Introduction

to Alternative Refrigerants

Contents

	Type	Key facts	GWP[2]	Sat temp[3]
R744	Carbon dioxide, CO_2	High pressures	1	-78°C
R717	Ammonia, NH_3	Toxic and mildly flammable	0	-33°C
R32	Hydro fluoro carbon, HFC	Mildly flammable	550	-52°C
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	Mildly flammable	7	-19°C
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	Flammable	3	-12°C
R290	Propane, C_3H_8, hydrocarbon (HC)	Flammable	3	-42°C
R1270	Propene (propylene), C_3H_6, hydrocarbon (HC)	Flammable	3	-48°C

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.realalternatives.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 Dutch, English, German, Italian and Polish.

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

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

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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.realalternatives.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 6 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. Optional Certification and Assessment is available either on line or using written exam papers. This is only available to those following a course of study under supervision at a REAL Alternatives recognised training provider or employer. CPD Certificates are issued through the REAL Alternatives partners (CPD = Continued Professional Development). A list of recognised training providers is available on the website.

Register your interest in alternative refrigerants at www.realalternatives.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 leaning programme was developed as part of a two-year project led by a consortium of six partners from across Europe funded by the EU Lifelong Learning Programme. It was 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 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 six consortium partners were:

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

Module 1 -

Introduction to Alternative Refrigerants

Aim of Module 1

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

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.

See REAL Alternatives References Appendix

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 which are now being trialled.

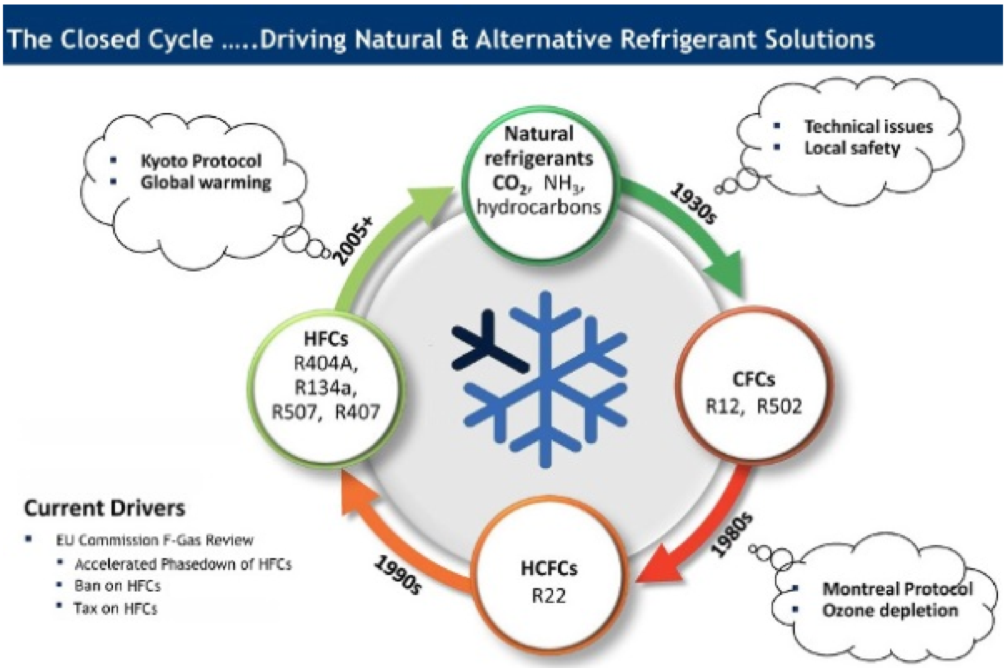


Image from www.fridgehub.com

[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 mildly flammable	0	-33°C	Industrial
R32	Hydro fluoro carbon, HFC	Mildly flammable	675	-52°C	Split air conditioning
R1234ze	Unsaturated HFC (aka hydro fluoro olefin, HFO)	Mildly flammable	7	-19°C	Chillers, split air conditioning, integrals
R600a	Isobutane, C_4H_{10}, hydrocarbon (HC)	Flammable	3	-12°C	Domestic and small commercial systems
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

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.

[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	Green	Amber	Amber	Green	Green	Amber
R717	Red	Red	Red	Green	Red	Amber
R32	Red	Amber	Green	Green	Amber	Green
R1234ze	Red	Amber	Green	Green	Amber	Green
R600a	Red	Red	Amber	Amber	Red	Green
R290 and R1270	Red	Red	Amber	Green	Red	Green

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 highest concentration level in an occupied space that will not result in escape impairing effects. For full information see EN378 Part 1 – F3.1

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.

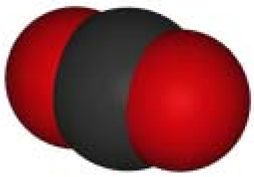
A brief introduction to each refrigerant or type of refrigerant is given below. For more details see the guide "Design differences for alternative refrigerant systems".

REAL Alternatives Guide 2, Design Differences with Alternative Refrigerant Systems

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"



CO_2 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"

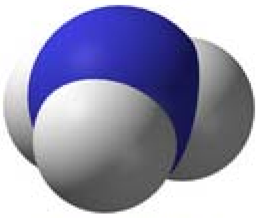
Currently (2014) R744 has been used in several 1000 retail systems and in industrial systems in Europe. It is starting to be used in heat pumps and in integral systems.

Shecco Guide Europe 2013

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

R717 (Ammonia, NH_3) – GWP = 0

R717 has a relatively high saturation temperature at atmospheric pressure, is highly toxic, mildly flammable 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.



NH_3 molecule

Institute of Refrigeration Safety Code Ammonia

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 EN378-1:2008 + A2:2012

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.

R32 molecule

Its mild 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.

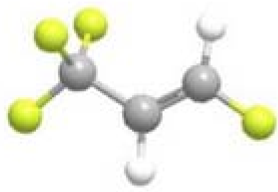
The operating pressures are higher than for most HFCs, but are similar to R410A. Typically the high side maximum pressure is 35 bar g.

R32 air conditioning units in production

R1234ze (GWP = 7) and other HFO refrigerants

R1234ze is also a low flammable HFC, marketed as an HFO – hydro fluoro olefin. This is a halocarbon containing hydrogen, fluorine and unsaturated carbon. It is in the same family of refrigerants as R1234yf which is now being used in some car air conditioning systems. It is possible that it might also be used in stationary systems in the future.

Bitzer refrigerant Report 17



R1234ze molecule

Its mild 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 saturation temperature 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 many 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 not yet widely available, but is being trialled in chillers and integral units.

Several blends using R1234ze are available for testing. They have lower saturation temperatures so are suitable for low temperature applications. They all have GWPs in excess of 300. Some are non-flammable, but these tend to have significantly higher GWPs.

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

R1234yf is a similar type of refrigerant to R1234ze and is starting to be used in car air conditioning.

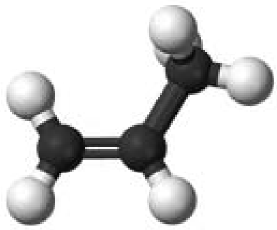
examples of equipment using R1234ze

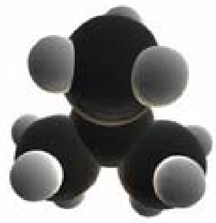
R290, R1270 and R600a (HCs) GWP = 3

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


Propane molecule


Propene molecule


Isobutene molecule

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.




examples of equipment designed to contain hydrocarbon

Safety

All alternative refrigerants covered in this guide have safety issues beyond those of the HFC refrigerants. These include:

- Flammability – mild (HFOs, R32 and R717) and high (HCs);
- Toxicity – low (R744) and high (R717);
- High pressures (R744).

Classification

The safety classifications below are defined in ISO817:2009 [5] and are also used in EN378-1:2008 A2:2012[6].

The classifications comprise two parts:

- A or B represents the degree of toxicity;
- 1, 2, 2L or 3 represents the degree of flammability.

The toxicity classification is as follows:

- Class A is lower toxicity (most refrigerants are class A);
- Class B is higher toxicity (R717 is class B).

The flammability classification is explained in table 3 below:

Table 3, safety classification

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

[5] ISO817:2009 Refrigerants – Definitions and safety classification. Note that the A2L classification is not yet adopted – it is in the current proposed revision of ISO817.

[6] EN378-1:2008+A2:2012, Refrigerating systems and heat pumps – Safety and environmental requirements, Part 1 – Basic requirements, definitions, classification and selection criteria

Note – it is proposed to include the **2L** safety classification in revisions of EN 378, ISO 817 and ISO5149. It is already used in ASHRAE standards (American Society of Heating, Refrigeration and Air Conditioning Engineers) and is in de facto use, so it is included in this document. To highlight that it is not yet in the standards referenced here it will be shown as "A2L (proposed)" in the text of this document.

Table 4, safety information

Refrigerant	Safety group [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	0.07
NH_3 R717	B2L (proposed)	0.116	630	0.00035	0.00022
HFC R32 [e]	A2L (proposed)	0.307	648	0.061	0.30
HFO R1234ze [f]	A2L (proposed)	0.303	368	0.061	0.28
HC R600a	A3	0.043	460	0.011	0.06
HC R290	A3	0.038	470	0.008	0.09
HC R1270	A3	0.047	455	0.008	0.002

a. The safety group 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 A3 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).
e. The information for R32 is from the current proposed revision of EN378.
f. R1234ze is not listed in the current version of EN378. The information is based on the current proposed revision. R1234ze does not exhibit flame limits under standard test conditions, but it does at temperatures above 30^oC. The LFL stated is at 60^oC.

Toxicity

Exposure

Inhalation of any refrigerant vapour in sufficient quantities can lead to asphyxiation, cardiac sensitisation or an effect on the central nervous system. Theses can lead to dizziness, lethargy or irregular heartbeat.

Toxicity

R717 is toxic and has a very low practical limited of $0.00035 kg/m^3$

Asphyixiation
All refrigerants are asphyxiants because they displace air. This is a hazard if a large amount is released particularly in an enclosed area, but a small amount leaking into the base of a well type display case is also a serious hazard. The use of Carbon Dioxide (R744) as a refrigerant is becoming more common and whilst most are aware of the high pressures involved, there is equal danger from a leak of refrigerant which could cause an increase in carbon dioxide in the atmosphere of a plant room for example. Technicians should be very mindful of the disorienting impact of reduced oxygen and if necessary consider the use of breathing apparatus if a large leak is suspected.

Products of decomposition
HFC and HFO form toxic products of decomposition when burnt eg during a compressor burnout. Hydrogen fluoride is produced which forms hydrofluoric acid in contact with moisture. The effects of inhalation or contact are very severe on human health and require hospital treatment.

Higher Pressures

The charts in figures 1 and 2 show the saturation temperature / pressure relationship for the alternative refrigerants as well as R404A and R134a:

Figure 1, pressure temperature, low and medium pressure refrigerants

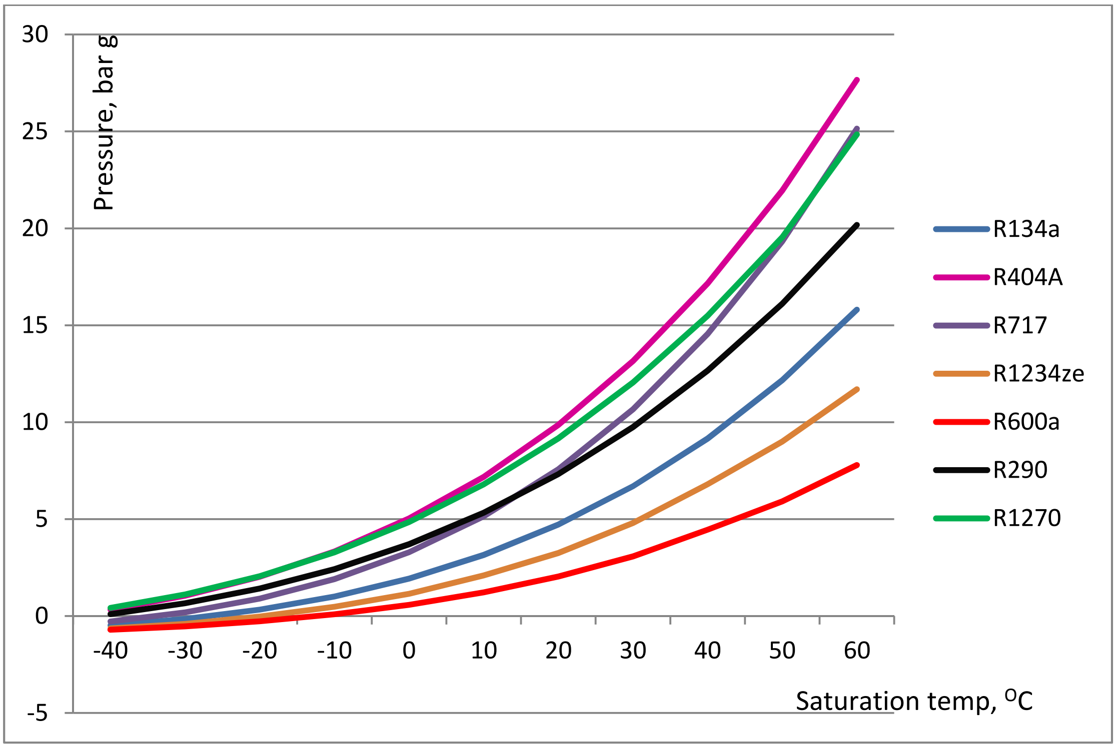
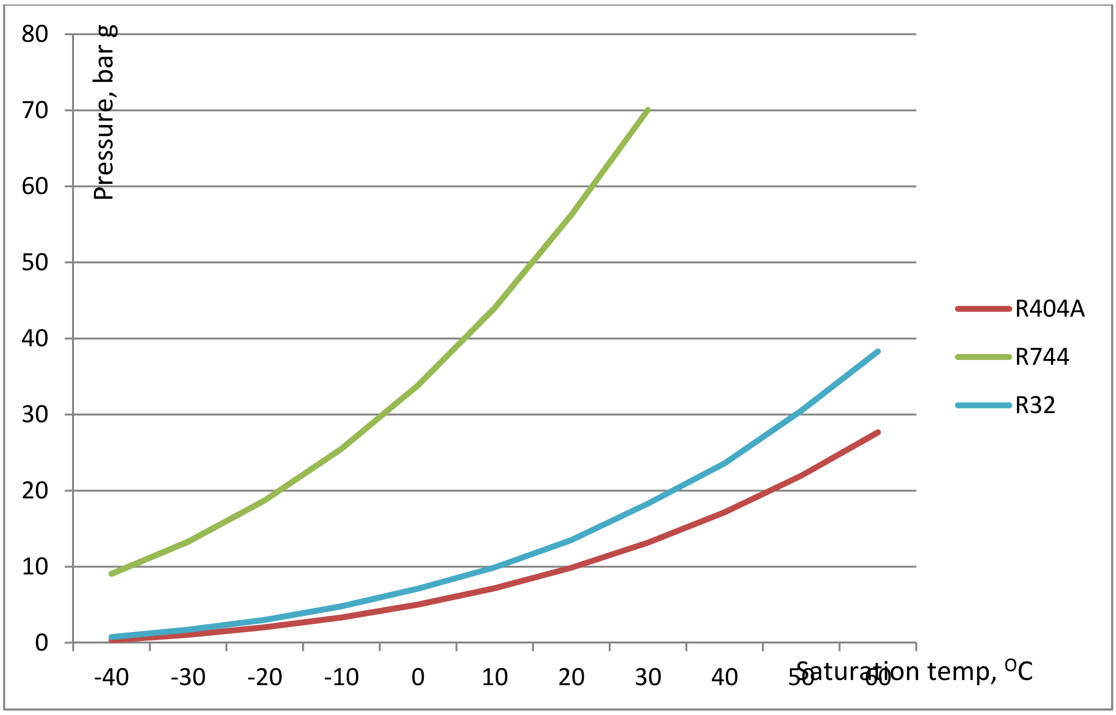


Figure 2, pressure temperature, high pressure refrigerants



Danfoss Refrigerant Slider App
Bitzer PT App

Most of the alternative refrigerants operate with lower pressures than R404A, thus enabling standard tools and equipment to be used (unless these are inappropriate for other safety reasons such as flammability or material compatibility such as with ammonia). However, R32 and R744 operate with higher pressures:

- The maximum condensing pressure in R32 systems is typically 35 bar g;
- The maximum high side operating pressure in R744 transcritical systems is typically 90 bar g. This is not shown in the pressure temperature chart above because it is above the critical temperature of 31°C. It is a function of either the control setting (for example in a central plant system used in the retail sector) or of the quantity of refrigerant in the system (in a typical integral type system);
- The maximum condensing pressure in R744 cascade systems is typically 35 bar g.

The higher operating pressures have an effect on:

- The rating of the components used;
- Pipe thickness;
- Tools used to access the system;
- Refrigerant recovery equipment.

Mostly the required components, tools and equipment are now readily available – but it is essential that the appropriate tools, components and equipment are used and are compatible for the refrigerant in use.

Restrictions on use such as maximum charge size

EN378[7] provides practical limits and maximum charge sizes for refrigerants. The practical limits are shown in table 4 and are based on the dominant hazard of the refrigerant:

- Toxicity (R717); or
- Flammability (R600a, R290, R1270, R32, R1234ze); or
- Asphyxiation (R744).

The practical limit (PL) is the highest concentration level in an occupied space that will not result in escape impairing effects. Where flammability is the dominant hazard it is 20% of the lower flammability level. PL is used to determine the maximum charge size for the refrigerant for systems where the refrigerant can leak into an enclosed occupied space.

EN378[8] specifies maximum charge sizes which depend on:

- Location of equipment, e.g. below or above ground level, within cooled space, in machine room;
- Occupancy of area being cooled, e.g. unrestricted access by the public or authorised access only;
- Type of system, e.g. direct expansion or secondary / refrigeration or air conditioning.

The tables below summarise the information in the extensive tables in EN378 - you should refer to the standard for detailed information.

Notes to Tables 5 & 6

1. Area being cooled, see table 7 below for full explanation and examples. If there is more than one category of occupancy the more stringent applies. If occupancies are isolated from each other the requirements of the individual category applies.
2. There is no restriction unless the system is located below ground or on upper floors with inadequate emergency exit.

The cells shaded in orange apply to non comfort cooling and heating applications only.

[7] EN378-1:2008 A2:2012, F3
[8] EN378-1:2008 A2:2012, table C1

Table 5, maximum charge for direct expansion (DX) systems

Area being cooled [1]	System location	Max charge, A1 refrigerants	Max charge, A2 refrigerants	Max charge, A3 refrigerants	Max charge, B2 refrigerants
All areas	Part or all of system below ground	See below	As below	1 kg	As below
General occupancy - class A	Human occupied space and occupied machine rooms	PL x room volume	38 x LFL	1.5 kg	PL x room volume
General occupancy - class A	Compressor and receiver in an unoccupied machine room or in the open air	PL x room volume	38 x LFL	1.5 kg	PL x room volume
General occupancy - class A	Whole of system in an unoccupied machine room or open air	No restriction	132 x LFL	5 kg	2.5 kg
Supervised occupancy – class B	Human occupied space and occupied machine rooms	PL x room volume [2] or no restriction	10 kg	2.5 kg	10 kg
Supervised occupancy – class B	Compressor and receiver in an unoccupied machine room or in the open air	No restriction	25 kg	2.5 kg	25 kg
Supervised occupancy – class B	Whole of system in an unoccupied machine room or open air	No restriction	No restriction	10 kg	No restriction
Authorised access – class C	Human occupied space and occupied machine rooms	PL x room volume * or no restriction	10 kg, or 50 kg if < 1 person per 10 m^2	10 kg	10 kg, or 50 kg if < 1 person per 10 m^2
Authorised access – class C	Compressor and receiver in an unoccupied machine room or in the open air	No restriction	25 kg, or no restriction if < 1 person per 10 m^2	25 kg	25 kg, or no restriction if < 1 person per 10 m^2
Authorised access – class C	Whole of system in an unoccupied machine room or open air	No restriction	No restriction	No restriction	No restriction

Table 6, maximum charge for indirect systems

Area being cooled [1]	System location	Max charge, A1 refrigerants	Max charge, A2 refrigerants	Max charge, A3 refrigerants	Max charge, B2 refrigerants
All areas	Part or all of system below ground	As below	As below	1 kg	As below
General occupancy - class A	Human occupied space and occupied machine rooms	Considered a direct system	Considered a direct system	Considered a direct system	Considered a direct system
General occupancy - class A	Compressor and receiver in an unoccupied machine room or in the open air	No restriction	PL x room volume or comfort cooling limit	1.5 kg	PL x room volume
General occupancy - class A	Whole of system in an unoccupied machine room or open air	No restriction	No restriction if exit to open air and no direct communication with A and B	5 kg	No restriction if exit to open air and no direct communication with A and B
Supervised occupancy – class B	Human occupied space and occupied machine rooms	Considered a direct system	Considered a direct system	Considered a direct system	Considered a direct system
Supervised occupancy – class B	Compressor and receiver in an unoccupied machine room or in the open air	No restriction	No restriction if exit to open air and no direct communication with A and B	2.5 kg	No restriction
Supervised occupancy – class B	Whole of system in an unoccupied machine room or open air	No restriction	No restriction if exit to open air and no direct communication with A and B	10 kg	No restriction
Authorised access – class C	Human occupied space and occupied machine rooms	Considered a direct system	Considered a direct system	Considered a direct system	Considered a direct system
Authorised access – class C	Compressor and receiver in an unoccupied machine room or in the open air	No restriction	No restriction	25 kg	No restriction
Authorised access – class C	Whole of system in an unoccupied machine room or open air	No restriction	No restriction	No restriction	No restriction

Maximum charge for comfort cooling and heating

For comfort cooling and heating the maximum charge is found from the following equation[9]:

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

M = max charge, kg
LFL = lower flammability limit, kg/m^3
(0.038 for R290, 0.040 for R1270)
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

Table 7, occupancy classification

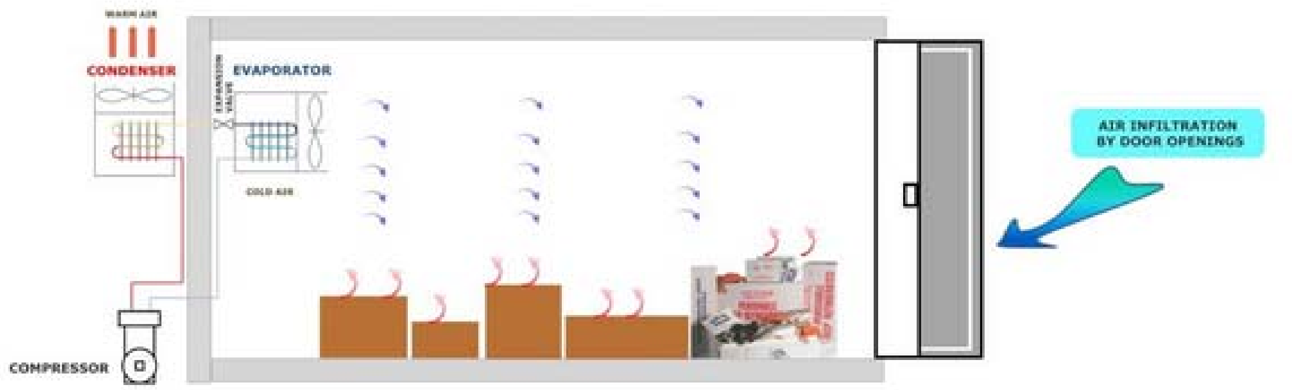
Class	Location where ...	Examples
A	People may sleep; The number of people present is not controlled; Any person has access without being personally acquainted with the personal safety precautions	Hospitals and nursing homes Prisons Theatres, lecture halls Supermarkets, restaurants, hotels Transport 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)

[9] EN378-1:2008 A2:2012, C3

Example 1 – Non comfort

Non comfort cooling or heating: An example of the application of the practical limit for R290 in a small walk in cold room is shown below:

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 practical limit = 0.008 kg/m^3;
Maximum charge = practical limit x room volume = 0.008 x 25.2 = 0.202 kg.

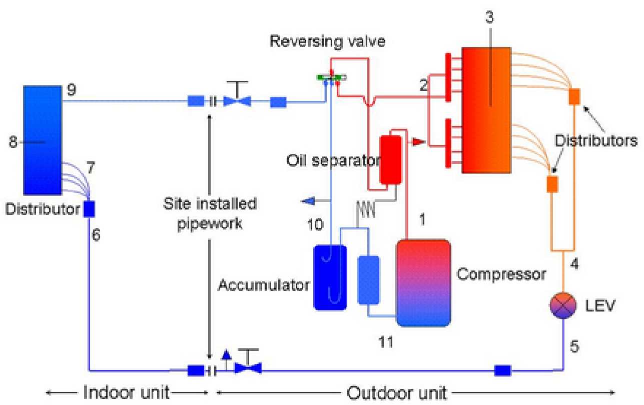


Example 2 – Comfort cooling/heating

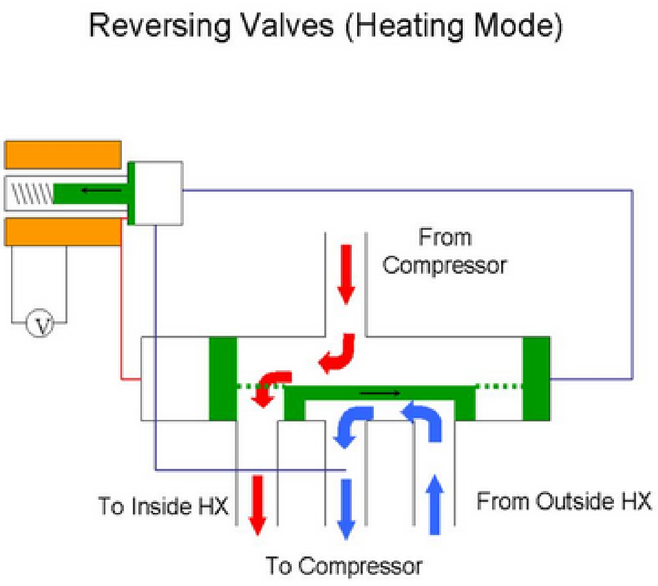
Comfort cooling or heating: An example of the comfort cooling / heating equation is for a room cooled by an R1234ze split air conditioning system with a ceiling mounted indoor unit is shown below:

$LFL_{R1234ze}$ = 0.303 kg/m^3
h = 2.2 for ceiling mounted unit
A = 9 m x 5.5 m = 49.5 m^2
M = 2.5 x $0.303^{1.25}$ x 2.2 x $\sqrt{49.5}$
M = 3.95 kg.

Typical Air Conditioner Refrigerant Circuit

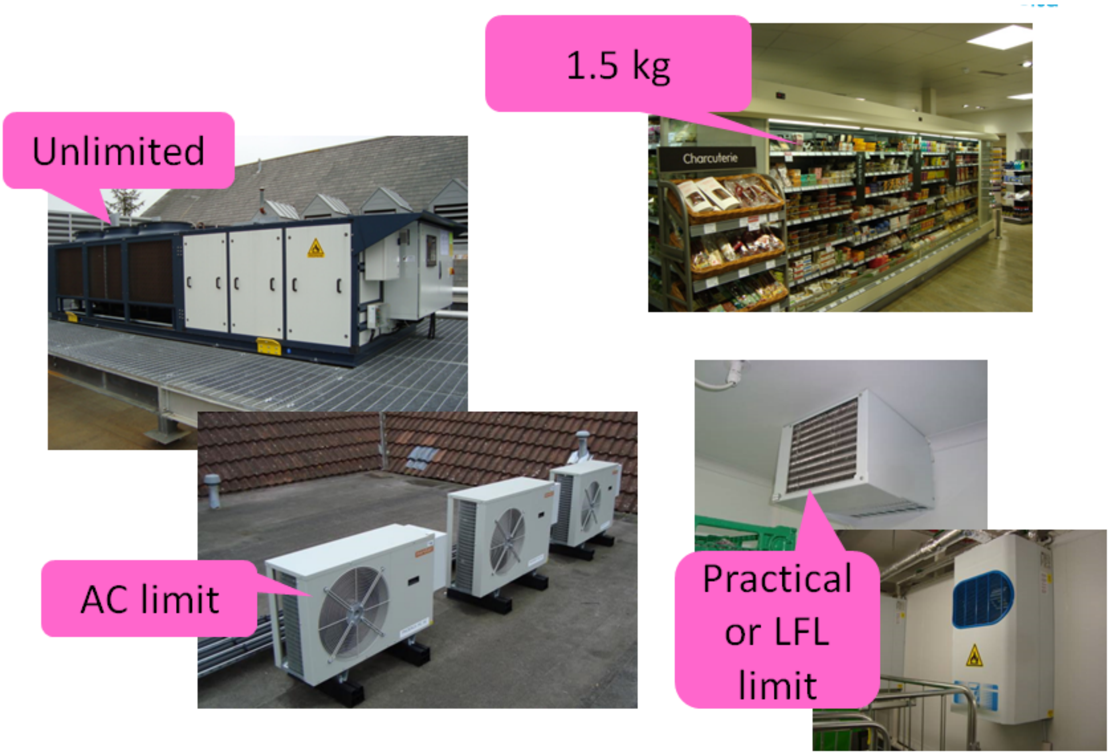


Reversing Valves (Heating Mode)


Reversing Valves (Heating Mode)
V
From Compressor
To Inside HX
From Outside HX
To Compressor

Determining Minimum Room Volume

The two calculations above can also be used to determine minimum room volume for a system with a specific charge.



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 17, pages 36, 37

Copeland Select 7 Software

Table 8, 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[10];
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.

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

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 14511-2:2007 “Air Conditioning, Liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. Test conditions”

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

Figure 3, displacement compared to R404A

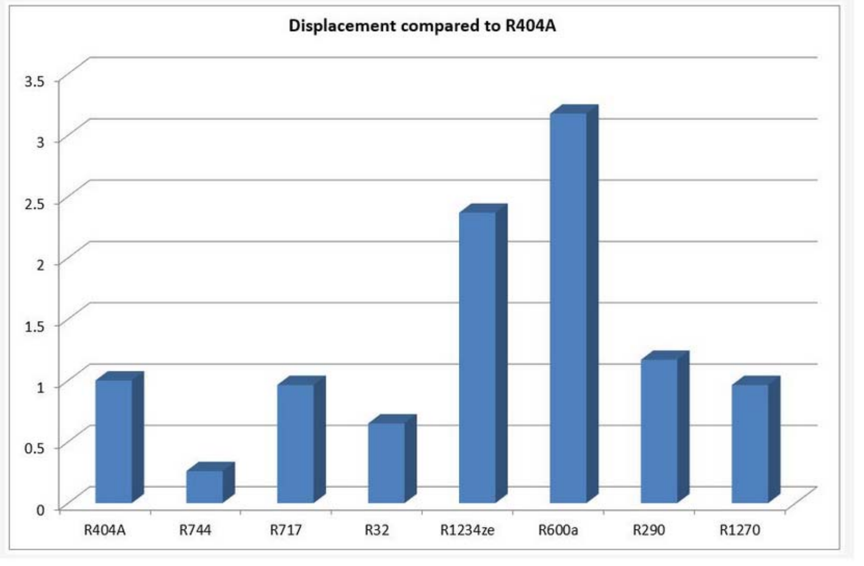
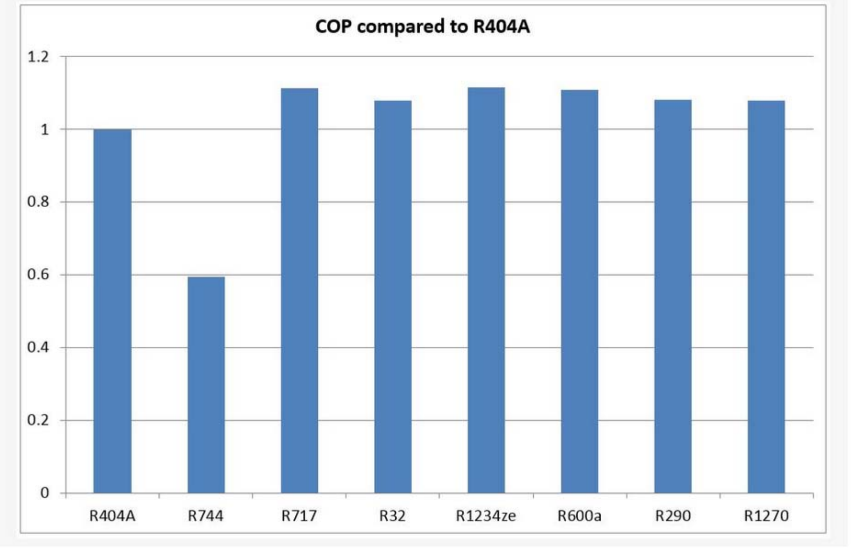


Figure 4, COP compared to R404A



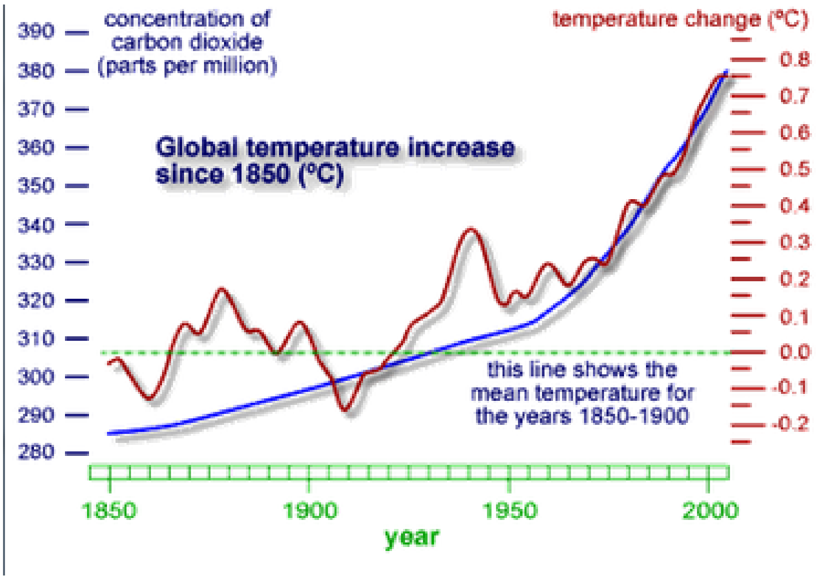
Note that the COP for R744 is low because this is a theoretical cycle comparison at conditions which most refrigeration systems would operate (including 35^{O}C condensing temperature). However, R744 is above the critical temperature for this comparison, and in reality the head pressure would be controlled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

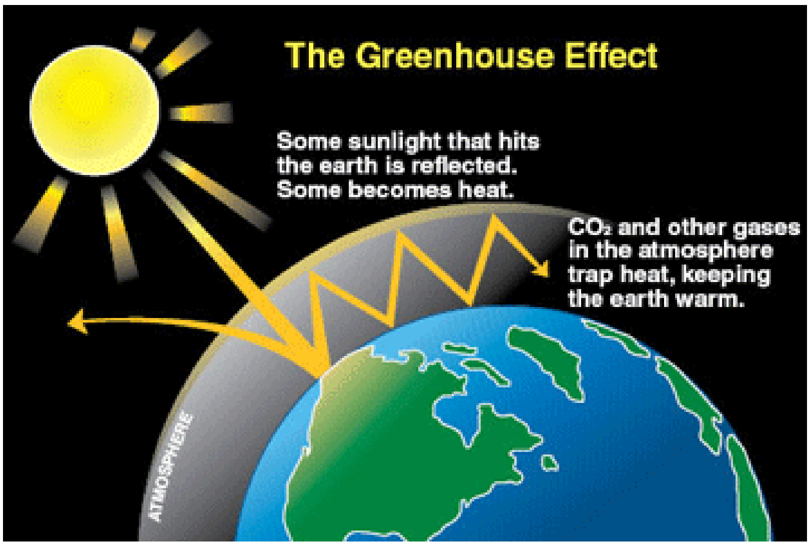
Environmental impact

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 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.

The GWP of R717 is zero, R744 is 1, R32 is 675, R1234ze is 7. R290, R1270 and R600a all have a GWP of 3. This can be compared to typical GWPs for higher GWP HFCs in common use for example R404A is 3922, R410A is 2088.





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

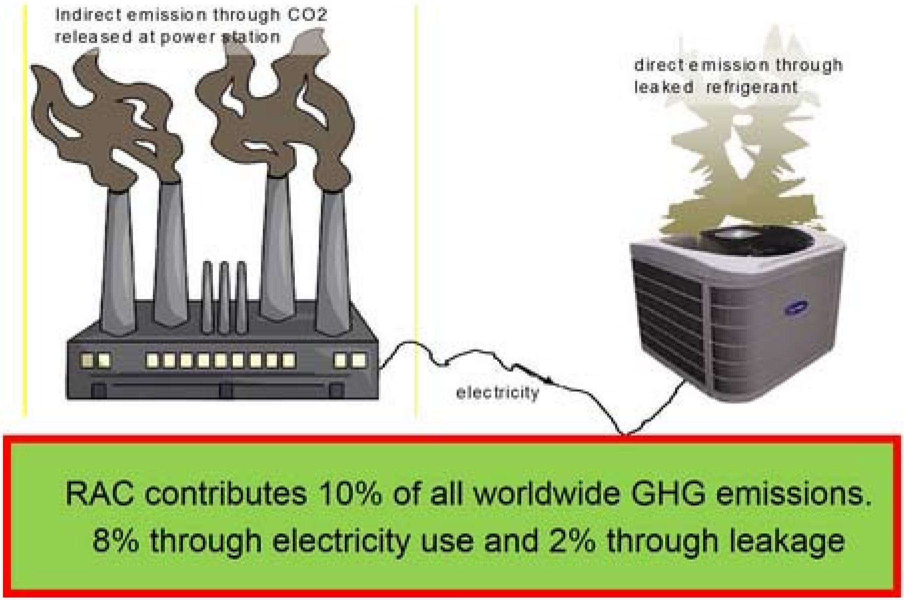
Total Equivalent Warming Impact

The total impact of a system and refrigerant on climate change is estimated using TEWI – the Total Equivalent Warming Impact[11]. It is a method of assessing the impact on climate change over the lifetime of a system by combining:

the direct contribution of refrigerant emissions into the atmosphere

+

the 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).

[11] 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.

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 9, availability of alternative refrigerants and associated items (estimated as at February 2015)

<table>
<tr><th></th><th>Refrigerant</th><th>Knowledge</th><th>Skills / Training</th><th>Components</th><th>Tools and equipment</th></tr>
<tr><td>R744</td><td>Refrigerant grade CO_2 available in a range of cylinder sizes</td><td>Wide range of system design options challenge design engineers</td><td>Hazards and range of system types challenge technicians. Training available</td><td>Available for large systems, less so for small systems</td><td>Available</td></tr>
<tr><td>R717</td><td>Refrigerant grade NH_3 widely available in a range of cylinder sizes</td><td>Widely understood in the industrial sector</td><td>Widely understood in the industrial sector. Training available</td><td>Widely available in the industrial sector</td><td>Widely available</td></tr>
<tr><td>R32</td><td>Available</td><td>Manufacturers of R32 equipment have a good understanding</td><td>Very little experience and questions regarding sources of ignition. HC training applicable and available</td><td>To be deployed in AC systems from 2015</td><td>Widely available (most HC tools / equipment are suitable)</td></tr>
<tr><td>R1234ze</td><td>Available only in trial quantities, expensive</td><td>Very limited knowledge</td><td>Very limited experience, but HC experience is applicable. HC training applicable and available</td><td>Compressors not readily available</td><td>Widely available (most HC tools / equipment are suitable)</td></tr>
<tr><td>R600a</td><td rowspan="3">Refrigerant grade HCs available in a range of cylinder sizes</td><td>Widely used and understood in the domestic sector</td><td>Very wide experience in the domestic sector. Training available</td><td>Widely deployed, components readily available</td><td rowspan="3">Widely available, except recovery machine is available from only one supplier</td></tr>
<tr><td>R290</td><td rowspan="2">Information readily available on application of HCs in commercial systems</td><td rowspan="2">Wide experience in the commercial sector. Training available</td><td rowspan="2">Widely deployed in integral systems and chillers, components readily available</td></tr>
<tr><td>R1270</td></tr>
</table>

Leakage issues

This section outlines issues associated with leakage of alternative refrigerants – more detailed information is provide in Module 3, Containment and Leak detection for Alternative Refrigerants.

REAL Alternatives Guide 3

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 10, 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 mild flammability	Good - odour and detection equipment available
R32	Medium • Medium to high operating pressures • Used in AC systems, but usually with brazed connections	Mild flammability	Detection equipment becoming available
R1234ze	Medium • Medium to low operating pressures • Used in chiller type systems with minimum joints	Mild 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	High flammability	Detection equipment available

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 in the Additional Resources Appendix booklet. The standards and legislation below are also explained more fully in Module 6 – Checklist of Legal Obligations.

Table 11, 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 378-1:2008 A2:2012	Refrigerating systems and heat pumps – Safety and environmental requirements, Basic requirements, definitions, classification and selection criteria	Practical limit Maximum charge sizes
EN 378-2:2008 A2:2012	Refrigerating systems and heat pumps – Safety and environmental requirements, Design, construction, testing, marking and documentation	High pressure protection Ventilated enclosures
EN 378-3:2008	Refrigerating systems and heat pumps – Safety and environmental requirements, Installation site and personal protection	Machinery rooms Refrigerant detectors
EN 378-4:2008 A2:2012	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 60079-0:2009	Explosive atmospheres – Equipment – general requirements	Categorisation of flammable gases Classification of equipment Zones
EN 60079-10-1:2009	Explosive atmospheres – Classification of areas – explosive gas atmospheres	Zones and classification of equipment Leak simulation testing Air flow requirements
EN 60079-14:2008	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 60335-2-40:2003	Household & similar electrical appliances – Particular requirements for electrical heat pumps, air conditioners and dehumidifiers	Design, application and servicing of AC systems using flammable refrigerants.
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

Self Test Module 1

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. Mild flammability
iii. High toxicity
iv. Mild toxicity

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 –

R290 is classified in EN378 as a refrigerant Class:

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

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. 0.4kg
III. 3.25
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.realalternatives.eu/e-library to explore any additional information you may find useful.

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

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

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

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