With contribution of the LIFE programme of the European Union

Introduction

to Alternative Refrigerants

Contents

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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
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.

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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 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

See eurammon "naturally cool" film

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

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.

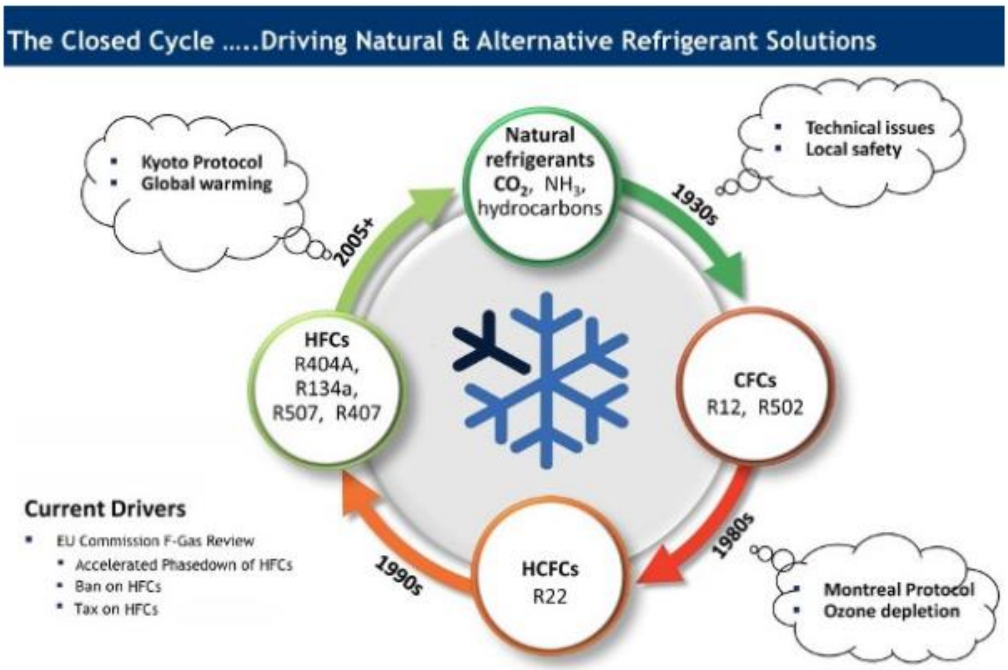


Image from www.fridgehub.com

[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	2	-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^{O}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"

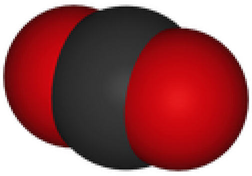


Figure 1 Carbon dioxide molecule

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^{O}C the R744 will be above the critical point (31^{O}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

Institute of Refrigeration Safety Code Ammonia

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.

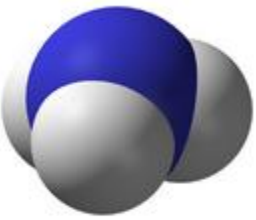


Figure 2, Ammonia molecule

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

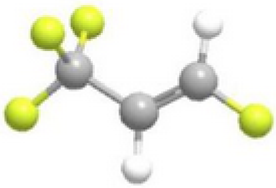


Figure 5, R1234ze molecule

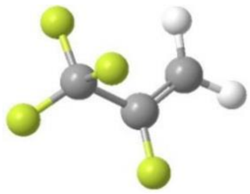


Figure 6, R1234yf molecule

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

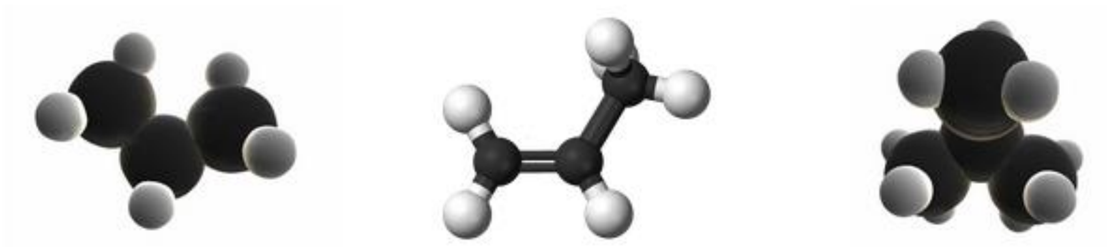


Figure 8, Propane, propene and isobutane molecules

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

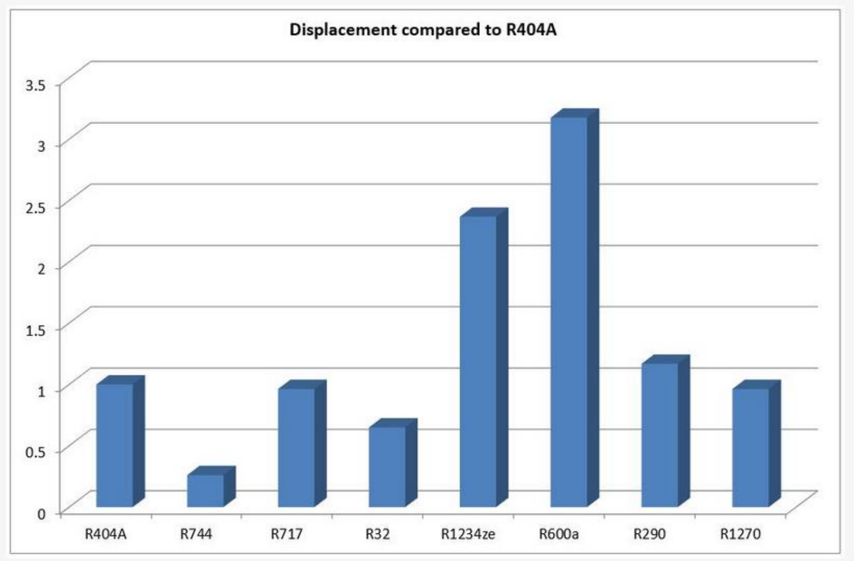
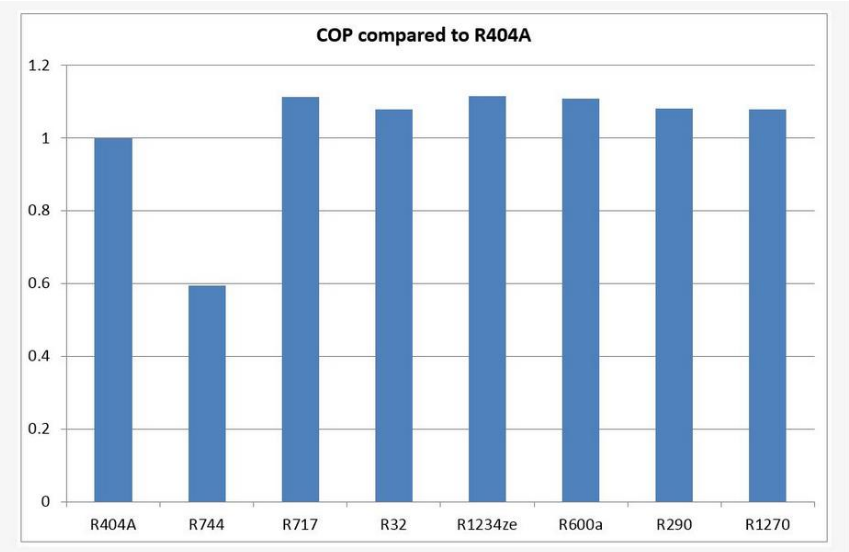


Figure 12, COP compared to R404A



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

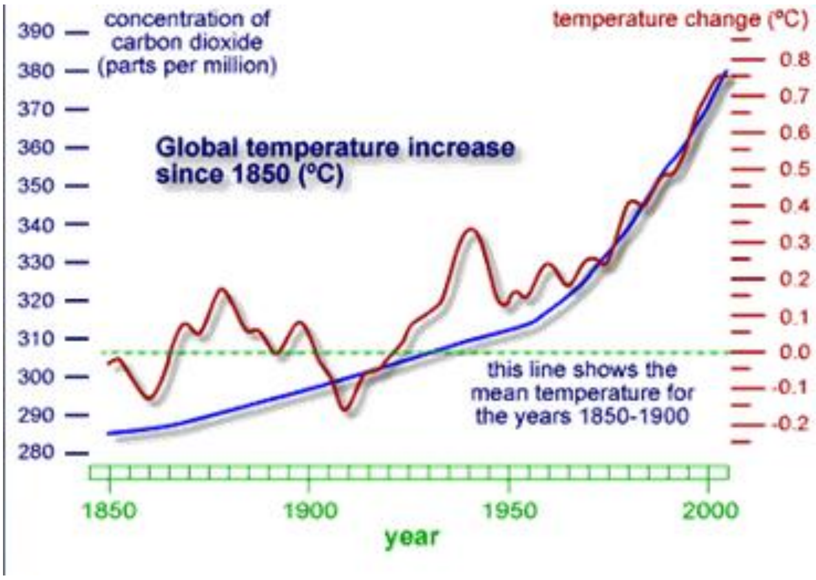
EER or Energy Efficiency Ratio can also be used to compare efficiencies in air conditioning and heat pump applications. This is the ratio of the cooling capacity of an air conditioner in kW or BTU per hour, compared to the total electrical input in kW or Watts at a given test criteria. This is normally 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”

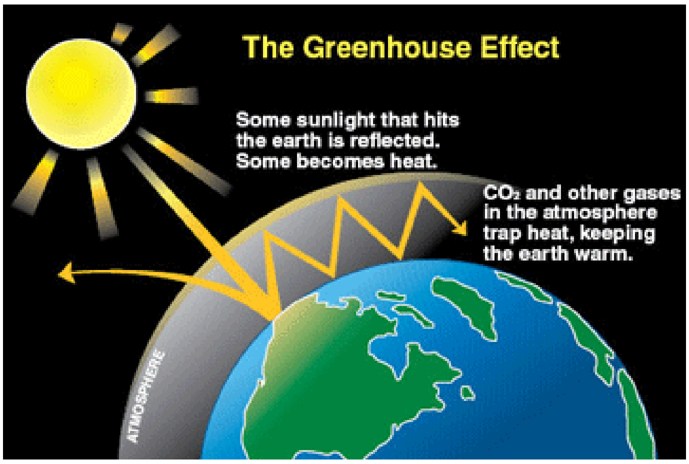
10 Environmental impact

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	1	0	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

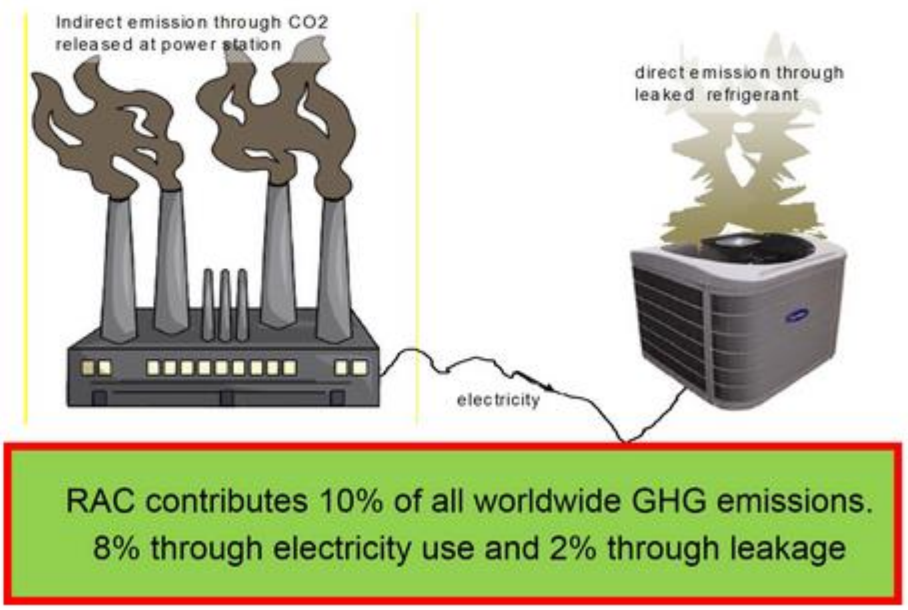
Total Equivalent Warming Impact

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:

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

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

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

REAL Alternatives Guide 4

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.

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.