ITALIAN
COOLING
SOLUTIONS

HiRef

A2L REFRIGERANTS

WHITE PAPER

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INDEX

1 A2L INTRODUCTION

The European F-Gas regulations mainly focus on the refrigerants used until now (HFCs) due to their high GWP1 value. In this respect, the regulations will impose, starting from 2020, a ban on the use of refrigerants with a GWP value of over 2500 in maintenance operations; additionally, a progressive phasing down of the quantities of greenhouse gases that may be marketed is also envisaged. This reduction is calculated on the basis of the equivalent quantities of GWP: compared to the total equivalent marketed in 2015, a gradual phase-down will be applied to reach -79% in 2030 (Figure 1), with impacts in terms of product costs as well as commercial availability.

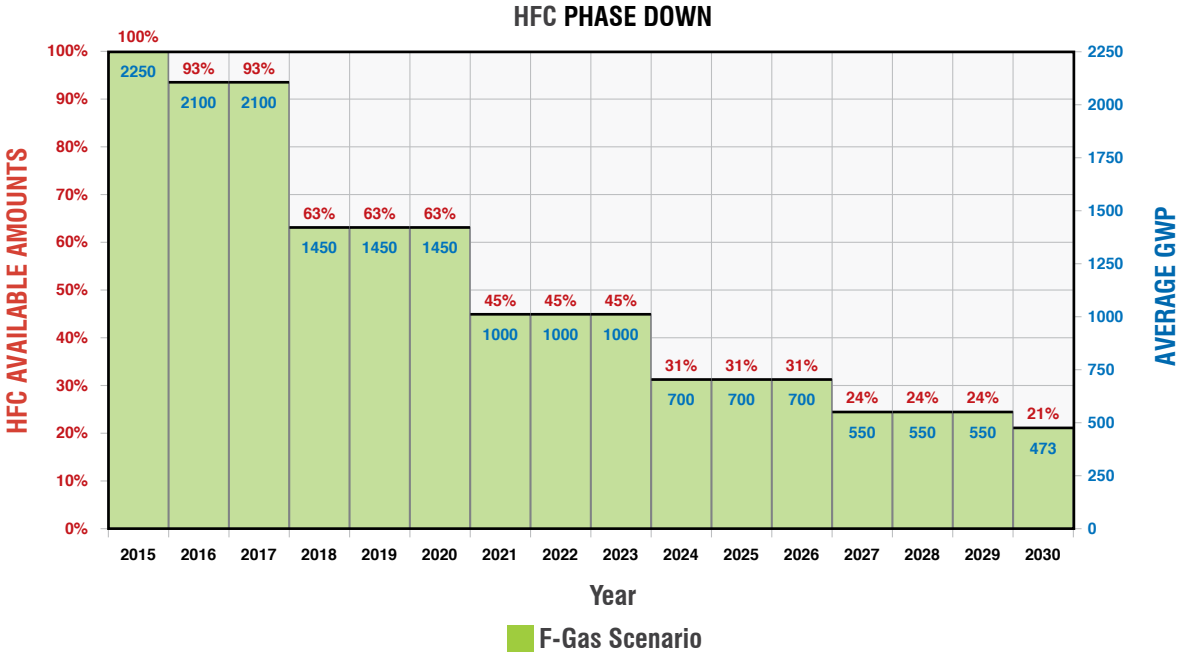


Figure 1 - F-Gas scenario: HFC phase down

As early as from 2017, effects have been observed on the cost of refrigerants, with continuous increases leading to prices that are currently 600% of the initial figure (Figure 2). The most heavily affected gases are those with higher GWPs such as R404A and R410A, but all the industry refrigerants, including R134a, are concerned - although to a more limited extent.

The need to find replacement products that are able to meet the new GWP limits indicated in the F-Gas regulation will result in major changes in the current use scenario. The most popular fluids today have a GWP value higher than 2000, while those with lower values are not very widely used yet.

[1] GWP (Global Warming Potential): impact of a given gas on the greenhouse effect compared to the effect of CO2, whose reference potential is 1.

The top refrigerant manufacturers forecast a future scenario characterised by refrigerants with a lower environmental impact, particularly of type A2L (mildly flammable), unlike those currently used, classified as A1 (non-flammable).

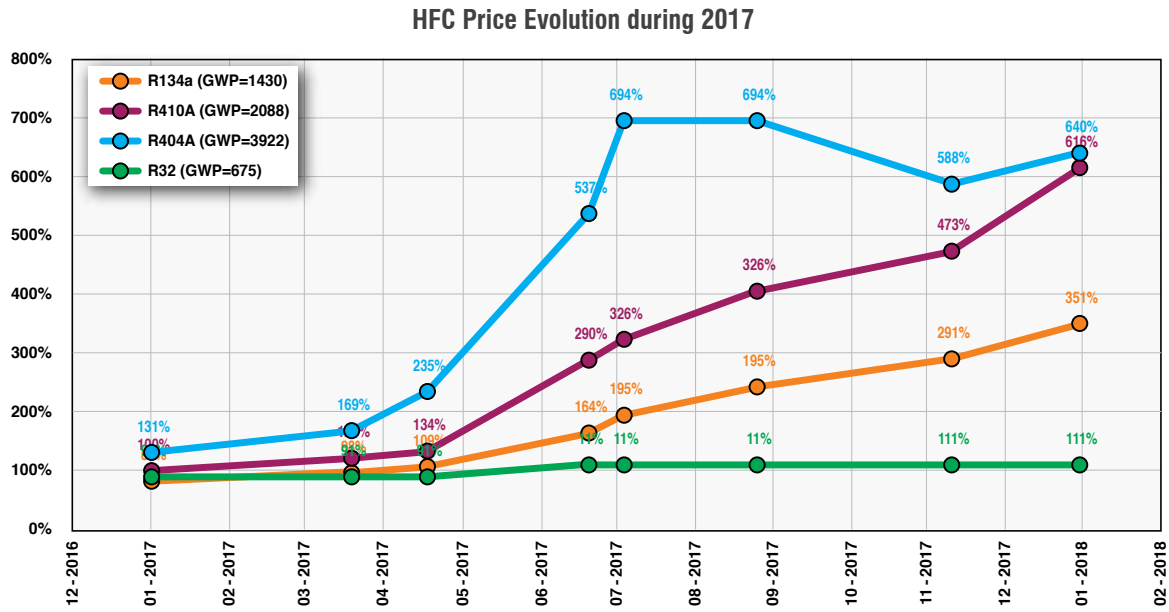


Figure 2 - Refrigerant cost evolution throughout the year 2017 [HiRef s.p.a]

A2L Refrigerants

ISO 817 [1] standard classifies refrigerants based on their degree of toxicity and flammability (Figure 3). The degree of toxicity is split into two categories: low toxicity (designated by letter «A») and high toxicity (designated by letter «B»), while flammability is split into four groups: non-flammable («1»), slightly flammable («2L»), flammable («2») and highly flammable («3»). By combining its toxicity and flammability characteristics, a given type of refrigerant can be identified.

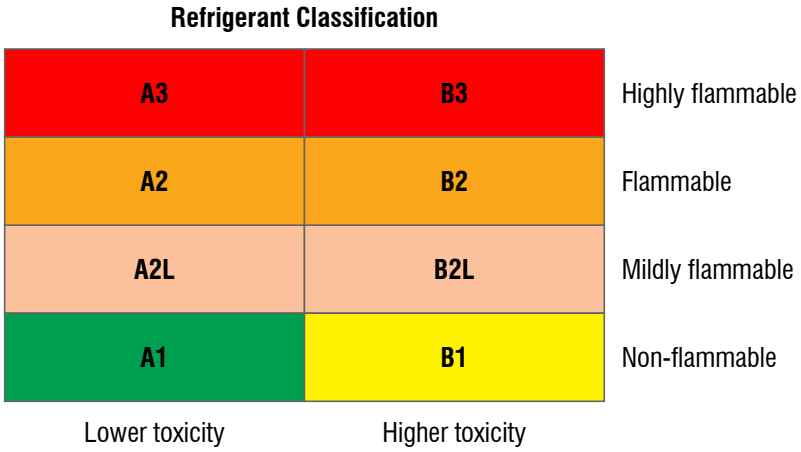


Figure 3 - Classification of refrigerants according to ISO 817

The A2L slightly flammable refrigerants are characterised by low combustion heat and a flame propagation speed (Burning Velocity) below 10 cm/sec (ASHRAE 34 - ISO5149).
In particular, the propagation rates of the most common A2L types are:

- 6.7 cm/sec for R32;
- 5.2 cm/sec for R454B;
- 3.0 cm/sec for R452B;
- 1.5 cm/sec for R1234yf;
- ~ 0 cm/sec for R1234ze.

Another characteristic shared by these types of refrigerant is the high value of the parameter MIE (Minimum Ignition Energy) - i.e. the minimum amount of energy required for ignition (the higher the MIE value, the lower the probability of ignition). For example, R32 has an MIE between 30 and 100 mJ, R1234yf between 5,000 and 10,000 mJ, and R1234ze between 61,000 and 64,000 mJ. For these refrigerants, a source of considerable energy - such as a naked flame or a very hot surface - is therefore necessary to start ignition. By comparison, class A3 refrigerants - e.g. propane and other hydrocarbons - are characterised by a value of MIE below 1 mJ, much lower than the abovementioned ones.
The low burning velocity and the considerable energy required for ignition lead to the designation of these refrigerants as slightly flammable: the probability of ignition is very low and, should it occur, their burning velocity would reach such speeds that they would be extinguishable by wind or minor air drafts (Figure 4).

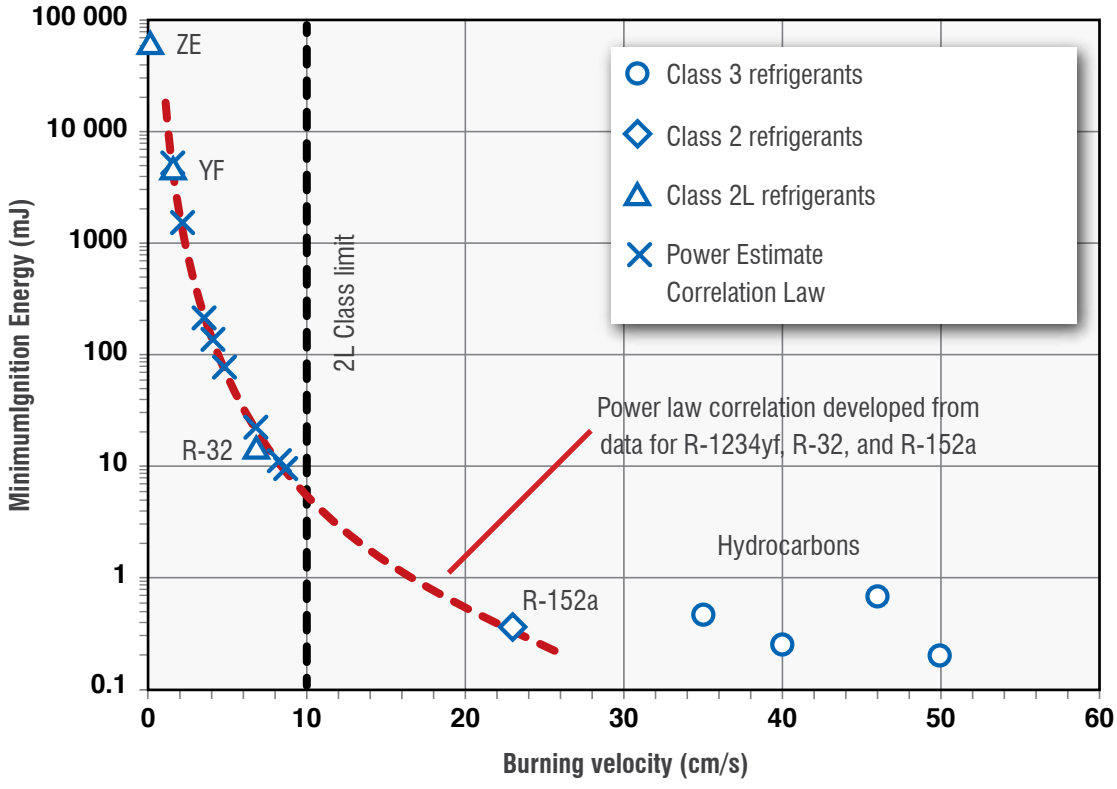


Figure 4 - Comparison between Minimum Ignition Energy and Burning Velocity for different refrigerants

The physical and chemical characteristics of A2L refrigerants are very similar to those of class A1 HFCs, which are therefore ideal potential replacements for today's refrigerants. Because of their slight flammability, however, special precautions are needed to avoid the - remote, but not zero - risk of ignition in case of fluid leakage to the environment. Refrigerant leaking from the refrigeration circuit could, in fact, create temporarily flammable spots.

The following tables show the possible replacements for the currently used refrigerants R410A and R134a.

Refrigerant	Components	Composition	GWP	Class
R410A	R32 + R125	50% / 50%	2088	A1
R32	Pure	---	675	A2L
R447B	R32 + R1234ze + R125	68% / 24% / 8%	741	A2L
R452B	R32 + R1234yf + R125	67% / 26% / 7%	676	A2L
R454B	R32 + R1234yf	68,9 % / 31,1 %	467	A2L

Table 1 - Possible replacements for R410A

Refrigerant	Components	Composition	GWP	Class
R134a	Pure	---	1430	A1
R450A	R1234ze + R134a	58% / 42%	547	A1
R513A	R1234yf + R134a	56% / 44%	573	A1
R1234ze	Pure	---	6	A2L
R1234yf	Pure	---	4	A2L

Table 2 - Possible replacements for R134a

The refrigerants shown in the tables are possible replacements for the fluids currently used, however, those with a value of GWP> 500 are medium-term choices only, because the ratio of the available amounts to the amount of refrigerant currently used would result in an average GWP value equal to 500 by 2030. With this in mind, R454B is an excellent substitute for high pressure (R410A) products while for low pressure (R134a) products the best option is pure refrigerant R1234ze (HFO). Both alternatives are A2L class refrigerants.

2 REFRIGERATION SYSTEM SAFETY DEVICES

The danger arising from the use of A2L refrigerant is linked to the case of gas leakage from the refrigeration circuit - which can create flammable areas inside the unit or in the installation environment.
Efficient design can help reduce this risk by preventing refrigerant from leaking and flowing out to possible ignition zones. To determine if there are possible ignition sources in these areas, the EN 60079-10-1:2009 [2] standard can be used to estimate the size and extent of the potential flammable area. This part of the standard deals with the classification of places where hazards due to the presence of flammable gases or vapours can occur, and can be used as a reference document to correctly choose and install equipment to be used in hazardous locations.
According to the EN 378 [3] standard, and specifically to part 2, components and equipment are not to be considered ignition triggers if they meet at least one of the following requirements:

- they must be positioned in such a way as to be outside of any possible flammable zone where leaked refrigerant can flow or stagnate;
- they must be ventilated either continuously or before powering the equipment, with a sufficient air flow rate to ensure that the concentration of refrigerant in the potential ignition source does not exceed 50% of the LFL2;
- they must comply with equipment protection requirements for zone types 0, 1 and 23 as defined by EN 60079 10-1;
- for electrical devices, the maximum possible energy generated by an arc must not cause the maximum flammable concentration of the refrigerant used to ignite.

It must also be ensured that the temperature of surfaces that may be exposed to an A2L refrigerant leakage does not exceed the refrigerant auto-ignition temperature decreased by 100 K.

Safety devices provided in HiRef units
The solutions proposed by HiRef aim at guaranteeing maximum personal and installation environment safety, by using passive and active safety systems in the refrigeration units.
Passive safety ensures that in case of leaks, no refrigerant ever comes into contact with possible sources of ignition present inside the unit.
Ignition requires:

- An ignition source;
- Fuel;
- Oxidiser.

The passive approach to safety involves avoiding the simultaneous presence of these three factors, thanks to some precautions to be adopted in the construction phase:

- isolating the electrical control panel from the components of the refrigerant circuit where the refrigerant flows (compressors, pipes, coils, etc.), to limit the possibility of refrigerant leaking out to potential ignition areas;

[2] LFL (Lower Flammable Limit): it indicates the minimum concentration above which the gas mixture becomes flammable.
[3] Zone 0: Area in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is present either permanently or for prolonged periods or frequently.
Zone 1: Area in which the formation of an explosive atmosphere, consisting of a mixture of air and flammable substances in the form of gases, vapours or mist, is likely to occur occasionally during normal activities.
Zone 2: Area in which, during normal activities, the formation of an explosive atmosphere, consisting of a mixture of air and flammable substances in the form of gases, vapour or mist is not likely, or may only occur for short periods of time.

- keeping the electrical control panel over-pressurised by uncontaminated air (for indoor installations, via connection to a duct coming from an uncontaminated environment and with an adequate ventilation system), to prevent the risk of having refrigerant in potential ignition areas;
- refrigerant presence sensors both in the electrical control panel and in the highest risk zones, such as the compressor compartment, to be able to adopt safety precautions at values well below the LEL;
- using a remote (optional) electrical control panel;
- using (optional) buffer batteries for the sensors.

Active safety devices work by ensuring safety conditions for the unit in the event of a leak. This is done by first performing a check upon start-up and then continuing to monitor the presence of gas during operation, according to predetermined procedures.

Startup procedure:

1. checking the correct operation of all leak detection devices; if one or more detectors are found faulty, an alarm is activated and machine power-on is prevented;
2. electrical control panel air changing and pressurisation before the compressors are switched on;
3. checking for refrigerant leaks and if any quantities are detected above the limit threshold, activation of an alarm and unit power-on disabling.

Procedure during operation:

1. checking for refrigerant leaks;
2. if a leak is detected above a first safety threshold, then the compressors, fans and pumps are disabled; the pressurising fans in the electrical control panel are operated at maximum speed; at the same time, a signal is generated to force ventilation in the machine room (if available) to reach its top speed;
3. if a leak is detected above the next safety threshold, a high severity alarm is operated and the leak risk is notified to the personnel in charge; special procedures are implemented to ensure on-site safety.

To ensure the correct visual and/or acoustic operation of the alarms even if the machine is shut down, an external or battery-operated power supply to the unit is provided; in this way the alarm signal remains active until an operator arrives.

Marking

For refrigeration systems that use A2L type refrigerants, the flammability pictogram is also indicated in the identification plate according to EN ISO 7010-W021 (minimum height 30 mm).

3 INSTALLATION ENVIRONMENT SAFETY DEVICES

Units in refrigeration systems that use A2L refrigerants must meet certain safety requirements due to the flammability of working fluids. The UNI EN 378 standard specifies the safety and environmental characteristics to be considered in the design, production, construction, installation, operation, maintenance, repair, dismantling and disposal of refrigeration systems and related equipment.
In this regard, part 1 of the standard provides a method for calculating the refrigerant charge limit according to refrigerating unit capacity, determined on the basis of:

- **the type of refrigerant:** A1, A2L, A2, A3, B1, B2, B2L, B3;
- **the appliance location:** in the occupied space (*Class I*), in the occupied space but with compressors in the machine room or in an open space (*Class II*), in the machine room or in an open space (*Class III*), or in a ventilated enclosure (*Class IV*);
- **the category of access mode to the room:** general unrestricted access (*Category a*), supervised access (*Category b*), authorised access (*Category c*);
- **the characteristics of the room:** dimensions, location (below ground basement, upper floors without emergency exits, other);
- **the use of the application:** human comfort, less than one person per 10 m^2, other applications;
- **the appliance type of installation:** floor mounted, wall mounted, or ceiling mounted.

This set of conditions identifies a limit quantity of refrigerant per unit, beyond which it is not possible to install the unit in safe conditions for the environment and for people (Figure 5).

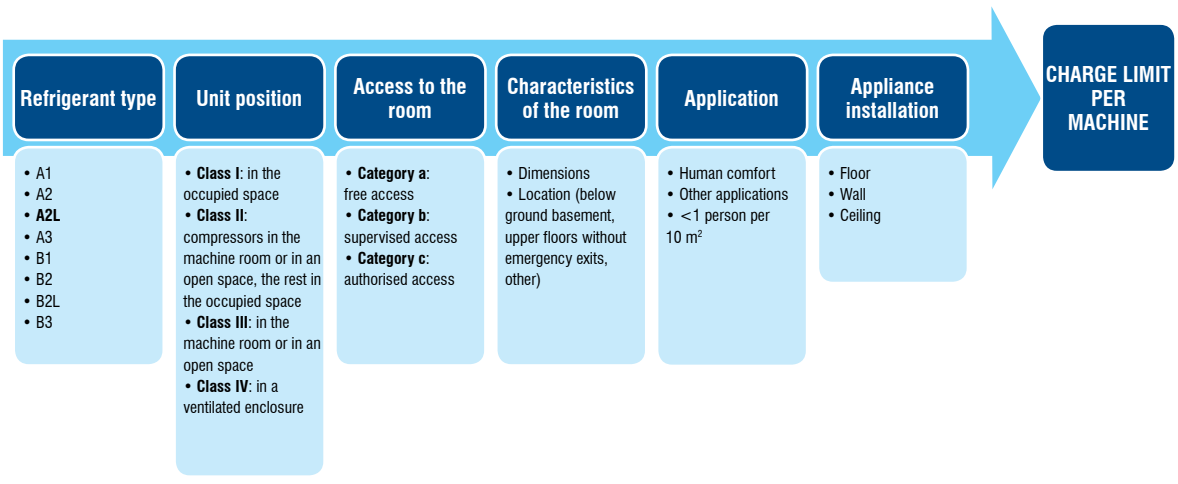


Figure 5 - Flow chart for calculating the charge limit

The unit installation environment plays a critical role in the calculation of the refrigerant charge limit. The applicable standard defines four location classes:

- *Class I*: systems installed in the occupied space;
- *Class II*: systems installed in the occupied space but with compressors in the machine room or in an open space;
- *Class III*: systems installed in the machine room or in an open space;
- *Class IV*: systems installed in a ventilated enclosure.

Installation in machine rooms or in open spaces does not imply any restriction for the amount of refrigerant contained in the units, provided that the requirements defined in part 3 of the same standard are met.

Open space

Refrigeration systems installed in open spaces must be positioned in such a way as to prevent refrigerant leakage into the building or creating temporarily flammable areas.
A room where at least one of the longer walls consists of a grid facing towards the outside with a free area portion equal to 75% and occupying at least 80% of the surface area of the wall in which it is positioned (or where there aren't one or more walls - ensuring direct communication of the installation room with the outdoor space) is considered an open space.

Machine room

When A2L refrigerants are used, in addition to the standard requirements that machine rooms must meet, other features must be considered to guarantee safety in the event of refrigerant leaks:

- installing a leak detector to monitor the presence of flammable gas. In the event that concentration exceeds 25% of the refrigerant LFL, an alarm must be activated together with mechanical emergency ventilation and system shutdown;
- installing an emergency ventilation system that is activated in case of leak detection inside the room; the extractor fan must comply with the requirements for installation in areas at risk of fire;
- avoiding any contact between the refrigerant and surfaces that exceed 80% of its auto-ignition temperature;
- providing escape routes if the amount of refrigerant exceeds the room volume by the practical limit[4] of the refrigerant.

[4] Practical limit: it represents the highest level of concentration in a space occupied which does not give rise to any acute damage.

Support tool provided by HiRef

In order to meet the new limits required by the applicable standard, HiRef has created a support tool for calculating the maximum permitted charge per unit. As seen above, the method uses different parameters to determine the limit value: the type of refrigerant, the unit installation position, access to the machine room, its characteristics, and the unit application and installation. The purpose of the created tool is to collect all this information in a single file, in order to quickly and easily obtain an indication of the maximum permissible charge for each combination of the various parameters.

The created tool allows an option to be selected for each category, according to the provisions contained in the standard; on completing each field, limit values are given for the charge in terms of toxicity and flammability, as well as the applicable charge limit value determined as the lowest between the two calculated values (Figure 6).

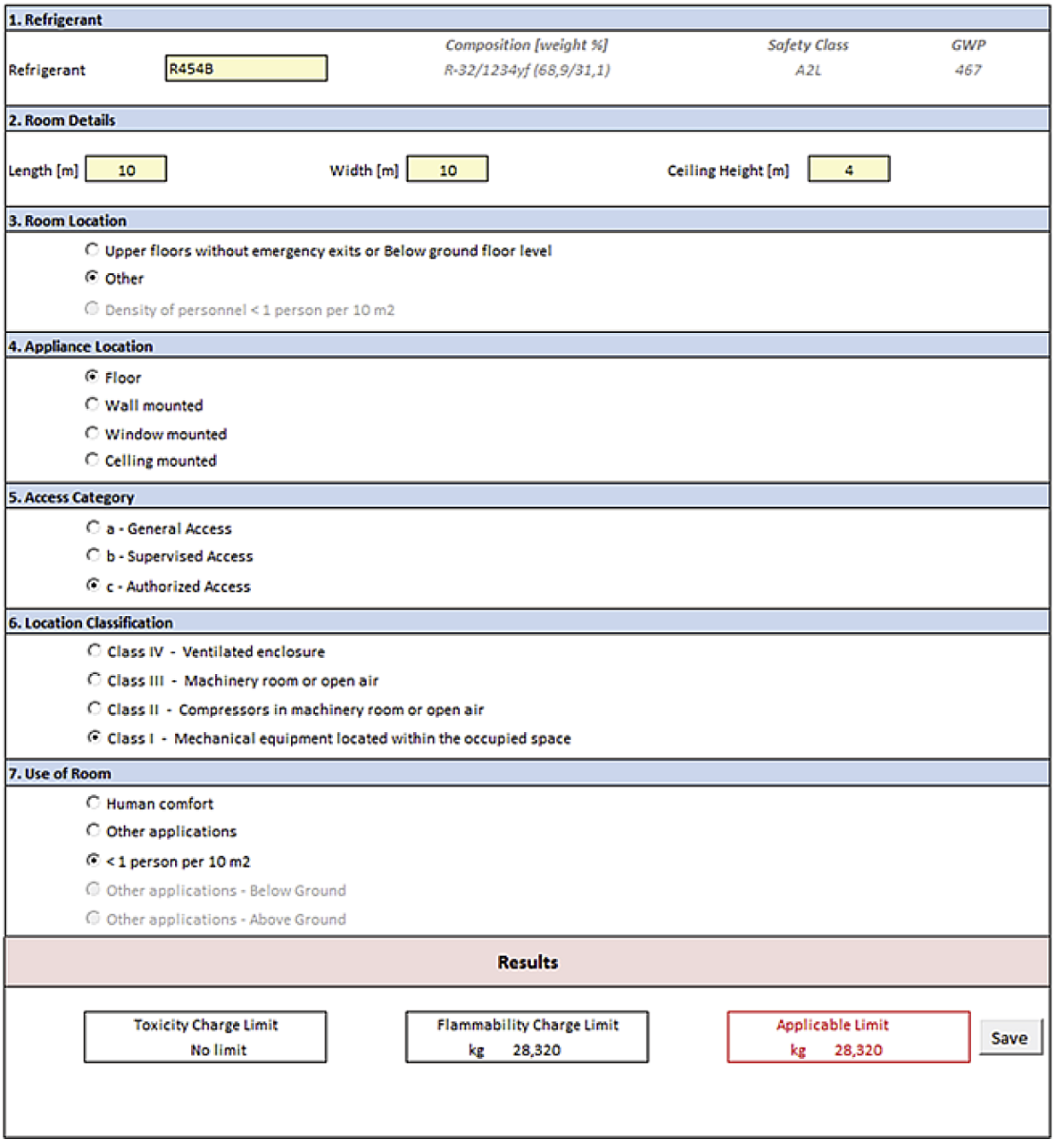
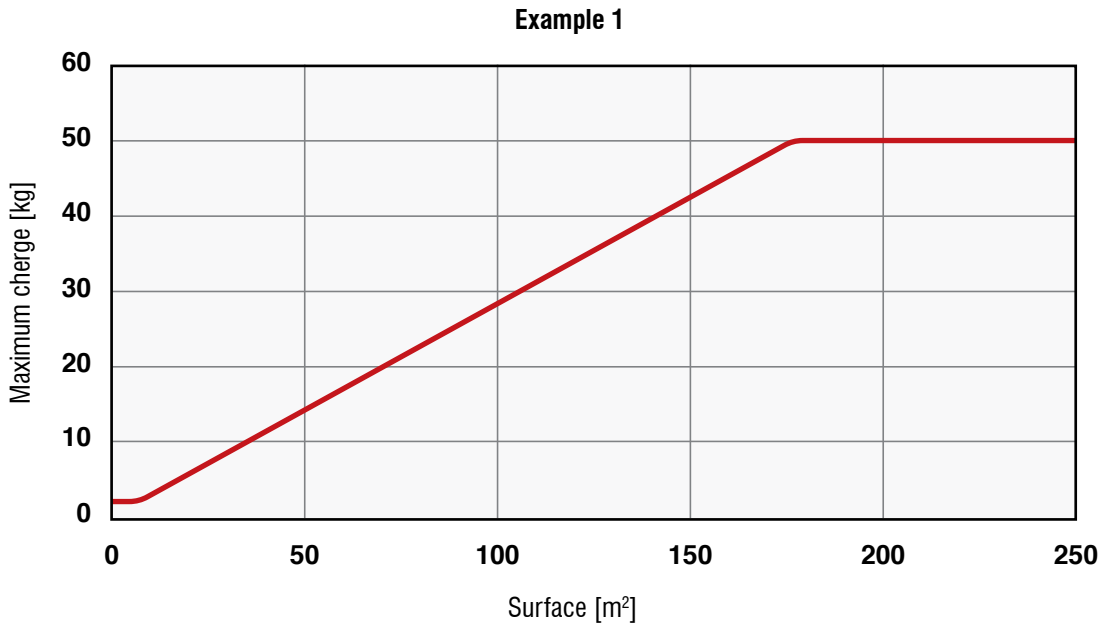


Figure 6 - HiRef tool for calculating the charge limit according to EN 378

The unit location classification defined by the regulations shows a substantial difference regarding charge limits depending on whether the unit has compressors on board the machine or outside the room to be cooled. Moreover, Class I machine conditions being the same, dependency exists, to a degree and below a given threshold, between the maximum permissible charge and the surface area of the room.
The following tables show some practical examples, the results have been obtained with the support tool developed by HiRef.

Example 1	
Environment	Datacenter
Unit	Close Control with on-board compressors
Refrigerant	R454B
Installation location	in the occupied space (Class I)
Access	authorised access (Category c)
Dimensions	10 m x 10 m (height 4 m)
Application	less than one person per 10 m^2
Appliance installation	Floor
Maximum permissible charge	28 kg



Maximum permissible charge dependency with plan surface area for the specified conditions

Table 3 - Example 1: Datacenter with Close Control unit with on-board compressors

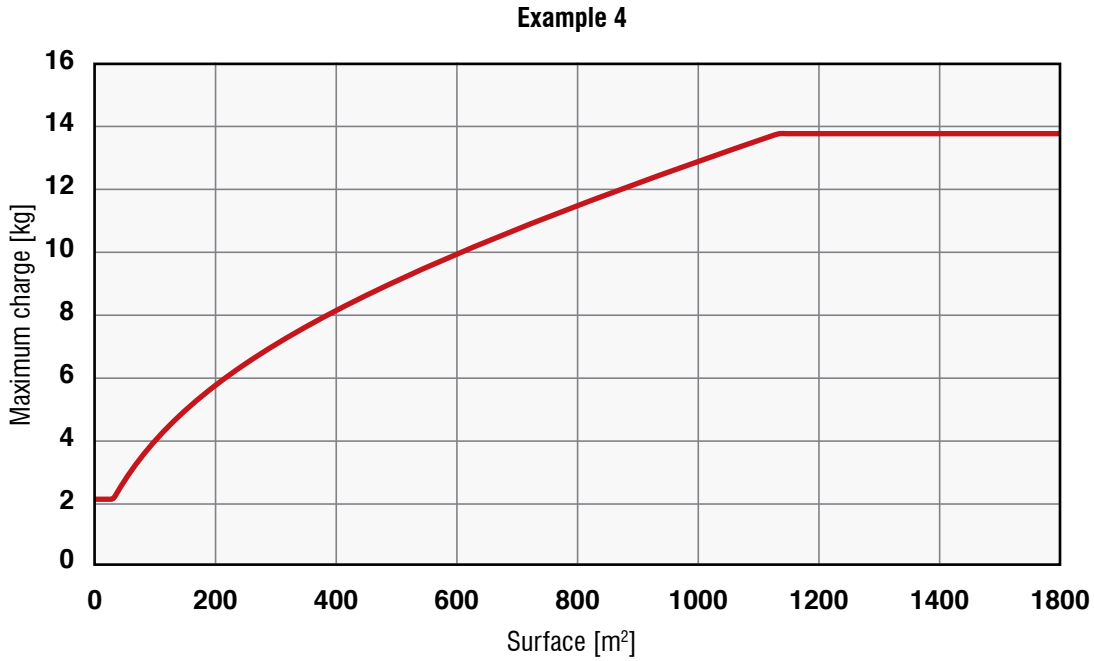
Example 2	
Environment	Datacenter
Unit	Close Control with compressors in machine room
Refrigerant	R454B
Installation location	in the occupied space but with compressors in the machine room or in an open space (Class II)
Access	authorised access (Category c)
Dimensions	10 m x 10 m (height 4 m)
Application	less than one person per 10 m^2
Appliance installation	Floor
Maximum permissible charge	NO LIMIT
No dependency with plan surface area for the specified conditions	

Table 4 - Example 2: Datacenter with Close Control unit with compressors in machine room

Example 3	
Environment	Hotel
Unit	Air/Water Unit
Refrigerant	R454B
Installation location	Open space (Class III)
Access	authorised access (Category c)
Dimensions	5 m x 4 m (height 3 m)
Application	Human Comfort
Appliance installation	Floor
Maximum permissible charge	NO LIMIT
No dependency with plan surface area for the specified conditions	

Table 5 - Example 3: Hotel with air/water unit installed outdoors

Example 4		
Environment	Home	
Unit	Indoor unit (such as a split unit with internal compressors or Water/Water monobloc)	
Refrigerant	R454B	
Installation location	in the occupied space (Class I)	
Access	authorised access (Category c)	
Dimensions	5 m x 4 m (height 2 m)	
Application	Human Comfort	
Appliance installation	Floor	
Maximum permissible charge	2 kg	



Maximum permissible charge dependency with plan surface area for the specified conditions

Table 6 - Example 4: Home with indoor unit installed in the garage

4 PRODUCTION AREAS SAFETY DEVICES

Leak detection test

This type of test is carried out to highlight the presence of leaks in the unit; it is performed in the factory or, in the event of on-site assembling or charging, at the installation venue.

For systems containing less than 5 kg of refrigerant, no leakage must be detected:

a) for factory-made joints:

- joints in sealed systems must be tested at a pressure of at least 0.25 x PS by means of a detection device with a capacity of 3 g/year of refrigerant or higher;
- joints in other systems must be tested at a pressure of at least 0.25 x PS by means of a detection device with a capacity of 5 g/year or higher;

b) for joints made at the installation site:

- joints must be tested with a device with a capacity of 5 g/year or higher, with the equipment switched off and in operation or with pressures that meet both conditions..

The leak detection method must take into account both the appliance response over time and the maximum distance between the leak and the equipment used to detect it.

Each detected leak must be repaired and then the test must be repeated.

For systems with a capacity of more than 5 kg, the leak test should not be performed using refrigerant as test fluid.

All components containing refrigerant must be tested by the manufacturer at a pressure not lower than the PS for which they were calibrated.

For refrigerants with GWP $\geq$ 150 the accepted condition is that no leakage is detected using a detection device with a capacity of 10-6 m3/s or higher.

For refrigerants with GWP $<$ 150 the accepted condition is that no leakage is detected using a detection device with a capacity of 10-3 m3/s or higher.

For refrigerants with GWP $<$150 alternative test methods can be used listed in EN 1779 [4].

Each detected leak at these sensitivity levels must be repaired and then the test must be repeated.

Safety and testing by HiRef

HiRef complies with the regulations in force applicable to A2L. To charge and test the units with this type of flammable refrigerants, a dedicated area has been set aside, downgraded for this purpose. It is a room with dimensions 15 m x 9 m and a height of 6 m, equipped with suitable devices for A2L in which to charge, test and performance-trial the machines. The room also has sensors for detecting potentially dangerous concentrations and related alarms to alert the staff instantly in case of detected faults. The safety system relies on emergency ventilation to keep the room under negative pressure conditions in case of leaks from the unit, to avoid the formation of flammable spots inside the room and to let out any dangerous mixtures.

5 TRANSPORT PROVISIONS

For transport purposes, A2L refrigerants are considered as flammable as any other flammable substance, without any distinction between light, medium or high flammability.
Transporting machinery or cylinders/bottles containing flammable refrigerant must be done in compliance with the provisions for transporting dangerous goods described in the standards:

- ADR, for road haulage;
- IMDG, for sea freight;;
- IATA, for air freight.

Road haulage of A2L cylinders
In regard to the transport of flammable refrigerants in cylinders, there are two different cases depending on the purpose of transport:

- if transport is done for inspection, maintenance, repair or servicing purposes up to the intended limit of 333 L, then no ADR requirements apply;
- if transport is done for sale purposes, “partially exempt transport” is allowed up to the limit of 333 kg, which requires:
  a) approved cylinders with special labelling;
  b) transport document (containing the information in section 14 of the safety data sheet, the number of cylinders, and the quantity in litres);
  c) the following requirements do not apply: driver’s license, safety instructions, orange panels, ADR safety bag;
  d) it is mandatory to have a 2 kg fire extinguisher and an explosion proof torch.

Gas transport separately from the machine
If the unit does not contain any refrigerant internally but refrigerant is transported separately in a cylinder packed, for example, in the crate that contains the unit, then the refrigerating machine is not required to comply with the provisions for the transport of dangerous goods, while the gas cylinder is subject to the requirements of ADR, IMDG and IATA.

Transporting machines containing A2L
According to the classification of refrigerating machines provided by the applicable standards, the units that contain A2L fall into the category “UN 3358: Refrigerating machines containing flammable and non-toxic liquefied gases” for which they must comply with the provisions applicable to this type of machine.
For UN 3358 machines, exemption from compliance with road and sea transport regulations is acceptable if they contain less than 12 kg or in the case of air freight up to 100 g.
If the amount transported in the machine exceeds 12 kg, transport requirements must be applied as shown in Table 4.

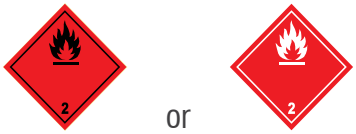
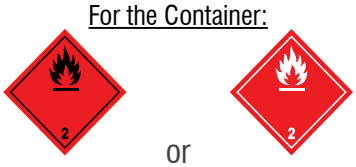
<table>
<tr><th colspan="3">Road haulage</th></tr>
<tr><th>Packing</th><th>Labelling</th><th>Documentation</th></tr>
<tr><td>The special packaging standard PP32 applies, according to which goods may be transported without packaging, in cages or with adequate overpacking</td><td> 
or
UN 3358</td><td>The transport document must list:
UN 3358, Refrigerating machines, 2, (D)
N. “x” packages
Mass expressed in kg, referred to the contained gas</td></tr>
<tr><th colspan="3">Sea transport</th></tr>
<tr><th>Packing</th><th>Labelling</th><th>Documentation</th></tr>
<tr><td>The special packaging standard PP32 applies, according to which goods may be transported without packaging, in cages or with adequate overpacking</td><td><u>For the Machine:</u>
 
or
UN 3358
REFRIGERATING MACHINES
<u>For the Container:</u>
 
or
UN 3358
ON THE 4 CONTAINER SIDES
(if over 4,000 kg)</td><td>The transport document must list:
UN 3358, Refrigerating machines, 2.2
N. “x” packages
Mass expressed in kg, referred to the contained gas</td></tr>
<tr><th colspan="3">Air freight</th></tr>
<tr><td colspan="3">Always prohibited</td></tr>
</table>

Table 7 - Provisions for the transport of machines containing flammable refrigerants in quantities above 12 kg

Special case: R1234ze

A special case concerns the R1234ze refrigerant: even if included in the category of A2L, the danger pictogram for flammability is not shown in its safety data sheet.

For safety data sheet purposes, a refrigerant is considered flammable when there is a concentration at room temperature such as to be flammable. The minimum flame temperature for R1234ze is 30 °C, therefore no pictogram is required (Figure 5).

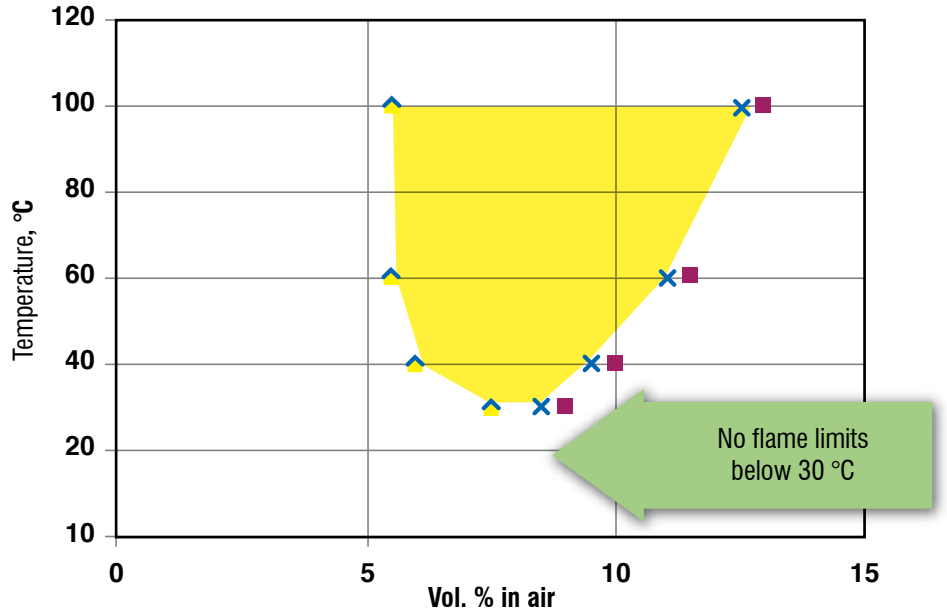


Figure 7 - Flame limit for R1234ze

For this reason, unlike what was previously indicated for A2L, this refrigerant is considered, as far as transport is concerned, a non-flammable gas. The machines containing R1234ze therefore fall into the same category as the A1 refrigerants used in “UN 2857: Refrigerating machines containing a non-flammable, non-toxic gas or ammonia solutions” and are treated as such.

6 USE AND MAINTENANCE INSTRUCTIONS

Continuous and efficient monitoring of leaks is required during operation of the refrigeration system. In the event that a dangerous situation is identified, appropriate systems must be activated to ensure the safety of the persons and of the room in which the unit is located.
Correct operation of all the detecting devices and their corresponding alarms must be checked, and any observed defect notified to the personnel in charge.

Repairing the refrigeration system (EN 378 - 4)
Before carrying out repairs on the refrigeration circuit, the following precautions must be taken:

- ensure that no flammable material is stored in the work area and that there is no possible source of ignition;
- check the availability of suitable fire-fighting equipment;
- ensure that the work area is properly ventilated before working on the refrigerant circuit;
- use leak detection devices suitable for use in hazardous areas;
- ensure that all maintenance personnel are properly trained.

The work area must be inspected with an appropriate refrigerant detector before and during maintenance to notify the technical staff of any air-borne flammable gas.
After any repair work, the efficient operation of safety devices such as refrigerant leak detectors and ventilation systems must be ensured.

Requirements for appointed personnel (EN 378 – 4)

Maintenance and repairs requiring the assistance of other qualified personnel must be carried out under the supervision of staff who must be experienced users of flammable refrigerants. Any person performing maintenance operations on a system or part thereof must be skilled according to EN 13313 [5].

Persons working on refrigerating systems with flammable refrigerants must have acquired the necessary skills in regard to safe use of flammable refrigerants through appropriate training. Such training must ensure that the following requirements are met:

- Familiarity with applicable legislative standards, provisions and regulations on flammable refrigerants;
- Ability to handle flammable refrigerants;
- In-depth knowledge of personal protective equipment, refrigerant leak prevention methods, cylinder handling,
- charging, leak detection, recovery and disposal.

7 REFERENCE STANDARDS

[1] ISO 817:2014 “Refrigerants - Designation and safety classification”

[2] EN 60079-10-1:2009 “Explosive atmospheres Part 10-1: Classification of areas – Explosive gas atmospheres”

[3] UNI EN 378:2017 “Refrigerating systems and heat pumps - Safety and environmental requirements”

- UNI EN 378-1 “Part 1: Basic requirements, definitions, classification and selection criteria”
- UNI EN 378-2 “Part 2: Design, construction, testing, marking and documentation”
- UNI EN 378-3 “Part 3: Installation site and personal protection”
- UNI EN 378-4 “Part 4: operation, maintenance, repair and recovery”

[4] EN 1779:2004 “Non-destructive testing – Leak testing – Criteria for method and technique selection”

[5] EN 13313:2011 “Refrigerating Systems And Heat Pumps - Competence Of Personnel”

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