refrigerants and its associated systems and equipment is to be done by qualified and trained technicians only.

APPENDIX 3: LIST OF COOPERATION PARTNERS

Please refer to Part 1.4 of this handbook "Identification of Cooperation Partners" for more information. Links are given where available for the cooperation partners listed below.

Industry associations

Brazilian Association of Refrigeration, Air Conditioning, Ventilation and Heating (ABRAVA) (www.abrava.com.br)
ABRAVA is the main trade associations within Brazil that represents the refrigeration and air conditioning industry.

Association of European Refrigeration Compressor and Controls Manufacturers (ASERCOM) (www.asercom.org)
It is the aim of ASERCOM to be the platform in dealing with scientific and technical challenges, promoting standards for performance and safety while focusing on better environmental protection and serving the refrigeration and air conditioning industry and its customers.

Associated Air conditioning and Refrigeration Contractors (ARC) (www.arc-uk.org.uk)
ARC is a nationwide organisation of selected air conditioning and refrigeration contractors who are privately owned and funded and whose primary aim is to provide good quality service. Our aim is to maintain the very highest standards in design, installation and after-sales service, but more than this, we are active in promoting energy conservation and maximum plant efficiency. It is the firm belief of our organisation that a satisfied client is the greatest asset any business can possess.

Air Conditioning and Refrigeration Industry Board (ACRIB) (www.acrib.org.uk)
ACRIB provides a central forum for all sectors and interests which fall within or are served by the air conditioning and refrigeration industry. Its member organisations represent manufacturers, distributors, contractors, consulting engineers, specifies, end users, training providers, researchers and others with a direct interest in the environmentally friendly and cost effective provision and use of refrigeration, air conditioning and mechanical ventilation equipment.

Association of Manufacturers of Domestic Appliances (AMDEA) (www.amdea.org.uk)
AMDEA is the trade association for large and small domestic appliances in the UK. The membership consists of companies who place domestic appliances on the UK market either as manufacturers, distributors or importers. It represents over 80% of the domestic appliances industry in the UK.

China Refrigeration and Air Conditioning Industry Association (CRAA) (www.chinacraa.org)
CRAA is a national non-profit industrial organisation mainly representing refrigeration and air conditioning manufacturers, and research, design institutes and academies as well, with the principal of voluntarily participation. CRAA is a major voice for the whole industry and works for its members' mutual interests and benefits.

Eurammon (www.eurammon.com)
eurammon is a joint initiative by companies, institutions and individuals committed to increasing the use of natural refrigerants and sees itself as centre of competence for the use of natural working fluids in refrigeration. The objective is to boost the general awareness and acceptance of natural refrigerants, to promote their use in the interests of a healthy environment, and to thereby continue developing a sustainable approach to refrigeration.

European Federation of Refrigeration and Air Conditioning Associations (AREA) (www.area-eur.be)
AREA is the European Federation of National Refrigeration and Air Conditioning Associations and covers all of Europe. Established in 1988, AREA represents the industry of refrigeration and air conditioning installation, particularly at European Commission (EC) and the United Nations Environmental Programme (UNEP) level.

European Heat Pump Association (EHPA) (www.ehpa.org)
The European Heat Pump Association promotes awareness and proper deployment of heat pump technology on the European market.

Federal Guild of German Refrigeration Plant Assemblers (BIV) (www.biv-kaelte.de)
The BIV represents enterprises responsible for the design, installation, maintenance and repair of refrigeration equipment. It supports the interests of its members in the skilled crafts of refrigeration plant construction in accordance with legal requirements. As a member of the Central Guild of German Trades (ZHD), BIV develops the political, national and commercial environment of its own trade. Traditionally, the work of the guilds and BIV focuses mainly on the professional trade. The objective of BIV is to increase the expertise of its member companies in terms of technological, design and commercial quality and to create a positive public image for the refrigeration trade.

Federation of Environmental Trade Associations (FETA) (www.feta.co.uk)
FETA is the recognised UK body which represents the interests of manufacturers, suppliers, installers and contractors within the heat pump, controls, ventilating, refrigeration & air conditioning industry. It is split into six principle associations ADCAS, BCIA, BFCMA, BRA, HEVAC and HPA. Of these, the British Refrigeration Association (BRA) is the trade association representing manufacturers, importers, wholesalers, distributors, contractors, specifiers and end-users of refrigeration plant, equipment and components. It also includes producers of refrigerants and lubricants, colleges and training establishments. It works closely with government, public bodies and other organisations, both in the UK and overseas, to further the interests of the refrigeration industry.

Green Cooling Association (GCA) (http://greencooling.org)
Green Cooling Association is an organisation for environmentally responsible refrigeration and air conditioning practitioners and anyone interested in promoting genuinely climate friendly refrigerant alternative. It is an Australian-based organisation concerned with the promotion of the transition to natural refrigerants in the refrigeration and air conditioning industries.

Hydrocarbons 21 (www.hydrocarbons21.com)
Hydrocarbons21.com is an internet site that supports the worldwide use of hydrocarbons as natural and energy-efficient refrigerants in heating and cooling. It contains daily news, a showcase of components and engineering options, a global directory, papers and other features.

Natural Refrigerants Fund (NRF) (www.nrfund.org)
NRF is an initiative to establish a natural refrigerants fund with the aim of encouraging the implementation of technologies with natural refrigerants in developing countries together with developed countries.

REFCOM (www.refcom.org.uk)
REFCOM is a registration scheme for companies that are competent to handle refrigerants. It was set up in 1994 in response to atmospheric damage caused by certain refrigerant gases. Since then the Register has evolved to cover fluorinated refrigerant gases which if released to atmosphere have a GWP significantly higher than CO_2.

Refrigerants, Naturally! (www.refrigerantsnaturally.com)
Refrigerants, Naturally! is a global initiative of companies committed to combat climate change and ozone layer depletion by substituting harmful fluorinated gases ("F-gases", such as CFCs, HCFCs and HFCs) with natural refrigerants. Current members of Refrigerants, Naturally! include The Coca-Cola Company, Unilever, McDonalds, Carlsberg, and PepsiCo. In addition to the corporate members, Greenpeace and the United Nations Environment Programme (UNEP) both support Refrigerants, Naturally! and take an advising role in its management.

Refrigeration and Air Conditioning Manufacturers Association (RAMA) (www.rama.org.in)
RAMA promotes the overall growth of the air conditioning and refrigeration industry in India. They are responsible for collecting and disseminating industry statistics relating to production, sales and other vital economic indicators to members and the Government; conducting and facilitating research about the AC&R industry; organising and facilitating seminars, conferences and lectures to benefit industry professionals; and working alongside industry associations and scientific bodies to keep RAMA members current on the latest standards and developments and to facilitate adoptions of standards related to manufacturing, energy efficiency and environment management.

Verband Deutscher Maschinen- und Anlagenbau e.V., [German Engineering Federation] (VDMA) (www.vdma.org)
The VDMA is one of the key association service providers in Europe and offers the largest engineering industry network in Europe. The VDMA represents 3,000 mainly small/medium size member companies in the engineering industry, making it one of the largest and most important industrial associations in Europe.

Institutes and associations

Chinese Association of Refrigeration (CAR) (www.car.org.cn)
CAR is a national scientific organisation in the field of refrigeration and air conditioning industry and trade, which is subordinated to China Association for Science and Technology (CAST). CAR aims at solidifying and serving CAR members and technical personnel in the field of refrigeration. For the development of science and technology of China refrigeration, CAR has conducted many activities, such as facilitating domestic and international scientific communication as well as formulating and revising standards of the technologies and products in the field of refrigeration.

German Society of Refrigerating and Air Conditioning (DKV) (www.dkv.org)
DKV is a unique German technical-research organisation for refrigeration, air conditioning and heat pump technology. The organisation was founded 1909 in Berlin and has to-date 1300 members in Germany as well as in foreign countries. The society's main objectives include: advancing the arts and science and research of refrigeration, heating and air conditioning and promoting the international relationship between technicians and scientists working in the same field as well as conducting joint research projects.

Heat Pump Centre (HPC) (www.heatpumpcentre.org)
The HPC is an international information service for heat pumping technologies, applications and markets. The goal is to accelerate the implementation of heat pumps and related heat pumping technologies, including air conditioning and refrigeration. It is the central information activity of the IEA Heat Pump Programme (HPP). HPP operates under the International Energy Agency (IEA) and its participants in different countries cooperate in projects.

International Institute of Refrigeration (IIR) (www.iifiir.org/en/)
The IIR is a scientific and technical intergovernmental organisation enabling pooling of scientific and industrial know-how in all refrigeration fields on a worldwide scale. The IIR's mission is to promote knowledge of refrigeration technology and all its applications in order to address today's major issues, including food safety and protection of the environment (reduction of global warming, prevention of ozone depletion), and the development of the least developed countries (food, health). The IIR commits itself to improving quality of life and promotes sustainable development.

International Institute of Ammonia Refrigeration (IIAR) (www.iiar.org)
IIAR is an organisation providing advocacy, education, standards and information for the benefit of the ammonia refrigeration industry worldwide. IIAR's vision is to be recognised as the world's leading advocate for the safe, reliable and efficient use of ammonia and other natural refrigerants for industrial applications.

Institute of Refrigeration (IOR) (www.ior.org.uk)
The IOR is an independent organisation for refrigeration and air conditioning professionals by refrigeration and air conditioning professionals. IOR's mission is to be the forum for all those involved professionally in Refrigeration Science and Engineering; to promote the technical advancement of refrigeration in all its applications, in relation both to the perfection of its methods and the minimisation of its effects on the environment; to encourage the extension of refrigeration, air conditioning and heat pump services for the benefit of the community; to promote means of communication for exchange of expertise and interchange of views, and to communicate knowledge of refrigeration and its communal benefits to the outside world; and to encourage invention and research in all matters relating to the science and practice of refrigeration.

Laboratory of Air Conditioning and Refrigeration in Brazil (LaAR) (www.laar.unb.br)
The LaAR aims to contribute to the scientific and technological advancement in the field of refrigeration, heating, ventilation and air conditioning. Through modern experimental techniques, modelling and simulation studies, the LaAR works in human resources education and research for the development of thermal systems more efficient and less environmental impact.

TÜV SÜD (www.tuev-sued.de/home_en)
TÜV SÜD Group is a globally active, future-oriented company, but also continues to enjoy success in its traditional services such as periodic vehicle roadworthiness testing, the testing and inspection of industrial plants, product testing and expert opinions. TÜV SÜD is represented international at 600 sites and it employed about 13,300 people. TÜV SÜD was established 140 years ago by boiler operators as a private-sector regulatory body with the business objective of "protection man, then environment and property against the adverse effects of technology in the industrial centres of the German Länder Baden-Württemberg, Bavaria, Hesse and Saxony. There followed a gradual expansion of the Company's scope of activities in line with technological process e.g. electrical power, motor vehicles, fire safety, power station, engineering, passenger lifts, ropeways, environmental protection, product safety and management systems. TÜV SÜD also internationalised its operations by establishing operations in other countries of the EU, in the USA and in the Far East. The range of services of the Centre of Competence for Refrigeration embraces consultancy, inspections, tests and expert opinions as well as certification and training. Long practical experience of our experts and the permanent cooperation in national and international committees complete our business activities. The CoC for Refrigeration is active on this sector over 30 years and obtains an own accredited laboratory.

Development agencies and international funds

United Nations Environment Programme (UNEP) (www.unep.org)
The United Nations Environment Programme (UNEP) is an advocate, educator, catalyst and facilitator, promoting the wise use of the planet's natural assets for sustainable development. UNEP's mission is to provide leadership and encourage partnership in caring for the environment by inspiring, informing and enabling nations and people to improve their quality of life without compromising that of future generations.

United Nations Development Programme (UNDP) (www.undp.org)
UNDP is the UN's global development network, an organisation advocating for change and connecting countries to knowledge, experience and resources to help people build a better life.

United Nations Industrial Development Organisation (UNIDO) (www.unido.org)
The United Nations Industrial Development Organisation is mandated to promote industrial development and international industrial cooperation.

Bilateral implementing agencies

A list of bilateral agencies can be found on the following website:
http://www.oecd.org/linklist/0,3435,en_2649_33721_1797105_1_1_1_1,00.html

Agence Française de Développement (AFD) (www.afd.fr/jahia/Jahia)
Agence Française de Développement, is a French bilateral development cooperation agency, which supports over 60 developing countries on behalf of the French Government.

Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) (www.gtz.de/de/index.htm)
As an international cooperation enterprise for sustainable development with worldwide operations, the federally owned Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH supports the German Government in achieving its development-policy objectives. It provides viable, forward-looking solutions for political, economic, ecological and social development in a globalised world. Working under difficult conditions, GTZ promotes complex reforms and change processes. Its corporate objective is to improve people's living conditions on a sustainable basis.

Swiss Agency for Development and Cooperation (SDC) (www.sdc.admin.ch)
The Swiss Agency for Development and Cooperation is Switzerland's international cooperation agency within the Federal Department of Foreign Affairs (FDFA).

International Funds

Clean Technology Fund (CTF) (www.climateinvestmentfunds.org/cif/node/2)
Established in July 2008, the Clean Technology Fund is one of the two (along with the Strategic Climate Fund) multi-donor Trust Funds within the World Bank's Climate Investment Funds (CIF). It aims to finance transformational actions by: providing positive incentives for the demonstration of low carbon development and mitigation of greenhouse gas emissions through public and private sector investments; promoting scaled-up deployment, diffusion and transfer of clean technologies by funding low carbon programmes and projects that are embedded in national plans and strategies to accelerate their implementation; promoting realisation of environmental and social co-benefits thus demonstrating the potential for low-carbon technologies to contribute to sustainable development and the achievement of the Millennium Development Goals; promoting international cooperation on climate change and supporting agreement on the future of the climate change regime; utilising skills and capabilities of the

MDBs to raise and deliver new and additional resources, including official and concessional funding, at significant scale; and providing experience and lessons in responding to the challenge of climate change through learning-by-doing.

Global Environment Facility (GEF) (www.thegef.org/gef)
The Global Environment Facility is an international partnership among 178 countries, international institutions, non-governmental organisations (NGOs), and the private sector to address global environmental issues while supporting national sustainable development initiatives. It provides grants for projects related to six focal areas: biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants.

International Climate Initiative (ICI) (www.bmu-klimaschutzinitiative.de/en/home_i)
The International Climate Initiative is a fund of the German Government. The overall objective of the fund is to provide financial support to international projects supporting climate change mitigation, adaptation and biodiversity projects with climate relevance. The German ICI provides financial support to international projects supporting climate change mitigation, adaptation and biodiversity projects with climate relevance. It aims to ensure that such investments will trigger private investments of a greater magnitude. It also aims to ensure that financed projects will strategically support the post-2012 climate change negotiations. For this purpose, it will support multilateral activities and funds focusing on adaptation and forest management.

Multilateral Fund for the Implementation of the Montreal Protocol (MLF) (www.multilateralfund.org)
Following the London Amendment to the Protocol in 1990, a financial mechanism called the Multilateral Fund was established to provide assistance in the form of grants and concessional loans to those countries (Article 5 countries) with an annual per capita consumption of ODS of less than 0.3 kg a year which needed help to achieve the Protocol's phase-out goals. Donations from developed countries sustain the Multilateral Fund and to date, pledges amount to US$ 2.55 billion over the period 1991 to 2009. The Fund provides finance for activities including the closure of ODS production plants and industrial conversion, technical assistance, information dissemination, training and capacity building aimed at phasing out the ODS used in a broad range of sectors.

Natural Refrigerants Fund (NRF) (www.nrfund.org)
The NRF is an initiative for establishing a natural refrigerants fund. The aim is the implementation of technologies with natural refrigerants in developing countries together with developed countries.

The Environmental Transformation Fund – International window (ETF – IW) (no internet site)
The Environmental Transformation Fund – International window is an initiative of the government of the UK that focuses on poverty reduction, environmental protection and helping developing countries tackle climate change. In the course of its development, a large proportion of the proposed funding of the ETF-IW has been allocated to the World Bank-administered Climate Investment Funds (CIFs).

The World Bank (www.worldbank.org)
The World Bank is a group of five international organisations providing financial and technical assistance to developing countries for the purposes of economic development and eliminating poverty.

National authorities

National Ozone Units
The National Ozone Units (NOUs) are national focal points for the implementation of the Montreal Protocol. NOUs are key to any decisions and actions related to the implementation of the phase-out plans for HCFCs in their countries. Contact details are available at UNEP's Ozone Action Branch internet site: www.unep.fr/ozonaction/information/contacts.htm

APPENDIX 4: FLAMMABLE CHARACTERISTICS OF HCs

Introduction

It is important to understand the characteristics of a fluid that describe its “flammability”, or the ease with which a substance will ignite. A variety of measures exist to evaluate this, but the main parameters which describe the ability of mixtures of substances in air to propagate a flame and/or explode include:

- Flash point temperature
- Lower flammable limit
- Upper flammable limit
- Stoichiometric concentration
- Auto-ignition temperature
- Minimum ignition energy
- Heat of combustion
- Adiabatic flame temperature
- Laminar flame speed

Few of these parameters are fundamental physical or chemical properties of a substance or mixture. Instead, most are defined by standardised tests and, for this reason values of the parameters will change if the test conditions are varied. For example, values will change considerably if the concentration of oxygen in the mixture or of the surrounding temperature or humidity is changed. Thus, the reported values of a given substance may be less relevant if the conditions within which it is used differ significantly from those of the test conditions.

Description of characteristics

A list of the flammable properties is provided in Table 24. Values for this data have been taken from a number of sources[43].

Flash point (°C)

This is the minimum temperature of a liquid substance that is needed to generate sufficient vapour so that it can be ignited. Thus, below the flash point temperature, there is insufficient vapour for a flame to occur. As with other characteristics, the flash point may be measured in different ways, although the preferred method is the “small scale closed-cup”. Substances with a flash point below +21°C are termed “extremely flammable”, whilst those with flash points between +21°C and +55°C are “flammable”, and those above +55°C are “combustible”. Common HC refrigerants are all extremely flammable.

Lower flammability limit (%, kg/m³)

This is the lowest concentration of gas in air that is necessary for the mixture to ignite in the presence of a source of ignition. Below the lower flammability limit, there is insufficient fuel for burning to occur. A range of values normally exist for any one substance, because of its sensitivity to choice of ignition source, pressure, mixture temperature and air humidity.

43 Coward, HF and GW Jones, 1952, Limits of flammability of gases and vapours, Bulletin 503, Bureau of Mines; Harris, RJ, 1983, Gas explosions in buildings and heating plant, British Gas Corp., EF & N Spon Ltd., UK; Kuchta, JM, 1985, Investigation of fire and explosion accidents in the chemical, mining, and fuel-related industries – a manual, Bulletin 680, U.S. Bureau of Mines; Woodward, JL, 1998, Estimating the flammable mass of a vapour cloud, Centre for Chemical Process Safety, American Institute of Chemical Engineers, New York, USA; Zabetakis, MG, 1965, Flammability characteristics of combustible gases and vapours, Bulletin 627, Bureau of Mines

Table 24: Flammable properties of several HC refrigerants

Property		R600a	R290	R1270	R290/ R600a †	R290/ R170 ‡
Flash point (°C)		-83	-104	-108	-94	-106
Auto-ignition temperature (°C)		460	470	455	465	470
Minimum ignition energy (mJ)		0.25	0.25	0.28	0.25	0.25
Lower Flammability Limit	(kg/m^3)	0.043	0.038	0.043	0.040	0.038
	(%)	1.80	2.10	2.50	1.95	2.15
Upper Flammability Limit	(kg/m^3)	0.202	0.171	0.174	0.186	0.172
	(%)	8.5	9.5	10.1	9.0	9.7
Stoichiometric concentration	(kg/m^3)	0.074	0.072	0.077	0.073	0.073
	(%)	3.1	4.0	4.4	3.5	4.1
Heat of combustion (kJ/kg)		49500	50500	49000	50000	50600
Adiabatic flame temperature (°C)		2010	1970	2050	1990	1960
Laminar flame speed (m/s)		0.37	0.43	0.48	0.40	0.43

† Based on 50% R290 and 50% R600a molar composition
‡ Based on 94% R290 and 6% R170 molar composition

Upper flammability limit (%, kg/m³)

This is the highest concentration of gas in air that allows for the mixture to ignite in the presence of a source of ignition. Above the upper flammability limit, there is insufficient oxygen for burning to occur. A range of values normally exist for any one substance, because of its sensitivity to choice of ignition source, pressure, mixture temperature and air humidity.

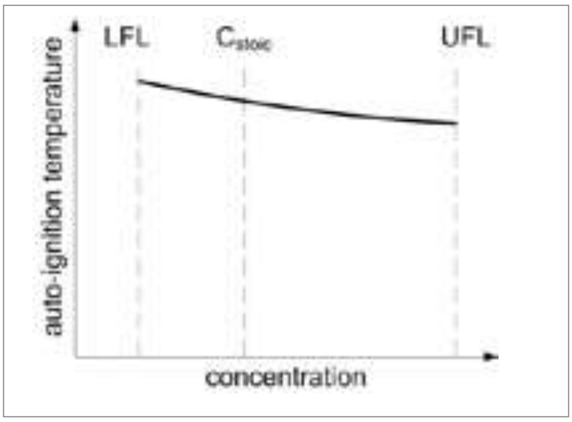
Stoichiometric concentration (%, kg/m³)

This is the concentration of a fuel in air where complete conversion, or oxidation, of all the fuel and consumption of all oxygen occurs. Thus, after burning of an HC in air, only carbon dioxide and water remain. Typically, the stoichiometric concentration is when the mixture is most reactive and therefore the "most flammable" concentration.

Auto-ignition temperature (°C)

This is the minimum temperature of a surface that can ignite the gas. Specifically it is defined as the lowest temperature to which a given mixture of a fuel and air must be heated to combust spontaneously in the absence of any other ignition source. It is determined as the lowest temperature of a glass surface (since it is assumed to be chemically inert) at which droplets of a liquid falling onto the surface will undergo spontaneous combustion. Because of catalytic effects, the values for other types of surfaces can be lower. There is also a time delay involved in auto-ignition temperature of the mixture, where a higher surface temperature will result in a faster occurrence of ignition. The auto-ignition temperature is also rather sensitive to air temperature, humidity and space dimensions. It also varies depending upon the concentration as indicated by Figure 73.

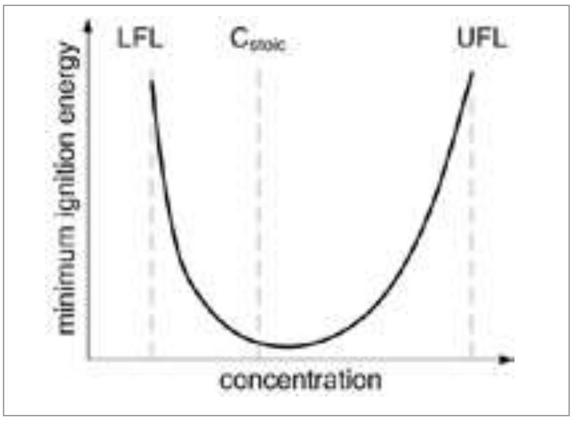
Figure 73: Variation of auto-ignition temperature with gas concentration



Minimum ignition energy (mJ)

This is the minimum energy that can ignite a mixture of a flammable substance and air, normally close to the stoichiometric concentration. Typically, the energy is generated by an electrostatic spark discharge released from a capacitive electrical circuit. Different test methods employ different circuit components and the arrangement of electrodes, resulting in a variation in values. There is a very wide variation of minimum ignition energy depending upon the mixture concentration, as illustrated in Figure 74. For example, the minimum ignition energy required to ignite a mixture close to the lower or upper flammability limits is several thousand times greater than at the stoichiometric concentration.

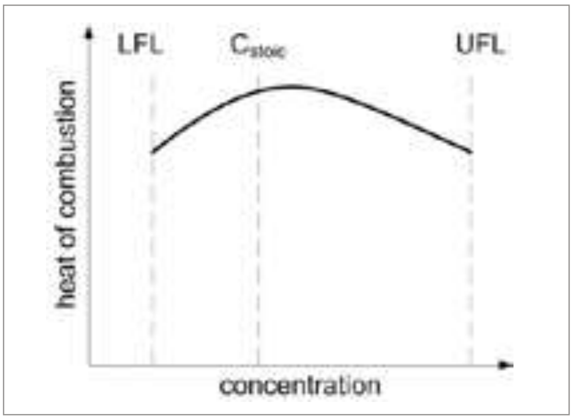
Figure 74: Variation of minimum ignition energy with gas concentration



Heat of combustion (kJ/kg)

The heat of combustion – or energy of combustion, heating value, calorific value, etc – is the amount of heat energy given off from complete burning of the fuel and air mixture (i.e., at stoichiometric concentration). At other concentrations, the heat of combustion is lower, as shown in Figure 75. The value can be obtained from enthalpy balance of burned and unburned mixture, and it is also determined through measurement. When considering the heat of combustion for fuel purposes, a number of variations are used depending upon what the final temperature of the burned mixture is, and whether the water vapour has condensed back to liquid.

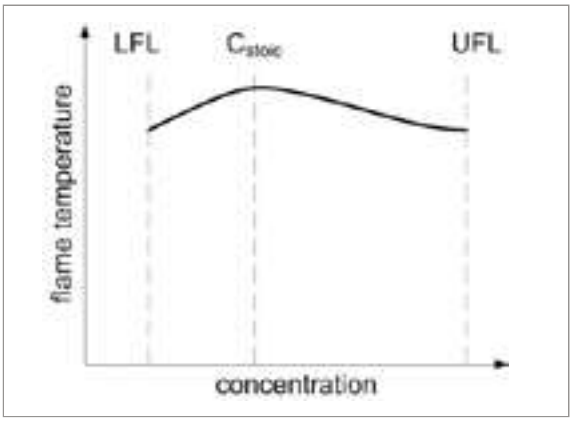
Figure 75: Variation of heat of combustion with gas concentration



Adiabatic flame temperature (°C)

This is the maximum temperature of the flame of the burned fuel-air mixture, close to the stoichiometric concentration and assuming no heat loss to the environment. For a given set of conditions, the adiabatic flame temperature can be calculated (though enthalpy balance of burned and unburned mixture), although measured values tend to be about 100 K lower than this. Values listed in Table 1 are the calculated ones. Since the heat of combustion varies with concentration, so does the flame temperature slightly, as indicated in Figure 76.

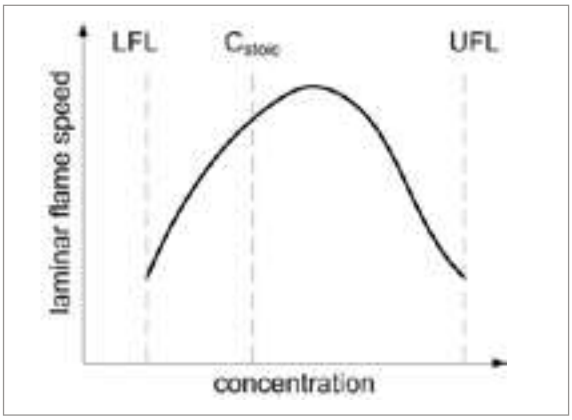
Figure 76: Variation of adiabatic flame temperature with gas concentration



Laminar flame speed (m/s)

Laminar flame speed – or laminar burning velocity – is a representation of the rate of expansion of the flame front as the mixture burns. The value is normally obtained through measurement, and is also highly sensitive to many factors, such as concentration (Figure 77). It provides an indication of how rapidly the fuel-air mixture burns under ideal, steady conditions. By comparison, turbulent flame speeds occur under non-uniform conditions, and can be several magnitudes higher.

Figure 77: Variation of laminar flame speed with gas concentration



APPENDIX 5: CALCULATION OF CONCENTRATIONS FROM A RELEASE

Introduction[44]

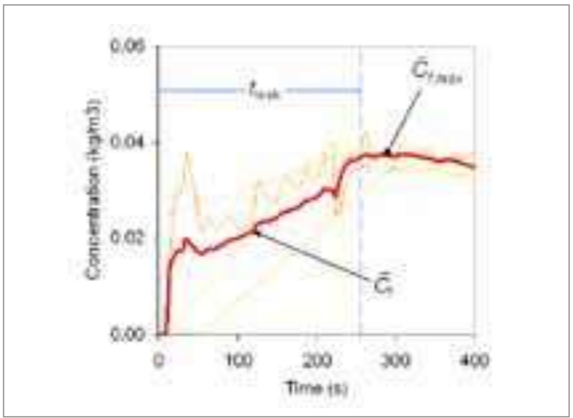
Sometimes it may be useful to try to estimate the likely concentrations arising from a release of refrigerant into a space. In general, the concentration development is rather variable and sensitive to a number of different parameters. However, a correlation is presented here in order to assist with carrying out such evaluations, which is based on a number of experiments and results from several different studies.

The calculation is based around two separate release scenarios:

- Determination of the maximum mean floor concentration ($\bar{C}_{f,max}$, in kg/m³) – which is an averaged value of all floor-level sampling points at each time increment, of which the highest value is taken – resulting from a "catastrophic" release
- Determination $\bar{C}_{f,max}$ for a prolonged release

Depending upon the combination of conditions, the concentration may vary extensively at a single point on the room floor, and the concentration at the same time will also differ widely amongst different positions across the floor. For this reason, the correlation is based around an average value for the floor at any given time (based on area-weighted concentration measurements at different locations across the room floor), $\bar{C}_f$, and the maximum of these averaged values, $\bar{C}_{f,max}$, is used as the concentration of interest. Given the high variations in local concentrations, the used of $\bar{C}_f$ and $\bar{C}_{f,max}$ have been shown to be the most robust indicators of the refrigerant dispersion. Figure 1 attempts to illustrate this concept, where the faint lines indicate local concentrations and the red line is $\bar{C}_f$, eventually peaking at $\bar{C}_{f,max}$.

Figure 78: Example of differing floor concentrations and averaged values



Calculation for catastrophic release[45]

A "catastrophic" release is considered to represent the most hazardous situation in terms of producing a high concentration, and in this case, is taken to be a release of the entire refrigerant charge over a period of 210 s, assuming a constant mass flow rate.

The $\bar{C}_f$ following a release is a function of various characteristics associated with the design and installation of that equipment. The independent variables – those that can be specified within the design and construction of the equipment – are:

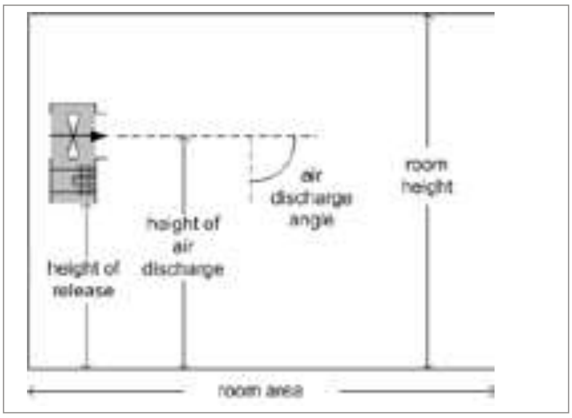
44 See Colbourne and Suen (2008); Colbourne and Suen (2003)

45 In reality, the mass flow of a real catastrophic leak is not constant; it tends to rise rapidly to a maximum value, and then depending upon the orifice size, after some period exhibits decay as the internal pressure falls and the remaining refrigerant desorbs from the compressor oil. Further, the time taken for some percentage of the refrigerant to exit the system is dependent upon the location and size of the orifice, whether the system is on or off, length and size of pipes and the presence and status of in-line controls such as solenoid valves, and so on.

- Refrigerant mass released, m_r (kg)
- Room air movement, such as airflow from a fan, V_d (m^3/s)
- Height that the air is discharged from, h_d (m)
- Direction if that air discharge, Θ(rad)
- Height of the release, h_r (m), such as the lowest of any refrigerant-containing parts
- Refrigerant density, ρ_r (kg/m^3)
- Room size, V_{Rm} (m^3) or room area, A_{Rm} (m^2)

Some of these parameters are indicated in Figure 79.

Figure 79: Schematic diagram of parameters involved in estimation of concentration



$\bar{C}_{f,max}$ is obtained from the product of the mixing effectiveness, ε , and $\bar{C}_{Rm}$ (equation 23), where ε is then established as a function of Richardson number, Ri , and the ratio h_d / h_r (equation 24).

$$\bar{C}_{f,max} = \varepsilon \bar{C}_{Rm} , \qquad \varepsilon \geq 1 \qquad \varepsilon \geq 1 \tag{23}$$

$$\varepsilon = 0.091 \sqrt{Ri} \left(\frac{h_d}{h_r} \right)^{1.63} , \varepsilon \geq 1 \qquad \varepsilon \geq 1 \tag{24}$$

The mean maximum concentration always occurs at floor level so $\bar{C}_{f,max}$ cannot be lower than the homogenous concentration; therefore equations. (23) and (24) are only valid when $\varepsilon \geq 1$. There are several numerical definitions of Ri in use, and in the present case the conventional equation definition of is employed (equation 25), but with the inclusion of a discharge angle adjustment factor (ξ).

$$Ri = g' \frac{h_r}{(\bar{u}_{Rm} \xi)^2} , \qquad \bar{u}_{Rm} \xi \geq \bar{u}_{Rm,min} \tag{25}$$

where $\bar{u}_{Rm,min}$ (m/s) is the minimum room air speed (as discussed below), and the reduced gravity (g') represents the buoyancy of the refrigerant relative to the air (equation 26).

$$g' = g \frac{\rho_r - \rho_a}{\rho_a} \tag{26}$$

where g is gravitational acceleration, ρ_r (kg/m^3) is density of the released gas (at room temperature), and ρ_a (kg/m3) is the density of air (based on room temperature and atmospheric pressure).

Since entrainment of a release into the air is normally a function of velocity, air volume flow rate from the unit and duct discharge area, A_d (m^2) are combined to obtain the mean room air speed, $\bar{u}_{Rm,min}$ (m/s). Equation 27 is used for calculating $\bar{u}_{Rm,min}$, whilst employing a discharge coefficient, $c_d = 0.45$.

$$\bar{u}_{Rm} = \frac{\dot{V}_d}{\sqrt{c_d A_d V_{Rm}^{1/3}}} \qquad (27)$$

The adjustment factor (ξ) is introduced and applied to $\bar{u}_{Rm}$ to account for the effect of non-horizontal air discharge (equation 28). It includes the relative height of air discharge to room height since it is expected that the influence of discharge angle on mixing is less apparent as the height of air discharge approaches floor level.

$$\xi = exp\,[\,(h_d / h_{Rm})(-1.21\Theta+1.46) \qquad (28)$$

The angle of the discharge, Θ (in radians) is defined relative to the vertical plane. For example, $\Theta = 90°$ = ∏ rad for a horizontal discharge and $\Theta = 60°$ = ∏ rad for a jet sloping downward.

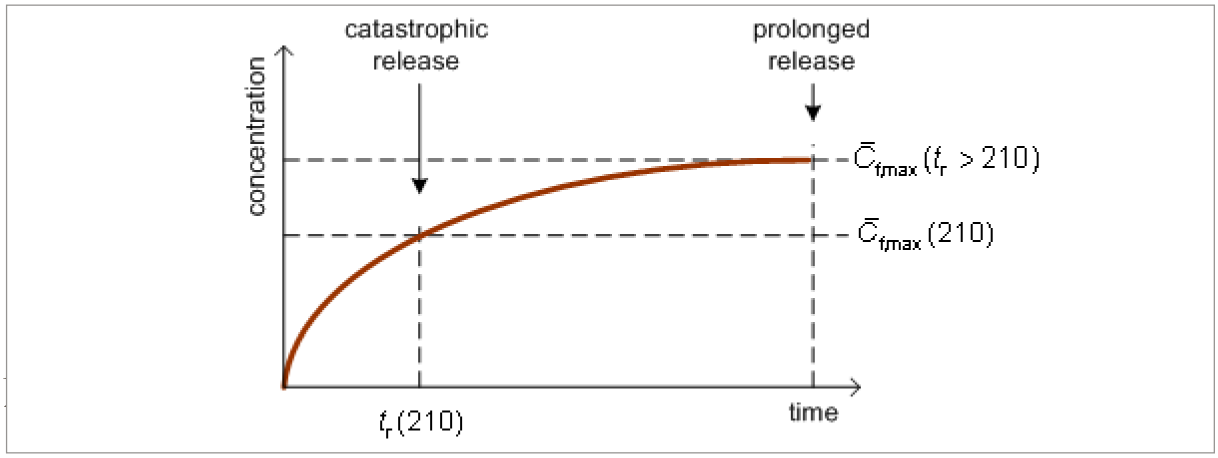
Lastly, where there is little or no forced air movement present ($\bar{u}_{Rm} \approx 0$) equation (23) and (24) give unrealistically high values of . This is because the air speed in a quiescent room is not actually "still" and typically in the range 0.03 – 0.05 m/s (regardless of the duration that it is left undisturbed). In order to address this situation, a formula for determining a minimum air speed was obtained. Thus, when there is a very low airspeed, the terms $\bar{u}_{Rm}\,\xi$ in equation (25) becomes $\bar{u}_{Rm,min}$ from equation (29).

$$\bar{u}_{Rm,min} = 0.1\frac{h_r^{3/2}}{h_{Rm}}\sqrt{\frac{g'}{A_{Rm}}}, \qquad \bar{u}_{Rm,min} \le \bar{u}_{Rm}\,\xi \qquad (29)$$

Calculation for non-catastrophic releases

Whilst evaluation of $\bar{C}_{f,max}$ may be important for predicting the worse case concentrations, it is also useful to predict the concentrations resulting from slower releases. This is particularly relevant when considering the case of a release continuing after forced airflow has ceased. Therefore, an additional set of formulae is used for releases lasting more than 210 s. This uses a characterisation of the concentration development over time, and the extrapolation of the concentration change of a catastrophic release over an extended duration, as illustrated in Figure 80.

Figure 80: Gradient of floor concentration development with time



Therefore, if $\bar{C}_{f,max}$ for a catastrophic release is calculated (as above), then the increase in concentration as the release continues past 210 s can then be estimated. By setting the first increment $\bar{C}_f = C_{f,max,210}$ and $t_r = t_{r,210}$ for a catastrophic release, equation (30) can be used to estimate C_f at any $t_r > 210$ s.

$$\bar{C}_f(t_r) = 1/\exp\left[\ln\left(\frac{t^n_{r,210}}{\bar{C}_{f,max,210}}\right) - n \ln t_r\right] \quad (30)$$

Based on the mass that is released after 210 s, $\bar{C}_{f,max,210}$ is calculated from equations (23) and (24),

but using $C_{Rm,max,210}$ (i.e., C_{Rm} had the release stopped at 210 s) instead of C_{Rm} (t_r), as obtained from equation (31).

$$\bar{C}_{Rm,210} = \left(t_{r,210}\frac{m_r}{t_r}\right)\frac{1}{V_{Rm}} \quad (31)$$

The index in equation (30) indicates the shape of the curve of the concentration development over time (following the first 50 – 100 s). Where the mixing is very effective (i.e., $\varepsilon \approx 1$), the gradient dC_f/dt is almost linear, implying that $n \approx 1$, whereas where the mixing is poor (a low ε) the gradient dC_f changes, and therefore $n < 1$. Subsequently the relation between n and ε in equation (32) can be used.

$$n = 1/\sqrt{\varepsilon} \quad (32)$$

Final remarks

As mentioned earlier, the local environmental conditions, room geometry, release characteristics and many other factors can affect the concentration of a refrigerant release within a space. These correlations help to provide an indication of the average concentrations that may arise within the room. Of course when a leak occurs from a system, the refrigerant will initially be at a concentration of 100%, and there will be localised concentrations at very high values at some positions within the space, irrespective of the quantity release or the other conditions.

These correlations were based on a number of experiments and compared against a large number of data from other studies. Across these comparisons, it was found that the calculated $C_{f,max}$ were within ± 50% of measurements for over 80% of the cases. In addition, on average the calculated values of $C_{f,max}$ were 16% higher than the measurement. By comparison with other models and correlations used for estimating concentrations arising from gas releases (for example, in other industries), this is considered to be a fairly accurate result. Of course it is important to consider the range of parameters under which these correlations were developed and to bear in mind that using them for situations outside these limits may lead to greater errors. In general, the limits are approximately:

- Refrigerant mass between 0.1 kg to 2.5 kg
- Room size from 5 m^2 to 50 m^2
- Air speed from 0.02 m/s to 0.4 m/s
- Refrigerant release height from 0.2 m to 3 m

Lastly, it should be noted that most of the measurements were carried out under conditions that would otherwise promote poor missing within the room, thereby aiming for as high a concentration as possible. These include very low release velocities, in vapour phase in a downward release direction, and using rooms that are well sealed to avoid any thermal or infiltration air currents. Therefore it is expected that these calculations will return the higher attainable concentrations for a given set of conditions.

APPENDIX 6: EQUIPMENT FOR TECHNICIAN TRAINING

List of tools and equipment

	Qt.	Description	Minimum required	Ideal
1	20	Tool box (metal)	✓	
2	20	Pair of safety gloves refrigerant handling (acid-resistant)	✓	
3	20	Pair of safety gloves for mechanical work	✓	
4	20	Safety goggles	✓	
5	20	Folding rules 2 m	✓	
6	20	Steel ruler (40 cm)		✓
7	20	Spirit level		✓
8	20	Quick square		✓
9	20	Digital calliper		✓
10	20	Flash light		✓
11	20	Centre punch		✓
12	20	Cable knife	✓	
13	20	Cable reel about 10 m	✓	
14	20	Hacksaw and extra blades (wide ca. 30 cm)	✓	
15	20	Hammer 300 gram	✓	
16	20	Sets of files (round, flat, triangle)		✓
17	20	Scratch awl		✓
18	20	Hex key set		✓
19	20	Combination wrenches (9 pieces) set	✓	
20	20	Adjustable wrenches (set of 3 different sizes)	✓	
21	20	Pipe wrench (35 cm)	✓	
22	20	Ratchet wrench (rota-lock)	✓	

	Qt.	Description	Minimum required	Ideal
23	20	Socket wrench and bit set	✓	
24	20	Vice grip pliers		✓
25	20	Pinch-off pliers	✓	
26	20	Piercing pliers 6 to 22 mm (with spare gaskets and needle)	✓	
27	20	Swaging tool set	✓	
28	10	Tube expander set (10 – 22 mm)		✓
29	20	Tube bender lever type or hydraulic set (10, 12, 16, 18, 22)	✓	
30	20	Tube cutter, midget and large	✓	
31	20	Flaring tool set	✓	
32	20	Inspection mirror	✓	
33	20	Set of inner/outer tube reamer & one pen type reamer	✓	
34	20	Capillary tube cutter	✓	
35	10	Capillary tube gauge		✓
36	20	Steel brush	✓	
37	10	Set of two process tube quick connector (for 6 mm / ¼”)	✓	
38	10	Brazing kit (propane/oxygen) if brazing installation according table (1)-2 not available		✓
39	20	Brazing heat shield (silicate fibre)		✓
40	5	Nitrogen (N_2) cylinder, 20 Litre, test pressure 300 bar, working pressure 200 bar, mounted and secured on trolley	✓	
41	5	Pressure regulator (N_2) complete with transfer hose, entr. Pressure 200 bar, working pressure 40 bar.	✓	
42	20	Set of screw driver (7 pieces) incl. straight, cross and Philips. Isolated 1000 Volt tested (EN60900)	✓	
43	20	Set of 4 pliers (Electro) isolated 1000 Volt tested (EN60900)	✓	
44	20	Wire stripper, isolated 1000 Volt tested (EN60900)	✓	

	Qt.	Description	Minimum required	Ideal
45	20	Pocket screw drivers set		✓
46	20	Cable ripper		✓
47	20	Socket, cable shoe, adapter set including iso. tape	✓	
48	20	Clamp on ampere-meter, current, voltage, resistance,	✓	
49	20	Mains tester with LED	✓	
50	10	Capacitor tester		✓
51	2	Test cord, compressor starting and testing device (hermetic compressors)		✓
52	20	Solenoid valve operating magnet		✓
53	20	Wire crimping tool, isolated 1000 Volt tested (EN60900)	✓	
54	20	Driller cordless, including set of bits and drill drivers		✓
55	20	Valve core removal tool		✓
56	20	4-valve manifold gauge set with refrigerant hoses (ball valves) 3x¼” SAE and 1x⅜” SAE & ⅜” vacuum hose	✓	
57	10	Set of two extra refrigerant hoses 150 cm with ball valve, spare gaskets and depressors		✓
58	20	Liquid charging adapter		✓
59	10	Flare caps ¼” SAE (set of 10 pieces)	✓	
60	10	Electronic vacuum gauge (micron, Pa, mbar) 20 bar overpressure protection	✓	
61	2	Compressor tester (compression checking)	✓	
62	20	Pocket thermometer	✓	
63	10	Precise electronic thermometer with two probes connection (-50 °C to 50°C)	✓	
64	10	Temperature and humidity logger with PC interface and software		✓
65	10	Electronic leak detector with visible and audible alarm, sensitivity 3 gram/year for halogenated refrigerants	✓	

	Qt.	Description	Minimum required	Ideal
66	10	Electronic leak detector with visible and audible alarm, sensitivity less than 50 ppm for HC refrigerants	✓	
67	2	Reference leak for leak detectors, rate of leak 5 gram/year	✓	
68	20	Leak detection fluid sprayer with solution for -6 °C to 120 °C surface detection temperature		✓
69	2	Sound meter		✓
70	2	Air velocity meter with extension handle air lock		✓
71	10	Electronic charging scales 50 kg, resolution 2 gram, accuracy +/- 0,5)%, battery powered	✓	
72	5	Charging cylinder, gram graduation, safety valve, fluctuation compensation, pressure/temperature indication,		✓
73	5	Refrigerant recovery cylinder heating belt, about 400 Watt, 230 Volt, 60 °C		✓
74	2	Refrigerant – Oil “Total Test” kit		✓
75	10	Can valve, ¼” SAE connection		

List of consumables

	Qt.	Description	Minimum required	Ideal
76		Copper tubes 6 to 22 mm, brazing rods (4 % silver and phosphorus) and flux, flare nuts, adapters, filter-drier, etc	✓	
77		HC refrigerant R-290 in about 30 pound (14 kg) cylinder, 99,5 % purity	✓	
78		HC refrigerant R-600a can, approx 400 gram, 99,5 % purity	✓	
79		HC blend 50 % R600a / 50% R-290 can, approx 400 gram, 99,5 % purity	✓	
80		Connection wires (multi-wire) different make	✓	
81		Isolated cable box, 140 x 140 x 80 mm, IP 65 (IP 54)	✓	
82		Capillary thermostat, domestic fridges and freezers, sealed design, different ranges	✓	
83		Plug-in compressor start relays, solid state (sealed), 1/12 to ½ HP	✓	
84		If available so-called sealed retrofit kits, domestic appliances, incl. (80-82) materials and refrigerator lighting	✓	
85		Compressor lubricant (mineral)	✓	
86		Several hermetic refrigeration appliances	✓	
87		Several hermetic compressors (used but functional)	✓	
88		Several semi-hermetic compressors (used but functional)	✓	

Other recommended equipment

	Qt.	Description	Minimum required	Ideal
1	10	Vacuum pump, two stage, about 150 Liter/min, 15 Micron rating, gas-ballast valve, ¼" and ⅜" SAE connections	v	
2	10	Refrigerant recovery unit, transportable, oil-less, ½ HP, complete with hoses and inline filter	✓	
3	10	Portable HC charging station, vacuum pump about 35 Liter/min, charging scales (0 – 2000 gram) 1 gram accuracy, refrigerant cylinder can support with valve, vacuum gauge, one LP gauge R-134a, R-12, R-22, one LP gauge R-600a, all necessary charging hoses with ball-valve, one venting hose length 10 m and OD min. 15 mm with vacuum pump exhaust port adapter,	✓	
4	2	Refrigerant recovery, recycling, evacuation and charging unit (MAC) with SAE J2788 certification, internal 30 lb recovery cylinder on electronic scale, non-condensable gas indication gauge and manual purging device, semi-automatic operation, HP and LP gauges for pressure/temperature indication	✓	
5	15	Refrigerant recovery cylinder 30 lb (14 kg) with two valve access. DOT or ADR P200 approval,	✓	
6	1	Refrigerant analyzer, portable, battery powered, with printer, CFCs, HCFC, HFC incl. popular blends (R-404A, R-407C, R-507A, R-410) and hydrocarbon	✓	
7	1	Refrigerant identifier, HCFC R-22 only	✓	
8	10	Refrigerators / freezers about 160 litre, different make	✓	
9	2	Bottle coolers about 110 litre		✓
10	2	Refrigerated water dispenser	✓	
11	2	Split air conditioning units (HCFC R-22) about 10000 BTU/h (3 kW)	✓	
12	2	Condensing unit with hermetic compressor		✓
13	1	Visible cooler about 500 litre		✓
14	1	Car AC compressor, reciprocating, vane, rotary, axial (1 no. each)		✓
15	1	No-Frost upright freezer 250 litre approx		✓

Descriptions of tools and equipment	
Picture	**Technical Specification**
	Set of four (4) insulated pliers: Universal pliers length 180 mm, long nose pliers 160 mm, cutting pliers 180 mm, wire stripper 160 mm. Jaw Length about 50 mm, Chrome Vanadium steel, GS VDE – EN 60900 Standards, insulated and tested for 1000 Volts AC
	Two pin voltage tester (mains tester), display optic, LEDs, metering capacity – 400 V AC/DC, 1.000 V AC, IP54
	7 Piece screwdriver set, ergonomic soft finish, insulated; slotted 2.5 x 75 mm / 4 x 100 mm / 5.5 x 125 mm; phillips PH1 and PH2; cross-head PZ1 and PZ2; chrome vanadium steel; GS VDE – EN 60900, insulated and tested for 1000 Volts AC
	Clamp-on ammeter, digital, 400 A - AC, voltage 600 AC, voltage 600 DC, resistance 20 MOhm, capacity tester 0-50 µF, LCD, +/-1.8% + 0.6 A AC current accuracy, includes test leads, carrying case, battery and instructions
	Set of three (3) adjustable wrenches: size 200 mm (8"), size 250 mm (10") 250 mm, size 300 mm (12"). chrome vanadium steel, chrome finish
	Locking pliers (vice grip) 5 mm to 16 mm, with guarded release trigger and adjusting screw. Heat treated alloy steel with nickel-plated finish for maximum durability.e
	Locking "piercing" pliers; adjustable 1/4"- 6 mm, with two spare piercing pins and two spare gaskets. Heat treated alloy steel with nickel-plated finish for maximum durabil-ity.

Descriptions of tools and equipment

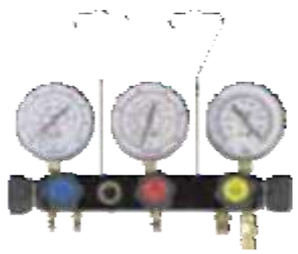
Picture	Technical Specification
	Locking "pinch-off" pliers, adjustable from 6 mm to 12mm. Heat treated alloy steel with nickel-plated finish for maximum durability.
	Capillary tube cutter for all capillary diameter
	Set of seven (7) allen keys; sizes 2,5 / 3 / 4 / 5 / 6 / 8 and 10, chrome vanadium steel
	Ratchet wrench square: 1/4" x 3/8" and 3/16" x 5/16", vanadium steel construction
	Line piercing valve for copper tubes of diameter 6 up to 10 mm. For refrigerant transfer hose connection 1/4" SAE
	Set of two (2) tube cutters, tube OD 3 to 16 mm and 7 to 41 mm, Large tube cutter with reamer and spare wheel
	Flac18 mm, complete with rugged carrying case
	Expander tool set complete with expander-pliers and seven (7) heads in steel box to cover sizes of 10, 12, 15, 16, 18, 22, 28 mm
	Cross-bow-type tube bender set with seven different heads, for annealed copper tubes, with special reverse direction bending function. Complete set in plastic box for tube sizes up to 22 mm diameter.

Descriptions of tools and equipment

Picture	Technical Specification
	Triple header tube bender (metric) for tubes OD 6 mm, 8 mm, 10 mm to 90° bends.
	Core removal tool, core removal without refrigerant losses, brass with magnetic tip, one 1/4" male flare SAE connection and one female 1/4" connection, equipped with ball-valve
	Set of two (2) process tube quick-connector tools complete and ready for use on 6 mm (1/4") diameter tubes, consisting of tube adapter with gaskets and insert, quick-coupler (hansen) male and female, hose adapter 1/4" flare union.
	Straight refrigerant hose / system quick connector / coupler
	Elbow refrigerant hose / system quick connector / coupler
	Extraction valve for extracting of refrigerants out of disposable refrigerant cans (420 g.)
	Digital-precision quick response thermometer for thermocouples and simultaneous connection of two (2) plug-in probes. Display in two, 4 digit LCD. Probe connection in two jacks for flat-pin plugs. Temperature drift 0.01 %/K. Accuracy +/- 1 digit (at nominal temperature 25°C. Two (2) K-type probes for measuring range -199°C to +999°C according EN 60584. Push buttons as membrane keys. Power supply 9V battery.

Descriptions of tools and equipment	
Picture	**Technical Specification**
	Electronic leak detector for HC refrigerants with flexible probe length of min 30 cm and with audible and visual alarms. Sensitivity less than 50 ppm of Propane, Isobutane and Methane. Response time 5 seconds. Operating temperature: 0°C to 50°C supplied with spare tips and rugged carrying case.
	Electronic leak detector with flexible probe length of min 30 cm and with audible and visual alarms. Variable sensitivity, refrigerants CFC, HFC, HCFC and blends, indication of leaks 3 g/yr (1/10oz), visible and audible leak indication, complete set with spare tips and rugged carrying case.
	Electronic weighting scale designed for charging and recovery. Capacity 50 kg, Resolution 5 g, Accuracy 0.5% of reading, measuring units in kg and lb. Zero function, Battery power and low-battery indication. Rugged portable case. CE certification.
	Electronic charging scale for HC refrigerants. Measuring range 0-2000 g, accuracy 1 g, battery powered, digital readings. Equipped with refrigerant disposal can support.
	Brazing unit complete: consisting of one 2 litre oxygen and one 0.425 kg propane (LPG) gas cylinder. Complete set including valves, safety valves, pressure gauges, constant pressure regulator, 3m hoses, torch and tips sizes 2 and 3 according EN 962 complete with carrying frame.
	Sets of 4-valve manifold pressure gauges (3x1/4" and 1x3/8" connections) pulse-free, bar measurement indication, gauges 68 mm with refrigerant scale for HC R600a, and one vacuum gauge 0-1000 mbar and pointer and safety valve

Descriptions of tools and equipment

Picture	Technical Specification
	Sets of 2-valve manifold pressure gauges (3x1/4” and 1x3/8” connections) pulse-free, bar measurement indication, gauges 80 mm with refrigerant scale for R22, R134a, R404A, R407C, including 3 refrigerant transfer hoses 90 cm (red, blue, yellow) with ball valves and 1x3/8” standard hose (vacuum pump) 2x3/8 female straight swivel ends; incl. carrying case. Gauges for HC refrigerants R-290 and R-600a available.
	Sets of 5-valve manifold pressure gauges (3x1/4” and 1x3/8” connections) pulse-free, bar measurement indication, gauges 80 mm with refrigerant scale for R22, R134a, R404A, R407C, one vacuum gauge 0-1000 mbar and pointer and safety valve, including 3 refrigerant transfer hoses 90 cm (red, blue, yellow) with ball valves and 1 x 3/8” standard hose (vacuum pump) 2 x 3/8 female straight swivel ends; incl. carrying case
	Refrigerant hoses with end-mounted ball-valves. Hoses colour marked red, blue and yellow. Hose connection in 1/4" SAE. Working pressure about 60 bar (870 PSI). Hose available in length of 90 cm (36"), 150 cm (60") and 180 cm (72"). (Ball valve side with core-depressor)
	Large 3/8" diameter heavy-duty vacuum pump connection hose. Shortest possible hose length for vacuum pump and manifold gauge connection to choose.
	Digital vacuum gauge, resolution 1 micron. Reads vacuum in 7 units: Micron, PSI, InHg, mbar, Pascal, Torr, mTorr. Cleaning port for cleaning of sensor. Accuracy ± 10 Micron from 100-1000 Micron. Overpressure protected up to 20 bar.

Descriptions of tools and equipment

Picture	Technical Specification
	Two stage rotary vacuum pumps with vacuum gauge, ø 80 mm with adjustable pointer, solenoid valve to prevent air from flushing back when turned off; Swept volume minimum 70 litre/min (2.5 cfm); end-vacuum: 15 micron; Oil level indicator with easy oil change capabilities; Normal and efficient operation in high ambient temperatures and high humidity conditions and to start under vacuum of 5 mbar, 230-1-50/60 power requirement; Hose connection 1/4" and 3/8" NPT. Including 2 litre of spare vacuum pump oil.
	Portable charging station for R-600a and HC blends; vacuum pump, double stage, minimum 35 litre/min (1.25 cfm) displacement, factory micron rating – 15 micron; electronic charging scale range 0 to 2000 g and 1 g accuracy; vacuum gauge 80 mm diameter with pointer; compound gauge, Ø 68 mm, –1 to +3 bar
	pressure with temperature scale for R-600a; compound gauge, Ø 68 mm, –1 to +10 bar pressure with temperature scale for R134a and R12 refrigerant; device for liquid filling of R-600a and HC blends; can valve for refrigerant extraction; all necessary charging hoses including one special hose of 5 metre length and minimum inside diameter 15 mm, in order to prevent any R-600a gas in the working area; hose adapter for vacuum pump exhaust port connection; for safety reasons gas must be led through this hose into the outside. Including 2 litre of spare vacuum pump oil.
	Portable HC charging set in aluminium case for accurate charging of refrigerant and air conditioning systems up to charge of 5 kg consisting of: > Digital scale > two quick coupler > extraction valve > PVC recovery hose 5m > two PVC charging hose 1.1m > ball valve > adapter for disposal refrigerant cylinder. Dimension of set 460*340*150 mm. Weight 5.2 kg

Descriptions of tools and equipment

Picture	Technical Specification
	Refillable refrigerant recovery cylinder equipped with double valve for liquid and vapour refrigerant transfer. Minimum capacity (water) 11.9 kg (26.2 lbs)
	Meeting DOT-4BA-400 or ADR P200 standard
	Set of nitrogen cylinder and pressure regulator DIN EN ISO 2503; cylinder 20 litre and 300 bar, regulator pressure 315/200 bar; working pressure 0-16/10 bar; inlet W24, 32x1/14“ RH; outlet G1/4“ RH; adapter for 1/4" NPT refrigerant hose; refrigerant hose with ball valve 150cm long
	R-600a refrigerant in cans with at least 400 g charge, purity ≥ 99.5%
	HC refrigerant blend (50% R-600a/50% R-290) in cans with at least a minimum of 150 g charge, thermodynamic similar pressures / temperatures as the CFC counterpart R-12, purity ≥ 99.5%

APPENDIX 7: CONTENT 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).[46] 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.

Categorisation of ARC topics

GENERAL JOB DESCRIPTION OF THE AREA Refrigeration Craftsman "ARC"	
Work environment	The ARC works in different locations e.g. his company's workshop, construction sites, retail shops, factories, industrial areas, … The type of installation, the equipment he works with and the complexity of the design vary with his specific order. 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 redesign of existing systems. The sub-sectors where they cover most activities, are primarily 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. Besides the refrigerating systems, the companies are involved in air treatment and electro-technical installations. They work generally countrywide but sometimes regionally or internationally. A substantial number of the refrigeration contracting companies are members of the national member associations of AREA. Typical customers are retailers, wholesalers, cold storages, food and pharmaceutical/medical industries, agro-businesses, manufacturing industries and office buildings constructors or operators.
Work content	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.
Responsibilities	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).

46 Further information can be found at www.area-eur.be

GENERAL JOB DESCRIPTION OF THE AREA Refrigeration Craftsman “ARC”	
Professional attitude	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. 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.
TRENDS	
Market changes	• 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
Regulations	• 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.
Technical and technological developments	• 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.

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

CORE ACTIVITIES 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 instruments needed for his work. He makes sure that no moisture or dirt can enter the pre-assembly.
Role and 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, on 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	CTo properly perform, the ARC needs tools and equipment like work bench, bending devices, brazing materials
Quality of process and 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 and dilemmas	The ARC has to take into account that: • 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 ACTIVITIES 2 INSTALLATION OF THE REFRIGERATION SYSTEM	
Process	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, specific components). The materials are mentioned on a list which specifies the main components, copper pipes or other piping, electrical switches and wiring, instruments and flexible insulation materials. 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.
Role and responsibilities	The ARC is responsible for: • 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
Compexity	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.
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 uses the tools that are put at his disposal by his employer or that he has specially rented
Quality of process and results	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.
Choices and dilemmas	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.

CORE ACTIVITIES 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 and responsibilities	The ARC is responsible for the correct assembling of the components and particularly 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 and 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 and dilemmas	The ARC could run into conflicting situations between his own company's interests, the client's company's position and regulatory constraints.

CORE ACTIVITIES 4 COMMISSIONING	
Process	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: • 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. 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.
Role and responsibilities	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.
Complexity	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.
Involved with	The ARC is has to work in cooperation with supervisors of other companies on the same site of the client.
Resources	The ARC has received his tools and equipment from his company to carry out his job.
Quality of process and results	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.
Choices and dilemmas	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.

CORE ACTIVITIES 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 and 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 organization.
Resources	The ARC receives his tools and equipment from his company to carry out his job.
Quality of process and 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 and 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 that 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 ACTIVITIES 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 advising 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 and 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 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 and 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 and 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 ACTIVITIES 7 DISMANTLING OF THE REFRIGERATION SYSTEM	
Process	Before dismantling, the ARC recovers all the 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 they can register that the refrigeration system is out of operation and the recovered refrigerant has been taken care of.
Role and 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 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 and 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 and 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							
1.1 Basic Thermodynamics **Description**	**The ARC is capable of giving a theoretical explanation about a basic compression refrigerating system**	**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
Success Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
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			X	X	X	X		EN 13313
1.1.6	Describe the operation and function of the main components used in a refrigeration system as compressor, condenser, 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							
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.**		**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
Success Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
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		EN 13313
2.1.3	Explain the lubricating system of the compressor		X	X	X	X	X		EN 13313
2.1.4	Explain the capacity control of the compressor		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		prEN 378-4 art. 5
2.1.11	Check the good working condition of the compressor		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		prEN 378-4 art. 4.3
2.1.13	Take the decision to repair the compressor		X		X	X	X		prEN 378-4 art. 4.3
2.1.14	Take the decision to replace the compressor				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							
2.2 Component: Condenser		**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
Description	**The ARC is capable of installing, putting into operation and carrying out the maintenance of air cooled and water cooled condensers.**								
Success Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
2.2.1	Explain the function of the condenser in the system	X	X	X	X	X	X	X	EN 13313
2.2.2	Explain the working of the condenser	X	X	X	X	X	X		EN 13313
2.2.3	Adjust a discharge pressure control of the condenser		X	X	X	X	X		EN 13313
2.2.4	Install the above mentioned types of condensers	X	X				X		prEN 378-2 art. 5.1
2.2.5	Connect the safety and control switches	X	X				X		prEN 378-2 art. 5.1
2.2.6	Install the discharge and liquid lines in the correct position	X	X				X		prEN 378-2 art. 5.1
2.2.7	Purge non condensable gases out of the condenser	X	X				X		prEN 378-2 art. 5.1
2.2.8	Start up and shut down all types of condensers		X	X	X	X	X	X	prEN 378-2 art. 6.3
2.2.9	Do measurements during operation of the refrigeration system		X	X	X	X	X		prEN 378-4 art. 4
2.2.10	Check the good working condition of the condenser		X	X	X	X	X		prEN 378-4 art. 4
2.2.11	Check the surface of the condenser		X	X	X	X	X		prEN 378-4 art. 4
2.2.12	Write a report about the condition of the condenser		X	X	X	X	X		prEN 378-4 art. 4.3
2.2.13	Take the decision to repair a part of the condenser				X	X	X		prEN 378-4 art. 4.3
2.2.14	Take the decision to replace the condenser				X	X	X		prEN 378-4 art. 4.3
Results	A perfectly working condenser contributes to a low energy consumption and a minimum of heat load to the environment.								

Job Competence		Core Activities							
2.3 Component: Evaporator		Pre-assembly	Installation	Technical Reports	Commis-sioning	Monitoring	Fault Finding	Dismantling	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
Description	**The ARC is capable of installing, putting into operation and carrying out the maintenance of air cooled and liquid cooled evaporators.**								
Success Criteria		1	2	3	4	5	6	7	
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		EN 13313
2.3.3	Explain the several ways of defrosting the evaporator		X	X	X	X	X		EN 13313
2.3.4	Adjust an evaporating pressure control of the evaporator		X	X	X	X	X		prEN 378-2 art. 5.1
2.3.5	Install the above mentioned kinds of evaporators	X	X				X		prEN 378-2 art. 5.1
2.3.6	Connect the safety and control switches	X	X				X		prEN 378-2 art. 5.1
2.3.7	Install the liquid and suction pipelines in the correct position	X	X				X		prEN 378-2 art. 5.1
2.3.8	Install the hot gas defrost pipeline in the right position	X	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		prEN 378-2 art. 6.3
2.3.11	Do measurements during operation of the refrigeration system		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		prEN 378-4 art. 4
2.3.13	Check the surface of the evaporator		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		prEN 378-4 art. 4.3
2.3.15	Take the decision to repair a part of the evaporator				X	X	X		prEN 378-4 art. 4.3
2.3.16	Take the decision to replace the evaporator				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							
2.4 Expansion valves & other components **Description**	**The ARC is capable of installing, putting into operation and servicing Thermostatic Expansion Valves (TEV) and other components.**	**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
Success Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
2.4.1	Explain the function of a TEV in the system		X		X	X	X		EN 13313
2.4.2	Explain the working of a TEV in the system	X	X		X	X			EN 13313
2.4.3	Explain the working principle of different kinds of expansion regulators		X		X	X	X		EN 13313
2.4.4	Fit a mechanical and electronic TEV	X	X				X		prEN 378-2 art. 5.1
2.4.5	Adjust a mechanical and electronic TEV				X	X	X		prEN 378-2 art. 5.1
2.4.6	Fit and adjust mechanical and electronic thermostats	X	X		X		X		prEN 378-2 art. 5.1
2.4.7	Fit and adjust mechanical and electronic pressure limiter	X	X		X		X		prEN 378-2 art. 5.1
2.4.8	Fit and check the working of an oil seperator	X	X		X	X	X		prEN 378-2 art. 5.1
2.4.9	Fit a liquid receiver	X	X						prEN 378-2 art. 5.1
2.4.10	Fit a sightglass and check the condition of the refrigerant	X	X		X	X	X		prEN 378-2 art. 5.1
2.4.11	Fit a filter dryer and check the condition of the dryer	X	X		X	X	X		prEN 378-2 art. 5.1
2.4.12	Fit and check a solenoid valve	X	X		X	X	X		prEN 378-2 art. 5.1
2.4.13	Fit a stop valve	X	X						prEN 378-2 art. 5.1
2.4.14	Fit and adjust a pressure regulated valve	X	X		X		X		prEN 378-2 art. 5.1
2.4.15	Write a report about the condition of the TEV or component			X	X	X	X		prEN 378-4 art. 4.3
2.4.16	Take the decision to repair a part of the TEV or component				X	X	X		prEN 378-4 art. 4.3
2.4.17	Take the decision to replace the TEV or component				X	X	X		prEN 378-4 art. 4.3
Results									
	A perfectly working TEV contributes to a low energy consumption, and a good performance as planned for the client.								
	A perfectly fitted and adjusted component contributes to the optimal working of the system.								

Job Competence		Core Activities							
3.1 Piping **Description**	**The ARC is capable of building a leak tight copper piping system in a refrigeration installation.**	**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
Success Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
3.1.1	Work with copper tubes from a diameter of ¼" (6mm) till 7/8" (28mm) and from 35 mm till 54 mm.	X	X				X	X	prEN378-2 art. 6.2
3.1.2	In particular in the following ways:								
3.1.3	- flared joints diameter of ¼"(6mm) till 3/4" (18mm)	X	X				X	X	prEN378-2 art. 6.2
3.1.4	- bends of copper tubes diameter of ¼"(6mm) till 3/4" (18mm).	X	X				X	X	
3.1.5	- fixed connections by hard soldering diameter ¼" (6mm) till 7/8" (28mm) and from 35 mm till 54 mm.	X	X				X	X	EN 13133
3.1.6	Make hard soldering joints for the following connections:								
3.1.7	• copper-copper	X	X				X		EN 13133
3.1.8	• copper-steel	X	X				X		EN 13133
3.1.9	• copper-brass	X	X				X		EN 13133
3.1.10	Install valves in the correct position	X	X				X		prEN 378-2 art. 5.1
3.1.11	Install solenoid, control valves and other devises in pipelines	X	X				X		prEN 378-2 art. 5.0
3.1.12	Install flexible insulation	X	X						prEN 378-2 art. 5.1
3.1.13	Make pipe supports	X	X				X		prEN378-2 art. 6.3
3.1.14	Perform a strength pressure test	X	X	X					prEN378-2 art. 6.3
3.1.15	Perform a tightness test		X	X			X		prEN378-2 art. 6.3
3.1.16	Perform a functional test	X	X	X					prEN378-2 art. 6.3
3.1.17	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							
4.1 Electricity **Description**	**The ARC is capable of installing the electrical cabling and wiring of a refrigeration system.**	**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
Success Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
4.1.1	Explain the use of different kinds of cables an wires	X	X				X		EN 50110 art.3.2.4
4.1.2	Explain the use of different kinds of classified connections	X	X				X		EN 50110 art.3.2.4
4.1.3	Explain the use of different kinds of classified IP	X	X				X		EN 50110 art.3.2.4
4.1.4	Explain the different kinds of safety fuses and switches		X		X	X	X		EN 50110 art.3.2.4
4.1.5	Install electrical equipment and motors		X				X		EN 50110 art.6.2
4.1.6	Lay cables in the cable routes	X	X				X		EN 50110 art.6.2
4.1.7	Do the wiring of a switch panel	X	X		X		X		EN 50110 art.6.2
4.1.8	Connect the power supply at the main switch panel		X		X		X		EN 60204-1
4.1.9	Connect a single and or three phase motor		X		X		X		EN 50110 art.6.2
4.1.10	Connect the electrical components	X	X		X		X		EN 50110 art.6.2
4.1.11	Check the electrical safety according to the EU and National regulations				X	X	X		EN 50110 art.5.3
4.1.12	Check the power consumption of a motor				X	X	X		EN 50110 art.5.3
4.1.13	Measure the electrical equipment and cabling		X		X	X	X		EN 50110 art.5.3
4.1.14	Adjust the electrical safety switches				X		X		EN 50110 art.5.3
4.1.15	Adjust the electrical equipment				X		X		EN 50110 art.5.3
4.1.16	Check the rotation direction of a motor				X		X		EN 50110 art.5.3
4.1.17	Take the decision to repair an electrical component			X		X	X		EN 13313
4.1.18	Take the decision to replace an electrical component			X		X	X		EN 13313
4.1.19	Write a report about the electrical equipment			X	X	X	X		EN 13313

Results

	A safe environment for the client and his personnel
	A reliable electrical system

Job Competence		Core Activities							
5.1 Measurements and Analysis		Pre-assembly	Installation	Technical Reports	Commis-sioning	Monitoring	Fault Finding	Dismantling	**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**
Description	**The ARC is capable of measuring and analyzing physical data, and of making a correct diagnosis.**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
	Success Criteria								
5.1.1	Use a manometer set				X	X	X	X	EN 13313
5.1.2	Use a thermometer				X	X	X		EN 13313
5.1.3	Use a Torr gauge				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		EN 13313
5.1.6	Use an acid test kit to check an oil sample				X	X	X		EN 13313
5.1.7	Use a recovery set				X		X	X	EN 13313
5.1.8	Handle a refrigerant cylinder				X		X	X	EN 13313
5.1.9	Drain oil out of a system				X		X	X	EN 13313
5.1.10	Use a multimeter for measuring Volt/Amp/Ohm				X	X	X		EN 13313
5.1.11	Use an electronic leak detection device				X	X	X		EN 13313
5.1.12	Use a vacuumpump				X		X		EN 13313
5.1.13	Place the data in a Log P/h diagram				X	X	X		EN 13313
5.1.14	Place the data in a h/x diagram				X	X	X		EN 13313
5.1.15	Use product information				X	X	X		EN 13313
5.1.16	Use a computer programme to control the system				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	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							
6.1 Communication **Description** **The ARC is capable of informing a client about the working procedures and the use of the refrigeration system.**		**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
Success Criteria		**1**	**2**	**3**	**4**	**5**	**6**	**7**	
6.1.1	Arrange an appointment with the client		X		X	X	X	X	F-gas regulation
6.1.2	Properly inform the client about the method of operation of the refrigeration system		X		X	X	X	X	prEN 378-4 Art. 4.2
6.1.3	Consider the client's wishes				X	X	X	X	F-gas regulation
6.1.4	Advise the client about maintenance planning				X	X	X		F-gas regulation
6.1.5	Advise the client on saving energy		X		X	X	X		F-gas regulation
6.1.6	Make the client aware of environmental issues		X		X	X	X	X	F-gas regulation
6.1.7	Advise the client on safety issues		X		X	X	X		prEN 378-4 Art. 4.2
6.1.8	Process client complaints				X	X	X		F-gas regulation
6.1.9	Advise the client with regard to shutting down the refrigeration system				X	X	X	X	F-gas regulation
6.1.10	Advise the client whether a new system, or the repair of components, is required					X	X		F-gas regulation
6.1.11	Explain to the client the work procedures		X		X	X	X		F-gas regulation
6.1.12	Explain to the client the content of a report		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							
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.**		**Pre-assembly**	**Installation**	**Technical Reports**	**Commis-sioning**	**Monitoring**	**Fault Finding**	**Dismantling**	**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**
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		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	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 tighness/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		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 8: 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	• 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	• 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	• 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: - Leakage implications (direct and indirect) - Thermodynamic properties - Cooling capacity and energy efficiency - Density - Not stenched • 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 CO_2 cascade systems, split AC systems, domestic fridge freezers (isobutane)
(IV) Understand the procedures for planning and preparing for work on HC RAC systems	• 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	• 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

Learning outcome (The learner will...)	Assessment criteria (The learner can...)
(VI) Understand the specific requirements for installing and testing HC RAC systems	• 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	• 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
(VIII) Be able to service and maintain HC RAC systems	• 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 pipework • 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	• 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

APPENDIX 9: RECORD SHEET FOR REFRIGERANT USE

RECORD SHEET FOR HYDROCARBON REFRIGERATION/AIR CONDITIONING PLANT			
General information			
Plant name			Reference no.
Location of plant			
Plant operator (name, address, telephone)			
Operator contact person			
Cooling/heating loads served			
Plant manufacturer			Year of installation
Refrigerant type			Refrigerant quantity
Refrigerant additions			
Date	Company/personnel/registration no.	Amount added (kg)	Reason for addition
Refrigerant removals			
Date	Company/personnel/registration no.	Amount removed (kg)	Reason for removal
Leak checks			
Date	Company/personnel/registration no.	Result (location and leak causes)	Follow-up actions required
Checks to electrical components/potential sources of ignition			
Date	Company/personnel/registration no.	Result (faulty items, corrections)	Follow-up actions required
Checks to automatic detection and emergency equipment (if applicable)			
Date	Company/personnel/registration no.	Result (faulty items, corrections)	Follow-up actions required
Follow-up actions			
Date	Company/personnel/registration no.	Related to testing/checks on	Actions taken

APPENDIX 10: VAPOUR PRESSURE AND LIQUID DENSITY TABLES

In order to determine test and working pressures of system components and assemblies, it is important to have data on the pressure-temperature relationship of the refrigerant. Data for five HC refrigerants are provided here, encompassing a typical temperature range.

- R600a
- R290
- R1270
- R290 (94% mol) / R170 (6% mol) blend
- R290 (50% mol) / R600a (50% mol) blend

The data has been generated using Refprop version 8[47], where data for other HCs and their mixtures can be obtained.

Table of vapour pressure and liquid density

Temp-erature	R600a (iso-butane)		R290 (propane)		R1270 (propylene)		R290/R170 blend		R290/R600a blend	
	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density
°C	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3
-40	28	625	111	579	142	599	148	574	68	604
-39	30	624	116	578	148	598	154	573	71	603
-38	32	623	121	577	154	597	160	572	74	602
-37	33	621	126	575	161	596	166	571	77	601
-36	35	620	132	574	167	594	173	570	80	600
-35	37	619	137	573	174	593	179	569	84	599
-34	38	618	143	572	182	592	186	567	88	598
-33	40	617	149	571	189	590	193	566	91	597
-32	42	616	155	570	196	589	201	565	95	595
-31	44	615	161	568	204	588	208	564	99	594
-30	46	614	168	567	212	586	216	562	104	593
-29	49	613	174	566	221	585	224	561	108	592
-28	51	612	181	565	229	584	232	560	112	591
-27	53	611	188	564	238	583	241	559	117	590
-26	56	610	196	562	247	581	249	558	122	589
-25	58	609	203	561	256	580	258	556	126	588
-24	61	608	211	560	266	579	267	555	131	586
-23	63	606	219	559	275	577	277	554	137	585
-22	66	605	227	557	286	576	286	553	142	584
-21	69	604	236	556	296	574	296	551	147	583
-20	72	603	244	555	307	573	306	550	153	582
-19	75	602	253	554	317	572	317	549	159	581
-18	78	601	263	552	329	570	327	547	165	579

47 http://www.nist.gov/srd/nist23.htm

Temp-erature	R600a (iso-butane)		R290 (propane)		R1270 (propylene)		R290/R170 blend		R290/R600a blend	
	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density
°C	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3
-17	82	600	272	551	340	569	338	546	171	578
-16	85	599	282	550	352	568	349	545	177	577
-15	89	598	292	549	364	566	361	544	184	576
-14	92	596	302	547	377	565	373	542	190	575
-13	96	595	312	546	389	563	385	541	197	574
-12	100	594	323	545	402	562	397	540	204	572
-11	104	593	334	543	416	561	410	538	211	571
-10	108	592	345	542	429	559	423	537	219	570
-9	112	591	357	541	444	558	436	536	226	569
-8	117	590	369	539	458	556	450	534	234	568
-7	121	589	381	538	473	555	463	533	242	566
-6	126	587	393	537	488	553	478	532	250	565
-5	131	586	406	535	503	552	492	530	259	564
-4	136	585	419	534	519	551	507	529	267	563
-3	141	584	433	533	535	549	522	528	276	561
-2	146	583	446	531	552	548	538	526	285	560
-1	151	582	460	530	569	546	554	525	294	559
0	157	580	475	529	586	545	570	523	304	558
1	162	579	489	527	604	543	586	522	314	556
2	168	578	504	526	622	542	603	521	324	555
3	174	577	520	525	640	540	620	519	334	554
4	180	576	535	523	659	539	638	518	344	553
5	186	575	551	522	678	537	656	516	355	551
6	193	573	568	520	698	536	674	515	366	550
7	199	572	584	519	718	534	693	513	377	549
8	206	571	602	518	739	532	712	512	388	548
9	213	570	619	516	760	531	732	511	400	546
10	220	569	637	515	781	529	752	509	412	545
11	228	567	655	513	803	528	772	508	424	544
12	235	566	674	512	825	526	793	506	437	542
13	243	565	693	510	848	525	814	505	449	541
14	251	564	712	509	871	523	835	503	462	540
15	259	562	732	507	895	521	857	502	476	538
16	267	561	752	506	919	520	880	500	489	537
17	275	560	773	504	943	518	902	499	503	536
18	284	559	794	503	968	516	926	497	517	534
19	293	557	815	501	994	515	949	496	532	533
20	302	556	837	500	1020	513	973	494	546	532
21	311	555	859	498	1046	511	998	492	561	530
22	321	554	882	497	1073	510	1023	491	577	529
23	330	552	905	495	1101	508	1048	489	592	528
24	340	551	928	494	1129	506	1074	488	608	526
25	350	550	952	492	1158	504	1101	486	624	525
26	361	549	977	490	1187	503	1127	484	641	523
27	371	547	1002	489	1216	501	1155	483	658	522
28	382	546	1027	487	1246	499	1182	481	675	521
29	393	545	1053	486	1277	497	1211	480	692	519

Temp-erature	R600a (iso-butane)		R290 (propane)		R1270 (propylene)		R290/R170 blend		R290/R600a blend	
	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density	Vapour pressure	Liquid density
°C	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3	kPa	kg/m^3
30	405	543	1079	484	1308	496	1239	478	710	518
31	416	542	1106	482	1340	494	1269	476	728	516
32	428	541	1133	481	1373	492	1298	474	747	515
33	440	539	1161	479	1405	490	1329	473	766	514
34	452	538	1189	477	1439	488	1360	471	785	512
35	465	537	1218	476	1473	486	1391	469	804	511
36	477	535	1247	474	1508	484	1423	468	824	509
37	490	534	1277	472	1543	483	1455	466	845	508
38	504	533	1307	471	1579	481	1488	464	865	506
39	517	531	1338	469	1615	479	1521	462	886	505
40	531	530	1370	467	1652	477	1555	460	907	503
41	545	529	1401	465	1690	475	1590	459	929	502
42	559	527	1434	464	1728	473	1625	457	951	500
43	574	526	1467	462	1767	471	1660	455	974	499
44	589	524	1500	460	1807	469	1697	453	997	497
45	604	523	1534	458	1847	467	1733	451	1020	496
46	620	522	1569	456	1888	464	1771	449	1043	494
47	635	520	1604	454	1929	462	1809	447	1067	492
48	652	519	1640	452	1972	460	1847	445	1092	491
49	668	517	1676	450	2014	458	1886	443	1117	489
50	685	516	1713	449	2058	456	1926	441	1142	488
51	702	515	1751	447	2102	454	1966	439	1167	486
52	719	513	1789	445	2147	451	2007	437	1193	484
53	736	512	1828	443	2193	449	2049	435	1220	483
54	754	510	1867	441	2239	447	2091	433	1247	481
55	773	509	1907	438	2286	444	2134	431	1274	480
56	791	507	1948	436	2334	442	2177	429	1302	478
57	810	506	1989	434	2382	440	2222	426	1330	476
58	829	504	2031	432	2432	437	2266	424	1359	474
59	849	503	2073	430	2482	435	2312	422	1388	473
60	869	501	2117	428	2532	432	2358	420	1417	471

The purpose of this publication is to present the existing information and guidance relating to the safe use of hydrocarbon refrigerants, but also to inform in a comprehensive manner such that all of the stages in the system life are covered in an interlinked way. It is recognised that simply describing technical requirements is not always sufficient in itself to ensure that a high level of safety is achieved; introducing a robust infrastructure is equally important. For example, how government or industry bodies may set up schemes for certification of technician training, or how manufacturers, distributors or contracting companies may organise their quality management systems to help with the ongoing improvement of safety levels, etc, are all important considerations.

This handbook shall function as a guidebook for policy-makers involved with designing nation-wide policies to support the use of natural refrigerants (i.e. regulatory aspects, standards, etc) and also for manufactures and installers of HCFC and HFC equipment to reliably assess the suitability of hydrocarbon options and subsequently implement them.

GIZ Proklima teamed up with TÜV SÜD to ensure that the safety system is described from both angles, both from a third party perspective and that of an implementing agency. Both organisations work with implementation of flammable refrigerants and they have joined forces to develop these guidelines.

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