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Study on the practical use of flammable and slightly flammable refrigerants

February 2022

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Study on the practical use of flammable and slightly flammable refrigerants

Final Report

February 2022

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INTRODUCTION

Regulatory requirements, in particular via EU Regulation 517/2014 on greenhouse gases (known as the F-Gas regulation), aim to progressively reduce the quantity of refrigerants that have an impact on the greenhouse effect. Under these conditions, the programmed reduction or prohibition of certain equipment and fluids, and the strengthening of leakage controls, encourage the replacement of these fluids by other "more neutral" fluids to the environment. However, some fluids with a low environmental impact do present other risks, such as flammability. The classification has been updated to include a new flammability subclass "2L" for flammable fluids that burn very slowly.

To integrate this new category, the NF EN 378 standard on safety and environmental requirements for refrigeration and environmental requirements for refrigeration systems and heat pumps has evolved. This evolution has made it possible to add the new flammability class "2L" and all the implications for design, load calculation and operation.

This study aims at characterizing these flammable fluids during the different phases of the life phases of an installation.

1. Flammable fluids : definition and characteristics

A refrigerant is a substance (or a mixture of substances) that ensures the transfer of energy in a thermodynamic system. According to the ISO 817 standard (2014), a refrigerant is classified based on 2 criteria: its toxicity (A or B) and its flammability (1 to 3).
The flammability of a fluid is defined by its capacity to propagate a flame from an ignition source.
Combustion is an exothermic chemical reaction between an oxidizer (air, oxygen) and a fuel. A body is said to be flammable when it burns with the production of flames.

Flammability Class	Lower flammability limit (kg/m³)	Combustion heat (MJ/kg)	Flame propagation speed (cm/s)	Associated risks
1 Non flammable	No flame propagation			
2L Slightly flammable	≥ 0,1 kg/m³	≤ 19 MJ/kg	≤ 10 cm/s	Thermal effect No overpressure effect
2 Flammable	≥ 0,1 kg/m³	≤ 19 MJ/kg	Limitless	Thermal effect Possible overpressure effect
3 Highly flammable	< 0,1 kg/m³	> 19 MJ/kg	-	Thermal and overpressure effect (explosion)

Figure 1: Characteristics related to the flammability of fluids

Some terms are defined in the following table.

Terminology	Definition
Lower flammability limit (LFL) (kg/m³)	It is the minimum concentration of refrigerant capable of propagating a flame in a homogenous mixture of refrigerant and air (can also be expressed as % volume in air)
Combustion heat (MJ/kg)	Amount of heat released by the combustion of a unit mass of fluid
Flame propagation speed (cm/s)	Speed at which the flame progresses in relation to the oxidizer (fresh air)
Ignition temperature (or flash point) (°C)	Temperature at which a fluid ignites in the presence of a flame
Minimum ignition energy (MJ)	Minimum energy required to ignite a flammable "air/gas" mixture. Any ignition source with an energy level below this value will not cause ignition
Auto-ignition point (°C)	Temperature at which a fluid ignites spontaneously without any heat input

Figure 2: Terminology

The three criteria: lower flammability limit, heat of combustion and burning rate, characterise the different classes of flammable fluids.

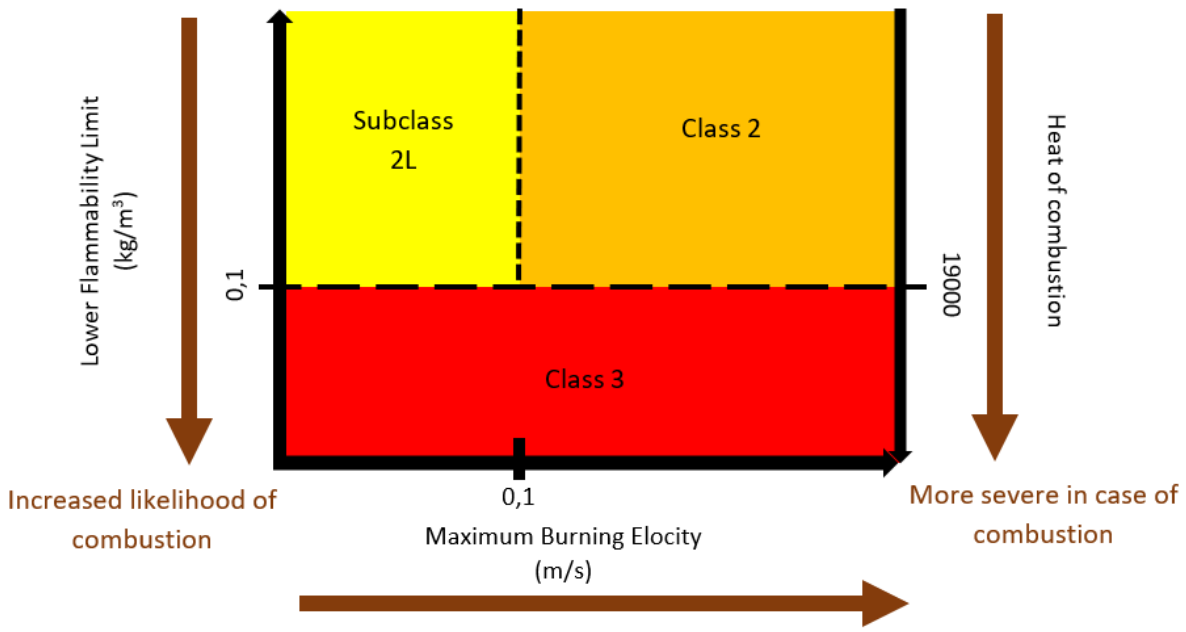


Figure 3: Risk level of flammable refrigerants

Some examples of fluids with their respective characteristics are presented below.

Refrigerant	Auto-ignition point (°C)	Flame propagation speed at 23°C dry air (cm/s)	Lower flammability limit at 23°C, 50%HR (kg/m³)	Combustion heat (MJ/kg)	Minimum ignition energy at 23°C, 50%HR (MJ)
R-32 (A2L)	648	6.7	0,307	9.4	30-100
R-452B (A2L)	-	4.2	0,309	-	100-300
R-454A (A2L)	-	2.4	0,278	10.04	300-1000
R-454B (A2L)	-	3.7	0,307	-	30-100
R-454C (A2L)	-	1.6	0,293	-	300-1000
R-1234yf (A2L)	405	1.5	0,289	10.7	5000 - 10000
R-1234ze (A2L)	368	1.2	0.303	-	61000 - 64000
R-455A (A2L)	473	< 1.5	0,431	10.2	317
R-152a (A2)	455	23	0.130	16.5	0.38
R-290 (A3)	470	46	0,038	50.3	0.25

Refrigerant	Auto-ignition point (°C)	Auto-ignition point on a hot surface (°C)	Maximum permissible surface temperature (°C)
R-32 (A2L)	648	> 800	700
R-452B (A2L)	-	> 800	700
R-454A (A2L)	-	> 800	700
R-454B (A2L)	-	> 800	700
R-454C (A2L)	-	> 800	700
R-1234yf (A2L)	405	> 800	700
R-1234ze (A2L)	368	> 800	700
R-455A (A2L)	473	-	-
R-152a (A2)	455	-	355
R-290 (A3)	470	-	370

Figure 4: Characteristics of some flammable fluids (according to NF EN 378, IEC 60335-2-40)

In case of a refrigerant leakage, two dangerous phenomena can occur: fire risk and explosion risk.

A fire is a chemical reaction resulting from the oxidation of a fuel by an oxidizer (combustion) which requires a source of energy to initiate this reaction. This phenomenon begins as a diffusion flame when a liquid or gaseous jet from an accidental leak ignites when in contact with an ignition source.

This risk can occur if 3 conditions are simultaneously met:

- The presence of a combustible, flammable material
- The presence of an oxidizer (oxygen)
- A source of ignition (source of energy necessary to start the combustion (flame, spark...)

This phenomenon is represented by the "fire triangle".

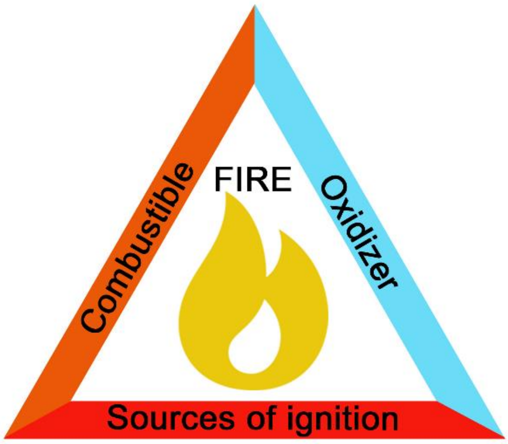


Figure 5: Fire triangle (according to INRS)

An **explosion** is an almost instantaneous combustion causing a deflagration (blast effect) accompanied by flames and heat. The flame can propagate at a speed of several m/s.

The explosion is the release into the atmosphere of a flammable product which, after having mixed with the oxygen in the ambient air to form a flammable mixture, encounters a source of ignition of sufficient energy. The source of ignition must have an energy ≥ the minimum ignition energy of the flammable mixture or the temperature must be > the self-ignition temperature of the fluid.

This dangerous phenomenon can occur in several places depending on the location of the leak point:

- In the jet itself: the refrigerant being in its pure state in the refrigeration system, will therefore have a concentration varying from 100% at the leak point to 0% in the far field. Between the two, there will be a zone where the concentration field will be in the explosive range.
- In the room: If the leakage occurs in a room and the room is not well ventilated, the refrigerant can accumulate in the room and form a flammable mixture again.

In addition to the 3 previously mentioned conditions necessary for a fire to start, 3 other conditions must be present to trigger an explosion:

- Presence of a fuel
- State of the fuel in suspension in the air in the form of gas/vapour, aerosol, dust
- Presence of an oxidizer (oxygen)
- Presence of an ignition source
- Concentration of the fuel in its flammable range (or explosiveness)
- Sufficient" containment (e.g., non-ventilated or poorly ventilated room).

The explosive range defined as the range of concentration of the fuel in air, within which the mixture is likely to explode when in the presence of an ignition source. This range lies between the lower explosive limit (LEL) and the upper explosive limit (UEL), also known as the flammability limits. Below the lower limit, the concentration of the fuel in the air is too low and above the upper limit, the concentration of fuel is too high resulting in insufficient air for combustion to take place.

The higher the LFL, the greater the amount of fluid required in the ambient air to initiate combustion: A2L fluids have a higher lower flammability limit than A3 fluids.

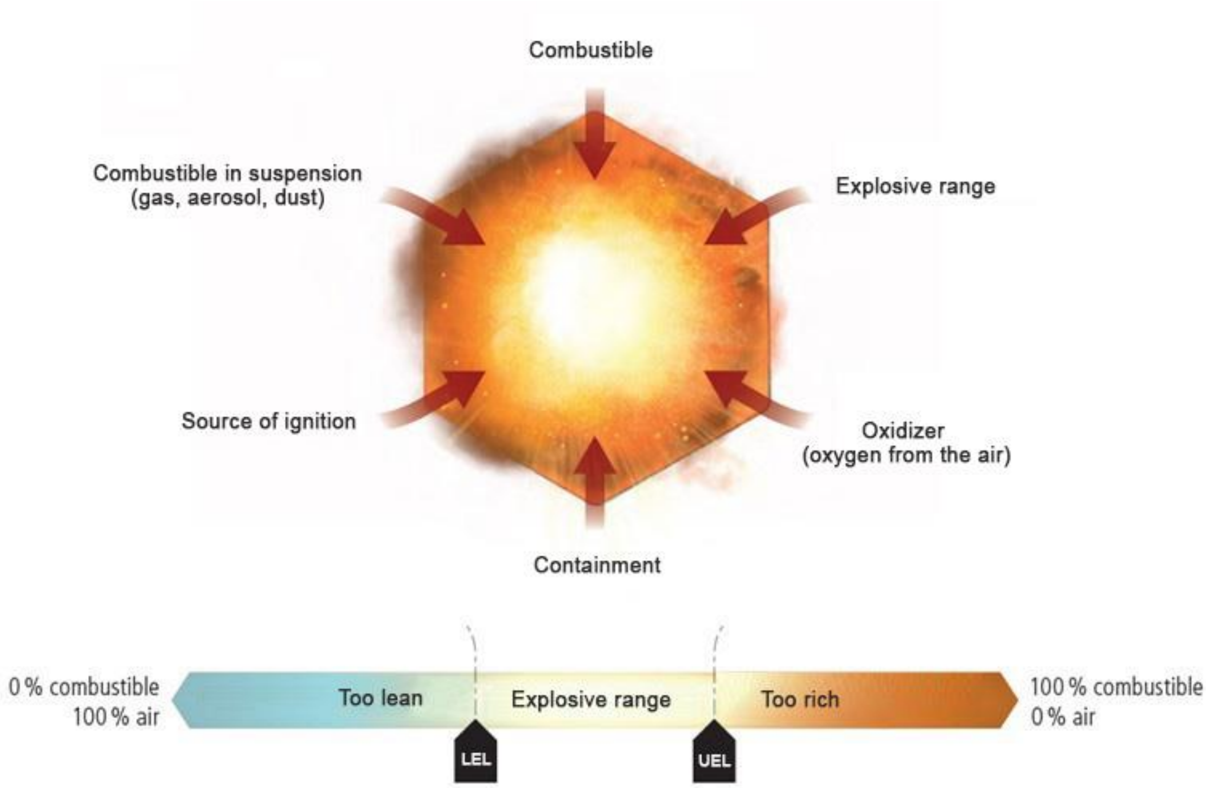


Figure 6: Hexagon of the explosion (according to INRS - ED6337)

In addition to these risks related to the flammability of the fluid, there is also **the risk of anoxia**. This risk exists for all fluids. It is due to a poor oxygen content within a confined space and particularly linked, to the replacement of oxygen by another gas during a leak in an installation.

2. Which fluids for which applications ?

Regardless of the nature of the fluid, the main flammable and slightly flammable fluids currently available on the market are classified hereunder.

Nature of the fluid	Flammability classes (GWP*)		
	A2L	A2	A3
Hydrocarbon fluids (not subject to F-Gas)			R-290 (GWP : 3/3) R-600 (GWP : 4/4) R-600a (GWP : 3/3) R-1270 (GWP : 2/2)
HFC (subject to F-Gas)	R-32 (GWP : 675/677) R-143a (GWP : 4470/4800)	R-152a (GWP : 124/138)	
HFO (not subject to F-Gas except for declaration)	R-1234yf (GWP : 4/<1) R-1234ze(E) (GWP : 7/<1)		
HFC-HFO blends (subject to F-Gas)	R-413A (GWP : 2053/1950) R-452B (GWP : 698/676) R-454A (GWP : 239/238) R-454B (GWP : 468/466) R-454C (GWP : 148/146) R-455A (GWP : 148/146) R-457A (GWP : 137/139) R-516A (GWP : 139/131)	R-465A (GWP : 144/143)	

*: the first value of GWP corresponds to that of the IPCC assessment report N°4 (AR4) which is the value taken into account in the F-GAS regulation N°517/2014 of April 16, 2014; the second value corresponds to that of the IPCC assessment report N°5 (AR5)

Figure 7: Main flammable fluids available

In addition to the fluids illustrated in the previous Table, we should note that R-717 (ammonia) is classified as a "toxic" (B) and "slightly flammable" (2L) fluid. This inorganic fluid has a zero GWP. Due to its toxic nature, this fluid is not addressed in this study.

Hydrocarbons despite having a low environmental impact are nevertheless characterised based on their high flammability.

HFO fluids (the latest generation of fluids) have a low environmental impact (close to natural fluids) and a "light" flammability.

The mixtures of "HFC and HFO" are intended to replace HFC fluids in the more or less long term, some of which have a significant environmental impact (GWP > 2500). HFC fluids classified as A2L are considered as medium-term solutions, especially for comfort air conditioning (GWP < 750).

Table 5 summarizes, for each sector and technical solution, the fluids that have been used for several years and the potential flammable refrigerants for the next few years. The list of these fluids is not exhaustive.

The flammable fluids mentioned in the table are generally dedicated to new equipment specially designed for an optimal operation with these fluids.

In the appendix, the thermodynamic characteristics of some fluids are defined.

Sector	Technical solution	Common fluids	Example of alternative flammable fluids on the market
Residential	Thermodynamic water heater	R-410A R-134a	R-290
	Air to air heat pump, air conditioning (split)	R-410A	R-32 R-290
	Air-water heat pump	R-410A	R-32 R-454C R-290
	Water-to-water heat pump	R-410A R-407C	R-32 R-290
	Heat pump + domestic hot water	R-410A	R-290
Tertiary and industry	air—to-air heat pump	R-410A	R-32
	VRF system, multi-split	R-410A R-407C	R-32 R-452B R-454B
	Roof top	R-410A	R-32
	Water chiller and heat pump (small and medium power) (spiral-orbital compressor)	R-410A	R-32 R-454C R-454B R-455A
	Water chiller and heat pump (high power - volumetric screw compressor)	R-410A R-407C R-134a	R-1234ze R-452B
	Water chiller and heat pump (high power - centrifugal compressor)	R-134a	R-1234ze
Food, commercial refrigeration	Condensing unit (positive cold)	R-410A R-134a R-404A	R-455A R-454A R-1234ze R-1234yf R-454C Hydrocarbons
	Condensation unit (negative cold)	R-410A R-404A R-744	R-455A R-454A R-454C
	Lodged groups	R-290	R-290

Figure 8: Current and potential fluid uses according to the field of application

3. Reconversion of an Installation with a flammable fluid

The objective of a reconversion operation is to keep the expensive elements of an installation (compressor for example) and proceed with the other changes of elements while maintaining satisfactory performances. The reconversion of an installation must therefore enable to prolong the life span of the installation by replacing its original fluid with a "more virtuous" but flammable fluid.

This operation only makes sense when the systems and powers involved are important and when these machines have a life span of several decades. The problem of reconversion does not really concern small air-conditioning installations intended for residential use. In fact, for those appliances, whose production is carried out in large series, it is generally more economical to change systems rather than to convert an existing installation.

The possibility of converting an installation arises for all fluids. It is, however, much more challenging with flammable fluids.

While the conversion of an existing installation with a slightly or highly flammable fluid is not encouraged, it is also not forbidden by regulation.

Considering the flammable nature of the fluid, a verification of compliance to safety-related directives and regulations (pressure equipment, machinery, etc.) must be carried out. In addition, the compatibility of the materials must be checked, and a risk analysis carried out.

4. The regulatory and normative context

4.1 Introduction

The regulatory and para-regulatory texts that are applicable to flammable fluids can be different and complementary depending on the type of building or the flammability class of the fluid.
The next table summarizes some essential texts according to the field of application and the type of building. These texts deal particularly with the specificities of design (calculation of fluid load, safety measures), installation and operation.
Depending on the fluids, other texts or standards are also to be considered, such as:

- The F-Gas regulation (European regulation N°517/2014 of April 16, 2014): tightness control for certain fluids (pure HFC or in mixture);
- The ATEX directives (directive 1999/92/EC of 16 December 1999 and directive 2014/34/EC of 26 February 2014) and the NF EN 60079-10-1 standard: characteristics of equipment according to the zone, determination of the extent of the leakage zone, protective devices for workers, equipment and protective systems intended for use in explosive atmospheres.
- The PED Directive (Directive 2014/68/EU of 15 May 2014), the Order of 20 November 2017, the Professional Technical Specification for the in-service monitoring of pressurized refrigeration systems of 23 July 2020: group of fluids and associated requirements, in-service monitoring.

All the afore-mentioned texts are further described in this chapter.

	Comfort application			Commercial and industrial refrigeration application		
	Residential	**Other buildings (tertiary-industrial)**	**HRB**	**Housed groups (plug in)**	**Furniture sales, storage**	**Others (cold rooms, industrial refrigeration systems...)**
Reference documents for implementation, load calculation, safety devices	NF EN 378	NF EN 378	Article GH37	Guide M (French ministry of interior)	NF EN 378	NF EN 378
Other possible documents	IEC 60335-2-40	IEC 60335-2-40 (according to the rated voltage)			IEC 60335-2-89	
Mandatory application of reference documents for implementation, load calculation, safety devices	No	No	Yes	Yes	No	No
Possible use of flammable fluids (A2L, A2, A3)	Yes	Yes	No	Oui sous conditions (cf. paragraphe 4.9)	Yes	Yes

4.2 The F-Gas regulation

The European Regulation N°517/2014 of April 16, 2014 on fluorinated greenhouse gases defines 3 main actions:

- The **prevention of fluid leaks with, in particular, a reinforcement of leakage controls**
- The timetable for **reducing the amount of greenhouse gases**
- **Progressive bans on marketing**

The fluids concerned by these requirements are hydrofluorocarbons. By definition, hydrofluorocarbons are HFC fluids and mixtures containing one of the following substances. The fluids concerned by these requirements are A2L fluids.

Fluids	
R-32 (HFC)	Subject to F-Gas
R-452B (HFC-HFO blend)	
R-454A (HFC-HFO blend)	
R-454B (HFC-HFO blend)	
R-454C (HFC-HFO blend)	
R-455A (HFC-HFO blend)	
R-1234ze(E) (HFO) R-1234zd(E) (HFO) R-1234yf (HFO) R-1233zd (HFO)	Not subject to F-Gas except for declaration
R-290 (hydrocarbon)	Not subject to F-Gas

Figure 9: Examples of fluids subject or not to F-Gas

Any person who installs, services, maintains, repairs or put into and out of service equipment must be certified for the fluids involved.

4.3 Machinery and Low Voltage Directives

The “new European normative approach” is based on the articulation, on one hand the regulation, which can take the form of Directives / European Regulations, and on the other hand, certain European standards (called harmonized standards) which support the regulation. **The Directives set the essential requirements to ensure the safety of a product with regard to its use and its environment…. The so-called harmonized standards describe the technical solutions to achieve the objectives of the Directive.**
Among the standards harmonized with these two directives is the standard NF EN 378“2 "Refrigerating systems and heat pumps - Safety and environmental requirements - Part 2: Design, construction, testing, marking and documentation".

The "Machinery" and "Low Voltage" Directives provide a framework for the design of equipment so that it does not present any electrical or mechanical safety risk.

The Low Voltage Directive applies to electrical equipment intended to be used at a nominal voltage ranging from 50 V to 1000 V in alternating current and from 75 V to 1500 V in direct current. This directive has been transposed into French law via Decree No. 2015-1083 of August 27, 2015.
The Machinery Directive applies to any equipment containing a moving part.

Depending on the field of application, equipment is subject to the BT Directive or the Machinery Directive. Compliance with requirements in terms of safety, environment allows the products to benefit from the CE marking.

Under these directives, **the manufacturer must provide an instruction manual, covering all phases of the product's life (assembly, commissioning, maintenance, use). For each phase, good practices and recommendations regarding risk prevention are indicated.**

The assembly of a system on site will be carried out by a professional according to the recommendations and technical documents of each element of the system (units, refrigeration links...). This assembly will be under the responsibility of the installer who will affix the CE mark.

The various components and installations dedicated to operate with flammable fluids are specifically designed for this application. Hence, the design is such that the electrical part is totally dissociated from the piping or from any element where there is a risk of leakage (safety valve for example). Also, the electrical box is designed to avoid any dangerous concentration of fluid in case of leakage.

4.4 Leak test for fluids not subject to F-Gas (hydrocarbons, HFO)

The Order of July 24, 2020 on the maintenance of **thermodynamic systems whose nominal power is between 4 kW and 70 KW included**, stipulates the obligation to ensure a maintenance of the systems with in particular the implementation of a **tightness control of the refrigerant circuit and this, for any refrigerant not concerned by the EU Regulation No. 517/2014 of 16 April 2014. This maintenance requirement therefore applies:**

- **To hydrocarbons: R-290, R-600a…**
- **HFO fluids: R-1234ze, R-1234yf...**

At the end of the service, the professional shall provide, for information purposes, advice on the system, its regulation but also on the refrigerant.
The first servicing of a thermodynamic system is carried out within two years after its installation or its replacement., For example, the first maintenance of the systems already established on July 1st, 2020 is carried out at the latest on July 1st, 2022. **The period between two leakage checks (two servicing) is ≤ 2 years and this, regardless of the fluid load in the system.**
Note that thermodynamic systems intended solely for the production of hot water for a single dwelling are not subject to these provisions.

The total quantity of flammable fluid "m_{max}" circulating in an installation is limited in order to avoid any fire risk in case of leakage. This quantity is determined according to the following formula, also defined in NF EN 378-1.

$$m_{max} = 2.5 \times LFL^{(5/4)} \times h_0 \times A^{(1/2)}$$

with:

LFL: lower flammability limit of the fluid (kg/m^3)

A: surface of the room (m^2)

h_0: coefficient related to the height of the lowest equipment in the room, whose value is equal to:

0.6 for floor mounting
1.1 for window mounting (1 according to NF EN 378-1)
1.8 for wall mounting
2.2 for ceiling mounting,

height of the lowest connection in the room if the latter is above 2.2 m.

No load restrictions are imposed in the following two cases:

- Presence of a **shut-off valve on the refrigerant circuit** and a **sensor-controlled ventilation system to maintain the refrigerant concentration in the room < lower flammability limit** of the fluid
- Installation of the system in a **machine room equipped** with:
  - A detection device (central detection unit and two sensors) triggering the mechanical air extraction and stopping the fluid circulation
  - A category 3 mechanical air extractor (according to Directive 2014/34/EU) ensuring, at extraction, a refrigerant **concentration < lower flammability limit of the fluid.**

The installation of the system is carried out according to the manufacturer's recommendations. **This installation will be subject to the preparation of a documentation, to be made available to the administrative authorities and any company working on the installation, which includes the following elements:**

- A plan of the pipe network
- A synoptic of the installation
- A detailed and justified calculation of the maximum quantity of refrigerant in the system
- An installation plan of the safety devices (detectors, solenoid valves, ventilation, etc.)
- Theoretical flow rates of the ventilations in case the maximum calculated quantity is exceeded
- Demonstration of the reliability and calibration of the detection device and the air renewal rate of the mechanical air extractor
- A correlation table of the different safety devices in case the maximum calculated quantity is exceeded

This document must be updated after each modification brought to the installation or the room. The installation must be checked annually, independently of the fluid load. In particular, the result of the search for leaks (direct or indirect) is indicated. Every year, at least 20% of the safety devices and controls must be checked so that all of them are checked over a period of 5 years.

4.5 The NF EN 378 "Refrigeration systems and heat pumps - Safety and environmental requirements"

4.5.1 Generalities

NF EN 318 is an environmental and safety standard. **It aims at reducing the possible dangers of refrigeration systems for people (installers, users, and technicians), goods and the environment.** It is divided into 4 parts:

- NF EN 378-1: Basic requirements, definitions, classification, and selection criteria
- NF EN 378-2 (harmonized with the Machinery, LV, and PED Directives): Design, construction, testing, marking and documentation
- NF EN 378-3: Installation in situ and protection of persons
- NF EN 378-4: Operation, maintenance, repair, and recovery

Note that this standard is not mandatory. However, it defines professional rules widely followed by the profession and required by the control offices.
This standard, version 2017, brings additional elements compared to the previous version, particularly concerning the addition of a new category of fluid (A2L) or the limits of fluid load.

In case of an incident, the quantity of fluid in a refrigeration system is decisive. For this reason, load restrictions are foreseen, depending on the combination of all the criteria mentioned in the following figure. The objective is to avoid an accumulation of concentration that could lead to fire and explosion risks.

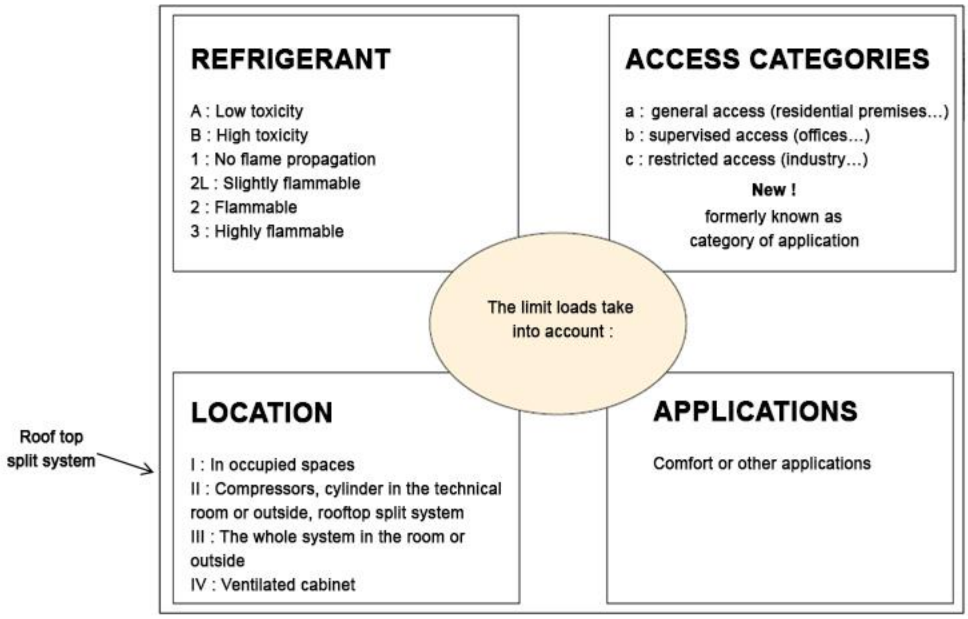


Figure 10: Boundary load stresses

The limit load to be considered depends on the toxicity and flammability characteristics of the fluid according to the following schema.

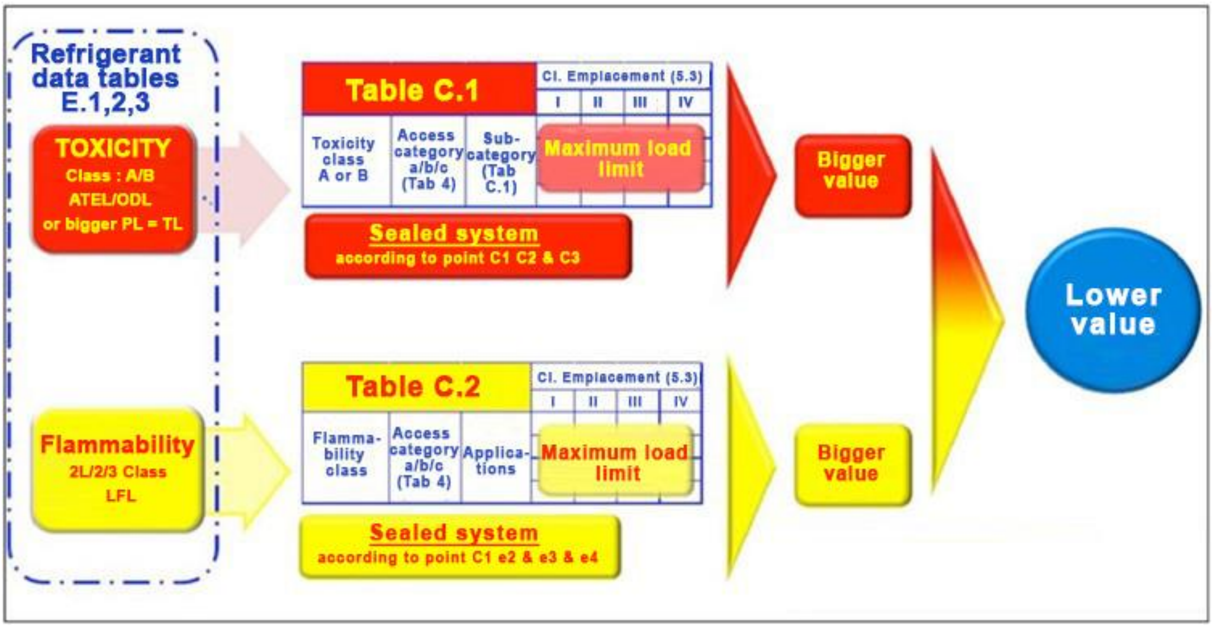


Figure 11: Flowchart to determine the fluid limit load (according to NF EN 378-1)

4.5.2 Determination of refrigerant limit loads

For flammable fluids A2L, A2 and A3, **the limit load is determined by its flammability** (not its toxicity).

There is no load restriction for refrigeration systems located in class III (machine room or open air) with a fluid classified 2L or 2.
For example, an HFO 1234ze chiller installed in a terrace (free air) and supplying an office building is not subject to any fluid load limit.

However, a refrigeration system supplied with "2L" or "2" fluid and installed in class II (compressor outside and other elements in occupied space) (split, roof top for example) **will be subject to a load limit.**

The access categories, divided into three groups, are characterized as follows:

Access Category	Description	Examples
General access "a"	Buildings, parts of buildings with uncontrolled number of people. Free access to all persons not necessarily having a knowledge of the safety measures. Places receiving the public	Dwellings Educational institutions Supermarkets, sales areas Theaters, meeting rooms Hotels Restaurants
Supervised access "b"	Buildings or parts of buildings with a limited number of people who can gather and some of whom are aware of the safety provisions	Professional premises (offices) "General" laboratory Cold room (if occupied for a significant period)
Restricted access "c"	Buildings, parts of buildings where access is limited only to authorized persons who know the security provisions	Supermarket areas not accessible to the public Food and pharmaceutical manufacturing premises, Cold stores, Machine rooms (occupied for extended periods for maintenance)

The next table summarizes the configurations.

Fluid	Access category	Restriction on fluid mass by system location		
		I (system in occupied space)	II (compressor outside or in a technical room)	III (complete system outside or in a technical room)
A2L	General access	Yes	Yes	No
	Supervised access			
	Restricted access		Yes unless low density for "other application" (< 1 person per 10 m²)	
A2	General access	Yes	Yes	No
	Supervised access			
	Restricted access			
A3	General access	Yes	Yes	Yes (5 kg max) (comfort application)
	Supervised access			Yes (10 kg max) (comfort application)
	Restricted access			No (comfort application)

Figure 12: Summary of configurations

For a **comfort application**, the 3 requirements for the **limit load calculation** are as follows:

- the **LFL (Lower Flammability Limit) of the fluid**
- the **surface of the room (A in m²)**
- the **installation height of the device** defined by a height coefficient "h_0":
  - h_0: 0,6 (for floor mounting)
  - h_0: 1 (for window mounting)
  - h_0:1.8 (for wall mounting)
  - h_0:2.2 (for ceiling mounting)

For A2L fluids (location class I and II) with quantity ≤ "1.5 x 4 x LFL", there are no special requirements regarding the room surface or the location of the indoor unit. The maximum fluid load to be considered without special requirements is hereafter recalled for some fluids.

Maximum fluid load without requirement (=1,5 x 4 x LFL) (kg)				
R-32 (LFL : 0.307 kg/m³)	R-452B (LFL : 0.309 kg/m³)	R-1234yf (LFL : 0.289 kg/m³)	R-1234ze(E) (LFL : 0.303 kg/m³)	R-455A (LFL : 0.431 kg/m³)
1.84	1.85	1.73	1.81	2.58

Figure 13: Maximum fluid load without specific requirements

Loading a refrigeration system with A2L fluid - comfort application - location I (occupied space) - access category: a, b, c

Refrigeration system with A2L fluid (comfort application) - location I (occupied space) - access categories: a, b, c		
General	**Examples**	**Requirements**
Load ≤ 1.5x4xLFL	Load R-32 ≤ 1.84 kg Load R-455A ≤ 2.58 kg	No specific requirements
1.5x4xLFL < load ≤ 1.5x26xLFL	1.84 < Load R-32 ≤ 11.9 kg 2.58 < Load R-455A ≤ 16.8 kg	Max. load according to (LFL, Surface of the space A and height of the equipment h_0) 2.5 x $LFL^{(5/4)}$ x h_0 x $A^{1/2}$ h_0 : 4 possible values only (0.6 ; 1 ; 1.8 ; 2.2)
Load > 1.5x26xLFL	Load R-32 > 11.9 kg Load R-455A > 16.8 kg	Not allowed

Loading a refrigeration system with A2L fluid - comfort application - location II - access category: a, b, c

For an A2L fluid - System II location, it is possible to exceed the maximum flammability load (formula related to LFL, A, h_0) provided that some conditions are met, among which

- a maximum load equal to "1.5 x 130 x LFL" (59 kg of R-32, 84 kg of R-455A)
- a location of the system in class II
- a system with a non-removable joint in the occupied space (except for joints directly connecting the indoor unit to the piping)
- protection of the interior parts containing refrigerant.

In this case, the following values (kg/m^3) are considered:
the limit concentration with minimum ventilation (LCMV) and the limit concentration with additional ventilation (LCAV).
The values "RCL", "LCMV" and "LCAV" are defined below.

Values	Characteristics
RCL (Refrigerant concentration limit) (kg/m^3)	Maximum fluid concentration in the air to reduce the risk of ignition
LCMV (limit concentration with minimum ventilation) (kg/m^3)	Loading density that would result in a concentration equal to RCL for moderately severe leakage
LCAV (limit concentration with additional ventilation) (kg/m^3)	Fluid load density that can lead to a hazardous situation

Refrigeration system with A2L fluid (comfort application) - location II (outdoor compressor) - access categories: a, b, c			
Determination of load calculation	**General**	**Examples**	**Requirements**
Load limit according to flammability (C2 of NF EN 378-1)	Load ≤ 1.5x4xLFL	Load R-32 ≤ 1.84 kg Load R-455A ≤ 2.58 kg	No specific requirements
	1.5x4xLFL < load ≤ 1.5x26xLFL	1.84 < Load R-32 ≤ 11.9 kg 2.58 < Load R-455A ≤ 16.8 kg	Load max according to (LFL, Surface of the space A and height of the equipment h_0) $2.5 \times LFL^{(5/4)} \times h_0 \times A^{1/2}$ h_0 : 4 possible values only (0.6 ; 1 ; 1.8 ; 2.2)
	Load > 1.5x26xLFL	Load R-32 > 11.9 kg Load R-455A > 16.8 kg	Not allowed
Other solution: load limit according to fluid limit quantity with ventilation (C3 of NF EN 378-1)	(Total load/room volume) ≤ LCMV et load≤1.5x130xLFL	(Load R-32/volume) ≤ 0.063 kg/m³ et load R-32 ≤ 59kg (Load R-455A/volume) ≤ 0.092 kg/m³ et load R-455A ≤ 84kg	No additional requirements
Any floor except the lowest floor in the basement	LCMV < (Total load/room volume) ≤ LCAV et load≤1.5x130xLFL	0.063 < Load R-32/volume ≤ 0.15 kg/m³ et load R-32 ≤ 59kg 0.092 < Load R-455A/volume ≤ 0.216 kg/m³ et load R-455A ≤ 84kg	At least 1 safety measure to be applied: Continuous or sensor-controlled ventilation, sensor-controlled isolation valves, sensor-controlled alarm (sensor action for level ≤ 25% LFL) (< LCMV)
	(Total load/room volume) > LCAV et Load≤1.5x130xLFL	(Load R-32/volume) > 0.15 kg/m³ et load R-32 ≤ 59kg (Load R-455A/volume) > 0.216 kg/m³ et load R-455A ≤ 84kg	At least 2 additional measures to be applied: Continuous or sensor-controlled ventilation, sensor-controlled isolation valves, sensor-controlled alarm (sensor action for level ≤ 25% LFL)
Alternative: load limit according to fluid limit quantity with ventilation (C3 of NF EN 378-1):	(Total load/room volume) ≤ RCL et load≤1.5x130xLFL	(Load R-32/volume) ≤ 0.061 kg/m³ and load R-32 ≤ 59kg (Load R-455A/volume) ≤ 0.086 kg/m³ and load R-455A ≤ 84kg	No additional requirements
Occupation of the lowest floor in the basement	RCL < (Total load/room volume) ≤ LCMV et load≤1.5x130xLFL	0.061 < Load R-32/volume ≤ 0.063 kg/m³ et load R-32 ≤ 59kg 0.086 < Load R-455A/volume ≤ 0.092 kg/m³ et load R-455A ≤ 84kg	At least 1 additional measure to be applied: Ventilation isolation valves, alarm, detector (concentration < RCL)
	LCMV < (Total load/room volume) ≤ LCAV et load≤1.5x130xLFL	0.063 < Load R-32/volume ≤ 0.15 kg/m³ et load R-32 ≤ 59kg 0.092 < Load R-455A/volume ≤ 0.216 kg/m³	At least 2 additional measures to be applied: Ventilation, isolation valves, alarm, detector

		et load R-455A ≤ 84kg	
Load limit	Load > 1.5x130xLFL	Load R-32 > 59 kg Load R-455A > 84 kg	Not allowed

Example:
Let's say a mono split unit serving **a hotel room of area "A": 30 m²**. Considering the criteria "LFL" and "A", along with the available heights, the maximum authorized load, for some fluids, is calculated according to the formula 2.5 x $LFL^{(5/4)}$ x h_0 x $A^{1/2}$:

	Maximum fluid load according to the installation of the unit (surface area of chamber A: 30 m²)	
Split installation height	**R-32 (A2L)**	**R-455A (A2L)**
Ground (h_0 : 0,6)	1.8	2.9
Window (h_0 : 1)	3.1	4.8
Wall (h_0 : 1,8)	5.6	8.6
Ceiling (h_0 : 2,2)	6.8	10.5

Figure 14: Example of load limit for a split serving one room

The higher the unit is placed, the greater the maximum possible load (and hence the power output). Also, the larger the surface area of the room, the greater the maximum fluid load. In all cases, the maximum load that can be installed under these conditions is equal to "1.5 x 26 x LFL": 11.9 kg (R-32) and 16.8kg (R-455A).

Considering the criteria "local volume" and "ventilation", **the limit load for an R-32 appliance in the hotel room of volume 90 m³** (surface of 30 m²) would be equal to 5,6 kg.
Safety conditions would be required for an R-32 fluid load:

5.6 < fluid load ≤ 13.5 kg (1 safety measure)

13< Fluid load > 13.5 kg (et ≤ 59 kg) (2 safety measures).

The greater the volume of the room, the greater the dilution phenomenon of a possible fluid leak and therefore the greater the possible load.

Loading a refrigeration system with A2L fluid - other applications - location I (occupied space) - access category: a, b, c

Refrigeration system with A2L fluid (other applications) - location I (occupied space) - access categories: a, b, c		
General	**Examples**	**Requirements**
Load ≤ 20% LFL x room volume et ≤ 1.5x26xLFL	R-32 load ≤ 0.061 x Room volume and ≤ 11.9 kg R-455A load ≤ 0.086 x Room volume and ≤ 16.8 kg	No specific requirements
For applications with low population density (< 1pers/10 m²) Load ≤ 20% LFL x room volume et ≤ 50 kg	R-32 load ≤ 0.061 x Room volume and ≤ 50 kg R-455A load ≤ 0.086 x Room volume and ≤ 50 kg	No specific requirements

Loading a refrigeration system with A2L fluid - other applications - location II - access category: a

Refrigeration system with A2L fluid (other applications) - location II (outdoor compressor) - access categories: a (general access)			
Determination of load calculation	**General**	**Examples**	**Requirements**
Load limit according to flammability	Load ≤ 20% LFL x room volume et ≤ 1.5x26xLFL	R-32 load ≤ 0.061 x Room volume et ≤ 11.9 kg Load R-455A ≤ 0.086 x Room volume et ≤ 16.8 kg	No additional requirements
Other solution: load limit according to fluid limit quantity with ventilation (C3 of NF EN 378-1) Any floor except the lowest floor in the basement	(Total load/room volume) ≤ LCMV et ≤ 1.5x130xLFL	(R-32 load/volume) ≤ 0.063 kg/m^3 et R-32 load ≤ 59kg (R-455A load/volume) ≤ 0.092 kg/m^3 et R-455A load ≤ 84kg	No additional requirements
	LCMV < (Total load/room volume) ≤ LCAV et load≤1.5x130xLFL	0.063 < R-32/volume load ≤ 0.15 kg/m^3 et R-32 load ≤ 59kg 0.092 < R-455A load/volume ≤ 0.216 kg/m^3 et R-455A load ≤ 84kg	At least 1 additional safety measure to be applied: Continuous or sensor controlled ventilation, sensor controlled isolation valves, sensor controlled alarm (sensor action for level ≤ 25% LFL) (concentration < LCMV)
	(Total load/room volume) > LCAV et Load≤1.5x130xLFL	(R-32 load/volume) > 0.15 kg/m^3 et R-32 load ≤ 59kg (R-455A load/volume) > 0.216 kg/m^3 et R-455A load ≤ 84kg	At least 2 additional measures to be applied: Continuous or sensor-controlled ventilation, sensor-controlled isolation valves, sensor-controlled alarm (sensor action for level ≤ 25% LFL)
Alternative: load limit according to fluid limit quantity with ventilation (C3 of NF EN 378-1): Occupation of the lowest floor in the basement	(Total load/room volume) ≤ RCL Et load≤1.5x130xLFL	(R-32/volume load) ≤ 0.061 kg/m^3 and R-32 load ≤ 59kg (R-455A load/volume) ≤ 0.086 kg/m^3 and R-455A load ≤ 84kg	No additional requirements
	RCL < (Total load/room volume) ≤ LCMV Et load≤1.5x130xLFL	0.061 < R-32/volume load ≤ 0.063 kg/m3 et R-32 load ≤ 59kg 0.086 < R-455A load/volume ≤ 0.092 kg/m3 et R-455A load ≤ 84kg	At least 1 additional measure to be applied: Ventilation isolation valves, alarm, detector (concentration < RCL)
	LCMV < (Total load/room volume) ≤ LCAV Et load≤1.5x130xLFL	0.063 < R-32/volume load ≤ 0.15 kg/m3 et R-32 load ≤ 59kg 0.092 < R-455A load/volume ≤ 0.216 kg/m3 et R-455A load ≤ 84kg	At least 2 additional measures to be applied: Ventilation, isolation valves, alarm, detector

Loading a refrigeration system with A2L fluid - other applications - location II - access category: b, c

Refrigeration system with A2L fluid (other applications) - location II (outdoor compressor) - access categories: b, c (supervised access, restricted access)			
Determination of load calculation	**General**	**Examples**	**Requirements**
Load limit according to flammability	Load ≤ 20% LFL x room volume et ≤ 25 kg (for any A2L fluid)	R-32 load ≤ 0.061 x Room volume et ≤ 25 kg R-455A load ≤ 0.086 x Room volume et ≤ 25 kg	No additional requirements
Other solution: load limit according to fluid limit quantity with ventilation (C3 of NF EN 378-1) Any floor except the lowest floor in the basement	(Total load/room volume) ≤ LCMV et ≤ 1.5x130xLFL	(R-32 load/volume) ≤ 0.063 kg/m3 et R-32 load ≤ 59kg (R-455A load/volume) ≤ 0.092 kg/m3 et R-455A load ≤ 84kg	No additional requirements
	LCMV < (Total load/room volume) ≤ LCAV et load≤1.5x130xLFL	0.063 < R-32/volume load ≤ 0.15 kg/m3 et R-32 load ≤ 59kg 0.092 < R-455A load/volume ≤ 0.216 kg/m3 et R-455A load ≤ 84kg	At least 1 additional safety measure to be applied: Continuous or sensor-controlled ventilation, sensor-controlled isolation valves, sensor-controlled alarm (sensor action for level ≤ 25% LFL)
	(Total load/room volume) > LCAV et Load≤1.5x130xLFL	(R-32 load/volume) > 0.15 kg/m3 et R-32 load ≤ 59kg (R-455A/volume load) > 0.216 kg/m3 et R-455A load ≤ 84kg	At least 2 additional measures to be applied: Continuous or sensor-controlled ventilation, sensor-controlled isolation valves, sensor-controlled alarm (sensor action for level ≤ 25% LFL)
Autre solution : limite de charge selon quantité limite de fluide avec ventilation (C3 de la NF EN 378-1) : Occupation de l'étage le plus bas en sous-sol	(Total load/room volume) ≤ RCL Et load≤1.5x130xLFL	(R-32/volume load) ≤ 0.061 kg/m3 and R-32 load ≤ 59kg (R-455A load/volume) ≤ 0.086 kg/m3 and R-455A load ≤ 84kg	No additional requirements
	RCL < (Total load/room volume) ≤ LCMV Et load≤1.5x130xLFL	0.061 < R-32/volume load ≤ 0.063 kg/m3 et R-32 load ≤ 59kg 0.086 < R-455A load/volume ≤ 0.092 kg/m3 et load R-455A ≤ 84kg	At least 1 additional measure to be applied: Ventilation, isolation valves, alarm, detector
	LCMV < (Total load/room volume) ≤ LCAV Et load≤1.5x130xLFL	0.063 < R-32 Load/volume ≤ 0.15 kg/m³ Et R-32 load ≤ 59kg 0.092 < R-455A load/volume ≤ 0.216 kg/m³ et R-455A load ≤ 84kg	At least 2 additional measures to be applied: Ventilation, isolation valves, alarm, detector

Example:
Consider a condensing unit connected to the evaporator of a cold room with a volume of 150 m3 (location II, access category: b). The limit load to be considered according to the flammability criterion is equal to:

12.9 kg of fluid R-455A
8.5 kg of fluid R-454C
9 kg of R-1234ze

In a restricted area ("c" access) and for an application other than comfort, there is no load restriction when the refrigeration system is in location II and the density of people in the room is low (< 1 person/10m²).

Whatever the safety measure adopted**, the fluid detector must allow, for a value ≤ 25% LFL, to activate either an alarm, a mechanical ventilation system or the circuit isolation valves.**
Also, to ensure the dilution of the fluid in case of leakage at the level of the indoor unit installed at a height < 1.8m in an "occupied space", it is necessary to provide a fan, circulator or other system operating continuously or controlled by a detector.

Loading a refrigeration system with A2L or A2 fluid - comfort and other applications - location III - access category: b, c

Refrigeration system with A2L or A2 fluid - "comfort" and "other applications" access categories: a, b, c	
Location III: Engine room	**Location III: open air**
No load restrictions	No load restrictions
If the fluid load > practical limit, it is necessary to have a door to the outside (or in a specific room with an automatically closing watertight door)	Preventive measures to prevent any fluid leakage from entering or stagnating in the building
Maximum hot surface temperature ≤ Auto-ignition temperature - 100 [K]	If there is a problem of fluid stagnation below ground level, have a fluid detection system, alarm, ventilation
	Ensure that no ignition sources are present in the area where the fluid may accumulate

Refrigeration system load in A2 fluid - comfort application - location I and II - access category: a, b, c

Refrigeration system with A2 fluid - "comfort" application - locations I and II - access categories: a, b, c		
General	**Examples**	**Requirements**
Load ≤ 4x LFL	R-152a load ≤ 0.520 kg	No specific requirements
4 x LFL < load ≤ 26 x LFL	0.52 < R-152a load ≤ 3.38 kg	Max. load according to (LFL, local area A and device height h_0) 2.5 x $LFL^{(5/4)}$ x h_0 x $A^{1/2}$ h_0 : 4 possible values only (0.6 ; 1 ; 1.8 ; 2.2)
Load > 26 x LFL	R-152a load > 3.38 kg	Not allowed

Loading a refrigeration system with A3 fluid - comfort application - locations I and II - access category: a, b, c

Refrigeration system with A3 fluid - "comfort" application - locations I and II - access categories: a, b, c		
General	**Examples**	**Requirements**
Load ≤ 4 x LFL	R-290 load ≤ 0.152 kg	No specific requirements
4 x LFL < load ≤ max (26 x LFL; 1.5kg)	0.152 < R-290 load ≤ 1.5 kg	Max. load according to (LFL, local area A and device height h_0) 2.5 x $LFL^{(5/4)}$ x h_0 x $A^{1/2}$ h_0 : 4 possible values only (0.6 ; 1 ; 1.8 ; 2.2)
Load > max (26 x LFL; 1,5kg)	R-290 load > 1,5 kg	Not allowed

Example:

Let's say a mono split unit serving a hotel room with a surface of 30 m². The maximum authorized load is defined below, according to the formula $2.5 \times LFL^{(5/4)} \times h_0 \times A^{1/2}$:

Split installation height	Maximum load in R-290 fluid according to the installation of the unit (surface " A " : 30 m²)
Ground (h_0 : 0,6)	0.138
Window (h_0 : 1)	0.230
Wall (h_0 : 1,8)	0.414
Ceiling (h_0 : 2,2)	0.505

Figure 15: Example of limit load for a split serving one room

For an installation loaded with 400 g of R-290 fluid, the minimum room surface is determined according to the installation height of the equipment as follows:

253 m² for an installation height of 0.6 m
91 m² for an installation height of 1 m
28 m² for an installation height of 1.8 m
19 m² for an installation height of 2.2 m

Loading a refrigeration system with A3 fluid - other applications - locations I and II - access category: a, b, c

Refrigeration system with A3 fluid - Other applications - locations I and II - access categories: a, b, c				
Access category		**General**	**Examples**	**Requirements**
Access categories: a (general access)	Below ground level	Load ≤ 20% LFL x room volume et ≤ 1kg	R-290 load ≤ 0.0076 x room volume et ≤ 1kg	Sealed systems
	Above ground level	Load ≤ 20% LFL x room volume et ≤ 1.5kg	R-290 load ≤ 0.0076 x room volume et ≤ 1.5 kg	Sealed systems
Access categories : b (supervised access)	Below ground level	Load ≤ 20% LFL x room volume et ≤ 1kg	R-290 load ≤ 0.0076 x room volume et ≤ 1kg	
	Above ground level	Load ≤ 20% LFL x room volume et ≤ 2.5kg	R-290 load ≤ 0.0076 x room volume et ≤ 2.5 kg	
Access categories : c (restricted access)	Below ground level	Load ≤ 20% LFL x room volume et ≤ 1kg	R-290 load ≤ 0.0076 x room volume et ≤ 1kg	
	Above ground level	Location I: Load ≤ 20% LFL x room volume and ≤ 10kg Location II: Load ≤ 20% LFL x room volume and ≤ 25kg	R-290 load ≤ 0.0076 x room volume et ≤ 10kg (I) or 25kg (II)	

For sealed systems charged with a flammable fluid, there is a maximum load below which there are no particular requirements, especially with regard to the surface area of the room and the location of the device.

Fluid	R-32 (A2L)	R-1234yf (A2L)	R-452B (A2L)	R-455A (A2L)	R-290 (A3)
Lower Flammability Limit (LFL) (kg/m³)	0.307	0.289	0.309	0.431	0.038
Maximum load (kg)	1.8	1.7	1.8	2.5	0.15

Figure 16: Maximum load without minimum room size requirement (sealed system)

4.5.3 Analysis of the requirements related to NF EN 378-2

The standard NF EN 378-2 "Refrigeration systems and heat pumps - Safety and environmental requirements: Design, construction, testing, marking and documentation" is a harmonized standard under the "Machinery", "Low Voltage" (and "PED") Directives. It supports these directives by establishing technical specifications that are considered suitable and sufficient to comply with European legislation. The application of the NF EN 378-2 (not compulsory) gives presumption of conformity to the essential requirements of these Directives.

The specific requirements relating to the use of flammable fluids are summarised in the following table.

Special points	Type of fluid involved	Requirements - details
Pipe/fitting	A2, A3	Separate element system: seal not removable in occupied space except for direct connection to indoor units.
Pipe installation	A2L, A2, A3	Evacuation of system fluid during brazing or soldering operation
Protection device	A2L	For systems with load < 30 kg: a pressure relief valve is sufficient (check that auto reset does not cause increased risk). Otherwise, pressure switch required for each compressor.
	A2, A3	Systems with load < 5 kg: a pressure relief valve is sufficient (check that auto reset does not cause increased risk). Otherwise, pressure switch required for each compressor.
Indirect system with load > 500kg	A2L, A2, A3	Designed so that fluid leakage does not end up in the heat transfer fluid
Liquid level indicator	A2L, A2	Presence of a liquid indicator for any system with a load > 25 kg
	A3	Presence of a liquid indicator for any system with a load > 2.5 kg
Protection against fire and explosion risks	A2L, A2, A3	No refrigerant leakage that could spread or stagnate in a potentially flammable area (area with components, materials that could be a source of ignition)*.
Relevant ignition sources	A2L, A2, A3	Hot surfaces (radiators) Flames - hot gases (gas water heaters) Sparks of mechanical origin Electrical equipment likely to produce a spark or an arc Static electricity (clothing, plastic)
Protection against hot surfaces (general)	A2L, A2, A3	Temperature of surfaces exposed to fluid leakage < Fluid auto-ignition temperature - 100 [K]

Safety zone around the equipment	A2L, A2, A3	Refer to the instruction manual for the potentially flammable area identified around the equipment (maintenance operation)
Points of access to the system for maintenance	A2L, A2, A3	Marking of access points with "flame" symbol 
Warning in the engine room	A2L, A2, A3	Presence of a warning notice at the entrance to the room
Warning for open air system	A3	Warning notice at the entrance to the area for any system with a load > 10 kg
Ventilated enclosures	A2L, A2, A3	No ignition sources in the ventilation duct. Ventilation rate ≥ 2 m3/h Permanent and monitored operation of ventilation or operation triggered by a fluid detector at a concentration < 25% LFL. Location of detector according to fluid density.
Marking of the refrigeration system	A2L, A2, A3	Mandatory marking with the "flame" symbol

*** A component or material will not be considered an ignition source if it meets at least one of the following conditions:**

- **be outside the potentially flammable area where the fluid leakage could spread or stagnate**
- **be vented at all times (or before it is energized) so that the fluid concentration at that component is ≤ 50% LFL (Lower Fluid Flammability Limit)**
- **comply with the requirements for equipment suitable for "Zone 2, Zone 1 or Zone 0" locations**
- **for electrical equipment, the maximum energy level of a spark or arc in its circuit does not cause the fluid to ignite.**

4.5.4 Analysis of the requirements related to NF EN 378-3

Part 3 of NF EN 378 defines the protection measures based on the nature of the premises or in case of exceeding the fluid load. The essential requirements specific to flammable fluids are summarized in the following table

Special points	Type of fluid involved	Requirements
Equipment in unoccupied space (not assigned as machine room)	A2L, A2, A3	If mechanical ventilation: linking mechanical ventilation to a fluid detection system. Triggering of ventilation at a concentration level = 25% x LFL.
Equipment in machine room below ground level	A3	If fluid load > 26 x LFL (> 0.988 kg R-290): presence of an additional gas detector and/or alarm.
Machine rooms - filing	A2L, A2, A3	Assessment of the area in terms of flammability and hazardous area classification The extent of the hazardous area is considered negligible
Machine room - surface temperatures	A2L, A2, A3	Maximum hot surface temperature ≤ maximum (0.8 x Auto-ignition temperature; Auto-ignition temperature - 100 [K])
Machine room - mechanical ventilation	A2L, A2, A3	Ventilation in normal operating condition or during occupancy: air exchange ≥ 4 vol/h
		Mechanical emergency ventilation by discharge controlled by a detector which acts for a level ≤ 25% LFL. Air renewal of 15 vol/h sufficient
Engine room - open flames	A2L, A2, A3	Open flames are not permitted. Except for welding, brazing or other operations and only if the concentration of the fluid is monitored (leak detector) and ventilation is provided.
Machine room - all electrical equipment	A2L	Power supply is isolated when concentration ≤ 25% LFL. Any equipment required to operate above these values must be risk appropriate.
Machine room - storage	A2L, A2, A3	No storage of flammable fluids or materials
Detector	A2L, A2, A3	1 detector minimum in each engine room or occupied space and/or in the lowest underground room.

Pressure equipment

The "Guidelines related to the Pressure Equipment Directive 2014/68/EU", is a document developed and approved by the European Commission's WG on Pressure Equipment, which allows, through questions and answers, the uniform application of this directive.

This regulation concerns pressure equipment and assemblies whose maximum allowable pressure is > 0.5 bar. It applies to the design, manufacturing, and conformity assessment phases of equipment: it concerns manufacturers and operators.

The maximum allowable pressure is specified by the manufacturer. It corresponds to the maximum pressure for which the pressure equipment is designed.
All the elements of an installation are concerned and are categorised as: container, piping, safety accessories, pressure accessories.

Terminology	Examples of elements
Container	Bottle, tank
	Hermetic compressor*
	Heat exchanger
Piping	Tubes, elbows, tees
	Heat exchanger made of tubes and verifying the 3 conditions: air as secondary fluid, use in refrigeration/conditioning/heat pump system, predominance of piping
	Safety accessory discharge piping (including with open end to atmosphere)
Security accessories	Valves
	Pressure switches
Pressurized accessories	Pressure regulator
	Pressure gauges
	Filters
	Faucets, valves

*: a hermetic or semi-hermetic compressor of category ≤ I and falling within the scope of the "Machine", "Low Voltage" or "ATEX" directive is excluded from the PED

Figure 17: Example of elements associated with the different PED terminologies

The classification of a pressure equipment depends on the following parameters:

- The type of equipment (container, piping, pressure fitting, safety fitting),
- The type of fluid: gas or liquid,
- The fluid group: group 1 or group 2.

Slightly flammable and flammable fluids are in group 1. An exception is the R-1234ze fluid which is in group 2 although its safety class is A2L.

Containers and piping will be subject to the requirements of pressure vessels if their characteristics matches the following conditions:

Group 1 fluids (2L, 2 et 3 : R-32, R-290, R-1234yf…)		Group 2 Fluids: R-1234ze	
Container (liquid bottle…)	Fluid piping	Container (liquid bottle…)	Fluid piping
V > 1 l and PS x V > 25 bars.l	NS (nominal size) > 25	V > 1 l and PS x V > 50 bars.l	NS > 32 et PS x NS > 1000 bars
PS > 200 bars		PS > 1000 bars	

Figure 18: Characteristics of components beyond which they are subject to pressure equipment requirements

Pressure equipment is classified into four categories (I to IV) according to the increasing risks. Safety accessories are falls into category IV. The equipment and assemblies whose characteristics are lower than those specified in the previous table belong to category 0: no specific requirements, nor CE marking according to article 4.3 of the Directive.

4.7 ATEX Regulations

4.7.1 General requirements

The regulations concerning explosive atmospheres (known as "ATEX regulations") are based on two European directives:

- Directive 1999/92/EC of December 16, 1999, on health and safety protection for workers potentially at risk from explosive atmospheres.
- Directive 2014/34/EC of February 26, 2014, on equipment and protective systems intended for use in explosive atmospheres.

According to the directives, an "explosive atmosphere" (ATEX) results from a mixture of air and flammable substances in such proportions that an ignition source of sufficient energy produces its explosion.
Any flammable substance is considered to be a substance that can lead to the formation of an explosive atmosphere.

According to the regulations, **the employer or the person in charge of the site must take all the necessary measures to prevent the risks of explosion and to protect against them**. In decreasing order of priority, and applicable in all cases :

- **Prevent the formation of explosive atmospheres**
- **Avoid the ignition of explosive atmospheres**
- **Mitigate the harmful effects** of an explosion.

The provisions of the Labour Code impose several obligations on the employer with regard to the risk of explosion:

- **Evaluate the risks** likely to be created, taking into account the probability of occurrence of explosive atmospheres, the probability of the appearance of sources of ignition
- **To carry out a zoning** of the various places for which an explosive atmosphere can be created
- **To indicate** the premises or locations likely to have an ATEX zone using the pictogram 

The classification of premises into ATEX Zones aims to delimit and prioritize the zones where explosive atmospheres can form. This zoning helps in the choice of equipment and safety devices according to the zone type.
The locations where an explosive atmosphere can form are classified into 3 zones based on the nature, frequency, and duration of the presence of this ATEX.

All equipment and protective systems (electrical and non-electrical) used in these hazardous areas must meet safety levels appropriate to the zone.

Considering **the flammable substance in the form of gas or vapour**, these three zones (with the category of equipment adapted to these zones) are as follows:

Definition of the zone according to the frequency and duration of the presence of an ATEX	Zone (flammable substance in the form of gas, vapour)	Characteristics of the devices to be used according to the zone	
		Category	Regulatory marking
Location in which an explosive atmosphere is present permanently or for a long period of time during normal operation: Permanent risk	Zone 0	Category 1	CE Ex II 1 G
Location in which an explosive atmosphere may occasionally occur during normal operation: Occasional risk	Zone 1	Category 2 (or 1)	CE Ex II 2 G (ou 1 G)
A location in which an explosive atmosphere is not likely to occur normally, but if it does, may exist only for a short time: Potential risk	Zone 2	Category 3 (or 2 or 1)	CE Ex II 3 G (ou 2 G ou 1 G)

Figure 19: Classification of zones and equipment categories for flammable gases and vapours

The regulatory marking of equipment as defined in Decree 2015-799 consists of the CE marking, the specific explosion protection marking, the equipment group (Group II) followed by the category of equipment intended for use in relation to the zone (1, 2 or 3). All equipment must be designed, tested, and maintained for use in these different zones.

4.7.2 Applications to refrigeration systems

The methodology for classifying zones as Explosive Atmospheres (ATEX) is defined by NF EN 60079-10-1. In the latest version of this standard (2016), the evaluation of hazardous areas (zones 0, 1, 2 seen previously) combines 3 factors:

- The degree of release of the flammable substance (fluid)
- The effectiveness of the ventilation and its ability to promote the dilution of the fluid
- The "availability" of ventilation.

With effective ventilation, the level of risk can be greatly reduced.
The degree of release of the fluid can be downgraded to a "secondary" release (release which does not occur during normal operation, and which is of short duration).

NF EN 378-3 considers that the extent of hazardous areas is negligible when flammable fluids are present in machine room.
The extent of the zone is the distance from the source of release of the fluid to the point where the air/fluid mixture is diluted to a concentration < LFL which eliminates any risk of ignition or explosion. This zone can be determined from NF EN 60079-10-1.

The risks of having a flammable atmosphere during an intervention on a refrigeration circuit exist and are to be taken into consideration. However, the use of an appropriate ventilation

system with a leak detection system to maintain a fluid concentration level < LFL will ensure a sufficient dilution to avoid the risk of explosion or ignition.
All the safety measures stipulated in the standards (NF EN 378, IEC 60335-2-40) and in the regulatory texts (amended decree of May 10, 2019) is directed towards, reducing as much as possible the degree of dangerousness of the environment near the system. Thus, depending on the configuration, a refrigeration equipment may not be concerned by an ATEX zone or even be classified in zone 2.

The manufacturers' manuals inform the installer of the constraints for the installation of the units (distance between units, distance from a wall...). In the presence of flammable fluids, the positioning of ATEX zones (zone 2) around the unit may also be mentioned, requiring the use of detection equipment and tools adapted to the zone.

Moreover, the installation of refrigeration equipment in an ATEX zone must meet all the requirements of the ATEX Directives, regardless of the nature of the fluid. The whole design of the system will have to be adapted to the zone.

4.8 Product standards

4.8.1 IEC 60335-2-40

This standard deals with the safety of the following domestic electrical appliances: **electric heat pumps, air conditioners and dehumidifiers equipped with hermetic or semi-hermetic motor compressors.** There is no power limitation but a voltage limitation to define the scope covered by the standard. The maximum rated voltage is not greater than 250V for single phase units and 600V for three phase units. These voltages fall within the scope of the Low Voltage Directive. This can concern both residential and tertiary sectors.

The equipment containing flammable fluids must have the following symbols, according to the flammability of the fluid.

Marking on equipment containing flammable fluids	
A2L fluid	A2 or A3 fluid
	

This standard details out certain points specified in NF EN 378, such as

- Possible sources of ignition with A2L fluids
- Leak detectors, their location (in the unit or remote), characteristics (detection activated for a level < 25% LFL)
- Fluid leak simulation tests with the criterion of not having a concentration > 25% LFL
- Requirements for commissioning, repair and maintenance phases.

In the presence of a non-fixed equipment using a flammable fluid, a "warning" is specified on the device with the minimum surface of the room where this equipment can be installed and operated. This information is required when the load is:

- 4 x LFL* for A2 and A3 fluids (* Lower flammability limit)
- 6 x LFL for A2L fluids

Fluid class	Nature of the fluid (Lower flammability limit)	Fluid load requiring the mention of "minimum area of the room where the unit is to be installed".
A2L	R-32 (LFL : 0,307 kg/m^3)	> 1.84 kg
	R-452B (LFL : 0,309 kg/m^3)	> 1.85 kg
	R-455A (LFL : 0,431 kg/m^3)	> 2.58 kg
A3	R-290 (LFL : 0,038 kg/m^3)	> 0.152 kg

Figure 20: Fluid load involving the mention of "minimum room surface" where the unit can be installed

Below these limit loads, there is no restriction on the area of the room. These minimum loads are in accordance with those defined in NF EN 378-1.
Above these quantities, limit loads will apply with specific provisions. The calculation of the limit load is determined based on:

- The flammability of the fluid
- The location of the device in the room
- The presence of a ventilation system integrated to the unit and the orientation of the air supply
- The type of ventilation in the room.

It should be noted that **these load limit provisions apply to direct expansion systems**: air/air heat pumps, air conditioners (mono, multi-split); systems for which a pipe "rupture" would lead to a possible leakage of fluid in the occupied space.
Thus, for indirect expansion systems, no restriction is defined on the fluid load or on the surface area of the room served by the system. It should also be noted that the recommendations are mainly for A2L fluids.
Let LFL be the lower flammability limit of the fluids (kg/m^3) and "mc" the maximum fluid load.

The minimum and maximum loads for which the standard does not define any particular requirement or does not address them are listed in the table hereafter.

Load limit - direct systems		Requirements
General	**Example**	
$m_c \leq 6$ LFL (A2L) $m_c \leq 4$ LFL (A2, A3) A2L, A2, A3	≤ 1.84 kg R-32 ≤ 2.58 kg R-455A ≤ 0.152 kg R-290	No special requirements
$m_c > 260$ LFL (A2L) $m_c > 130$ LFL (A2, A3) A2L, A2, A3	> 79.8 kg de R-32 > 112 kg de R-455A > 4.94 kg de R-290	Not considered by the standard

Figure 21: Minimum and maximum load values

The limit loads not taken into consideration in this standard are higher than those defined in NF EN 378-1.

The permissible fluid loads according to the surfaces and volumes of the rooms in which these products are installed are summarized in the next table.

Overall, it may be possible to increase the system's fluid load or to reduce the available surface area necessary for the installation provided that additional protection (sealing) and/or safety measures are taken: integrated ventilation, additional ventilation, isolation valves, alarms linked to a fluid leak detection system.

Load limit		Requirements
General	**Example**	
Fluids A2L, A2, A3 Specific application: non-factory sealed unit 6 LFL < mc ≤ 12 LFL (A2L) 4 LFL < mc ≤ 8 LFL (A2, A3)	1.84 < R-32 ≤ 3.68 kg 2.58 < R-455A ≤ 5.17 kg 0.152 < R-290 ≤ 0.304 kg	Max. load according to (LFL, room area A) m_c : 0.25 x LFL x A x 2.2 Min. surface area : m_c/(0.25 x LFL x 2.2) + various tests (vibrations, fall...)
Fluids A2L, A2, A3 6 LFL < m_c ≤ 52 LFL (A2L) 4 LFL < m_c ≤ 26 LFL (A2, A3)	1.84 < R-32 ≤ 15.9 kg 2.58 < R-455A ≤ 22.4 kg 0.152 < R-290 ≤ 0.98 kg	Unventilated area. Load according to (LFL, area of room A, height of leakage h_0). Presence of guardrails on load and room surface. Max. load « m_c » : 2.5 x $LFL^{(5/4)}$ x h_0 x $A^{1/2}$ and m_c ≤ 0.75 x LFL x h_0 x A Min. surface area A_{min} : $(m_c/(2.5 \times LFL^{(5/4)} \times h_0))^2$ And A_{min} ≥ (m_c / 0.75 x LFL x h_0) Possibility of having h_0 > 2.2 m
Fluids A2L 6 LFL < m_c ≤ 52 LFL (A2L)	1.84 < R-32 ≤ 15.9 kg 2.58 < R-455A ≤ 22.4 kg	Fan integrated in the unit with continuous operation or controlled by a leak detection system activated at level < 25% LFL. Minimum airflow (30x m_c/LFL) Max. load according to (LFL, area of room A, height reached by system air flow "h_{ra}") (h_{ra} ≤ 2.2m) Max. load « m_c » : 0.75 x LFL x h_{ra} x A and Min. surface area A_{min} : m_c/(0.75 x LFL x h_{ra})
Fluids A2L Application: direct ducted system (ductable) 6 LFL < m_c ≤ 260 LFL	1.84 < R-32 ≤ 79.8 kg 2.58 < R-455A ≤ 112 kg	Load according to (LFL, total area treated TA) Max. load « m_c » : 0.5 x LFL x 2.2 x TA Min. space TA : m_c/(0.5 x 2.2 x LFL) Unit with leak detection system acting on the compressor, the "zoning" dampers, the ventilation or with continuous fan operation and flow measurement. Min. air flow: 60xm_c / LFL
Fluids A2L	1.84 < R-32 ≤ 63.8 kg 2.58 < R-455A ≤ 89.6 kg	Load according to (LFL, room area A, room height H)

Application: direct system with improved sealing (permanent joints except for unit connections, pipe protection, leak test...) 6 LFL < m_c ≤ 208 LFL		Max. load « m_c » ≤ 0.25 x LFL x H x A m_c R-32 ≤ 0.076 x H x A m_c R-455A ≤ 0.107 x H x A possibility of having H > 2.2 m according to the height of the leak h_0
Fluids A2L Application: direct system with improved sealing (permanent joints except for unit connections, pipe protection, leak test...) 6 LFL < m_c ≤ 208 LFL Any level except the lowest basement floor		Load according to (LFL, area of room A, height of room H) + safety measures to be added (ventilation, isolation valves, alarm linked with leak detection system) 0.25 x LFL x H x A < « m_c » ≤ 0.5 x LFL x H x A + 1 safety measure m_c > 0.5 x LFL x H x A + 2 safety measures m_c R-32 > 0.153 x H x A m_c R-455A > 0.215 x H x A
Fluids A2L Application: direct system with improved sealing (permanent joints except for unit connections, pipe protection, leak test...) 6 LFL < m_c ≤ 208 LFL Occupancy of the lowest floor in the basement		Load according to (LFL, area of room A, height of room H) + safety measures to be added (ventilation, isolation valves, alarm linked with leak detection system) 0.25 x LFL x H x A < « m_c » ≤ 0.5 x LFL x H x A + 2 safety measures
Fluids A2L, A2, A3 Fixed direct system 6 LFL < m_c ≤ 260 LFL (A2L) 4 LFL < m_c ≤ 130 LFL (A2, A3)	1.84 < R-32 ≤ 79.8 kg 2.58 < R-455A ≤ 112 kg 0.152 < R-290 ≤ 4.94 kg	Additional ventilation system (natural or mechanical). Maximum load for natural opening (m^2) or air volume flow (m^3/h)

Figure 22: Summary of the provisions to consider according to the fluid load

4.8.2 IEC 60335-2-89

This standard deals with the safety requirements for commercial refrigeration and ice machines with an integrated or remote refrigerant unit or motor compressor.
Sales and storage of refrigeration units are included in this scope. However, industrial cold rooms and refrigeration systems are not covered.

To be within the scope of this standard, the maximum refrigerant load must not exceed the following values.

Equipment	Maximum fluid load (in accordance with IEC 60335-2-89)	
	Maximum load	Example
Device with built-in refrigerant unit or motor compressor	Min. between (13xLFL ; 1.2)/ refrigeration circuit (and molar mass of the fluid ≥ 30 kg/kmol)	≤ 1.2 kg R-32 ≤ 494 g R-290
Unit with refrigerant unit or remote motor compressor (split system)	150 g (any fluid)/fluid system	

Figure 23: Maximum fluid load for refrigeration unit (according to IEC 60335-2-89)

In general, the maximum load will be :
- 1.2 kg for A2L and A2 fluids
- 13 x LFL for A3 fluids.

Above these loads, the present standard does not apply. Reference should thereafter be made to NF EN 378.

Refrigeration appliances containing flammable fluids must have the warning sign as shown in the adjacent figure. The warning sign must be visible on the rating plate after installation.

Additional markings are used depending on the configuration.

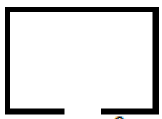
Equiment		Marking	
		Marking / symbol	Example
Device with a load > 150 g (device with built-in refrigerant unit or motor compressor)		Maximum allowable pressure for which the system is designed	> 150g for all fluids
Unit with a load > : (unit with built-in refrigerant unit or motor compressor)	Load > 6 LFL (Fluids A2L)	 ≥ A m²	
	Load > 4 LFL (Fluids A2-A3)	(minimum floor area of the test chamber)	> 152 g R-290

Figure 24: Marking applicable (according to IEC 60335-2-89)

The “A” value must be ≥ A_{lim} = Mass of fluid (kg)/(2.2 x (0.25 x LFL))

In addition to the distinctive marking for devices with flammable fluid, it is also necessary to have instructions, notices specifying among other things warning messages:

“keep clear all ventilation openings found within the enclosure of the device or those recessed in the structure";

"Do not use mechanical or other devices to accelerate defrosting, except those recommended by the manufacturer.

Finally, certain provisions must be respected (design phases, installation) in relation to the flammability of the fluid (A2L, A2 and A3).

Equipment	Provisions to be respected
Device with load > 150 g of fluid	Impact protection of any part containing refrigerant.
	Reduction of vibrations in the piping system caused by the operation of the device
	No concentration of fluid around the device in case of a leak
	Specificities on the connection of the pipes of the refrigeration circuit: no welding alloy at low temperature (melting point < 450°C)
Any device	No stagnation of fluid at the device in case of a leak
	Surface temperatures of the elements exposed to the fluid leakage must be < (Self-ignition temperature of the fluid - 100 K)

Figure 26: Safety provisions to consider

4.9 Synthesis

The limit loads based on the installation height of the unit and the surface area of the room differ depending on whether you consider NF EN 378-1or IEC 60335-2-40.
NF EN 378-1 defines 4 possible installation heights with a maximum height of 2.2m. The 4 installation heights are also considered in the two other texts but with the possibility to consider a height > 2.2m: being able to consider a superior height allows to increase the fluid load of the system and not to "penalize" rooms with a ceiling height higher than 2.2m.

Regardless of the refrigeration system and its location, the NF EN 378 standard considers all A2L, A2 and A3 flammable fluids. The IEC 60335-2-40 standard deals mainly with A2L fluids (in connection with direct systems). A specific marking for A2L fluids as opposed to A2-A3 fluids is presented in IEC 60335-2-40.

The use of higher fluid loads requires in all cases the consideration of additional safety measures. These measures include ventilation, an alarm system or isolation valves in the refrigerant circuit. All these parameters are controlled by a leak detection system. The servocontrol is triggered for a leak detection corresponding to a value:

< 25% LFL (according to IEC 60335-2-40)
≤ 25% LFL (according to NF EN 378-3)
< LFL (according to order of May 10, 2019, modifying article CH35)

Note that it is specified in NF EN 378-3 that, in general, as soon as the concentration of the fluid may exceed its practical limit, an alarm is required. For flammable fluids, the practical limit corresponds to approximately 20% LFL.

Finally, we note a homogeneity in the standards concerning the minimum load below which no requirement is made on the load, the surface.... This load is defined from the Lower Flammability Limit (LFL) of the fluid as follows:

≤ 6 LFL for A2L fluids
≤ 4 LFL for A2 and A3 fluids

The use of additional safety measures allows in all cases to consider higher loads, with a maximum equal to:

- 260 LFL for an A2L fluid (according to IEC 60335-2-40)
- 195 LFL for an A2L fluid (according to NF EN 378)

The leakage test differs depending on whether the fluid is subject to F-Gas or not. For HFC refrigerants (R-32) and HFC-HFO mixtures (R-454B, R-454C, R-455A...), **the frequency of the leakage test varies between 6 and 24 months** depending on the quantity of fluid and the presence or not of a leak detection device. For HFO fluids (R-1234ze, R-1234yf) and hydrocarbons (R-290...), the **frequency of the leakage control is maximum 24 months** and is applicable for any system of power ≤ 70 kW.

The following tables summarise the main requirements for each type of building and/or field of application (comfort, commercial and industrial refrigeration). The criteria used are common to the various standards or regulations.

	Residential sector - comfort Direct system (complete system or only indoor unit in occupied space)					
	A2L		A2		A3	
	NF EN 378	IEC 60335-2-40	NF EN 378	IEC 60335-2-40	NF EN 378	IEC 60335-2-40
Calculation of the load	According to (LFL, surface area A, installation height h_0) and ≤ 39 x LFL (4 possible values of h_0 : 0.6 ; 1 ; 1.8 ; 2.2) According to quantity limit with ventilation LCMV, LCAV and ≤ 195 x LFL + measures (non-removable connections, protection, location II...)	According to (LFL, surface area A, height of the leak h_0) Values of h_0 ≥ 0.6 ; 1 ; 1.8 ; 2.2 ; > 2.2 According to (LFL, A, air flow height h_{ra} or height of room) According to (LFL, area of room A, height of room H) with system sealing reinforcement (non-removable connections, test, protection...)	According to (LFL, surface area A, installation height h_0) 4 values of h_0 : 0.6 ; 1 ; 1.8 ; 2.2 And ≤ 26 x LFL	According to (LFL, surface area A, height of the leak h_0) Values of h_0 ≥ 0.6 ; 1 ; 1.8 ; 2.2 ; > 2.2	According to (LFL, area A, installation height h_0) 4 values of h_0 : 0.6 ; 1 ; 1.8 ; 2.2 And ≤ max (26 x LFL ; 1.5 kg)	According to (LFL, area A, leakage height h_0) Values of h_0 ≥ 0.6 ; 1 ; 1.8 ; 2.2 ; > 2.2
Exceeding of the calculated load	Yes (for configuration with LCMV, LCAV)	Yes (for systems with reinforced sealing)	No	Yes	No	Yes
Safety measures to increase the load	Ventilation Isolation valves Alarm Sensor control for level ≤ 25% LFL	Additional ventilation Isolation valves Alarm Leak detector control for level < 25% LFL		Mechanical ventilation with minimum flow rate Permanent ventilation with flow measurement or ventilation controlled by leak detection < 25% LFL		Mechanical ventilation with minimum flow rate Permanent ventilation with flow measurement or ventilation controlled by leak detection < 25% LFL
Fluid load without requirements	≤ 1.5 x 4 x LFL	≤ 6 x LFL	≤ 4 x LFL	≤ 4 x LFL	≤ 4 x LFL	≤ 4 x LFL

	Commercial and industrial refrigeration sector			
	Refrigeration equipment (integrated or remote unit or motor compressor) (sales refrigeration units, storage) (complete system or only indoor unit in occupied space)			
	A2L, A2, A3 IEC 60335-2-89	A2L NF EN 378	A2 NF EN 378	A3 NF EN 378
Maximum allowed load	≤ 150 g (unit or remote motor compressor)	≤ 26 x LFL (1) ≤ 25 kg (1) - restricted access ≤ 195 x LFL (2)	≤ 26 x LFL (general and restricted access) Ground floor, floors, and restricted access: ≤ 25 kg	Above ground level: ≤ 1.5 kg (general access) ≤ 2.5 kg (supervised access) ≤ 10 kg (restricted access - in occupied space I) ≤ 25 kg (restricted access - outdoor compressor II)
	≤ minimum (13 x LFL; 1.2 kg) (unit or built-in motor compressor)	-	Basement and restricted access: ≤ 10 kg	Below ground level: ≤ 1kg (basement)
Calculation of the load	-	≤ 20% x LFL x Room Volume (1) OR related (volume, LCMV, LCAV) (2)	≤ 20% x LFL x Room volume	≤ 20% x LFL x Room volume
Possible exceeding of the calculated load	-	Yes for configuration with LCMV, LCAV with additional measures: detection, ventilation, isolation valves.	No	No
Safety distance	-	Protection devices against fire and explosion risks in case of fluid leakage. Identification of ignition sources. No contact with potential fluid leaks.		
Specificities	-	-	-	Sealed system in occupied space (location I)

In addition to these specificities, a list of additional points to be checked according to the life cycle of the system is provided in Appendix 2.

The following elements are also included in Appendix 3:

- Memento summarizing the steps to consider for the "design - installation" and "operation - maintenance" phases
- Case study on:
  - A chiller in a machine room (A2L fluid) - plant system
  - A condensing unit and an evaporator in a cold room (A2L fluid) - field assembled system

5. General conditions of transport and storage

Transportation

The transport of dangerous goods by road is regulated at the European level by the ADR (European Agreement concerning the International Carriage of Dangerous Goods by Road). In France, the ADR is supplemented by the decree of May 29, 2009, on the transport of dangerous goods by land (known as the "TDG decree").
Every dangerous good falls under one or more specific types of danger and has a number called "UN number", preceded by the mention "UN".

Different hazard classes (between 1 and 9) are defined: **refrigerants are in class 2 (gases) and more specifically, flammable fluids, in class 2F.**

This regulation provides for exemptions, in particular those relating to the quantities transported. This exemption is intended to facilitate the transport by companies of small quantities of fluids for their own use. In the majority of cases, the transport movements undertaken by the building construction companies (and in particular the HVAC companies) fall under this exemption. The provisions applicable under these conditions are summarised in the following table.

Provisions concerned		Conditions for own-account transport according to the exemption regime linked to the quantities transported	Transport on public account by a carrier (full ADR)
Packages	Approved packaging	Yes	Yes
	UN Number	Yes	Yes
	Label	Yes	Yes
Documents	Shipping document	No	No (but information from the carrier on the total mass of goods)
	Safety instructions	No	Yes
Vehicles	Fire extinguisher	Yes (2kg powder)	Yes (max 12 kg of powder)
	Various equipment (wedges, warning signals)	No	Yes
	Labels / marks	No	Non
	Orange signs	No	Yes
	Ventilation for closed vehicles	Yes for flammable gases	Yes for flammable gases
	Passenger transport	Possible: ensure that products are physically separated from the passenger compartment	No
Participants	ADR 1.3 training	Yes	Yes
Driver	Basic ADR 8.2 training	No	Yes

Figure 26: Applicable provisions (according to OPPBTP - prevention sheet)

The transport by road must be carried out in **a vehicle that is preferably open or closed with top and bottom ventilation.** If there is no ventilation in closed vehicles, a sticker with the words "Caution confined space, open with care" must be affixed onto the access door to the load.

The main requirements to be met before and during loading are

- Ensure that the cylinder is leak free before loading;
- Check that the cylinder valve is closed and that the equipment (regulator, hoses) is removed;
- place the cylinders in an upright position and tie them down.

During these operations, the operator must wear safety shoes and safety gloves. it is also essential not to bring any source of ignition in the vehicle (no smoking, no open flame in or near the vehicle).

The maximum quantities vary according to the nature and dangerousness of the materials transported. For information, in the case of the exemption regime linked to the quantities transported, **the maximum quantity for the fluid R-290 is 333 kg**, i.e. 9 propane cylinders of 35 kg each.

The ADR is regularly revised. Since January 1, 2019, the new version of the ADR (ADR 2019) is applicable and is mandatory since July 1, 2019. Among the evolutions, we note the addition of dangerous goods transport categories (UN 3537 to UN 3548). Thus, as of January 1, 2023, the transport of heat pumps containing a flammable fluid will be partially covered by the ADR and will be named under the category UN3537: object containing flammable gas.

5.2 Storage

Every fluid cylinder must bear an information label affixed by the supplier. It contains principally the information related to the dangers of gases being transported and the storage phases. The nature of gases and their dangers are defined as follows

- flammable gas (hydrocarbons): risk of ignition, explosion.

Fluid cylinders must be stored in a dedicated, cool, dry area protected from the risk of fire, direct sunlight, and direct heating sources.

To reduce any risk of gas accumulation in case of leakage, the storage room must be ventilated (in accordance with NF EN 378-4). The machine room must not be used for the storage of refrigerants (EN 378-3).

The container valve must be closed and protected when not in use.

6. Risk assessment and specific provisions

Any company using or storing combustible or flammable products have to carry out a risk analysis and describe the means of prevention and protection to be implemented.
The risk analysis must be carried out according to

- the fluid load necessary to ensure the proper functioning of the system;
- the presence of potential sources of ignition in the vicinity

6.1 Types of claims recorded by insurers

The use and handling of new flammable refrigerants can lead to additional risks for the personnel. It is the employer's responsibility:

- To have **an insurance contract adapted to the activities carried out**
- To draw up the Single Risk Assessment Document (SRAD).

The SRAD must list the professional risks incurred by the workers and the prevention and protection actions that result from them.

During a presentation made by an insurance broker in the field of "Cooling", he mentioned the main types of claims recorded and their main causes:

Type of claims	Main causes
Loss of goods (≈ 60% of serious claims). (large-scale food distribution, industries)	Alarm management (absence, non functioning)
	Compressor breakage
	Human error (system not restarted, forced operation maintained: frost/ice on evaporator, compressor failure, etc.)
Fire, explosion (≈ 40% of severe losses).	Electrical installations (bare cables)
	Hot work operations
	Repair work on installations with "new fluids"

To date, the use of the new fluids has not significantly increased the frequency or severity of claims.

6.2 Assessing the risks

The main objective of the risk analysis is to identify the major accident scenarios and the safety measures that prevent these scenarios from occurring or to limit their effects.

In the presence of flammable fluids (A2L, A2, A3), the main risks are fire and explosion. These risks are the consequence of a combination of dangerous phenomena and dangerous situations.

Flammable fluid	Dangerous phenomenon	Dangerous situation (= situation involving a risk for people, the environment)	Main risk
A2L	Leakage of a flammable fluid	Leakage of flammable fluid near a source of ignition	Fire
A2-A3			Fire Explosion

"Assessing the risks" implies characterizing the different criteria that may be at the origin of the dangerous phenomenon and the dangerous situation:

- Make an inventory of the combustible products (flammable fluid)
- Analyze the refrigeration system, its operation and its environment
- Analyze the causes leading to the risk by distinguishing the different life phases of the system
- Identify the sources of ignition

6.2.1 Inventory of combustible products

The combustible product is the flammable refrigerant. The essential characteristics of the fluid to be considered are:

- Nature of the fluid
- Safety class
- PED group
- Density
- Lower and upper flammability limits
- Ignition temperature

Moreover, the quantity of fluid present as well as its storage are to be inventoried.

The **Safety Data Sheet (SDS) of the refrigerant** is an essential document to collect the characteristics of the fluid. In addition to the physical characteristics, the safety advice (prevention, intervention, storage) as well as the danger labels are defined. The fluids 2L, 2 and 3 are characterized by:

- H220: extremely flammable gas (A2-A3);
- H221: flammable gas (A2L);
- H280: gas under pressure. May explode under heat.

6.2.2 Analysis of the refrigeration system

The system analysis includes the pressure-temperature characteristics of the system, including the maximum operating pressure. In addition to the operating characteristics, its "location" and "access category" (as defined in EN 378-1), the nature of the system (direct or indirect) and its fluid load are important data for an analysis of the frequency and severity of the risk.

6.2.3 Analysis of the causes leading to the risk

Depending on the different phases of the system's life, the **causes for the leakage of the flammable fluid** can be diverse.

System Life Phase	Possible causes of fluid leakage
Construction (on site) Installation (on site)	Lack of seal
	Bad soldering
	Poor quality of the weld
	Poorly tightened fittings
	Unsuitable component (e.g. regulator)
	Pipe failure (mechanical weakness of the assembly)
	Incorrect handling during the load
Mise en service	defective tooling (pressure gauge hose)
	Unsuitable equipment
	Setting error
Exploitation	Aging, wear of a seal (valve, tap)
	Screw-in fittings (loosening, cracked nut)
	Corrosion brazing (environment, realization)
	Defective equipment, tools (hose)
	Unsuitable equipment
	Fluid discharge
	Pressure switch (bellows rupture)
	Safety valve (leakage)
	Pipe breakage (shocks, vibration, frozen evaporator)
	Schrader coupling (missing cap, valve deterioration)

Figure 27: Examples of causes of fluid leakage according to the stages of implementation

6.2.4 Identification of ignition sources

Ignition sources can have different origins: electrical, electrostatic, thermal, mechanical.
The main sources of ignition are:

- hot surfaces (de-icing resistors, radiators, etc.)
- open flames (matches, welding flames, etc.)
- sparks generated mechanically (friction process, shock generally accompanied by heating)
- electrical materials and equipment (sparks of electrical origin: false contact, opening of a circuit...)
- static electricity

For there to be a risk of explosion (or fire), the ignition source must have an energy ≥ the minimum ignition energy of the air/flammable fluid mixture.
In the presence of an A2L fluid, there are fewer ignition sources than in the presence of an A3 fluid.

Sources of "open flame" or hot surfaces are a risk regardless of the flammability class of the fluid.
The "frequency" and "severity" criteria complete the risk analysis. However, these criteria vary depending on the installation and its direct environment. The following table defines the level of severity noted + (lower severity) to +++ (higher severity) according to the criteria of the installation.

Criteria		Severity level (+ to +++)
Fluid load		+ to +++
Flammability class	A2L	+ (++)
	A2-A3	+++
Access category (according to NF EN 378-1)	"a" (general access)	+++
	"b" (supervised access)	++
	"c" (restricted access)	+
Location of the system (according to NF EN 378-1)	I (occupied space)	+++
	II (compressor in technical room or outside)	++
	III (system in technical room or outside)	+
	IV	+

Figure 28: Evolution of the level of seriousness

6.3 Defining the preventive measures

To avoid the formation of an explosive atmosphere or even its ignition, it is necessary to be able to act on the "trigger" elements as described previously.
The first step is to limit any risk of fluid leakage.
In the event of a leak, the formation of an ATEX zone (and the risk of fire) must be avoided.

- Act on the installation:
  - Carry out regular maintenance operations
  - Regularly check all "potentially leaking" points of an installation (leakage checks)
  - Ensure that access points are marked with the "flame" symbol in order to inform operators and avoid any handling error
  - Define the safety conditions associated with the fluid load in the installation

- Act on the refrigerants
  - Choose a fluid with a lower flammability class
  - Reduce the fluid load as much as possible
  - Identify the explosive and flammable characteristics of the fluid in order to guarantee a concentration level outside its ignition range

- Act on the sources of ignition / prevent
  - Prohibit open flames in the vicinity

- Prohibit smoking
- Eliminate all sources of sparks
- Limit the temperature of hot surfaces near potential sources of leaks: ensure that the temperature is 100 K lower than the fluid's auto-ignition temperature

- Adapt the equipment to the predefined risk zone

- Control the direct environment around the system
  - Install an ambient detector to guarantee a concentration of < 25% x LFL of the fluid (pay attention to the sensitivity of the detector, its response time and its location)
  - Ensure sufficient air renewal
  - Have a visual/sound alarm

- Organize the work
  - Train personnel on the risks of fire and explosion
  - Establish intervention procedures
  - Adapt the equipment (vacuum pump, recovery machine, cylinder, detector, etc.) to the flammability class of the fluid
  - Mark the areas where the risk exists
  - Adapt work clothes (antistatic material)

In summary, the risk of fire (or even explosion) happens when the 3 conditions are simultaneously met:

- **A flammable refrigerant with its proportion in the air ranging between its lower and upper explosive limits**
- **An oxidizer (ambient air)**
- **An ignition source with sufficient energy to ignite the fluid**

Under these conditions, the formation of an explosive zone must be avoided by ensuring the following:

- **Reduce the leakage time by detecting and stopping the system;**
- **Reduce the effects by detecting and starting additional ventilation so that the concentration in the room near the system and the potential leaks is always well below the lower flammability limit of the fluid.**

In appendix 4, a risk analysis table is presented for several configurations corresponding to the different life phases of an installation. This analysis table is based on the work carried out by the SNEFCCA (Risk analysis - refrigeration installations).

7. Maintenance procedures applicable to fluids A3

During maintenance interventions on a refrigeration system (opening of the circuit, repair...), there is a risk of a flammable atmosphere. Every operator must be informed of this risk and must be able to prepare his intervention and act in full safety.

These procedures are detailed for the R-290 fluid, classified A3. The provisions are identical for all fluids classified A3 or A2.
All fluid handling requires the wearing of PPE: protective gloves and safety glasses are a minimum.

7.1 Tools and handling precautions required prior to intervention

Because of its flammability, the equipment used for any fluid handling operation in a refrigeration circuit must be labelled "A3" **approved equipment**:

- A3 specific vacuum pump with protection on the entire electrical part. For small installations (< 300 g of fluid), a manual vacuum pump can be used
- Specific recovery station for hydrocarbons

- Leak detector adapted to hydrocarbons in terms of sensitivity
- Specific recovery bottle for flammable fluids: the bottle can be recognized by its "red neck" and its red pictogram (flame on a red background).

Figure 29: R-290 recovery cylinder

The electronic pressure gauge or 4-way manifold (with hoses) must be adapted to the hydrocarbons (the thermodynamic characteristics of the hydrocarbons must be taken into account).

The weighing scale is not specific to the fluid.

For safety reasons, **cylinders of flammable refrigerants use fittings with reverse left-hand threads**. This specific connection (reversed thread) is essential to connect the hose.

In addition to this specific equipment, the intervention on a propane loaded installation must be carried out carefully by:

- Having a "hot work” permit if necessary if working on the circuit
- **Signalling and marking out the work area** to alert people of the danger (no cigarettes, no open flames, etc.)
- **Defining a safety perimeter** of a few meters around the work area and make sure that there are no flammable materials or sources of ignition in this area
- **Making sure there is a suitable fire extinguisher** nearby
- **Checking the presence and functionality of any safety devices in the work area**: sensors and detection system, alarm, ventilation
- **Having a portable electronic leak detector calibrated and adapted** to R-290 (no sparking or other), operating permanently and placed at the bottom, to detect, in the event of a leak, the accumulation of the fluid at ground level (propane is heavier than air)
- Being in a ventilated area
- Turning off the power of the system before doing any repair work
- Not desoldering or cutting with a flame torch any fluid piping or other component of the refrigeration system until and unless all fluid has been removed and the system has been purged with dry nitrogen.
- Wearing suitable work clothes.

7.2 Procedure for loading an installation

7.2.1 Vacuum procedure

Before loading any fluid, it is necessary to evacuate the system. The procedure aims at evacuating the air from the circuit and especially the humidity.
The procedure is similar regardless of the fluid. The vacuum pump is specific to hydrocarbons.

Vacuuming an installation consists in:

- connecting the BP and HP valves of the manifold to the suction and discharge valves of the compressor respectively;
- opening the LP and HP valves;
- Connecting the vacuum pump and the service line of the manifold with a hose;
- Placing the vacuum gauge on the vacuum pump;
- Switching on the vacuum pump;
- Observing the pressure in the circuit via the vacuum gauge (until the desired vacuum level in the circuit is reached);
- closing the BP and HP valves of the manifold;
- stopping the vacuum pump.

Also do think about vacuuming the hoses.

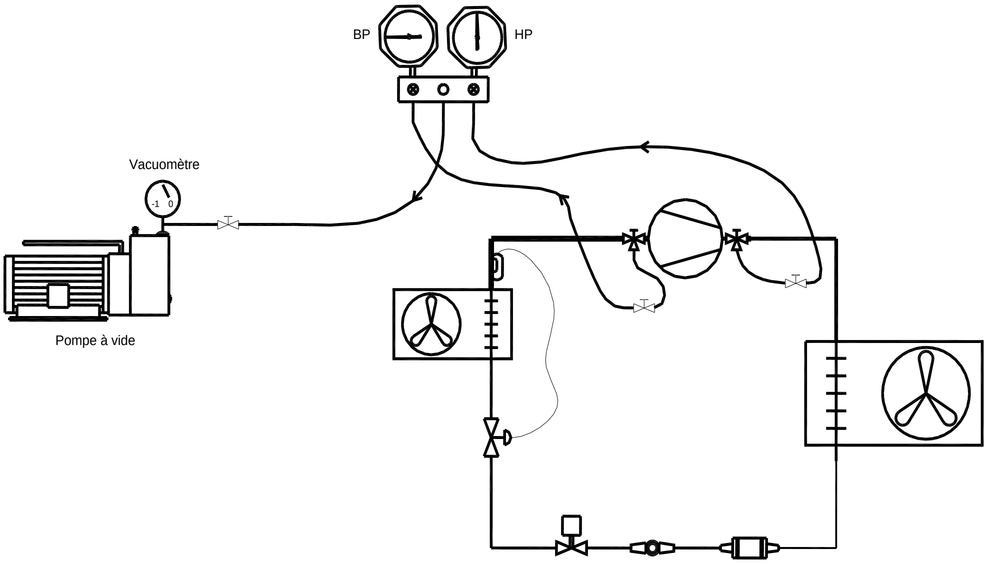


Figure 30: Procedure for evacuating an installation

For information, the adjacent figure gives the minimum pressure values to be obtained depending on the ambient temperature. In all cases, the pressure must be lower than the pressure necessary for the passage of water from the liquid state to the vapour state (boiling temperature).

We will try to go lower than this pressure; by referring to the prescriptions given in the NF EN 378-2: "following the tightness test, the vacuum must allow to reach an absolute pressure < 270 Pa".

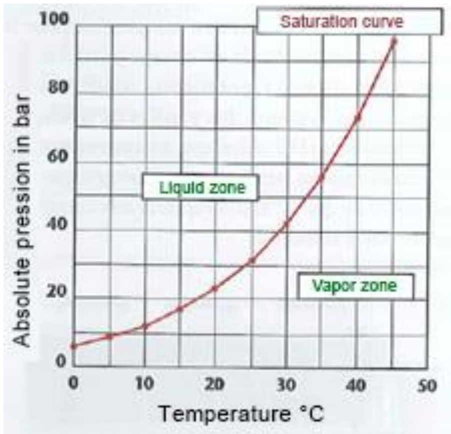


Figure 1 : Water saturation curve

After the system has been vacuumed, it is necessary to quickly load it with refrigerant. No installation shall be kept in a vacuum state.

7.2.2 Fluid loading

A system load is the filling of the system with refrigerant.
Only R-290 should be used as refrigerant.
The loading is carried out by firstly placing the **refrigerant cylinder on a weighing scale**.

The loading is carried out with the system switched off **by means of a pressure difference** (between the cylinder and the system). It can be carried out differently depending on whether there is a load valve on the liquid line or not. In the presence of a load valve, the liquid valve of the load cylinder is directly connected to the former of the circuit located after the condenser (before the expansion valve). If there is no load valve on the system liquid line, the liquid valve on the cylinder is connected directly to the service valve on the manifold.

The procedures are as follows:

Loading procedure	
Loading on a system with a load valve	**Loading on a system without a load valve**
Place the fluid cylinder, previously placed on a scale, near the circuit to be loaded	
Connect the liquid valve of the cylinder to the service valve (marked 3) with a hose.	Connect the liquid valve of the cylinder to the service valve of the manifold with a hose
Open valves 3 and 4 located between the cylinder and the system to allow the fluid to be transferred to the system by pressure difference	Open valves 4 and 6 to allow pressure difference transfer to the system on the discharge side of the compressor
Close valves 3 and 4	Close valves 4 and 6
Remove the fluid cylinder	

Figure 32: Detail of loading procedures

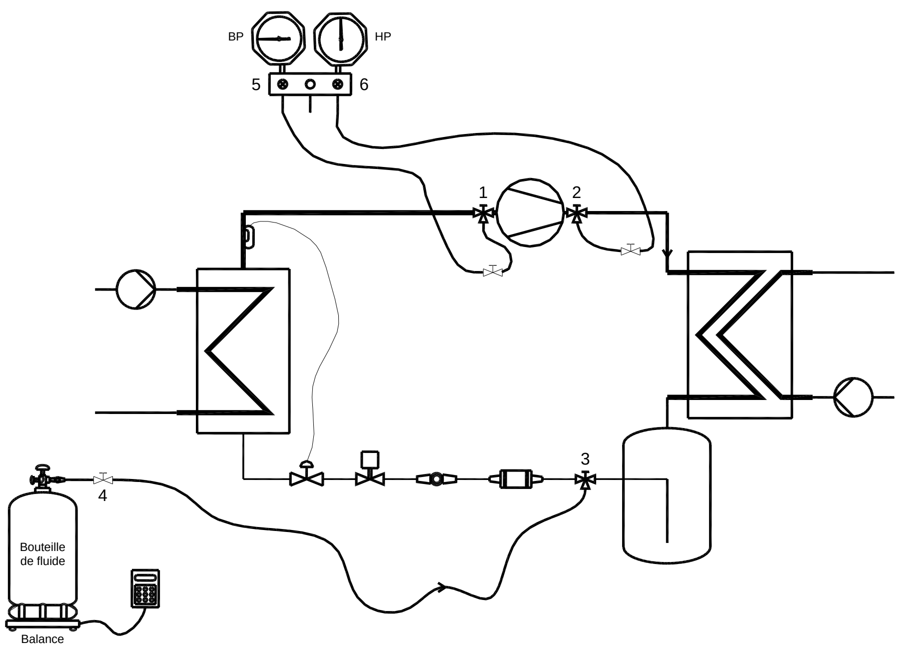


Figure 33: Loading of a system with a load valve on the liquid line

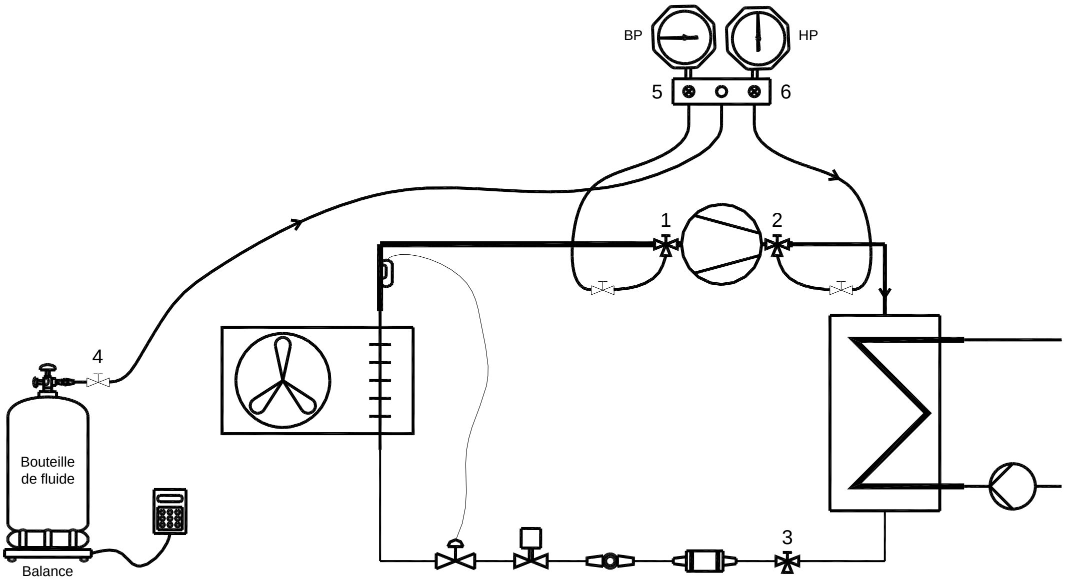


Figure 34: Loading of a system without a load valve

Depending on the size of the installation**, the additional loading** is carried out after the installation has been put into operation. It can be done in vapour phase (pure fluid) at the compressor suction or in liquid phase.

CAUTION, do not use a heating belt with a flammable fluid.

7.3 Procedure for emptying an installation

To date, **the recovery of R-290 fluid is not subject to any regulatory obligation**.
Given its characteristics, there are two possibilities to ensure the draining of an R-290 installation

- to discharge the fluid towards the outside;
- to ensure its recovery in a specific cylinder.

These possibilities are described hereafter:
However, **for economic and environmental reasons, the recovery of this fluid will be a preferred solution, in line with its eventual reprocessing.**

7.3.1 Discharge of the fluid to the outside

During the fluid discharge phase, it is essential **to ensure that the "discharge area" outside the building contains no ignition sources**. A hazard warning sign (flammable gas, no smoking, no open flames) should be placed in the area where the hydrocarbon is released. In addition, care must be taken to ensure that the fluid being discharged, which is heavier than air, cannot concentrate and get trapped in low areas at ground level.

The main steps are:

- To Connect the LP and HP valves of the manifold to the LP (evaporating side) and HP (condensing side) valves of the system via hoses
- To Connect the service line of the manifold to the outside environment (out of the danger zone) with a hose equipped with a pressure reducer.

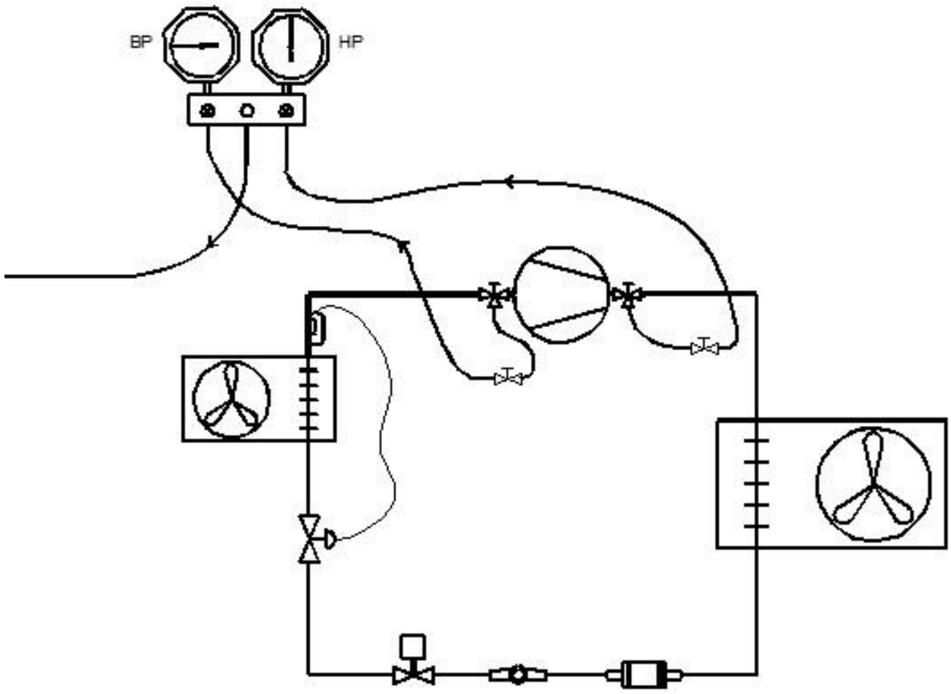


Figure 35: Outdoor Fluid Release Procedure

7.3.2 Fluid recovery

Even if there is no regulatory obligation, propane can also be recovered in **a specific recovery cylinder for flammable fluids**.

The recovery is preferably done in liquid phase, which is faster. The procedure is as follows:

- connect the manifold;
- Place the recovery unit and the recovery bottle, previously placed on a scale, near the circuit to be treated;
- Connect the hose between the recovery unit and the liquid valve of the recovery bottle;
- Connect the hose between the service valve of the manifold and the recovery unit;
- Close the valve (solenoid valve) on the liquid line between the condenser and the expansion valve to prevent fluid flow;
- Recover all the fluid charge in the condenser (or in the liquid cylinder of the system) until a BP of 0 bar is read (recovery via operation of the system compressor);
- Shut down the system to be drained;
- Start the recovery unit;
- End the recovery phase in the vapour phase;

-Stop the recovery operation when the absolute pressure of the circuit to be emptied is around 0.4 bar (pressure generally corresponding to the automatic stop of the recovery unit);

- Close the various connection valves.

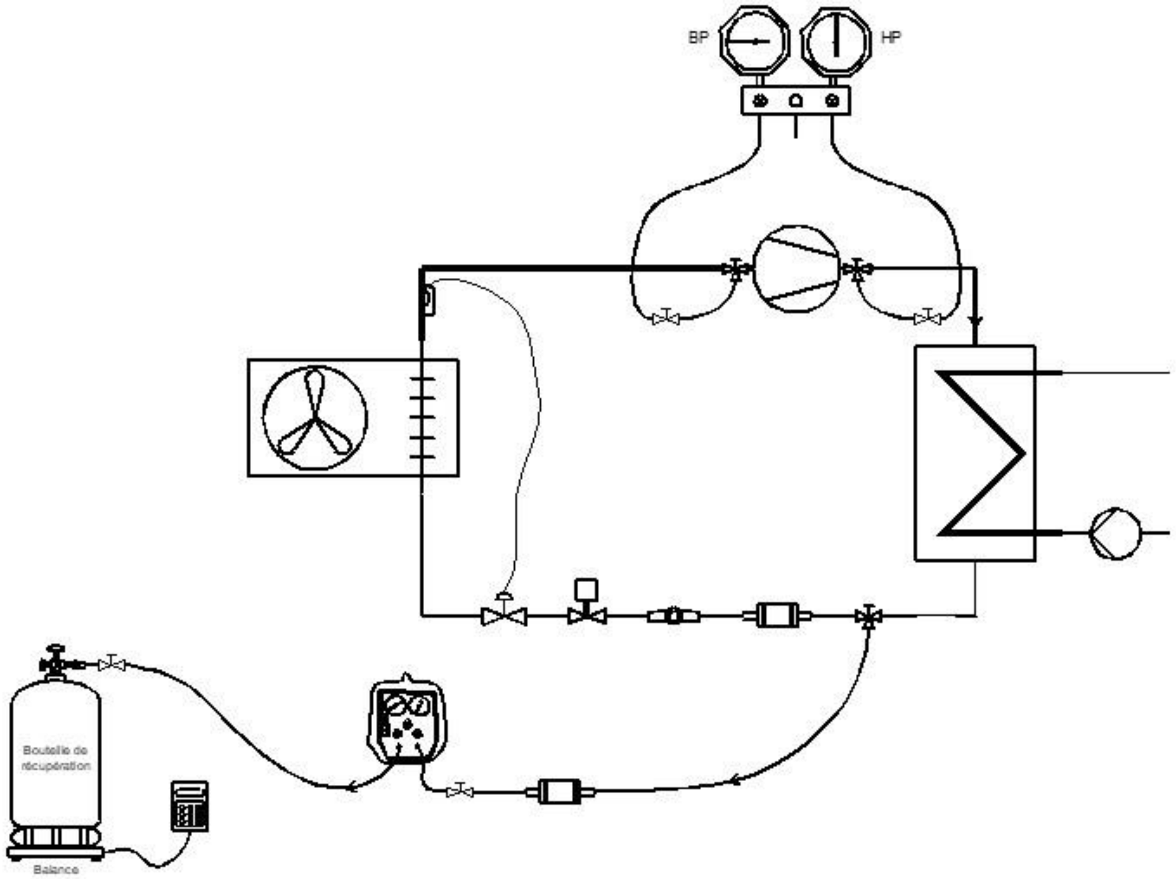


Figure 36: Liquid phase recovery procedure

8. Maintenance procedures applicable to A2L fluids

During maintenance interventions on a refrigeration system (opening of the circuit, repair...), there is a risk of flammable atmosphere. Every operator must be informed of this risk and must be able to plan his intervention and act in complete safety.

8.1 Tools and handling precautions

Some tools may be common to A2L and A1 fluids. However, the "flammable" nature of the fluid requires some appropriate tools. In all cases, it is advisable to check with the manufacturer that the equipment is compatible with the fluid to be handled.

Tools	Features
Pressure gauge	Electronic pressure gauge : can be common to several types of fluid Needle pressure gauge : specific to a fluid
Hoses	Common to different families of fluids
Weighing scale	Common to different families of fluids
Vacuum meter	Common to different families of fluids
Leak detector	Electronic detector: common or specific according to manufacturer's instructions
Vacuum pump	Common or specific according to the manufacturer's instructions. To be compatible with A2L fluids, the vacuum pump is equipped with anti-spark electrical components.
Recovery machine	Specific to A2L fluids (can be used with A1 fluids according to manufacturer's instructions)
Recovery cylinder	Specific to flammable fluids (red ogive and pictogram "flammable gas"). Requires a specific fitting with inverted thread

Table 37: Tools for A2L fluid

Figure 38: R-32 recovery cylinder (left) and R-32 fluid cylinder (right)

The slightly flammable nature of this fluid requires precautions for its handling. It is therefore necessary to ensure the following:

- In possession of a permit for “hot work” if necessary, when working on the circuit
- **Signalling, delimiting the work area** to alert people of the danger (no cigarettes, no naked flames...)
- **Define a safety perimeter** of a few meters around the work area and make sure that there are no flammable materials or sources of ignition in this area
- Make sure there is a suitable fire extinguisher nearby
- **Check the presence of any safety devices in the work area**: sensors and detection system, alarm, ventilation
- **Have a portable electronic leak detector calibrated and adapted** to the fluid, which is continuously functioning
- Be in a ventilated area
- Switch off the installation before repair work
- Do not desolder or cut with blow torch any fluid piping or other refrigeration system components until all fluid has been removed and the system has been purged with dry nitrogen.

The loading and recovery procedures detailed in the following paragraphs are general.
A loading and recovery operation of R-32 fluid has been performed on a split system. The description of these procedures on the R-32 split system is given in Appendix 5.

8.2 Procedure for loading an installation

8.2.1 Vacuum procedure

Before any fluid is loaded, it is necessary to evacuate the system. The procedure aims at evacuating the air from the circuit and especially the humidity. **The procedure is similar regardless of the fluid.**
The vacuum pump is suitable for slightly flammable media.

Vacuuming an installation consists of:

- Connecting the LP and HP valves of the manifold to the suction and discharge valves of the compressor respectively;
- opening the LP and HP valves;
- Connect the vacuum pump and the service line of the manifold with a hose;
- Placing the vacuum gauge on the vacuum pump;
- Switching on the vacuum pump;
- Observing the pressure in the circuit via the vacuum gauge (until the desired vacuum level in the circuit is reached);
- closing the BP and HP valves of the manifold;
- stopping the vacuum pump.

Also do think about vacuuming the hoses.

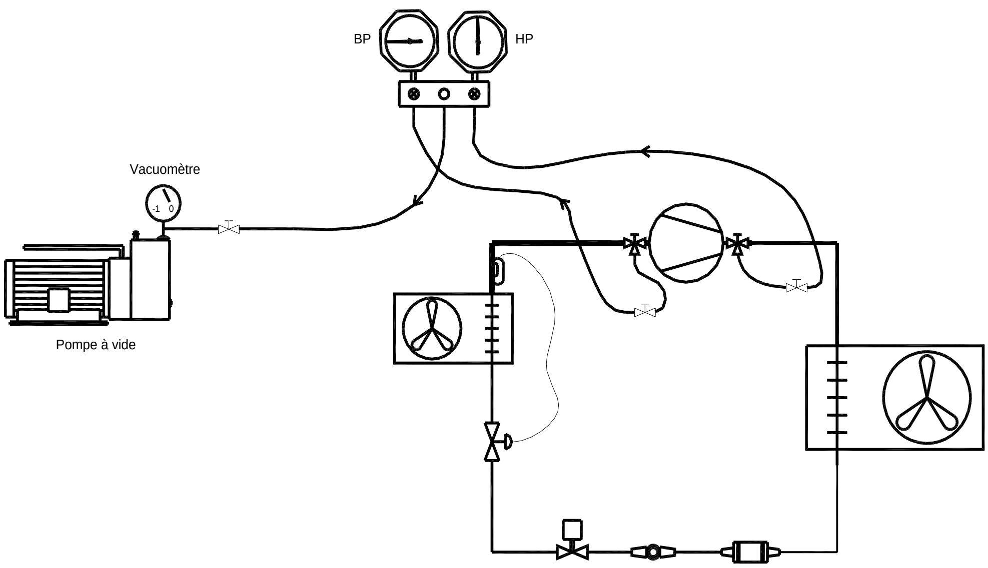


Figure 39: Procedure for evacuating an installation

For information, the adjacent figure gives the minimum pressure values to be obtained depending on the ambient temperature. In all cases, the pressure must be lower than the pressure necessary for the passage of water from the liquid state to the vapour state (boiling temperature).
We will try to go lower than this pressure; by referring to the prescriptions given in the NF EN 378-2: "following the tightness test, the vacuum must allow to reach an absolute pressure < 270 Pa".

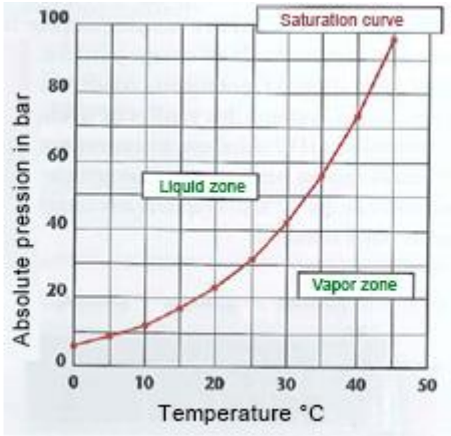


Figure 2 : Water saturation curve

After the system has been evacuated, it is necessary to quickly load it with refrigerant. Indeed, you should never leave an installation in vacuum.

8.2.2 Fluid loading

The loading of a system consists of filling the system with refrigerant.

Loading is carried out by firstly placing the **refrigerant cylinder on a weighing scale**.

Loading is carried out with the system switched off, **by pressure difference** (between the cylinder and the system). It can be carried out differently depending on whether there is a loading valve or not on the liquid line. In the presence of loading valve, the liquid valve of the charge cylinder is directly connected to the former valve of the circuit located after the condenser (before the expansion valve). If there is no system liquid line load valve, the liquid valve on the cylinder is connected directly to the service valve on the manifold.

The procedures are as follows:

Loading process	
Loading of a system with a charging valve	**Loading of a system without a charging valve**
Place the fluid bottle, previously placed on a tared scale, near the circuit to be charged	
Connect the liquid valve of the cylinder to the charging valve by means of a hose	Connect the liquid valve of the cylinder to the service valve of the manifold with a hose
Open valves 3 and 4 located between the cylinder and the system to allow the fluid to be transferred to the system by pressure difference	Open valves 4 and 6 to allow pressure difference transfer to the system on the discharge side of the compressor
Close valves 3 and 4	Close valves 4 and 6
Remove the fluid cylinder	

Figure 41: Detail of the loading procedures

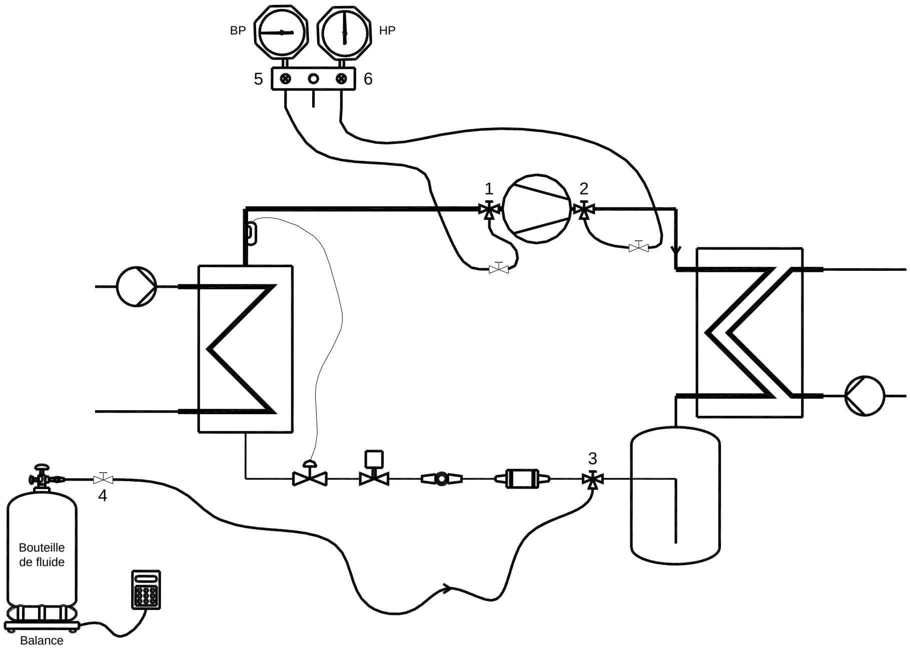


Figure 42: Loading of a system with a loading valve in the liquid line

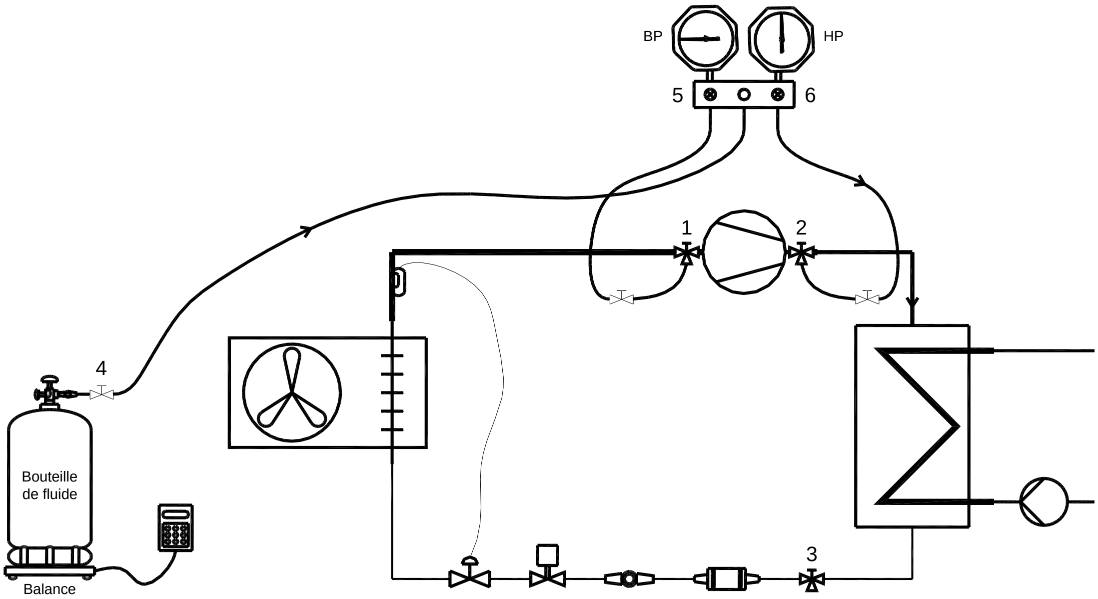


Figure 43: Loading of a system without a loading valve

Then, depending on the size of the installation**, the additional load** is carried out after the installation has been put into operation. It can be done in vapour phase (pure fluid) at the compressor suction or in liquid phase.

CAUTION, do not use a heating belt with a flammable fluid.

8.3 Fluid recovery procedure

Recovery is preferably done in the liquid phase, which is the fastest recovery phase.
The intervention procedure is as follows, with the installation stopped

- connect the manifold ;
- Place the recovery unit and the recovery bottle, previously placed on a scale tared to 0 kg, near the concerned circuit;
- connect the hose between the recovery unit and the valve of the recovery bottle;
- Connect the hose between the manifold service valve and the recovery unit;
- Close the valve (solenoid valve) on the liquid line between the condenser and the expansion valve to prevent fluid flow;
- Recover all the fluid load in the condenser (or in the liquid cylinder of the system) until a BP of 0 bar is read (recovery via operation of the system compressor);
- Shut down the system to be drained;
- Start the recovery unit;
- End the recovery phase in the vapour phase;
- Stop the recovery operation when the absolute pressure of the circuit to be emptied is around 0.4 bar (pressure corresponding in general to the automatic stop of the recovery unit);
- purge the recovery station ("purge" function on the machine) to recover the remaining fluid;
- Close the various connection valves.

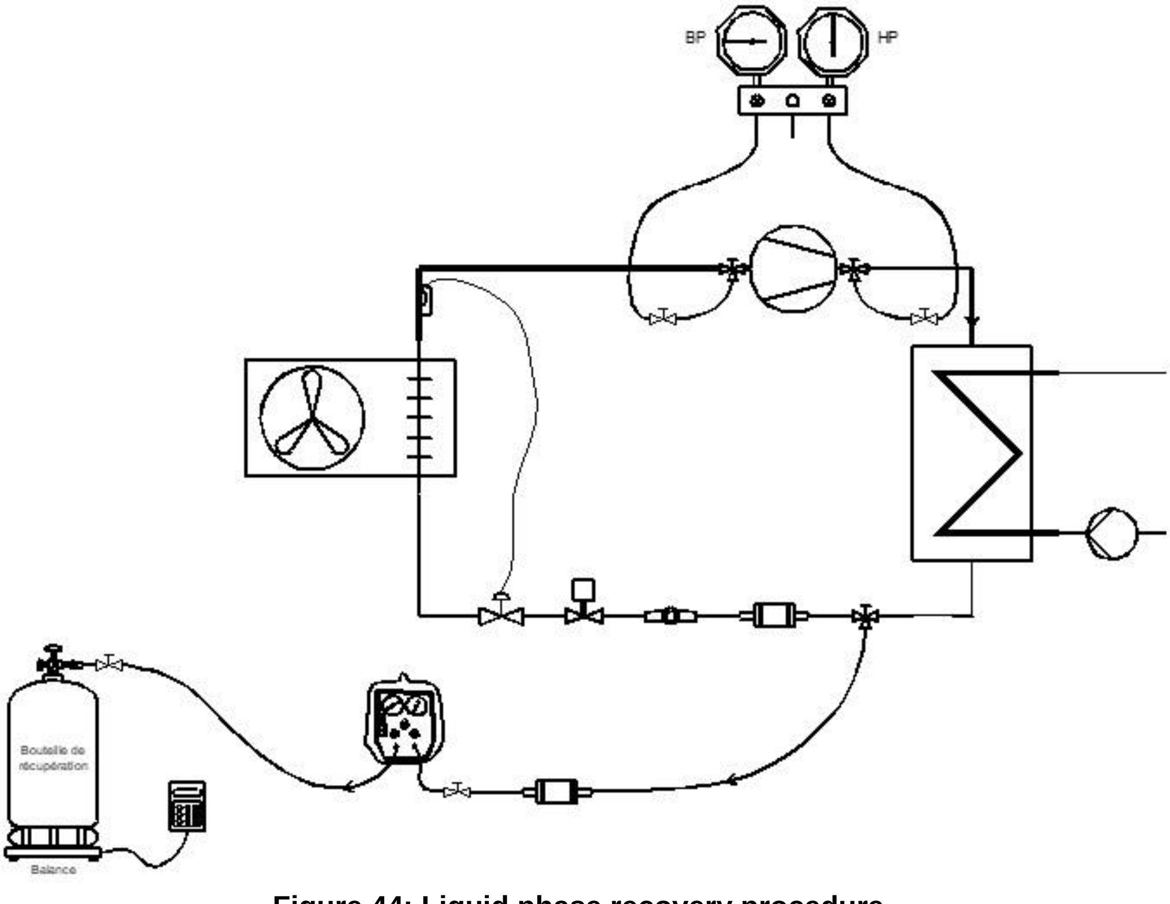


Figure 44: Liquid phase recovery procedure

Figure 45: Recovery station adapted to R-32

9. Post-recovery fluid management

The management of fluids recovered from equipment is governed by the use of Waste Monitoring Form (WMF). All recovery cylinders must be accompanied by this slip.
Flammable fluid recovery cylinders can be recognized by their red head.

The waste tracking form is different depending on the nature of the fluid recovered and its "origin".

Type of waste	Situation	Form to complete
HFC refrigerant, HFC-HFO blends Examples: R-32, R-454B, R-454C, R-455A	1 installation in 1 or more bottles	Cerfa 15497*02 form (Intervention form - Waste Monitoring Form)
	Multiple installations in 1 bottle	Annex 1 of the Cerfa 15497*02 form
Pure HFO refrigerants, hydrocarbons Examples: R-1234ze, R-1234yf, R-290	1 installation in 1 or more bottles	Cerfa 12571*01 form (Hazardous waste monitoring form)
	Multiple installations in 1 bottle	Annex 1 of Cerfa Form 12571*01

The two Cerfa forms are presented in Appendix 6.

Once the fluid has been recovered, it is analysed for possible regeneration or destruction. Regeneration is the treatment of a recovered fluid so that it has equivalent performance to that of the virgin fluid.

The use of regenerated fluids can respond to fluid supply constraints but also to a growing desire to control its environmental impact.
In terms of regeneration, a distinction must be made according to the nature of the fluids:
- Pure fluids (A2L, A2): regeneration possible
- Fluid mixtures (A2L, A2): regeneration is possible provided that the composition of the different substances in the mixture is at least preserved.
In all cases, regardless of the flammability class of the fluid (2L or 2), the regeneration of these fluids requires ATEX equipment.

Concerning the hydrocarbons, the returns to the distributor are very low because the operators do not recover these fluids. To date, the recovered hydrocarbons are destroyed by incineration.

10. Economic aspects

CITEPA and OKO-RECHERCHE have communicated on the availability of fluids and their purchase price trends. Starting in mid-2017, average purchase prices for HFC fluids with a high environmental impact increased sharply until 2018, with costs between 6 and 13 times higher than the initial reference price, estimated in 2014 (base 100). Since 2018, prices have been steadily declining.

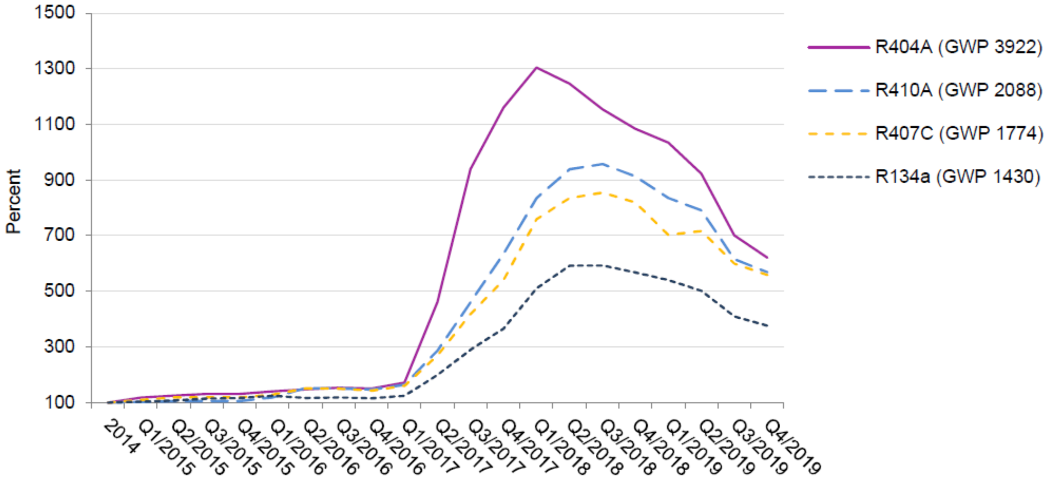


Figure 46: Evolution of the average purchase price of fluids (reference taken in 2014)

Since the second quarter of 2017, alternative (low environmental impact) fluids have been increasingly used. Their average purchase price has known minor changes between 2017 and the end of 2019.

The potential supply issues for these fluids mentioned in 2017 no longer exists.

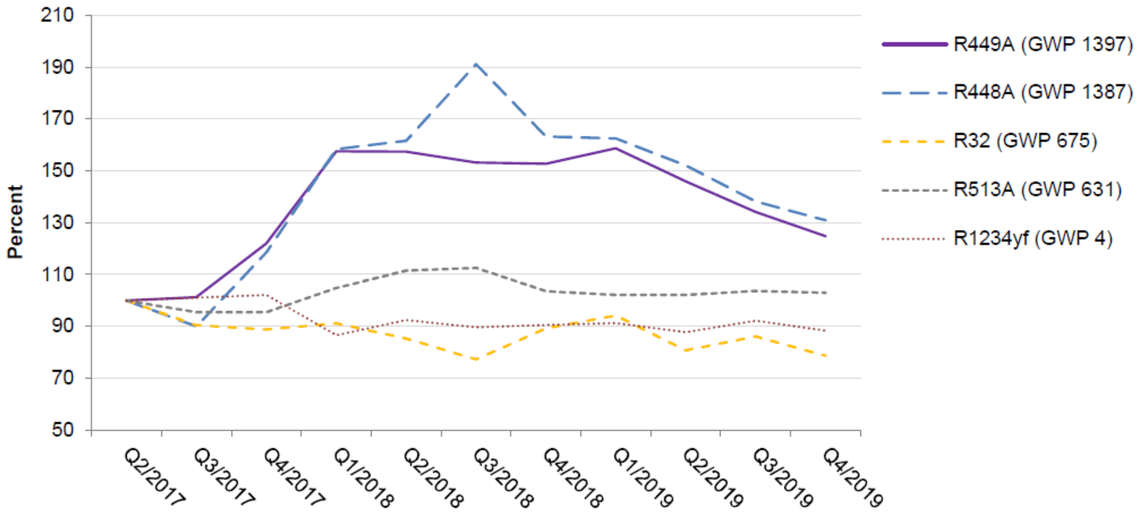


Figure 47: Evolution of the average purchase price of fluids with less or low environmental impact (reference taken from the second quarter of 2017)

The low evolution of purchase prices is even more striking with hydrocarbon and inorganic fluids. To date, the availability of these fluids on the market is good.

Figure 48: Evolution of the average purchase price of inorganic fluids and hydrocarbons (reference taken from the second quarter of 2017)

During 2020, the prices of fluids (HFC, HFO, blends) have known little change between the different quarters.
Regardless of the evolution of these costs, the cost of hydrocarbons (R-290) can be around 30% lower than that of HFC fluids and in particular R-32 (according to www.eurorefrigerant.com).

Hereafter, some orders of magnitude of cost (public tariff) of fluid (order of magnitude defined for similar quantities). The cost varies according to the quantity purchased and the packaging.

Refrigerant	Cost (€HT/kg)
R-455A / R-454C	70
R-32	40
R-1234ze	80
R-1234yf	150
R-290	40
R-600a/R-1270	50

Figure 49: Order of magnitude of average cost - Public price

The "share" in the recovery of HFC and HFO fluids is about 1.4 €/kg of fluid.

11. Feedback

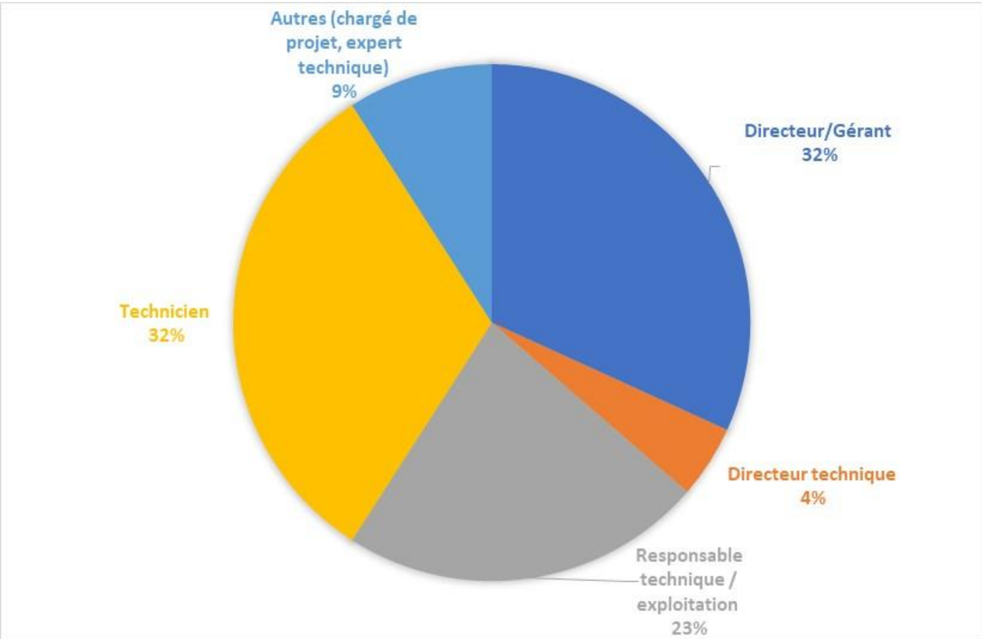
A survey was carried out in order to collect feedback, opinions and requests from professionals.
This survey was addressed to all the stakeholders involved in the different phases of the life of an installation: design, installation, development, operation.
The objective of the survey is twofold:

- To evaluate the current practice and knowledge of professionals;
- To know their expectations regarding flammable fluids.

The 25 professionals who participated in the survey belong to companies of varying sizes with the following specificities

- Industrial manufacturer
- Air conditioning and maintenance companies
- Commercial and industrial refrigeration installation company
- Air conditioning and heating installation company
- Installation/commissioning/maintenance of refrigeration machines

The occupations of the respondents to the questionnaire is presented below.



The occupations of the individuals did not have a significant impact on the observed responses.

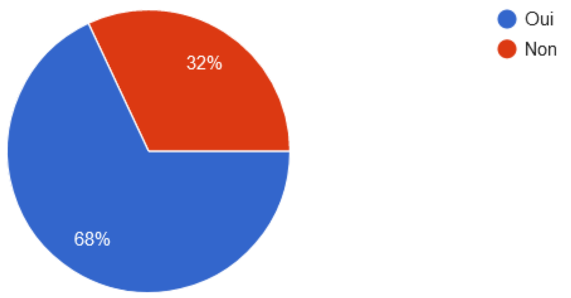
All the questions and answers are given in Appendix 8. The main results obtained are as follows.

A considerable proportion of professionals have already handled flammable fluids:

- 68% for slightly flammable fluids (A2L)
- 40% for highly flammable fluids (A3)

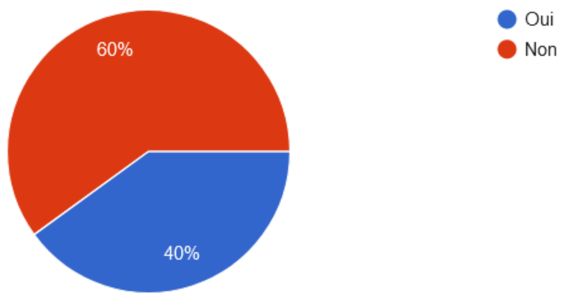
Avez-vous déjà manipulé des fluides légèrement inflammables (R32, R1234ze, R454B...) :

25 réponses



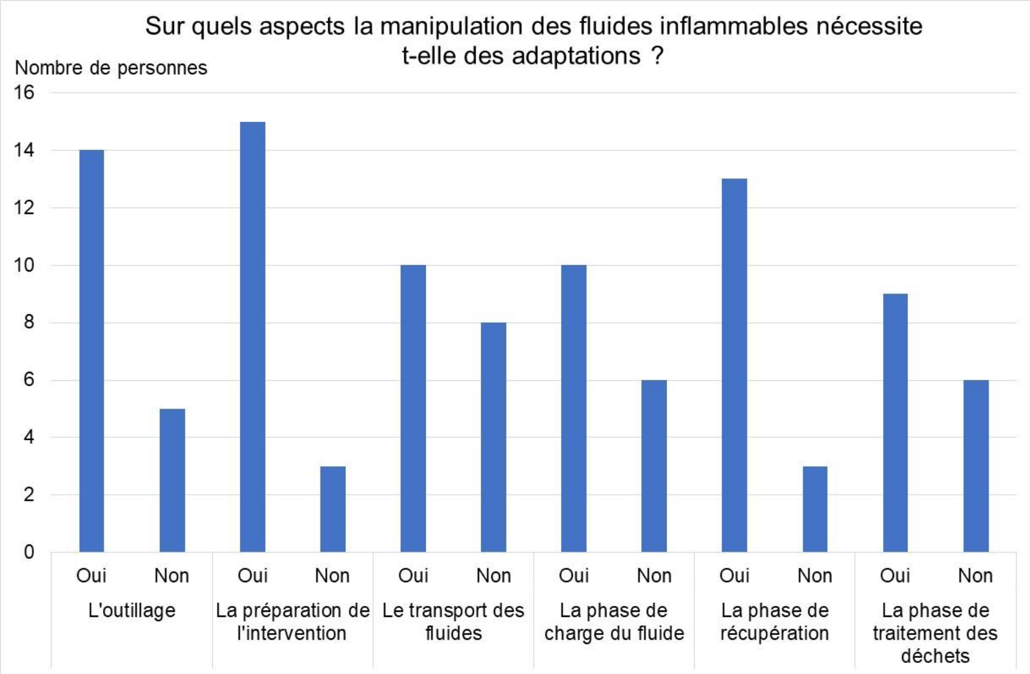
Avez-vous déjà manipulé des fluides hautement inflammables (hydrocarbures : R290, R600a...) :

25 réponses



According to the participants, the handling of flammable fluids represents in 80% of the cases in an adjustment of the procedures concerning particularly:

- Planning of the intervention
- Tools
- The recovery phase.



It is to be noted that in nearly 80% of the cases, the draining procedure using R-290 consist of discharging into the atmosphere (procedure totally forbidden with the other fluids HFC, mixtures HFC-HFO or HFO).

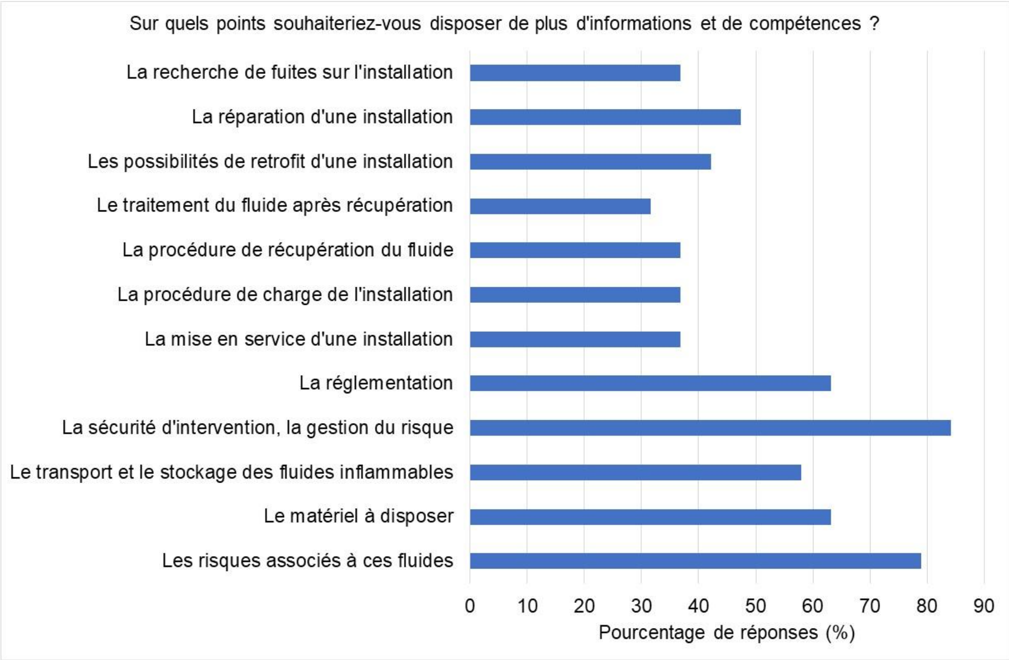
Some safety precautions and other measures considered essential for the handling of refrigerants have been reported by professionals:

- Carry out an evacuation before any intervention on an installation (total absence of fluid before any handling)
- Adapt all equipment to the characteristics of the fluid
- Cut off all power to the equipment's electrical components
- Carry out a brazing operation under a nitrogen net
- Have a suitable fire extinguisher near the work area
- Make sure there are no heat sources in the vicinity
- Make sure the room is well ventilated
- Train the operators dedicated to this handling
- Clarify the zone classification and the obligations of the site manager with regard to the risk assessment document (SRAD and EPD)

However, it is important to note that 76% of the professionals surveyed believe that they are insufficiently trained in handling these fluids.

More than 50% of the professionals surveyed would like to receive more information and to improve their skills in the following areas

Intervention safety, risk management (84% of responses)
The risks associated with flammable fluids (79%)
Regulations (63%)
Equipment to be made available (63%)
Transport and storage (58%).



The requests made by the professionals, regarding the list of "theoretical" points to be elaborated are in line with the contents of the trainings analysed in the previous chapter.

GLOSSARY

GWP: Global Warming Potential (kg CO_2/kg fluid)

LFL: Lower flammability limit (kg/m^3) (according to NF EN 378-1)

RCL: Refrigerant concentration limit (kg/m3) (according to NF EN 378-1)

LCAV: Limit concentration with additional ventilation (according to NF EN 378-1)

LCMV: Limit concentration with minimum ventilation (according to NF EN 378-1)

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APPENDICES

APPENDIX 1 : THERMODYNAMIC CHARACTERISTICS OF FLUIDS

	Refrigerant R-32
Type	HFC (pure substance)
Security class	A2L
PED fluid group	1
GWP (AR4 - value taken into account in the F-GAS Regulation N°517/2014 of 16 April 2014 /AR5) (kg CO2/kg fluid)	675/677
Molar mass (g/mol)	52
Lower flammability limit (kg/m³)	0.307 (13.3%)
Auto-ignition temperature (°C)	648
Ignition temperature on hot surface (°C)	> 800
Flashpoint (°C)	< -50
Critical T°C (°C)	78.1
Critical P (bar)	57.82
Boiling T°C (°C) (at 1,013 bar)	-51.7
Temperature shift at 1.013 bar (K)	0
Toxicity limit / oxygen deprivation limit (ATEL / ODL) (kg/m³)	0.301
Practical limit (kg/m³)	0.061
Latent heat of vaporization at boiling point (kJ/kg)	381
Type of lubricant	Specific POE type oil

	Refrigerant R-454B
Type	HFO/HFC blend Mixture : 68.9% R-32 / 31.1% R-1234yf
Security class	A2L
PED fluid group	1
GWP (AR4 - value taken into account in the F-GAS Regulation N°517/2014 of 16 April 2014 /AR5) (kg CO2/kg fluid)	468/466
Molar mass (g/mol)	62.6
Lower flammability limit (kg/m³)	0.307
Auto-ignition temperature (°C)	498
Ignition temperature on hot surface (°C)	> 800
Critical T°C (°C)	77
Critical P (bar)	-
Boiling T°C (°C) (at 1,013 bar)	-50.9 (boiling point)
Temperature shift at 1.013 bar (K)	1.5
Toxicity limit / oxygen deprivation limit (ATEL / ODL) (kg/m³)	0.435
Practical limit (kg/m³)	0.039
Type of lubricant	Synthetic POE oil

	Refrigerant R-454C
Type	HFO/HFC blend Mixture : 21.5% R-32 / 78.5% R-1234yf
Security class	A2L
PED fluid group	1
GWP (AR4 - value taken into account in the F-GAS Regulation N°517/2014 of 16 April 2014 /AR5) (kg CO2/kg fluid)	148/146
Molar mass (g/mol)	90.8
Lower flammability limit (kg/m³)	0.286
Auto-ignition temperature (°C)	-
Ignition temperature on hot surface (°C)	> 800
Critical T°C (°C)	82.4
Critical P (bar)	-
Boiling T°C (°C) (at 1,013 bar)	-45.9 (boiling point)
Temperature shift at 1.013 bar (K)	6
Toxicity limit / oxygen deprivation limit (ATEL / ODL) (kg/m³)	0.445
Type of lubricant	Synthetic POE oil

	Fluide frigorigène R-455A
Type	HFO/HFC blend Mixture : 3% R-744 / 21.5% R-32 / 75.5% R-1234yf
Security class	A2L
PED fluid group	1
GWP (AR4 - value taken into account in the F-GAS Regulation N°517/2014 of 16 April 2014 /AR5) (kg CO2/kg fluid)	148/146
Molar mass (g/mol)	87.45
Lower flammability limit (kg/m³)	0.423
Auto-ignition temperature (°C)	473
Ignition temperature on hot surface (°C)	-
Critical T°C (°C)	85.6
Critical P (bar)	48.2
Boiling T°C (°C) (at 1,013 bar)	-52.1 (boiling point) (-40)
Temperature shift at 1.013 bar (K)	12.8
Latent heat of vaporization at boiling point at 1.013 bar (kJ/kg)	239.46
Toxicity limit / oxygen deprivation limit (ATEL / ODL) (kg/m³)	0.429
Practical limit (kg/m³)	-
Type of lubricant	Synthetic POE oil

	Refrigerant R-1234ze(E)
Type	HFO
Security class	A2L
PED fluid group	2
GWP (AR4 - value taken into account in the F-GAS Regulation N°517/2014 of 16 April 2014 /AR5) (kg CO2/kg fluid)	7/< 1
Molar mass (g/mol)	114
Lower flammability limit (kg/m^3)	0.303
Auto-ignition temperature (°C)	368°C
Ignition temperature on hot surface (°C)	> 800
Critical T°C (°C)	109.4
Critical P (bar)	363.5
Boiling T°C (°C) (at 1,013 bar)	-19
Temperature shift at 1.013 bar (K)	0
Latent heat of vaporization at boiling point at 1.013 bar (kJ/kg)	195.62
Toxicity limit / oxygen deprivation limit (ATEL / ODL) (kg/m^3)	0.28
Practical limit (kg/m^3)	0.061
Type of lubricant	POE, PAG synthetic oil

	Refrigerant R-290
Type	Hydrocarbon
Security class	A3
PED fluid group	1
GWP (AR4 - value taken into account in the F-GAS Regulation N°517/2014 of 16 April 2014 /AR5) (kg CO2/kg fluid)	3/3
Molar mass (g/mol)	44
Lower flammability limit (kg/m^3)	0.038 (2.2%)
Auto-ignition temperature (°C)	470°C
Maximum allowable surface temperature (°C)	370°C
Flashpoint (°C)	-105
Critical T°C (°C)	96.7
Critical P (bar)	42.51
Boiling T°C (°C) (at 1,013 bar)	-42.1
Temperature shift at 1.013 bar (K)	0
Latent heat of vaporization at boiling point at 1.013 bar (kJ/kg)	425.3
Toxicity limit / oxygen deprivation limit (ATEL / ODL) (kg/m^3)	0.09
Practical limit (kg/m^3)	0.008
Type of lubricant	Mineral oil (naphthenic) Synthetic oil (AB, PAO)

APPENDIX 2 : EXAMPLES OF CHECKLIST AND RECOMMENDATIONS

Design stage	System assembled on site and loaded on site	Factory system placed outside	Plant system placed in ventilated enclosure (IV)	Factory system placed in machine room
The various components of an installation must be designed for operation with a flammable fluid	x	x	x	x
In the event of a refrigerant leak, the refrigerant cannot enter the building		x		
The fluid load in the system is calculated and verified according to the type of building, its location, the type of system (in compliance with regulations or standards)	x	x	x	x
In the presence of a fluid load related to the LCMV, LCAV values, additional measures are to be considered	x			
No ignition sources in the direct vicinity of the refrigeration system (or equipment appropriate to the risk of the area)	x	x	x	x
The power supply of the refrigeration system is independent of the system's safety equipment (ventilation, alarm, lighting)	x	x	x	x
The power supply to any electrical element is cut when the fluid concentration reaches 25% LFL				x
Electrical equipment that is made to operate in an environment with fluid concentration levels > 25% LFL must be suitable for such operation				x
Leak detectors are calibrated to act on security systems (alarm, shutdown, ventilation) at a level ≤ 25% LFL or < LFL (depending on building)	x		x	x
The leak detection system is adapted to the measured fluid	x		x	x
The detection system is placed where there is a risk of fluid stagnation (depending on fluid density)	x		x	x

Installation phase	System assembled on site and loaded on site	Factory system placed outside	Plant system placed in ventilated enclosure (IV)	Factory system placed in machine room
A risk analysis is conducted for the installation of the system	x			x
The piping connection is in conformity with the use of the fluid: screwed connections, brazed connections	x			
The brazing is to be done with a nitrogen shielding gas	x			
Pipe connections in occupied spaces are made with non-removable fittings (except indoor unit connection)	x			
The pressurization of the system is done with dehydrated nitrogen	x			
System access points are labelled with the appropriate "flame" symbol	x	x	x	x
A warning notice is set up		x		x
All sources of ignition are kept away from the system	x	x	x	x
The floor space / room volume is adapted to the fluid load of the system	x			
Safety measures are adapted to the amount of fluid in the system, its location	x	x	x	x
Before any loading of the fluid, the ventilation system of the room is started (and its operation is checked)	x			

Commissioning phase	System assembled on site and loaded on site	Factory system placed outside	Plant system placed in ventilated enclosure (IV)	Factory system placed in machine room
The presence and operation of the ventilation system is checked to prevent the formation of a flammable atmosphere	X			
The equipment (vacuum pump, weighing scale, recovery machine, fluid bottle) is adapted to the type of fluid	x			
A system leakage test is performed before loading	x			
The loading procedure is defined	x			
A tightness check is carried out after the system is loaded	x			
The leak detection system is tested, verified	x			x
Installation documentation is complete and verified	x	x	x	x
All safety equipment is checked before commissioning	x	x	x	x
Immediately after commissioning, check the pipes for any abnormal vibration that could lead to a risk of rupture	x			

Operating phase (maintenance, repair)	System assembled on site and loaded on site	Factory system placed outside	Plant system placed in ventilated enclosure (IV)	Plant system placed in machine room
The level of operator skills is consistent with the use of flammable fluids	x	x	x	x
All security equipment (alarms, detectors, ventilation) are checked and serviced at intervals in accordance with the manufacturer's instructions	x		x	x
An analysis of the dangers and an appreciation of the risks are carried out before any intervention (zones to be delimited, precautions, checks) to limit any risk (no source of ignition in potential zone of stagnation of fluid in case of leak)	x	x	x	x
A marking of the maintenance / repair area should be present or to be carried out	x	x	x	x
Handling equipment is adapted to the flammability of the fluids (PAV, portable leak detector, pressure gauge, bottles, recovery station). At least, non-sparking tools for A2L fluids.	x	x	x	x
The portable leak detector is adapted to the fluid and is calibrated	x	x	x	x
The portable leak detector is set to a level < 25% LFL	x	x	x	x
The portable fluid detector is switched on before entering the work area	x		x	x
The concentration of fluid in the work area is continuously monitored	x	x	x	x
No flammable materials or ignition sources in the work area	x	x	x	x
Before any operation, make sure that the work area is permanently ventilated	x		x	x
For any repair, obtain if necessary an authorization of work for “hot works”	x	x	x	x
Before any work, the power supply of the installation is s**witched** off	x	x	x	x
A leakage test is performed prior to the work to ensure that there is no risk of leakage	x	x	x	x
The opening of the pipes is done with a pipe cutter only. No open flame	x			
The system is purged with dry nitrogen before and after the repair	x	x	x	x
Before any electrical work, check the gas concentration in the atmosphere	x	x	x	x