Department for Environment, Food and Rural Affairs

Guidance on Minimising Greenhouse Gas Emissions from Refrigeration, Air-conditioning and Heat Pump Systems

Guidance: F Gas and Ozone Regulations

Information Sheet RAC 7: Alternatives

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Contents

This Information Sheet provides information to help users and designers of stationary refrigeration, air-conditioning and heat pump systems (RAC systems) understand how to minimise greenhouse gas (GHG) emissions and, in particular, the options available for refrigerant selection.

Selecting the best refrigerant for a particular RAC system can be a fairly daunting task. There are a wide range of different applications of refrigeration technology, each of which has different characteristics in terms of refrigerant selection. Some of the key differences include:

- **Temperature Level.** RAC systems operate at widely varying temperatures, from below -200°C for cryogenic applications up to around +100°C for heat pumps. A variety of different refrigerants are required to span this wide temperature range.
- **Size.** Plant size varies by at least four orders of magnitude from under 1 kW to over 10 MW of cooling. This also affects refrigerant choice.
- **Location.** Some plants operate in areas with public access whilst others are in restricted areas – this can have a major influence, especially in relation to the use of flammable or toxic refrigerants.

Section 1 of this Information Sheet provides an overview of GHG emissions from RAC systems and explains how they can be minimised. Section 2 provides information about different refrigerant types and gives advice about how to select the best refrigerant for a given application. Section 3 explains the advantages and disadvantages of secondary refrigerant systems and Section 4 gives details about the safe application of flammable or toxic refrigerants.

1 GHG Emissions from RAC Systems

1.1 Types of GHG Emission

When designing, purchasing or operating a plant it is vital to take into account the two different types of GHG emission that can come from an RAC system. These are:

- The "direct" emissions related to loss of refrigerant from the system through leakage, during maintenance or during end of life decommissioning. Many refrigerants are very powerful GHGs, so even a small leak can have a significant environmental impact.
- The "indirect" energy related emissions from the electricity (or other fuel) used to run the system. These are referred to as indirect emissions as they usually take place at another location (i.e. at a power station).

In most situations it is the indirect energy related emission that dominates the overall GHG emissions from RAC systems. It has been estimated[1] that for all UK RAC systems the average split of emissions is 85% from the indirect energy component and 15% from refrigerant leakage.

Given the importance of the energy related emission it is vital not to sacrifice efficiency to achieve a small reduction in direct emissions. Ways of reducing energy related emissions are briefly discussed in Section 1.3, although it is strongly advised that you seek more comprehensive guidance about efficiency opportunities.

1.2 Reducing Direct Emissions of Refrigerant

There are two options to reduce the "direct" leakage related emissions from RAC systems. These are:

- **To use a zero (or low) GWP refrigerant.** GWP is "global warming potential" and it measures how much global warming is caused by 1 kg of refrigerant emission compared to 1 kg of CO_2. Most fluorocarbon refrigerants, including HCFCs like R22 and HFCs like R134a and R404A have very high GWPs that are more than a thousand times higher than CO2 (see Table 1 for examples). A number of alternatives are available that have zero or very low GWPs, as illustrated in the table. If these are used, the direct emissions can be zero or negligible in comparison to the indirect energy emissions.

- **To design and operate a leak free system.** Whilst the selection of a zero GWP refrigerant has obvious environmental benefits it is not the only solution. Historically many types of RAC system have been prone to high rates of leakage. Leakage in the range of 10% to 30% of the refrigerant charge per year is not uncommon. This can be avoided through good design, maintenance and system decommissioning. It is not unreasonable to target leakage levels well below 5% of the refrigerant charge per year for all types of RAC system and below 1% per year for factory built systems[2].

Using these strategies it is practical to reduce direct GHG emissions to zero or to a very low level.

If using ammonia or hydrocarbons, leakage emissions are not important in terms of global warming impact, although low leakage rates are vital for safety reasons. Systems using refrigerants of these types are successfully built with very low leak rates. There is no technical reason why systems using the high GWP HFC refrigerants should not achieve equally low leak rates.

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[1] DEFRA 1999, UK Emissions of HFCs, PFCs and SF_6

[2] Recommended further reading: Institute of Refrigeration Real Zero project www.realzero.org.uk

Table 1 Examples of Refrigerant Global Warming Potential (GWP)

Refrigerant	GWP[3]	ODP[4]	Comments
CFC 12	8100	1	Banned in EU since 2000
HCFC 22	1500	0.05	Being phased out in EU 2010 to 2015
HFC 134a	1300	0	Various HFCs used since mid-1990s as alternatives to ozone-depleting CFCs and HCFCs in a wide variety of stationary and mobile RAC applications. 3 examples given here – around 20 others also available.
HFC 404A	3300	0	
HFC 410A	1725	0	
New FCs	~10	0	New refrigerants; very low GWP. Not yet commercially available
CO_2	1	0	Operates at very high pressure.
Hydrocarbons	3	0	Widely used in very small systems; highly flammable
Ammonia	0	0	Used in large industrial systems, toxic and flammable

1.3 Reducing Energy Related Emissions

There are numerous ways of reducing the energy consumption of RAC systems. It is beyond the scope of this document to address energy efficiency issues, but it is nevertheless useful to describe the overall potential for savings[5]. Most RAC systems are electrically driven "vapour compression" systems. In general terms, efficiency improvements for this type of system can be achieved by:

- **Reducing the cooling demand.** Changes to the main cooling requirement and to auxiliary heat loads like fans and pumps can lead to significant reductions in energy use. Savings in excess of 50% are sometimes possible.

- **Reducing the "temperature lift".** Implementing measures to raise the evaporating temperature and / or to reduce the condensing temperature of a refrigeration system can lead to major improvements in efficiency. Savings in excess of 30% can often be achieved.

- **Improving the plant design.** Careful selection of the overall cycle configuration and of individual components can improve efficiency. Savings in excess of 20% can often be achieved.

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[3] GWP: Global Warming Potential based on 100 year values in EU F Gas Regulation

[4] ODP: Ozone Depletion Potential

[5] For further information on efficient refrigeration contact the Institute of Refrigeration or the Carbon Trust.

- **Improving operation and maintenance.** Ensuring that the plant is running under optimum conditions can often save in excess of 20%.

- **Ensuring the correct selection of refrigerant.** The choice of refrigerant can also have an impact on RAC plant efficiency. The best refrigerant for a particular application could give 10% better efficiency than other options.

Given the relative importance of energy related emissions the designers of new RAC systems need to take into account all the above opportunities to maximise system efficiency. It is also worth being aware of a number of other related opportunities. These are a little more complex as they relate to the way the RAC system integrates with other energy using systems on the site. These opportunities include:

- **Heat Recovery.** It may be possible to use the heat rejected by a refrigeration plant to provide useful heat to another process. The choice of refrigerant has a significant impact on the potential to recover heat.

- **Using waste heat to run a refrigeration plant.** In some specialised situations it is possible to use waste heat from another process to run an absorption refrigeration plant and hence obtain cooling "free".

- **Trigeneration.** CHP plants (combined heat and power) are used to generate electricity on-site so that the waste heat can be used for process or space heating. In some situations it is cost effective to use some or all of the waste heat from a CHP plant to produce cooling via absorption refrigeration. This is often referred to as trigeneration.

- **Using low carbon electricity.** It is possible to achieve zero energy related GHG emissions from an RAC system if you use a renewable energy source, such as wind power to operate the plant.

2 Selecting the Best Refrigerant

2.1 Desirable Refrigerant Characteristics

The choice of the best refrigerant for a given application is complex and it involves the evaluation of a number of competing characteristics. An "ideal" refrigerant would:

- Have excellent global environmental characteristics i.e. zero ODP and zero or very low GWP.

- Be non-toxic and non-flammable.

- Have excellent thermodynamic properties for the given application. This means that the refrigeration cycle efficiency would be as high as possible.

- Be a “practical” fluid to incorporate in the plant design. This includes factors such as materials compatibility (it is helpful if the refrigerant is compatible with a wide range of metals and other materials such as seals and gaskets), lubricating oil compatibility and operating pressure level (evaporating pressure must not be too low and condensing pressure must not be too high).

- Be low cost, widely available and familiar to designers, installers and maintenance contractors.

There is no single refrigerant or family of refrigerants currently available that possess all these characteristics. The main options available are “mapped” against the above characteristics in Table 2 and are discussed in more detail in the sections that follow.

Table 2 Comparison of Refrigerant Characteristics[6]

Refrigerant	HFCs	HCs	Ammonia	CO_2	Low GWP HFCs
GWP	✗✗	✓	✓✓	✓✓	✓
Toxicity	✓✓	✓✓	✗✗	✓	✓✓
Flammability	✓✓	✗✗	✗	✓✓	? ✗
Efficiency	✓	✓	✓	✓	✓
Materials	✓	✓	✗	✓	✓
Pressure	✓	✓	✓	✗✗[7]	✓
Cost	✓	✓✓	✓✓	✓✓	?
Availability	✓✓	✓	✓	✓	✗✗
Familiarity	✓✓	✓	✓	✗	✗

It should be noted that all refrigerants have been characterised as “good” in terms of efficiency. All these refrigerant types have the potential to have “very good” efficiency if the system design is carefully optimised. However, poor design could lead to poor efficiency.

2.2 HFCs (hydrofluorocarbons)

The HFC family have been used in a wide range of RAC systems since the mid-1990s as alternatives for CFC and HCFC refrigerants that damage the ozone layer.

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[6] The comparison in Table 2 is valid for “mainstream” refrigeration and air-conditioning applications with evaporating temperatures between -40°C and +5°C and for condensing temperatures between 10°C and 50°C. The comparisons may not be valid outside these ranges (e.g. for very low temperature cryogenic systems or high temperature heat pump applications).

[7] It should be noted that CO_2 has been categorised “very poor” in terms of pressure because the RAC industry will need to learn to cope with using a fluid at 120 bar, which is much higher than the current peak pressures of around 20 bar. However, the high pressure does deliver some desirable characteristics such as smaller pipe diameters and less compressor swept volume.

From Table 2 it is clear that apart from the GWP the family of HFC refrigerants has very desirable characteristics. However, the GWPs are very high – typically in the range of 1300 to 3300, which gives a strong incentive to find a cost effective alternative.

HFCs are currently used in most types of RAC system including domestic, commercial and industrial systems. HFC 134a is used for all car air-conditioning systems, for many small commercial systems (e.g. retail equipment such as vending and display cabinets) and for a range of chiller and industrial applications. HFC 404A is widely used in supermarkets and for low temperature process cooling and storage. HFC 410A has taken a growing share of the split system air-conditioning market.

Circumstances where HFCs may be best choice:

- The flammability and toxicity characteristics are very favourable for HFCs. This makes them strongly advantageous for systems used in areas occupied by untrained members of the public.
- HFCs are a family of fluids that have a range of thermodynamic properties. This makes it easier to select a refrigerant that precisely matches the temperature requirements of the application. This could lead to improved efficiency. It also allows selection of a specialised refrigerant for very low temperature applications or for high temperature heat pumps.
- Certain HFC blends can be used to "retrofill" existing HCFC systems (e.g. R22 systems). HCFCs are being phased out from the end of 2009. If existing HCFC equipment is to be re-used with an alternative refrigerant then HFC blends may be the only practical option.

Circumstances where HFCs should be avoided:

- In very small hermetically sealed systems, where HCs have been shown to be safe, cost effective and very efficient. CO_2 is also an alternative option for very small systems.
- In very large systems, such as large air-conditioning water chillers or large industrial cooling systems, where ammonia, HCs or CO_2 can be used.
- For car air-conditioning, where high GWP HFCs are banned after 2011 (in new vehicle types).

Key Rules to be followed if HFCs are used[8]:

- Design for very low leakage. Use materials and components that have very good leakage performance. Use a low refrigerant charge. For larger systems, build in instrumentation that will identify leakage.

- Design for very high efficiency. The use of HFCs can only be justified if the efficiency is equal to or, preferably, better than that achieved by competing alternatives. Ensure all the guidance in Section 1.3 is adhered to.

- Compliance with F gas Regulation. The use of HFCs is regulated by EU Regulation 842/2006. This places obligations on operators of systems using HFCs and companies and individuals involved in their supply and maintenance.

2.3 HCs (Hydrocarbons)

Hydrocarbon refrigerants have been used for many years in specialised industrial applications (e.g. petrochemical plants). Since the late 1990s the use of HCs has grown significantly. Most domestic refrigerators and freezers made in Europe now use HCs as the refrigerant (iso-butane) and as the foam blowing agent (pentane). There are well in excess of 100 million small domestic HC systems operating in Europe – illustrating that they can be cost effective and safe. The thermodynamic properties of HCs make them well suited for high efficiency designs.

The key characteristic that limits the use of HCs is high flammability. This makes it difficult to use in circumstances where a leak could prove a safety risk. Safety codes allow systems with less than 150g of refrigerant to be used in any location. Domestic refrigerators and freezers and small commercial systems, such as vending machines and retail displays, fall below this threshold and are in widespread use. See Section 4 for further details on quantities of HCs allowed in different locations.

In larger systems HC plant must be located in areas with restricted access – usually a special plant room or an external location. In such systems it is necessary to use a secondary refrigerant (such as chilled water or glycol) to transfer the cooling to the desired location. The plant room must be fitted with safety equipment to cope with refrigerant leakage (e.g. automatic ventilation). HCs are generally not suitable for “split system” applications containing a few kg of refrigerant (e.g. spilt system air-conditioning or small cold stores) as it is difficult to cater for the leakage risk.

Most very small HC systems utilise iso-butane as the refrigerant. Larger systems often use propane. For very low temperature applications HCs such as methane, ethane, ethylene and propylene are also used.

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[8] For further information about using HFCs refer to: Institute of Refrigeration Safety Code of Practice for Refrigerating Systems Utilising A1 Refrigerants (including HFCs), 2008.

Circumstances where HCs may be best choice:

- HCs are well suited to very small factory built hermetically sealed systems including domestic and small commercial equipment.
- HCs can be considered for large secondary refrigerant systems, although other options, such as ammonia or HFCs, may be more cost effective.
- HCs are a family of fluids that have a range of thermodynamic properties. This makes it easier to select a refrigerant that precisely matches the temperature requirements and size of the application. This could lead to improved efficiency. It also allows selection of a specialised refrigerant for very low temperature applications.

Circumstances where HCs should be avoided:

- In situations where the flammability of the refrigerant poses too great a risk.

Key Rules to be followed if HCs are used[9]:

- Design to safely cater for the high flammability of the refrigerant.
- Design for very low leakage (for safety reasons). Use materials and components that have very good leakage performance. Use a low refrigerant charge. For larger systems, build in instrumentation that will identify leakage.
- Design for very high efficiency. The use of HCs can only be justified if the efficiency is equal to or, preferably, better than that achieved by competing alternatives. Ensure all the guidance in Section 1.3 is adhered to.

2.4 Ammonia

Ammonia has been in widespread use for industrial refrigeration systems for well over 100 years. The thermodynamic properties make it well suited for chilling or freezing applications down to evaporating temperatures of around -40°C. The main market sectors that have a long history in the use of ammonia are food and drink manufacturing and cold storage. Also, ammonia are used in very small absorption refrigerators, such as those used in some hotel rooms or in boats and caravans.

The main difficulty using ammonia is the high toxicity. It cannot be used in locations accessible by untrained members of the general public except in very small quantities. Ammonia is also slightly flammable / explosive and it is incompatible with any metal components containing copper.

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[9] For further information about using HCs refer to: Institute of Refrigeration Safety Code of Practice for Refrigerating Systems Utilising A2 and A3 Refrigerants, 2008.

The main applications for ammonia include: (a) industrial chiller systems for process cooling, and (b) distributed process cooling systems e.g. for blast freezers or large cold stores. In recent years there has been growth of the use of ammonia for building air-conditioning water chillers. In technical terms there are no major barriers to this application as chillers are usually located in restricted access plant rooms which can be designed to cope with an ammonia leak. However, in cost terms there is often a significant premium to pay compared to an HFC water chiller.

Circumstances where ammonia may be best choice:

- Large industrial cooling systems e.g. in food and drink manufacture, chemical processing, cold storage.
- Large secondary refrigerant systems e.g. chilled water for building air-conditioning or chilled glycol for process cooling. Some secondary refrigerant systems with ammonia have been trialled for supermarkets, but these have not proved popular – CO_2 appears to be a better alternative for this market.
- In situations where hot water at 50 to 70°C is used in large quantities – ammonia systems are slightly more effective from a heat recovery perspective than HFCs.

Circumstances where ammonia should be avoided:

- In situations where the toxicity of the refrigerant poses too great a risk.
- Below about -40°C the suction pressure of ammonia systems is reaching an impractical level well below atmospheric pressure. Below that temperature certain other refrigerants are likely to have better performance.

Key Rules to be followed if ammonia is used:

- Design to safely cater for the flammability and high toxicity of the refrigerant[10].
- Only use steel components (e.g. copper and alloys containing copper must not be used) and ensure gaskets and seals are compatible with ammonia.
- Design for very low leakage (for safety reasons). Use materials and components that have very good leakage performance. Use a low refrigerant charge. For larger systems, build in instrumentation that will identify leakage.
- Design for very high efficiency. The use of ammonia can only be justified if the efficiency is equal to or, preferably, better than that achieved by competing alternatives. Ensure all the guidance in Section 1.3 is adhered to.

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[10] For further information about using ammonia refer to: Institute of Refrigeration Safety Code of Practice for Refrigerating Systems Utilising Ammonia, 2002 (currently being revised).

2.5 Carbon Dioxide (CO_2)

In the early years of mechanical refrigeration CO_2 was a quite widely used refrigerant. For example, it was used in refrigerated ships, being considered a safer refrigerant than other available options, such as ammonia. By the 1950s it had been largely replaced with alternatives, especially CFCs.

During the last 10 years there has been growing interest in CO_2 as a refrigerant. Table 2 shows that CO_2 has many desirable characteristics. The main problem relates to operating pressure. At typical summer time conditions HFC plants and ammonia plants will have a compressor discharge pressure of around 15 bar(g). A CO_2 plant operating in similar ambient temperature will have a compressor discharge pressure nearly 10 times higher than this at about 120 bar(g). Also, the summer time discharge pressure of a CO_2 system is above the critical pressure of CO_2. The cycle has to operate as a "trans-critical cycle" and heat is rejected in a gas cooler instead of a condenser. Whilst these are not insurmountable problems, it is unfamiliar territory for most refrigeration engineers.

CO_2 has some characteristics that make it particularly attractive for refrigeration. For example, the diameter of refrigerant pipework is much smaller than for HFCs or ammonia and compressors are smaller. CO_2 has especially good characteristics for heat recovery – enabling hot water at up to 90°C to be produced. It also has good properties for use as a secondary refrigerant in place of chilled water or glycol.

There are a number of markets showing significant interest in CO_2. These include (a) mobile air-conditioning for cars, (b) supermarket refrigeration, (c) various industrial applications, (d) small commercial systems (e.g. bottle coolers for soft drink retailing) and (e) small water heating heat pumps (for which there is already a major market in Japan). CO_2 might become a much more popular refrigerant during the next 10 years, although the hurdles related to high operating pressure and lack of familiarity will be difficult to overcome. There is still some uncertainty regarding the energy efficiency of CO_2 systems compared to the best competing HFC systems.

Circumstances where CO_2 may be best choice:

- For systems where the flammability or toxicity of HCs and ammonia make these unacceptable options (e.g. supermarkets, mobile air-conditioning).
- For systems that can benefit from the heat recovery characteristics of CO_2.
- As an alternative more energy efficient secondary refrigerant in place of chilled water or glycol.

Circumstances where CO_2 should be avoided:

- Where design and maintenance engineers are unfamiliar with CO_2.

Key Rules to be followed if CO_2 used[11]**:**

- Ensure good leak detection and good ventilation following a leak. Although CO_2 is not toxic it is harmful at concentrations above 5,000 ppm.

- Design to cope with high pressures and trans-critical operation.

- Design for very low leakage. Use materials and components that have very good leakage performance. Use a low refrigerant charge.

- Design for very high efficiency. The use of CO_2 can only be justified if the efficiency is equal to or, preferably, better than that achieved by competing alternatives. Ensure all the guidance in Section 1.3 is adhered to.

2.6 Low GWP FCs (fluorocarbons)

All HFCs in common usage for RAC applications have very high GWPs, typically in the range of 1,300 to 3,300. For some years refrigerant manufacturers have been trying to identify much lower GWP alternatives that have the other favourable characteristics of HFCs, in particular zero flammability and toxicity.

Refrigerant producers have in recent years developed new types of HFCs known as hydrofluoro-olefins (HFOs). These new refrigerants have properties that are similar to existing HFCs, but have very low GWPs, estimated to be less than 10. Originally conceived in response to the ban on use of refrigerants with high GWPs in air conditioning in cars and light vans, there are moves to extend their application to the RAC sector, such as in chillers.

These refrigerants are slightly flammable, although the level of flammability is thought to be low enough to be acceptable in applications such as mobile air-conditioning. Toxicity is thought to be very minimal.

The current drawback for these refrigerants is that they are not yet technically proven in all areas or commercially available on a wide scale. However, if they meet the expectations of their manufacturers they could become credible alternatives.

Circumstances where low GWP FCs may be best choice (if they become available):

- Applications that currently use HFC 134a.

- Other HFC applications e.g. 404A or 410A if the refrigerant properties turn out to be suitable (this is not yet certain).

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[11] For further information about using CO_2 refer to: Institute of Refrigeration Safety Code of Practice for Refrigerating Systems utilising carbon dioxide refrigerant, 2008.

Circumstances where low GWP FCs should be avoided:

- Certain applications where equipment needs to be purchased in the near future. There are possible limits to the availability of these refrigerants and the feasibility of their use in all circumstances. This could change over time.

Key Rules to be followed if low GWP FCs are used:

- Design for very low leakage. Use materials and components that have very good leakage performance. Use a low refrigerant charge. For larger systems, build in instrumentation that will identify leakage.

- Design for very high efficiency. The use of low GWP FCs can only be justified if the efficiency is equal to or, preferably, better than that achieved by competing alternatives. Ensure all the guidance in Section 1.3 is adhered to.

3 Using Secondary Refrigerant Systems

When designing a new refrigeration system it is important to decide whether the direct use of a primary refrigerant is best or whether it is better to use a secondary refrigerant such as chilled water or glycol.

Examples of primary and secondary refrigerant systems

A system that uses a primary refrigerant is one where the actual refrigerant is used to cool the load. The most common example is a domestic refrigerator. Most modern European refrigerators use a hydrocarbon refrigerant. This is circulated through the evaporator which is inside the refrigerator. Other examples include split system air-conditioning units, with an HFC refrigerant evaporator inside the room being cooled or an industrial blast freezer with ammonia evaporators inside the chamber that is freezing a food product.

A system that uses a secondary refrigerant is one where the primary refrigerant is used to cool a secondary fluid (such as water). The secondary fluid is then pumped to a heat exchanger that is used to cool the load. Common examples are chilled water systems for building air-conditioning and glycol systems for industrial cooling e.g. in a brewery.

Why are secondary systems sometimes used?

There are a number of advantages of using a secondary refrigerant that make them popular in certain situations. These include:

- It allows use of toxic or flammable refrigerants such as ammonia or HCs as these primary refrigerants can be used in a remote location and a “safe” secondary fluid is used to transmit the cold to occupied areas.

- The chiller, which contains all the complex primary refrigeration equipment, can be factory built. The on-site construction of pipework is only for “low technology” water pipework (or similar). This can reduce cost, lead to a higher quality plant with very low levels of leakage.

- Secondary systems are well suited to situations where there is a requirement for cooling in lots of different locations (e.g. different rooms in a large building or different parts of a food processing factory).

In general, secondary systems are thought to be practical and cost effective in large applications. In a small building air-conditioning would usually be provided by a primary refrigerant system (e.g. a split system cassette unit) whereas in a large building a water chiller secondary system is more common.

Potential environmental penalties with secondary systems

Whilst secondary systems seem to have a clear environmental advantage i.e. they allow the use of ammonia or HCs for medium sized and large RAC systems, there is the potential to create excessive CO_2 emissions through poor energy efficiency. There are 3 ways in which the efficiency of a secondary system can be worse than a primary system:

- There is an extra temperature difference introduced between the primary and secondary refrigerant. If this is large the system efficiency will be reduced.

- The secondary refrigerant needs to be pumped to the various loads. This creates an extra electrical load and also adds a heat load to the system. If the pumping system is not well designed this can create a significant energy penalty.

- With a secondary system it is tempting to mix loads of different temperatures on one system. For example, in a brewery some cooling is done at -1°C and some is done at +10°C. It is common to put both loads on a glycol system with glycol at, say, -6°C and a primary evaporating temperature of -9°C. Cooling a +10°C load with a primary evaporating temperature of -9°C is very inefficient. If the load was on a dedicated system directly using a primary refrigerant, the evaporating temperature could be around +7°C and the plant would use about half the energy of the secondary system.

It is vital that these considerations are taken into account when considering alternatives for high GWP HFCs. If you can avoid excessive leaks then a high efficiency primary HFC system may be preferable to a low efficiency ammonia secondary system.

Avoiding “lowest common denominator systems” that mix loads at different temperature levels is especially important (see 3rd bullet above). Whilst this problem is most common on secondary systems it should be noted that it can also apply to primary systems. For example, it is common to have a single primary system serving a blast freezer (requiring a refrigerant evaporating temperature of -40°C) on the same system as a cold store (which might be able to operate with an evaporating temperature of around -25°C). This introduces an energy penalty of about 40% for the cold store load.

Most secondary refrigerant systems use a liquid, such as water or glycol. These become increasingly viscous at lower temperatures – requiring extra pumping power. Recent developments in the use of CO_2 as a "volatile secondary" look very interesting from an efficiency perspective. The mass flow of secondary refrigerant required is much lower (because the CO_2 boils, making use of its latent heat capacity). This leads to the need for considerably lower pumping power.

4 Safely Using Flammable or Toxic Refrigerants

The quantity of refrigerant that can safely be used in different locations and different types of occupancy are defined in the European safety standard BS EN 378:2008 ("Refrigerating systems and heat pumps – Safety and environmental requirements"). You are advised to refer to this standard for details of safety requirements. A short overview of some information from the standard is given below.

BS EN 378:2008 sets out rules for maximum allowable quantities of all types of refrigerant. The rules are based on a refrigerant safety classification and on the type of location and occupancy.

4.1 Safety Groups

The standard gives a safety group for each refrigerant. The classification is based on toxicity and flammability. The toxicity classes are:

A = non-toxic; B = toxic

The flammability classes are:

1 = non- flammable; 2 = some flammability; 3 = highly flammable

Some examples of safety classifications are given in Table 3.

Table 3 Examples of Safety Groups from BS EN 378:2008

Refrigerant	Safety Group
HFC 134a	A1
HFC 404A	A1
CO_2	A1
Ammonia	B2
Hydrocarbons	A3

4.2 Occupancy Categories

The standard defines three categories of occupancy as show in Table 4.

Table 4 Occupancy Categories from BS EN 378:2008

Category A **General Occupancy**	A location where people may sleep or where the number of people present is not controlled or to which any person has access without being personally acquainted with the personal safety precautions. For example: supermarkets, shops, hotels, restaurants, hospitals, courts, schools
Category B **Supervised Occupancy**	Rooms, parts of buildings or buildings, where only a limited number of people may be assembled, some of them being necessarily acquainted with the general safety precautions. For example: business or professional offices.
Category C **Authorised Occupancy**	An occupancy which is not open to public and where only authorised persons are granted access. Authorised persons shall be acquainted with general safety precautions of the establishment. For example: industrial production facilities or special machinery rooms with restricted access.

4.3 Allowed quantities of hydrocarbons

HC refrigerants such as R290 (propane), R600a (iso-butane) and R1270 (propylene) are all in safety group A3. This means they are highly flammable and the quantity of refrigerant is severely restricted unless all the parts of the refrigeration system that contain HCs are in an unoccupied machinery room[12] or in the open air.

The rules to calculate the allowable quantity are complex in some situations. They depend on the type and exact positioning of the RAC system as well as the Occupancy Category.

There are 2 fairly simple rules:

- RAC systems with up to 150 g of HC refrigerant can be used in any location or occupancy. This includes very small systems such as domestic refrigerators and freezers.
- If the system is in a location below ground level it is never allowed more than 1 kg of HC refrigerant.

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[12] A machinery room is defined in BS EN 378:2008 as: "A complete enclosed room or space, vented by mechanical ventilation and only accessible to authorised persons, which is intended for the installation of components of the refrigerating system or of the complete refrigerating system. Other equipment may also be installed provided it is compatible with the safety requirements for the refrigerating system".

The other rules are much more complex. The charge is often dependent on the room volume. For split system air-conditioning equipment the allowable charge is also dependent on the height of the cooler unit above the floor. You must refer to BS EN 378:2008 for the full details. Some examples from the rules include:

- In a Category A general occupancy location, where part or all of the system containing HCs is in the human occupied space, the maximum charge is restricted to 1.5 kg, irrespective of room volume. In small rooms the allowable charge will be below this value. A larger charge of up to 5 kg may be allowable if the equipment is in a ventilated enclosure or outdoors.

- In a Category B supervised occupancy location, where part or all of the system containing HCs is in the human occupied space the maximum charge is restricted to 2.5 kg, irrespective of room volume. In small rooms the allowable charge will be below this value. A larger charge of up to 5 kg may be allowable if the equipment is in a ventilated enclosure or up to 10 kg if the equipment is outdoors.

- In a Category C authorised occupancy location, where all of the system containing HCs is in the human occupied space the maximum charge is restricted to 10 kg, irrespective of room volume. In small rooms the allowable charge will be below this value. A larger charge of up to 25 kg may be allowable if the compressor and receiver part of the system is in a ventilated enclosure or is outdoors.

- There is no restriction on HC refrigerant charge where the entire system is located in an unoccupied machinery room or in the open air.

4.4 Allowed quantities of ammonia

Ammonia is in safety group B2. This means ammonia is highly toxic and slightly flammable. The quantity of refrigerant is severely restricted unless the parts of the refrigeration system that contain ammonia are located in an unoccupied machinery room or in the open air.

You must refer to BS EN 378:2008 for the full details of ammonia charge restrictions. The allowable charge is often dependant on the room volume and the system type as well as the occupancy. Some examples from the rules include:

- In a Category A general occupancy location, where part or all of the system containing ammonia is in the human occupied space, the maximum charge (in kg) is restricted to 0.00035 * room volume (in m^3). This makes it almost impossible to use ammonia in Category A occupancy. An exception to this rule is for sealed[13] absorption systems, where 2.5 kg is the charge limit.

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[13] A sealed system is defined in BS EN 378:2008 as: “A refrigerating system in which all refrigerant containing parts are made tight by welding, brazing or a similar permanent connection

- In a Category B supervised occupancy location, where all of the system containing ammonia is in the human occupied space the maximum charge is restricted to 10 kg, irrespective of room volume. A larger charge of up to 25 kg is allowable if the compressor and liquid receiver are in an unoccupied machinery room or in the open air.

- In a Category C authorised occupancy location, where all of the system containing ammonia is in the human occupied space the maximum charge is restricted to 10 kg, or 50 kg if the density of personnel is less than 1 per 10m3 and sufficient emergency exits are available. A larger charge of up to 25 kg is allowable if the compressor and receiver part of the system is in an unoccupied machinery room or in the open air; in these circumstances there is no charge restriction if the density of personnel is less than 1 per $10m^3$.

There is no restriction on ammonia refrigerant charge where the entire system is located in an unoccupied machinery room or in the open air.