



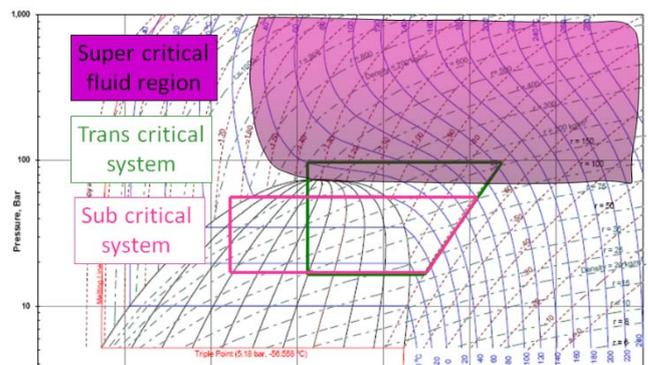
With contribution of  
the LIFE programme  
of the European Union

# Design Differences

## For Alternative Refrigerants

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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](http://www.realalternatives4life.eu)

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

## Programme modules:

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

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

[www.realalternatives4life.eu](http://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](http://www.realalternatives4life.eu/e-library). You can also add extra resources such as weblinks, technical manuals or presentations to the library if you think others will find them valuable. Module 7 provides a complete list of relevant legislation and standards referred to within the programme.

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

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

## Register your interest in alternative refrigerants at

[www.realalternatives4life.eu](http://www.realalternatives4life.eu) to receive updates, news and event invitations related to training, skills and refrigeration industry developments.

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## Background to the programme and how it

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

### The consortium partners were:

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

### With thanks to our stakeholders:

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

# Module 3 – Design Differences for Alternative Refrigerants

## Aim of this Module

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

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

Table 1, Characteristics which affect the design of systems

Refrigerant	Pressure	Flammability	Toxicity	Cooling capacity	Critical temperature	Discharge temperature	Materials
R744	Very high		Mild	Very high	Low	High	
R717		Mild	High			High	No copper or copper alloys
R32	High	Mild		High			
R1234ze	Low	Mild		Low			
R600a	Very low	High		Very low			
R290 R1270		High					

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

Issues associated with flammability affect all the alternative refrigerants except R744, so Appendix 1 includes this information to avoid repetition within the document.

Typical maximum allowable pressures (PS<sup>1</sup>) are given for all refrigerants. In all cases except for R744 these pressures are based on a maximum ambient of 32°C and a maximum condensing temperature of 55°C.

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

# 1 Minimising Leak Potential

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

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



See REAL Alternatives  
Guide 4 “Containment  
and Leak Detection”

## 2 R744 (Carbon dioxide)

See REAL Alternatives Guide 1, figure 2

The properties of R744 effect how the refrigerant is applied:

	Type	Key facts	GWP <sup>2</sup>	Sat temp <sup>3</sup>	Typical applications
R744	Carbon dioxide, CO <sub>2</sub>	High pressures	1	-78°C	Retail refrigeration, heat pumps, integrals

- All components must be suitable for a high pressure rating because of the high maximum operating and standstill pressures of R744;
- R744 has a lower practical limit than most HFCs because of its low toxicity. (Refer to Module 4 for more details on fixed leak detection);
- The practical limit for a refrigerant represents the highest concentration level in an occupied space that will not result in escape impairing effects for the individual. For full information see the Safety Standard EN378-1, table E.1;
- R744 is an asphyxiant and a fixed leak detection system should be fitted if a leak in an enclosed occupied space such as a cold room, or in plant areas, could result in a concentration which will result in escape impairing effects. It is recommended that the alarm level is set at 50% Acute Toxicity Exposure Limit (ATEL) or Oxygen Deprivation Limit (ODL) as specified in EN378 for machinery rooms. This is the level above which there is an adverse effect that results either from a single or multiple exposures in a short space of time (usually less than 24 hours). For R744 the ATEL / ODL is 0.072 kg/m<sup>3</sup>, so the alarm should be set at 0.036m<sup>3</sup> (approximately 20,000 ppm). Typically there will also be a pre alarm at 5,000 ppm because of the rapid rise in concentration in the event of a leak due to the high pressures of R744;
- Compressor displacement and pipe diameters are smaller because of the high cooling capacity of R744 compared to other refrigerants. For example the compressors displacement is approximately 1/5<sup>th</sup> of that needed for R404A;
- The low critical temperature of R744 results in differences in overall system design. R744 is used in the following types of system:
  - **Transcritical systems:** These systems operate above the critical temperature on the high side for all or part of the time. In these are systems the heat is rejected from the R744 to ambient air and is therefore transcritical at high ambient conditions, typically when the ambient temperature exceeds 21 to 25°C. Small transcritical systems such as beverage coolers, located inside a building, will normally operate transcritically all of the time.
  - **Cascade systems:** These systems are always subcritical. In these systems R744 is the low stage refrigerant in a cascade system, and the heat rejected by the condensing R744 is absorbed by the evaporating high stage refrigerant. The high stage system is usually a conventional system using HFC or HC or R717. On some

See REAL Alternatives Guide 4

<sup>2</sup> GWP is from F Gas Regulation EU 517:2014

<sup>3</sup> Sat temp is the surface temperature of solid R744 at atmospheric pressure

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

- **Secondary systems:** The R744 is used as a secondary fluid and is pumped around the heat exchangers. Partial evaporation can occur because of the volatility of R744, but saturated refrigerant will exit the evaporator (i.e. it will not be superheated as in the systems above). The R744 is cooled by a chiller.
- Two stage compression is used for transcritical low temperature (LT) systems due to the high discharge temperatures that are possible.
- Mechanical subcooling such as the use of suction to liquid line heat exchangers is used in many systems where normally the liquid temperature is below ambient temperature because of the system configuration - natural liquid subcooling will therefore not occur.

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



Figure 1, Example of an R744 system

## 2.1 Transcritical operation

### Critical temperature

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

- R744 systems are subcritical when the condensing temperature is below  $31^{\circ}\text{C}$ .
- R744 systems are transcritical when the “gas cooling temperature” is above  $31^{\circ}\text{C}$ .

HFC, HC and R717 systems are always subcritical because the condensing temperature never exceeds the critical temperature (e.g.  $101^{\circ}\text{C}$  in the case of R134a).

Danfoss video, CO<sub>2</sub>  
phase change

NaReCO2 manual  
Natural Refrigerant CO<sub>2</sub>

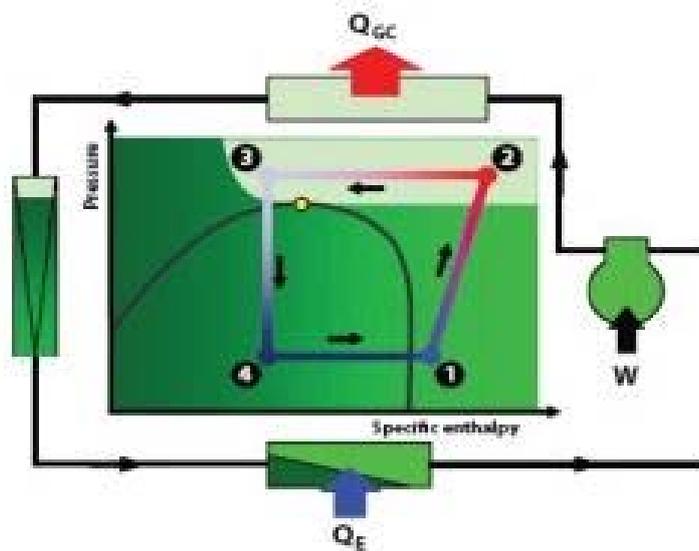


Figure 2, PH chart showing a transcritical system, from [www.danfoss.com](http://www.danfoss.com)

### Simple Transcritical System

A simple transcritical system is shown in figure 4.

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

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

Danfoss “Transcritical refrigeration Systems with CO<sub>2</sub>, how to design a small capacity system “

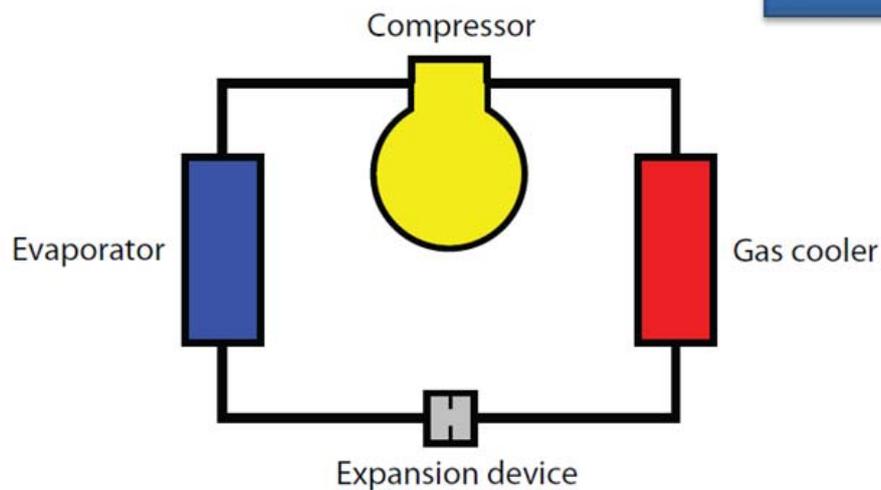


Figure 3, simple transcritical system

## P-h Chart – Simple System

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

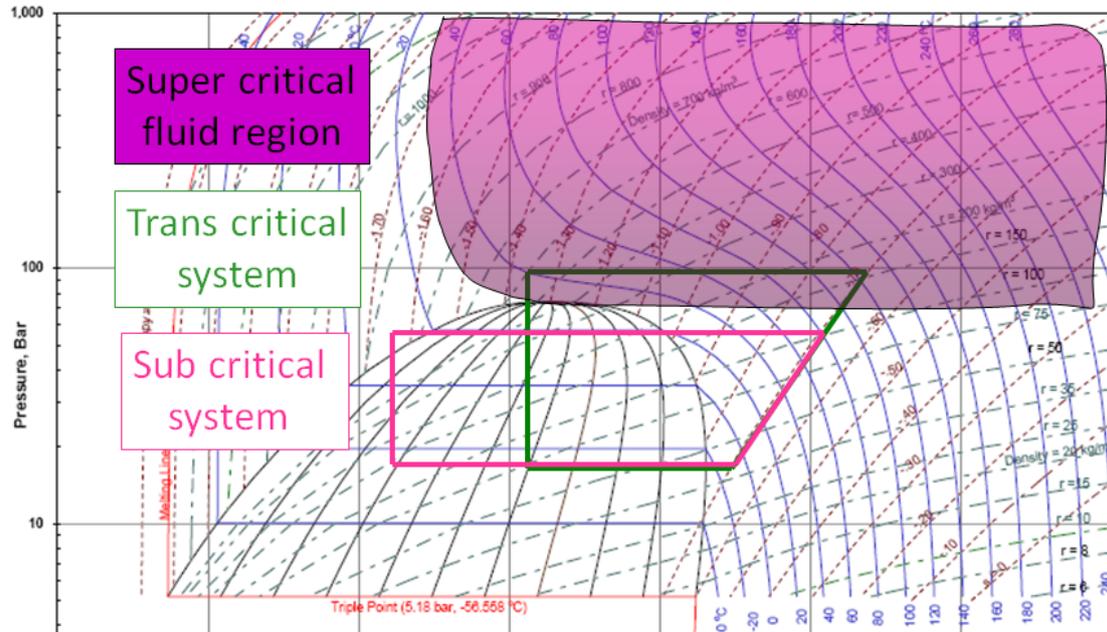


Figure 4, Pressure enthalpy chart showing sub and transcritical operation

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

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

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

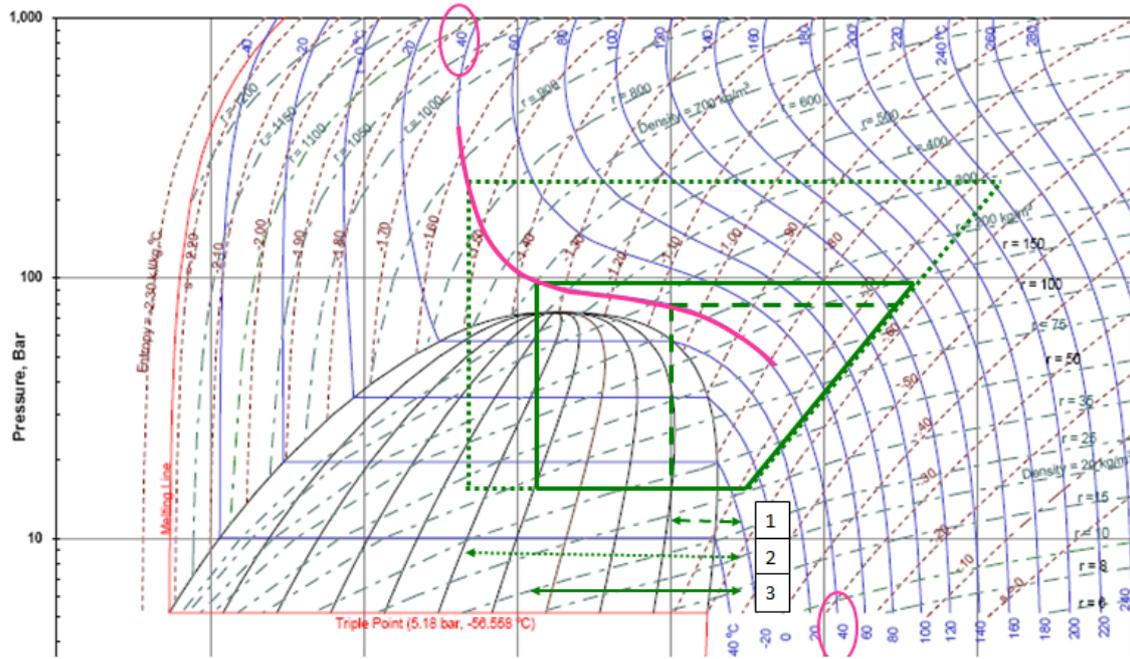


Figure 5, Pressure enthalpy chart showing three gas cooler pressure conditions

## Large Transcritical System

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

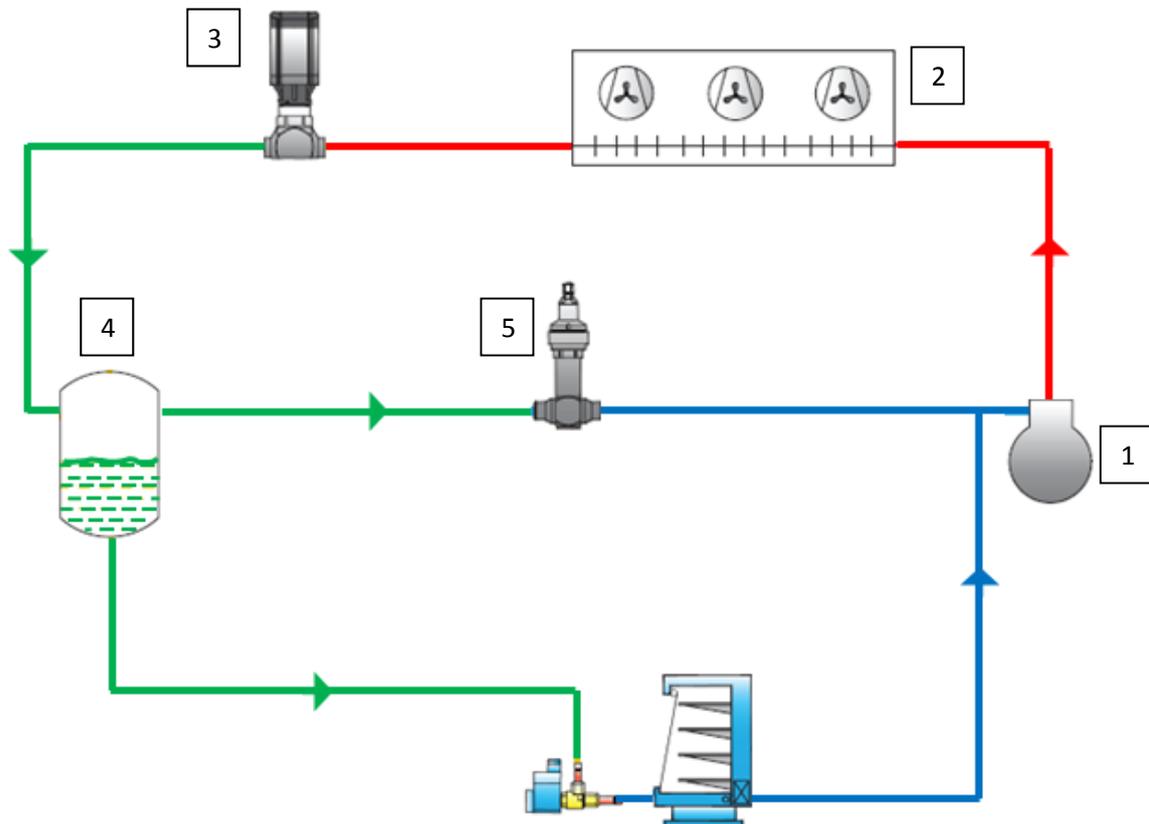


Figure 6, Typical transcritical system

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

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

Danfoss "Food Retail CO<sub>2</sub> Refrigeration"

Emerson Guide, "Introduction to R744 Systems"

Emerson Guide "R744 System Design"

## 2.2 Subcritical cascade systems

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

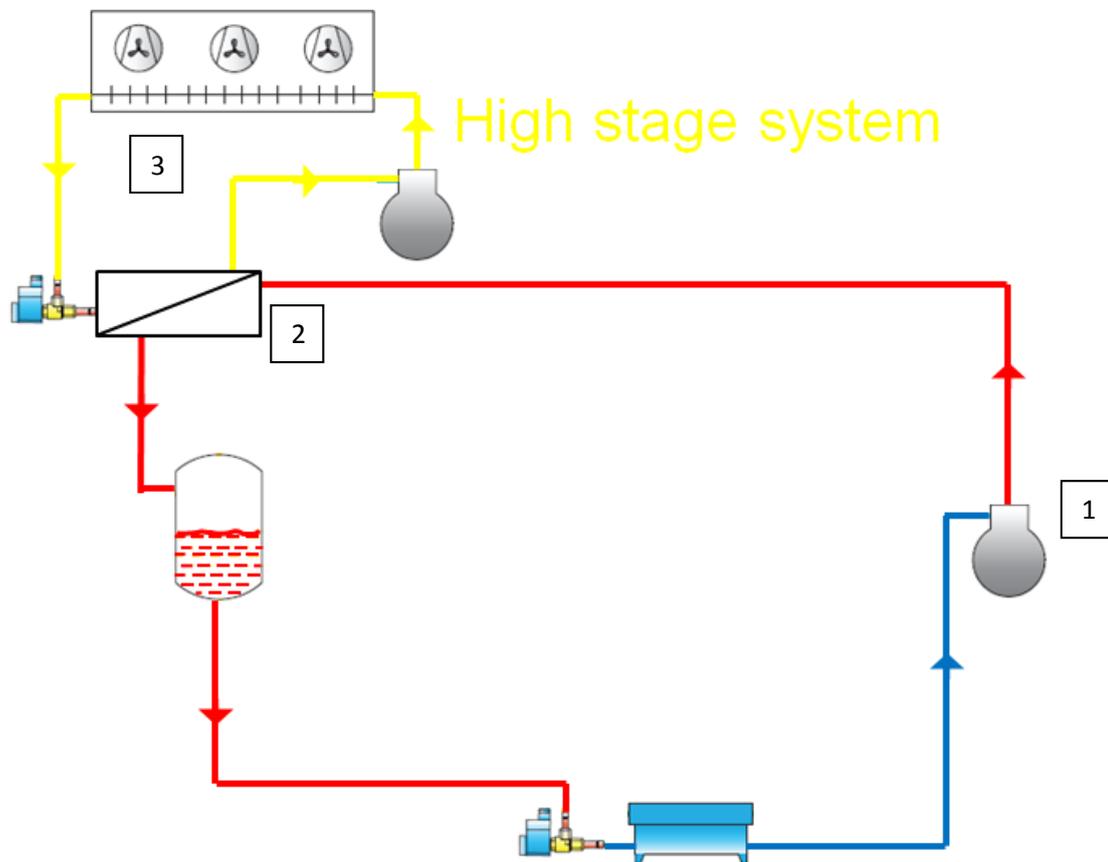


Figure 7, Simple cascade system

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

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

Danfoss "Cascade CO<sub>2</sub> System"

Emerson Guide "Introduction to R744 Systems"

Emerson Guide "R744 System Design"

## 2.3 Secondary Systems

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

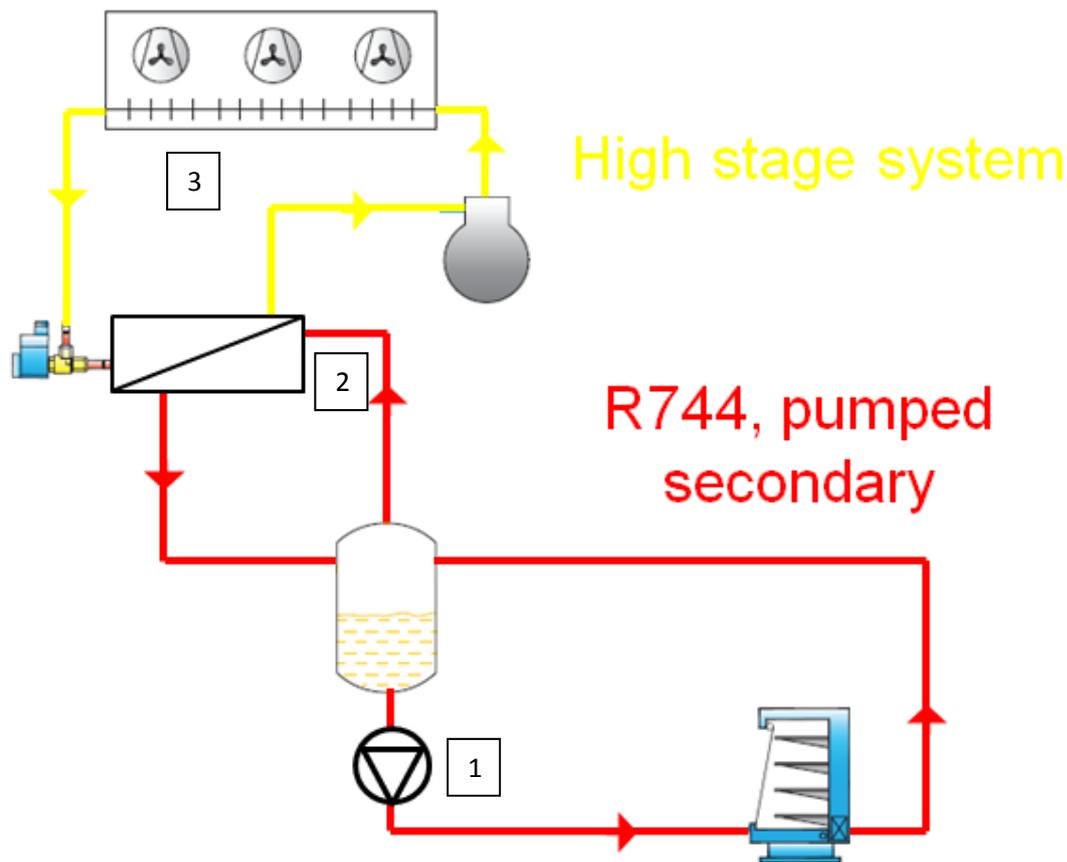


Figure 8, Simple pumped secondary system

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

### R744 has advantages over other secondary fluids:

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

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

## 2.4 Pressures

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

**Table 2, Typical R744 pressures**

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

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

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

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

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

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

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

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

## 2.5 Cooling Capacity

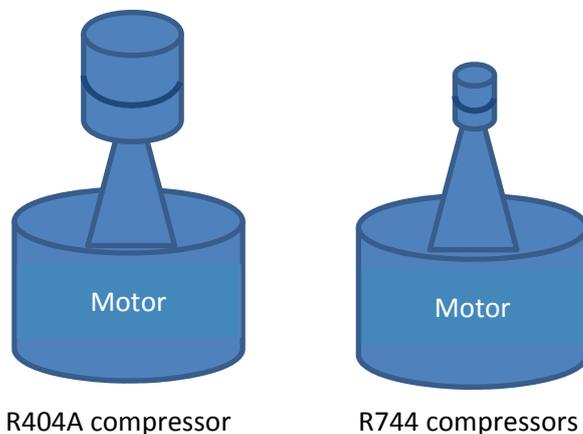
As shown in Module 1 the cooling capacity of R744 is several times that of more commonly used refrigerants. This has an impact on:

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

See REAL Alternatives Guide 1 “Introduction”

Emerson Guide “R744 System Design”

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

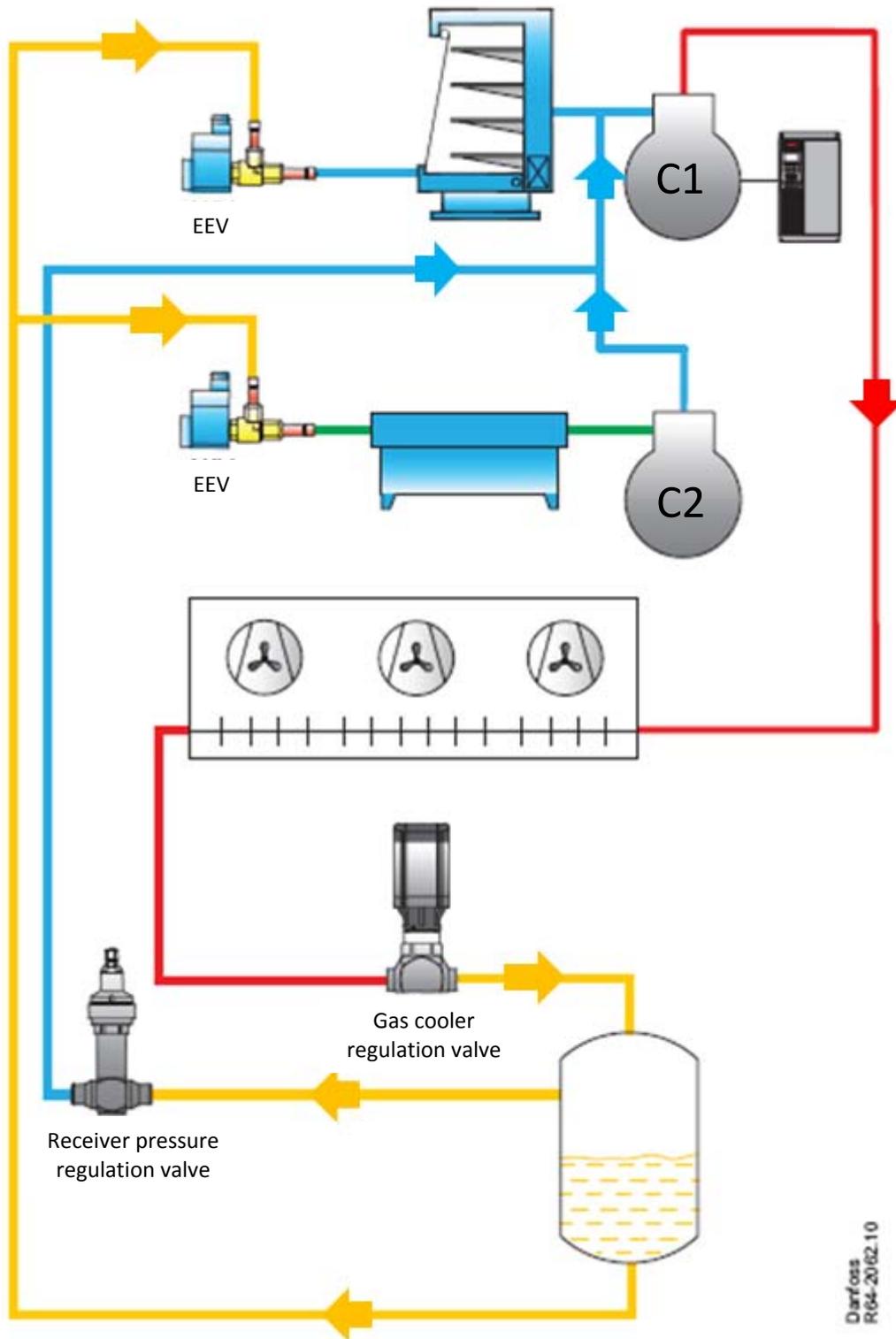


Both compressors provide same cooling capacity and use approximately the same power.

## 2.6 Two stage compression (booster)

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

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

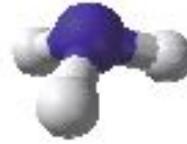


Danfoss  
R04-20/02.10

Figure 9, Transcritical booster system

## 3 R717 (Ammonia)

NH<sub>3</sub>  
1 Nitrogen molecule  
3 Hydrogen molecules



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

	Type	Key facts	GWP <sup>5</sup>	Sat temp <sup>6</sup>	Typical applications
R717	Ammonia, NH <sub>3</sub>	Toxic and mildly flammable	0	-33°C	Industrial

- Charge size is limited because of toxicity, see Guide 1 for more information (R717 is classified as a group B2L refrigerant);
- Some electrical components are designed for use in an explosive atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to lower flammability refrigerants such as R717;
- Typical maximum system pressure (PS) for the high side is 22 bar g, and typical PS for the low side is 11.4 bar g, so pressures are not excessively high;
- Two stage compression is used for low temperature applications such as the processing and storage of frozen food to avoid excessive discharge temperatures;
- R717 corrodes copper, so pipe work and fittings are usually steel and open drive compressors specifically designed for use with R717 are used
- R717 is total immiscible with compressor lubricant so lubricant which enters the low side of the refrigeration system stays there as a layer of oil below the R717. Lubricant recovery devices should be installed, preferably an integral oil recovery system that collects oil and returns it to the oil reservoir.

See REAL Alternatives Guide 1 "Introduction"

Danfoss Refrigerant Slider App  
Bitzer PT App

IoR Safety Code of Practice for Refrigerating Systems utilizing R717



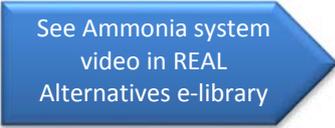
Figure 10, Examples of R717 systems

<sup>5</sup> GWP is from F Gas Regulation EU 517:2014

<sup>6</sup> Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

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

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



See Ammonia system  
video in REAL  
Alternatives e-library

## 4 R32

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

	Boiling point °C	Safety group	Lower flammability level kg/m <sub>3</sub>	Practical limit kg/m <sub>3</sub>	Ignition temp °C	GWP
R32	-51	A2L	0.307	0.061	648	675

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

- Charge size is limited, see Module 1 for more information (R32 is classified as a group A2L refrigerant);
- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to lower flammability refrigerants such as R32.

See REAL Alternatives Guide 1

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

See REAL Alternatives Guide 1, figure 2

Danfoss Refrigerant Slider App  
Bitzer PT App

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

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



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

<sup>7</sup> GWP is from F Gas Regulation EU 517:2014

<sup>8</sup> Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

## 5 R1234ze

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

- Charge size is limited, see Module 1 for more information (R1234ze is classified as a group A2L refrigerant);
- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to mildly flammable refrigerants such as R1234ze;
- Typical maximum system pressure (PS) for the high side is 10.3 bar g, and typical PS for the low side is 5.1 bar g, so components and pipe work can be specified for a significantly lower pressure than for other HFCs;
- The cooling capacity is approximately 75% that of R134a and the COP is very similar. So the compressor would have a similar sized motor, but a displacement 30% greater than for R134a to provide the same capacity. Currently few compressors are available for use on R1234ze.

See REAL Alternatives Guide 1

See REAL Alternatives Guide 1, figure 1

Danfoss Refrigerant Slider App  
Bitzer PT App

UNEP Case Study including Waitrose trial

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



Figure 12, Examples of equipment designed to use R1234ze

<sup>9</sup> GWP is from F Gas Regulation EU 517:2014

<sup>10</sup> Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

## 6 R600a (Iso butane)

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

- Charge size is limited, see Guide 1 for more information (R600a is classified as a group A3 refrigerant);
- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to flammable refrigerants such as 600a;
- Typical maximum system pressure (PS) for the high side is 6.8 bar g, and typical PS for the low side is 3.3 bar g, so components and pipe work can be specified for a significantly lower pressure than for other HFCs;
- The cooling capacity is approximately 50% that of R134a and the COP is very similar. So the compressor has greater displacement to provide the same cooling capacity, but a similar sized motor. Compressors for R600a are widely available for domestic and small commercial sized systems, but not for larger systems.

See REAL Alternatives Guide 1

See REAL Alternatives Guide 1, figure 1

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	Type	Key facts	GWP <sup>11</sup>	Sat temp <sup>12</sup>	Typical applications
R600a	Isobutane, C <sub>4</sub> H <sub>10</sub> , hydrocarbon (HC)	Flammable	3	-12°C	Domestic and small commercial systems

<sup>11</sup> GWP is from F Gas Regulation EU 517:2014

<sup>12</sup> Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

## 7 R290 and R1270 (Propane and Propene)

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

- Charge size is limited, see Guide 1 for more information (R290 and R1270 are classified as group A3 refrigerants);
- Some electrical components are designed for use in a flammable atmosphere. Appendix 1 provides more detail about the design process for systems which use a flammable refrigerant. This applies to flammable refrigerants such as R290 and R1270.

See REAL Alternatives  
Guide 1

See REAL Alternatives  
Guide 1, figure 1

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Typical maximum system pressures (PS) are as follows:

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

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

	Type	Key facts	GWP <sup>13</sup>	Sat temp <sup>14</sup>	Typical applications
R290	Propane, C <sub>3</sub> H <sub>8</sub> , hydrocarbon (HC)	Flammable	3	-42°C	Chillers, integrals
R1270	Propene (propylene), C <sub>3</sub> H <sub>6</sub> , hydrocarbon (HC)	Flammable	3	-48°C	Chillers, integrals



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

<sup>13</sup> GWP is from F Gas Regulation EU 517:2014

<sup>14</sup> Sat temp is the saturation temperature at atmospheric pressure (1 bar g)

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

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

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

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

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

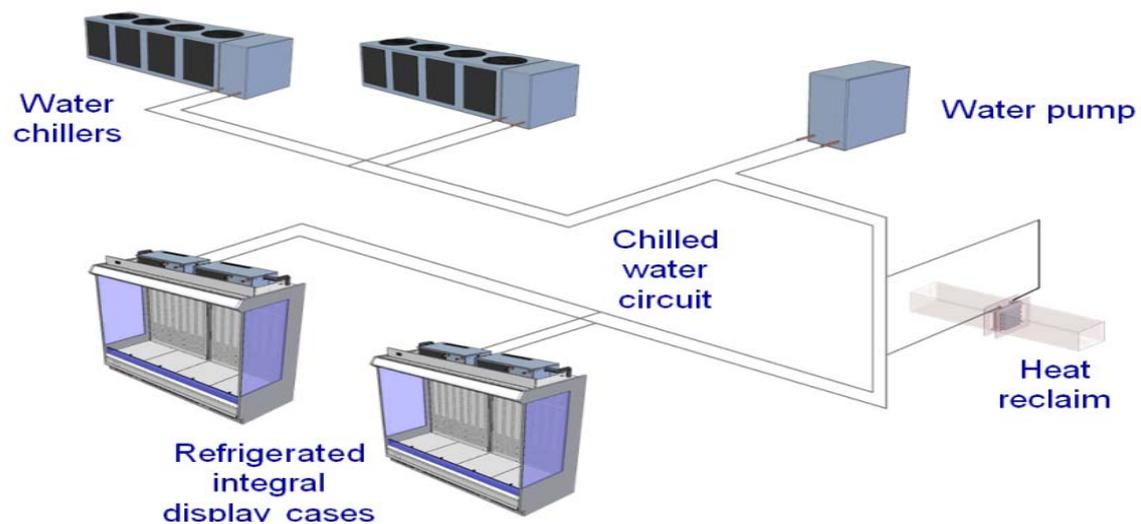
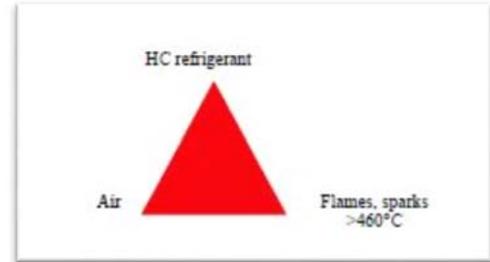


Figure 14, Schematic of water cooled cabinets and chiller

## 8 Appendix 1, Design Process for Flammable Refrigerant Systems

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



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

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

Refer to the following standards for more detailed information:

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

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

## The design process

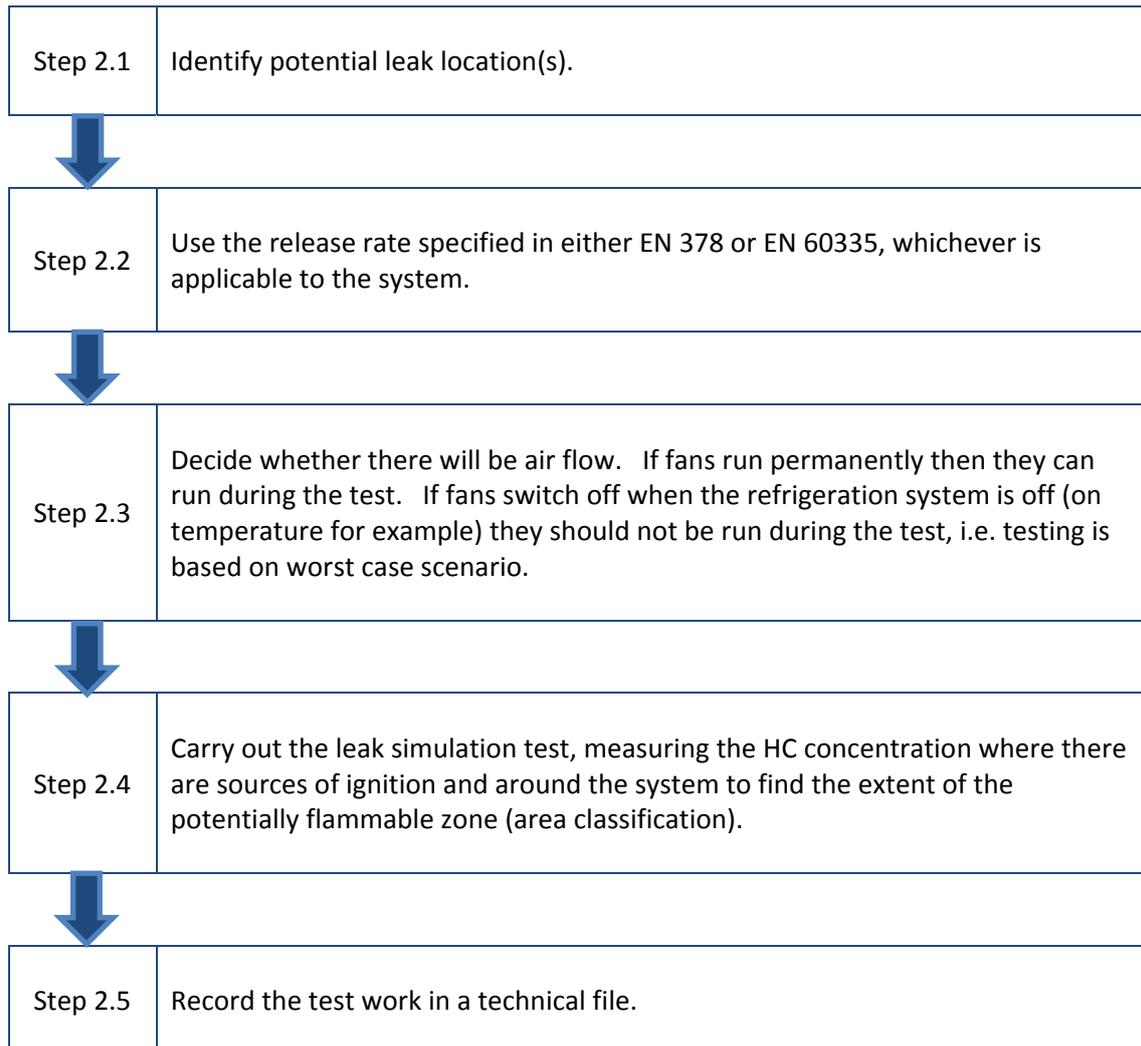
The design process for ensuring flammable refrigerant systems are safe is summarised below for any system which contains sources of ignition, regardless of the charge size.

Step 1.1	Carry out flammable zone testing (area classification) to determine the extent of the potentially flammable zone in the event of a leak.	
		
Step 1.2	Identify sources of ignition within the potentially flammable zone.	
		
Step 1.3	Option 1 or Option 2 or Option 3 or Option 4	<p>Move the source of ignition outside the potentially flammable zone. EN60079-14 (Explosive atmospheres – Electrical installations design, selection and erection) requires that, wherever possible, electrical equipment should be located in non-hazardous areas.</p> <p>Replace the source of ignition with a suitable device.</p> <p>Increase the air flow and / or maintain a permanent air flow to reduce the potentially flammable zone.</p> <p>Locate the source of ignition in a suitable enclosure (this is usually cost prohibitive for small systems and difficult to achieve).</p>

## Simulated leak testing

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

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



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

## Potential leak points

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

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

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

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

## Electrical devices

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

- Produce an arc or spark (unless that arc or spark is prevented from causing ignition in accordance with IEC EN60079-15 Explosive atmospheres – Equipment protection by type of protection “n”, clauses 16 to 20);
- Develop a maximum surface temperature in excess of the maximum appropriate to the temperature class of the apparatus (unless the temperature is prevented from causing ignition in accordance with IEC EN60079-15, clauses 16 to 20).

## Sources of ignition

Sources of ignition associated with refrigeration systems typically include:

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

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<sup>16</sup> EN60079-10-1:2015 Explosive atmospheres – Classification of areas – explosive gas atmospheres,

heater surface temperature should be demonstrated by testing in the operating environment maximum ambient, assuming defrost termination has failed).

- Hot surfaces above 360 degrees C.

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

The following items are generally not sources of ignition:

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

### Dealing with sources of ignition

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

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

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

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

WARNING – do not separate when energised

<sup>17</sup> EN60079-15:2010 Explosive atmospheres – Equipment protection by type of protection “n”, 9.1

<sup>18</sup> EN60079-15:2010 Explosive atmospheres – Equipment protection by type of protection “n”, 10.1 and 24.3.1

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

WARNING – do not remove or replace fuse when energised

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

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

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

or

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

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

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<sup>19</sup> EN60079-15:2010 Explosive atmospheres – Equipment protection by type of protection “n”, 9.4

<sup>20</sup> EN60079-14:2014 Explosive atmospheres – Electrical installations design, selection and erection

## 9 Self Test Module 2

Try the sample multiple choice assessments below to check your learning

### Question 1 -

What is the pressure of R744 in a system which is at standstill in an ambient temperature of 20°C?

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

### Question 2 –

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

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

### Question 3 –

Below which condensing temperature is a R744 system subcritical?

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

### Question 4 –

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

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

The answers are on the bottom of the next page.

## What next?

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

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

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

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

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