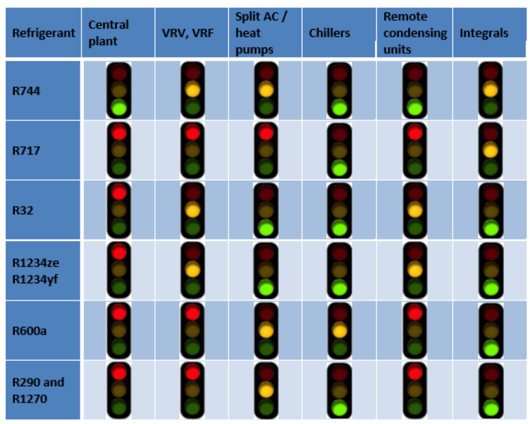
With contribution of the LIFE programme of the European Union

Introduction

to Alternative Refrigerants

Contents



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With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives 4 LIFE Blended Learning Programme

This learning booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives4LIFE.eu

REAL Alternatives 4 LIFE has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Croatian, Czech, Dutch, English, French, German, Italian, Polish, Romanian, Spanish and Turkish.

Real Alternatives Europe Programme Modules	
1	Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2	Safety and Risk Management
3	System design using alternative refrigerants
4	Containment and leak detection of alternative refrigerants
5	Maintenance and repair of alternative refrigerant systems
6	Retrofitting with low GWP refrigerants
7	Checklist of legal obligations when working with alternative refrigerants
8	Measuring the financial and environmental impact of leakage
9	Tools and guidance for conducting site surveys

You can study each module individually or complete the whole course and assessment.

www.realalternatives4life.eu

More information is available in the on line reference e-library.

Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives4life.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

Assessment options are available if you want to gain a recognised CPD Certificate.

At the end of each module are some simple self-test questions and exercises to help you evaluate your own learning. Certification and Assessment will be available from licensed REAL Alternatives training providers when you attend a course of study. The list of recognised training providers will be available on the website.

Register your interest in alternative refrigerants

at rwww.realalternatives4life.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

You can use and distribute this material

Background to the programme and how it was developed.

This learning programme was developed as part of EU co-funded projects led by a consortium of partners from across Europe. It is designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders from across Europe drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed.

The consortium partners were:

- Association of European Refrigeration Air Conditioning & Heat Pump Contractors, Belgium
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- International Institute of Refrigeration
- University College Leuven-Limburg, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

With thanks to our stakeholders:

- CNI National Confederation of Installers, Spain
- CHKT Czech Association for cooling and air conditioning technology
- HURKT, Croatian Refrigeration Airconditioning and Heat Pumps Association
- RGAR Association General of Refrigeration, Romania
- SOSIAD Association of Refrigeration Industry and Businessmen, Turkey
- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 1 -

Introduction to Alternative Refrigerants

Aim of this Module

In this Module we will provide a general introduction to the different alternatives to high global warming potential (GWP) hydro fluoro carbon (HFC) refrigerants and to compare their properties, performance, safety issues, environmental impact and ease of use. These refrigerants are used in new, specially designed systems – they are rarely suitable to replace refrigerants in existing systems. The main alternatives have low to zero GWP, but it is important that a refrigerant is not selected on the basis of low GWP alone; other characteristics should be taken into account such as:

- Operating pressures;
- Performance – capacity and efficiency;
- Material compatibility, including compressor lubricant;
- Safety, including flammability and toxicity;
- Temperature glide;
- Ease of use and skill level of design engineers and technicians who install, service and maintenance.

This is useful reference material for anyone working in the refrigeration, air conditioning and heat pump (RACHP) industry. It assumes you already have knowledge of RACHP systems which use HFC refrigerants.

Limitations

This document provides an introduction to this topic. It does not replace practical training and experience.

Source of additional information and links

Throughout the modules you will find links to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

See REAL Alternatives References

Use of Standards

To avoid copyright infringement no part of international, European or National standards has been reproduced in this document. Standards are an invaluable source of information so reference to them is made and their use is strongly recommended.

Scope

The following refrigerants are included:

- R744 (carbon dioxide, CO_2)
- R717 (ammonia, NH_3)
- R32 (HFC with a lower GWP compared to other commonly used HFCs)
- R1234ze (low GWP hydro fluoro olefin)
- R290 (propane), R1270 (propene, propylene) and R600a (iso butane).

Brief History

To find out more about the history of the development of different synthetic and alternative refrigerants see the eurammon film "naturally cool"

See eurammon "naturally cool" film

R744, R717 and R290 were among the earliest refrigerants used for mechanical cooling systems. Their use declined when CFCs and HCFCs were developed and R744 and R290 were rarely used. R717 continued to be used in industrial systems. When the ozone depleting refrigerants[1] were phased out R290 and other hydrocarbons started to be used again. At the same time HFC refrigerants were introduced and widely used, but their high global warming potential coupled with high leak rates in some applications has caused some of the industry to use lower GWP alternatives. These include R744 which has been used in retail systems since the year 2000, and lower GWP HFCs.

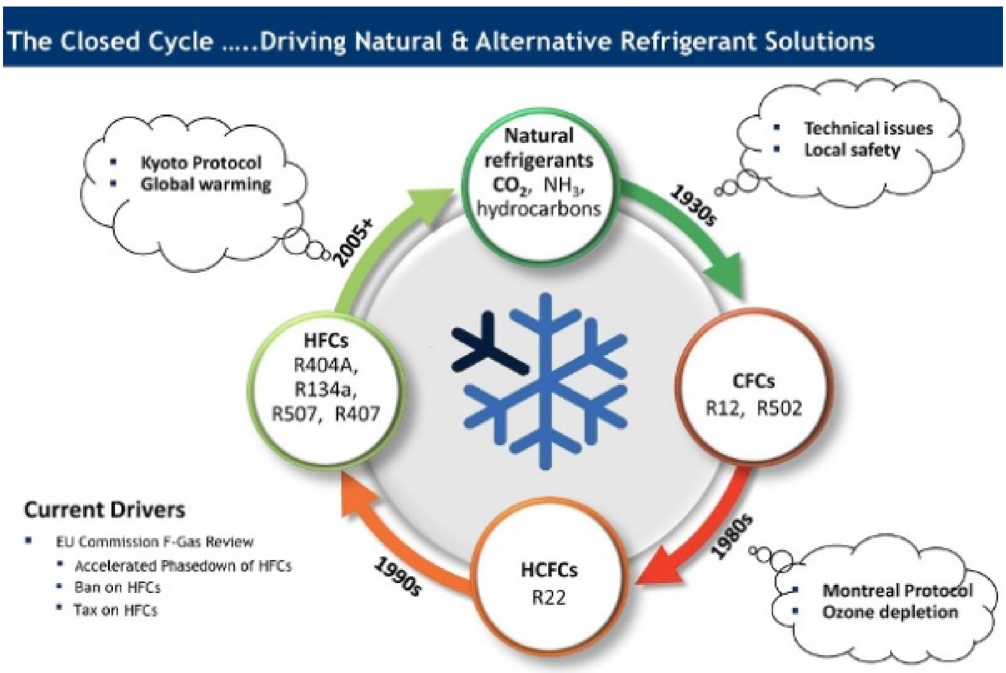


Image from www.fridgehub.com

[1] Chloro fluoro carbons (CFCs) and hydro chloro fluoro carbons (HCFCs)

Basic Properties

The basic properties of these refrigerants are shown in table 1 below.

Table 1, basic alternative refrigerant properties

	Type	Key facts	GWP[2]	Sat temp[3]	Typical applications
R744	Carbon dioxide, CO_2	High pressures	1	-78°C	Retail refrigeration, heat pumps, integrals
R717	Ammonia, NH_3	Toxic and Lower flammability	0	-33°C	Industrial
R32	Hydro fluoro carbon, HFC	Lower flammability	675	-52°C	Split air conditioning
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	Lower flammability	7	-19°C	Chillers, split air conditioning, integrals
R1234yf	Unsaturated HFC (aka hydro fluoro olefin, HFO)	Lower flammability	4	-29.5°C	Chillers, air conditioning, heat pumps
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	Higher flammability	3	-12°C	Domestic and small commercial systems
R290	Propane, C_3H_8, hydrocarbon (HC)	Higher flammability	3	-42°C	Chillers, integrals
R1270	Propene (propylene), C_3H_6, hydrocarbon (HC)	Higher flammability	3	-48°C	Chillers, integrals

Some of these refrigerants are already widely used, others are starting to be trialled and deployed. Their application is often limited by flammability and toxicity - the table below summarises the applications they are most suitable for.

Flammable refrigerants are categorised as having either lower of higher flammability, dependent on the concentration required for ignition to be possible, the heat of combustion and flame propagation. Lower flammability does not mean non-flammable.

[2] GWP is from F Gas Regulation EU 517:2014
[3] Sat temp is the saturation temperature at atmospheric pressure (1 bar g), except for R744 where it is the surface temperature of solid R744 at atmospheric pressure

Table 2, application of alternative refrigerants

Refrigerant	Central plant	VRV, VRF	Split AC / heat pumps	Chillers	Remote condensing units	Integrals
R744						
R717						
R32						
R1234ze R1234yf						
R600a						
R290 and R1270						

The table indicates the type of system the refrigerant is most appropriate for – it does not show where these refrigerants are actually being used. The section below gives more information on current applications.

Green – these systems are suitable for the refrigerant type indicated, and the charge size is **usually** within the limits specified in EN378. Some design changes are required, for example to electrical devices and / or ventilation.

Amber – these systems can and are used with the refrigerant type indicated, but there are restrictions because of the maximum charge or practical limit specified in EN378 (see note 2 below). Some design changes are required to electrical devices and / or ventilation. In some cases the volumetric capacity of the refrigerant means it is not ideal for the application.

Red – these systems should not be used with the refrigerant type indicated, usually because the charge size exceeds the maximum specified in EN378-1.

Notes:
(1) VRV (Variable Refrigerant Volume) and VRF (Variable Refrigerant Flow)
(2) The practical limit for refrigerant represents the concentration used for simplified calculation to determine the maximum acceptable amount of refrigerant in an occupied space. It is based on either toxicity or flammability. For full information see EN378 Part 1 – Table E.1.

Suitability of Alternative Refrigerants for Retrofit

Most alternative refrigerants are not normally suitable for retrofit to systems which were designed for conventional (non flammable) HFC or HCFC refrigerants. However some HFO refrigerants may be used for retrofit – See Module 5 for details.

A brief introduction to each refrigerant or type of refrigerant is given below. For more details see the guide “Design differences for alternative refrigerant systems”.

REAL Alternatives Guide 2, Design Differences with Alternative Refrigerant Systems

2 R744 (carbon dioxide, CO_2) GWP = 1

R744 has high operating pressures, a low critical temperature (31°C) and a high triple point. Its volumetric cooling capacity is between 5 and 8 times that of HFCs, reducing the required compressor displacement and pipe size. Its properties have an effect on how the system is designed and operates, especially in high ambient temperatures. It has a high discharge temperature, necessitating two stage compression for low temperature systems. The document highlighted on the right has detailed information on how these properties effect the application of R744.

Danfoss Application Handbooks "Food retail CO_2 refrigeration systems" and "CO_2 for industrial refrigeration"

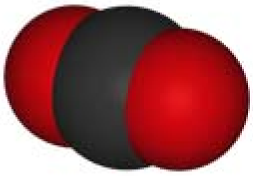


Figure 1 Carbon dioxide molecule

R744 is used in the following system types:

- Pumped secondary – where R744 is the secondary fluid cooled by a primary system. R744 is a volatile secondary which, coupled with the high capacity and density, reduces the required pump power compared to other secondary fluids such as glycol.

- Cascade – where the heat rejected by the condensing R744 is absorbed by the evaporating refrigerant in a separate high stage system. In these systems the R744 operates below the critical point and the high side pressure is generally below 40 bar g. The high stage system can be R744 (see below), or it can be HFC, HC, HFO or R717.

Danfoss Application Handbook "Cascade HC/HFC – CO_2 system"

- Transcritical systems – where the R744 heat is rejected to ambient air and at ambient temperatures above approximately 21°C the R744 will be above the critical point (31°C) – i.e. it will be transcritical. The R744 does not condense – it remains a super critical fluid until its pressure is reduced to below the critical pressure (72.8 bar g). The high side pressure is typically 90 bar g when transcritical.

Danfoss CO_2 Handbook. Danfoss article "Transcritical refrigeration systems with CO_2"

R744 has been used in many 1000 retail systems and in industrial systems in Europe. It is also used in heat pumps and in integral systems.

Shecco Guide Europe 2014

The application of R744 has required additional skills for design engineers and service technicians, and availability of new components.

3 R717 (Ammonia, NH_3) – GWP = 0

R717 has a relatively high saturation temperature at atmospheric pressure, is highly toxic, has lower flammability and has a pungent odour. It can be smelt at concentrations of just 3 mg/m^3, so it is evident at levels much lower than those which are hazardous (the ATEL / ODL[4] is 350 mg/m^3). It is the only commonly used refrigerant which is lighter than air which means that dispersion of any leaked refrigerant takes place quickly.

Institute of Refrigeration Safety Code Ammonia

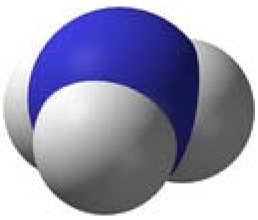


Figure 2, Ammonia molecule

The relatively high saturation temperature means that many low temperature applications (e.g. frozen food cold rooms and blast freezers) run at sub atmospheric pressures on the low side.

R717 also operates with very high discharge temperatures. Single stage compression can therefore normally be used above -10^{O}C evaporating temperature. Below this, two stage compression with interstage cooling is required.

The high toxicity limits the application of R717 to very low charge systems or industrial systems (i.e. systems in areas which are not accessible by the general public). This typically includes distribution cold stores and food processing plants, usually using secondary systems where R717 is the primary refrigerant.

Some examples of ammonia packaged systems are shown below:



Ammonia corrodes copper so steel pipe work and open drive compressors are used. It is also immiscible with conventional mineral oils, making oil rectification an additional requirement of the refrigeration systems. The use of steel pipe, open drive compressors and oil rectification impact on the capital cost of an ammonia installation.

REAL Alternatives Video Example of Ammonia System design in e-library

[4] ATEL / ODL is the Acute Toxicity Exposure Limit / Oxygen Deprivation Limit, whichever is lower, and is listed in EN378-1:2016

4 R32 (HFC) GWP 675

R32 is a low flammable HFC. Its performance and operating pressures are very similar to R410A and it is starting to be used in similar applications – heat pumps, split air conditioning systems and chillers. For further information on suitability of application of this refrigerant you should always contact your equipment supplier.

Institute of Refrigeration Safety Code for Flammable Refrigerants

Figure 3, R32 molecule

Its lower flammability limits the refrigerant charge size, but not to the same extent as the more flammable hydrocarbons. Electrical devices on the system will be the non-sparking type if a leak can result in a flammable concentration around the electrical device.

The operating pressures are higher than for most HFCs, but are similar to R410A. Typically the high side maximum pressure is 35 bar g.

Figure 4, R32 units in production

5 R1234ze and other HFO refrigerants

The main HFO (hydro fluoro olefin) refrigerants are R1234ze and R1234yf. These are both pure substances in the same family, consisting of hydrogen, fluorine and unsaturated carbon. These are both have lower flammability and have very low GWP.

An HFO – hydro fluoro olefin is a halocarbon containing hydrogen, fluorine and unsaturated carbon.

Bitzer refrigerant Report 19

Institute of Refrigeration Safety Code for Flammable Refrigerants

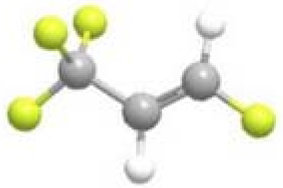


Figure 5, R1234ze molecule

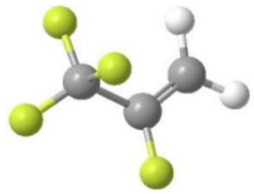


Figure 6, R1234yf molecule

Their lower flammability limits the refrigerant charge size, but not to the same extent as the higher flammability hydrocarbons. Electrical devices on the system will be the non-sparking type if a leak can result in a flammable concentration around the electrical device.

The saturation temperature of R1234ze at atmospheric pressure is high compared to other refrigerants so it will operate on a vacuum on the low pressure side of the system for low temperature applications. It is therefore most suitable for medium and high temperature applications such as water chillers. Its cooling capacity is also low compared to other HFCs which means that different compressors are required, with a larger displacement relative to the motor.

R1234ze is available and used in chillers and integral units.

R1234yf is in widespread use in car air conditioning. It has now started to be used in commercial chiller applications. It is similar to 1234ze in that it will operate on a vacuum on the low pressure side of the system for low temperature applications making it more suitable for medium and high temperature applications such as water chillers. However, it has a capacity very similar to R134a which means that the same compressors can be used.

Several blends using HFOs are in commercial use. They have lower GWPs than pure HFCs such as R404A and R134a, but some are flammable. See Module 5 for more information.

Honeywell leaflet: Solstice – a full range of … refrigerant solutions

Climalife website for IDS Chemours refrigerant information

Figure 7, Examples of equipment using R1234ze

6 R290, R1270 and R600a (HCs) GWP = 3

R290 (propane), R1270 (propene, propylene) and R600a (isobutane) are all hydrocarbons. They are highly flammable, so refrigerant charge size is limited on many applications. This limits the application of HCs mainly to integral systems, chillers and some split air conditioning systems. Electrical devices on the system will be the non-sparking type if a leak can result in a flammable concentration around the electrical device.

Institute of Refrigeration Safety Code for Flammable Refrigerants

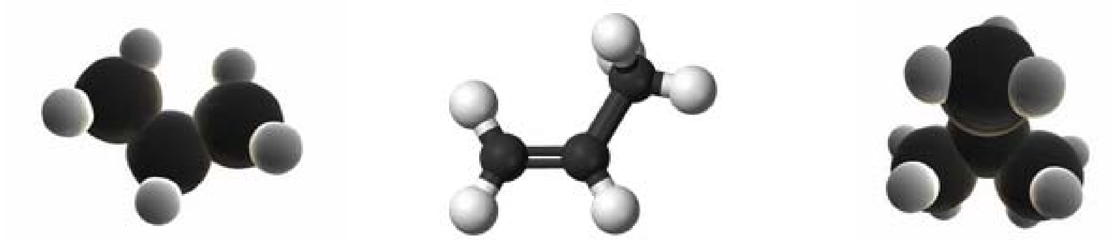


Figure 8, Propane, propene and isobutane molecules

R290 and R1270 have similar performance and operating pressures to R404A and they are used in high, medium and low temperature commercial applications. R600a has a much higher saturation temperature than other refrigerants and operates at a vacuum on the low side in most applications. Its use is limited to domestic and very small commercial refrigeration systems with minimal leakage so that ingress of air and moisture due to leakage rarely occurs.

Blends of HCs are also available, such as Care 30 (propane and isobutene) and Care 50 (propane and ethane). They are also highly flammable, and have significant temperature glide.

Figure 9, Examples of hydrocarbon refrigerant systems

7 Safety

All alternative refrigerants covered in this guide have additional hazards compared to the traditional HFC refrigerants. These include:

- Flammability;
- Toxicity;
- High pressures.

The table below summarises the hazards of the alternative refrigerants. The traffic light system indicates the severity of the hazard compared to R404A.

Table 3, hazards of alternative refrigerants compared to R404A

Refrig.	Inhalation	Flammability	Pressure	Other
R744	Low toxicity	Non flammable	Much higher	Pressure rise of trapped liquid high and risk of trapping cold liquid high. Possibility of solid R744 formation.
R717	Highly toxic	Low flammable	Lower	
R32	Asphyxiant	Low flammable	Higher	Products of decomposition highly toxic
R1234ze	Asphyxiant	Low flammable	Lower	Products of decomposition highly toxic
R600a	Asphyxiant	Highly flammable	Much lower	
R290	Asphyxiant	Highly flammable	Similar	
R1270	Asphyxiant	Highly flammable	Similar	

Green – similar to R404A or not as severe;
Amber – slightly more severe than R404A;
Red – significantly more severe than R404A.

For all refrigerants – risk is reduced by minimising leak potential.

Safety Classification

The safety classifications below are defined in ISO817:2014 [5] and are also used in EN378-1:2016[6].

The classification comprises two parts: A or B followed by 1, 2L, 2 or 3.

- A or B represents the degree of toxicity
    - A is lower toxicity (most refrigerants are class A);
    - B is higher toxicity (R717 is class B).

- 1, 2L, 2 or 3 represents the degree of flammability
    - 1, non flammable;
    - 2L, lower flammability;
    - 2, flammability;
    - 3, higher flammability.

The table below lists the safety classification of the common alternative refrigerants.

Table 2, safety information

Refrigerant	Safety classification [a]	LFL, kg/m^3 [b]	Auto ignition temp, ^oC	PL, kg/m^3 [c]	ATEL / ODL [d]
CO_2 R744	A1	Not applicable	Not applicable	0.1	0.072
NH_3 R717	B2L	0.116	630	0.00035	0.00022
HFC R32	A2L	0.307	648	0.061	0.30
HFO R1234ze	A2L	0.303	368	0.061	0.28
HFO R1234yf	A2L	0.289	405	0.058	0.47
HC R600a	A3	0.043	460	0.011	0.059
HC R290	A3	0.038	470	0.008	0.09
HC R1270	A3	0.047	455	0.008	0.0017

a. The safety classification is as listed in EN378-1.
b. LFL (kg/m^3) is the Lower Flammability Limit as listed in EN378-1.
c. PL is the Practical Limit as listed in EN378-1. For A1 refrigerants it is the highest concentration in an occupied space that will not result in escape impairing effects. For flammable refrigerants it is approximately 20% LFL.
d. ATEL / ODL is the Acute Toxicity Exposure Limit / Oxygen Deprivation Limit as listed in EN378-1. This is the level above which there is an adverse effect that results either from a single or multiple exposures in a short space of time (usually less than 24 hours).

[5] ISO817:2014 Refrigerants – Definitions and safety classification.

[6] EN378-1:2016, Refrigerating systems and heat pumps – Safety and environmental requirements, Part 1 – Basic requirements, definitions, classification and selection criteria

8 Restrictions on use such as maximum charge size

EN378[7] provides charge size restrictions for RACHP equipment:

- Table C.1 is for refrigerants which have toxicity as the dominant hazard, e.g. R717 and R744;
- Table C.2 is for refrigerants which have flammability as the dominant hazard, e.g. HCs and A2L refrigerants.

The maximum charge size depends on:

- Location of equipment, e.g. whether some or all of the equipment is in the occupied space;
- Access category of the area being cooled, e.g. unrestricted access by the public or authorised access only;
- Type of system – for comfort cooling / heating or other applications.

There are three access categories as shown in the table below.

Table 5, occupancy classification

Category	Location where …	Examples
A	People may sleep; The number of people present is not controlled; Any person has access without being personally acquainted with the personal safety precautions	Hospitals and nursing homes Prisons Theatres, lecture halls Supermarkets, restaurants, hotels Transport termini Ice rinks
B	Only a limited number of people may be assembled, some of them being necessarily acquainted with the general safety precautions. May be a room or part of a building.	Laboratories Places for general manufacturing Office buildings
C	Not open to the general public where only authorised persons are granted access. Authorised persons are acquainted with general safety precautions.	Cold stores and abattoirs Refineries Non public areas in supermarkets Manufacturing facilities (e.g. chemicals, food)

There are four equipment location classifications:

Class I –all mechanical equipment is located within the occupied space;
Class II – compressors are in a machinery room or in open air;
Class III – all refrigerating equipment is in a machinery room or the open air;
Class IV – all refrigeration equipment is in a ventilated enclosure.

Some common examples of charge size restrictions are given below, but you must refer to EN 378 for full information.

[7] EN378-1:2016 Annex C

Example 1 – Cold room using R290 at ground level with a remote condensing unit located outside

The refrigerant is safety classification A3, so table C.2 in EN 378-1:2016 applies.
Access category is **B** for this example.
Application is “other applications”.
System is above ground.
Equipment location classification is II because the condensing unit is located outside.

Table C.2 specifies the maximum charge as follows:

20% x LFL x room volume and not more than 2.5 kg.

Cold room size 3.5 m by 3 m by 2.4 m high;
Cold room volume = 3.5 x 3 x 2.4 = 25.2 m^3;
R290 LFL = 0.038 kg/m^3;

Maximum charge = 0.2 x LFL x volume
= 0.2 x 0.038 x 25.2 = 0.192 kg.

This is below 2.5 kg.

Figure 10, Example of HC cold room mono block systems

Example 2 – R32 split air conditioning with a ceiling mounted indoor unit

The refrigerant is safety classification A2L, so table C.2 in EN 378-1:2016 applies.
Access category is A for this example.
Application is comfort cooling / heating.
Equipment location classification is II because the condensing unit is located outside.

Table C.2 specifies the maximum charge as follows:

Equation C2 and not more than m_2 x 1.5 kg

Equation C2 is:

$M = 2.5 \times LFL^{1.25} \times h \times \sqrt{A}$

M = max charge, kg
LFL = lower flammability limit, kg/m^3
h = height of unit, m
(0.6 for floor mounted, 1.0 for window, 1.8 for wall, 2.2 for ceiling)
A = floor area, m^2

$m_2 = 26 \times LFL$

$LFL_{R32} = 0.307$ kg/m^3
A = 9 m x 5.5 m = 49.5 m^2

$M = 2.5 \times 0.307^{1.25} \times 2.2 \times \sqrt{49.5}$
M = 8.84 kg.

This is below m_2 x 1.5 = 26 x 0.307 x 1.5 = 12 kg.

Note – EN 378 allows greater charge sizes if alternative safety provisions are made, including refrigerant detection / alarms, shut off valves and ventilation.

Example 3 - R744 Central plant system cooling shop floor cabinets and cold rooms

The refrigerant is safety classification A1, so table C.1 in EN 378-1:2016 applies. Access category is A and B for this example (shop floor is a, cold rooms accessed only by store staff are **B.** Equipment location classification is II because pack is located outside.

For the shop floor (access category **A**) table C.1 specifies the maximum charge as follows:

Toxicity limit x room volume

Shop floor is 25 m by 50 m by 5 m high
ATEL for R744 is 0.072 kg/m^3

M = 0.072 x 25 x 50 x 5 = 450 kg

For the cold rooms (which are access category **B)** there is no charge restriction. However, EN 378-3:2016 section 9.1 specifies that if the concentration can exceed the practical limit refrigerant detectors should be used which will activate an alarm. For R744 the detector should alarm at 50% ATEL / ODL, so at 0.5 x 0.072 for R744 (0.036 kg/m^3). Note – the practical limit for R744 is 0.1 kg/m^3 so this is likely to be exceeded in small cold rooms in the event of a leak.

In addition table C.1 refers to EN 378-3:2016 4.2 for plant located outside and specifies that refrigerant should not be able to flow into buildings in the event of a leak. If there is any risk that leaked refrigerant could exceed the safety limits set by EN378, including in the event of pooling or stagnation, then a gas detection and alarm system will be required.

Example 4 – R717 chiller located outside

The refrigerant is safety classification B2L so table C.1 applies.

For an outside chiller the equipment location is III. There is no charge restriction for any access category.

In addition table C.1 refers to EN 378-3:2016 4.2 for plant located outside and specifies that refrigerant should not be able to flow into buildings in the event of a leak. If there is any risk that leaked refrigerant could exceed the safety limits set by EN378, including in the event of pooling or stagnation, then a gas detection and alarm system will be required.

Example 5 – calculation of minimum room volume for a delicatessen counter with a 350 g R1270 charge

The refrigerant is safety classification A3, so table C.2 in EN 378-1:2016 applies.

Access category is **A** for this example.

Application is other applications.

Equipment location classification is I for an integral cabinet.

Table C.2 specifies the maximum charge as follows:

20% x LFL x room volume and not more than 1.5 kg

So minimum room volume = charge / 0.2 x LFL = 0.35 / 0.2 x 0.046 = 38 m^3.

9 Performance and operating conditions

The table below provides an indication of performance of the alternative refrigerants. R404A is included for comparison purposes. This information has been derived from CoolPack software except where specified.

The figures below provide an indication of comparative performance as it is based on a theoretical cycle. Actual comparisons depend on compressor technology, application, ambient and system type. Manufacturer's data / software will provide a more accurate comparison for a specific application.

This is especially so for R744 where expected COP, for example, would be higher than indicated below for the type of system and operating conditions where R744 is typically deployed.

Coolpack Software

Bitzer selection software
Bitzer Refrigerant Report 19, pages 38, 39

Copeland Select 7.15 Software

Table 4, performance comparison

Refrigerant	Saturation temperature at 0 bar g, °C	Required displacement m^3/h	COP	Discharge temperature, °C	Compression ratio [a]
R404A	-46	14.84	2.94	57	3.82
R744	-78	3.88	1.75 [c]	114	3.42
R717	-33	14.3	3.27	152	4.82
R32 [b]	-52	9.65	3.17	99.5	3.77
R1234ze [b]	-19	35.14	3.28	52	4.54
R600a	-12	47.13	3.26	51	4.40
R290	-42	17.35	3.18	59	3.61
R1270	-48	14.3	3.17	67	3.53

a. Compression ratio is the discharge pressure divided by the suction pressure, both in bar abs;
b. Data from Refprop[8];
c. All the COPs given in this table are theoretical COP of the refrigeration cycle. R744 operates above the critical point at the reference cycle, in practice the COP will be higher than shown in the simple comparison above.

The comparison has been estimated at the following conditions:

Cooling capacity, 10kW
Evaporating temperature, -10°C
Condensing temperature, 35°C (R744 is trans critical and has a gas cooler exit temperature of 35°C)
Useful superheat, 5K
Subcooling, 2K
Pressure losses are equivalent to 0.5K
Isentropic efficiency, 0.7.

[8] Refprop (Reference Fluid Thermodynamic and Transport Properties Database) is available from www.nist.gov

The charts below show the displacement required for a given cooling capacity and the COP compared to R404A at the above operating conditions.

Figure 11, displacement compared to R404A

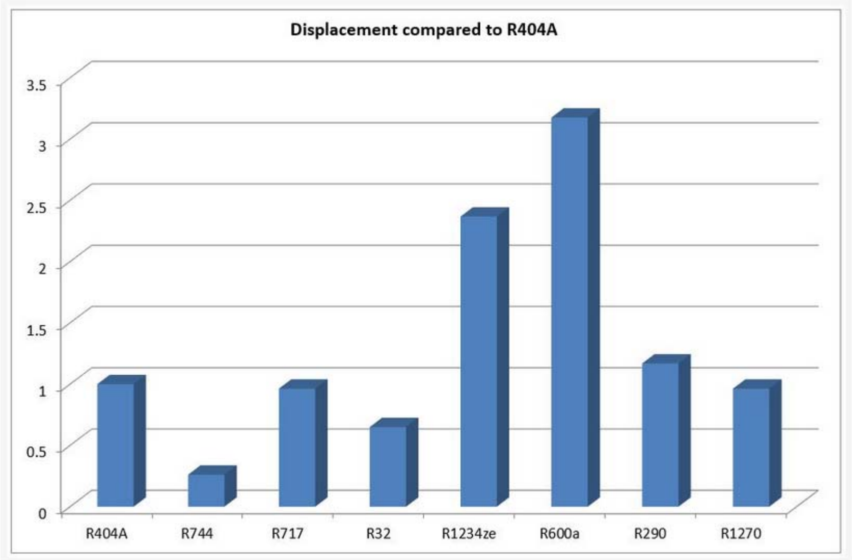
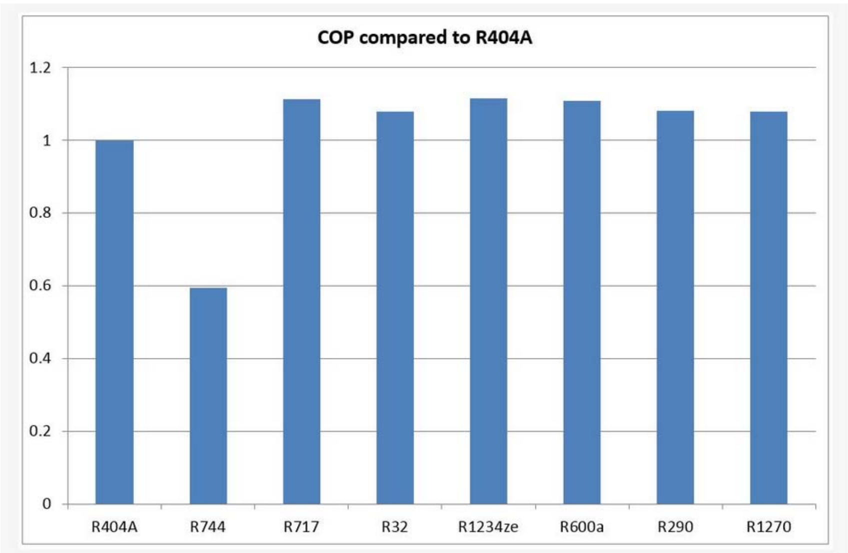


Figure 12, COP compared to R404A



Note that the COP for R744 is low because this is a theoretical cycle comparison at conditions which most refrigeration systems would operate (including 35^{O}C condensing temperature). However, R744 is above the critical temperature for this comparison, and in reality the head pressure would be controlled to a different pressure to provide improved COP.

Energy Efficiency Ratio

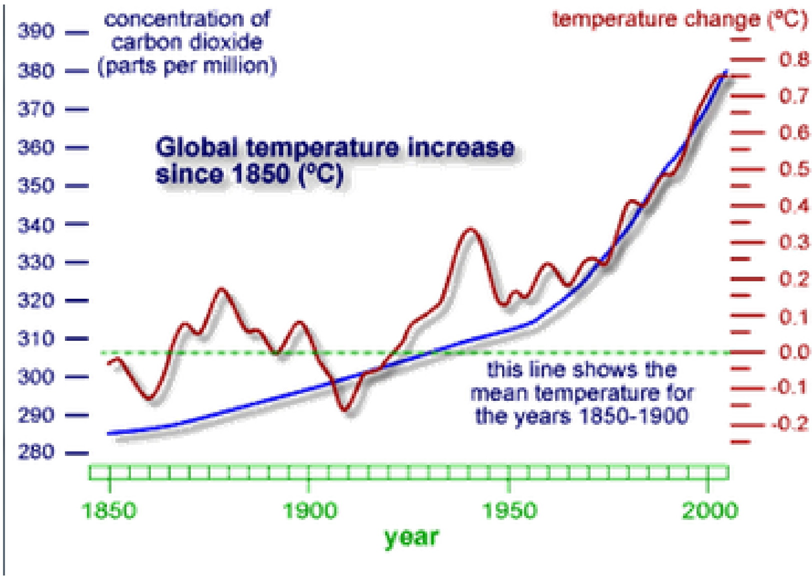
EER or Energy Efficiency Ratio can also be used to compare efficiencies in air conditioning and heat pump applications. This is the ratio of the cooling capacity of an air conditioner in kW or BTU per hour, compared to the total electrical input in kW or Watts at a given test criteria. This is normally based on the European Standard EN 14511-2:2011 “Air Conditioning, Liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. Test conditions”

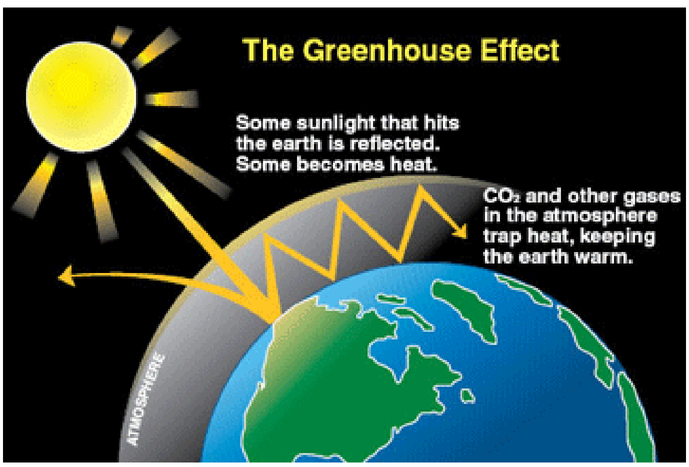
10 Environmental impact

Global Warming Potential (GWP)

The data in table 1 provides the direct global warming potential (GWP) of the alternative refrigerants. This should not be considered in isolation when selecting a refrigerant for a particular application. The impact of the refrigerant's GWP is much less if the refrigerant does not leak during normal operation and the system is serviced without refrigerant loss. However, the revision of the F Gas regulation will necessitate the application of low GWP refrigerants.

Ref	R744	R717	R32	R1234yf	R1234ze	HCs	R404A	R410A
GWP	0	1	675	4	7	3	3922	2088





The greenhouse effect is thrown out of balance by too much man-made carbon dioxide.
Image courtesy of Washington State Department of Ecology

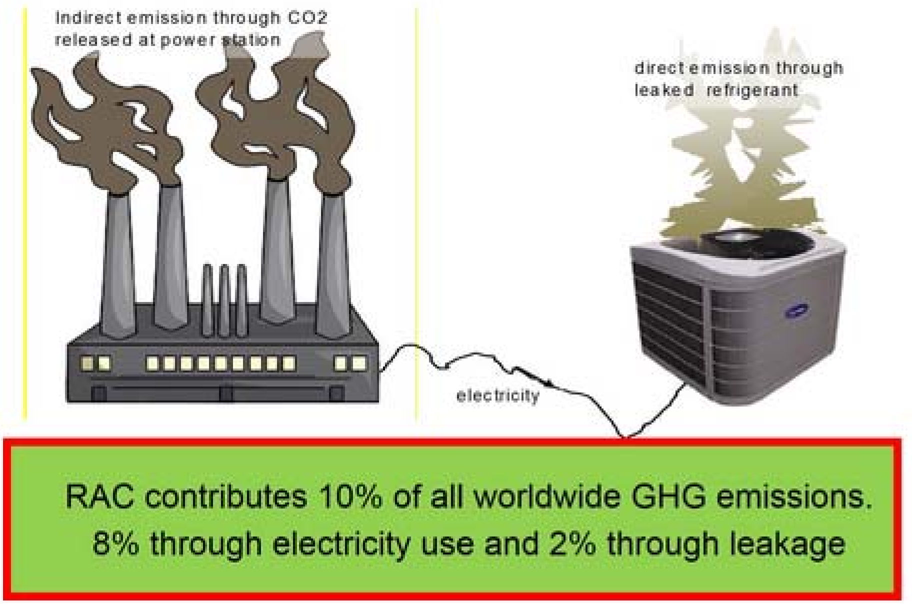
Total Equivalent Warming Impact

The total impact of a system and refrigerant on climate change is estimated using TEWI – the Total Equivalent Warming Impact[9]. It is a method of assessing the impact on climate change over the lifetime of a system by combining:

direct contribution of refrigerant emissions into the atmosphere

+

indirect contribution of the CO_2 resulting from energy to operate the system



It is a very useful method of comparing different system and refrigerant options at the design stage or when considering a retrofit, for example from R22.

There are many ways TEWI can be minimised, including:

- Minimising refrigerant leakage (which reduces both the direct and indirect impact because leaking systems use more energy);
- Use of low GWP refrigerants;
- Minimising cooling load;
- Maximising energy efficiency through appropriate design and installation;
- Maintaining the system correctly;
- Minimising refrigerant loss during service;
- Recovery and recycling of used refrigerant (and used insulation where this has a blowing agent which has a GWP).

[9] EN378 part 1, Annex B

TEWI is calculated as follows:

TEWI = impact of leakage losses + impact of recovery losses + impact of energy consumption

Impact of leakage losses = GWP x L x n

Impact of recovery losses = GWP x m x (1-$\alpha_{recovery}$)

Impact of energy consumption = n x E_{annual} x β

Where:

L = leakage in kg/year
n = system operating time in years
m = refrigerant charge in kg
$\alpha_{recovery}$ = recovery / recycling factor, between 0 and 1
E_{annual} = energy consumption in kWh per year
β = CO_2 emission in kg / kWh, note – this varies significantly from country to country.

Many of the factors used in this calculation vary significantly and are system specific. You can decide the factors for yourself from your own experience (for example leakage), use known factors (for example for β) or use industry recommended factors such as those available in the UK from the British Refrigeration Association.

British Refrigeration Association Guideline Method for Calculating TEWI

To more accurately compare very different system options it is useful to use specific TEWI:

http://sdfab.se/downloads/program/TEWI/

TEWI / ($E_{useful\ cooling}$ + $E_{heating}$ + $E_{heat\ reclaim}$)

Where:

$E_{useful\ cooling}$ is the useful cooling capacity (cooling systems) in kWh/year
$E_{useful\ heating}$ is the useful heating capacity (heat pumps) in kWh / year
$E_{heat\ reclaim}$ is the useful heat reclaim in kWh / year.

11 Availability of refrigerant, components, information and skilled engineers / technicians

The table below gives an indication of how widely available important aspects of alternative refrigerant systems are. The simple traffic light system provides a quick reference to availability and hence current ease of deployment. Green – readily available; Orange – partially available; Red – not currently available.

Table 5, availability of alternative refrigerants and associated items (estimated as at 2018)

	Refrigerant	Knowledge	Skills / Training	Components	Tools and equipment
R744	Refrigerant grade CO_2 available in a range of cylinder sizes	Wide range of system design options challenge design engineers	Hazards and range of system types challenge technicians. Training available	Available for large systems, less so for small systems	Available
R717	Refrigerant grade NH_3 widely available in a range of cylinder sizes	Widely understood in the industrial sector	Widely understood in the industrial sector. Training available	Widely available in the industrial sector	Widely available
R32	Available	Manufacturers of R32 equipment have a good understanding	Very little experience and questions regarding sources of ignition. HC training applicable and available	Deployed in AC systems since 2015	Widely available (most HC tools / equipment are suitable)
R1234ze	Available in limited quantities, expensive	Very limited knowledge	Very limited experience, but HC experience is applicable. HC training applicable and available	Compressors not readily available	Widely available (most HC tools / equipment are suitable)
R1234yf	Commercially available expensive	Limited knowledge but wide use in auto a/c	Very limited experience, but HC experience is applicable. HC training applicable and available	Compressors not readily available	Widely available (most HC tools / equipment are suitable)
R600a	Refrigerant grade HCs available in a range of cylinder sizes	Widely used and understood in the domestic sector	Very wide experience in the domestic sector. Training available	Widely deployed, components readily available	Widely available, although recovery machine is available from only one supplier
R290 R1270		Information readily available on application of HCs in commercial systems	Wide experience in the commercial sector. Training available	Widely deployed in integral systems and chillers, components readily available	

12 Leakage issues

This section outlines issues associated with leakage of alternative refrigerants – more detailed information is provide in Module 4, Containment and Leak detection for Alternative Refrigerants.

REAL Alternatives Guide 4

Whatever refrigerant is used leak potential should be minimised. Low GWP alternative refrigerants usually have hazards associated with high pressure, flammability or toxicity, so leakage is a safety concern. In addition – any leaking system consumes more power and so has a greater indirect impact on climate change.

The potential for leakage is a combination of factors such as operating pressure, molecule size and system size / type. This is summarised in the table below, with hazards associated with leakage and ease of leak detection.

Table 6, leak potential, hazards and ease of leak detection

Refrigerant	Leak potential	Hazards	Ease of detection
R744	High • High operating pressures • Used in large systems with multiple joints • Vented during service	High pressures during operation and standstill	Good – detection equipment available
R717	Medium • Medium to low operating pressures • Usually used in chiller type systems with minimum joints • Open compressors with shaft seals	Toxicity and lower flammability	Good – has a pungent odour and detection equipment available
R32	Medium • Medium to high operating pressures • Used in AC systems, but usually with brazed connections	Lower flammability	Detection equipment becoming available
R1234ze **R1234yf**	Medium • Medium to low operating pressures • Used in chiller type systems with minimum joints	Lower flammability	Detection equipment becoming available
R600a **R290** **R1270**	Low • Medium to low operating pressures • Used in systems with low charge in line with requirements for A3 refrigerants	Higher flammability	Detection equipment available

13 Outline of relevant standards and legislation

The table below shows the most useful standards and regulations relevant to the application of alternative refrigerants. More information is available in the e-library and key standards and legislation are explained more fully in Module 7 – Checklist of Legal Obligations.

Table 7, standards and regulations

Document	Title	Guidance (relevant to flammable refrigerants)
ISO 817:2014	Refrigerants -- Designation and Safety Classification	An unambiguous system for numbering refrigerants. It includes safety classifications (A1, A2, A3).
EN 378-1:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Basic requirements, definitions, classification and selection criteria	Practical limit Maximum charge sizes
EN 378-2:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation	High pressure protection Ventilated enclosures Leak simulation testing for flammable refrigerants
EN 378-3:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Installation site and personal protection	Machinery rooms Refrigerant detectors
EN 378-4:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Operation, maintenance, repair and recovery	Repairs to flammable refrigerant systems Competence of personnel working on flammable refrigerant systems
EN 60079-0:2012+A1 2013	Explosive atmospheres – Equipment – general requirements	Categorisation of flammable gases Classification of equipment Zones
EN 60079-10-1:2015	Explosive atmospheres – Classification of areas – explosive gas atmospheres	Zones and classification of equipment Leak simulation testing Air flow requirements
EN 60079-14:2014	Explosive atmospheres – Electrical installations design, selection and erection	Location of sources of ignition Wiring
EN 60079-15:2010	Explosive atmospheres – Equipment protection by type of protection "n"	Electrical equipment and enclosures for use in potentially flammable areas Labelling of electrical equipment
EN 60335-2-24:2010	Household & similar electrical appliances – Safety Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances & ice-makers	Systems with less than 150 g flammable refrigerant charge.
EN 60335-2-40:2012	Household & similar electrical appliances – Particular requirements for electrical heat	Design, application and servicing of AC systems using flammable refrigerants.

	pumps, air conditioners and dehumidifiers	
EN 60335-2-89:2010	Household & similar electrical appliances – Safety Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor	Systems with less than 150 g flammable refrigerant charge, leak simulation testing for area classification.
ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road	Transport of flammable gases in systems or equipment by road
RID	Regulations concerning the international carriage of dangerous goods by rail	Transport of flammable gases in systems or equipment by rail
ATEX	European Directive on Minimum Requirements for Improving the Safety and Health Protection of Workers Potentially at Risk from Explosive Atmospheres	Applies to wotk places where flammable refrigerants are used

14 Self Test Module 1

Try the sample multiple choice assessments below to check your learning:

Question 1 -

What is an HFO:

i. Hydrogen plus fluorine plus oil
ii. Hydrogen plus fluorine plus carbon Hydro carbon
iii. An ozone depleting refrigerant

Question 2 –

What is the maximum charge of R290 that can be used on a supermarket shop floor (occupancy category **A**)

i. It cannot be used in this application
ii. 150 g
iii. 1.5 kg
iv. There is no limit

Question 3 –

Which alternative refrigerant has the highest GWP:

I. R717
II. R32
III. R744
IV. R1270

Question 4 –

According to EN 378, what is the max refrigerant charge of a R290 direct expansion system cooling a walk in room (size 5x4m high 2.5m) and having compressor, condenser, receiver outside the room?

I. 1.5kg
II. 0.38kg
III. 2.6
IV. 0.15kg

(answers are shown on the bottom of the following page)

What next?

The information in this guide is an introduction to the most common alternative refrigerants. There is much more information in the documents highlighted in the links. Go to the on line reference e-library at www.realalternatives4life.eu/e-library to explore any additional information you may find useful.

If you would like to gain a REAL Alternatives 4 LIFE Certificate you need to take a full end of course assessment at a licensed REAL Alternatives 4 LIFE training centre. Information about assessments is available at http://www.realalternatives4life.eu

You can now continue your self-study with one of the following **Real Alternatives 4 LIFE** programme Modules:

1. Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2. Safety and risk management
3. System design using alternative refrigerants
4. Containment and leak detection of alternative refrigerants
5. Maintenance and repair of alternative refrigerant systems
6. Retrofitting with low GWP refrigerants
7. Checklist of legal obligations when working with alternative refrigerants
8. Measuring the financial and environmental impact of leakage
9. Tools and guidance for conducting site surveys

This project has been funded with support from the European Commission. This publication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Correct answers: Q1 = ii, Q2 = iii. Q3 = ii, Q4 = ii.

With contribution of the LIFE programme of the European Union

Safety and Risk Management

with Alternative Refrigerants

Contents

With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives 4 LIFE Blended Learning Programme

This learning booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives4LIFE.eu

REAL Alternatives 4 LIFE has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Croatian, Czech, Dutch, English, French, German, Italian, Polish, Romanian, Spanish and Turkish.

Programme Modules	
1	Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2	Safety and Risk Management
3	System design using alternative refrigerants
4	Containment and leak detection of alternative refrigerants
5	Maintenance and repair of alternative refrigerant systems
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9	Tools and guidance for conducting site surveys

You can study each module individually or complete the whole course and assessment.

www.realalternatives4life.eu

More information is available in the on line reference e-library.

Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives4life.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

Assessment options are available if you want to gain a recognised CPD Certificate.

At the end of each module are some simple self-test questions and exercises to help you evaluate your own learning. Certification and Assessment will be available from licensed REAL Alternatives 4 LIFE training providers when you attend a course of study. The list of recognised training providers will be available on the website.

Register your interest in alternative refrigerants

at www.realalternatives4life.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

You can use and distribute this material

Background to the programme and how it was developed.

This learning programme was developed as part of EU co-funded projects led by a consortium of partners from across Europe. It is designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders from across Europe drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed.

The consortium partners:

- Association of European Refrigeration Air Conditioning & Heat Pump Contractors, Belgium
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- International Institute of Refrigeration
- University College Leuven-Limburg, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

With thanks to our stakeholders:

- CNI National Confederation of Installers, Spain
- CHKT Czech Association for cooling and air conditioning technology
- HURKT, Croatian Refrigeration Airconditioning and Heat Pumps Association
- RGAR Association General of Refrigeration, Romania
- SOSIAD Association of Refrigeration Industry and Businessmen, Turkey
- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 2 -

Introduction to Safety and risk management with Alternative Refrigerants

Aim of this Module

This Module brings together information about the hazards of alternative refrigerants and summarises how to safely apply and work with them. More detailed information about using these refrigerants is included in modules 1 (Introduction), 3 (Design), 4 (Leak Detection) and 5 (Service). This module:

- Identifies the hazards of the alternative refrigerants
- Shows how they are minimised during design, installation, service and at the end of life
- Shows how risk is assessed and managed

This module does not replace practical training which is essential when working with these refrigerants. Throughout this guide you will find references to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you need further information.

1 Outline of Safety Hazards

All alternative refrigerants covered in this guide have additional hazards compared to the traditional HFC refrigerants. These include:

- Flammability
- Toxicity
- High pressures

The table below summarises the hazards of the alternative refrigerants.

Table 1, hazards of alternative refrigerants

Refrigerant	Inhalation	Flammability	Pressure[1]	Other
R744	Lower toxicity	Non flammable	Much higher	Pressure rise of trapped liquid high and risk of trapping cold liquid high. Possibility of solid R744 formation.
R717	Higher toxic	Lower flammability	Lower	
R32	Asphyxiant	Lower flammability	Higher	Products of decomposition highly toxic
R1234ze	Asphyxiant	Lower flammability	Lower	Products of decomposition highly toxic
R600a	Asphyxiant	Higher flammability	Much lower	
R290	Asphyxiant	Higher flammability	Similar	
R1270	Asphyxiant	Higher flammability	Similar	

For all refrigerants – risk is reduced by minimising leak potential.

[1] Compared to R404A

2 Safety Classification

The safety classifications below are defined in ISO817:2014 [2] and are also used in EN378-1:2016[3]. The classification has two parts: A or B followed by 1, 2L, 2 or 3.

- A or B represents the degree of toxicity
  - A is lower toxicity (most refrigerants are class A)
  - B is higher toxicity (R717 is class B)

- 1, 2L, 2 or 3 represents the degree of flammability
  - 1, non flammable
  - 2L, lower flammability
  - 2, flammable
  - 3, higher flammability

The table below lists the safety classification of the common alternative refrigerants.

Table 2, safety information

Refrigerant	Safety classification [a]	LFL, kg/m³ [b]	Auto ignition temp, °C	PL, kg/m³ [c]	ATEL / ODL [d] kg/m³
CO_2 R744	A1	Not applicable	Not applicable	0.1	0.072
NH_3 R717	B2L	0.116	630	0.00035	0.00022
HFC R32	A2L	0.307	648	0.061	0.30
HFO R1234ze	A2L	0.303	368	0.061	0.28
HFO R1234yf	A2L	0.289	405	0.058	0.47
HC R600a	A3	0.043	460	0.011	0.059
HC R290	A3	0.038	470	0.008	0.09
HC R1270	A3	0.047	455	0.008	0.0017

a. The safety classification is as listed in EN378-1.
b. LFL (kg/m^3) is the Lower Flammability Limit as listed in EN378-1.
c. PL is the Practical Limit as listed in EN378-1. For A1 refrigerants it is the highest concentration in an occupied space that will not result in escape impairing effects. For flammable refrigerants it is approximately 20% LFL.
d. ATEL / ODL is the Acute Toxicity Exposure Limit / Oxygen Deprivation Limit as listed in EN378-1. This is the level above which there is an adverse effect that results either from a single or multiple exposures in a short space of time (usually less than 24 hours).

[2] ISO817:2014 Refrigerants – Definitions and safety classification.
[3] EN378-1:2016, Refrigerating systems and heat pumps – Safety and environmental requirements, Part 1 – Basic requirements, definitions, classification and selection criteria

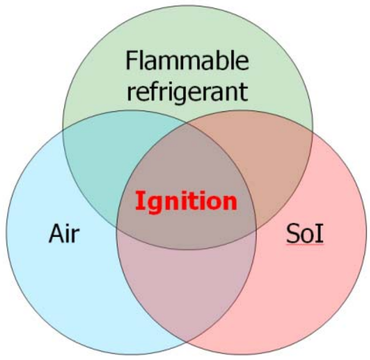
3 Flammability

The flammability classification is explained in table 3 below.

Table 3, flammability classification

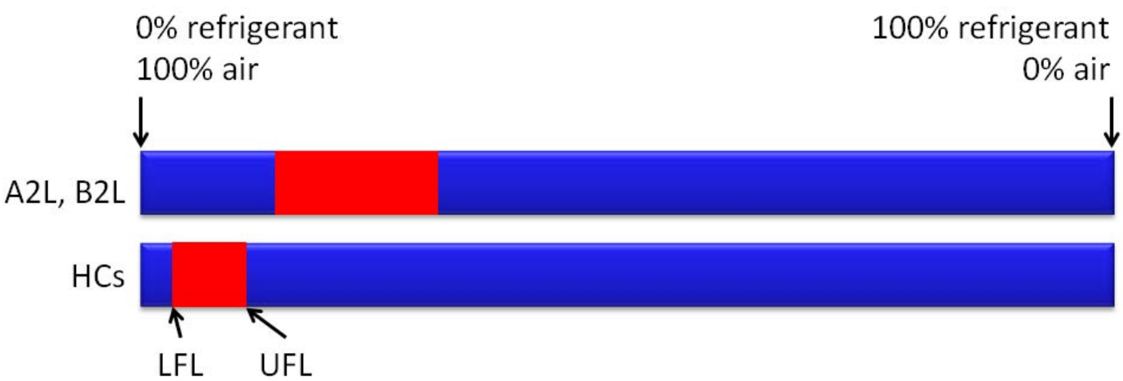
Safety classification	Lower Flammability level, % in air by volume [4]	Heat of combustion, J/kg	Flame propagation
1	No flame propagation when tested at 60°C and 101.3 kPa		
2L, lower flammability	> 3.5	< 19,000	Exhibit flame propagation when tested at 60°C and 101.3 kPa and have a maximum burning velocity of ≤ 10 cm/s when tested at 23°C and 101.3 kPa
2, flammable	> 3.5	< 19,000	Exhibit flame propagation when tested at 60°C and 101.3 kPa
3, higher flammability	≤ 3.5	≥ 19,000	Exhibit flame propagation when tested at 60°C and 101.3 kPa

Note – the **2L** safety classification is a new class and is now included in EN 378.



Three conditions are required for combustion – fuel, oxygen and a source of ignition. For all flammable refrigerants combustion will occur if the refrigerant concentration in air is between the lower and upper flammability levels and if there is a source of ignition.

The flammable range for HCs, A2L refrigerants and R717 is shown in the chart below (the lower flammability level is also listed in table 2):



[4] For example, R290 has an LFL of 0.038 which is approximately 2% in air by volume

An open flame will ignite all flammable refrigerants, e.g. a brazing flame, match, cigarette lighter.

Sparking electrical devices will ignite A3 (HC) refrigerants and possibly 2L refrigerants. Sparking electrical devices can include:

- On / off switches, e.g. on electrical sockets, vacuum pumps, recovery machines
- Contactors
- Light switches
- Standard thermostats
- Standard compressor relays and overload protectors (klixons)
- Standard pressure switches (high pressure, low pressure, oil differential pressure)
- Standard light starters (ballasts)
- Standard timers (e.g. for defrost) and controllers
- Electronic leak testers

Electrical devices which comply with EN60079 part 7[5] or 15[6] are not sources of ignition when applied to a zone 2 classification. The type of electrical protection is related to zone. Typically zone 2 applies but if the zone is different other component classifications might apply.

[5] EN 60079-7:2015 Explosive atmospheres. Equipment protection by increased safety "e"
[6] EN 60079-15:2010 Explosive atmosphere. Equipment protection by type protection “n”

4 Asphyxiation and Toxicity

All refrigerants are asphyxiants because they displace air. Inhalation of any refrigerant vapour in sufficient quantities can cause asphyxiation and cardiac sensitisation and have an effect on the central nervous system. These can lead to dizziness, lethargy or irregular heartbeat. Asphyxiation is a hazard if a large amount is released, particularly into an enclosed area such as a cold room or plant room.

R717 is toxic and has a very low practical limit (0.00035kg/m^3). R717 is irritating and corrosive.

- Inhalation: exposure to high concentrations causes immediate burning of the nose, throat and respiratory tract. This can result in respiratory distress or failure. Inhalation of lower concentrations can cause coughing, and nose and throat irritation. R717's pungent odor provides early warning of its presence, but exposure also causes odor fatigue, reducing awareness of one's prolonged exposure at low concentrations.

- Skin contact: exposure to low concentrations of R717 may produce rapid skin or eye irritation. Higher concentrations of ammonia may cause severe injury and burns. Contact with liquid R717 can also cause frostbite, as with all refrigerants.

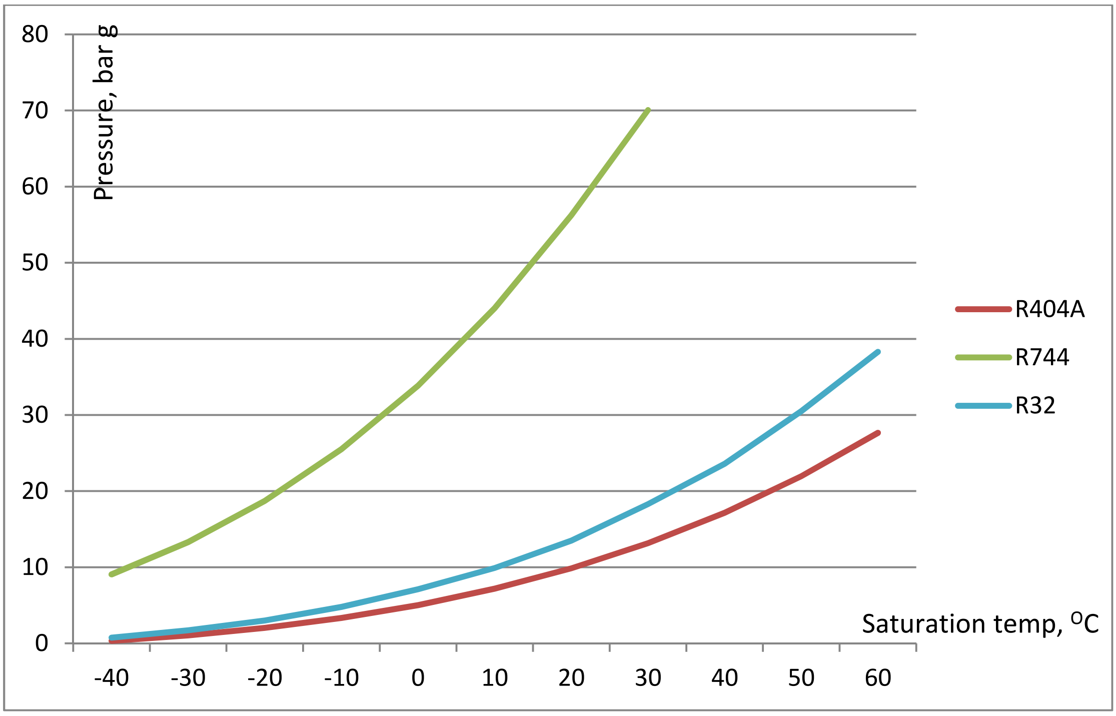
Products of decomposition

HFC and HFO form toxic products of decomposition when burnt e.g. when an A2L refrigerant such as R32 is ignited by an open flame. Hydrogen fluoride is produced which forms hydrofluoric acid when in contact with moisture (e.g. in the air or in your mouth). The effects of inhalation or contact are very severe and usually require hospital treatment. This is a hazard with all HFC refrigerants, but A2L HFCs and HFOs pose a greater risk because they are ignited by an open flame such as a brazing torch.

5 Higher Pressures

Most of the alternative refrigerants operate at pressures less than or similar to R404A. But R32 and R744 operate at higher pressure, as shown in the graph below.

Figure 1, pressure temperature, high pressure refrigerants



The operating and standstill pressures of R32 are similar to R410A (currently commonly used in air conditioning systems).

The table below shows typical pressures for R744:

Danfoss Refrigerant Slider App
Bitzer PT App

Table 2, Typical R744 pressures

	Typical pressure Bar g (MPa)
Setting of PRV in high side of transcritical system (i.e. PS)	120 (12)
High side of transcritical system, operating above the critical point	90 (9)
Intermediate pressure in a transcritical system	35 to 65 (3.5 to 6.5)
Setting of PRV in high side of the low stage of a cascade system (i.e. PS)	40 (4)
High side pressure in the low stage of a cascade system	30 (3)
Low temperature (LT) evaporator	15 (1.5)
High temperature (HT) evaporator	30 (3)
Cylinder standing outside in an ambient of 5°C	40 (4)
Plant at stand still in an ambient of 20°C	55 (5.5)

6 Using R744 safely

Summary of key hazards which are more severe than for traditional refrigerants:

Asphyxiation. The practical limit is lower than for other low toxicity (safety class A) refrigerants. Hyperventilation followed by hypoventilation will occur at concentrations as low as 30,000 ppm. The concentration of R744 resulting from a leak will rise rapidly due to the higher pressure and consequent rate of escape from the system.

High pressure. The operating pressure is up to 90 bar g on transcritical systems. The pressure in a new cylinder of R744 will be approximately 99 bar g in a 40^{O}C ambient.

Pressure rise of trapped liquid. The pressure of trapped liquid will rise by approximately 10 bar for every 1K temperature increase. This is greater than for other refrigerants and in addition the potential for trapping cold liquid refrigerant is greater on R744 system because of the low liquid line temperatures (they are usually below ambient temperature).

Dry ice. Dry ice will be formed when the pressure of R744 vapour is reduced to below 4.2 barg (the triple point). This can, for example, block vent lines.

Design to reduce risk

See REAL Alternatives Guide 3

All components, including pipe work and fittings, must be suitable for the PS values.

See REAL Alternatives Guide 4

Fixed leak detection should be fitted wherever a leak could result in a concentration greater than the ATEL. For R744 the ATEL / ODL is 0.072 kg/m^3, so the alarm should be set at 0.036m^3 (approximately 20,000 ppm). Typically there will also be a pre alarm at 5,000 ppm because of the rapid rise in concentration in the event of a leak due to the high pressures of R744.

Working safely

See REAL Alternatives Guide 5

Appropriate personal protective equipment (PPE) should be worn by anyone working invasively on R744 systems. This includes gloves and safety goggles, and ear defenders when venting refrigerant.

Enclosed areas should not be entered if the fixed gas detection is alarming or if there is any other indication of a leak. A personal R744 detector should be used if there is no fixed leak detection.

Work should be carried out in a well ventilated area.

Charging and connection equipment should be suitable for the pressure. This depends on the ambient (and hence cylinder pressure) and the pressure of the system / section of system being charged or vented.

All charging and vent lines should be secured so they cannot whip.

Clear procedures should be prepared for all service activities which eliminate the potential for trapping cold liquid either in the system or the charging / access equipment.

R744 should be vented as liquid so that the majority of the refrigerant is vented from the system prior to reaching the triple point. Care should be taken to avoid dry ice formation in the vent line during this process. Using a short vent line with a large diameter (greater than 12 mm diameter) will minimise the risk of this.

7 Using R717 safely

Summary of key hazards which are more severe than for traditional refrigerants:

Toxicity. R717 is toxic and corrosive. Inhalation damages the nose, throat and lungs. Skin contact causes irritation and burns.

Low flammability. R717 in air can potentially be ignited by a naked flame and unsealed electrical devices.

Design to reduce risk

See REAL Alternatives Guide 1

The charge size should be restricted in accordance with EN 378 part 1 Annex C table C.1.

See REAL Alternatives Guide 4

R717 is has a very low practical limit (0.00035 kg/m^3). Fixed leak detection should be used if a leak can result in a concentration exceeding this. The low level should be set at 500 ppm and should activate mechanical ventilation and a supervised audible alarm. The high level should be set at 30,000 ppm and should stop the plant and isolate electrics.

See REAL Alternatives Guide 3

The system should be designed to prevent ignition in the event of a leak (see next section on flammable refrigerants for further information).

Working safely

See REAL Alternatives Guide 5

Appropriate personal protective equipment (PPE) should be worn by anyone working invasively on R717 systems. This includes gloves and safety goggles**.** Breathing apparatus may also be necessary.

Enclosed areas should not be entered if the gas detector is alarming or if there is any other indication of a leak.

The work area must be well ventilated with no source of ignition within 3 m of the system and associated equipment.

All equipment used should be suitable for use with R717.

8 Using flammable refrigerants safely

Summary of key hazards which are more severe than for traditional refrigerants:

Flammability. A2L, B2L and A3 refrigerants are potentially flammable in air. They will be ignited by an open flame and by sparks from unsealed electrical devices.

Design to reduce risk

See REAL Alternatives Guide 1

The charge size should be restricted in accordance with EN 378 part 1 Annex C table C.2 (except for R717 where toxicity is the dominant hazard and table C.1 applies).

See REAL Alternatives Guide 3

Leak simulation testing should be carried out to identify if sources of ignition (e.g. sparking electrical devices) are in a flammable zone in the event of a leak. If the testing identifies that sources of ignition are in a potentially flammable zone one of the following options should be adopted:

- The use of suitable safe (e.g. Ex rated) electrical devices;
- Re positioning electrical devices outside the flammable zone;
- Sufficient permanent ventilation.

See REAL Alternatives Guide 4

Gas detection may be required for some systems / refrigerants (EN 378 Part 1 specifies when they should be used).

Working safely

See REAL Alternatives Guide 5

Appropriate personal protective equipment (PPE) should be worn by anyone working invasively on flammable refrigerant systems. This includes gloves and safety goggles. In addition a flammable refrigerant monitor should be used to continuously monitor the work area for the presence of flammable gas.

The work area must be well ventilated with no source of ignition within 3 m of the system and associated equipment.

The recovery machine and leak detector must be suitable for use with the flammable refrigerant.

Prior to unbrazing (or debrazing) connections any remaining refrigerant charge should be removed from the system, the system evacuated and then purged at low pressure with oxygen free dry nitrogen.

If electrical devices are to be replaced like for like replacements should be used.

See IoR Guidance Note 19

The European ATEX[7] Workplace Directive applies to workplaces where flammable substances are used, including areas where technicians are

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[7] ATEX is the name commonly given to the European Directive on Minimum Requirements for Improving the Safety and Health Protection of Workers Potentially at Risk from Explosive Atmospheres

working invasively on flammable refrigerant systems.   The points above are based on this directive, but you should refer to ATEX 137 for full information.   The UK Institute of Refrigeration has a guidance note which summarises this.

9 Risk assessment

A risk assessment is the method by which you decide how likely it is that harm will occur from a particular activity (i.e. the level of risk) and what measures to take to control the risk. Risk is part of everyday life – you are not expected to eliminate risks, but you should know what the main risks are and how to manage them responsibly. This guide deals only with the risks associated with the use of alternative refrigerants - they have additional hazards compared to traditional refrigerants.

A **hazard** is something that could cause harm. A **risk** is the likelihood that a hazard could cause harm.

There are four stages to risk assessment:

1. Identify the hazards, use sections 1, 6, 7 and 8 for this;
2. Identify who could be harmed, typically this is the technician and in some cases other workers and the general public;
3. Evaluate the risks, taking into account the likelihood of occurrence and the consequent severity. Take into account control measures, see sections 6, 7 and 8 for this;
4. Record the findings.

UK HSE documents
Risk Assessment
How to control risks at work

If the risk assessed is high you will need to consider other control measures. For example, when working on a flammable refrigerant appliance moving the appliance to outside to work on it could reduce risk to a low level.

The risk assessment below is an example covering the recovery of R1270 from a display cabinet with a charge of 850 g, fitted with Schrader valves on the high and low side. Recovery is to take place on the shop floor.

Activity	R1270 recovery
Location	XX supermarket
Assessed by	XX
Assessment date	XX

Likelihood (L)

1	Unlikely
2	Likely
3	Almost certain

Severity (S)

1	Minor injury
2	Serious injury
3	Catastrophic injury or fatality

Evaluation matrix

Severity	3	Medium	High	High
	2	Low	Medium	High
	1	Low	Low	Medium
		1	2	3
		Likelihood		

Risk level (R)

Low	
Medium	
High	

Persons at risk	Hazards identified	Control measures	Risks after controls		
			L	S	R
Refrigeration technician Shop staff	Combustion	Work is carried out outside trading hours. Barriers are erected around the work area to keep shop staff away. The work area is well ventilated. There are no sources of ignition within 3 m of the HC cabinet and service equipment. A recovery machine suitable for use with HC refrigerant is used, and is switched outside the 3 m work area. A fire extinguisher is located within the work area. An HC detector is used to warn of an HC leak into the work area. The technician has received training and been assessed in safe handling of HC refrigerants.	1	2	2
Refrigeration technician Shop staff	Overfilled recovery cylinder	Cylinders are clearly marked with the HC safe fill weight. Scales are used to weigh the cylinder during recovery to ensure the safe fill weight is not exceeded.	1	2	2
Refrigeration technician	Freeze burns	Technician wears gloves and safety goggles while working.	2	1	2
Refrigeration technician Shop staff	Asphyxiation	Work area is well ventilated. An HC detector is used to want of an HC leak into the work area.	1	1	1

10 Self Test Module 2

Try the sample multiple choice assessments below to check your learning:

Question 1 -
The hazards of R32 include which of the following:

i. High flammability
ii. Low flammability
iii. High toxicity
iv. Dry ice formation

Question 2 –
R290 is classified in EN378 as a refrigerant Class:

I. A2
II. A3
III. B2
IV. A2L

Question 3 –
Which of the following will not ignite an A3 refrigerant:

I. An HFC leak detector
II. An open flame
III. Ex rated fan motor
IV. A standard compressor relay

Question 4 –
A fixed leak detector for use with R717 should alarm at:

I. 500 ppm
II. 5,000 ppm
III. 50,000 ppm
IV. Leak detection is not required with R717.

(answers are shown on the bottom of the following page)

What next?

The information in this provides an introduction to the safety hazards and how they should be managed for the most common alternative refrigerants. There is much more information in the documents highlighted in the links. Go to the on line reference e-library at www.realalternatives4life.eu/e-library to explore any additional information you may find useful.

If you would like to gain a REAL Alternatives Certificate you need to take a full end of course assessment at a licensed REAL Alternatives training centre. Information about assessments is available at http://www.realalternatives4life.eu

You can now continue your self-study with one of the following **Real Alternatives 4 LIFE** programme Modules:

1. Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2. Safety and risk management
3. System design using alternative refrigerants
4. Containment and leak detection of alternative refrigerants
5. Maintenance and repair of alternative refrigerant systems
6. Retrofitting with low GWP refrigerants
7. Checklist of legal obligations when working with alternative refrigerants
8. Measuring the financial and environmental impact of leakage
9. Tools and guidance for conducting site surveys

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

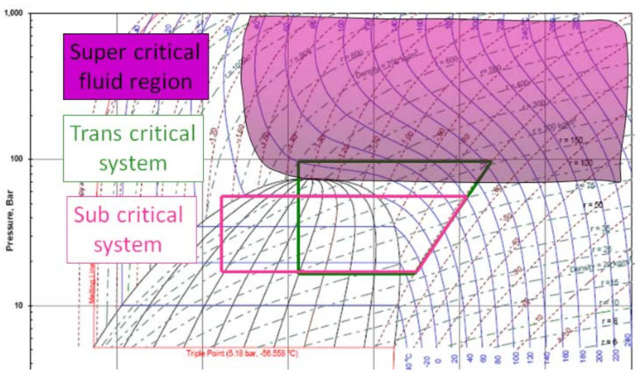
Correct answers: Q1 = ii, Q2 = ii. Q3 = iii, Q4 = i.

With contribution of the LIFE programme of the European Union

Design Differences

For Alternative Refrigerants

Contents



With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives 4 LIFE Blended Learning Programme

This learning booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives4life.eu

REAL Alternatives 4 LIFE has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU Lifelong Learning Programme, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Croatian, Czech, Dutch, English, French, German, Italian, Polish, Romanian, Spanish and Turkish.

Programme modules:

1. **Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice**
2. **Safety and risk management**
3. **System design using alternative refrigerants**
4. **Containment and leak detection of alternative refrigerants**
5. **Maintenance and repair of alternative refrigerant systems**
6. **Retrofitting with low GWP refrigerants**
7. **Checklist of legal obligations when working with alternative refrigerants**
8. **Measuring the financial and environmental impact of leakage**
9. **Tools and guidance for conducting site surveys**

You can study each module individually or complete the whole course and assessment.

www.realalternatives4life.eu

More information is available in the on line reference e-library. Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives4life.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

Assessment options are available if you want to gain a recognised CPD Certificate. At the end of each module are some simple self-test questions and exercises to help you evaluate your own learning. Certification and Assessment will be available from licenced REAL Alternatives 4 LIFE training providers when you attend a course of study. The list of recognised training providers will be available on the website.

Register your interest in alternative refrigerants at www.realalternatives4life.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

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Background to the programme and how it was developed. This learning programme was developed as part of EU co-funded projects led by a consortium of partners from across Europe. It is designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders from across Europe drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed.

The consortium partners were:

- Association of European Refrigeration Air Conditioning & Heat Pump Contractors, Belgium
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- International Institute of Refrigeration
- University College Leuven-Limburg, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

With thanks to our stakeholders:

- CNI National Confederation of Installers, Spain
- CHKT Czech Association for cooling and air conditioning technology
- HURKT, Croatian Refrigeration Airconditioning and Heat Pumps Association
- RGAR Association General of Refrigeration, Romania
- SOSIAD Association of Refrigeration Industry and Businessmen, Turkey
- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 3 –

Design Differences for Alternative Refrigerants

Aim of this Module

This Module provides an introduction to design differences. It does not replace practical training and experience. Throughout the guide you will find references to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

In this Module we will look at the key differences in the design of new systems which operate with alternative refrigerants. In all cases the basic principles of efficient design should be followed. The refrigerant characteristics define the differences, as shown in table 1 below. In the table these defining characteristics are compared to R404A. Where the cell is blank, there is no significant different to R404A for that particular characteristic. R404A was selected for illustrative purposes although it is primarily a low temperature refrigerant.

Table 1, Characteristics which affect the design of systems

Refrigerant	Pressure	Flamma-bility	Toxicity	Cooling capacity	Critical temp-erature	Discharge temp-erature	Materials
R744	Very high		Mild	Very high	Low	High	
R717		Mild	High			High	No copper or copper alloys
R32	High	Mild		High			
R1234ze	Low	Mild		Low			
R600a	Very low	High		Very low			
R290 R1270		High					

The design differences for each refrigerant are covered in the next section. The differences associated with R744 are more significant than for other refrigerants so there is greater detail on R744 system design. Those most significant differences with R717 are HC are safety related.

Issues associated with flammability affect all the alternative refrigerants except R744, so Appendix 1 includes this information to avoid repetition within the document.
Typical maximum allowable pressures (PS[1]) are given for all refrigerants. In all cases except for R744 these pressures are based on a maximum ambient of 32^{O}C and a maximum condensing temperature of 55^{O}C.

[1] PS is defined in EN378-1:2016, Refrigerating systems and heat pumps – Safety and environmental requirements, Basic requirements, definitions, classification and selection criteria, see Module 5 for more information

1 Minimising Leak Potential

Irrespective of the refrigerant it is important that leak potential is minimised, therefore:

- ✓ Keep it simple;
- ✓ Minimise the number of joints;
- ✓ Minimise the number of components;
- ✓ Close couple the system;
- ✓ Minimise the operating and standstill pressures;
- ✓ Minimise the number of access points to the system and locate them where they are most useful;
- ✓ Avoid using Schrader valves, but if an access valve is absolutely necessary use a ball valve with a flare connector (and ensure it is capped when not in use);
- ✓ Avoid using open drive compressors where possible. If they must be used, ensure that they have shaft seals;
- ✓ Ensure pipe is correctly clamped and vibration transmission is eliminated;
- ✓ Provide information:
  - – Showing the location of access points on the isometric drawing in the plant room;
  - – On torque values;
- ✓ Design in ease of service to aid leak detection and other vital maintenance activities.

See REAL Alternatives Guide 4 “Containment and Leak Detection”

2 R744 (Carbon dioxide)

See REAL Alternatives Guide 1, figure 2

The properties of R744 effect how the refrigerant is applied:

	Type	Key facts	GWP[2]	Sat temp[3]	Typical applications
R744	Carbon dioxide, CO_2	High pressures	1	-78°C	Retail refrigeration, heat pumps, integrals

- All components must be suitable for a high pressure rating because of the high maximum operating and standstill pressures of R744;

- R744 has a lower practical limit than most HFCs because of its low toxicity. (Refer to Module 4 for more details on fixed leak detection);

See REAL Alternatives Guide 4

- The practical limit for a refrigerant represents the highest concentration level in an occupied space that will not result in escape impairing effects for the individual. For full information see the Safety Standard EN378-1, table E.1;

- R744 is an asphyxiant and a fixed leak detection system should be fitted if a leak in an enclosed occupied space such as a cold room, or in plant areas, could result in a concentration which will result in escape impairing effects. It is recommended that the alarm level is set at 50% Acute Toxicity Exposure Limit (ATEL) or Oxygen Deprivation Limit (ODL) as specified in EN378 for machinery rooms. This is the level above which there is an adverse effect that results either from a single or multiple exposures in a short space of time (usually less than 24 hours). For R744 the ATEL / ODL is 0.072 kg/m^3, so the alarm should be set at 0.036m^3 (approximately 20,000 ppm). Typically there will also be a pre alarm at 5,000 ppm because of the rapid rise in concentration in the event of a leak due to the high pressures of R744;

- Compressor displacement and pipe diameters are smaller because of the high cooling capacity of R744 compared to other refrigerants. For example the compressors displacement is approximately 1/5th of that needed for R404A;

- The low critical temperature of R744 results in differences in overall system design. R744 is used in the following types of system:

  - **Transcritical systems**: These systems operate above the critical temperature on the high side for all or part of the time. In these are systems the heat is rejected from the R744 to ambient air and is therefore transcritical at high ambient conditions, typically when the ambient temperature exceeds 21 to 25°C. Small transcritical systems such as beverage coolers, located inside a building, will normally operate transcritically all of the time.

  - **Cascade systems**: These systems are always subcritical. In these systems R744 is the low stage refrigerant in a cascade system, and the heat rejected by the condensing R744 is absorbed by the evaporating high stage refrigerant. The high stage system is usually a conventional system using HFC or HC or R717**.** On some

[2] GWP is from F Gas Regulation EU 517:2014

[3] Sat temp is the surface temperature of solid R744 at atmospheric pressure

systems R744 is used in the high stage as well as the low stage. In this case the R744 in the low stage is always subcritical, but in the high stage will be transcritical at high ambient conditions.

- **Secondary systems**: The R744 is used as a secondary fluid and is pumped around the heat exchangers. Partial evaporation can occur because of the volatility of R744, but saturated refrigerant will exit the evaporator (i.e. it will not be superheated as in the systems above). The R744 is cooled by a chiller.

- Two stage compression is used for transcritical low temperature (LT) systems due to the high discharge temperatures that are possible.

- Mechanical subcooling such as the use of suction to liquid line heat exchangers is used in many systems where normally the liquid temperature is below ambient temperature because of the system configuration - natural liquid subcooling will therefore not occur.

Many R744 systems combine two or more of the system types above, for example a cascade system can include a pumped secondary circuit and / or can be cooled by a transcritical R744 system.

Figure 1, Example of an R744 system

2.1 Transcritical operation

Critical temperature

Danfoss video, CO_2 phase change

NaReCO2 manual Natural Refrigerant CO2

A major difference with R744 compared to all other refrigerants is its operation above the critical temperature (31°C) in many systems. For an explanation of the critical point see the video shown in the link. Most R744 systems which reject their heat to ambient air operate above the critical point for some or all of the time. In these systems the condenser is referred to as a "gas cooler" because the refrigerant does not condense in this component when transcritical, the R744 turns to liquid only when the pressure is reduced:

- R744 systems are subcritical when the condensing temperature is below 31°C.
- R744 systems are transcritical when the "gas cooling temperature" is above 31°C.

HFC, HC and R717 systems are always subcritical because the condensing temperature never exceeds the critical temperature (e.g. 101°C in the case of R134a).

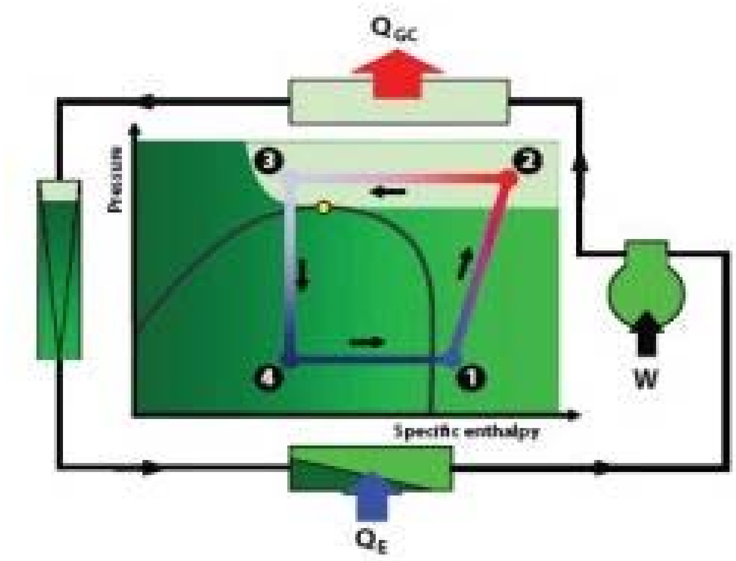


Figure 2, PH chart showing a transcritical system, from www.danfoss.com

Simple Transcritical System

A simple transcritical system is shown in figure 4.

In such a system the gas cooler pressure depends on the amount of refrigerant in the system, so the capacity and efficiency vary significantly.

More detail about small transcritical systems is provided in the Danfoss document shown in the link.

Danfoss "Transcritical refrigeration Systems with CO_2, how to design a small capacity system "

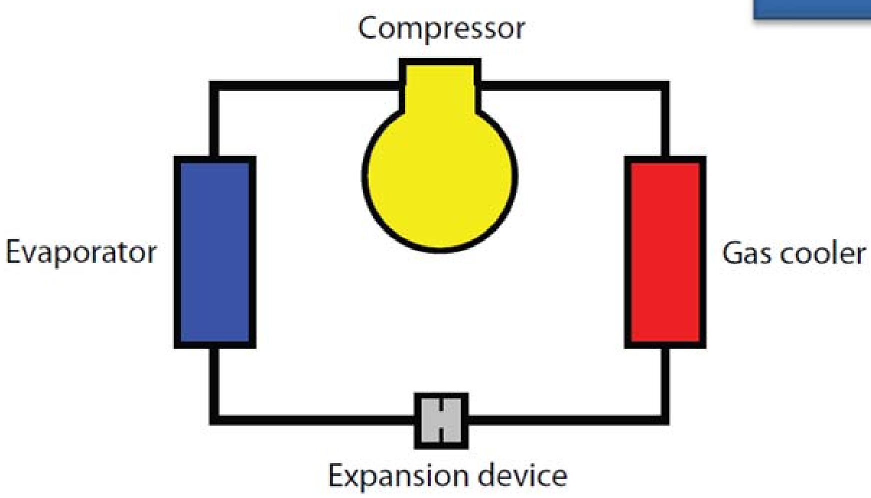


Figure 3, simple transcritical system

P-h Chart – Simple System

The pressure enthalpy chart below shows an example simple R744 system operating subcritically at a low ambient temperature (the pink cycle) and transcritically at a higher ambient temperature (the green cycle). The chart shows that the cooling capacity at the evaporator is significantly less for transcritical operation.

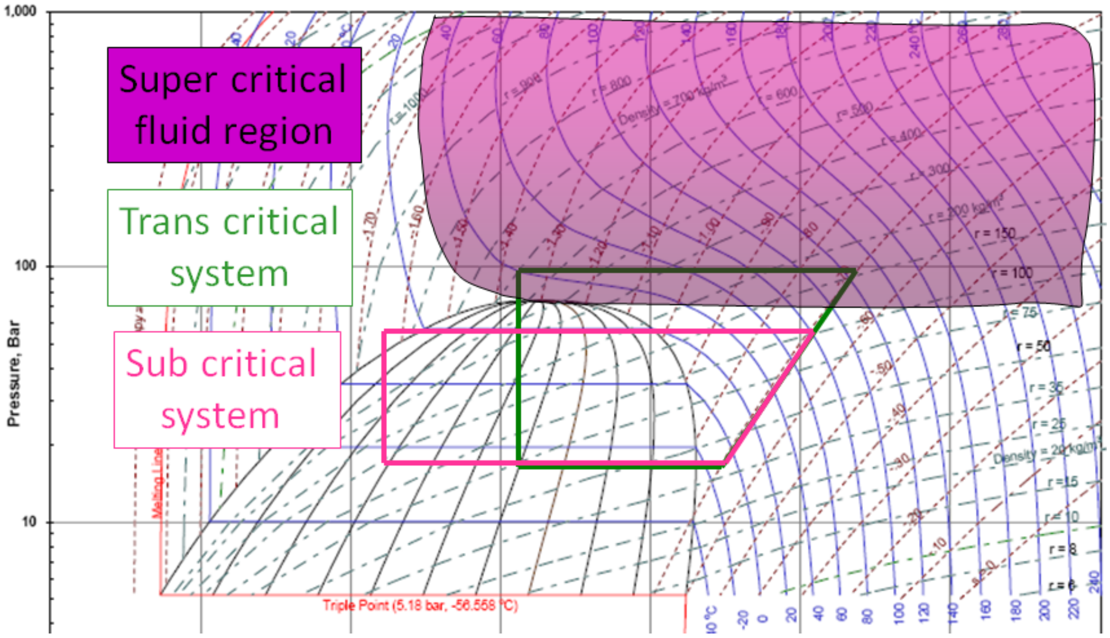


Figure 4, Pressure enthalpy chart showing sub and transcritical operation

When it is transcritical the refrigerant does not condense in the gas cooler, its temperature drops and heat is rejected. The refrigerant does not condense until its pressure is dropped below the critical pressure (72.8 bar g).

When transcritical, the gas cooler pressure is a function of the quantity of refrigerant in the gas cooler (unless it is controlled). The supercritical fluid temperature reduces as it passes through the gas cooler and its temperature at the exit of the gas cooler is a function of the gas cooler size and the air on temperature.

When operating above the critical point, an increase in the high side pressure increases the cooling capacity, as can be seen from the pressure enthalpy chart in figure 3. The best operating pressure is condition 3 because there is not a significant energy penalty for the increase in capacity compared to condition 1.

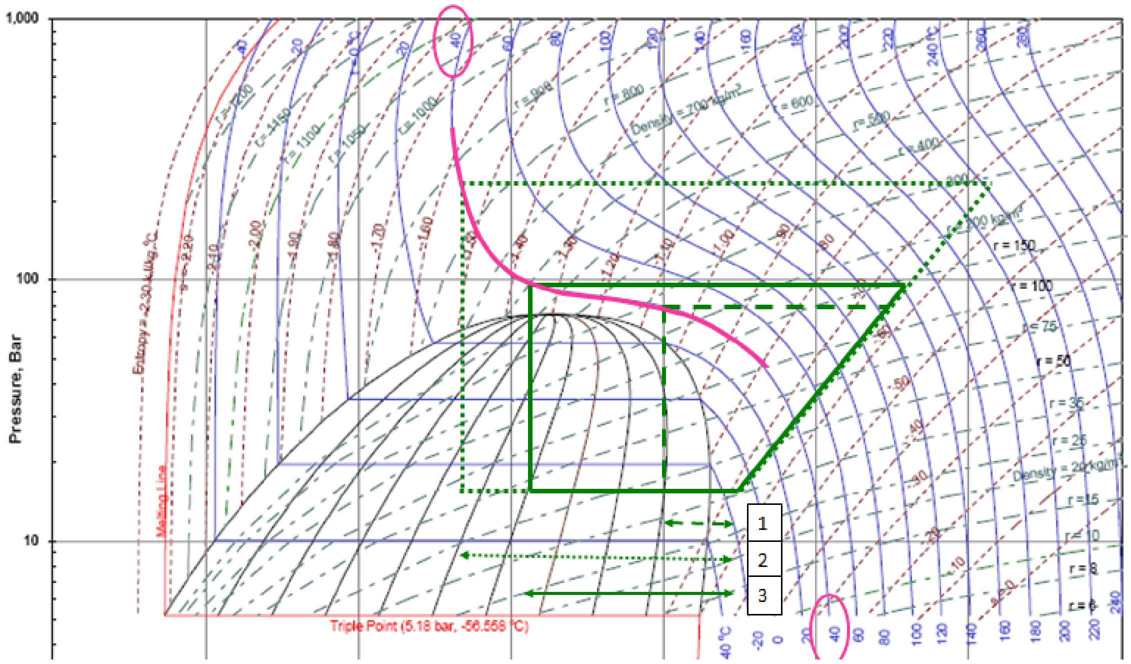


Figure 5, Pressure enthalpy chart showing three gas cooler pressure conditions

Large Transcritical System

In a typical large transcritical system the head pressure is controlled. The diagram below shows a simplified circuit of such as system.

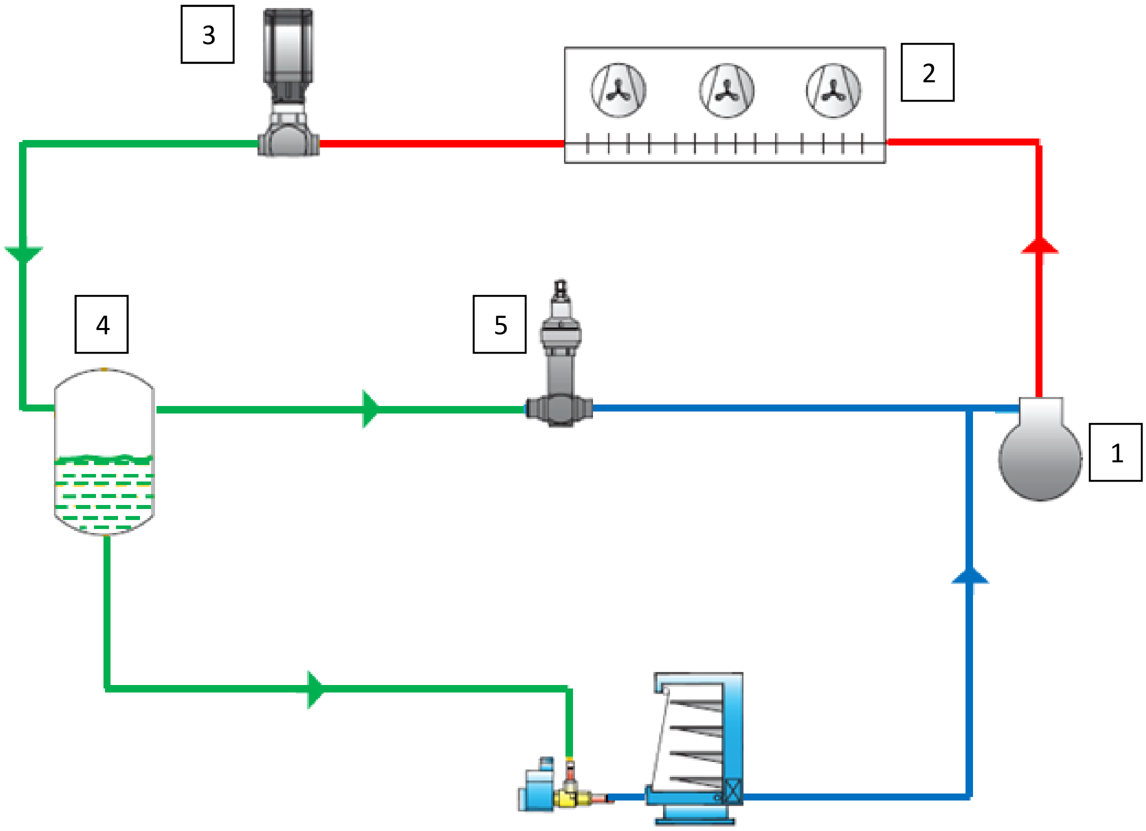


Figure 6, Typical transcritical system

1. The compressor is a transcritical compressor, designed for the higher pressures and high cooling capacity of the refrigerant;
2. The gas cooler is similar in design to a conventional condenser, although pipe diameters might be smaller and it will need to withstand a higher pressure;
3. The gas cooler regulation valve is controlled by the pressure in the gas cooler and holds the pressure at the optimum setting (usually 90 bar g when the system is transcritical, typically when the ambient temperature is above 21^{O}C to 25^{O}C);
4. The liquid receiver and associated liquid pipe work (shown in green) is at the intermediate pressure;
5. The receiver pressure regulating valve is controlled by the pressure in the receiver and controls the intermediate pressure to a level specified by the designer (usually in the range 35 to 65 bar g).

For more detail about transcritical systems see the Danfoss and Emerson documents shown in the links.

Danfoss "Food Retail CO_2 Refrigeration"

Emerson Guide, "Introduction to R744 Systems "

Emerson Guide "R744 System Design"

2.2 Subcritical cascade systems

R744 is also used in cascade systems, as shown below.

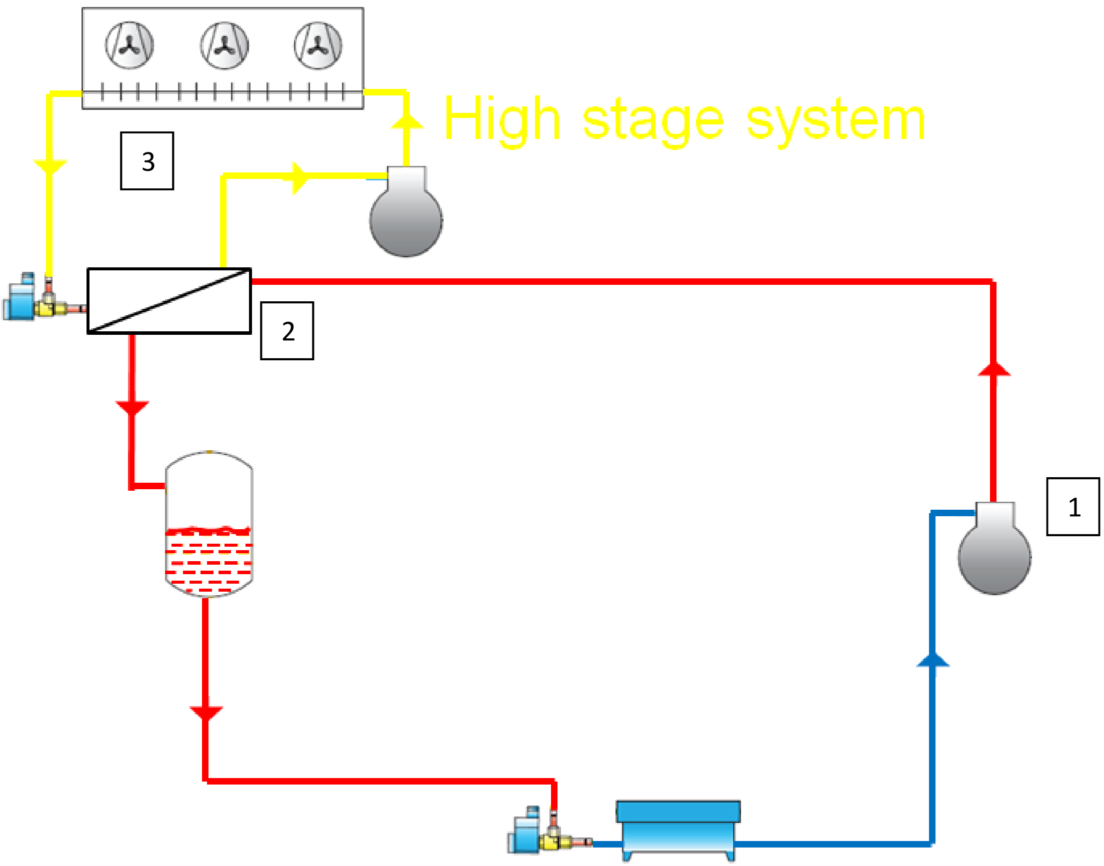


Figure 7, Simple cascade system

1. The compressor for R744 is typically similar to that for R410A (it will usually operate at similar pressures);
2. R744 condenses in the cascade heat exchanger, rejecting its heat to the evaporating high stage refrigerant;
3. The high stage system is usually a simple chiller type system, operating using HFC, HC or R717. The high stage can also use R744, in which case it will be transcritical for some of the time. The operation of the high stage is generally controlled by the pressure in the R744 liquid receiver.

Further information about cascade systems is provided in the documents shown in the links.

Danfoss “Cascade CO_2 System”

Emerson Guide “Introduction to R744 Systems “

Emerson Guide “R744 System Design”

2.3 Secondary Systems

R744 is also used as a secondary refrigerant, as shown below.

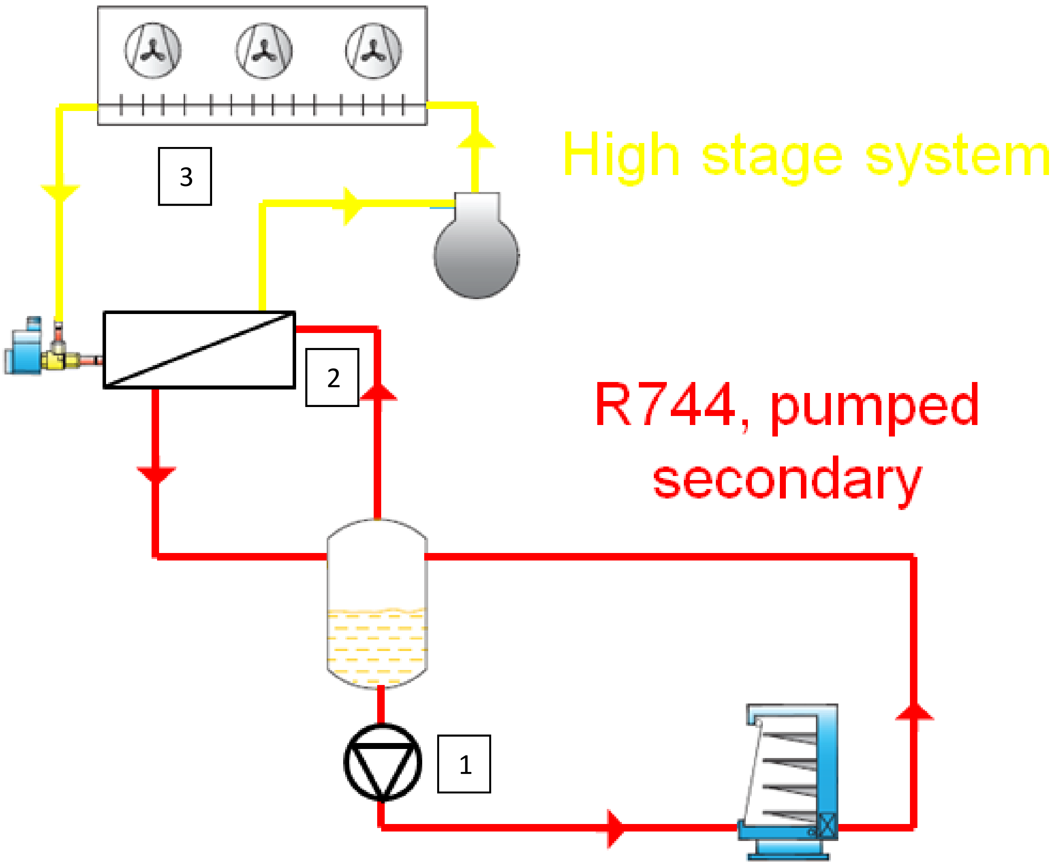


Figure 8, Simple pumped secondary system

1. The R744 liquid pump is typically a centrifugal type, cooled by the liquid refrigerant. It is important that a constant supply of liquid enters the pump to prevent cavitation and a resultant deterioration in its reliability and performance;
2. R744 condenses in the heat exchanger, rejecting its heat to the evaporating high stage refrigerant;
3. The high stage system is usually a simple chiller type system, operating using HFC, HC or R717. And its operation is generally controlled by the pressure in the R744 liquid receiver.

R744 has advantages over other secondary fluids:

- Being volatile, it partially evaporates in the heat exchanger (evaporator), thus absorbing latent heat. This reduces the temperature difference across the heat exchanger;
- The high density of R744 means that less pump power is required.

However, the R744 pressure will be significantly higher than for other secondary fluids. For example at a temperature of -3^{O}C the pressure is approximately 30 bar g.

2.4 Pressures

Typical pressures in R744 systems are shown in table 2 below.

Table 2, Typical R744 pressures

	Typical pressure Bar g (MPa)	Typical PS[4] Bar g (MPa)
High side of transcritical system, operating above the critical point	90 (9)	120 (12)
Intermediate pressure in a transcritical system	35 to 65 (3.5 to 6.5)	45 to 75 (4.5 to 7.5)
High side pressure in the low stage of a cascade system	30 (3)	40 (4)
Low temperature (LT) evaporator	15 (1.5)	30 (3.0)
High temperature (HT) evaporator	30 (3)	52 (5.2)
Plant at stand still in an ambient of 20^{O}C	55 (5.5)	

The high pressure of R744 can lead to an increase in leakage with a consequent increase in energy consumption and indirect environmental impact. To minimise leak potential the pipe work and components must be suitable for the PS of that part of the system. In many cases this entails using different components compared to those used for HFC systems, and using pipe with a thicker wall, or using steel pipe work.

Joints should be brazed or welded and mechanical joints should be avoided wherever possible.

Where Schrader valves are used they must be suitable for the pressure and temperature range and carbon dioxide and the compressor lubricant.

Components such as cascade heat exchangers could potentially operate with a high temperature difference between the inlet and outlet. This will cause thermal shock which leads to leakage so this should be taken into account when selecting the component. The temperature difference can be reduced by de-superheating the gas before it reaches the condenser.

Loss of refrigerant also occurs because of issues associated with pressure relief valves (PRVs). There should be sufficient difference between PS (and therefore the PRV vent pressure) and the typical operating pressure for that part of the system so that venting of R744 through PRVs is minimised. In many systems this is not the case, and even a small increase in the operating pressure causes the PRV to vent. This is made worse because R744 pressure can increase very rapidly, reaching the PRV vent pressure before the high pressure switch has operated and shut off the system (as with other systems the setting of the high pressure switch should not be more than 90% of PS).

If multiple vents occur the PRV spring weakens and the vent pressure reduces, increasing the incidence of venting. In addition to this problem, leakage occurs if the PRV does not then re seat correctly, even after a single vent.

[4] PS is defined in EN378-1:2016, Refrigerating systems and heat pumps – Safety and environmental requirements, Basic requirements, definitions, classification and selection criteria, see Module 6 – Legal Obligations, for more information.

2.5 Cooling Capacity

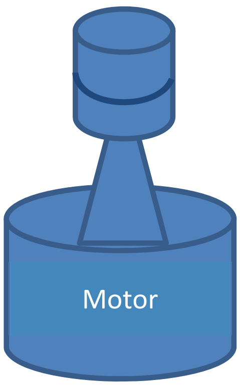
See REAL Alternatives Guide 1 “Introduction”

Emerson Guide “R744 System Design”

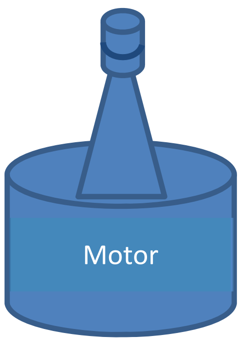
As shown in Module 1 the cooling capacity of R744 is several times that of more commonly used refrigerants. This has an impact on:

- Compressor design – less displacement is required relative to the motor size, so compressors specifically for R744 are used;
- Pipe sizing – the pipe diameter is less;
- Heat exchangers – smaller evaporators and condensers can be used to achieve the same temperature difference (TD). If the condenser and evaporator sizes are not reduced the TD will be lower and the system capacity and efficiency will be improved.

Do not confuse cooling capacity with efficiency. The cooling capacity is the amount of heat that will be absorbed by the refrigerant in the evaporator. The cooling capacity is high compared to other refrigerants, the efficiency is similar.



R404A compressor



R744 compressors

Both compressors provide same cooling capacity and use approximately the same power.

2.6 Two stage compression (booster)

Excessively high discharge temperature will occur on low temperature (frozen food) systems that reject their heat to ambient air. To avoid this, two stages of compression are used. The interstage between the low and high stage compressors is generally cooled by the suction gas from the high temperature load and the gas from the receiver pressure regulating valve. The diagram in below is a typical transcritical booster system commonly used in retail applications.

The gas from the low temperature evaporator enters the suction of the low stage compressor (C1). This compressor discharges into the suction of the high stage compressor (C2). The gas from the high temperature load, and the gas from the receiver pressure regulating valve also enters the suction of the high stage compressor (C2).

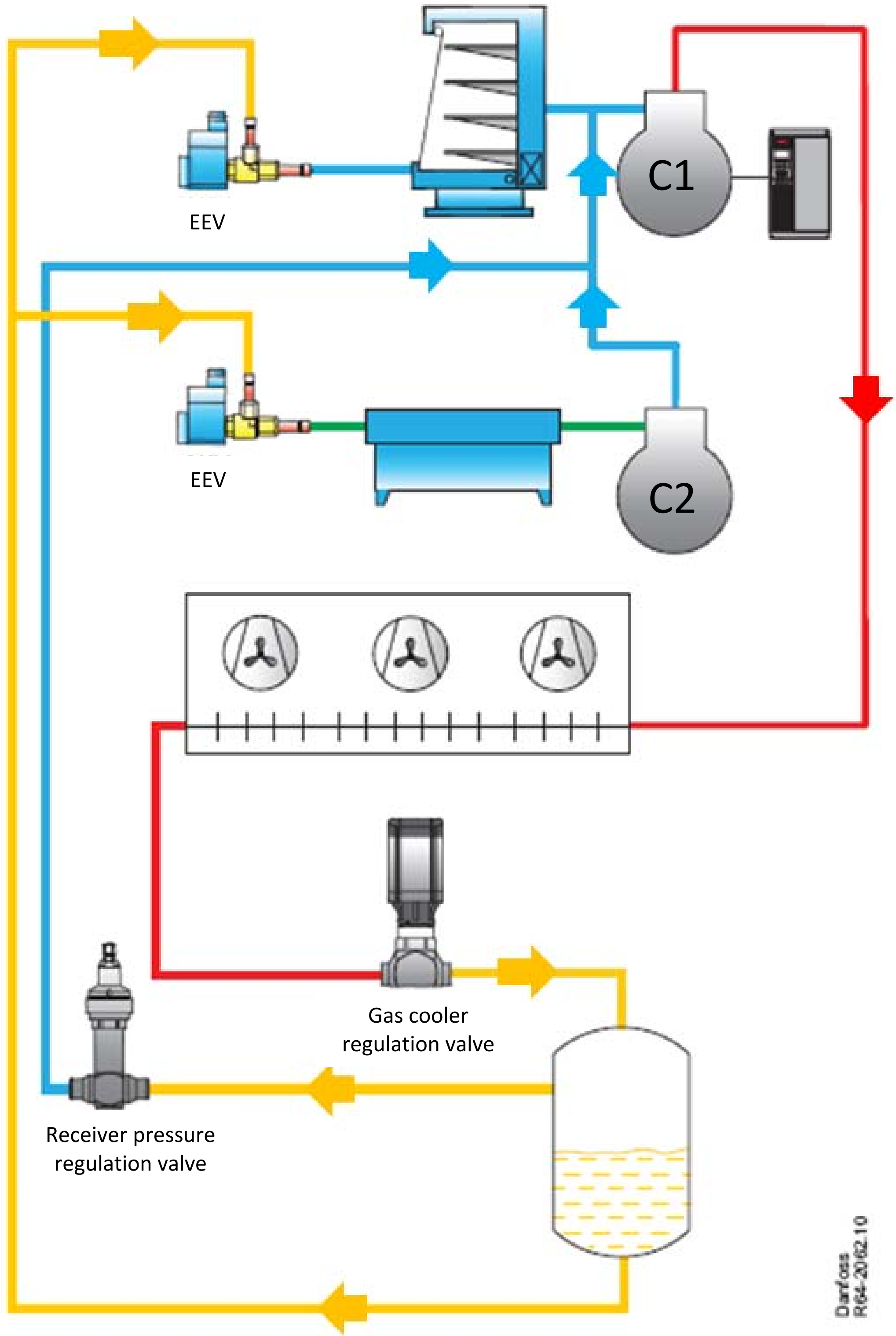
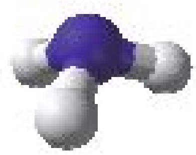


Figure 9, Transcritical booster system

3 R717 (Ammonia)

NH_3
1 Nitrogen molecule
3 Hydrogen molecules



R717 design differences are mainly due to its toxicity, mild flammability, high discharge temperature, materials incompatibility and immiscibility with oil:

	Type	Key facts	GWP[5]	Sat temp[6]	Typical applications
R717	Ammonia, NH_3	Toxic and mildly flammable	0	$-33^{O}C$	Industrial

- Charge size is limited because of toxicity, see Guide 1 for more information (R717 is classified as a group B2L refrigerant);

See REAL Alternatives Guide 1 "Introduction"

- Some electrical components are designed for use in an explosive atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to lower flammability refrigerants such as R717;

- Typical maximum system pressure (PS) for the high side is 22 bar g, and typical PS for the low side is 11.4 bar g, so pressures are not excessively high;

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Bitzer PT App

- Two stage compression is used for low temperature applications such as the processing and storage of frozen food to avoid excessive discharge temperatures;

- R717 corrodes copper, so pipe work and fittings are usually steel and open drive compressors specifically designed for use with R717 are used

IoR Safety Code of Practice for Refrigerating Systems utilizing R717

- R717 is total immiscible with compressor lubricant so lubricant which enters the low side of the refrigeration system stays there as a layer of oil below the R717. Lubricant recovery devices should be installed, preferably an integral oil recovery system that collects oil and returns it to the oil reservoir.

Figure 10, Examples of R717 systems

[5] GWP is from F Gas Regulation EU 517:2014
[6] Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

- R717 is toxic and has a very low practical limit (0.00035 kg/m^3). Fixed leak detection should be used if a leak can result in a concentration exceeding this. The low level should be set at 500 ppm and should activate mechanical ventilation and a supervised audible alarm. The high level should be set at 30,000 ppm and should stop the plant and isolate electrics.

Low charge R717 systems are being developed for use in commercial systems which would traditionally have used HFCs.

See Ammonia system video in REAL Alternatives e-library

4 R32

R32 is very similar to R410A but it is classified as lower flammability (A2L), see Guide 1, Classification for further information.

	Boiling point °C	Safety group	Lower flamma-bility level kg/m$_3$	Practical limit kg/m$_3$	Ignition temp °C	GWP
R32	**-51**	**A2L**	**0.307**	**0.061**	**648**	**675**

Most system components are the same as those used for R410A. The difference is driven by the low flammability:

- Charge size is limited, see Module 1 for more information (R32 is classified as a group A2L refrigerant);

See REAL Alternatives Guide 1

- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to lower flammability refrigerants such as R32.

R32 operating and standstill pressures are almost identical to those for R410A, so components used must be suitable for those pressures; components used for other HFCs may not be suitable. Typical maximum system pressure (PS) for the high side is 34.2 bar g, and typical PS for the low side is 19.3 bar g

See REAL Alternatives Guide 1, figure 2

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The cooling capacity of R32 is similar to R410A, so components sized for R410A should be used.

	Type	Key facts	GWP[7]	Sat temp[8]	Typical applications
R32	Hydro fluoro carbon, HFC	low flammable	675	-52°C	Split air conditioning

Figure 11, Example of equipment being manufactured for use with R32

7 GWP is from F Gas Regulation EU 517:2014
8 Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

5 R1234ze

R1234ze design differences are due to its lower flammability and its low pressure and capacity:

- Charge size is limited, see Module 1 for more information (R1234ze is classified as a group A2L refrigerant);

See REAL Alternatives Guide 1

- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to mildly flammable refrigerants such as R1234ze;

See REAL Alternatives Guide 1, figure 1

- Typical maximum system pressure (PS) for the high side is 10.3 bar g, and typical PS for the low side is 5.1 bar g, so components and pipe work can be specified for a significantly lower pressure than for other HFCs;

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- The cooling capacity is approximately 75% that of R134a and the COP is very similar. So the compressor would have a similar sized motor, but a displacement 30% greater than for R134a to provide the same capacity. Currently few compressors are available for use on R1234ze.

UNEP Case Study including Waitrose trial

	Type	Key facts	GWP[9]	Sat temp[10]	Typical applications
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	Mildly flammable	7	-19°C	Chillers, split air conditioning, integrals

Figure 12, Examples of equipment designed to use R1234ze

[9] GWP is from F Gas Regulation EU 517:2014
[10] Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

6 R600a (Iso butane)

The design differences associated with R600a are due to its higher flammability and its very low pressure and capacity:

- Charge size is limited, see Guide 1 for more information (R600a is classified as a group A3 refrigerant);

See REAL Alternatives Guide 1

- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to flammable refrigerants such as 600a;

See REAL Alternatives Guide 1, figure 1

- Typical maximum system pressure (PS) for the high side is 6.8 bar g, and typical PS for the low side is 3.3 bar g, so components and pipe work can be specified for a significantly lower pressure than for other HFCs;

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- The cooling capacity is approximately 50% that of R134a and the COP is very similar. So the compressor has greater displacement to provide the same cooling capacity, but a similar sized motor. Compressors for R600a are widely available for domestic and small commercial sized systems, but not for larger systems.

	Type	Key facts	GWP[11]	Sat temp[12]	Typical applications
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	Flammable	3	-12°C	Domestic and small commercial systems

[11] GWP is from F Gas Regulation EU 517:2014

[12] Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

7 R290 and R1270 (Propane and Propene)

R290 and R1270 have a similar pressure temperature relationship and cooling capacity to R404A. The main design difference is due to the higher flammability of these two refrigerants:

- Charge size is limited, see Guide 1 for more information (R290 and R1270 are classified as group A3 refrigerants);

See REAL Alternatives Guide 1

- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to flammable refrigerants such as R290 and R1270.

See REAL Alternatives Guide 1, figure 1

Typical maximum system pressures (PS) are as follows:

- For the high side, 18.1 bar g for R290 and 21.8 for R1270
- For the low side, 10.4 bar g for R290 and 12.7 bar g for R1270

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Bitzer PT App

Typically R404A components are used for systems running with R290 and R1270, apart from electrical devices – see next section.

	Type	Key facts	GWP[13]	Sat temp[14]	Typical applications
R290	Propane, C_3H_8, hydrocarbon (HC)	Flammable	3	-42°C	Chillers, integrals
R1270	Propene (propylene), C_3H_6, hydrocarbon (HC)	Flammable	3	-48°C	Chillers, integrals

Figure 13, Examples of supermarket installations using hydrocarbon based systems in the UK

[13] GWP is from F Gas Regulation EU 517:2014
[14] Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

Case Study - Small simple system design for hydrocarbon supermarket systems in the UK

In the UK small simple hydrocarbon refrigerant systems have been used instead of large central plant systems in over 100 supermarkets. The “water loop” systems typically comprise integral cabinets with water cooled condensers and monoblock cold room systems also with water cooled condensers. Glycol chillers located outside cool the glycol required at the cabinets and monoblocks to remove the heat rejected at the individual water cooled condensers (see figure below).

Air cooled split air conditioning units are also used. The system is designed to enable to the use of R1270. They are all low charge systems and, except for the split AC systems, are factory tested and charged.

Leakage rates are typically 1% of the total charge per year, compared to up to 100% for central plant systems. So increases in energy consumption due to leakage do not occur.

This type of simple system can be more resilient – for example being less prone to having set points changed during service which significantly effects energy consumption. The application of HC refrigerant encouraged the application of smaller systems with a limited charge, resulting in a major reduction in leakage.

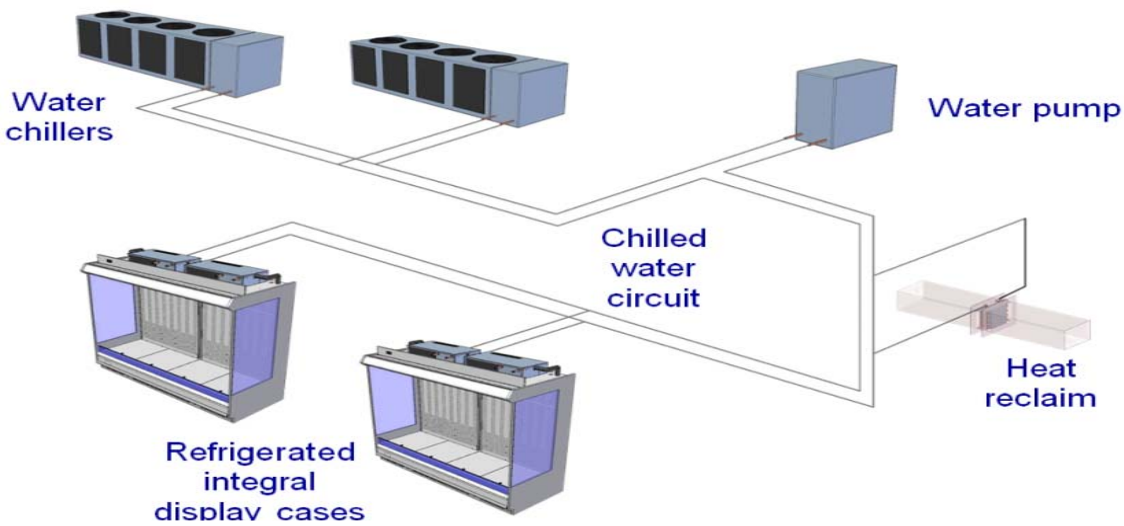
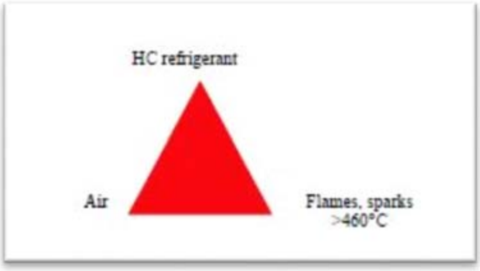


Figure 14, Schematic of water cooled cabinets and chiller

8 Appendix 1, Design Process for Flammable Refrigerant Systems



In the event of a leak there is the potential for a flammable atmosphere around the system. Combustion will occur if there is a source of ignition in this flammable area. The principles of ATEX[15] should be followed:

- To identify the extent of a flammable zone in the event of a leak;
- For electrical devices within a potentially flammable zone in the event of a leak.

This appendix provides more detail about the design process for systems which use a flammable refrigerant. Sources of ignition within a potentially flammable zone will be a hazard in the event of a leak. An essential part of the design process is to ensure there are no sources of ignition inside potentially flammable zones. This can be achieved by ensuring leaks do not result in a flammable zone or by removing sources of ignition from the flammable zone.

Refer to the following standards for more detailed information:

- EN60079-10-1 Explosive atmospheres – Classification of areas – explosive gas atmospheres
- EN60335-2-89 Household & similar electrical appliances – Safety, Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor
- EN 389-2, Annex I Leak simulation testing for flammable refrigerants.

[15] ATEX 95 (94/9/EC - Equipment) – ESP (The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmosphere Regulations)

The design process

The design process for ensuring flammable refrigerant systems are safe is summarised below for any system which contains sources of ignition, regardless of the charge size.

Step 1.1	Carry out flammable zone testing (area classification) to determine the extent of the potentially flammable zone in the event of a leak.

Step 1.2	Identify sources of ignition within the potentially flammable zone.

Step 1.3	Option 1 or	Move the source of ignition outside the potentially flammable zone. EN60079-14 (Explosive atmospheres – Electrical installations design, selection and erection) requires that, wherever possible, electrical equipment should be located in non-hazardous areas.
	Option 2 or	Replace the source of ignition with a suitable device.
	Option 3 or	Increase the air flow and / or maintain a permanent air flow to reduce the potentially flammable zone.
	Option 4	Locate the source of ignition in a suitable enclosure (this is usually cost prohibitive for small systems and difficult to achieve).

GTZ Hydrocarbon Guide

Simulated leak testing

Simulated leak testing is carried out to determine the extent of a potentially flammable zone in the event of a leak. This testing must only be carried out by a competent person.

The test work should comply with EN60079-10-1 Explosive atmospheres – Classification of areas – explosive gas atmospheres. The procedure below summarises the process, reference should be made to the standard for full information. EN 378 and EN 60335 both include guidance on leak simulation testing.

Step 2.1	Identify potential leak location(s).
Step 2.2	Use the release rate specified in either EN 378 or EN 60335, whichever is applicable to the system.
Step 2.3	Decide whether there will be air flow. If fans run permanently then they can run during the test. If fans switch off when the refrigeration system is off (on temperature for example) they should not be run during the test, i.e. testing is based on worst case scenario.
Step 2.4	Carry out the leak simulation test, measuring the HC concentration where there are sources of ignition and around the system to find the extent of the potentially flammable zone (area classification).
Step 2.5	Record the test work in a technical file.

The leak simulation testing should be carried out in an environment similar to that where the system will be located. Consideration should be given to room size and adjacent equipment with regards to ignition sources during the testing.

Potential leak points

Potential leak points typically include joints, a bend of more than 90^{O}, pipe and components which are exposed to damage and any other weak point in the system.

Care should be taken to ensure that the installation of the leak source (e.g. the tube connected to the HC cylinder through which the leak is introduced into the area), the positioning of the refrigeration system and the refrigerant sampling equipment do not notably influence the test results. The equipment for measuring the refrigerant concentration should have sufficiently rapid response to changes in concentration, typically 2 to 3 seconds.

Any location where the concentration is above 50% of the LFL for any part of the test is deemed to be potentially flammable [16]. The factor of 0.5 is used because a flammable refrigerant leak is defined as a secondary release.

The simulated leak testing also identifies the area around a system which must be free from sources of ignition. If a potentially flammable zone can occur beyond the footprint of the system it is important that other equipment located within this area is suitable for use in a potentially flammable environment.

Electrical devices

The simulated leak testing will identify whether sources of ignition are within the potentially flammable zone. Electrical devices within the potentially flammable zone must not:

- Produce an arc or spark (unless that arc or spark is prevented from causing ignition in accordance with IEC EN60079-15 Explosive atmospheres – Equipment protection by type of protection “n”, clauses 16 to 20);

- Develop a maximum surface temperature in excess of the maximum appropriate to the temperature class of the apparatus (unless the temperature is prevented from causing ignition in accordance with IEC EN60079-15, clauses 16 to 20).

Sources of ignition

Sources of ignition associated with refrigeration systems typically include:

- On / off switches or contactors;
- Relays (e.g. on controls and single phase compressors);
- Pressure switches;
- Thermal overloads;
- Fan motors;
- Thermostats;
- Condensate pumps;
- Miniature circuit breakers (MCBs);
- Defrost heaters if the surface temperature can exceed a temperature $100^{O}C$ less than the ignition temperature for the refrigerant, e.g. $360^{O}C$ for HCs (maximum

[16] EN60079-10-1:2015 Explosive atmospheres – Classification of areas – explosive gas atmospheres,

heater surface temperature should be demonstrated by testing in the operating environment maximum ambient, assuming defrost termination has failed).
- Hot surfaces above 360 degrees C.

This is not an exhaustive list, but includes the most common electrical devices which need to be considered.

The following items are generally not sources of ignition:

- Lighting (the switch, starter and terminations must be considered even for low voltage lighting),
- Capacitors (it is recommended that bleed resistors are fitted to minimise the hazard caused by discharge during service);
- Solenoid valve coils;
- Wiring connections (accidental disconnection, for example during service, can produce a spark. To minimise this risk with push crimp terminals, tagged terminations that cannot be accidentally disconnected are recommended);
- Fuses (deemed non sparking devices if they are non-rewirable, non-indicating cartridge types or indicating cartridge types, according to IEC60269-3 (Low-voltage fuses – Part 3: Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household and similar applications) – Examples of standardized systems of fuses A to F), operating within their rating [17]).

Dealing with sources of ignition

There are various options for dealing with sources of ignition within a potentially flammable zone as shown in Step 1.3.

Where option 2 (“suitable devices”) is selected the device should comply with IEC EN60079-15. This standard defines type “n” protection as that which, in normal operation and in certain specified abnormal conditions, is not capable of igniting a surrounding explosive gas atmosphere. Switching electrical devices which are located in a potentially flammable atmosphere should therefore be type “n” in accordance with IEC EN60079-15 Explosive atmospheres – Equipment protection by type of protection “n” .

Devices which are type “n” must be tested by an approved notified body and correctly documented.

Electrical connections within a potentially flammable zone are hazardous if disconnected while energised. Plugs and sockets, if they are allocated and connected to only one part of the equipment, shall be secured mechanically to prevent unintentional separation or have a minimum separation force of 15 Nm. The equipment shall be marked as follows [18]:

WARNING – do not separate when energised

[17] EN60079-15:2010 Explosive atmospheres – Equipment protection by type of protection “n”, 9.1
[18] EN60079-15:2010 Explosive atmospheres – Equipment protection by type of protection “n”, 10.1 and 24.3.1

Fuse enclosures shall be interlocked so that the fuses can only be removed or replaced with the supply disconnected or the enclosure shall carry the following warning label [19]:

WARNING – do not remove or replace fuse when energised

Non sheathed single cores shall not be used for live conductors, unless they are installed inside switch boards, enclosures or conduit systems [20].

Fans. Ventilation can negate the need for changes to electrical devices or enclosures either:

- Condenser fans can be run constantly (i.e. not switched off when the system is down to temperature). This will increase the power consumption of the system;

  or

- A supplementary fan can be switched on when the condenser fan is off. Sufficient air flow is usually provided by a smaller fan than that used for condenser cooling, so the power requirement associated with this option is usually less than constantly running a condenser fan. The airflow of the supplementary fan must be tested with leak simulation to ensure the airflow is sufficient to disperse the HC refrigerant.

Careful consideration should be given to fouled condensers or failed fan motors which would significantly reduce available airflow, especially if they are the primary protection method for sources of ignition.

[19] EN60079-15:2010 Explosive atmospheres – Equipment protection by type of protection “n” , 9.4
[20] EN60079-14:2014 Explosive atmospheres – Electrical installations design, selection and erection

9 Self Test Module 2

Try the sample multiple choice assessments below to check your learning

Question 1 -

What is the pressure of R744 in a system which is at standstill in an ambient temperature of 20^{O}C?

i. 4.9 bar g
ii. 7.4 bar g
iii. 55 bar g
iv. 72.8 bar g

Question 2 –

What is the approximate displacement required for a compressor operating on R600a compared to one operating on R134a to give the same cooling capacity?

I. Seven times
II. Two times
III. The same
IV. Half

Question 3 –

Below which condensing temperature is a R744 system subcritical?

I. 55° C
II. 43° C
III. 31° C
IV. 72° C

Question 4 –

When using R1270 above which temperature do hot surfaces become sources of ignition?

I. 60° C
II. 150° C
III. 260° C
IV. 360° C

The answers are on the bottom of the next page.

What next?

The information in this guide is an introduction to the most common alternative refrigerants. There is much more information in the documents highlighted in the links. Go to the on line reference e-library at www.realalternatives4life.eu/e-library to explore any additional information you may find useful.

If you would like to gain a REAL Alternatives 4 LIFE Certificate you need to take a full end of course assessment under supervision at a recognised REAL Alternatives 4 LIFE training centre. Information about assessments is available at http://www.realalternatives4life.eu

You can now continue your self-study with one of the following Modules:

1. Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2. Safety and risk management
3. System design using alternative refrigerants
4. Containment and leak detection of alternative refrigerants
5. Maintenance and repair of alternative refrigerant systems
6. Retrofitting existing systems with low GWP refrigerants
7. Checklist of legal obligations when working with alternative refrigerants
8. Measuring the financial and environmental impact of leakage
9. Tools and guidance for conducting site surveys

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Correct answers: Q1 = iii, Q2 = ii. Q3 = iii, Q4 = iv.

With contribution of the LIFE programme of the European Union

Containment & Leak Detection

of Alternative Refrigerants

Contents

With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives Europe Blended Learning Programme

This learning booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives4life.eu

REAL Alternatives has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU Lifelong Learning Programme, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Croatian, Czech, Dutch, English, French, German, Italian, Polish, Romanian, Spanish and Turkish.

Real Alternatives Europe Programme Modules	
1	Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2	Safety and Risk Management
3	System design using alternative refrigerants
4	Containment and leak detection of alternative refrigerants
5	Maintenance and repair of alternative refrigerant systems
6	Retrofitting with low GWP refrigerants
7	Checklist of legal obligations when working with alternative refrigerants
8	Measuring the financial and environmental impact of leakage
9	Tools and guidance for conducting site surveys

You can study each module individually or complete the whole course and assessment.

www.realalternatives4life.eu

More information is available in the on line reference e-library. Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives4life.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

Assessment options are available if you want to gain a recognised CPD Certificate. At the end of each module are some simple self-test questions and exercises to help you evaluate your own learning. Certification and Assessment will be available from licensed REAL Alternatives training providers when you attend a course of study. The list of recognised training providers will be available on the website.

Register your interest in alternative refrigerants at www.realalternatives4life.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

Background to the programme and how it was developed. This learning programme was developed as part of EU co-funded projects led by a consortium of partners from across Europe. It is designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders from across Europe drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed.

The consortium partners:

- Association of European Refrigeration Air Conditioning & Heat Pump Contractors, Belgium
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- International Institute of Refrigeration
- University College Leuven-Limburg, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

With thanks to our stakeholders:

- CNI National Confederation of Installers, Spain
- CHKT Czech Association for cooling and air conditioning technology
- HURKT, Croatian Refrigeration Airconditioning and Heat Pumps Association
- RGAR Association General of Refrigeration, Romania
- SOSIAD Association of Refrigeration Industry and Businessmen, Turkey
- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 4 –

Containment and Leak Detection

1 Introduction

This Module provides and introduction to the topic of leakage reduction. It does not replace practical training and experience. At the end of the Module you will find links to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics. In this Module we will look at containment and leak detection of charged, operating systems. Reducing leakage is important for all refrigerants for the following reasons:

Figure 1, Electronic leak detector for HC refrigerant

- For safety - all refrigerants are asphyxiants, many of the alternatives are flammable and R717 is toxic;
- To maintain performance – a leaking system has less capacity and consumes more power than a fully charged system;
- To minimise the cost associated with refrigerant replacement, service and the additional energy consumption;
- To improve reliability and minimize consequential losses;
- To minimise the direct effect on climate change – some of the alternatives have a significant global warming potential;
- To minimise indirect CO_2 emissions associated with additional power consumption;
- It is a legal requirement for fluorinated gases (F Gases) – this includes R32.

Effective leak detection is important, but it is even more important to ensure that refrigerant containment is a high priority.

There is a lot of detail about R717 leak detection because it is significantly different from HFC detection.

2 Effective Leak testing

This section covers the different methods of leak testing and shows how they should be carried out.

The table below summarises the methods which can be used to detect each alternative refrigerant.

Table 1, Leak detection Methods

<table>
<tr><th>Refrigerant</th><th>Leak detection spray [1]</th><th>Electronic leak detector [1]</th><th>Fluorescent additive</th><th>Ultrasonic</th></tr>
<tr><td>R744</td><td rowspan="5">Good</td><td>Good, ensure the detector is sensitive to R744</td><td>OK</td><td rowspan="5">Good</td></tr>
<tr><td>R717</td><td>Good, ensure the detector is sensitive to R717</td><td>Not suitable</td></tr>
<tr><td>R32</td><td rowspan="3">Good, ensure the detector is sensitive to the refrigerant type and is safe with a flammable refrigerant</td><td rowspan="3">Good</td></tr>
<tr><td>R1234ze
R1234yf</td></tr>
<tr><td>HCs (R600a, R290, R1270)</td></tr>
</table>

1. Ensure the system pressure is positive (i.e. above atmospheric pressure) when using either of these methods. This is especially important with R717, R1234ze, R1234yf and R600a which operate with lower pressures than other refrigerants.

For many of the methods the pressure needs to be as high as possible:

- When checking the high pressure side the system should be running, with the condensing pressure as high as possible;
- When checking the low pressure side the system should be off (but not pumped down). For example the operating pressure of an R290 system evaporating at -30^{o}C is 0.6 bar g, but at standstill in an ambient of 20^{o}C the pressure will be 7.4 bar g. Don't switch off R744 systems if this would result in PRVs venting;
- For a system which has saturated gas defrost, it should be on defrost when checking the low side;
- For reverse cycle heat pumps both sides of the system should be checked at the highest possible condensing pressure.

Figure 2, Leak testing

With all methods it is important that the test is carried out methodically and that all parts of the system are tested, including spurs such as pressure switch connections and pressure relief valve vent lines. All leaks should be found – the first leak found is probably not the only leak.

Leaks should be repaired as soon as possible and the leakage point re tested.

Videos showing how bubble solution, hand held leak detectors and additive can be used effectively to identify leaks; and demonstration of a combined UV and ultrasonic device used for identifying leak points are available in the REAL Alternatives e-library.

REAL Alternatives e-library

Leak detection spray

It is recommended that a proprietary leak detection spray is used instead of a "home-made" soap or detergent solution. Home-made solutions can be too thin, so bubbles won't form, or too thick, so they actually mask a leak.

A proprietary leak detection spray is usually a non-corrosive substance which is of the right consistency to form bubbles easily. It can also contain an anti-freeze so it can be used on pipe work below $0^{O}C$. The spray method is a good method for pinpointing leaks, but is time consuming on a large system with many joints. It cannot be used on insulated pipe work, or on sections of the system which are running at a pressure lower than atmospheric pressure. It can take many seconds for a bubble to form if the leak rate and / or the pressure is low.

It is a good method for pinpointing the exact location of a leak which has been found by an electronic leak detector.

Figure 3, Example of bubbling caused by leakage

Videos available in the REAL Alternatives e-library demonstrate examples of leaking refrigerant causing bubbling of the detection spray and the difficulty of identifying leakage points.

REAL Alternatives e-library

Electronic Leak Detectors

Electronic leak detectors are test instruments which need to be looked after, checked and maintained to ensure accuracy. It is recommended they are checked every time they are used. Under the F Gas regulations, which are relevant to R32 and R1234ze, they should be checked once a year. This is a minimum requirement – for optimum reliability they should be checked more frequently.

The detector should not be contaminated with oil, and the filter

(where fitted) should be replaced regularly.

The three types of leak detector most commonly used rely on different methods of detection:

- Heated diode detectors – the diode needs changing usually after 100 hours use. The photo shows a typical heated diode. This is usually the cheapest method and is the most widely used for HFC refrigerants.

- Infra red (IR) detectors – the IR sensor needs changing less frequently. The photo shows a typical IR leak detector.

- Semi conductor – the sensor general lasts several years. The photo shows a typical detector used for HCs. Similar technology is used for R717.

It is important that where electronic leak detectors are used with flammable refrigerants (R600a, R290, R1270, R32 and R1234ze for example), they are safe as well as being sufficiently sensitive to detect the refrigerant. Many electronic leak detectors which are used for HFCs are not safe for use with flammable refrigerants.

A reference leak should be used to check the detector is working correctly – just opening a cylinder or a connection on the system to check the detector is not accurate enough. The photo shows a simple calibrated reference leak device that fits onto the cylinder valve or onto a connection on the system. When the valve is

opened the flow through the device is approximately 5 g / year with the specified refrigerant. If the leak detector does not pick this up it needs servicing. This method can be used with most refrigerants, although its leak rate will vary. Its use with R744 should be checked with the supplier – the R744 pressure may exceed the maximum pressure of the device.

Reference leaks are also available for some refrigerant types. Typically these are supplied in a small container and leak at a rate of 5 g/year at 20^{O}C.

High air flow can disperse leaking refrigerant so that it cannot be detected by an electronic leak detector. If possible condenser and evaporator fans should be stopped when checking around these components. Take care that high pressure switches do not trip and pressure relief valves do not vent as a result of switching off condenser fans. If possible, plant room ventilation and any other fans in plant rooms should be switched off to check equipment within the room. Take care that this does not result in a flammable atmosphere in the event that there is a leak.

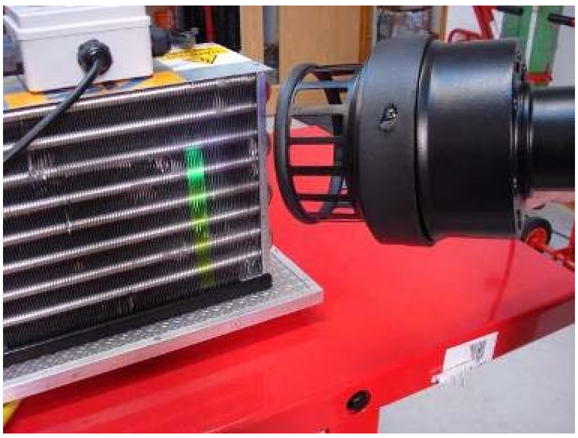
All alternative refrigerants except R717 are heavier than air, so the underside of all joints should be checked. When entering a cold room the air at floor level should be checked. Where risers are fitted in cupboards the bottom of the cupboard should be checked.

A video in the REAL Alternatives e-library demonstrates methods of testing the operation of your hand held leak detector.

REAL Alternatives e-library

Fluorescent Additive

A fluorescent additive can be added to the oil in a system. In the event of a leak the additive and oil leak and can be detected with an ultra violet lamp. The advantage of this method is that it will show a leak even if the joint or component is not leaking during the test, a useful feature for intermittent leakage or where the entire charge has already been lost. The additive stains the pipe work and should be removed after detection.



This method does have some disadvantages:

- Some compressor manufacturers will not give warranty if the additive has been used;
- Coalescing oil separators separate out the additive so it does not enter the remainder of the system. This is particularly relevant to R744 central plant systems which usually use this type of oil separator.

Ultrasonic Leak Detectors

Ultrasonic leak detectors amplify the sound of a leak out of or into pipe work. An example is shown in the photo.

Typically these detectors have a built in receiver that detects frequencies of sound within a specific range, i.e. similar to that of leaking refrigerant. The output can be via headphones, or a visible / audible alarm.

An advantage of this method is that it can be used with any refrigerant in the system (or with nitrogen), and on parts of the system where the operating pressure is below atmospheric pressure.

Litmus

R717 can be detected by a paper which changes colour dependent on pH (acidity). Leak detection by means of phenolphthalein paper (colour change on a test strip) has poorer detection sensitivity than an electronic leak detector so is not the recommended method as a detection method on its own. However, wetted paper can be used to pinpoint the leak point, for example on a flange or pipe of an ammonia system. The litmus paper changes colour detecting a change in pH due to the absorption of ammonia into wetted paper.

Visual checks

A visual check is not included in the table of leak test methods, but its use should not be underestimated. Indicators include:

- Oil stains on pipe work;
- Oil stained insulation;
- Dust sticking to oil on pipe work;
- Corrosion, excessive wear or damaged components.

Oil stains should be cleaned after the leak has been repaired so they do not give a subsequent false indication of leakage.

The indicator (tell-tale) on a pressure relief valve should be checked because PRVs which have operated do not always seal correctly.

The main cause of a continually flashing liquid line sight glass is insufficient refrigerant, usually caused by leakage. However, a leak does not always result in flash gas in the liquid line, especially if the load and / or the ambient temperature are low, so the system should be leak tested even if the sight glass shows clear liquid.

Many receivers are fitted with low liquid level indicators and they can be used to show that the system is undercharged. They should be checked to ensure they are functioning, for example by watching the rise in liquid level on the indicator as the system is pumped down. Again, a system can still have a leak even if the receiver liquid level indicator is not showing undercharge.

Figure 4, Examples of visual indicators of leakage

Odour

Most refrigerants do not smell but R717 has a very pungent odour and R1270 has a very slight “gassy” smell.

R717 can be easily detected by smell and can be perceived by smell at low levels of at 5 ppm = 3.5 mg/m3. Leaks will need to be pinpointed using an electronic leak detector or litmus paper.

The smell of R1270 is not strong enough for it to be used as a reliable indicator of leakage.

Indirect Leak Test Methods

A leaking system’s operating conditions will usually vary from normal conditions:

- The suction pressure will be lower (unless it is controlled, for example in a central plant system);
- The useful superheat (i.e. the superheat achieved in the evaporator) will increase;
- The subcooling will reduce;
- The discharge pressure will reduce (unless it is controlled).

IOR Guidance Note on Measuring Superheat and Subcooling

REAL Alternatives e-library video on superheat and subcooling

IOR Guidance Note on indirect leak checking

Excessive superheat and low or zero subcooling are both good indicators of low refrigerant charge

Measuring the liquid level in a receiver can also identify loss of refrigerant, however, liquid levels naturally vary with changing load conditions and ambient conditions.

R717 Systems

Leak Testing before initial commissioning

- ✓ Leak tests should be carried out on the basis of nationally approved standards.
- ✓ Of particular importance is the detection and repair of leaks on high pressure parts of the plant which will become difficult to access when the plant is put into operation.

Leak Testing in existing plants

- ✓ As soon as ammonia can be smelt, leak detection is necessary. Here again, this should be based on nationally approved standards
- ✓ Leak detectors can only estimate the leakage rate (small, medium, large) as opposed to a measured flow rate.
- ✓ Leak detection sprays have far poorer sensitivity that electronic detectors.
- ✓ If the leakage rate of an ammonia leak has to be quantified, detection instruments can be used that work according to the principle of photoacoustic infrared absorption.

Competence Requirements

Leaks testing and any faults on Ammonia systems must be monitored and rectified immediately by a qualified, competent person according to national legislation. After a fault has been rectified, the plant must be recommissioned after carrying out suitable pressure testing.

IOR Code of Practice Ammonia Refrigeration Systems

Leak Detection

- ✓ Ammonia is easily detected due to its strong smell (human perception limit 5 ppm = 3.5mg/m^3) which will indicate the need to search for leaks.
- ✓ Leaks which under certain circumstances can remain undetected in HFC plants for a period of time are simply inconceivable in ammonia plants.
- ✓ Very small leaks in ammonia refrigeration plants (leakage rate of approx. 100g NH_3/a) cannot be detected by smell as an ammonia concentration of 5 ppm is not reached.

Principles of Avoiding Risk

- ✓ Keep the refrigerant quantity as low as possible: refrigerant that is not in the system cannot leak.
- ✓ A well planned refrigeration plant with appropriate equipment selection and use of isolation valves will reduce refrigerant emissions during maintenance and servicing.
- ✓ Components that seal well should be selected to minimise leakage. Allowance should be made for regular leak tests.
- ✓ It is important to select materials with suitable compatibility otherwise leak paths may occur. The volume of elastomers for example can increase (swell) or decrease (shrink) in combination with certain oils and ammonia.

Pipework

- ✓ Because ammonia is corrosive with copper, ammonia systems will normally be constructed using carbon or stainless steel pipework and fittings. More details on the best practice associated with ammonia pipework is detailed in the IOR's Ammonia Refrigeration Systems Code of Practice.

- ✓ In principle welded joints should be used in preference to flanged joints to minimize the risk of leakage.
- ✓ For pipework of less than 40mm diameter socket weld fittings should be used as opposed to butt welded joints.

Monitoring water circuits for ammonia leaks

- ✓ According to EN 378 refrigeration plants with more than 500k should include measures to ascertain the presence of refrigerant in all connected water or fluid circuits.
- ✓ Ammonia must be prevented from entering the sewerage system or the cooling water of an evaporative condenser.
- ✓ The most common measuring system at present is to monitor the pH values. An ammonia leak in a water circuit causes the pH value to increase. It is advisable to install a device for differential measurement of the pH value between the inlet and outlet of the heat exchanger with automatic temperature compensation. In the case of a pH alarm, it is necessary for the heat exchanger to be shut off on the water and ammonia side by means of motor valves or by hand. Newer ion-selective measuring devices are much more precise.
- ✓ Another possibility is to use an ammonia-sensitive electrode. Differential measurement is not necessary in this case.

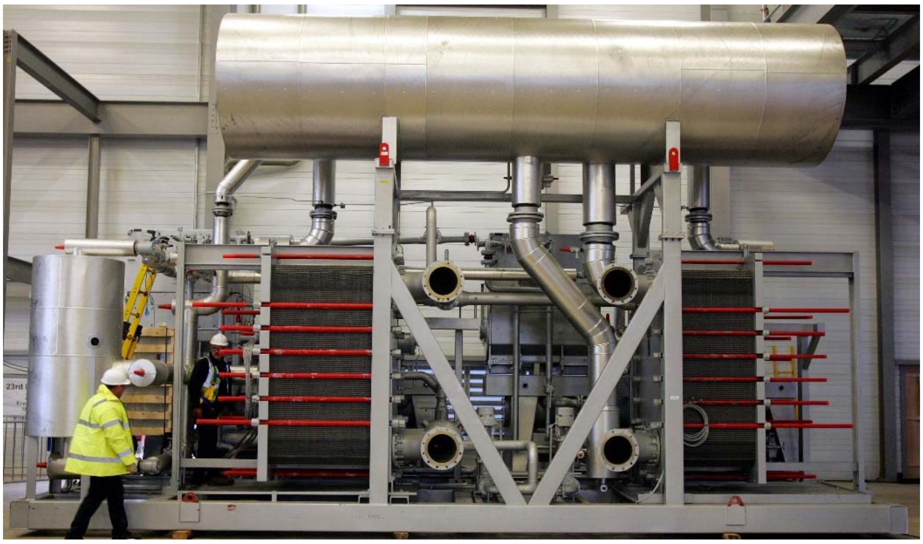


Figure 5, Example of an ammonia chiller with stainless steel pipework

3 Pressure Testing Using Nitrogen

If leaks cannot be found using the methods outlined above, or if the entire refrigerant charge has leaked, the system will need to be pressure tested using nitrogen.

The system should be slowly filled with nitrogen to the maximum allowable pressure (PS)[1] and then either:

IOR SES Good Practice Guide 24 – Pressurising installed systems with nitrogen to find leaks

- Each joint should be checked with leak detection spray;

  Or
- The system should be held under pressure for a period of at least 12 hours and the pressure checked at the end of the test to ensure it has not reduced.

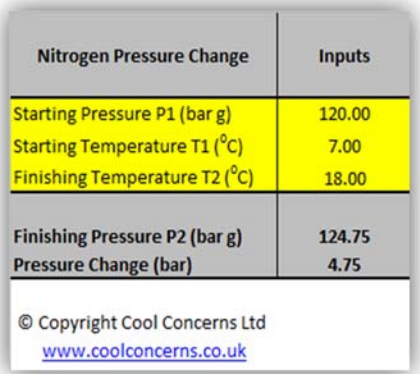
Effect of ambient temperature on pressure

Note that if the latter method is used the ambient temperature must also be taken into account because of the relationship between the temperature and pressure of the nitrogen gas in the system. If this is not done then an ambient temperature increase could mask a nitrogen loss. In accordance with Gay-Lussac's Law (also called Amontons' Law of Pressure-Temperature):

P2 = (P1 x T2) / T1

Where:

P1 is the pressure at the start of the test in bar absolute
P2 is the pressure at the end of the test in bar absolute
T1 is the ambient temperature at the start of the test in Kelvin
T2 is the ambient temperature at the end of the test in Kelvin.



Nitrogen Pressure Change	Inputs
Starting Pressure P1 (bar g)	120.00
Starting Temperature T1 (°C)	7.00
Finishing Temperature T2 (°C)	18.00
Finishing Pressure P2 (bar g)	124.75
Pressure Change (bar)	4.75

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Typically, for most pressures, the pressure will change by 0.7 bar for a 5K change in temperature. For pressures associated with R744 the change will be greater.

An excel calculator can be used to do this calculation – the picture is an example of the output for a pressure test on the high side of an R744 transcritical system.

Premix trace gas

The pressure test can also be carried out using a proprietary mix of nitrogen with a trace of helium or hydrogen, typically 5% trace gas in 95% nitrogen. The advantage of using helium or hydrogen trace gas is that both have small molecules and low gas velocity and molecular mass, so they leak faster and diffuse more readily. An electronic leak

A Gas information on Trace-A-Gas

[1] EN378-2:2016 Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation 6.2.2

detector sensitive to the trace gas must be used, but these are readily available. The photo shows an example of one which detects both hydrogen and hydrocarbon refrigerant.

Note – pre mixed trace gas is widely available and should be used, it should not be mixed on site.

REAL Alternatives e-library videos on using premix trace gas

4 Potential Leak Points

Potential leak points on systems operating with alternative refrigerants are similar to those on conventional systems. The leak potential on HC systems tends to be low because the systems are usually close coupled with a small number of joints. The leak potential for R744 systems is generally higher as it tends to be used in central plant systems with many joints and higher operating and standstill pressures. It also has a small molecule size which diffuses more readily.

See REAL Alternatives Module 1 section on Leakage Issues

As with all refrigerants, the following are important factors in minimising leak potential:

- ✓ The system type – large central plant systems inherently leak more than close coupled systems – this is partly due to the on site installation and the increased number of joints in a central system;
- ✓ The operating and standstill pressures – with higher pressures even greater care is needed in the selection of components, jointing, installation and leak detection;
- ✓ The specification of components – they must be appropriate for the pressure, temperature, refrigerant and oil. This includes everything from Schrader valve cores to brazed plate heat exchangers and compressors;
- ✓ Compressors - avoid the use of open drive compressors where possible. If they must be used, ensure that they have shaft seals;
- ✓ Essential information – accurate drawings should be provided which show the location of all joints and access points;
- ✓ Design for ease of service – joints should be accessible to ensure leak detection can be easily and thoroughly carried out;
- ✓ The pipe thickness – this must be adequate for the pressure. For some parts of R744 systems steel pipe work or K65 copper tube[2] will need to be used to contain the high pressures;
- ✓ The method of joining pipe to pipe and pipe to component – brazed or welded joints will always have a lower leak potential than any type of mechanical joint. Technicians who braze or weld should have an appropriate qualification to demonstrate their competence. The correct jointing materials should be specified;
- ✓ Pipe work design and installation - pipe routing should be such that vibration is minimised, pipe should be adequately clamped (not just supported) in accordance with EN378[3]. Pipe work should be installed so that is it does not chafe;
- ✓ Component installation – many components should be wet ragged during hot works to prevent damage. Schrader valve cores should be removed during hot works. Compressors should be mounted in accordance with the manufacturer's instruction to ensure they do not transmit vibration;

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[2] K65 tube has 2.5% ferrous and is suitable for the high side of R744 trans critical systems

[3] EN378-2:2016 Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation, 6.2.3

- ✓ Adequate pressure testing to identify leaks before putting the system into service - systems should be pressure tested for strength and leak tightness in accordance with EN378[4]. Time must be allowed for the tightness test to be thorough and for failures to be repaired and re tested;

- ✓ High pressure switch setting - in accordance with EN378[5] the setting should be no more than 90% of PS where pressure relief valves (PRVs) are fitted. If this is not the case the PRV can vent on rapid rise of pressure because the high pressure switch does not switch the system off in time;

- ✓ Maintenance - the maintenance regime should be appropriate for the plant type. The leak test frequency specified in the F Gas regulations[6] should be used as a minimum for all refrigerant types (see section 6), but many systems will benefit from more frequent leak testing, for example weekly or monthly. Any leaks found should be repaired immediately and the system re leak tested;

- ✓ Appropriate service - all valves should be capped, condensers kept clean to minimise pressure, controller set points should minimise head pressure and any vibration issues should be corrected.

Flared connections

The use of flared connections should be minimised, but on some connections a demountable joint is preferred (for example on liquid line filter driers on HC systems so these can be changed without the need for unbrazing). In this case a flare solder adaptor should be used. This machine made connection has a lower leak potential than a manually made flare.

The flare nut should be tightened to the correct torque using a torque wrench. Correct torque values are provided by the manufacturer of the flare solder adaptor, and also in EN378[7] for manually made flares.

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[4] EN378-2:2016 Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation, 6.3
[5] EN378-2:2016 Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation, 6.2.2
[6] EC 842/2006 and EU 517/2014
[7] EN378-2:2016 Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation, 6.2.3.2.3.3

Figure 6, Flare solder adaptor and tightening to the correct torque

Schrader valves

The work carried out for the UK Real Zero project in 2007 highlighted 13 common points where leaks occur and how to prevent them. A visual guide to these leakage points can be downloaded from the REAL Alternatives e-library. It is critical that all these points are leak tested. Three key areas are identified from this work and subsequent experience with alternative refrigerants. These are where there is the most potential for major improvements as outlined below.

The valve cores must be selected so they are suitable for the refrigerant and oil type and the pressure and temperature range – different systems and refrigerants can require different types of Schrader core.

The core must be removed prior to brazing the Schrader body into the system, and then re fitted when the body is cool. The core must then be tightened to the correct torque.

Figure 7, Hex cap, Schrader valve and Schrader torque tool

The valve must be capped. Note that the cap commonly used has a seal which degrades and leaks if it gets hot – a hexagonal nut or Shrader valve cap which can be carefully tightened with a specialist tool is a better option. The nut should be selected so that it does not depress the Schrader when tightened.

R744 system pressure relief valves (PRVs)

Pressure relief valves on R744 systems are a common leak point for various reasons:

- Pressures in R744 systems can rapidly rise in the event of a change in conditions or a fault;
- The standstill pressure is often higher than PS (and hence the PRV setting) for some parts of the system;
- The operating pressure is often close to PS.

PRVs don't always re seat after discharge so it is essential they are leak tested. After multiple discharges the spring weakens, reducing the PRV vent pressure and exacerbating the issues highlighted above.

To reduce PRV discharges and leakage there should be sufficient difference between the normal operating pressure and PS for each part of the system.

To the right is an example of just one type of R744 PRV; others are available from a range of manufacturers.

5 Legal Requirements

The leak test frequency must be appropriate for the system type and its age and condition. For R32 the leak test frequency is specified in the 2014 European Fluorinated Gas Regulation 517/2014. It is recommended that all non-hermetic stationary systems (even those containing low GWP alternative refrigerants) should be leak tested regularly as part of a planned maintenance regime and results recorded for internal management and reporting purposes.

F Gas Regulation 517/2014

From 1st January 2015 the required leak test frequency for systems containing fluorinated gases is shown below:

Table 2, F Gas Regulation Leak test frequency, after 01.01.2015

System Charge	Leak test frequency
5 to 50 tonnes CO_2 equivalent **i.e. 7.4 to 74 kg R32**	1 / year 1 / 2 years if a fixed leak detection system is fitted
50 to 500 tonnes CO_2 equivalent **i.e. 74 to 740 kg R32**	2 / year 1 / year if a fixed leak detection system is fitted
More than 500 tonnes CO_2 equivalent **Fixed leak detection must be fitted** **i.e. more than 740 kg R32**	4 / year 2 / year if a fixed leak detection system is fitted

If a leak is found it must be fixed as soon as possible and the system re-tested at the point of repair within one month.

It is important to view this leak test frequency as a minimum. More frequent leak tests should be carried out on systems which:

- Have a high number of potential leak points (e.g. central plant systems);
- Operate at high pressure (e.g. R744 and R32 systems);
- Are old or in poor condition.

This will save money by maximizing reliability, minimizing energy use, failure and down time.

Leakage has been shown to be significantly reduced on systems which are leak tested more frequently, for example once a month.

Asda Supermarket case study paper from Institute of Refrigeration

6 System Records

System records are an essential tool in reducing leakage and are a mandatory requirement for many HFC systems (and therefore R32 and R1234ze systems). System records should be interrogated to identify common patterns of leakage, to enable comparison with similar systems and to identify ways of minimizing leakage in the future. They should also be kept for non HFC systems and should include the following information:

- The type and quantity of refrigerant in the system;
- The system PS values (maximum allowable pressure)[8];
- Leak testing carried out;
- Location of leaks found;
- Repairs carried out.

The system should also be clearly labelled with the refrigerant type and weight, for HFC systems this must be expressed in CO_2 e (Carbon Dioxide equivalent eg for R32 the CO_2e is 675 per kilo)

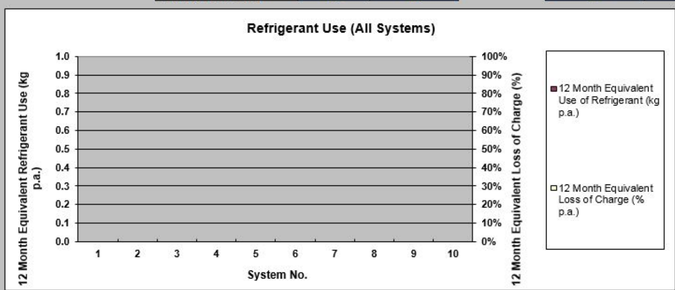
Below is an example template for a system log – see more in Module 9 "Tools and Guidance on Site Surveys"

F Gas Refrigerant Monitoring Tool
Institute of Refrigeration (IOR) REAL Zero Project

Site Name:			
Site Address:			
Postcode:		Telephone No.	
Time Period Recorded	From:	To:	

			REFRIGERANT		TIME PERIOD			REFRIGERANT LOSS			REFRIGERANT EMISSIONS	
System No.	Plant Name	Plant Reference No.	Refrigerant Type	Refrigerant GWP (relative to CO_2)	First Record Date	Latest Record Date	Period Covered (years)	Total Refrigerant Use (kg)	12 Month Equivalent Use of Refrigerant (kg p.a.)	12 Month Equivalent Loss of Charge (% p.a.)	Carbon Equivalent of Lost Refrigerant (tonneCO_2e)	12 Month Carbon Equivalent of Lost Refrigerant (tonneCO_2e p.a.)
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
						Totals (all systems)		0.0	0.0		0.0	0.0

Time Period Covered by This Report (years)	0.00
Carbon Equivalent of Refrigerant Emissions Over This Period (tonneCO_2e)	0.0
12 Month Carbon Equivalent of Refrigerant Emissions (tonneCO2e p.a.)	0.0
Total Refrigerant Used Over This Period - All Systems (kg)	0.0
Total Entrained Mass of Refrigerant - All Systems (kg)	0.00
Total Refrigerant Charge Lost Over This Period - All Systems (%)	#DIV/0!



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Labels

It is a legal requirement to label systems containing F Gas Refrigerants and the contents of the label are specified in the regulations. However additional reminders (such as the examples below) can be used as labels on systems, leak detectors and refrigerant cylinders to highlight to technicians the importance of leak detection. These are available to download from the REAL Alternatives e-library.

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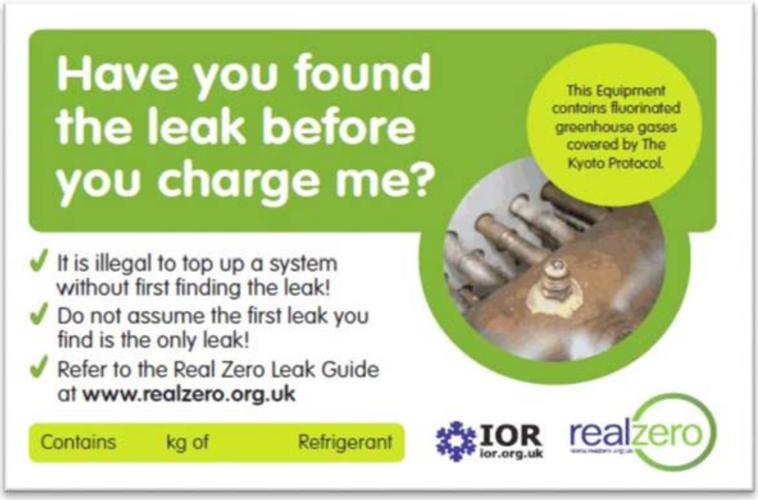
[8] PS is defined in EN378-1:2016, Refrigerating systems and heat pumps – Safety and environmental requirements, Basic requirements, definitions, classification and selection criteria, see Module 6 – Legal Obligations, for more information.


Have you checked that I'm working before you use me?
✓ Have you checked your leak detector sensitivity against a calibrated leak?
✓ Do not assume the first leak you find is the only leak!
✓ Refer to the Real Zero Leak Guide at www.realzero.org.uk
IOR
ior.org.uk
realzero


Have you found the leak before you use me?
✓ It is illegal to top up a system without first finding the leak!
✓ Refer to the Real Zero Leak Guide at www.realzero.org.uk
IOR
ior.org.uk
realzero


Have you found the leak before you charge me?
This Equipment contains fluorinated greenhouse gases covered by The Kyoto Protocol.
✓ It is illegal to top up a system without first finding the leak!
✓ Do not assume the first leak you find is the only leak!
✓ Refer to the Real Zero Leak Guide at www.realzero.org.uk
Contains kg of Refrigerant
IOR
ior.org.uk
realzero

7 Fixed Leak Detection Systems

IOR Guidance Note on Fixed Refrigerant Detection Systems

Danfoss Gas Detection in Refrigeration Systems

Eurammon Ammonia 5 Leak Monitoring at Ammonia Ref Plant

IOR Guidance Note 10 Working with Ammonia

Fixed leak detection is used for safety reasons and in some cases because it is a legal requirement (see previous section for HFCs). Fixed leak detection is not an alternative to manual leak checking.

Any fixed leak detection system should positively detect refrigerant in the air around the system and alarm in the event refrigerant is detected. The alarm should be treated as a priority.

Alarm level should be set at 25% of the LFL or 50% of the ATEL / ODL, whichever is the lowest[9]. Alarm levels for the alternative refrigerants are provided in the table below. Refer to EN 378 for full details about detector type and location and specific information about R717 alarms.

Refrigerant	LFL, kg/m^3	ATEL, kg/m^3	Alarm level, kg/m^3
R744	na	0.072	0.036
R717	0.116	0.00022	0.00011
R32	0.307	0.30	0.077
R1234ze	0.303	0.28	0.076
R600a	0.043	0.059	0.011
R290	0.038	0.09	0.010
R1270	0.047	0.0017	0.00085

Sensors

The sensors should be fitted at low level for all refrigerants except R717, which should be at high level. Alternatively, sensors should be fitted in the return air to the evaporator. There should be sufficient sensors to provide protection for the entire area. Sensors should be fitted in areas which pipe work passes through such as riser cupboards and ceiling voids.

The picture to the right is an example of one type of fixed leak detection device.

Calibration/Service

The fixed leak detection system should be accessible for calibration / service and protected from damage. There should be a facility to test the alarm. Alarms should be bump tested once a year as a minimum. Ideally the alarm system should warn both visibly and audibly with a buzzer (sounder) at least 15 dBA above the background noise level, both inside and outside the space.

[9] EN 378-3:2016 9.3.1

R717 Detection Systems

Ammonia refrigeration machine rooms are monitored with fixed detectors as specified in EN 378 as a compulsory feature for plants filled with a quantity of more than 50kg. Smaller leaks are not detected because of the higher trigger threshold of approx. 500ppm.

Sensor Types
Toxic gases are normally detected in industrial environments by electro-chemical cells. Semi-conductor and pellistor (or catalytic) sensors are used for flammable gas detection. Sensors and systems for use in ammonia plantrooms must be intrinsically safe and suitable for Zone 2 hazardous areas.

a) Electro-chemical cells

- ✓ Electro-chemical sensors are designed to detect low levels of ammonia (50ppm and 500ppm) The sensors are essentially small batteries which start to discharge as soon as they are manufactured.
- ✓ The discharge rate is increased when in the presence of the target gas (and in some instances, but to a lesser extent, by other gases). They have a lifetime of perhaps eighteen months to four years (dependant on background gas levels and operational conditions of temperature and humidity).
- ✓ When using electrochemical cells, it must be accepted that they are consumable items which need replacement at regular intervals and that this may be expensive.

b) Semi-conductor Sensors

- ✓ The 10,000 ppm ammonia gas detection level can be covered with rugged semi-conductor sensors.
- ✓ The main advantages of semi-conductor sensors are long life, their ability to operate in harsh environments, fast response time and lower power consumption.
- ✓ The major disadvantage is their response to other gases, leading in some cases to spurious alarms.

c) Pellistor (or Catalytic) Sensors

- ✓ These sensors can also be used to detect the 10,000 ppm ammonia concentrations. The fundamental principle of the pellistor sensor is that the flammable gas is burnt on the surface of a heated platinum wire coated with a catalyst. Rises in temperature and resistance are detected electrically.
- ✓ However the sensor head can be "poisoned" by other compounds and the sensitivity can be markedly reduced if the sensor is immersed in large concentrations of the gas it is supposed to be detecting.
- ✓ Note, a pellistor may not detect if switched on in the presence of a gas with a concentration above the Lower Explosive Limit (LEL)

Infra Red Detection Systems

With this system, a small vacuum pump is used to draw filtered samples from several points and deliver them in sequence to an infrared analyser. The analyser searches the sample for the presence of the specific gas and can identify the zone from which it was taken. The analyser can detect ammonia levels in the range 0 ppm to 10,000 ppm.

Alarm Thresholds and switching function

- ✓ BS EN378 calls for low concentration level action at not greater than 500 ppm and for high concentration level action at not greater than 30,000 ppm.

- ✓ The low concentration level alarms are associated with toxic levels. At the low concentration level the mechanical ventilation shall be activated. In addition, an alert can be sent if the plant is remotely monitored.
- ✓ At the high concentration level all electrical circuits within the plant room except the vent fans must be isolated. Emergency lighting etc should be switched on.

Spread of gas and positioning the sensors

- ✓ The number and placement of gas detectors on a job will relate to its size and the amount of machinery specified. A detector can normally cover an area of about $36m^2$.
- ✓ Priority should be given to positions close to compressor shafts seals and liquid pumps. In general for ammonia the sensors should be placed above the machinery, however on pumped ammonia installations one sensor should be placed at low level near the pumps to detect liquid spillage.
- ✓ It may be appropriate to fit several sensors around the machinery room, however at least one sensor shall be suitable to detect the low alarm level.
- ✓ A sensor in the safety valve discharge pipework can monitor for leaks or triggering. A rupture disks with pressure monitoring is also suitable.

8 Self Test Module 3

Try the sample multiple choice assessments below to check your learning

Question 1 -
According to the latest F Gas regulation (EU517/2014) how frequently must an R1234ze system with a charge of 300kg and no fixed leak detection system.

I. It does not need to be leak tested
II. Once per year
III. Twice per year
IV. Four times per year

Question 2-
Which refrigerant can be detected by the use of litmus paper?

I. R32
II. R744
III. R290
IV. R717

Question 3-
Which of these refrigerants is lighter than air?

I. R744
II. R32
III. R717
IV. R290

Question 4-
According to F Gas Regulation 517/2014 a system needs a fixed leak detection system when it contains tonnes CO_2 equivalent more than:

I. 50
II. 150
III. 300
IV. 500

The answers are on the bottom of the next page

What next?

The information in this guide is an introduction to the most common alternative refrigerants. There is much more information in the documents highlighted in the links. Go to the on line reference e-library at www.realalternatives4life.eu/e-library to explore any additional information you may find useful.

If you would like to gain a REAL Alternatives 4 LIFE Certificate you need to take a full end of course assessment at a licensed REAL Alternatives 4 LIFE training centre. Information about assessments is available at http://www.realalternatives4life.eu

You can now continue your self-study with one of the following **Real Alternatives 4 LIFE** programme Modules:

1. Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2. Safety and risk management
3. System design using alternative refrigerants
4. Containment and leak detection of alternative refrigerants
5. Maintenance and repair of alternative refrigerant systems
6. Retrofitting with low GWP refrigerants
7. Checklist of legal obligations when working with alternative refrigerants
8. Measuring the financial and environmental impact of leakage
9. Tools and guidance for conducting site surveys

This project has been funded with support from the European Commission. This publication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Correct answers: Q1 = i, Q2 =iv, Q3 = iii, Q4 = iv

With contribution of the LIFE programme of the European Union

Maintenance & Repair

of Alternative Refrigerant Systems

Contents

Refrig.	Inhalation	Flammability	Pressure	Other
R744	Low toxicity	Non flammable	Much higher	Pressure rise of trapped liquid high and risk of trapping cold liquid high. Possibility of solid R744 formation.
R717	Highly toxic	Mildly flammable	Lower	
R32	Asphyxiant	Mildly flammable	Higher	Products of decomposition highly toxic
R1234ze	Asphyxiant	Mildly flammable	Lower	Products of decomposition highly toxic
R600a	Asphyxiant	Highly flammable	Much lower	
R290	Asphyxiant	Highly flammable	Similar	
R1270	Asphyxiant	Highly flammable	Similar	

With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives Europe Blended Learning Programme

This learning booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives4LIFE.eu

REAL Alternatives 4 LIFE has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Croatian, Czech, Dutch, English, French, German, Italian, Polish, Romanian, Spanish and Turkish.

Real Alternatives Europe Programme Modules	
1	Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2	Safety and Risk Management
3	System design using alternative refrigerants
4	Containment and leak detection of alternative refrigerants
5	Maintenance and repair of alternative refrigerant systems
6	Retrofitting with low GWP refrigerants
7	Checklist of legal obligations when working with alternative refrigerants
8	Measuring the financial and environmental impact of leakage
9	Tools and guidance for conducting site surveys

You can study each module individually or complete the whole course and assessment.

www.realalternatives4life.eu

More information is available in the on line reference e-library. Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives4life.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

Assessment options are available if you want to gain a recognised CPD Certificate. At the end of each module are some simple self-test questions and exercises to help you evaluate your own learning. Certification and Assessment will be available from licensed REAL Alternatives training providers when you attend a course of study. The list of recognised training providers will be available on the website.

Register your interest in alternative refrigerants at www.realalternatives4life.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

Background to the programme and how it was developed. This learning programme was developed as part of EU co-funded projects led by a consortium of partners from across Europe. It is designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders from across Europe drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed.

The consortium partners:

- Association of European Refrigeration Air Conditioning & Heat Pump Contractors, Belgium
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- International Institute of Refrigeration
- University College Leuven-Limburg, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

With thanks to our stakeholders:

- CNI National Confederation of Installers, Spain
- CHKT Czech Association for cooling and air conditioning technology
- HURKT, Croatian Refrigeration Airconditioning and Heat Pumps Association
- RGAR Association General of Refrigeration, Romania
- SOSIAD Association of Refrigeration Industry and Businessmen, Turkey
- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 5 -

Guidance on the Maintenance and Repair of Alternative Refrigerant Systems

This Module focusses on the differences when servicing and maintaining systems which use an alternative refrigerant. It provides an introduction to this topic. It does not replace practical training and experience. At the end of the module you will find links to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

The following pages focus on the differences when servicing and maintaining systems which use an alternative refrigerant. It is based on good refrigeration practice, with additional information relevant to working with flammable refrigerants, toxic refrigerant and very high pressure refrigerant.

Information about the safe working environment is included as well as the following procedures where relevant:

- Leak testing
- Recovery / disposal
- Evacuation
- Un brazing and brazing
- Charging
- Component replacement.

Full procedures are not provided – the information outlines the critical points which differ from those for conventional refrigerants. The information is intended for experienced service and maintenance technicians. It is recommended that technicians have an individual F Gas certificate to demonstrate competence in handling traditional refrigerants, and undergo additional training on the specific alternative refrigerant.

Technicians should attend in depth training before working with alternative refrigerants.

1 Hazards of Refrigerants

REAL Alternatives Module 2

The table below is a reminder of the hazards of the alternative refrigerants; full details are in Module 2 Safety and Risk Management. The traffic light system indicates the severity of the hazard compared to R404A as an example. You will need to carry out or refer to a risk assessment prior to carrying out any work. The risks are assessed according to the type of work, environment and other people in the area.

Table 1, hazards of alternative refrigerants

Refrig.	Inhalation	Flammability	Pressure	Other
R744	Low toxicity	Non flammable	Much higher	Pressure rise of trapped liquid high and risk of trapping cold liquid high. Possibility of solid R744 formation.
R717	Highly toxic	Low flammable	Lower	
R32	Asphyxiant	Low flammable	Higher	Products of decomposition highly toxic
R1234ze	Asphyxiant	Low flammable	Lower	Products of decomposition highly toxic
R600a	Asphyxiant	Highly flammable	Much lower	
R290	Asphyxiant	Highly flammable	Similar	
R1270	Asphyxiant	Highly flammable	Similar	

Green – similar to R404A or not as severe;
Amber – slightly more severe than R404A;
Red – significantly more severe than R404A.

Service Procedure Differences

The properties of the alternative refrigerants, and in particular their hazards, affect how systems are serviced and maintained. The impact on the main procedures (where different from traditional HFCs) is summarised in the table below, and covered in more detail in the remainder of this guide.

Remember
If you are unsure of anything - Do Not Proceed.
Stop work and ask the question!

Table 2, service procedure differences

Refrig.	Work area	Equipment	Leak testing	Charging	Recovery / disposal
R744	Very well ventilated	Suitable for the very high pressure	Method must be sensitive to R744	Initial charge should be gas to prevent dry ice formation	Venting is the usual practice
R717	Very well ventilated and free from sources of ignition	Suitable for use with R717 and free from sources of ignition	Method must be safe and sensitive to R717		Recovered
R32		Suitable for the high pressure and free from sources of ignition	Method must be safe and sensitive to R32		Recovered
R1234ze		Free from sources of ignition	Method must be safe and sensitive to R1234ze		Recovered
R600a **R290** **R1270**			Method must be safe and sensitive to HCs	Charge weight is less so accuracy important	Small amounts* can be vented, otherwise HC is recovered

*Small amounts are usually considered to be less than 150g.

Suitable gloves and safety glasses should be worn when working with any refrigerant, and when carrying out hot works (brazing / welding).

2 Working Safely with Flammable Refrigerants

This section covers the safe handling of:

- Hydrocarbons (R600a, R290, R1270);
- R32;
- R1234ze;
- R717 (which is also covered in a separate section).

The safe working environment and Personal Protective Equipment (PPE)

When you work with flammable refrigerants the area must:

- Be well ventilated
- Have no source of ignition within 3 m (a typical safe area when working on flammable refrigerant systems).

If necessary introduce forced ventilation using a suitable fan assembly. This has an Ex rated fan motor and a 5m cable which enables it to be switched on outside the safe work area.

Figure 1, suitable ventilation fan

When carrying out invasive work, or if a leak is suspected, check and monitor the work area using an HC detector. It is important that the detector cannot be zeroed out to background flammable refrigerant levels and alarms at 20% of the lower flammability level. The photo shows suitable detectors for HCs.

Figure 2, flammable gas detectors

Figure 3, dry powder fire extinguisher

Figure 4, CO2 fire extinguisher

You should also have a fire extinguisher to hand. This should either be a dry power type with a capacity of at least 2 kg, or an equivalent sized CO_2 type.

Equipment

Some standard tools and equipment can be used safely with flammable refrigerants, including gauge manifold sets. Note – this is not the case for R717.

Most standard vacuum pumps can be safely used because usually the only potential source of ignition is the on / off switch. In addition, the flammable refrigerant discharged by the pump is usually safely dispersed and does not result in a flammable zone, providing the pump is located in a well-ventilated area. The section on evacuation below shows how you can avoid the hazard associated with the switch.

Figure 5, Example of equipment used for servicing HC systems

Standard recovery machines cannot be safely used to recover flammable refrigerants and therefore must not be used. Unlike vacuum pumps there are several sources of ignition (e.g. on / off switches, relays, pressure switches). In addition, a leak would result in a flammable zone around the machine. These hazards cannot be avoided; therefore the correct recovery machine must be used as specified in the section on recovery.

BRA Guide to servicing hydrocarbon refrigerants in a commercial environment

Most electronic leak detectors used for HFC and HCFC leak detection are not safe and sensitive for use with flammable refrigerants, so electronic detectors specifically for flammable gases (or leak detection spray) must be used, as described in the section on leak testing.

Leak testing

Flammable refrigerant systems must be leak tested using a method that is safe and sensitive:

See REAL Alternatives Guide 4 Guide on leak testing

- Leak detection spray
- A suitable electronic flammable gas detector (examples are shown in the photos below).

If you cannot find leaks using these methods you should recover the remaining charge and leak tightness test the system, using nitrogen or nitrogen with a trace of helium or hydrogen.



Figure 6, electronic leak detectors suitable for HCs

Refrigerant recovery

Flammable refrigerant must be recovered using a suitable recovery machine such as the Care Saver recovery machine (a standard recovery machine for halocarbon type refrigerants must not be used). Note – this is not suitable for use with R717.

- Evacuate the recovery cylinder to remove air before filling it with flammable refrigerant.
- Do not mix flammable refrigerants with other types of refrigerant in a recovery cylinder.
- When recovering hydrocarbon refrigerants, do not fill the recovery cylinders with more than 45% of the HFC safe fill weight.
- Label the recovery cylinder to show it contains a flammable substance.

Figure 7, Recovery machine for use with HCs, R32 and R1234ze

Evacuation

The vacuum pump must be checked to ensure the on / off switch is the only source of ignition. If this is the case the vacuum pump can be safely used with flammable refrigerant if the on / off switch is not used:

- Move the switch to the on position and plug the pump into a socket outside the 3 m zone and control it from this socket.
- Locate the vacuum pump in a well-ventilated area or outside.

Un-brazing (disconnecting a brazed joint by applying heat)

To safely un-braze joints:

- Continuously monitor the area with a flammable refrigerant detector.
- Ensure there is good natural or forced ventilation.
- Recover the flammable refrigerant from the system (see recovery procedure), making sure you are recovering all the refrigerant from the entire system.
- Run the recovery machine for long enough so the system is under vacuum and as much of the refrigerant is removed from the system as possible.
- Fill the system with oxygen free dry nitrogen to a pressure of 0.1 bar g.
- Connect a vent line to the system, open to atmosphere.
- Un-braze the connections.

Ensure all the refrigerant has been removed prior to unbrazing by connecting to both the high and low sides of the system.

Brazing

To safely braze joints:

- Continuously monitor the area with a flammable refrigerant detector.
- Ensure there is good natural or forced ventilation.

- When re-brazing connections, ensure at least one access point on the system open to atmosphere and purge with dry nitrogen.

Charging

- Ensure there is good natural or forced ventilation.
- For HCs – use refrigerant grade HC, do not use lpg / fuel gas.
- If charging lines are not evacuated purge them carefully (by opening then closing the cylinder valve before purging).
- Do not over charge the system (for example, the HC charge weight is approximately 45% the charge weight for an equivalent HFC system).
- Accurately weigh in the charge when charging critically charged systems. The tolerance is typically ±5%. Do not adjust refrigerant charges, always use the manufacturer's indicated charge.

Component replacement

- Replace electrical devices and compressors with **like for like** components.
- Ensure sealed electrical boxes are correctly re sealed before putting the system back into operation.
- Do not modify components or relocate components.

3 Working Safely with R744 (Carbon Dioxide)

The main differences when working with R744 are associated with high pressures, the increased risk and likelihood of trapping liquid and issues associated with dry ice formation.

The safe working environment and PPE

Figure 8, personal CO2 alarm

The work area should be very well ventilated and monitored with a CO_2 detector (either the fixed detection in the area or with a personal detector). Typical alarm levels are:

- Pre alarm at 1%, 10,000 ppm
- Main alarm at 2%, 20,000 ppm.

R744 is an asphyxiant and can cause hyperventilation and disorientation. Ear defenders will also be necessary when venting R744 systems.

Most R744 systems are more complex than traditional system so before working on an R744 system ensure you know how the system works and what all the components do, especially isolation valves.

Equipment

On trans critical systems the pressure will be up to 120 bar g, and on cascade sub critical systems it will typically be up to 45 bar g. The cylinder pressure will be high, e.g. 99 bar g when the cylinder temperature is 40^{O}C.

Tools and equipment must be rated for the pressure:

- Hoses (braided steel, copper tube or pneumatic hose);
- Gauges / gauge manifold set;
- Connections to cylinders / cylinder adaptors;
- Nitrogen regulator and manifold for pressure testing - a strength test pressure of up to 132 bar g may be necessary (the photo shows an appropriate regulator).

Figure 9, appropriate regulator for pressure testing R744 systems

When connecting to systems:

- Ensure R744 is not trapped in lines, fittings etc;
- If a pressure relief valve is fitted to access equipment ensure it vents in a safe direction.

The photos show examples of appropriate charging equipment.

Figure 10, cylinder connected to charging equipment

Figure 11, connection to system

Figure 12, connection to cylinder

Leak detection

CO_2 has a smaller molecule size compared to HFC refrigerants and diffuses more easily. This, coupled with the higher pressure, means that R744 systems have a greater leak potential. Leak detection methods include:

See REAL Alternatives Guide 4 on Leak Testing

- A visual check - for example look for oil stains;
- Leak detection spray;
- Suitable electronic leak detectors such as those shown in the photo (there is CO_2 in the atmosphere so these will detect a leak above this level).

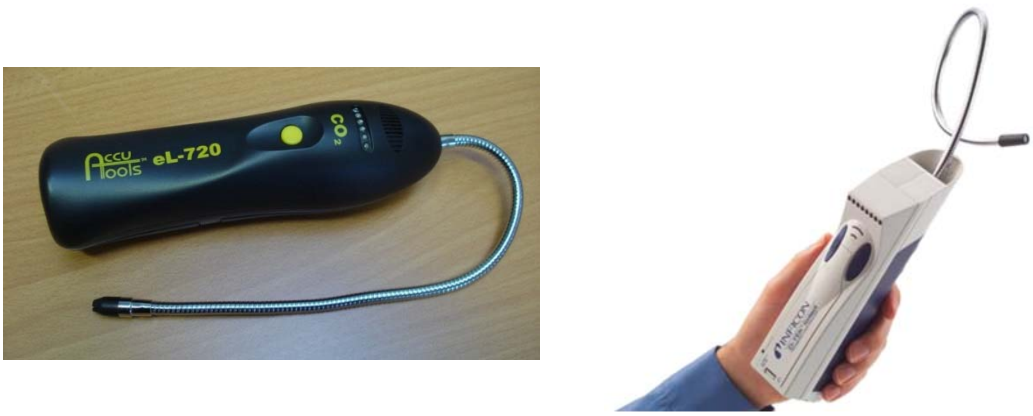


Figure 13, leak detectors suitable for R744

Disposal

R744 is usually vented rather than recovered:

- Vent into a very well ventilated area or outside;
- Beware of the asphyxiation hazard;
- Beware of the very high noise level (wear ear defenders);
- Beware of dry ice formation in the system (e.g. at orifice plates) and in the vent line when approaching the triple point. Dry ice can block the vent line so it appears that all the refrigerant has been vented;
- Wear appropriate gloves - the pipe temperature will drop;
- Beware of the very high pressures - secure the vent line so it cannot whip;
- Do not leave the system unattended while venting.

Dry Ice

If dry ice forms the pressure will drop to 0 bar g. When the dry ice sublimes the pressure will rapidly increase due to the change of state coupled with the temperature increase. Check the pressure in the system before accessing it. If dry ice does form:

- Do not heat it;
- Isolate the vent line and monitor the system pressure;
- You will see when the dry ice has sublimed – it can take a long time;
- Continue venting.

Evacuation

Systems must be evacuated if they have been open to air or after pressure testing. Moistures produces acids which are harmful to the system:

CO_2 + moisture = carbonic acid

Air in trans critical systems causes major problems because it is a non-condensable gas and increases the system pressures (as it will with all refrigerant systems, but the additional pressure is more critical in an R744 system).

Charging

Many R744 systems have a fixed permanent charging point to reduce cylinder handling (see the example in the photo). These lines should either have a valve at only one end so they cannot trap refrigerant or be fitted with a PRV and always primed with gas (not liquid).

Figure 14, example of a remote charging point

When charging with R744:

- Ensure the area is very well ventilated;
- Ensure refrigerant grade CO_2 (i.e. R744) is used;
- Ensure cylinders are upright and secure, for example in a suitable trolley;
- Open cylinders slowly, remember the high pressure can de stabilise a cylinder;
- Purge the lines carefully to eliminate air, moisture and other contaminants.

It is important to prevent dry ice formation:

- Charge gas (from cylinders) until the system pressure is above the triple point of 4.2 bar g (e.g. charge to 10 bar g);
- Then charge liquid (from cylinders or bulk).

The charging sequence for cascade systems is important - charge and run the high side first.

After charging you must ensure R744 is not trapped in charging equipment or hoses so open all valves on the charging equipment. Do not close valves until you are sure there is only R744 gas in the lines at a low pressure, e.g. 10 bar g.

In many systems the setting of the pressure relief valve (PRV) protecting the section of the system you are charging will be below the pressure of the R744 in the cylinder. You must charge slowly and carefully to prevent the PRV venting.

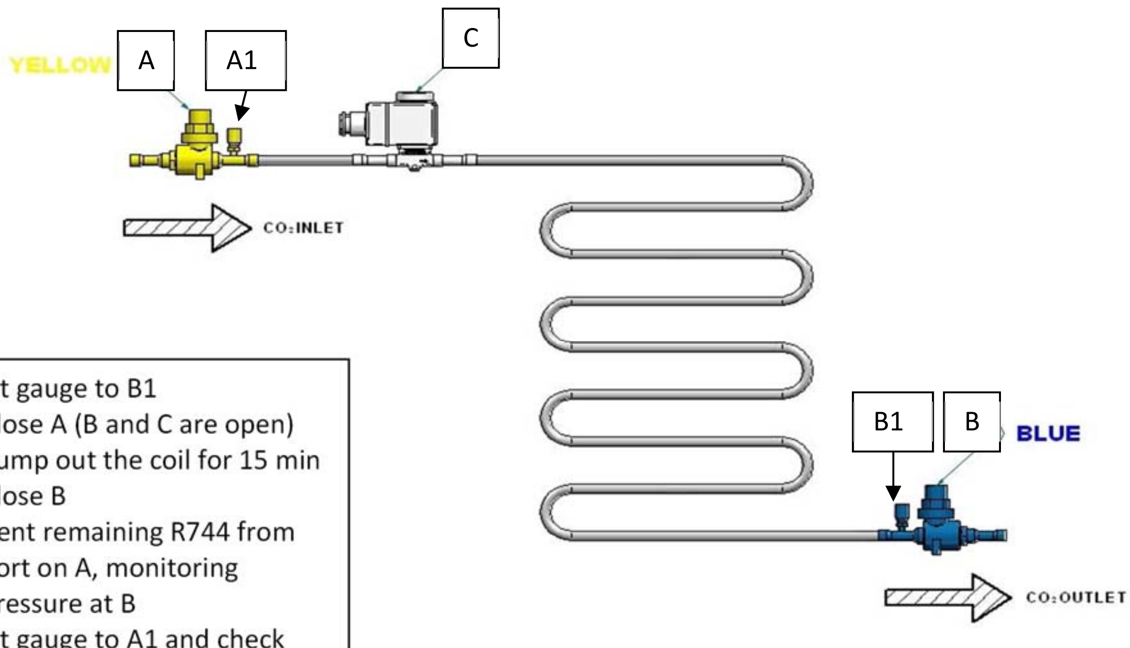
Isolating / replacing components

The R744 must be removed either by:

- Venting as described above;

  or
- Transferring liquid to another part of the system;

  or
- Evaporating liquid as described below.



1. Fit gauge to B1
2. Close A (B and C are open)
3. Pump out the coil for 15 min
4. Close B
5. Vent remaining R744 from port on A, monitoring pressure at B
6. Fit gauge to A1 and check pressure

Figure 15, removing R744 from an evaporator

Ensure that you …

- Do not trap R744 liquid;
- Do not use control valves as isolation valves;
- Do not braze or weld pipe work / components containing R744.

Note - a magnet might not open a solenoid valve because of the very high pressure - listen to ensure it opens.

Dry Ice

Dry ice can be formed in the system when venting R744.

It is very cold, so when you open the system the surfaces are very cold and moisture will condense more readily on these surfaces.   This must be dried as thoroughly as possible and the system evacuated before being put back into service.

The photos below show an example of this during a drier core replacement.

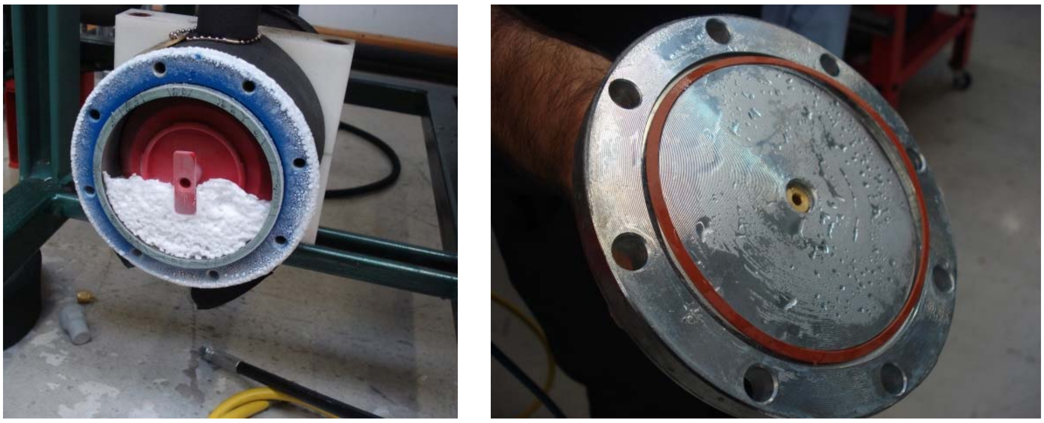


Figure 16, example of dry ice and moisture within a drier core housing

4 Working Safely with R717 (Ammonia)

The safe working environment and PPE

In addition to the precautions taken with other flammable refrigerants, positive pressure breathing apparatus may also be necessary. You must be trained in the use of this safety equipment before using it.

Figure 17, example of breathing apparatus

Personal protection equipment shall be worn when working with R717 and when purging oil and this should include at least chemical resistant gauntlet gloves, well-fitting goggles and a canister type respirator.

Access to eye wash solution should be available and for ammonia charges in excess of 1000 kg, an emergency temperature controlled water drench shower.

All procedures that involve opening the system up must be subject to detailed risk assessments and method statements with appropriate actions taken to minimise the risk to personnel. Ventilation is vital.

IOR Guidance Note on Ammonia Servicing

REAL Alternatives Guide 4 on Leak Testing

The Guidance Note from the Institute of Refrigeration includes more detailed information and covers, for example, the recommendation not to work alone, and to provide information about the work to a third party.

Equipment

All equipment used must be suitable for use with R717. Copper and brass components and fittings must not be used. On the whole, equipment used for HFC refrigerants is **not** suitable for use with R717.

The photo shows a belt driven vacuum pump suitable for use with R717.

Figure 18, vacuum pump suitable for use with R717

Leak detection

R717 leaks can be detected by the following means:

- A visual check - for example look for oil stains;
- Leak detection spray;
- A suitable electronic leak detector;
- Phenolphthalein paper.

Removal of refrigerant for service

Systems would usually be pumped down – either to another part of the system or into storage vessels – to carry out service work. A small amount of gas can be vented. Large systems may have dedicated pump out devices:

- For vapour - typically a compressor and condenser set capable of operation to low back pressure;
- For liquid - a pump unit.

Figure 19, Example of an ammonia pump

Oil recovery

Because ammonia and mineral oil are almost totally immiscible, any lubricant that enters the low side of a system tends to stay there as a layer of oil below the ammonia unless lubricant recovery devices are installed or oil is purged from the system. So for some systems the oil must be periodically manually recovered and new oil charged into the system.

Oil should be drained into a suitable open metal container and then disposed of in accordance with the relevant waste handling regulations. Never remove oil from the system without first pumping down and properly isolating the component or section of the system from which you are draining the oil.

IOR Guidance Note of Oil draining from Ammonia Systems

For safety reasons it is essential that the correct procedure is followed and is carried out by a suitably trained and certified person.

5 Self Test Module 5

Try the sample multiple choice assessments below to check your learning:

Question 1 –

When working with R1270 what is the recommended radius around the work area that should be free from sources of ignition?

I. 0.3 m
II. 1 m
III. 3 m
IV. 10 m

Question 2-

What is the usual method for removing R744 from a system?

I. It is vented in an area that is well ventilated
II. It is recovered using a high pressure recovery machine
III. It is pumped into high pressure cylinders
IV. The system is pumped down

Question 3 –

For which refrigerant is the charge weight particularly important?

I. R32
II. R1234ze
III. R744
IV. R600a

Question 4 –

When you have to do invasive work on a system containing flammable refrigerant, the working area has to be monitored by a leak detector that alarms at which percentage of the lower flammability limit for that refrigerant?

I. 100%
II. 20%
III. 50%
IV. 150%

The answers are on the bottom of the next page

What next?

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This project has been funded with support from the European Commission. This publication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

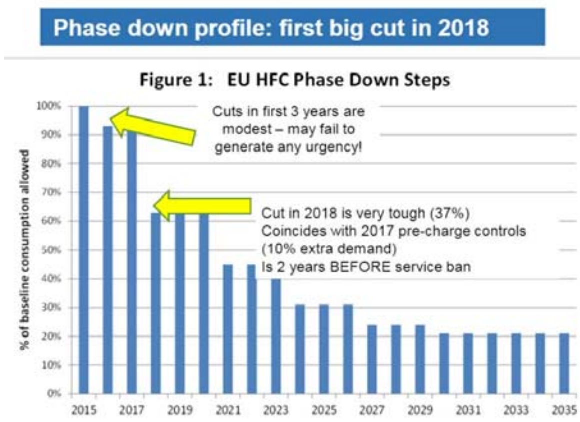
Correct answers@ Q1 =iii, Q2 = 1, Q3 = iv, Q4 = ii

With contribution of the LIFE programme of the European Union

Retrofitting Existing Systems

with low GWP Alternative Refrigerants

Contents



With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives Europe Blended Learning Programme

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www.realalternatives4life.eu

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- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
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- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 6 -

Retrofitting existing systems with alternative refrigerants

This Module covers retrofitting with alternative refrigerants. It provides an introduction to this topic. It does not replace practical training and experience. At the end of the module you will find links to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

The pages that follow will focus on options for replacing R404A or R507 and other high GWP refrigerants with lower GWP alternatives in existing systems. The emphasis is on emerging HFOs but content will be generic to other new substances as they emerge.

The retrofit of existing systems to Ammonia, Hydrocarbon and Carbon Dioxide is not generally recommended due to safety and incompatibility of components, lubricants and pipework.

Retrofit with a traditional high GWP refrigerant is also not included in this module as this is not a long term solution and should be discouraged.

1 F Gas Phase Down

See REAL Alternatives Guide 7 Legislation and Standards

The 2015 F Gas Regulation[1] includes a quota system which, from 2017, will restrict the supply of the high GWP refrigerants which are still widely used in a wide range of RAC systems. The table below shows the phase down in the supply of HFC within Europe.

Year	Phase down %	Average GWP
2015	100%	2300
2016 - 17	93%	2139
2018 – 20	63%	1449
2021 – 23	45%	1035
2024 - 26	31%	713
2027 - 30	24%	552
2030	21%	483

The phase down percentage is based on CO_2 equivalent. For example in 2018, if suppliers continue to sell the same weight of refrigerant as in 2015 its average GWP would have to reduce in 1449. Alternatively a greater weight of HFC could be sold if its average GWP is lower and vice versa.

The likely impact of the quota is that the higher GWP refrigerants will not be available or will be in short supply by 2018. This includes R404A, R507, R422D, the R407 series and R410A.

These refrigerants (with the exception of R422D) are all still used in new systems, so these systems will be difficult to service, especially in the event of a leak, well before their expected end of life.

[1] EU Regulation EU517/2014, see Guide 6 for more information

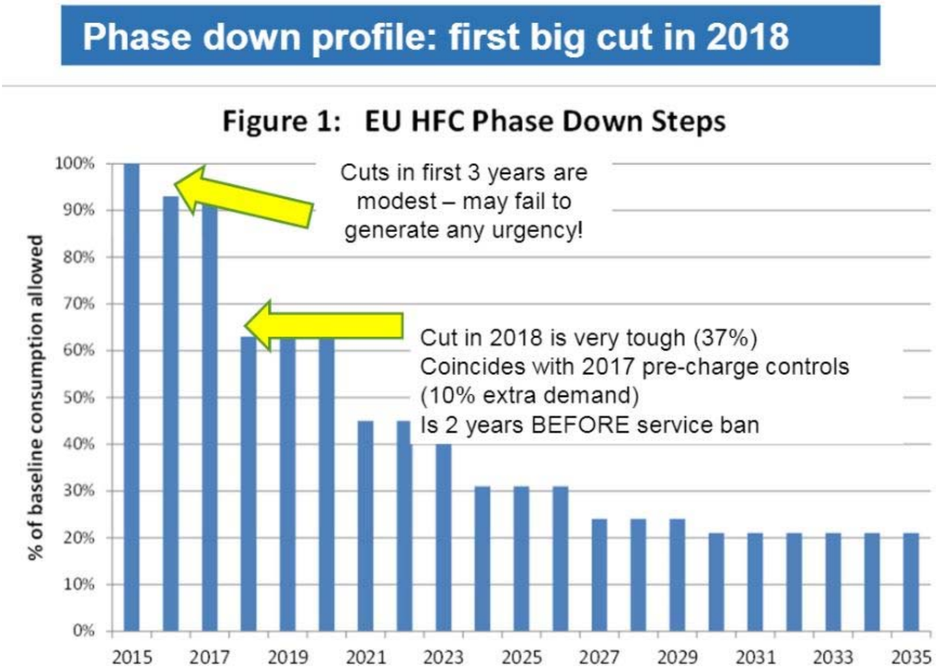

Figure 1, Chart showing HFC phase down, Gluckman consulting 2015

HFC Recovery

It is a legal requirement that HFC refrigerants being disposed of at end-of-life must undergo a recovery process. Refrigerant must be recovered by a certified technician. Recovery machines should be able to remove well over 95% of the refrigerant in an existing system. Recovered F Gases can either be:

- Sent for destruction by incineration at a licensed waste facility;
- Sent to a specialist plant that can re-process the old refrigerant into a gas with properties identical to virgin refrigerant, to create “reclaimed refrigerant”;
- Given a basic cleaning process, to create “recycled refrigerant” for reuse.

HFC refrigerant sent for reclamation may have a residual value. However if the refrigerant is very badly contaminated it cannot be reclaimed and must be sent for destruction. Some reclaim centres cannot separate mixed refrigerant so in this case it is important that different refrigerants are not mixed in a recovery cylinder.

2 Conversion

Most of the alternative refrigerants that have been included in the Real Alternatives information are not suitable for retrofit in existing systems because of their flammability, toxicity and/or high operating pressures. Refrigerant suppliers are developing a range of blends based on HFO refrigerants (R1234ze and R1234yf) which are suitable for the conversion of existing systems.

The range of HFO blends is increasing as more suppliers develop different blends. Each blend has been developed for specific applications and to replace specific existing refrigerants in that application. For example there are refrigerants available to replace:

- R134a in medium temperature applications;
- R404A in medium and low temperature stationary applications;
- R404A in medium temperature transport applications;
- R404A in low temperature applications.
- R404A in air conditioning and heat pump applications

Those blends which are suitable as R404A replacements are likely to also be suitable to replace the R407 series of refrigerants.

EN 378[2] provides guidance on change of refrigerant type. The information below is based on this.

When selecting a replacement refrigerant the following criteria must be considered:

- **Flammability** – some of the HFO blends have low flammability (safety classification A2L) and may therefore not be suitable for most existing applications – for more information about safety classifications is available in Module 1.2 – Safety and Risk management;

See REAL Alternatives Guides 1 Introduction and 2 Safety and Risk

- **Performance** – if the existing system is oversized then a small reduction in cooling capacity might be acceptable. A reduction in energy efficiency should never be acceptable;
- **Pressure** – if the operating and standstill pressures are higher with the new refrigerant this will potentially have an impact on the PS (maximum allowable pressure) of the system. Pressure relief devices, where fitted, would need replacement and the high pressure switch set point would need to be changed. More importantly, the system would need to be re assessed under the Pressure Equipment Directive as the change of refrigerant would be a major change in the system. It is possible that, even though the new refrigerant has higher operating pressures, the existing PS values can be retained. The margin between maximum

[2] EN 378-4:2016, clause 5.4.

operating / standstill pressures and PS will determine whether the PS actually needs to increase for the converted system;

- **Discharge temperature** – for many blends the discharge temperature will be higher than for the existing refrigerant and this may cause problems in particular with low temperature systems;

- **Temperature glide** – many of the blends have a high temperature glide so expansion valves will need to be checked and readjusted. It is possible that a high glide refrigerant will not be suitable for some systems, e.g. those with a flooded evaporator;

- **Oil** – it is usually necessary to check that the oil used within the existing system will be compatible with the replacement refrigerant;

- **Component compatibility –** the original equipment manufacturer should be consulted prior to undertaking a retrofit to ensure compatibility of components such as compressor, condenser, heat exchanger etc, in order not to invalidate any warranty and to ensure that the original performance and cooling capacity changes are taken into account;

- **PRV discharge capacity –** the required discharge capacity of the pressure relief valves may be higher with an alternative refrigerant;

- **Current ratings –** the required current rating of motors and switchgear may be higher than for the current system.

Software is available to help simulate the impacts of changes from a potential replacement of refrigerant and is a useful aid to decision making.

A video produced as an example from one such software tool showing comparisons when replacing an R404A system with an HFO blend is available in the REAL Alternatives e-library.

CoolTool video demonstration in e-library

Conversion Procedure

The generic conversion procedure below can be adapted for specific systems.

1. Record the operating temperatures, pressures and current consumption of the system with the current refrigerant;

2. Correct any issues identified;

3. Leak test the system and repair any leaks found;

4. Recover the refrigerant and ensure it is sent for reclaim or disposal. Do not vent the refrigerant;

5. Change components as required, especially seals which may leak after the conversion;

6. Carry out a tightness test using nitrogen;

7. Evacuate the system;

8. Charge with the new refrigerant (the charge weight may differ due to density difference);

9. Adjust control and protection device settings if required;

10. Amend labels and documentation;

11. Check and record operating temperatures, pressures and current consumption of the system with the current refrigerant.

It may also be necessary to change the compressor lubricant, although most of the alternative refrigerants will use the same lubricant as the HFC you are replacing.

3 Available Refrigerants

No single substance low GWP refrigerant is available to replace HFCs such as R404A. Refrigerant manufacturers and suppliers are developing a range of HFO based blends and the list of available refrigerants is changing rapidly. Contact your suppliers for more information about the latest blend availability and suitability. Links to key suppliers are shown on the Additional Resources page.

For more information about the properties of HFO refrigerants refer to Module 1 – Introduction to Alternative Refrigerants and Module 2 – Safety and Risk Management.

See REAL Alternatives Guides 1 Introduction and 2 Safety and Risk

Refrigerant	Composition	GWP	Replaces	Flammability
R450A	R1234ze/R134a	605	R134a HM	A1
R456A	R32/R1234ze/R134a	687	R134a	A1
R513A	R1234yf/R134a	631	R134a HM	A1
R513B	R1234yf/R134a	596	R134a	A1
R407A	R32/R125/R134a	2107	R404A	A1
R407F	R32/R125/R134a	1825	R404A	A1
R407H	R32/R125/R134a	1378	R404A	A1
R448A	R32/R125/R1234yf/R134a/R1234ze	1386	R404A ML	A1
R449A	R32/R125/R1234yf/R134a	1397	R404A ML	A1
R449B	R32/R125/R1234yf/R134a	1412	R404A	A1
R452A	R32/R125/R1234yf	2141	R404A ML, transport	A1
R452C	R32/R125/R1234yf	2220	R404A	A1
R460A	R32/R125/R1234ze/R134a	2103	R404A	A1
R460B	R32/R125/R1234ze/R134a	1352	R404A	A1
R444A	R32/R152a/R1234ze	92	R134a	A2L
R445A	R32/R152a/R1234ze	90	R134a M	A2L
R454C	R32/R1234yf	148	R404A	A2L
R455A	R744/R32/R1234yf	145	R404A R407 series	A2L
R457A	R32/R1234yf/R152a	139	R404A	A2L
R459B	R32/R1234yf/R1234ze	144	R404A	A2L

Figure 2, Examples of available refrigerants for retrofit as at December 2017

H, high temperature applications, including air conditioning and heat pumps
M, medium temperature applications
L, low temperature applications.
There is no non flammable alternative to R410 (R32 must not be used to convert R410A systems).

4 Additional Resources

The information in this Module covers the basics of retrofitting existing systems. It is not designed to replace practical training and work based experience. If you would like to find out more about some of the topics covered you can explore some of the recommended free resources below. These are often produced by manufacturers or specialist associations. All material has been peer reviewed by our panel to ensure it provides good quality technical advice and information, which is more detailed than we can provide in our e-learning programme. Inclusion as a link does not imply endorsement of produce and there is no commercial link with any of the companies referred to.

Suppliers of low GWP HFO alternatives suitable for retrofit:

- Honeywell – Solstice guide: http://www.honeywell-refrigerants.com/europe/product/solstice-1234ze/
- Mexichem Fluor via Harp International Refrigerants: http://www.harpintl.com/refrigerants.php
- Opteon Refrigerants: www.chemours.com
- Bitzer Refrigerant Report 19: https://www.bitzer.de/shared_media/documentation/a-501-19.pdf
- Emerson listing of all refrigerants and lubricants approved for its Copeland compressors https://opi.emersonclimate.com/CPID/GRAPHICS/Types/AEB/93-11.pdf
- Cool Tool Software for evaluating of refrigerant options (free sample version available) : http://www.cooltool-software.com/index_english.htm

Additional recommended resources added regularly to the REAL Alternatives 4 LIFE e-library at www.realalternatives4life.eu/e-library

There is no assessment associated with this Module.
This module is designed as a list of essential information only.

What next?

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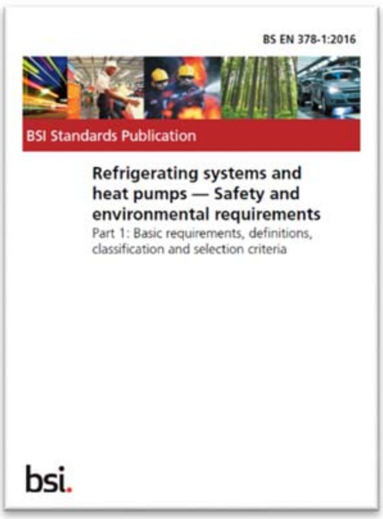
Legislation & Standards

For Alternative Refrigerants


BS EN 378-1:2016

BSI Standards Publication

Refrigerating systems and heat pumps — Safety and environmental requirements

Part 1: Basic requirements, definitions, classification and selection criteria

bsi.

Contents

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Module 6 –

Checklist of Legal Obligations for Alternative Refrigerants

This Module covers **key** legal obligations related to low GWP alternative refrigerants. It provides a general summary of the most significant legislation and standards. Additional requirements may be in place depending on the refrigerant and application under consideration.

REAL Alternatives References Supplementary Guide

Throughout the module you will find a list of links to the documents referred to and useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

The following pages include information about the most important legislation and standards which apply specifically to RACHP systems which use an alternative refrigerant.

Guidance to a fuller range of standards and regulations is provided in the Reference Guide highlighted right and in Guide 1 (Introduction).

REAL Alternatives Guide 1, Introduction

1 General – Key Standards

EN378 Refrigerating systems and heat pumps – Safety and environmental requirements (Revised 2016)

This is the "horizontal standard[1]" that covers most refrigeration, air conditioning and heat pump systems. The table below shows the four parts of the standard and lists some of the guidance which is most relevant to the differences of alternative refrigerants.

Table 1, EN378

Document	Title	Guidance (relevant to alternative refrigerants)
EN378-1:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Basic requirements, definitions, classification and selection criteria	Refrigerant practical limit Maximum charge sizes
EN378-2:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation	High pressure protection Ventilated enclosures Leak simulation testing for flammable refrigerant systems
EN378-3:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Installation site and personal protection	Requirements for machinery rooms Refrigerant detectors
EN378-4:2016	Refrigerating systems and heat pumps – Safety and environmental requirements, Operation, maintenance, repair and recovery	Repairs to systems using flammable refrigerants Competence of personnel working on systems using flammable refrigerants

ISO817 Refrigerants - Designation and safety classification

This international standard provides an unambiguous system for numbering refrigerants and classification of flammability and toxicity.

Note: Other standards may apply depending on the application. This selection is not exhaustive.

[1] Horizontal Standard covers fundamental principles, concepts, terminology or technical characteristics

2 Key Regulations

Pressure Equipment Directive 2014/68/EU

The Pressure Equipment Directive (PED) is a European directive that sets out the standards for the design, testing and fabrication of pressure equipment generally over one litre in volume and having a maximum pressure more than 0.5 bar gauge (such as refrigeration systems). It also sets the administrative requirements for the "conformity assessment" of pressure equipment, for the free placing on the European market without local legislative barriers. It has been mandatory throughout the EU since 30 May 2002.

R717, R32 and the hydrocarbon refrigerants are classified as group 1 fluids.
R744 and R1234ze are group 2 fluids.

Pressure Systems Safety Regulations (PSSR) 2000

The PSSR applies to systems with a total installed power exceeding 25kW. A written scheme of examination is required which in effect means that liquid receivers and pressure relief devices should be checked every five years by a competent person.

Institute of Refrigeration Guidance Note 21 “Pressure Equipment and Systems Guide to Regulations

3 Fluorinated Gases

UK DEFRA F Gas Support

AREA Guides for contractors

Summary of F Gas Regulation

The Fluorinated Greenhouse Gas Regulations (EU517/2014) apply to HFCs including R32. The Table shows a summary of the regulation:

Table 2, Summary of F Gas regulation

Leak Checks	Regular checks for leakage; use of automatic leak detection on large systems.
Recovery	• Refrigerant recovery during plant servicing and maintenance and at end of life.
Records	• Appropriate records kept for equipment containing 3 kg or more of F gases.
Training & Certification	• Use of personnel with appropriate qualifications. • Company Certification required for all companies employing personnel to undertake work on equipment containing or designed to contain F gases (includes sole traders). • Companies taking delivery of F gases need to employ personnel with appropriate qualifications if undertaking leak checking, refrigerant recovery, plant installation, maintenance or servicing. • Refrigerant in cylinders can only be supplied to companies or individuals who hold F Gas Certification. • Information to be made available on Alternatives to high GWP HFC technologies.
Other	• Certain other actions including labelling of new equipment and a schedule for the phase down of supply of HFC refrigerants in Europe.

This regulation replaces EC 842/2006 and came into force on 1st January 2015.

F Gas Leak testing

In EU517/2014 the requirement for leak testing existing systems is based on the charge size in tonnes of CO_2 equivalent.

ACRIB Guidance on calculating GWP and CO_2 equivalent values

The GWP of single substance refrigerants is provided in an Annex 1 to EU 517 / 2014 and for blended refrigerants it must be calculated from the GWP of the individual components (see the ACRIB document right for information on this).

AREA calculator

The leak test frequency is given in table 3, with some example charge sizes for R32.

Table 3, Leak test frequency

System charge	Leak test frequency
5* to < 50 tonnes CO_2 equiv. e.g. 7.4 to < 74 kg R32	1 / year 1 / 2 years if a fixed leak detection system is fitted
50 to < 500 tonnes CO_2 equiv. e.g. 74 to < 741 kg R32	2 / year 1 / year if a fixed leak detection system is fitted
> 500 tonnes CO_2 equiv. Fixed leak detection must be fitted e.g. > 741 kg R32	4 / year 2 / year if a fixed leak detection system is fitted

*10 tonnes CO_2 equivalent for hermetically sealed systems. This was applicable from 1st January 2017.

Fixed leak detection is required for existing systems containing over 500 CO_2e tonnes and must alert the operator of the system or the service company and must be checked once a year.

The requirement for maintaining system logs changes from 3kg HFC system charge to an equivalent charge of 5 tonnes CO_2

F Gas Training and Certification

Previously issued and still current F Gas qualification for individuals granted according to EC 303/2008 remain valid in accordance with their terms of issue. However, there is an additional requirement that certification programmes and training should include:

"Information on relevant technologies to replace or to reduce the use of fluorinated greenhouse gases and their safe handling."

This is likely to include hydrocarbon refrigerants, R744, R717 and HFOs. Clarification from the Commission on the requirements is awaited (as at March 2015).

Service of Equipment Containing F Gases

From 1st January 2020 the use of F Gases with GWP > 2500 for service will be prohibited for systems which contain more than 40 tonnes CO_2 equivalent. There is an exclusion - recycled or reclaimed refrigerant can be used until 1st January 2030.

Placing on the Market Bans

There is a gradual phase out of the use of some HFCs, dependent on GWP and application. The most applicable are shown in table 4 below.

Table 4, Bans for application of some HFCs

Ban effective from 1st Jan:	Application	Ban effective for refrigerants with a GWP greater than:
2015	Domestic fridges, freezers	150
2020	Commercial fridges, freezers	2500
2022	Commercial fridges, freezers	150
2020	Most stationary HFC equipment	2500
2022	Central plant greater than 40 kW cooling capacity (The high stage of a cascade can use HFC with a GWP up to 1500)	150
2020	Moveable room air conditioning	150
2025	Single split air conditioning with less than 3kg charge	750

Note – this is for new systems placed on the market from the dates shown, not existing systems.

Pre Charged Systems

Non hermetically sealed pre charged unit will only be able to be installed by a company which employs engineers who hold an F Gas qualification. An example of such a system is a split air conditioning unit where the outdoor unit is pre charged with the refrigerant.

4 Flammable Refrigerant Legislation

There are additional regulations and standards which cover the design of flammable refrigerant systems and components.

ATEX

ATEX is the name commonly given to the legal requirements for controlling explosive atmospheres and the suitability of equipment and protective systems used in them.

- ATEX 95 (94/9/EC) covers the design of equipment and protective systems intended for use in potentially explosive atmospheres.
- ATEX 137 (99/92/EC) covers the minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres. It applies, for example, to service engineers working on HC systems.
- In the UK DSEAR is the implementing regulation for ATEX 137.

EN378 is not harmonised with the ATEX directive and it does not specify that ATEX applies, but it does reference ATEX harmonised standards such as EN60079. System designers and manufacturers should follow ATEX to assess whether the risk of an explosive atmosphere can occur.

The following documents include guidance on systems using flammable refrigerants.

Table 4, Reference documents for flammable refrigerants

Document	Title	Guidance (relevant to flammable refrigerants)
EN60079-0:2012+A1 2013	Explosive atmospheres – Equipment – general requirements	Categorisation of flammable gases Classification of equipment Zones
EN60079-10-1:2015	Explosive atmospheres – Classification of areas – explosive gas atmospheres	Zones and classification of equipment Leak simulation testing Air flow requirements
EN60079-14:2014	Explosive atmospheres – Electrical installations design, selection and erection	Location of sources of ignition Wiring
EN60079-15:2010	Explosive atmospheres – Equipment protection by type of protection "n"	Electrical equipment and enclosures for use in potentially flammable areas Labelling of electrical equipment
EN 378	Refrigerating systems and heat pumps – Safety and environmental requirements	See section on EN 378
EN60335-2-24:2010	Household & similar electrical appliances – Safety Part 2-24: Particular requirements for refrigerating appliances, ice-cream appliances & ice-makers	Systems with less than 150 g flammable refrigerant charge.

EN60335-2-40:2012	Household & similar electrical appliances – Particular requirements for electrical heat pumps, air conditioners and dehumidifiers	Design, application and servicing of AC systems using flammable refrigerants.
EN60335-2-89:2010	Household & similar electrical appliances – Safety Part 2-89: Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant condensing unit or compressor	Systems with less than 150 g flammable refrigerant charge, leak simulation testing for area classification.

DSEAR

In the UK DSEAR is the implementing regulation for ATEX 137. DSEAR stands for the Dangerous Substances and Explosive Atmospheres Regulations 2002. DSEAR puts duties on employers and the self-employed to protect people from risks to their safety from fires, explosions and similar events in the workplace, this includes members of the public who may be put at risk by work activity. Employers must:

- find out what dangerous substances are in their workplace and what the fire and explosion risks are;
- put control measures in place to either remove those risks or, where this is not possible, control them;
- put controls in place to reduce the effects of any incidents involving dangerous substances;
- prepare plans and procedures to deal with accidents, incidents and emergencies involving dangerous substances;
- make sure employees are properly informed about and trained to control or deal with the risks from the dangerous substances;
- identify and classify areas of the workplace where explosive atmospheres may occur and avoid ignition sources (from unprotected equipment, for example) in those areas.

What next?

There is no assessment associated with this Module. This module is designed as a checklist of essential information only.

To find out more about some of the topics covered see the recommended resources below. Where they are produced by manufacturers or specialist associations material has been peer reviewed by our panel to ensure it provides good quality technical advice and information. It is more detailed than we can provide in our e-learning programme. Inclusion as a link does not imply endorsement of products and there are no commercial links with any of the companies referred to.

Additional learner recommended resources are also available in the REAL Alternatives e-library at http://www.realalternatives.eu/e-library

ISO International standards

ISO 817:2014, Refrigerants -- Designation system, An unambiguous system for numbering refrigerants. It includes safety classifications (A1, A2L, A2, A3). Available to purchase from the International Standards Association
http://www.iso.org/iso/store.htm

European standards

EN378 Refrigerating systems and heat pumps – Safety and environmental requirements
Available to purchase from European Standards Association
http://standards.cen.eu/dyn/www/f?p=CENWEB:5:::NO:::
or in English from BSI
http://shop.bsigroup.com/ProductDetail/?pid=000000000030291772

Institute of Refrigeration Publications

IOR Guides to Standards, Regulations and Legislation
www.ior.org.uk

European Regulations and Directives

-Pressure Equipment Directive 2014/68/EU
https://ec.europa.eu/growth/sectors/pressure-gas/pressure-equipment/directive_en
(UK guidance at http://www.realalternatives.eu/guide-to-thpressure-equipment-directive-for-service-engineers)

-The Fluorinated Greenhouse Gas Regulations (EU517/2014) New F Gas Regulation 2014 and Leak testing requirements
http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&from=EN

-F Gas Regulation pursuant regulation on training – 303/2008
http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008R0303

-ATEX
https://ec.europa.eu/growth/sectors/mechanical-engineering/atex_en DSEAR

http://www.hse.gov.uk/fireandexplosion/dsear.htm
(UK checklist guidance http://www.ior.org.uk/app/images/pdf/DSEAR%20Self-Assessment%204%20page.pdf)

F Gas Regulation useful guidance

F Gas Support documents (UK)
https://www.gov.uk/government/collections/eu-f-gas-regulation-guidance-for-users-producers-and-traders

EPEE (EU)
http://www.epeeglobal.org/refrigerants/

AREA Guide to the new F Gas Regulations for contractors
http://area-eur.be/publications/guide-new-f-gas-regulation

Note: The information in this guide is an introduction to key legislation. It is not comprehensive and may not cover additional national or European requirements that you must also follow. There is much more information in the documents highlighted in the links. Go to the on line reference e-library at www.realalternatives.eu/e-library to explore any additional information you may find useful.

You can now continue your self-study with one of the following **Real Alternatives 4 LIFE** programme Modules:

1. Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2. Safety and risk management
3. System design using alternative refrigerants
4. Containment and leak detection of alternative refrigerants
5. Maintenance and repair of alternative refrigerant systems
6. Retrofitting with low GWP refrigerants
7. Checklist of legal obligations when working with alternative refrigerants
8. Measuring the financial and environmental impact of leakage
9. Tools and guidance for conducting site surveys

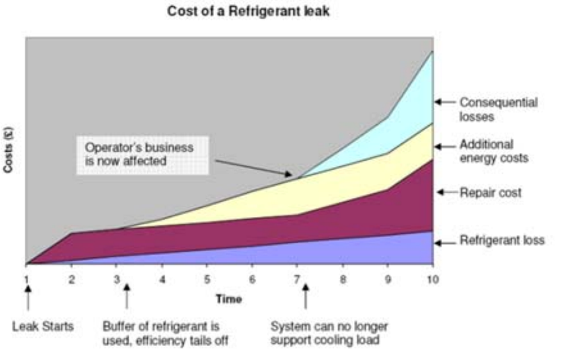
This project has been funded with support from the European Commission. This publication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

With contribution of the LIFE programme of the European Union

Financial, environmental, safety & reliability costs of leakage

Alternative Refrigerants & Leakage

Contents



With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives

4 LIFE Blended Learning Programme

This learning booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives4LIFE.eu

REAL Alternatives 4 LIFE has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Croatian, Czech, Dutch, English, French, German, Italian, Polish, Romanian, Spanish and Turkish.

Real Alternatives Europe Programme Modules	
1	Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2	Safety and Risk Management
3	System design using alternative refrigerants
4	Containment and leak detection of alternative refrigerants
5	Maintenance and repair of alternative refrigerant systems
6	Retrofitting with low GWP refrigerants
7	Checklist of legal obligations when working with alternative refrigerants
8	Measuring the financial and environmental impact of leakage
9	Tools and guidance for conducting site surveys

You can study each module individually or complete the whole course and assessment.

www.realalternatives4life.eu

More information is available in the on line reference e-library. Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives4life.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

Assessment options are available if you want to gain a recognised CPD Certificate. At the end of each module are some simple self-test questions and exercises to help you evaluate your own learning. Certification and Assessment will be available from licensed REAL Alternatives training providers when you attend a course of study. The list of recognised training providers will be available on the website.

Register your interest in alternative refrigerants at www.realalternatives4life.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

Background to the programme and how it was developed. This learning programme was developed as part of EU co-funded projects led by a consortium of partners from across Europe. It is designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders from across Europe drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed.

The consortium partners were:

- Association of European Refrigeration Air Conditioning & Heat Pump Contractors, Belgium
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- International Institute of Refrigeration
- University College Leuven-Limburg, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

With thanks to our stakeholders:

- CNI National Confederation of Installers, Spain
- CHKT Czech Association for cooling and air conditioning technology
- HURKT, Croatian Refrigeration Airconditioning and Heat Pumps Association
- RGAR Association General of Refrigeration, Romania
- SOSIAD Association of Refrigeration Industry and Businessmen, Turkey
- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 7 -

Measuring the Financial, Environmental, Safety and Reliability Costs of Refrigerant Leakage

This Module provides an introduction to evaluating the financial, environmental, safety and reliability costs of refrigerant leakage. It does not replace practical training and experience. Throughout the module you will find references to useful additional information from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

The following pages detail the costs of refrigerant leakage. A leaking system:

- Has a lower cooling capacity (and therefore the capacity may not meet the load);
- Can consume more power (which has an indirect environmental impact);
- Is less reliable (an undercharged system works harder and is therefore are more prone to failure);
- Is more hazardous – all refrigerants are asphyxiants, many alternative refrigerants are flammable and R717 is also toxic.

Most alternative refrigerants have a low direct global warming potential, but the other impacts of leakage (e.g. on energy consumption) are similar to those for traditional refrigerants. So leakage matters and must be minimised whatever the refrigerant.

1 Environmental Impact of Refrigerant Leakage & RAC System Operation

Leaking refrigerant has a double impact on climate change:

- A direct effect if the refrigerant has a global warming potential;
- An indirect effect because of the increase in power consumption.

Increases costs – service, refrigerant, electricity, downtime

Leaking refrigerant

Increases adverse climate change - the "direct" effect

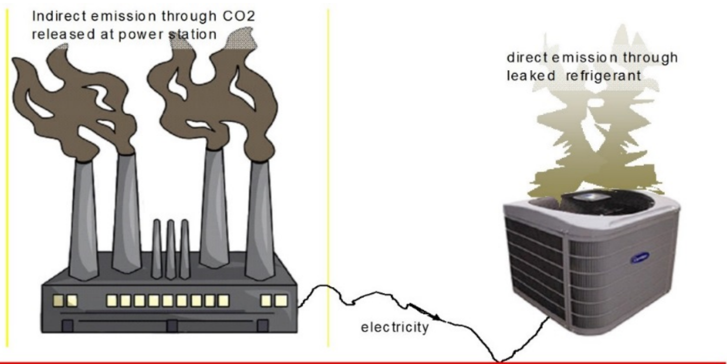
Reduces system efficiency

Increases power consumption

Increases CO_2 emissions (at the power station)

Increases adverse climate change - the "indirect" effect

The total carbon emissions of a system include both the effect of leaking refrigerant and the power consumption of a system.



RAC contributes 10% of all worldwide GHG emissions.
8% through electricity use and 2% through leakage

The next section provides more information on this. In addition, the Total Equivalent Warming Impact (TEWI) is outlined in Module 1.

REAL Alternatives Guide 1 - Introduction

Global warming potential (GWP)

The global warming potential (GWP) of a refrigerant is a measure of how much a given mass of greenhouse gas (e.g. HFC refrigerant) is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide (whose GWP is by definition 1). A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless.

Substances such as HFCs which have a high GWP tend also to absorb a lot of infra-red radiation and have a long atmospheric lifetime.

The GWP of alternative refrigerants is shown below:

	Type	Key facts	GWP (1)	Typical applications
R744	Carbon dioxide, CO_2	High pressures	1	Retail refrigeration, heat pumps, integrals
R717	Ammonia, NH_3	Toxic and mildly flammable	0	Industrial
R32	Hydro fluoro carbon, HFC	low flammable	675	Split air conditioning
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	low flammable	7	Chillers, split air conditioning, integrals
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	high Flammable	3	Domestic and small commercial systems
R290	Propane, C_3H_8, hydrocarbon (HC)	high Flammable	3	Chillers, integrals
R1270	Propene (propylene), C_3H_6, hydrocarbon (HC)	high Flammable	3	Chillers, integrals

(1) GWP is from F Gas Regulation EU 517: 2014

GWP and carbon dioxide equivalency

Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years). The carbon dioxide equivalency for a gas is obtained by multiplying the mass (weight) and the GWP of the gas. The following units are commonly used:

- kg of carbon dioxide equivalents (kg CO_2e).
- tonnes of carbon dioxide equivalents (T CO_2e).
- million tonnes of carbon dioxide equivalents (MT CO_2e).

For example, the GWP for R290 (propane) over 100 years is 3 and for R32 is 675. This means that a leak of:

- 1 tonne of R290 is equivalent to emissions of 3 tonnes of carbon dioxide (T CO_2e).
- 1 tonne of R32 is equivalent to emissions of 675 tonnes of carbon dioxide (T CO_2e).

Calculating the environmental cost of leakage

The direct impact of leakage on climate change is calculated simply by multiplying the GWP of the refrigerant by the amount which has leaked in a given time. Two examples are shown below:

	Example A traditional HFC System	Example B system containing a low GWP refrigerant
Refrigerant	R404A	R32
Charge size	10kg	10kg
GWP	3922	675
Leakage recorded	Over a 12 month period 2 kg is added to both systems to replace refrigerant lost - Leakage rate is 20%	
Total Direct Impact	2 x 3922 = 7822 CO_2e	2 x 675 = 1350 CO_2e

Comparing refrigerant leakage to other environmentally damaging activities

It is useful to relate the impact of refrigerant leakage to other activities which impact on climate change, such as driving a vehicle. You need to know some key figures to be able to do this – these are provided in Appendix 1 of this Guide as typical figures for making carbon calculations.

This information allows you to compare the impact of climate change of refrigerant leakage to activities such as driving a vehicle, flying, running an appliance etc.

In Example B above the direct impact of 2kg of R32 leakage is 1350 CO_2e – this is equivalent to driving 6750 km in a car (assuming 0.200 of kg CO_2 per km for an average petrol car).

Indirect Impact

So far we have only considered the direct effect of leakage, not the indirect effect caused by less efficient operation which can happen when a system is under-charged. This is covered in the next section – it can be more significant than the direct impact for most of the alternative refrigerants.

2 Measuring the financial cost of leakage

It is very difficult to accurately calculate the total financial cost of leakage. The following contribute to the cost:

Table 1, illustrative refrigerant costs

Refrigerant	Typical cost € / kg
R744	3.75
R717	1.50
R32	7.50
R1234ze	37.50
R600a	9.30
R290	11.90
R1270	12.40

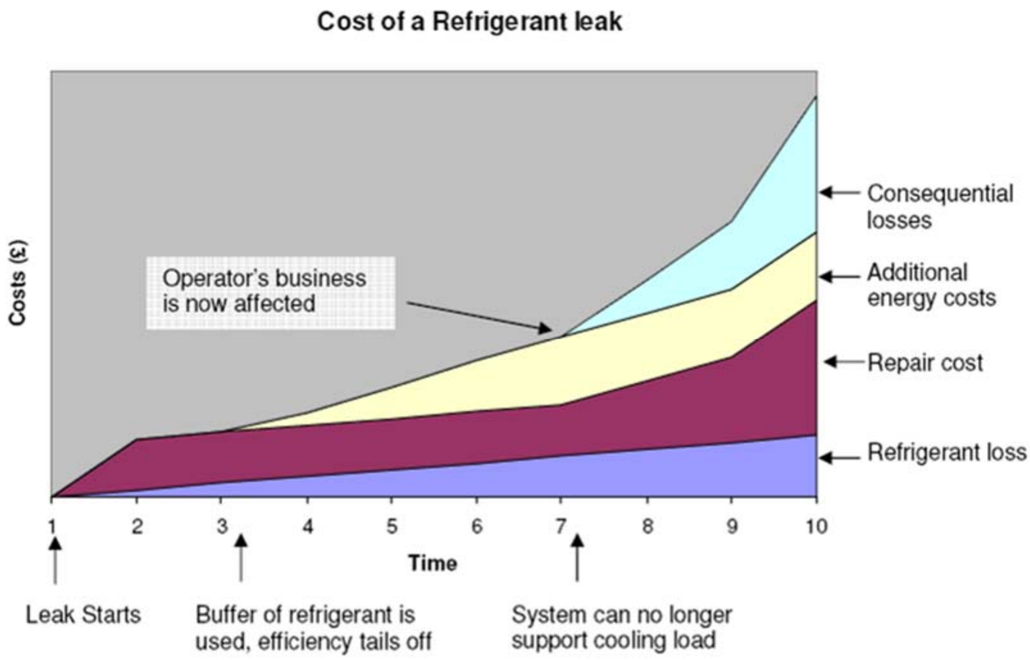
- Refrigerant – this is easy to calculate from the buying price of the refrigerant and the amounts used (note – buying prices vary significantly and depend on the discount provided by the supplier). As a guide typical costs are given in table 1;

- Cost of labour (and materials) to find and repair the leak and re charge with refrigerant – this should be easy to find from the service records but there will be a wide range as the work that needs to be carried out to fix a leak varies significantly depending on the location and magnitude of the leak and the type of system;

- Additional running cost of the system due to under charge of refrigerant – this can be very difficult to estimate as the profile of energy consumption vs. charge amount varies with different systems and there is very little practical data available. A simple example is given later in this section;

- Downtime and consequential losses – some end users have this information, but it varies significantly.

The costs will vary depending on how quickly the leak is found and repaired, as shown in the diagram below.



System running cost

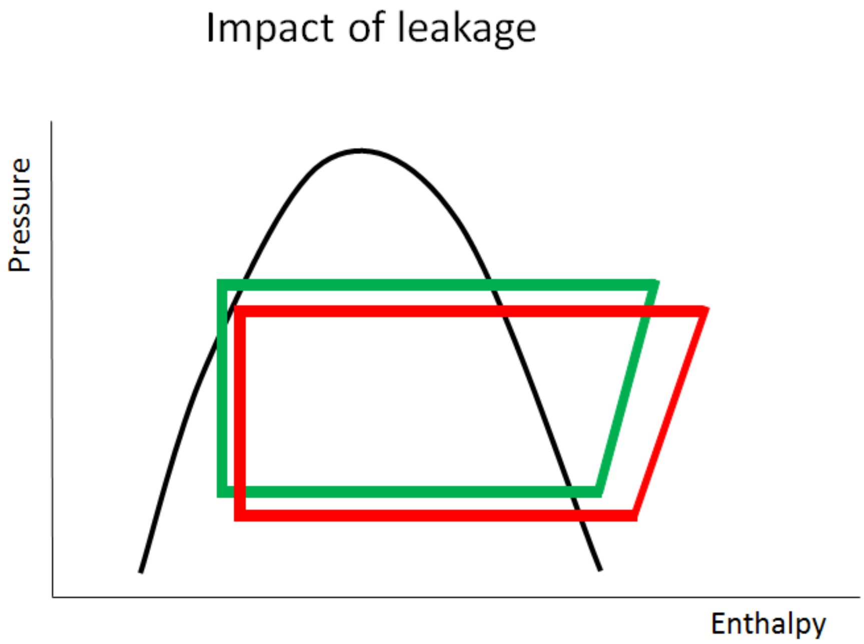
There is no simple correlation between leakage and energy efficiency - the impact of refrigerant leakage on energy consumption varies widely depending on the system as shown in the tale below.

Figure 1, Impact of refrigerant leak on different types of system

System type	Impact of leakage
Small system with no liquid receiver (i.e. a critically charged system), e.g. many integral systems, split AC systems.	A loss of just 5% of the charge will reduce the efficiency because the refrigerant in the liquid line will be saturated rather than sub cooled, so less liquid refrigerant will flow into the evaporator. This reduces the suction pressure and the saturated evaporating temperature. A drop of just $1^{O}C$ in evaporating temperature will reduce efficiency (and increase electricity consumption) by between 2 and 4%.
Simple condensing unit evaporator systems with a liquid receiver, e.g. small retail systems, cold room systems, liquid chillers.	The receiver contains a buffer of refrigerant which is only required at extreme operating conditions (e.g. maximum load and maximum ambient). Once this buffer has leaked the effect is similar to that outlined above. The time taken to reach the critical charge will vary depending on the degree of leakage, load and ambient. While the buffer is leaking there is no effect on energy consumption (but there is a potential safety and environmental hazard).
Central plant systems with multiple compressors and evaporators, e.g. large supermarket systems, industrial plant.	As with the simple system above the receiver buffer will leak before there is an effect on performance. At this point the furthest evaporator from the pack will receive insufficient refrigerant and the solenoid valve will be open longer to get the desired refrigeration effect. As the leakage continues more evaporators will be starved. The effect is that the pack will run longer to provide the same cooling effect.

Showing the impact of leakage on a pressure enthalpy chart

The Figure below illustrates how refrigerant leakage can affect system performance on a Ph Chart. It shows that leakage reduces discharge and suction pressure but increases superheat.



The following graph shows the impact of leakage on COP based upon a number of experimental studies. It can be seen that a 10% reduction in charge can reduce COP by 10%. In addition, there is an associated reduction in cooling capacity.

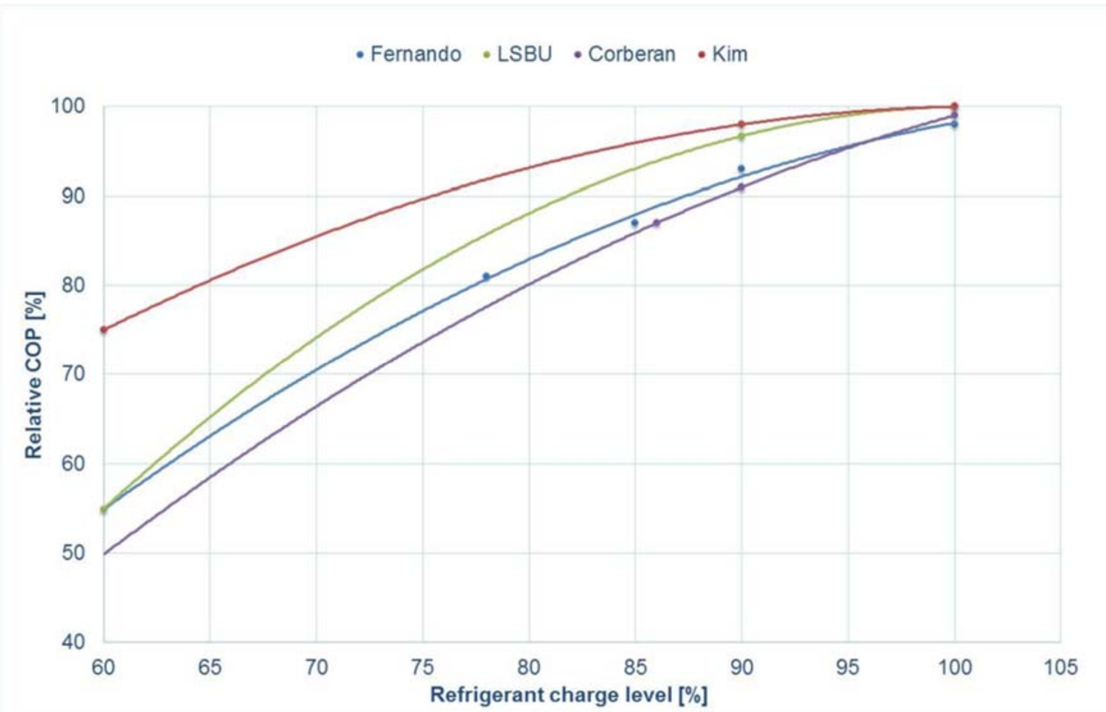


Figure 2, DECC Report on Impact of Leakage of Refrigerants from Heat Pumps, April 2014

Energy Costs Associated with Leakage

Example 1

The example below is for a simple single condensing unit single evaporator system. It is a low temperature cold room with a load of 10 kW. The system has the following operating conditions when fully charged:

- Evaporating temperature of -25^{O}C,
- 5 K useful superheat,
- -15^{O}C suction return temperature,
- 7K liquid sub cooling
- Condenser temperature difference (TD) of 10K.

The system performance is calculated in the table below:

	Fully charged system	Under charged system
Capacity, kW	12.9	**9.9**
Power input, kW	8.2	**8.0**
COP*	1.56	**1.24**
Annual running cost	**€5725**	**€6955**

*COP (Coefficient of Performance) is capacity / power input.

The above table includes the annual energy cost based upon full load operation for one year and an electricity cost of 0.175 euro / kW And highlights the significant increase in running cost of the undercharged system.

To accurately determine the increase in cost for a leak on this type of system you would need to know:

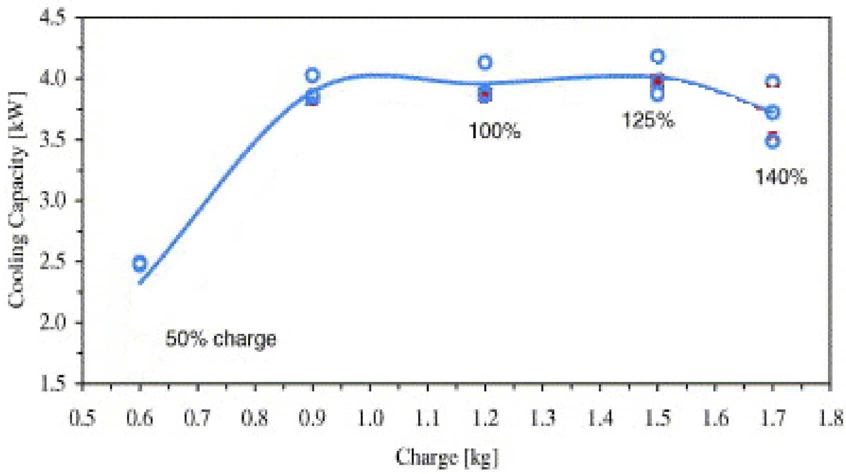
- Design operating conditions;
- Operating conditions when undercharged (this is likely to change as the leak continues);
- Length of time the system has been undercharged;
- Effect on operating conditions of under charge of refrigerant;
- System / compressor data, ambient temperature profile and load profile to calculate the performance and running cost of the system fully charged and under charged.

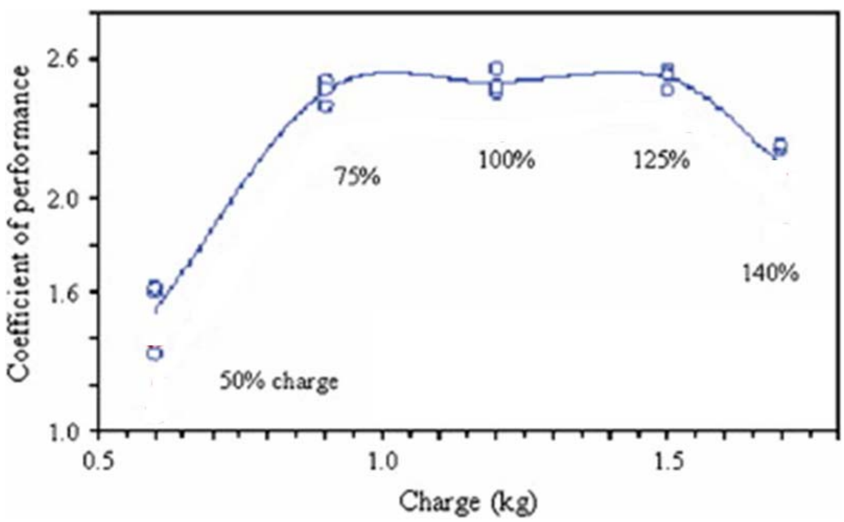
For many systems this information is not all available, but often an estimate can be made on the basis of that shown in the example above.

In addition, cooling capacity may be affected resulting in the system not meeting the cooling demand.

Example 2

The graphs below show the results of research on one system type to determine the effect of leakage on one system[1]:





Systems operate inefficiently for many reasons and there is often the opportunity to improve systems efficiency by simple, cost effective measures. These are outlined in five Guides available in the REAL Alternatives e-library.

Carbon Trust Guides for Owners of Refrigeration Equipment on Efficiency

In particular the following two guides will be helpful in reducing running costs of existing systems:

- Operational efficiency improvements for refrigeration systems;
- Results of site investigations.

[1] Graph modified from Grace, I.N., Datta, D. and Tassou, S.A. (2005), Sensitivity of refrigeration system performance to charge levels and parameters for on-line leak detection. Applied Thermal Engineering, 25 (2005), pp. 557–566

3 Safety

All alternative refrigerants are hazardous, so in the event of a leak there is a safety concern. The hazards associated with alternative refrigerants are summarised in the table below. More detailed information is provided in Guides 1 and 2.

REAL Alternatives Guides 1, Introduction and 2 Safety and Risk

	Type	Key hazards
R744	Carbon dioxide, CO_2	Asphyxiant. High operating and standstill pressures. Contact with liquid or dry ice will cause freeze burns.
R717	Ammonia, NH_3	Toxic Lower flammability. Asphyxiant. Contact with liquid will cause freeze burns.
R32	Hydro fluoro carbon, HFC	Lower flammability. Asphyxiant. Contact with liquid will cause freeze burns.
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	Higher flammability. Asphyxiant. Contact with liquid will cause freeze burns.
R290	Propane, C_3H_8, hydrocarbon (HC)	
R1270	Propene (propylene), C_3H_6, hydrocarbon (HC)	

Gas detection should be used if a dangerous concentration can be exceeded in the event of a leak. For example:

- EN 378 Part 3 Clauses 8 and 9 define specific requirements for gas detection. Clause 9.1 states "when the concentration can exceed the practical limit … detectors shall at least actuate an alarm".

REAL Alternatives 4 Containment

- For flammable refrigerants such as R717, R290 and R1270 leak detection must be installed to alarm at levels no greater than 25% of the LFL.

If a risk assessment identifies that a "dangerous concentration can be exceeded" - whether from a flammable or toxic refrigerant in areas such as machinery rooms or other spaces (particularly where people are present) gas detection must be installed.

It is important that this equipment is functional, and that its operation is checked periodically (e.g. annually).

1. Making a case for reducing leakage

Reducing leakage makes business, financial and environmental sense.

The benefits to business include:

- ☑ Compliance with legislation including the F Gas regulation;
- ☑ Improved “green” credentials;
- ☑ Reduced production down time / increased sales fixture availability / improved staff comfort as a result of improved reliability;
- ☑ Less health and safety risk from refrigeration or air conditioning – directly from refrigerant emissions and, for food applications, indirectly as a result of improved reliability.

In addition there are financial benefits:

- ☑ Less refrigerant cost;
- ☑ Less service cost;
- ☑ Lower costs associated with plant down time;
- ☑ No loss of energy efficiency associated with reduced refrigerant charge.

These costs may need to be offset against increased maintenance or some additional capital expenditure, but usually the difference is positive.

The environmental benefits are in parallel with the benefits identified above and include:

- ☑ More efficient operation of RACHP systems and hence lower emissions of CO_2 at the power station;
- ☑ Lower emissions of greenhouse gases.

5 Tools for tracking refrigerant use

Real Alternatives Carbon Emissions Calculator

As part of this learning programme a Carbon Emissions Calculator Software and Refrigerant Leakage Log tool has been developed to record information about systems in an electronic format. The workbook can help system owners to meet the mandatory requirements of the F-Gas Regulations and provide refrigerant emissions and cost calculations for all refrigerants including alternatives.

The workbook includes:

- An electronic refrigerant leakage log for recording system parameters, refrigerant use, leak test and system repair data for up to 10 different systems.
- A calculator for Carbon equivalent emissions and costs that uses the logged data to estimate the impact of refrigerant use with information presented in graphical and tabular format. Up to date GWP figures are automatically included.
- A site summary report tool consolidating emissions data for all systems on the site on a single sheet.
- A graphical representation of refrigerant use that can be used to prioritize maintenance and leakage reduction actions

The freely available software tool can be downloaded from the REAL Alternatives 4 LIFE website (www.realalternatives4life.eu)

A sample screen from the calculator showing refrigerant use in table and graph form is shown below. A demonstration video on how to use the spreadsheet tool is available in the REAL Alternatives 4 LIFE e-library.

Video on Refrigerant Calculator in REAL Alternatives e-library

Menu - click to navigate (macros must be enabled)

Refrigerant Leakage Log Data Sheet	Print	Save and Exit	
Carbon Emissions and Costs	Total Refrigerant Use for Site	Data Sheet	User Guide

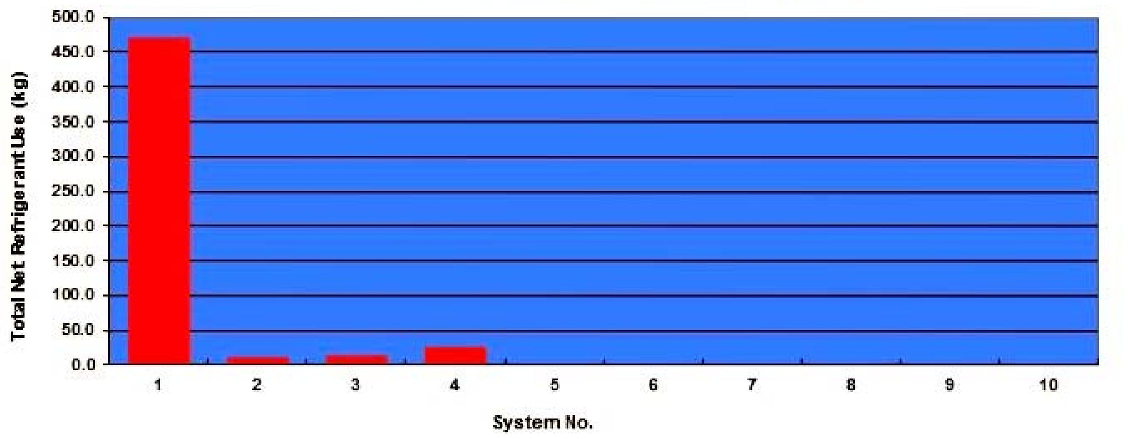
Refrigerant Leakage Log and Calculated Carbon Equivalent Emissions - Summary for Site

Plant/Site Name:	REAL Alternatives Europe		
Site Address:	Europe		
Postcode:	EU	Site Telephone Number:	+442086477033
Time Period Recorded:	From: 31/01/2008	To: 16/02/2014	

System No.	Plant Name	Plant Ref. No.	REFRIGERANT: Refrigerant Type	REFRIGERANT: Refrigerant GWP (relative to CO2)	TIME PERIOD: First Record Date	TIME PERIOD: Latest Record Date	TIME PERIOD: Period Covered (Years)	REFRIGERANT ADDITIONS: Total Net Refrigerant Use (kg)	REFRIGERANT ADDITIONS: 12 Month Equivalent Use of Refrigerant (kg p.a.)	REFRIGERANT ADDITIONS: 12 Month Equivalent Loss of Charge (% p.a.)	REFRIGERANT EMISSIONS: Carbon Equivalent of Lost Refrigerant (tonneCO2e)	REFRIGERANT EMISSIONS: 12 Month Carbon Equivalent of Lost Refrigerant (tonneCO2e p.a.)
1	Chiller	RAE1	R22	1700	05/11/2011	16/02/2014	2.28	472.4	206.7	516.86	803.1	351.5
2		RAE2	R410A	1980	22/08/2008	10/04/2011	2.63	10.5	4.0	14.24	20.8	7.9
3	Food Store	RAE3	R404A	3922	31/01/2008	18/02/2011	3.05	14.9	4.9	19.53	58.4	19.1
4		RAE4	R717		01/03/2010	22/03/2011	1.06	26.0	24.6	14.05		
5												
6												
7												
8												
9												
10			R407C	1650	12/12/2013	12/12/2013		1.0	N/A		1.7	N/A
						Totals (all systems)		524.8	240.2		884.0	378.5

Time Period Covered by This Report (Years)	6.05
Carbon Equivalent of Refrigerant Emissions Over This Period (tonneCO2e)	884.0
12 Month Carbon Equivalent of Refrigerant Emissions (tonneCO2e p.a.)	378.5
Total Refrigerant Used Over This Period - All Systems (kg)	524.8
Total Entrained Mass of Refrigerant - All Systems (kg)	268.00
Total Refrigerant Charge Lost Over This Period - All Systems (%)	196%

Total Refrigerant Use for Site (All Systems)



Appendix 1, Fuel Conversion Factors

	Conversion to CO_2 (gross CV basis)[2]	
Fuel	**Units**	**Carbon Factor kgCO_2e / unit**
Grid electricity (UK)[3]	kWh	0.412
Natural gas	kWh Therms	0.184 5.392
LPG	kWh therms litres	0.214 6.288 1.505
Diesel	tonnes kWh litres	3,108 0.246 2.611
Petrol	tonnes kWh litres	2,993 0.233 2.197

Petrol and diesel vehicles	kg CO_2 e/ mile	kg CO_2 e/ km
Up to 1.4 litre petrol engine	0.258	0.160
1.4 to 2 litre petrol engine	0.322	0.200
Over 2 litre petrol car	0.474	0.295
Up to 1.7 litre diesel engine	0.236	0.147
1.7 to 2 litre diesel engine	0.286	0.177
Over 2 litre diesel car	0.362	0.255

Mode of public transport	kg CO_2 e/ passenger km
Average bus and coach	0.102
National rail	0.049
Long haul international flight	0.020
Short haul international flight	0.018
Domestic flight	0.1030

The information in these tables is for the UK and is from a Carbon Trust fact sheet CTL153, Energy and conversion factors published in 2016 available from http://www.carbontrust.co.uk/resource/conversion_factors/default.htm

There is no assessment associated with this Module.
This module is designed a list of essential information only.

[2] Emission factors are calculated on a gross calorific value (CV) basis in common with most energy billing
[3] This figure is for the UK and will vary depend on method of electricity generation.

What next?

The information in this guide is an introduction to the most common alternative refrigerants. There is much more information in the documents highlighted in the links. Go to the on line reference e-library at www.realalternatives4life.eu/e-library to explore any additional information you may find useful.

If you would like to gain a REAL Alternatives 4 LIFE Certificate you need to take a full end of course assessment at a licensed REAL Alternatives 4 LIFE training centre. Information about assessments is available at http://www.realalternatives4life.eu

You can now continue your self-study with one of the following **Real Alternatives 4 LIFE** programme Modules:

1. Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2. Safety and risk management
3. System design using alternative refrigerants
4. Containment and leak detection of alternative refrigerants
5. Maintenance and repair of alternative refrigerant systems
6. Retrofitting with low GWP refrigerants
7. Checklist of legal obligations when working with alternative refrigerants
8. Measuring the financial and environmental impact of leakage
9. Tools and guidance for conducting site surveys

This project has been funded with support from the European Commission. This publication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

With contribution of
the LIFE programme
of the European Union

Site Surveys & Advice tools for

Reducing leakage of refrigerant

Contents

Table 1, Refrigerant leak rates

Type of Equipment	Typical Range in Charge Capacity (kg)	Installation Emission Factor (% of initial charge)	Operating Emissions (% of initial charge/ year)	Refrigerant remaining at disposal (% of initial charge)	Refrigerant recovered (% of remaining charge)
Domestic Refrigeration	0.05 - 0.5	1.0%	0.3%	80%	99.0%
Stand-alone Commercial Applications	0.2 - 6	1.5%	2.0%	80%	94.5%
Medium & Large Commercial Applications	50 - 2,000	2.0%	11.0%	100%	95.0%
Transport Refrigeration	3 - 8	1.0%	8.0%	50%	94.0%
Industrial Refrigeration (inc. food processing and	10 - 10,000	1.0%	8.0%	100%	95.0%

With contribution of the LIFE programme of the European Union

Welcome to the REAL Alternatives

4 LIFE Blended Learning Programme

This learning booklet is part of a blended learning programme for technicians working in the refrigeration, air conditioning and heat pump sector designed to improve skills and knowledge in safety, efficiency, reliability and containment of alternative refrigerants. The programme is supported by a mix of interactive e-learning, printed training guides, tools, assessments for use by training providers and an e-library of additional resources signposted by users at www.realalternatives4LIFE.eu

REAL Alternatives 4 LIFE has been developed by a consortium of associations and training bodies from across Europe co-funded by the EU, with the support of industry stakeholders. Educators, manufacturers and designers across Europe have contributed to the content. The materials will be available in Croatian, Czech, Dutch, English, French, German, Italian, Polish, Romanian, Spanish and Turkish.

Real Alternatives Europe Programme Modules	
1	Introduction to Alternative Refrigerants - safety, efficiency, reliability and good practice
2	Safety and Risk Management
3	System design using alternative refrigerants
4	Containment and leak detection of alternative refrigerants
5	Maintenance and repair of alternative refrigerant systems
6	Retrofitting with low GWP refrigerants
7	Checklist of legal obligations when working with alternative refrigerants
8	Measuring the financial and environmental impact of leakage
9	Tools and guidance for conducting site surveys

You can study each module individually or complete the whole course and assessment.

www.realalternatives4life.eu

More information is available in the on line reference e-library. Throughout the text of each module you will find references to sources of more detailed information. When you have completed the module you can go back and look up any references you want to find out more about at www.realalternatives4life.eu/e-library. You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

Assessment options are available if you want to gain a recognised CPD Certificate. At the end of each module are some simple self-test questions and exercises to help you evaluate your own learning. Certification and Assessment will be available from licensed REAL Alternatives training providers when you attend a course of study. The list of recognised training providers will be available on the website.

Register your interest in alternative refrigerants at rwww.realalternatives4life.eu to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

You can use and distribute this material for individual training purposes. The learning booklets and contents remain copyright of the Institute of Refrigeration and partners. Material may be reproduced either as a whole or as extracts for training purposes on written application to the REAL Alternatives Consortium, c/o Institute of Refrigeration, UK email: ior@ior.org.uk. Any queries about the content or the learning programme should also be addressed to ior@ior.org.uk.

Background to the programme and how it was developed. This learning programme was developed as part of EU co-funded projects led by a consortium of partners from across Europe. It is designed to address skills shortages amongst refrigeration, air conditioning and heat pump technicians related to the safe use of alternative refrigerants. It provides independent and up to date information in an easy to use format. The project consortium included training and professional institutes as well as employer representative bodies. Stakeholders from across Europe drawn from employers, manufacturers, trade associations and professional institutes also contributed learning material, advised on content and reviewed the programme as it was developed.

The consortium partners were:

- Association of European Refrigeration Air Conditioning & Heat Pump Contractors, Belgium
- Associazione Tecnici del Freddo, Italy
- IKKE training centre Duisburg, Germany
- Institute of Refrigeration, UK
- International Institute of Refrigeration
- University College Leuven-Limburg, Belgium
- London South Bank University, UK
- PROZON recycling programme, Poland.

With thanks to our stakeholders:

- CNI National Confederation of Installers, Spain
- CHKT Czech Association for cooling and air conditioning technology
- HURKT, Croatian Refrigeration Airconditioning and Heat Pumps Association
- RGAR Association General of Refrigeration, Romania
- SOSIAD Association of Refrigeration Industry and Businessmen, Turkey
- SZ CHKT Slovak Association for Cooling and Airconditioning technology

Module 9 –

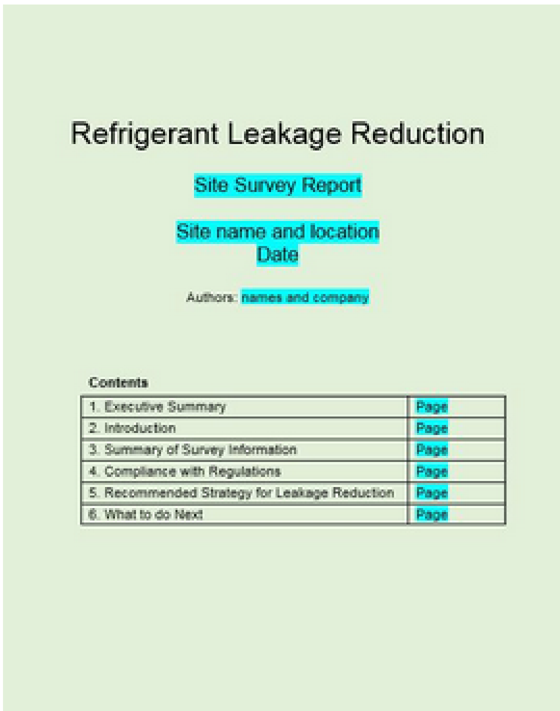
Reducing Leakage of Alternative Refrigerants through Site Surveys and Advice

This Module covers surveys and guidance to advisee customers containment strategies. It provides an introduction to this topic. It does not replace practical training and experience. Throughout the module you will find links to useful information, templates, tools and documents from a range of sources that have been peer reviewed and are recommended technical guidance if you would like to find out more about these topics.

The guide shows how information from site surveys should be structured and recorded, so that it can be used to develop an effective leak reduction strategy. Advice is included on the preparation of reports and recommendations using appropriate tools and templates.

You should study Modules 1-8 before starting this module or using the tools recommended. On successful completion you should be able to:

- Undertake effective site surveys;
- Assess how a system can be improved to reduce leak risk;
- Assess leakage risks and the potential for leakage reduction;
- Calculate the refrigerant charge in a system using a charge calculator and other methods;
- Collect and evaluate site survey data using the recommended site survey record sheet ;
- Provide advice and recommendations to customers on reducing refrigerant leakage at their sites;
- Write a practical site survey report for customers;
- Evaluate the effectiveness of site surveys and follow up actions to reduce leakage and contain refrigerant.


Refrigerant Leakage Reduction

Site Survey Report

Site name and location
Date

Authors: names and company

Contents

1. Executive Summary	Page
2. Introduction	Page
3. Summary of Survey Information	Page
4. Compliance with Regulations	Page
5. Recommended Strategy for Leakage Reduction	Page
6. What to do Next	Page

1. Introduction to Site Surveys

Aim of Site Survey

The aim of the site survey is to gather information about the RAC equipment:

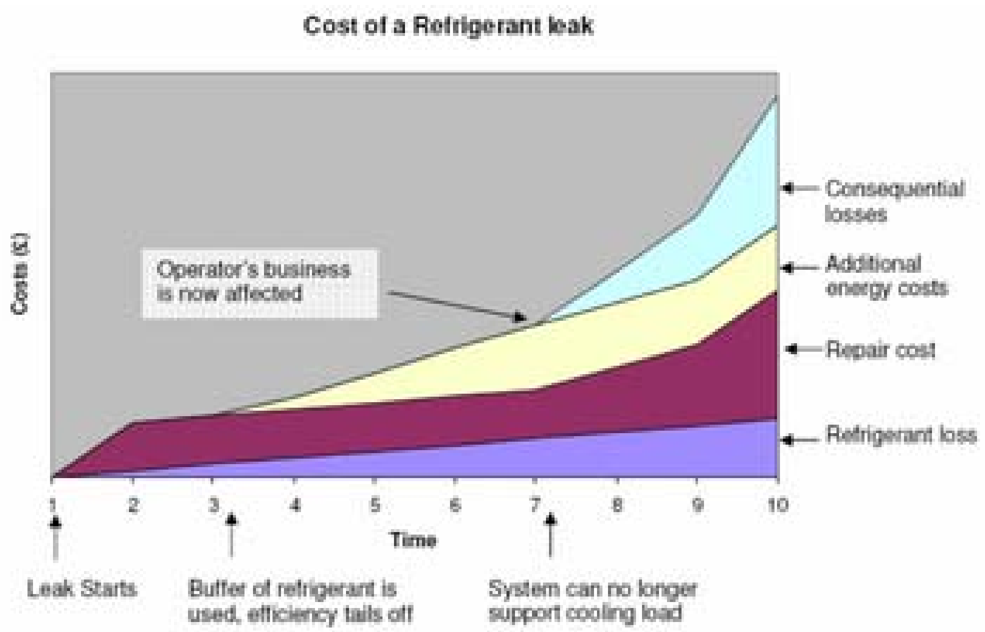
- Its age and condition;
- Its level of maintenance;
- Current leakage and leakage potential;
- Historical leakage points.

This information, coupled with generic information provided in the REAL Alternatives 4 LIFE modules, will enable you to develop a strategy to reduce leakage from the systems surveyed. The tools and templates that are provided as part of this module will help you to record the information collected and to generate your report and recommendations.

These surveys are particularly beneficial on systems which often have a high leak rate including:

- R744 central plant such as that used in many supermarkets;
- Other systems where the evaporator is remote from the condensing unit (which would potentially use R717, R744, R32 or R1234ze);
- Split air conditioning systems (including VRV and VRF systems which would potentially use R32).

Equipment which is predominantly integral ("plug in") will not generally have a high leak potential so it is not usually worthwhile including them in this process.   Many close coupled systems such as chillers also generally have a low leak rate.

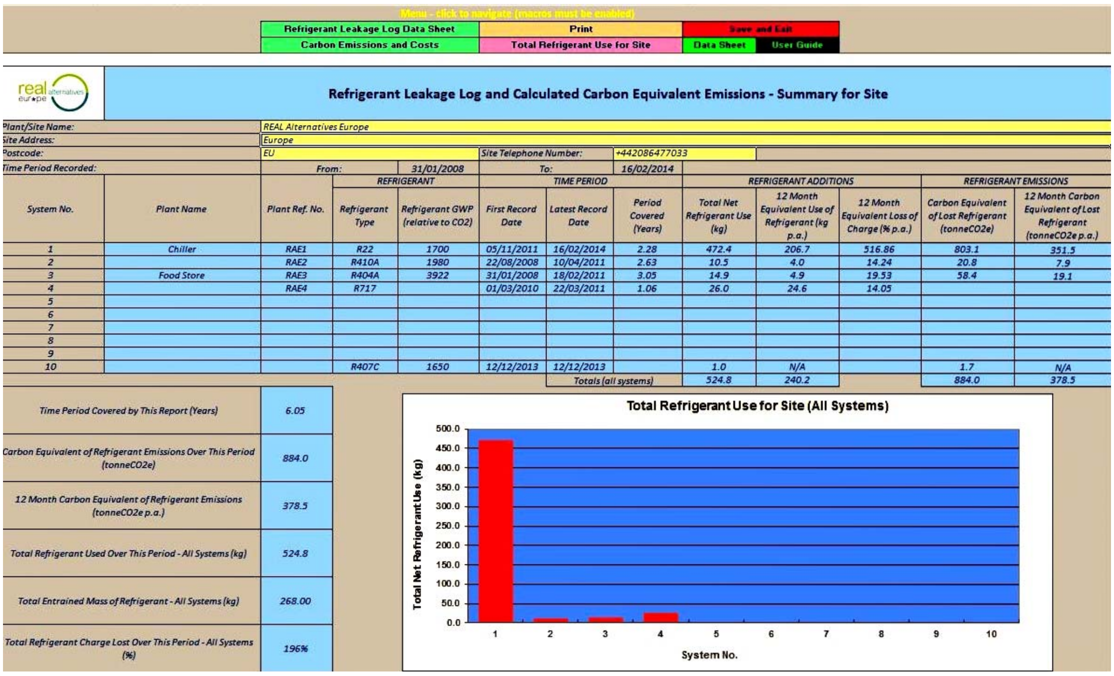


2. Site Survey Procedure

General

A typical site survey procedure is as follows:

- Identify potential sites for survey, e.g. with existing customers or end users you have identified who would benefit from this service;
- Outline to the customer the process and potential outcome;
- Assemble information about the site, including the refrigerant usage logs and maintenance records (if available);
- Carry out the survey;
- Consider how leakage can be reduced on the site – use information from Guides 1 to 7;
- Prepare a strategy for the customer to reduce leakage;
- Arrange a follow up meeting with the customer to discuss the strategy and how best to implement it.



Menu - click to navigate (macros must be enabled)

Refrigerant Leakage Log Data Sheet | Print | Save and Exit

Carbon Emissions and Costs | Total Refrigerant Use for Site | Data Sheet | User Guide

Refrigerant Leakage Log and Calculated Carbon Equivalent Emissions - Summary for Site

Plant/Site Name: REAL Alternatives Europe

Site Address: Europe

Postcode: EU — Site Telephone Number: +442086477033

Time Period Recorded: From: 31/01/2008 To: 16/02/2014

			REFRIGERANT		TIME PERIOD			REFRIGERANT ADDITIONS			REFRIGERANT EMISSIONS	
System No.	Plant Name	Plant Ref. No.	Refrigerant Type	Refrigerant GWP (relative to CO2)	First Record Date	Latest Record Date	Period Covered (Years)	Total Net Refrigerant Use (kg)	12 Month Equivalent Use of Refrigerant (kg p.a.)	12 Month Equivalent Loss of Charge (% p.a.)	Carbon Equivalent of Lost Refrigerant (tonneCO2e)	12 Month Carbon Equivalent of Lost Refrigerant (tonneCO2e p.a.)
1	Chiller	RAE1	R22	1700	05/11/2011	16/02/2014	2.28	472.4	206.7	516.86	803.1	351.5
2		RAE2	R410A	1980	22/08/2008	10/04/2011	2.63	10.5	4.0	14.24	20.8	7.9
3	Food Store	RAE3	R404A	3922	31/01/2008	18/02/2011	3.05	14.9	4.9	19.53	58.4	19.1
4		RAE4	R717		01/03/2010	22/03/2011	1.06	26.0	24.6	14.05		
5												
6												
7												
8												
9												
10			R407C	1650	12/12/2013	12/12/2013		1.0	N/A		1.7	N/A
						Totals (all systems)		524.8	240.2		884.0	378.5

Time Period Covered by This Report (Years)	6.05
Carbon Equivalent of Refrigerant Emissions Over This Period (tonneCO2e)	884.0
12 Month Carbon Equivalent of Refrigerant Emissions (tonneCO2e p.a.)	378.5
Total Refrigerant Used Over This Period - All Systems (kg)	524.8
Total Entrained Mass of Refrigerant - All Systems (kg)	268.00
Total Refrigerant Charge Lost Over This Period - All Systems (%)	196%

example of a refrigerant use recording report

Explaining the process

In order to gain access to refrigeration sites it is important that end users understand the benefits of the survey and how it will help them improve system performance and reduce the costs and the impact on the environment of the RACHP equipment. There is a template for a survey contact letter in the link which:

Download a Template
www.realalternatives4life.eu
/downloads

- Introduces REAL Alternatives 4 LIFE concepts;
- Highlights the importance of leakage reduction, whatever the refrigerant;
- Explains the process and the access to the RAC equipment and information that will be required;
- Outlines the potential benefits and how these will be reported.

The template letter can be adapted to your own requirements, but it is recommended that the information and content is not changed significantly.

Template Letter to End Users

This template can be completed and sent to end users to explain the site survey procedure and what the expected outcomes are. Text highlighted needs to be completed by you.

Dear

Refrigerant leakage reduction site survey

Real Alternatives (Refrigerant Emissions and Leakage Zero for Alternative Refrigerants) is a best practice approach and methodology for reducing leakage of alternative refrigerants and higher GWP HFCs. It is part of an EU Leonardo LifeLong Learning co-funded project which provides practical information, tools and training, all available from www.realalternatives.eu

Refrigeration systems are key to many businesses' performance. You can't afford to ignore the risk of reduced reliability and efficiency if systems are allowed to leak whichever refrigerant they contain. Leaking systems:

- Cost more to run because they are less efficient;
- Have increased costs associated with service, refrigerant and down time;
- Have a higher direct environmental impact if high global warming potential refrigerants are used;
- Have a higher indirect environmental impact due to reduced efficiency.

I can provide a service which includes:

1. Gathering information from you and your refrigeration contractor about the site, including the refrigerant usage records, which should log details of leak tests and repairs and refrigerant additions and removals.
2. Carrying out an equipment survey. This will require access to the systems and is a visual check, which also includes a leak test, carried out using a portable leak detector. I will require approximately ?? days on site.
3. Development of a practical strategy to reduce leakage. This will include advice on maintenance regimes and recommended improvement works such as component or joint replacements. The strategy can provide the foundation of a business case to justify, where necessary, any investment required to reduce the operational cost and environmental impact of your RAC equipment.
4. Provision of a full report of:
   - Summary of current carbon and financial costs due to leakage
   - The survey information;
   - Results of the leak testing carried out during the survey;
   - Details about the condition and maintenance of the system;
   - An indication of how the equipment leakage found during the survey and from the refrigerant usage records compares to other similar systems;
   - A summary of the environmental impact of the refrigerant leakage on your site over the period covered by available records;
   - A recommended strategy to reduce leakage on your site.

Carrying out the survey

The survey is a visual check of the system plus a leak check and it is this survey that will form the basis of your site report and leakage reduction strategy. To complete the report you will need to use the site survey record workbook to collect the data and the template site survey report to write your report.

Site Survey Record and report from www.realalternatives4life.eu/downloads

The site survey report template which you will use to draft your report is self explanatory. Most of the information to be included will be available from:

- The visual check of the system, which will include an indirect assessment of the level of refrigerant charge;
- The refrigerant usage records (F Gas log for R32);
- General questioning of site staff regarding the level of reliability and historical problems with the site;
- A leak check using an electronic leak detector.

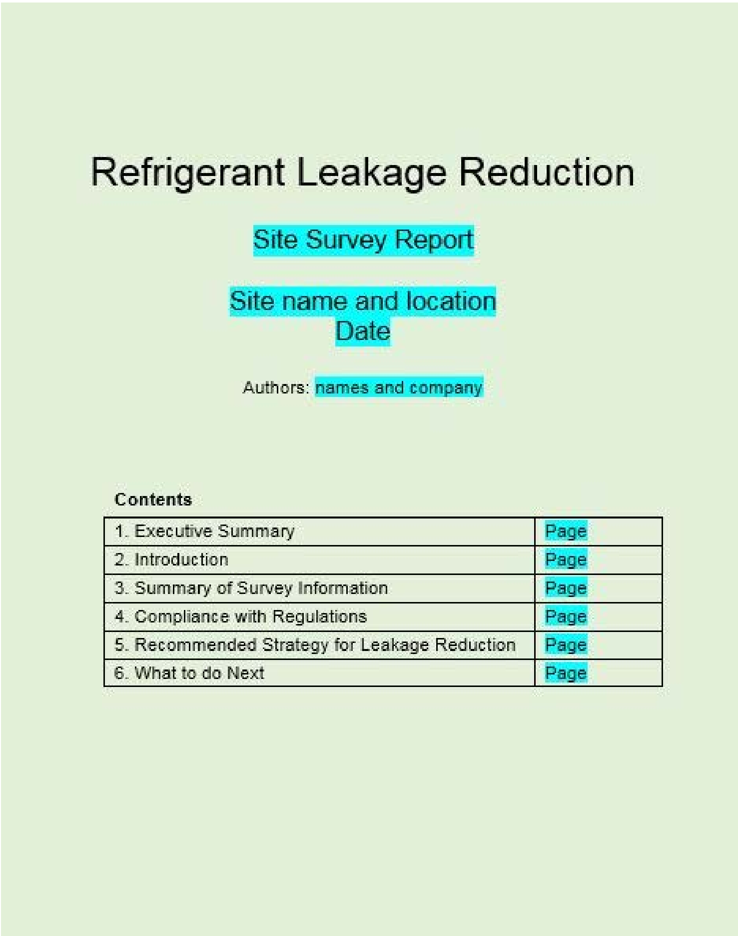
You may need to estimate the refrigerant charge if this is not available. Details on how to do this are provided in Appendix 1.

The survey includes a leak test of the system. This is not intended to be a full leak test unless required by the end user. However, it should be possible to check most joints. You should:

REAL Alternatives Module 4 Leak Testing

- Use a handheld electronic leak detector which is safe and sensitive for the refrigerant;
- Check it against a reference leak to ensure it is accurate;
- Leak test as many joints as you can easily access, including common leak points such as pressure switches and pressure relief valve vent lines.

You will need to use the site survey record workbook to collect the data required for the survey. You can either print out the site survey record workbook to fill out manually on site, transferring the data to the spreadsheet at a later date; or complete the spreadsheet electronically during the survey.



Refrigerant Leakage Reduction

Site Survey Report

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Importance of correct refrigerant charge

It can be useful to relate refrigerant leakage to the refrigerant charge size (also called entrained volume) to provide a leak rate as an annual loss percentage. For example a leak of 20 kg a year in a system with an ideal charge of 40 kg is a 50% annual refrigerant loss. This allows systems to be bench marked and comparisons made to average leak rates so problem systems can be highlighted and targeted.

The correct charge amount is the minimum charge required for the system to run with sub cooled liquid at the entry to all expansion devices throughout the entire range of load and ambient conditions.

Some systems contain more refrigerant than required – the excess refrigerant is held in the high pressure liquid receiver. In the event of a leak the excess refrigerant is lost before the leak results in insufficient liquid in the liquid line (e.g. seen as flashing in the liquid line sight glass) and the performance drops. The system is not technically over charged because it does not result in liquid backing up in the condenser with a subsequent increase in condensing pressure. But the excess refrigerant is not required and increases the potential direct environmental impact in the event of a leak.

Some systems are undercharged because they were not charged with the correct amount of refrigerant during commissioning or service. This is often the case when systems are charged to a full liquid line sight glass when the system is not fully loaded. The system appears adequately charged at low load, but when the load increases, demanding more liquid refrigerant, it is not available.

Systems fitted with high pressure liquid receivers have a significant margin between being undercharged and overcharged.

3. Preparing a Strategy for Containment

The following topics are those which you could potentially include in your strategy. Not all of these will be relevant to every system, and there may be other equipment specific information which you can add.

Background to the strategy with key points from the survey:

- Current and historical leakage;
- Current standard of service and maintenance and its impact – positive and negative – on leakage;
- Age and condition of equipment;
- Compliance with the F Gas regulation if appropriate

Recommendations for improved service and maintenance, including:

- Modifications to the current maintenance scheme or a new maintenance regime where necessary;
- Increase in the frequency of leak testing and the type of leak detection equipment used;
- A complete service if necessary, for example to carry out a thorough leak test, cap valves and replace minor components and joints.

Recommendations for re work or replacement of components or systems, possibly including:

- Pipe work improvements;
- Joint changes, e.g. from mechanical to brazed joints;
- Components changes;
- System replacement;
- Improved access.

You will need to use the following information to develop a practical strategy:

- Historical and current leakage information;
- Current level of service and maintenance;
- Compliance with F Gas regulation if relevant;
- Type, age and condition of equipment;
- Potential for leakage.

These are covered in more detail in the following sections, with general recommendations for improvements from which site specific advice can be produced.

Leakage Records

Historical and current leakage information

This comprises information from the refrigerant usage log and your own leak checking during the survey. From this information you should be able to determine:

- Annual leak rate as a percentage of system charge;
- Leakage points, and in particular problem areas where leaks have recurred;
- Reasons for Leaks – external damage, catastrophic failure or gradual loss of refrigerant;
- Whether leak test has been carried out in accordance with the F-Gas regulations (R32) and / or are appropriate for the plant.

Reasons for leaks vary. Where leaks have been caused by damage from an external source, for example, a fork lift truck, you need to identify vulnerable areas and recommend protection. Catastrophic leaks are usually a result of stress, for example in pipe work. To identify the potential for catastrophic leaks you need to examine pipe routing, support and vibration elimination. Smaller leaks have many causes as outlined in the illustrated guide to 13 common leak points (GN2). You should refer to this guide for solutions to these types of leaks. Further information about solutions to leaks can be found in the other Real Alternatives 4 LIFE modules. EN378 also provides guidance which should help prevent catastrophic leakage.

REAL Skills Guide to 13 on common leak points

Current level of service and maintenance

The standard of service and maintenance will be obvious from a visual check of the system and examination of service records. Maintenance is vital to minimise refrigerant leaks. The maintenance regime should be appropriate to the age, condition and type of system. Refer to module 4 for detailed information about maintenance to minimise leakage, and adapt this information for the recommended strategy.

REAL Alternatives Guide 4 on Leak Testing

In addition to good maintenance, good service practice is essential. This includes basic good practice such as:

- Capping valves;
- Changing gaskets when covers, flanges etc are removed;
- Changing pressure relief devices if they have operated;
- Checking and changing seals when necessary.

Where leaks have occurred on the system you have surveyed you could refer to the REAL skills guide to 13 common leaks available in the Additional Resources section for solutions and include these in the strategy

Compliance with the F Gas Regulation

The system operator (usually the end user) is responsible for complying with the F Gas Regulations although under the revised Regulations there are new obligations on those carrying out Service and Maintenance as well (refer to the AREA summary of requirements for contractors available in the Additional Resources page of this Module).
The leakage reduction strategy must recommend a regime in compliance with the F Gas if appropriate and any other HFC refrigerant in use, but this should be seen as a minimum standard – for many systems more frequent leak detection is beneficial. This is especially so for systems:

- With many joints;
- Which have mechanical joints such as flares;
- Which historically have a high leak rate (e.g. R744 central plant systems);
- With open drive compressors.

Type, age, condition of equipment and potential for leakage

You will need to consider the age and condition of the equipment when developing the strategy for leakage reduction. It is less likely to be cost effective to make investments in improvements to systems which are near the end of their life. You should consider access to equipment – if access is difficult maintenance is less likely to be carried out.

This may also be a health and safety issue – this is a consideration which will change the balance of investment vs. pay back.

Potential for leakage

In addition to examining current and historical leakage, you should also examine the equipment for future potential for leaks. This includes considering:

- The effect of vibration and whether vibration is correctly eliminated;
- Pipe routing and support;
- Whether pipes can chafe;
- The potential for external damage;
- The types of joint used.

4. Reporting on leakage reduction strategies

Preparation of reports and recommendations

Good clear reporting is essential if the strategy you develop is to be implemented.

The report should include:

- The general impact of leakage and specifically which refrigerants have the greatest impact, but remember that refrigerant leak reduction is important for all refrigerants;
- Background information on the Real Alternative project;
- Indication of typical leak rates for the type of equipment surveyed and whether this equipment is better or worse than similar typical systems;
- How the survey was conducted and key findings, including photos;
- An evaluation of the adequacy of current refrigerant usage records;
- The recommended strategy for reducing leakage;
- A business case for reducing leakage where applicable;
- What to do next.

You should follow up the report with a meeting with key personnel where possible to provide practical advice on how to implement the strategy and work out an action plan. A follow up survey is often beneficial to check the success of the strategy.

Appendix 1, Estimating the Refrigerant Charge Weight

The correct charge can be calculated from:

- The quantity of refrigerant held in each evaporator and condenser (usually available from the manufactacturer in kg or, as a volume, litres).
  plus
- The volume of the liquid line, condensate line, (between condenser outlet and recciever inlet,) and any other pipework which contains liquid refrigerant.
  plus
- The capacity or volume of the liquid receiver at 25% full and other vessels which contain liquid refrigerant.

It is not usually necessary to consider the volume of the pipe work and vessels which contain only refrigerant gas at this will be a very small proportion of the total charge.

There is also a refrigerant calculator and guidance note on calculating refrigerant charge produced by DEFRA in the UK which provides an approximate charge size from simple information about the system (see link from e-library).

DEFRA F Gas Support Refrigerant calculator and guidance notes

5. Additional Resources

This guide is designed as an introduction to the topic of preparing leakage reduction strategies. To find out more you can explore some of the resources below. These are produced by related projects or specialist associations. All material has been peer reviewed by our panel to ensure it provides good quality technical advice and information, which is more detailed than we can provide in our e-learning programme. Inclusion as a link does not imply endorsement of produce and there is no commercial links with any of the companies referred to. All are available from www.realalternatives4life.eu/e-library

Essential Downloads and Templates for Site Surveys

Refrigerant Tracking Software
Site survey record
Template client letter
Template site report

Environmental impact

Refer to REAL Alternatives 4 LIFE Module 1 – Introduction to Alternative Refrigerants
Carbon Trust fact sheet CTL018, Energy and conversion factors (UK)

Real Skills Europe Guidance

GN1: Guide to good leak testing
GN2: Illustrated guide to 13 common leaks
GN3: Designing out leaks: design standards and practices
GN4: Leakage matters: the service and maintenance contractor's responsibility
GN5: Leakage matters: the equipment owner's responsibility
Environmental, Cost and Legal Aspects of Refrigerant Leakage

Efficiency

End User Guides covering Efficiency of Refrigeration plant available from ior.org.uk

Safety

Refer to REAL Alternatives 4 LIFE Module 1 – Introduction to Alternative Refrigerants

F Gas Requirements

AREA Guides for Contractors and CarbonDioxide Equivalent calculators
Tool for helping to calculate volume of refrigerant in a system www.realalternatives.eu/app/images/Tools/fgas-refrigerant-calculator.xls

6. What Next?

This is the final guide in the REAL Alternatives 4 Life Blended Learning Series. There is no assessment associated with this Module as it is designed for information purposes only.

There is more information in the documents highlighted in the links and the on line reference e-library at www.realalternatives4life.eu/e-library to explore any additional information you may find useful.

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