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Refrigerants in Building Services

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In partnership with

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A BSRIA topic guide

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Introduction

The UK Government has set a target of achieving net zero carbon emissions by 2050 as part of their attempt to address the climate change emergency and the associated impact. The built environment is responsible for around 40% of total carbon emissions, and an environmental audit committee report[1] highlighted that 3% of UK greenhouse gas emissions are of HFCs. It is clear that radical change is needed in the sector in order to meet this target.

High carbon fossil fuels are increasingly being replaced with low carbon alternatives for heating and the decarbonisation of the electricity grid is driving a shift towards electric heating technologies with heat pumps forecast to make up a significant part.

The Committee on Climate Change has said that to meet the commitment to reach net zero by 2050, 19 million heat pumps will need to be installed and that hybrid heat pumps should be widely used by 2035. Heat pumps are not a new technology – they have been used in a variety of different applications for many years.

The increased use of air conditioning has been borne out of necessity to maintain comfortable temperature ranges, humidity levels and ventilation rates within the built environment. The use of mechanical cooling is now recognised as essential in many buildings to overcome solar and internal heat gains. In addition, noise pollution, air quality and city centre microclimates eliminate the opportunity for free cooling using ambient air in many applications.

The increased use of both heat pumps and air conditioning comes at a time when the legislative landscape is looking increasingly at restricting or limiting the use of refrigerants that have a direct environmental impact. This places additional considerations on the building services designer with regard to which refrigerants can be used and what the likelihood is of restrictions on their use over time.

This guide aims to provide an overview of the different applications with regard to what refrigerant options are available and what the implications may be for using certain refrigerants in certain applications. It gives the reader a good understanding of why the selection of refrigerant type is important in consideration of the expected lifecycle of the system. It provides a high level overview of legislation in the global context of the developing Montreal Protocol and reference to refrigerants now banned from working with but still in use in many systems.

The guide has not considered some refrigerants such as R404A which has been used in commercial applications but is now effectively being phased out due to restrictions on the use of certain refrigerants under the F-Gas Regulations. It also does not consider Ammonia because it is predominantly used in industrial process cooling or large-scale freezer applications rather than the building services sector.

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The legislative background – *Where we are now*

Environmental legal obligations

Whilst the building designer has a primary role to provide the appropriate environment for human comfort, any design should address environmental implications and meet the latest industry codes of practice and any regulations, where appropriate.

Legislation prohibits the use of certain refrigerants either altogether or in some cases for particular equipment and applications.

In the UK, the Ozone-Depleting Substances Regulations 2015 (ODS) and the Fluorinated Greenhouse Gases Regulations 2015 (F-Gas) prohibit substances with a significant ozone depleting or global warming potential, such as CFCs and HCFCs. These are listed in Annex I of the EU Ozone Regulations[2].

Similarly, HFCs with a global warming potential (GWP) above certain thresholds are prohibited from various types of equipment.

The ODS regulations prevent any charging of a CFC or HCFC refrigerant. This means that no top-ups or additions of refrigerant are allowed to a system after a leak. Also, any repairs to a system or component replacement which necessitates a decanting of the charge of refrigerant to access the circuit would result in that charge of refrigerant having to be sent to an authorised waste destruction facility for destruction.

Even attaching a gauge manifold set to a refrigerant circuit containing a CFC or HCFC means the refrigerant charge must then be recovered and sent for destruction. There was an allowance for the use of reclaimed or recycled HCFCs in existing systems for some time after the ban in new systems came into effect, but that use of reclaimed or recycled HCFCs has also been outlawed since 1st January 2015.

It is still permissible to use systems containing HCFCs or CFCs subject to the servicing restrictions outlined above, and those systems must be leak checked at intervals set out in the F-Gas Regulations and at least annually.

The Kigali Amendment to the Montreal Protocol also places obligations on the UK to phase down the production and use of HFCs (fluorinated greenhouse gases) by 85% between 2019 and 2036. Further information on future legislation implications can be found on page 7.

Safety requirements

Various regulations impose requirements on the use of substances which may be used as refrigerants for certain situations. Primarily these are safety regulations, such as Pressure Equipment (Safety) Regulations 2016, Supply of Machinery (Safety) Regulations 2008 and Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 2016. The text of all UK legislation can be found at **www.legislation.gov.uk**, and guidance on meeting health and safety legislation can be found and **www.hse.gov.uk**.

In general, such regulations do not prohibit the use of any substances that may be used as refrigerants, but systems using refrigerants with higher operating pressures, higher toxicity or flammability can become more expensive.

Safety standards (such as the BS EN 378 series[3], BS EN 60335-2-40[5] and BS EN 60335-2-89[6]) tend to be more prescriptive and can disallow certain refrigerants being used for particular installations. However, safety standards are not mandatory provided alternative means can be used to satisfy the requirements of the safety regulations.

The refrigerant choice may have safety implications as fluorinated greenhouse gases are phased out or become more scarce, because the lower-GWP alternatives are often flammable to some extent and could be toxic or introduce very high working pressures.

Efficiency

The overall efficiency of a system can be heavily influenced by the choice of refrigerant used as the heat exchange fluid as much as the type of system employed in the building.

It is crucial that the building designer does not specify the use of a refrigerant based only on one criterion. For example, choosing equipment solely on the GWP of the refrigerant used without taking into account the overall energy efficiency of the system may result in higher energy consumption and may make it difficult to comply with Part L of the Building Regulations for England or equivalents in devolved nations.

Energy consumption, lifecycle cost and total equivalent warming impact (TEWI) of the system are paramount. The system should be designed to take maximum advantage of natural or low-cost energy sources. This should include free cooling and heat recovery.

TEWI offers the designer maximum opportunity of calculating the global warming impact of the building over its operating life. It considers both direct emissions (by calculating refrigerant leaked over the system's lifecycle), and indirect emissions from power consumed over the system's lifecycle. Because TEWI considers system leakage, in some cases the TEWI of a system may be worse with a lower-GWP refrigerant in use if the system is not designed appropriately, for example if it is not leak tight. TEWI gives a better reflection of environmental impact than a straightforward consideration of the GWP of the refrigerant. It is calculated as follows:

TEWI (kg CO_2) = direct emissions + indirect emissions = (GWP x L x N) + (E_a x β x n)

where GWP = global warming potential of refrigerant

L = annual leakage rate in the systems (kg CO_2 per annum)

N = life of the system (years)

E_a = energy consumption (kWh per annum)

β = carbon dioxide emission factor of electricity used (CO_2 equivalent per kWh)

n = system running time (years)

In order to make a fair comparison between different options, accurate data needs to be available; however, this may be difficult to obtain, particularly with the annual leakage rate of the system. Energy consumption can be estimated from the heating or cooling load placed on the system and its seasonal energy efficiency ratio (SEER) or seasonal coefficient of performance (SCOP).

System components should be suited to the refrigerant used. Sometimes components are unavailable for certain refrigerants and system types. Also, availability of some components for repair purposes may become problematic in the future as some refrigerants become phased out by legislation.

Refrigerant availability

With the phase down of some refrigerants and the ban on service use on others imposed by the F-Gas Regulations, certain higher-GWP refrigerants will have limited availability in the future.

It is important that the building services designer considers the wider political agenda on the future of refrigerants. For example, the Kigali Amendment to the Montreal Protocol will have an impact on the use of, and potential shortages of, some refrigerants over the expected lifecycle of the system being specified or considered.

Technician competence

Given the wide variety of refrigerants' characteristics, technicians seldom have competency to work on all refrigerants and on all types of equipment. Therefore, when selecting a refrigerant, it must be ensured that the technicians available to work on those systems are suitably qualified. For example, the ACRIB SKILLcard identifies the technician's refrigerant qualifications and skills.

The F-Gas Regulations stipulate that the technician working on systems containing, or designed to contain, fluorinated greenhouse gases must hold a current qualification certificate covering the relevant refrigerants listed in the Regulations. It is important to understand that F-Gas qualifications are not competence based. Rather they are concerned with ensuring the technician has an environmental awareness of the implications of refrigerants being released into the atmosphere. Industry bodies recommend training to a minimum of level 2 or equivalent to demonstrate competence, and to also hold a training attestation in the handling of flammable refrigerants going forward. Further information on competence requirements can be found in REFCOM TB018[7].

F-Gas Regulations – *Where we are going*

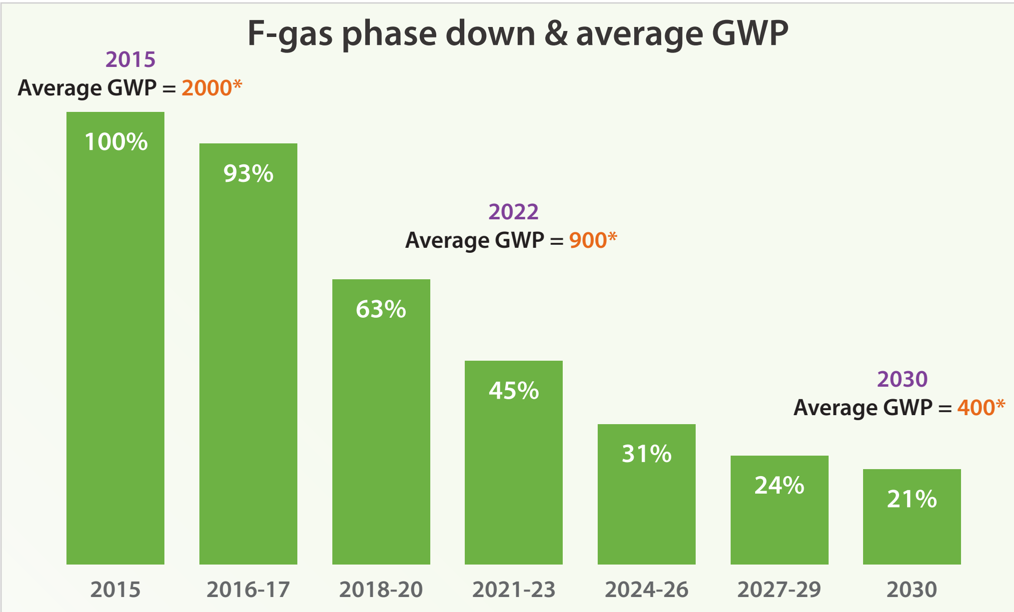
F-Gas Regulations

On 1st January 2021 the GB ODS and F-Gas Regulations came into effect, replacing the European Union regulation EC517/2014. All of the rules applied under the European legislation were retained for Great Britain but the statutory authority for reporting and implementation became the responsibility of the Environment Agency for England and devolved equivalents for Scotland and Wales. Northern Ireland was retained as part of the EU single market and the four UK administrations agreed to work together under a common framework. Further details about the common framework are available in the REFCOM guidance note[8] and more detail about the F-Gas regulations can be found on the Environment Agency website **www.gov.uk/government/collections/fluorinated-gas-f-gas-guidance-for-users-producers-and-traders**.

Proposals have been made to revise the F-Gas Regulations. At this point, it is not know what changes are likely to occur, or when these will come into effect.

Phase down

The phase down of refrigerants (shown in the chart below) works by averaging the total amount of F-gas refrigerants that can be placed on the market in any given year under quota allowances issued by the Environment Agency and reducing that quota every 2 years. The total amount is expressed in terms of the tonnes CO_2 equivalent to account for differing GWP levels for each substance under control.



*Source: European Commission

By phasing down based on an average of the total refrigerant placed on the market it is possible to actively encourage use of lower-GWP refrigerants by market forces.

The global warming potential (GWP) is an indicator of how potent the substance is as a greenhouse warming substance compared to CO_2 as the base level of GWP=1. Table 1 gives an indication of some common refrigerants in use in building services to see how they compare in terms of their GWP. A complete list can be found in Annexes 1 and 2 to the EU F-gas regulations[9].

The equivalent tonnes CO_2 value for a refrigerant charge is derived by multiplying the quantity of refrigerant (expressed in kilograms) by the GWP figure and then dividing this by 1000.

For example, R410A has a GWP of 2088 so the CO_2 tonnes equivalent for a charge of 5 kg would be:

5 x 2088 ÷ 1000 = **10.44 tonnes CO_2**

Table 1: Common refrigerants in use in building services

R Number	Toxicity	Flammability	GWP	LFL (kg/m³)	Notes
22	A	1	1810	0	This is an HCFC now phased out for new use but still allowable in existing systems
32	A	2L	675	0.307	Mostly used in split and small VRF/VRV systems
134a	A	1	1430	0	Restricted availability will result in price rises
290	A	3	3	0.038	Propane
407C	A	1	1774	0	Restricted availability will result in price rises
410A	A	1	2088	0	Restricted availability will result in price rises
454B	A	2L	467	0.354	Common alternative to R410A in split systems
600a	A	3	3	0.043	Isobutane
744	A	1	1	0	Carbon Dioxide (CO_2)
1234ze	A	2L	7	0.303	Mostly used in chiller applications

The purpose of the phase down being set to work in this way is to encourage refrigerant suppliers to move away from supplying higher-GWP refrigerants as the sale of these will use more of their allowable annual quota. The reduced supply of higher-GWP refrigerants has an effect on the price of the refrigerant on the market making it less attractive to users who will then be more likely to choose lower-GWP alternatives where possible. This phase down approach has already seen an increase in the take up of lower-GWP refrigerants such as R32, R454B and R1234ze as alternatives to R410A and R134a due to the rising price of the latter refrigerants.

Alternative refrigerants

The downside to the move towards lower-GWP refrigerants has been seen in the application of those refrigerants due to their safety classifications. There are frequently restrictions on the use of flammable substances at airports and railway stations, for example, which may prevent the use of a system containing a flammable refrigerant.

Refrigerants have several factors in their safety classification depending on their toxicity rating (A or B) and flammability rating (1, 2L, 2 or 3), as shown in table 2. The two types of classification are combined, for example A1, B2 etc.

Older, medium-GWP refrigerants, such as R134a and R410A have a flammability rating of 1 whereas R32 has a rating of 2L indicating lower flammability when compared with R290 (Propane) or R600a (Isobutane) which both have a flammability rating of 3.

The flammability rating brings with it increasing restrictions on charge limits allowable under the safety standard BS EN 378[3]. This brings into consideration for the building services designer or specifier issues of suitability for some applications and in some building types or locations. Further information on the application of lower flammability refrigerants can be found in REFCOM TB033[10].

2L refrigerants are considered safer than class 2 or 3 flammable refrigerants because they are hard to ignite, requiring high ignition trigger incidence, and burn slowly and generally with a lower temperature and intensity. However, the categories given in table 2 above are industry categories set by ASHRAE and are not recognised by the HSE in the UK which regards substances to be either flammable or non-flammable. Several additional considerations need to therefore be taken when dealing with an installation or work involving a refrigerant classified as 2L or higher for flammability.

In particular, for a new installation, there needs to be a risk assessment carried out which reviews the application, refrigerant charge, location of components, and occupancy of any room containing refrigerant holding components. BS EN 378-1[4] contains design information crucial to this risk assessment and management process and should always be referred to in the planning stage of an installation. The standard is used for calculating the maximum permissible refrigerant charge in a system based on both toxicity and flammability.

Table 2 ASHRAE refrigerant safety classifications

Classification		Explanation
Toxicity	**Class A**	Refrigerants that have an occupational exposure limit (OEL) of 400 ppm or greater
	Class B	Refrigerants that have an occupational exposure limit (OEL) of less than 400 ppm
Flammability	**Class 1**	No flame propagation in air at 60°C and 101.325 kPa
	Class 2L	Class 2 refrigerants may be classified as 2L if they exhibit maximum burning capacity of no more than 100 mm/s at 23°C and 101.325 kPa
	Class 2	Exhibits flame propagation in air at 60°C and 101.325 kPa, lower flammability limit (LFL) greater than 0.10 kg/m3 at 23°C and 101.325 kPa, and a heat of combustion less than 19,000 kJ/kg
	Class 3	Exhibits flame propagation in air at 60°C and 101.325 kPa, lower flammability limit (LFL) less than or equal to 0.10 kg/m^3 at 23°C and 101.325 kPa, or a heat of combustion greater than or equal to 19,000 kJ/kg

Whereas the earlier version of BS EN 378, published in 2008, was fairly straightforward in dealing with flammability, there is now a more complicated design methodology to go through to calculate what maximum charge can be applied to a system if an A2L refrigerant is used. Further details can be found in Appendix A of REFCOM TB033[10] which has detail provided by FETA (The Federation of Environmental Trade Associations).

Future options

As higher-GWP refrigerants are phased down, or effectively phased out, numerous alternative blends are being produced by the manufacturers with varying degrees of flammability. Equipment manufacturers must be consulted when deciding which option to choose at design stage so that mitigating measures can be designed into a project to allow for refrigerant charge sizes to be set at appropriate levels to maximise efficiency.

These mitigating measures, as set out in BS EN 378[3] may include fixed refrigerant leak detection, audible and visual alarms and forced ventilation to dilute any refrigerant build up. A combination of these mitigating measures will often allow for a much greater refrigerant charge to be applied than without them.

Applications

Chillers (including heat pump chillers)

In recent years, the most common refrigerant used in chillers has been R134a. With A GWP of 1430 it will clearly be affected by the phase down of higher-GWP refrigerants as this is more than three times the average of refrigerants placed on the market by 2030, as shown in the chart on page 7. With a relatively high charge volume of refrigerant, if chillers continue to use R134a, then they would be using a significant portion of the UK's quota for any given year it is placed on the market.

For this reason, manufacturers have been looking at suitable alternative refrigerants which have similar, or better, operating conditions in terms of energy efficiency whilst reducing the GWP of the refrigerant in use to as low as possible. The most common alternative to R134a available at the moment is R1234ze. This refrigerant has a GWP of only 7 and has similar operating characteristics to R134a, although the slightly reduced refrigerating capacity means the footprint of a chiller would increase by approximately 20% to achieve the same cooling output.

R1234ze is classed as an A2L refrigerant when in use so restrictions on use or risk assessment implications outlined in section 2 will apply. However, because the nature of the chiller will normally mean that the system is in an outdoor location, often in a restricted zone as outlined in BS EN 378[3], then the risk assessment should account for this, and the charge quantity of the refrigerant will more readily be acceptable than systems located in open access zones, again as outlined in BS EN 378.

DX heat exchange coils in AHUs

An air handling unit (AHU) may contain direct expansion (DX) coils to cool air as it is drawn into a building. They can be connected to a standard split system outdoor unit using proprietary electronic interface controls supplied by the manufacturer of the outdoor unit so that the coil acts in the same manner as a split system indoor unit.

Standard split system outdoor units can operate with a variety of refrigerants, most commonly R410A or R32. As the coil is upstream of the fan section of the AHU it is good practice to install a leak detection system in the air flow downstream of the coil to guard against any leak on the coil allowing refrigerant to be drawn into the building through the supply ductwork.

A risk assessment for the AHU should consider the possibility of refrigerant accumulating in small rooms, resulting in the concentration level of the refrigerant rising above the occupational exposure limit (OEL). If the refrigerant is flammable, then this risk assessment should also consider the possibility of the concentration level rising above the lower flammability level (LFL) and therefore becoming a fire hazard in the building. A leak detection system which disables the AHU system and shuts down the fan in the event of a measured refrigerant leak can significantly reduce the risk associated with using these coils with an AHU installation.

The use of standard split system outdoor units and a DX coil results in a relatively small refrigerant charge. The longer term availability of these refrigerants should therefore be fairly stable, although the price of R410A is likely to rise steeply in the lead-up to 2030, by which time the average GWP of all refrigerants placed on the market will be one fifth that of R410A.

VRF/VRV systems

Variable refrigerant flow (VRF), also known as variable refrigerant volume (VRV) systems, normally use R410A or R32.

There are limitations on the quantity of R32 that can be used due to its A2L classification, but by taking mitigating steps the risk can be reduced sufficiently to enable its use in VRF/VRV systems in some cases.

Mitigating steps include:

- The installation of automatic leak detection systems which trigger alarms and possibly shut down the system to minimise leakage by reducing the operating pressure
- The installation of mechanical ventilation to dilute the concentration of refrigerant in the room should the leak detector be triggered
- Controlling the use of the room itself to change its occupancy rating under BS EN 378[3].

R410A does not have the same refrigerant charge restrictions as it is an A1 class refrigerant. However, its GWP of 2088 is 5 times the average of refrigerants placed on the market by 2030 and so it will undoubtedly become increasingly scarce over time and, therefore, more expensive. This may be a factor over the lifecycle of the system if a catastrophic component failure or third party damage necessitates a re-charge of the system where the original charge was not recovered.

Split and multi-split systems including reverse cycle heat pumps

The vast majority of split and multi-split systems use R32 these days. With a GWP of 675, approximately 3 times the volume of R32 is allowed to be placed on the market compared with R410A, which has similar operating characteristics. As such it has become the refrigerant of choice for equipment manufacturers looking to maintain supplies to market as the phase down steps start to take effect.

Although the GWP is 69% above that of the average of refrigerants placed on the market by 2030, it is expected to be available for longer because the larger charge size systems, such as chillers and VRF systems, will be more likely to have migrated to much lower-GWP refrigerants for the longer term allowing more flexibility for use of R32 for the smaller system end of the market.

As an A2L, however, it can present issues of flammability which may prevent its use in certain applications or locations. Mitigating measures as outlined in BS EN 378[3] may be necessary to allow for sufficient refrigerant charge to be used for some of these systems or where the unit is located in small, unvented rooms which may be infrequently occupied. A full risk assessment should take the unit's location and the use of lower-flammability refrigerants into account and advise whether additional mitigating measures should be applied to allow for the refrigerant charge required.

Similarly, R454B is sometimes seen as an alternative refrigerant to R410A by some manufacturers. The same A2L limitations apply with this refrigerant as with R32, although the GWP level for R454B is considerably lower at 467.

Monoblock heat pumps

Monoblock heat pumps are where the entire system, comprising compressor, evaporator, condenser, and expansion device are built into a single unit so the refrigerant circuit is completed, tested and charged in a factory environment. Stand-alone domestic-style air-to-water heat pumps are the most common type of monoblock heat pumps.

As the entire circuit is made in a factory environment, the risk assessment tends to be a more straightforward process and this often allows the use of highly flammable refrigerants such as R290 (propane) or R600a (isobutane) to be used. There may be implications for the location of the system itself because of the use of a highly flammable refrigerant so the risk assessment should take this into account and may demand some mitigating measures to be put in place to allow the use of these refrigerants.

There are also some heat pumps being developed for small commercial use using CO_2 as a refrigerant. CO_2 is non-flammable, but it does readily displace oxygen and, therefore, also demands a strict risk assessment to be carried out, particularly when it is to be used in occupied or freely accessible areas.

There are some major advantages to using a CO_2 heat pump in some commercial applications. These systems have a particularly high compressor discharge pressure and corresponding temperature which can often be readily piped in such a way as to facilitate relatively high grade heat recovery. In small commercial applications with high domestic hot water (DHW) demands such as hotels or commercial kitchens in restaurants this can be used to heat DHW. The capital cost relative to other heat pump systems can make it difficult to justify the capital outlay in some cases; but by integrating a CO_2 heat pump into the DHW system and balancing the cost of DHW provision against other means of generating that hot water it can sometimes be a useful approach where the longer term net zero agenda is of critical importance. The GWP of CO_2 is of course only 1, which makes it a very valuable consideration in many cases when considering the TEWI.

References and further reading

1. House of Commons Environmental Audit Committee HC 469 2018 *UK Progress on reducing F-gas Emissions Fifth Report of Session 2017–19*
   Available from **publications.parliament.uk**
2. Regulation (EC) No 1005/2009 of the European Parliament and of the Council of 16 September 2009 on substances that deplete the ozone layer (recast) (Text with EEA relevance)
   Available from **www.legislation.gov.uk**
3. BS EN 378 series of standards: *Refrigerating systems and heat pumps – Safety and environmental requirements*
   Available from **shop.bsigroup.com**
4. BS EN 378-1:2016+A1:2020 *Refrigerating systems and heat pumps. Safety and environmental requirements - Basic requirements, definitions, classification and selection criteria*
   Available from **shop.bsigroup.com**
5. BS EN 60335-2-40:2003+A13:2012 *Household and similar electrical appliances. Safety - Particular requirements for electrical heat pumps, air-conditioners and dehumidifiers*
   Available from **shop.bsigroup.com**
6. BS EN 60335-2-89:2010+A2:2017 *Household and similar electrical appliances. Safety - Particular requirements for commercial refrigerating appliances with an incorporated or remote refrigerant unit or compressor*
   Available from **shop.bsigroup.com**
7. REFCOM Technical Bulletin TB018 *Competence requirements for the RACHP sector*
   Available from **www.refcom.org.uk**
8. REFCOM guidance note *Summary of proposed common framework for ozone-depleting substances (ODS) and fluorinated greenhouse gases (F-Gases)*
   Available from **www.refcom.org.uk**
9. Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 (Text with EEA relevance)
   Available from **www.legislation.gov.uk**
10. REFCOM Technical Bulletin TB033 *Working with Lower Flammability Refrigerants*
    Available from **www.refcom.org.uk**

FURTHER READING

REFCOM TB015 *Leak Checking: Direct or Indirect Methods*
Available from **www.refcom.org.uk**

REFCOM TB047 *Refrigerants banned from use as of 1 January 2020*
Available from **www.refcom.org.uk**

Institute of Refrigeration GN37 *Refrigerant Selection*
Available from **ior.org.uk**

Further more detailed technical guidance is available **ior.org.uk**

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