An introduction to A2L refrigerants and their use in Refrigeration, Air Conditioning and Heat Pump applications

OVERVIEW

The 2015 F-gas regulation is driving industry to use lower GWP[1] refrigerants in many applications. The EU regulation (517/2014), which came into force on the 1st January 2015, introduces a ban on new equipment using HFC refrigerants with a GWP of over 2500 by 2020. The regulation also introduces a phase down, related to GWP and measured in CO_2 equivalent tonnes, which will drive industry to use lower GWP options.

As a result, a new family of refrigerants – both pure fluids and blends – has been (and continues to be) developed - these are Hydro Fluoro Olefins (HFO).

A feature of many of these products (and some existing refrigerants such as R32 and Ammonia) is that they exhibit lower flammability[2], and hence a new classification has been introduced by ASHRAE[3] to cover this feature – A2L. (In the case of Ammonia the classification is B2L, due to its toxicity)

This guidance note has been written by members of FETA Associations to give an overview of these new refrigerants, and some basic advice as to their use in the field.

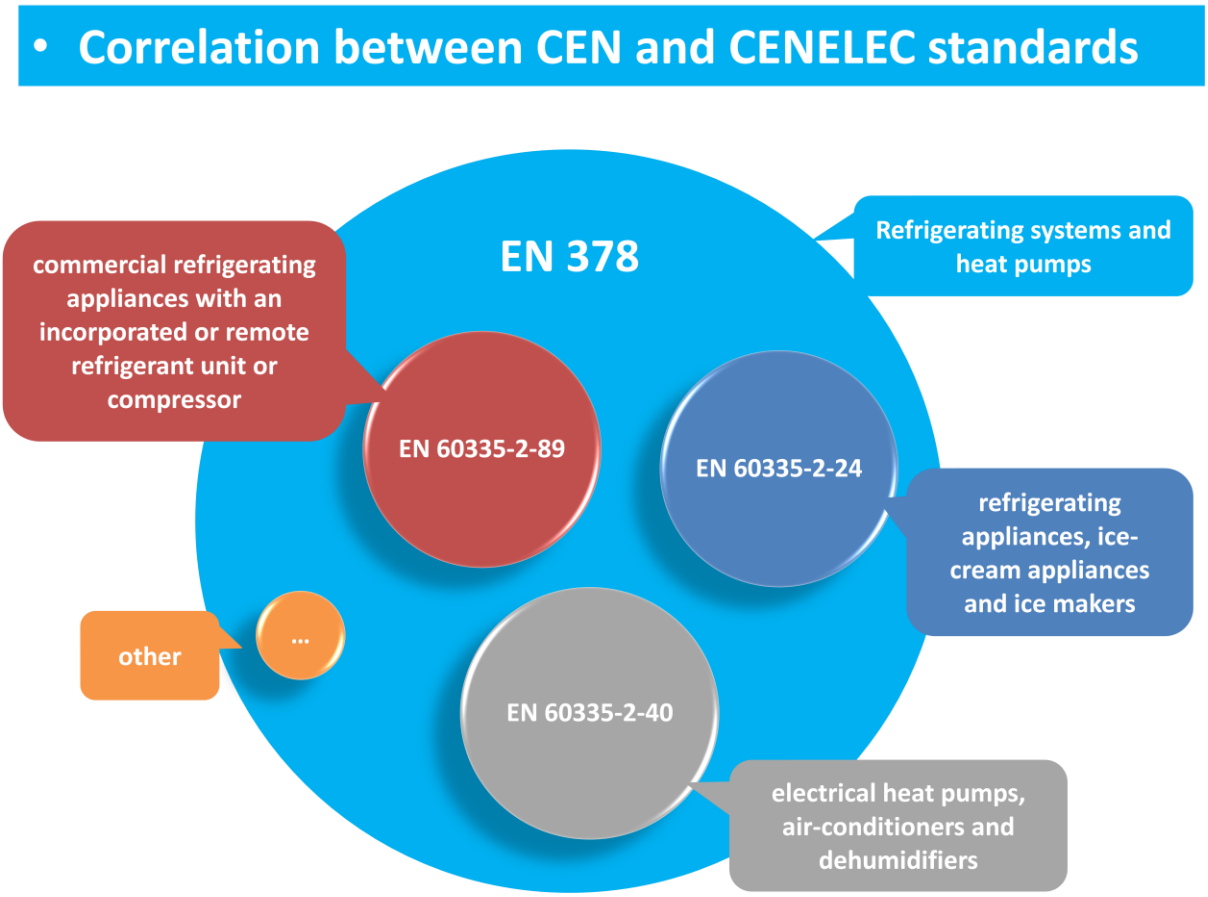
REGULATORY BACKGROUND

ISO[4] and IEC[5] standards are international safety in use type standards. European Norms or EN standards are typically based on an international standard. The relationship between International and European Union standards is highlighted in the table below.

Standard Type		International	Europe
Refrigerant Classification		ISO 817	Follows ISO 817
Safety in Use	General	ISO 5149	EN 378
	Equipment Specific	IEC 60335-2-24 IEC 60335-2-40 IEC 60335-2-89	EN 60335-2-24 EN 60335-2-40 EN 60335-2-89

[1] **G**lobal **W**arming **P**otential
[2] A2L refrigerants are commonly referred to as "mildly flammable". This guide uses "lower flammability" to be consistent with standards phraseology
[3] **A**merican **S**ociety of **H**eating, **R**efrigerating and **A**ir Conditioning **E**ngineers
[4] **I**nternational **S**tandards **O**rganisation
[5] **I**nternational **E**lectrotechnical **C**ommission

The graphic below shows the interaction between the various standards noted above, and EN378 in particular, which is the primary standard that designers and installers use when considering the safety and design limitations of a system.



[CEN – European Committee for Standardisation]

[CENELEC – European Committee for Electrotechnical Standardisation]

Standards and regulations are constantly evolving, and future changes will enable the industry to make use of the new family of A2L refrigerants more extensively.

It should be noted, however, that the A2L classification is only used in reference to refrigeration, air conditioning and heat pump system safety, and is used by standards such as EN378 and ISO 5149 to determine maximum allowable charge size, etc. It **IS NOT** recognised by transport regulations (ADR[6]) and is not a recognised classification on Material Safety Data Sheets (MSDS). GHS[7] is the agreed international standard in this instance. When A2L products are stored and transported, they are classified as an extremely flammable gas, much the same as acetylene and MAP gas, commonly used by the industry for brazing. The exception to this is HFO R-1234ze (E), which GHS classifies as non-flammable (at 20 deg C). There should be no significant changes required to vehicles that transport A2L refrigerants, but there should be some form of ventilation and signage to inform authorities if there is an accident. Storage on site and at installer's premises should also comply with ADR and MSDS rules.

[6] International Carriage of Dangerous Goods by Road

[7] **G**lobal **H**armonised **S**ystem of Classification and Labelling of Chemicals

Currently, the HSE[8] in the UK does not recognise the A2L classification and views these products as highly flammable. Hence, safety guidance will also need to be reviewed for installations containing A2L refrigerants using DSEAR[9] in the UK, and ATEX[10] guidance in Europe. This requires a risk assessment to be undertaken, reviewing the application, location of components, and the installed refrigerant charge. In these circumstances, installation guidelines can form the framework for such risk assessments. By choosing the right refrigerant, equipment and location as dictated by EN378 the probability of forming a flammable atmosphere can be eliminated, making this assessment potentially very straightforward as many manufacturers are including data to carryout risk assessments within their technical documentation.

CURRENT REFRIGERANTS

Refrigerants are classified as below:

ISO 817 Refrigerant Classification Scheme

A3	B3	Higher Flammability
A2	B2	Flammable
A2L	B2L	Lower Flammability
A1	B1	Non-Flammable
Lower Toxicity	Higher Toxicity	

The vast majority of HFC and HFC/HFO blend refrigerants in current use are classified as A1, with low toxicity and zero flammability. Ammonia, which has been in use for many years, is classified as B2L; R-152a is an A2 refrigerant, and all hydrocarbons are classified as A3. It is vital to understand what refrigerants are in your system, and to make sure that the system complies with the requirements for leak checking and the phase down schedule of your particular gas. All refrigerants in the table below are A1.

[8] **H**ealth and **S**afety **E**xecutive
[9] **D**angerous **S**ubstances and **E**xplosive **A**tmospheres **R**egulation
[10] **AT**mosphere **EX**plosibles (French)

List of Common refrigerants			
Refrigerant	GWP[11]	Comments	Suggested Action
HFC R-407C	1774	AC/HP most DX systems using this refrigerant are now several years old so having a replacement plan would be advisable. Some chiller manufactures are still using this refrigerant in new equipment so check that this is the best refrigerant to use for your application.	
HFC R-407A/F	2107/1825	These refrigerants are being used in commercial refrigeration as an interim replacement for systems currently using R404A	New equipment should not be installed using R-404A/507
HFO/HFC R-448A/ 449A	~1400	These refrigerants are now being used in commercial refrigeration as a longer term replacement for systems currently using R404A/R507	New equipment should not be installed using R-404A/507. Plan to retrofit existing equipment with R448A/R449A
HFC R-410A	2088	This refrigerant is predominately used in DX equipment in the A/C industry.	Ensure that when using R410A that the correct F-Gas checks are in place. If installing small systems, try to use equipment manufacturer recommended low GWP alternatives where possible.
HFC R-404A	3922	This refrigerant will be banned in most new equipment and for service use from 2020	Plan to replace this gas **as soon as possible** using either R407A/F, or one of the lower GWP HFO blends such as R448A, R449A or R452A.
HFC R-134a	1430	This refrigerant has applications in A/C and refrigeration. It has a medium GWP and availability is likely to be effected in the later stages of the phase down.	This gas can continue to be used for the time being, but it is sensible to review the alternatives available.
HFO/HFC R-452A	2141	This refrigerant is now being used in transport and small commercial refrigeration as a longer term replacement for systems currently using R404A/R507	New equipment should not be installed using R-404A/507.
HFO/HFC R-513A/ R-450A		These refrigerants are now being used in commercial refrigeration and AC as a longer term replacement for systems currently using R134a	

[11] Taken from the IPCC 4 assessment as recognised in the F-Gas regulation

List of A2L refrigerants

(those in bold are in current use; the others are beginning to appear on the market)

Refrigerant	Other names	GWP	Applications
R-1234yf		**4**	**Automotive A/C**
R-1234ze		**6**	**Chillers, Aerosol Propellant**
R-32		**675**	**R-410A replacement**
R-454A	XL40	238	R-404A replacement
R-454C	XL20	146	R-404A replacement
R-455A	L40X	145	R-404A replacement
R-447A	L41	>500	R-410A replacement
R-452B	XL55	676	R-410A replacement
R-454B	XL41	467	R-410A replacement

WHAT DOES THE A2L CLASSIFICATION MEAN?

The main differences between A1 refrigerants, such as R-410A, R-134a, R-407C, and A2L refrigerants such as R-32, HFO R-1234yf and HFO R-1234ze is the ability to propagate a flame. A2L refrigerants will burn, but their burning velocity is below 10cm/s, which is lower than an A3 refrigerant such as R-290 which actually burn explosively when ignited; hence the new classification. In practical terms, it is very difficult to ignite 2L gases, but some precautions must be taken to prevent accidental build-up of refrigerant, particularly during charging of systems. Manufacturers are suggesting that extract fans be used during this process, especially if the outdoor unit is in an enclosed area

All flammable refrigerants (class 2L and above) will not ignite if the concentration level in a room stays below their lower flammability limit (LFL). International and European safety legislation and standards such as ISO 5149 and EN 378 define requirements to remain far below the lower flammable limit in case of accidental leakage.

USE OF A2L REFRIGERANTS

IT IS VITAL TO UNDERSTAND THAT A2L REFRIGERANTS **MUST ONLY** BE USED IN SYSTEMS DESIGNED SPECIFICALLY TO TAKE INTO ACCOUNT THEIR FLAMMABILITY CHARACTERISTICS. THEY SHOULD **NEVER** BE USED TO REPLACE NON-FLAMMABLE REFRIGERANTS IN RETROFIT SITUATIONS **without a full risk assessment and necessary modifications.**

This is because of safety issues and the possibility of a relatively large charge of an A2L being released by accident into an area that has not been risk assessed for use with this class of refrigerants.

Due to their lower flammability, A2L refrigerants are intended for use in equipment specifically designed for these products and should always be used in accordance with the relevant national and international standards. Please consult the appropriate equipment manufacturer regarding which refrigerants can be used in the equipment

APPLICATIONS

A2L refrigerants are already in use in a variety of applications.

From 1st January 2017, all NEW cars produced in Europe must contain a refrigerant with a GWP of less than 150 in their A/C system. The product of choice is HFO R-1234yf. There are currently over 12.5m cars on European roads that use this refrigerant, and this is expected to rise to 29m by the end of 2017. The automotive industry carried out exhaustive tests and risk assessments before using R-1234yf, and found it to present no more risk than its predecessor, R-134a. Manufacturers are well versed in the use of this refrigerant on production lines, although it does require those servicing cars to be aware of the differences.

R-32 (an HFC classified as A2L) is now being widely marketed as an alternative to R-410A in new air conditioning systems, due to its similarity in performance to R-410A. There are well over 4m systems operating on R-32 in Japan – although it should be noted that their regulations on the use of flammable refrigerants are different to Europe.

Some large chillers are now using R-1234ze as an alternative to R-134a. R-1234ze is an HFO and is classified as A2L, but, as previously noted, it is actually non-flammable at temperatures below 30^0C. R-1234yf is a closer match to the performance of R-134a, which makes it suitable for use in chillers where the system is designed to use a lower flammability refrigerant. Because of its non-flammability at ambient temperatures, R-1234ze is also being used in some aerosol applications.

Refrigerant manufacturers are also trialling A2L HFO blends as replacements for R-404A, R-410A, etc type applications.

PRACTICAL ASPECTS OF USING A2L REFRIGERANTS

All technicians that carry out work on stationary RACHP systems must hold an F-Gas handling certificate. This requirement applies both to in house staff and to personnel employed by external contractors. Existing certificates issued in accordance with the 2006 EU F-Gas Regulation remain valid, in accordance with the conditions under which they were originally issued, and therefore installers existing training covers new A2L refrigerants. However, it should be noted that additional training has to be given on alternatives when the F-gas certificate is updated.

Service Equipment

Many of the service tools used for current A1 refrigerants can be used for servicing A2L refrigerants. However, some service equipment, due to the electrical components and motors, should be specifically designed for use with lower flammability A2L refrigerants (e.g. R-1234yf, R-32, etc.). All service should be conducted in a safe manner and relevant risk assessments need to be carried out. Equally, tools such as manifolds, leak detectors and reclaim devices need to be compatible for use with A2L refrigerants. Flare connections and pipework, as well as pressure testing requirements, remain the same. Providing the required assessments have been made beforehand, installation of an A2L system should be no more difficult than an A1 system. New A2L service items should be available as there are an increasing number of service equipment companies providing these tools.

Safe working considerations

1. Make sure all relief and purge vent piping is routed outdoors and away from all air intakes to the building, per local codes, regulations and EN standards.
2. Make certain the area is well ventilated. Use auxiliary ventilation, rated for A2L refrigerants, such as blowers or fans, if necessary, to disperse refrigerant vapours, especially in confined areas such as light wells and enclosed plant rooms. (This is a recommendation for R-410A anyway)
3. Test the work area for available oxygen before entering enclosed areas. **Do not use a leak**

monitor to test for oxygen. A refrigerant leak detector will not tell you if adequate oxygen is present to sustain life.

4. Install an A2L flammable rated refrigerant leakage detection and oxygen monitoring equipment in the work areas. Guidance is available in EN378

Leakage situations (applicable to ALL refrigerants)

Do not attempt to enter the area to repair equipment until the vapours are dispersed, OR until you are equipped with proper breathing apparatus. Evacuate everyone until the area has been ventilated. Use blowers or fans to circulate air at the floor level and in any basement or low areas.

1. Appropriate protection systems should be readily available in case of a large release, especially when dealing with large charges in enclosed areas.
2. Personnel should be trained how to use this equipment.
3. Consult the most recent version of ISO 5149 or EN378 for additional information.

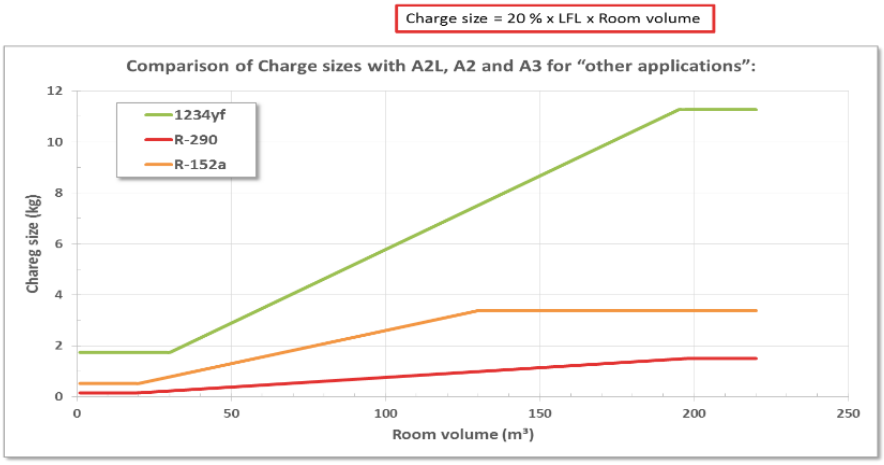
System Filling Charges for A2L Refrigerants

Filling charges are usually covered by the respective standards for refrigeration equipment - the general safety and use standard ISO 5149 and EN378 "*Refrigeration systems and heat pumps*". There are also more specific standards covering selected appliances, such as the IEC 60335-2 series, that manufacturers use when designing equipment.

The new version of EN378:2016 gives guidelines for ensuring that systems do not exceed the maximum amount of charge in a specific area, which is normally referred to as the Lower Flammable Limit. Check your local regulations and the correct standards such as those listed above to verify the allowable filling charge, new equipment design and safe handling requirements for the intended application, or ask your manufacture for guidance on the subject

See appendix A for examples of calculations

The graph below shows that you can typically use more than 10 times the charge of an A2L refrigerant compared to an A3 highly flammable refrigerant (consult EN378 for the limits for specific equipment, location and application)



SUMMARY

To meet the requirements of the F Gas regulation phase down process, it will be necessary to make use of refrigerants with much lower GWPs. This means that the RACHP industry will need to begin to use the new A2L refrigerants as part of this process, as the effects of the HFC phase down begin to bite. There is no reason why these new refrigerants cannot be used safely in a wide range of applications, providing guidance and regulations are observed, and good practice is used.

FETA acknowledges the contribution of a number of its member companies in the preparation of this article

REFERENCES

There are a number of useful reference documents that add further detail to this document:

BS EN378:2016
This standard (in four parts) can be purchased from
http://shop.bsigroup.com/Navigate-by/Standards/

Institute of Refrigeration
The IoR have issued a guidance note (29) on the changes to BS EN378, available from:
http://www.ior.org.uk/bs-en378-2016-summary-of-changes-ior-gn29-

AREA
AREA (European Association of RACHP Contractors) has published a guide to equipment for flammable refrigerants, available at :
http://area-eur.be/publications/guide-equipment-low-gwp-refrigerants

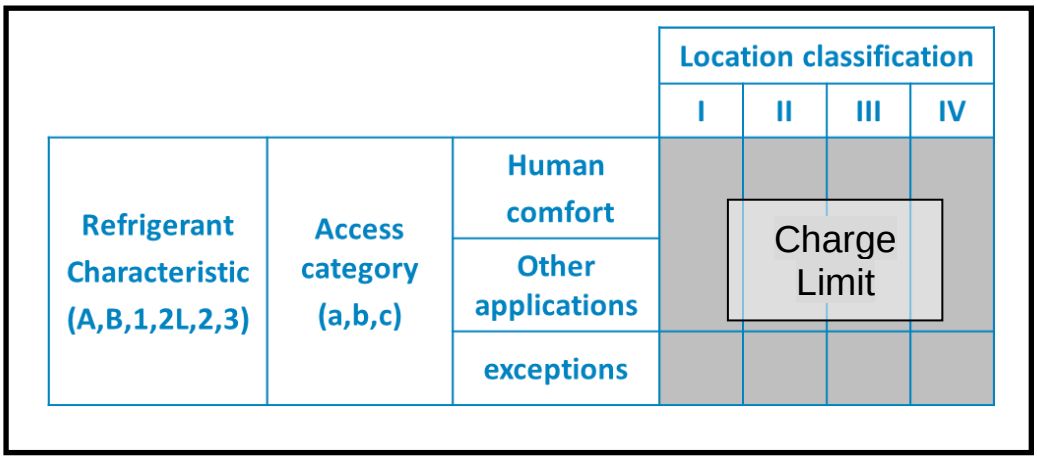
REAL alternatives
This European project offers e-learning which covers A2L refrigerants and their properties.
http://www.realalternatives.eu/home

Appendix A - Practical Advice on using A1 and A2L refrigerants in Air Conditioning, Heat Pump and Refrigeration applications using EN378:2016

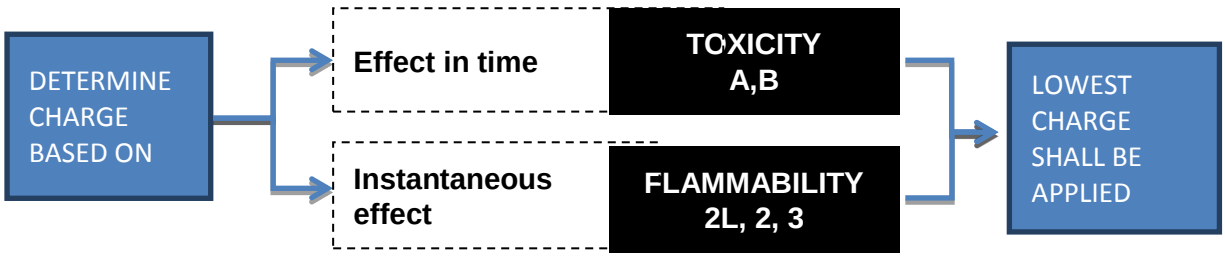
As mentioned previously, EN378:2016, now recognises the use of A2L refrigerants, and also changes the methodology for calculating charge limits based on three characteristics:

- Refrigerant properties
- Access categories
- Location classification

The table below gives an overview of the process.



It should be noted that Class 1 and 2 have charge limits, whereas Class 3 systems in general have no charge limitations except for refrigerants in flammability class 3. Machinery room requirements apply at all times. The process can be defined as in the diagram below:



Examples of this are:

Examples	Toxicity limit	Flammability limit*	Charges are defined by
R-717 (Ammonia)	0,00035 kg/m³	0,023 kg/m³	➔ Toxicity
R-32	0,3 kg/m³	0,061 kg/m³	➔ Flammability

EN378 also allows for the provision of leak detection and ventilation that are **Requirements for alternative provisions. This** brings into play the following terms; QMLV, QLAV, and RCL

QLMV: Quantity Limit with Minimum Ventilation in kg/m^3
QLAV: Quantity Limit with Additional Ventilation in kg/m^3
RCL: Refrigerant Concentration Limit in kg/m^3

The standard now accepts that the maximum leakage into an occupied space is assumed to be not greater than a pinhole leak, and the maximum charge is calculated on that basis. This has enabled the allowable refrigerant charges to be calculated. The full methodology is stated in the standard so that the QLAV and QLMV can be calculated for all refrigerants. The table below states the figures for the most popular gases in use today.

Refrigerant	Allowable concentration (kg/m^3) RCL	QLMV (kg/m^3)	QLAV (kg/m^3)
R-22	0.21	0.28	0.50 [a]
R-134a	0.21	0.28	0.58 [a]
R-407C	0.27	0.44	0.49 [a]
R-410A	0.39	0.42	0.42 [a]
R-744	0.072	0.074	0.18 [b]
R-32	0.061	0.063	0.15 [c]
R-1234yf	0.058	0.060	0.14 [c]
R-1234ze	0.061	0.063	0.15 [c]

a Based on ODL
b Based on a volume fraction of 10 %
c Based on 50 % LFL

The table above is used where additional measures are required, for example when an indoor unit or piping passes through an occupied space and the whole gas charge was to escape into the space.

There are also further stipulations that take precedence:

- If the indoor unit is below 1.8 metres high a fan or ventilation system must be activated to prevent stagnation of the gas in the space, this can be started by a leak detection system. Pipe work must be securely mounted to prevent accidental damage occurring
- Ventilation and dilution transfer openings must have sufficient volume to prevent the QLMV limit from being exceeded. Extract fans must have a grille no higher than 0.2 metres above the floor level and can be continuously operated or switched on by a leak detection system. Transfer grills must be used at high and low levels and can be divided into more than one grille. Safety shut off valves may also be used but must be located to prevent an ingress of gas that would exceed the QLMV, which generally means close to the indoor unit or pipe work that is running through the enclosed area.
- Safety alarms must provide a visual and audible warning with the latter being at least 15 dB(A) louder than the ambient sound level.

SYSTEM EXAMPLE

A VRF/VRV system using R-410A in a hotel with bedrooms of 5m x 3m x 2.2m

As the refrigerant is designated A1, this example would use Table C.1 in EN378

Table C.1 — Charge limit requirements for refrigerating systems based on toxicity

Toxicity class	Access category		Location classification			
			I	II	III	IV
A	a		Toxicity limit × Room volume or see C.3	No charge restriction [a]	No charge restriction [a]	The charge requirements based on toxicity shall be assessed according to location I, II or III, depending on the location of the ventilated enclosure
	b	Upper floors without emergency exits or Below ground floor level	Toxicity limit × Room volume or see C.3			
		Other	No charge restriction [a]			
	c	Upper floors without emergency exits or Below ground floor level	Toxicity limit × Room volume or see C.3			
		Other	No charge restriction [a]			

Hotel rooms are designated as general access (a) and the location classification is designated as II. Hence, the maximum charge would be calculated as follows:

Room size = 5m x 3m x 2.2m

Room volume = $33m^3$

RCL =0.39
QLAV =0.42
QLMV =0.42

Maximum charge at RCL = 33m^3 x 0.39 kg/m^3 = 12.87 kg
Maximum charge at QLAV = 33m^3 x 0.42 kg/m^3 = 13.86 kg
Maximum charge at QLMV = 33m^3 x 0.42 kg/m^3 = 13.86 kg

[Note QLAV and QLMV for R-410A are the same]

If part of the system is below ground, the RCL room volume has to be used, and if any of the room volumes are exceeded, a leak detection system must be used.
It should be noted that for all other occupancy types b & c there are no charge restrictions unless the office space is below ground level

The calculations for A2L refrigerants are more complex, as there are more limitations due to the mild flammability properties of these gasses. The same process regarding charge limits is used, but there are differing limits depending on the location of indoor unit and access category as can be seen in the table below.

Table C.2 — Charge limit requirements for refrigerating systems based on flammability

Flammability class	Access category		Location classification			
			I	II	III	IV
2L	a	Human comfort	According to C.2 and not more than m_2 [a] × 1,5 or According to C.3 and not more than m_3 [b] × 1,5		No charge restriction [c]	Refrigerant charge not more than m_3 [b] × 1,5
		Other applications	20 % x LFL × Room volume and not more than m_2 [a] × 1,5 or According to C.3 and not more than m_3 [b] × 1,5			
	b	Human comfort	According to C.2 and not more than m_2 [a] × 1,5 or According to C.3 and not more than m_3 [b] × 1,5			
		Other applications	20 % × LFL × Room volume and not more than m_2 [a] × 1,5 or according to C.3 and not more than m_3 [b] × 1,5	20 % × LFL × Room volume and not more than 25 kg [c] or according to C.3 and not more than m_3 [b] × 1,5		
	c	Human comfort	According to C.2 and not more than m_2 [a] × 1,5 or According to C.3 and not more than m_3 [b] × 1,5			
		Other applications	20 % × LFL × Room volume and not more than m_2 [a] × 1,5 or according to C.3 and not more than m_3 [b] × 1,5	20 % × LFL × Room volume and not more than 25 kg [c] or according to C.3 and not more than m_3 [b] × 1,5		
		< 1 person per 10 m²	20 % × LFL × Room volume and not more than 50 kg [a] or according to C.3 and not	No charge restriction [c]		

The procedure for calculating the charge limit are broken down into 3 cap factors m_1,m_2, and m_3 these equate to

— m1 = 4 m^3 × LFL
— m2 = 26 m^3 × LFL
— m3 = 130 m^3 × LFL
Calculate formula C1 (A2L)

C1 - mmax= 2.5 × LFL 5/4 × h0 × A1/2

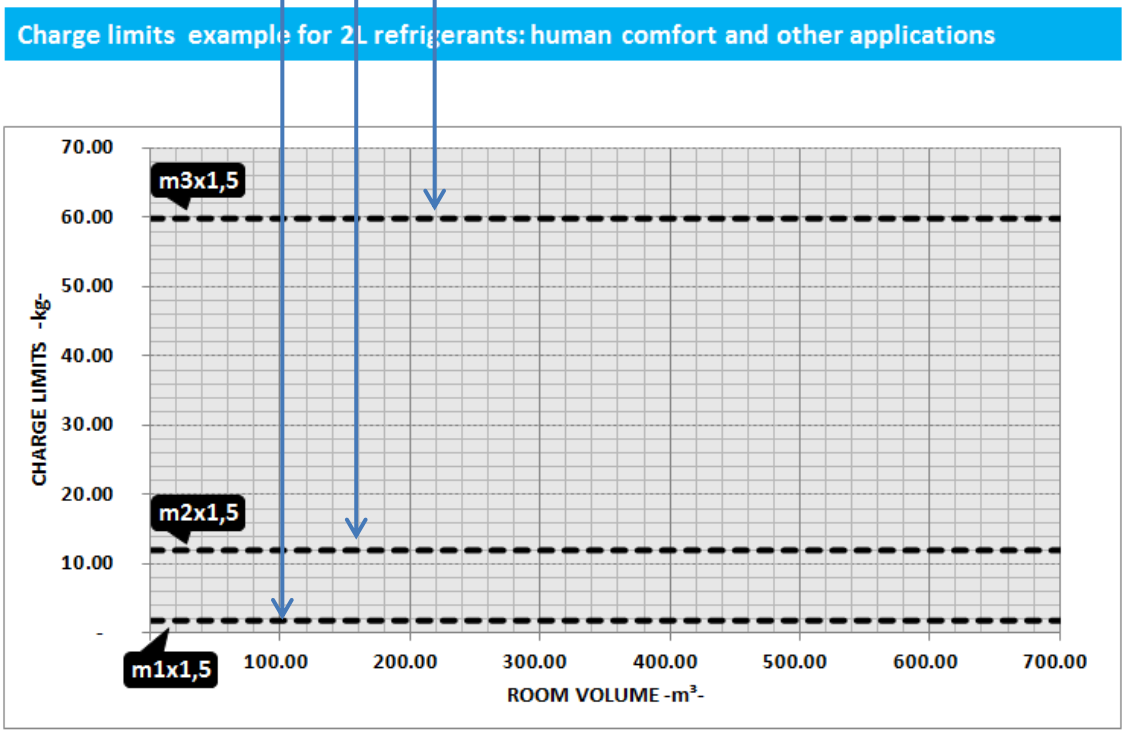
Mmax is the allowable maximum charge in a room in kg;
m is the refrigerant charge amount in the system in kg;
Amin is the required minimum room area in m^2;
A is the room area in m^2;
LFL is the Lower Flammable Limit in kg/m3, as defined in Annex E;
h0 is the height factor of the appliance:
— 0.6 for floor location;
— 1.8 for wall mounted;
— 1.0 for window mounted;
— 2.2 for ceiling mounted,
Where the LFL is in kg/m^3 from Annex E and the molecular mass of the refrigerant is greater than 42 g/mol.

Procedure for calculating A2L charge limit

If mmax = less than M_1 = No restrictions
If mmax = more than M_1 but less than M_2
Then one additional measure is required plus leak detection

If mmax = more than M_2 but less than M_3
Two additional measures are required plus leak detection

If mmax = more than M_3 the system is not allowed

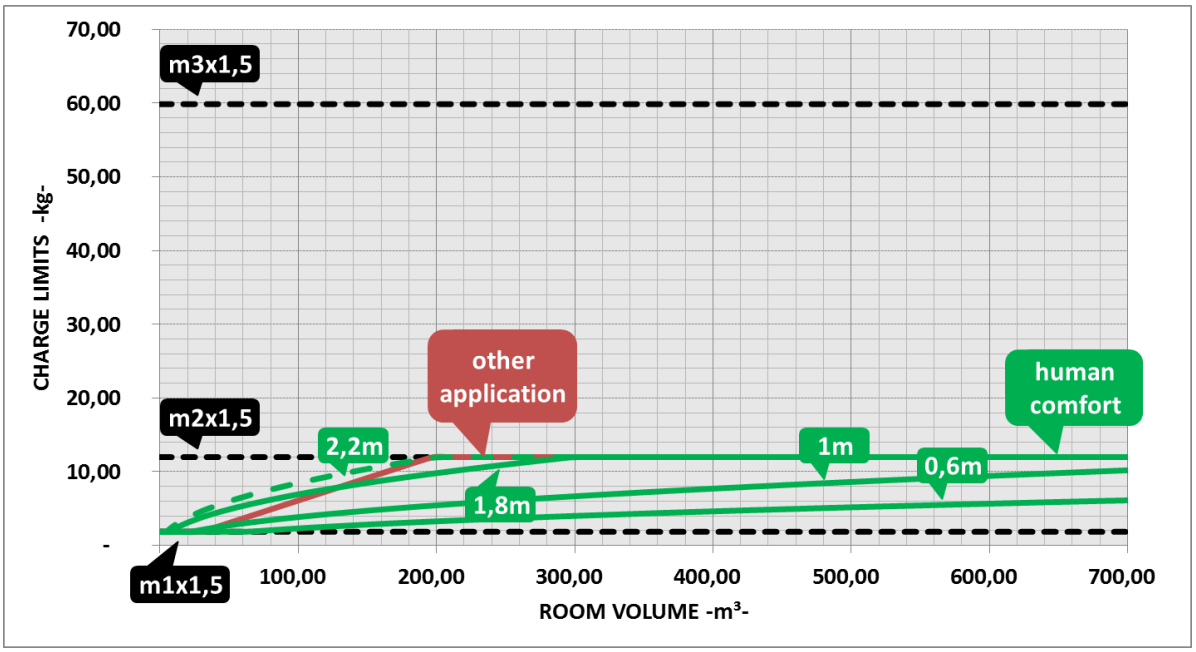


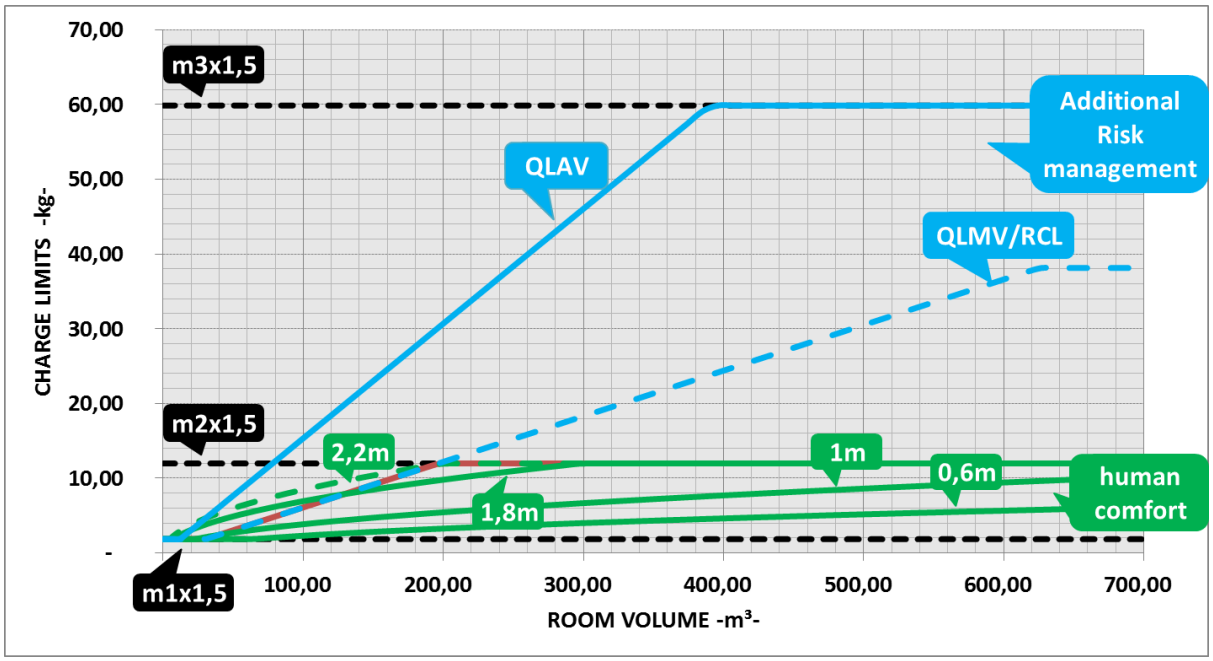
Calculation based on R1234yf and R32.

Addition measures =

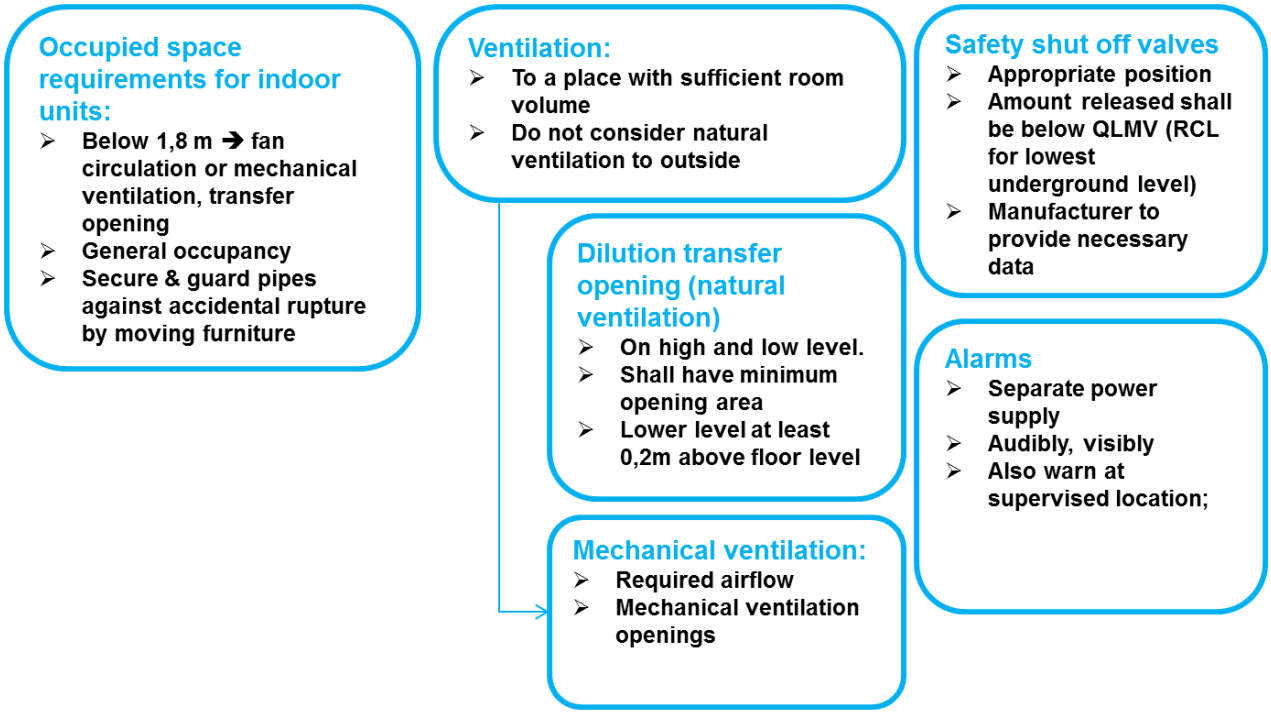
1. Leak detection system
2. Ventilation to meet section C3 QLAV
3. Isolation valves are required

The calculation will vary depending on the unit location so to clarify the graph below gives an indication of charge limits that will one additional measure and the second graph uses the same calculation with two additional measures





To clarify the additional measures, we can use the following diagram to explain the different types of additional measures used across the standard



For other cooling systems such as chillers, the standard remains the same and there no restrictions other than chillers that are using A3 refrigerants and the limitations are as follows: -

Refrigerant class 3	System class III
a general occupancy	5kg (except below ground = 1kg)
b supervised occupancy	10kg (except below ground = 1kg)
c authorised occupancy	No restrictions (except below ground = 1kg)