ENERGY EFFICIENCY STATE OF THE ART OF AVAILABLE LOW-GWP REFRIGERANTS AND SYSTEMS

Final Report

September 2018

Study commissioned by the AFCE and carried out by EReIE, the Cemafroid, and the CITEPA

Authors : Stéphanie Barrault (CITEPA)

Olivier Calmels (Cemafroid)

Denis Clodic (EReIE)

Thomas Michineau (Cemafroid)

ACKNOWLEDGEMENTS

We sincerely thank the members of the Steering Committee for their contributions:

Bénédicte BALLOT-MIGUET, EDF

Emmanuelle BRIERE, UNICLIMA

Tristan HUBE, Service Entreprises et Dynamiques Industrielles, ADEME

Laurent GUEGAN, François HEYNDRICKX, Régis LEPORTIER, François PIGNARD, AFCE.

We would also like to thank all the professionals contacted as part of the study

CONTENT

LIST OF FIGURES

List of Tables

Glossary

AHRI: Air-conditioning, Heating, and Refrigeration Institute.

Anoxia: Breathing air contains about 21% O2. Below about 17% the risk of sudden loss of consciousness without warning, is to be feared, this is anoxia.

ASERCOM: Association of European Refrigeration Component Manufacturers.

Azeotrop: Azeotropic mixture (a privative, of the Greek zêin boiling and tropos action of turning) is a mixture of two or more refrigerants of different volatilities which, under certain conditions of composition and pressure, present identical (or almost identical) compositions of the liquid and vapor phases. Under constant pressure, the change of liquid-vapor phase of the azeotrop is done at substantially constant temperature and composition (unlike zeotropes). Azeotropic refrigerants are conventionally assigned the R-500 series.

CFC: Member of a family of organic compounds with chlorine, fluorine and carbon atoms. Their high chemical stability gives them a high potential for ozone depletion (high ODP, "Ozone Depletion Potential"). These fully halogenated substances were commonly used as refrigerants, insulating plastic foaming agents, aerosols, sterilizing agents, cleaning solvents, and in many other applications. Because of their ability to destroy stratospheric ozone, their elimination is programmed under the Montreal Protocol (1987).

Chiller: Equipment designed for the production of chilled water for air conditioining systems or units.

COP: Coefficient of Performance; it is the ratio between the useful capacity (cooling capacity for a refrigeration equipment, heating capacity for a heat pump) and the power consumed by the compressor. The COP can also include the power consumption of pumps and fans depending on the boundary conditions of the balance.

CTMS: Centralized Technical Management System. Computer system enabling the proper operation and control of technical systems by data acquisition from a large number of sensors and by driving actuators at distance.

Dew température: Temperature at which water vapor in humid air is saturated (relative humidity of 100%). From this temperature begins, by cooling, the condensation of the water vapor (on walls or impurity particles) for a given nd pressure.

Drop-in: Retrofit of installation corresponding only to the change of refrigerant, preferably less harmful to the environment, in refrigeration plants of all kinds, and not involving modifications to the installation other than minor modifications.

ERP: Public Building where external people are admitted (for example theaters, stores, training institutions, places of worship,)

Flash fire: In case of ignition of a gas cloud in its flammable range, i.e. if the concentration of gas in the air is between the lower flammability limit of (LFL) and the upper flammability limit (UFL), it will be observed a phenomenon called flash fire. This flash fire will generate thermal effects and overpressure effects.

Flashlight: Flashlights are the result of leakage of flammable refrigerants, which produce ignited jets of high calorific value in contact with a source of ignition.

F-gas: European regulation aiming at the reduction of emissions of gases with global warming potential.

FP: Food Processes.

GWP: Global Warming Potential. Warming potential of a substance released to the atmosphere relatively to that of CO_2, equal to 1 by definition. Conventionally, it is calculated over a 100-year period.

HCFC: Member of a family of chemical compounds related to CFCs but containing atoms of hydrogen, chlorine, fluorine and carbon. HCFCs are partially halogenated and have a significantly lower Ozone Depletion Potential (ODP) than that of CFCs. Examples of HCFCs include R-22 (CHClF2) or R-123 (CHCl2CF3).

HFC: Member of a family of CFC-related chemical compounds consisting of one or more carbon atoms surrounded by hydrogen and fluorine atoms. Since HFCs do not contain bromine or chlorine, they do not contribute to the destruction of the ozone layer. HFCs are widely used as refrigerants. Examples of HFCs include R-134a (CF3-CH2F) or R-152a (CHF2CH3).

HP: High Pressure. On refrigerating systems, means that part of the system going schematically from the compressor output to the expander inlet.

INERIS: the National Institute of the Industrial Environment and Risks is a public institution under the supervision of the ministry of the environment. It conducts research programs focused on understanding phenomena that may lead to situations of risk or harm to the environment and health

LCCP: Life Cycle Climate Performance. Comprehensive assessment of the impact of refrigeration units on global warming. It covers all emissions produced during the life cycle of the installation (from cradle to grave) and includes, in addition to emissions (direct and indirect) due to operation, emissions produced during the manufacture of compounds, chemical or not, installation and emissions produced during disposal or recycling.

LP: Low Pressure. For a refrigeration system, indicates the component going from the expander to the suction port of the compressor.

Normal Boiling Temperature: Temperature at which the refrigerant evaporates under normal pressure conditions, ie 101 325 Pa.

ODP: Ozone Depletion Potential. Index indicating, in relative value, the importance of the destruction of ozone caused by the presence in the atmosphere of chemical substances. The reference level of 1 is the destruction of ozone caused by R-11.

Overpressure: Effect that can be driven by a VCE (Vapour Cloud Explosion). Sudden increase in pressure causing internal lung and eardrum damage as well as injury from flying debris.

PTN: Professional Technical Notebook

Quasi-Azeotrop: A mixture characterized by a temperature glide sufficiently reduced to be neglected without causing significant error in the analysis of a specific application.

Retrofit or conversion: Improvement or adjustment of equipment in such a way that it can be used under modified conditions; for example, refrigeration equipment that is to be operated with a non-ozone-depleting refrigerant instead of a CFC or HCFC.

TWH: Thermodynamic water heater.

VCE: Vapor Cloud Explosion.

Volumetric capacity (kJ/m^3): Cooling capacity (or heating capacity for a heat pump) produced by the volumetric flow rate of the compressor in the reference conditions for condensation and evaporation temperatures. This value allows the comparison of refrigerants with regard to the compressor sizes and indirectly the price of the installation.

VRF: Air-conditioning system with variable refrigerant flow allowing to feed several indoor units by the regulation of the refrigerant flow used by each indoor unit and necessary to air conditioned a room.

Zeotrope: Mixture of two or more refrigerants of different volatilities, whose liquid and vapor phases in equilibrium have different compositions. Under constant pressure, the the liquid-vapor phase change of a zeotrope is made at a non-constant temperature and composition (unlike azeotropes). The R-400 series is conventionally assigned to zeotropic refrigerants.

KEYWORDS

Alternatives, ammonia, CFC, Thermodynamic water heater, Chillers, Air Conditioning, CO_2, Vapor compression, Natural refrigerants, Refrigerant, Low GWP refrigerants, Training, HCFC, HFC, HFO, Hydrocarbon, Heat pump, Propane, F-Gas Regulation, Refrigeration System.

EXECUTIVE SUMMARY

This report is the restitution of the extension of the **study on alternatives to high-GWP HFCs** published in 2014 by the AFCE and carried out by the same consortium. It aims to update the progresses of available option options by focusing on the **impact of available refrigerants on the energy efficiency** of equipment.

Since its entry into force on January 1st 2015, the European Regulation (EU) 517/2014 called "**F-Gas**" has introduced a progressive reduction of the quantities of HFCs authorized to be sold on the European market as well as sectorial bans of use, for new equipment and for the maintenance of refrigeration and air-conditioning installations. As a result, the regulation and the use made of their quotas by HFC producers have strongly constrained the market.

It should be noted that the definition of **high-GWP** refrigerant has evolved and that chemists concentrate their efforts on the development and promotion of refrigerants with a GWP of less than 150. **Any refrigerant with a GWP greater than this value will be led to become scarce in the short or medium term**. It can be seen that the HFO refrigerants and low GWP HFC-HFO mixtures are all **slightly flammable (A2L)**. In addition, hydrocarbons (A3), ammonia and CO_2 have their uses significantly expanded in some applications, and equipment technologies have been improved. However, the conditions of use of hydrocarbons and ammonia must be studied in detail as indicated by the safety standards.

At the same time, **the regulatory and normative framework is evolving rapidly**. Ecodesign regulations impose increasingly ambitious targets, in terms of energy efficiency, for a certain number of equipment in the refrigeration and air conditioning sectors. The “product” standards impose charge limits and warning requirements for flammable refrigerants. The standard **NF EN 378, 2017 version**, updates the safety and environmental requirements, integrates the new refrigerant category A2L and introduces new indexes for the calculation of limit charge and the notion of risk analysis throughout the installation lifecycle. Finally, **the French regulation concerning fire safety in public buildings prohibits** the use of flammable refrigerants to date, which is a limit for the development of low-GWP alternative options. Work has been launched to bring CH 35 in line with the objectives of the European F-Gas Regulation.

It was therefore necessary to **update the current corpus** and the recently published technical guides.

The analysis of replacement options is done by application sector and concerns, on the one hand, **new installations** and, on the other hand, **installations in operation** for which the retrofit or drop-in options are more limited.

For **domestic refrigeration**, the R-600a is now the only refrigerant used in Europe in refrigerators and freezers, and now achieves the A ++++ label in terms of energy efficiency.

For the segment of **small commercial refrigeration** hermetically-sealed units, the transition from R-134a to hydrocarbon alternatives has begun and CO_2 has been introduced into vending machines; R-1234yf is an energetically feasible option for this type of equipment. Regarding the replacement of R-404A, A2L mixtures (R-454A or R-455A) are proposed, with energy efficiency superior or comparable to that of R-404A.

Alternatives to high-GWP refrigerants exist for **condensing units**. However, not all products are mature and personnel trained in the use of flammable refrigerants is still scarce. These facts push some manufacturers to choose HFO (R-1234yf or R-1234ze). CO_2 begins to be proposed including **major** manufacturers. Manufacturers also offer the R-448A or R-449A as a transition refrigerant to meet immediate demand, but this option is not sustainable.

Different alternatives to direct expansion systems using R-404A are currently available for centralized super and hypermarket installations. The European Commission report of 4 August 2017 makes an initial assessment and shows that on the one hand the R-134a / CO_2 options are energetically efficient and well established in Europe and that, on the other hand, the alternatives "transcritical CO2" tend to reduce their cost and energy consumption. There are many articles in the literature that compare HFC / CO_2 cascade systems with transcritical CO_2 systems. Recent technological progress allows transcritical CO_2 installations to improve their energy efficiency and to be considered in a temperate / warm climate even if the experience feedback needs to be consolidated for the medium-temperature level. The HFC-HFO mixtures with GWP close to 600, prove to be effective substitutes for R-134a in the HFC / CO_2 cascade systems and can be considered, for some, as quasi-drop-in options. Options with GWP below the threshold of 150 exist (R-455A, R454C). Still very scarce in France, indirect systems or cascade systems with ammonia are used in Europe and are very effective, especially in cascade system.

However, the maintenance needs for **commercial refrigeration** installations using R-404A remain significant. The proposed replacement refrigerants with GWP around 1300 can reduce energy consumption by 4 to 20% depending on the configurations, in the cases studied in the literature.

The **air-conditioning** market is global. It is dominated by Japanese, American, Korean and now Chinese companies. The massively used refrigerant is R-410A. For hermetically sealed systems, R-290 (propane) is an option but its use is currently limited to portable units. In split or multi-split systems, the alternative favored by large companies is R-32. The replacement refrigerants for R-407C, which is used to make profitable production lines for R-22 equipment, are R-454C and R-455A. For high-power multi-split systems, VRF and Rooftop systems, there is currently no alternative other than R-32 that is proven more efficient than R-410A.

Heat pumps, other than reversible air conditioners treated above, which transfer the heat in a water loop, use mainly R-410A. Again, R-32 is offered by several Japanese brands. R-290 is already on the market outside Europe and will probably see its use growing in France, driven by European companies. For both replacement refrigerants, the energy efficiency achieved is equal to or greater than that of R-410A.

For **Mobile Air Conditioning**, due to the ban on January 1st 2017 in Europe, refrigerants with GWP greater than 150 (Directive 40/2006), the **R-1234yf** is the refrigerant chosen by the equipment manufacturers. The mass production of automotive air conditioning with this refrigerant, whose efficiency compared to R-134a has been demonstrated, is in place.

Chillers can be segmented according to the type of compression (volumetric, centrifugal) and depending on the power. For centrifugal chillers, the European market is dominated by R-134a. The most common alternative is R-1234ze, which is 5-10% more energy efficient than R134a. The R-1233zd, which is an HCFO, has also established itself outside Europe, replacing the R-123 (HCFC banned by the Montreal Protocol). By order of increasing power, the alternatives for chillers with volumetric compression are R-290, R-32, ammonia, and R-1234ze for the highest power, alternative options allowing both a gain in GWP and a reduction of energy consumption.

For medium-temperature direct expansion systems used in **industrial processes**, ammonia is already widely used as an alternative to R-404A. Other options are R-1234yf or R-1234ze. For low-temperature applications, ammonia is also possible in cascade at both temperature levels. The Ammonia / CO_2 cascade remains the option allowing the best gains in terms of energy consumption. R-404A can also be replaced by R-455A or R-454C, whose measured energy efficiencies are higher than R-404A according to the first feedback. Currently there is no low-GWP mixture and low temperature glide suitable for flooded installations.

Finally, in the field of **refrigerated transport**, the alternative to R-404A is, currently, R-452A. CO_2 technology is now available on the market.

To illustrate the performance of the alternatives to the reference systems, case studies are presented in the field of refrigerated transport, stand-alone display cases and a centralized refrigerating system in a supermarket. In all three cases presented, the performance measures demonstrated a performance improvement of the alternatives compared to the reference systems.

The safe implementation of alternative options requires special skills for operators handling these refrigerants. A number of European directives already require to provide adequate training to personnel working with alternative refrigerants. The lack of a European certification requirement may suggest that there is no binding requirement for training on HFC substitutes, which is not at all the case.

1 - INTRODUCTION

1.1 PURPOSE OF THE STUDY

AFCE is a non-profit association that promotes a responsible attitude towards the use of refrigerants. As such, it follows the regulatory work on halogenated refrigerants and, in general, the energy efficiency of refrigeration systems.

In the continuation of the study published in 2014 on alternatives to the use of HFCs with high GWP, the AFCE asked the same consortium and commissioned EReIE, the Cemafroid and the CITEPA, a second independent study. This second report updates the inventory of available options with a special focus on the impact of available refrigerants on the energy efficiency of equipment.

Since its entry into force on January 1st 2015, the European Regulation (EU) No 517/2014, known as "F-Gas", has introduced a progressive reduction in the placing of HFCs on the European market through the introduction of allocated quotas to producers and importers in the European territory as well as sectorial bans of use fornew equipment and for the maintenance of refrigeration and air-conditioning installations. As a result, the regulation and the use of their quotas by HFC producers have significantly changed the market.

At the same time, Ecodesign regulations impose increasingly ambitious targets in terms of energy efficiency.

Over the past five years, the HFC offer has evolved considerably: new refrigerants, HFOs, have been developed and, on the other hand, hydrocarbons, ammonia and CO_2 have seen their uses significantly widen in certain segments.

The objectives of the study are:

- To list and describe, from a thermodynamic point of view, the refrigerants available, by application, to replace traditionally used high-GWP HFCs: hydrocarbons, ammonia, CO_2, pure HFOs, mixtures composed of HFCs and HFOs, even HC;
- To identify the associated technical options but also the technological evolutions related to the use of these alternatives;
- Analyze the advantages and disadvantages of each option, particularly in terms of energy consumption;
- Explain the standards and regulations associated with the use of the proposed alternatives;
- To make an inventory of existing training courses necessary for the implementation of alternatives.

The calculation of environmental indicators (LCCP or TEWI) is outside the scope of this study. An analysis of this magnitude could not be conducted as part of this study but will, as far as possible, refer to the publications identified on the subject.

Note: The LCCP (Life Cycle Climate Performance) distinguishes direct emissions, related to the refrigerant use during the equipment lifetime, from indirect emissions related to both the energy consumption of the equipment but also to the equipment manufacturing, the refrigerant production and the equipment dismantling (IIR, 2015).

The TEWI (Total Equivalent Warming Impact), another indicator, only considers energy consumption in the estimation of indirect emissions.

These indicators are used in several studies to compare the environmental impact of refrigerants in certain equipment by considering all the emissions, both direct depending on the GWP and the emission rates, but also indirect, mainly the emissions related to the energy consumption of the equipment.

In the LCCP approach, all indirect emissions seek to be accounted for but with a large number of approximations, and non-energy-consumption emissions account for less than 10% of total emissions. Software dedicated to certain applications has been developed (Mobile air conditioning, Heat pumps, ...).

The objective of this study is mainly to update the previous study considering all the alternatives currently on the market, focusing the analysis on the energy efficiency gains they can offer in view of the latest publications. The disadvantages, in terms of safety, technicality, toxicity or availability will also be underlined.

1.2 Sponsors

AFCE 55b, Rue Porte Rabel 61300 L'AIGLE	**EDF – Département R&D** Avenue des Renardières F-77818 Moret sur Loing
ADC3R Immeuble Le Diamant, 14, rue de la République, 92800 Puteaux	**DAIKIN** ZA du Petit Nanterre 31, rue des Hautes Pâtures 92737 Nanterre Cedex
ASERCOM 35 rue du Congrès B-1000 BRUXELLES	**UNICLIMA** 11-17, rue de l'Amiral Hamelin 75783 PARIS CEDEX 16

1.3 Presentation of Organizations that carried out the study

The consortium performing this study consists of:

• the CEMAFROID, center of expertise of the cold chain, coordinator of the study

• the CITEPA, State Operator for the Ministry of the Environment in charge of the development, verification and dissemination of information on greenhouse gases and air pollutants.

• EReIE, a company specializing in refrigeration technology.

These three entities have complementary skills and personnel who have extended knowledge of refrigeration systems, a global reputation on refrigerant inventories, a network of relationships with all stakeholders: ministries, he European Commission, chemical engineering companies specialized in refrigerants, large companies in climate and refrigeration engineering, large user companies, professional unions.

In addition, the activities of these organizations are independent of the manufacturing and commercialization activities of the technologies covered by the study, which ensures an unbiased and independent assessment of the state of the art.

2 - METHODOLOGICAL APPROACH OF THE STUDY

2.1 EVOLUTIONS COMPARED TO THE PREVIOUS STUDY

Compared to the study performed in 2014 by the same consortium for AFCE, certain evolutions are to be noted:

- Only pure refrigerants or mixtures with a standardized number according to the latest update of ASHRAE 34 will be considered;
- The comparison of the proposed options will be based on the feedback of the owners and operators referred to facilities using these alternatives, on guarantees from equipment manufacturers or on publications submitted to a review committee.
- The study will focus on alternative options for new equipment considering the energy efficiency of the proposed options.
- Retrofit options, for which the energy efficiency data are more uncertain (because the optimization is limited to the settings of the existing installation) will also be listed.
- Case studies performed by the Cemafroid will illustrate comparisons of alternatives with the reference refrigerants.

Similarly, to the previous study, the structuration for the description of equipment will be based on that of the *Refrigeration, Air-conditioning and Heat Pumps Technical Option Committee* by UNEP, which is present 8 large application domains:

- Domestic refrigeration,
- Food refrigeration,
- Air Conditioning,
- Heat pumps,
- Mobile Air Conditioning,
- Chillers,
- Refrigeration in Food Processing,
- Refrigerated transport.

Within these sectors, different types of installations or equipment are used, differentiated by different technologies (e.g. centrifugal compressor, volumetric compressor), different system structures (direct-expansion system, indirect system including one, even two heat-transfer refrigerant loops) or different refrigerants.

After a regulatory and normative review, the report will present an overview of alternative refrigerants.

Alternatives by sector of equipment will be detailed to present:

- Reference refrigerants, used historically;
- The analysis of commercialized alternatives for new equipment. This will consider lessons learned, literature review, manufacturers' choices and case studies;
- For each sector, an analysis of the refrigerant bank is presented. A bank means refrigerant quantities contained in equipment constituting the installed base in France. Graphs have been established, with the authorization of the Ministry of the Environment, based on the results of the Inventory study of refrigerants - France metropole - Year 2016 by Armines (S. Barrault, A. Zoughaib) in collaboration with EReIE (D. Clodic) on behalf of the Ministry of Ecological and Solidarity Transition. The aim is to show the banks resulting from trends for the use of identified alternatives to systems using high-GWP HFCs and not to count the installed bases using alternatives.

Finally, in a last part, the study will address the needs identified in terms of training.

2.2 THE SUMMARY SHEET BY APPLICATION

A summary sheet is established for each selected application in the segmentation resulting from the analysis of the user sectors of refrigeration and air conditioning. Each summary sheet consists of 3 parts.

The first part is entitled "Description of the reference system" gives the following information for each relevant application:

- The most commonly used refrigerant when the so-called technical reference is based on the use of high-GWP HFCs;
- If it is a mixture, the refrigerants that compose it and in what proportions;
- The GWP of the refrigerant (s) used. The GWP values selected are those published in the IPCC's *4th assessment report*. From those values, the GWP of blends composed of several pure refrigerants is calculated and the value is rounded to the unit. This is valid for the GWP of the summary sheets as well as for any GWP value specified in this report;
- The refrigerant safety category according to the NF EN 378 or ASHRAE 34 standard;
- The average charge per equipment, given in kilograms;
- The equipment lifetime. This theoretical lifetime does not consider the effect that anticipated restriction measures would have on the use of the commonly used refrigerant. This lifetime therefore provides an indicator that makes it possible to judge whether a possible restriction measure would have an impact or not on the obsolescence of the installed base of equipment;
- The refrigerant bank in France;
- A technical rationale for the choice of this option that has been made in the past;
- A summary of the regulations applicable to the sector in France and in Europe.

The second part, entitled "Technical Alternatives for New Installations" presents the elements hereafter. For each case, several alternative options are possible, the following elements are then presented for each alternative.

- The name of the alternative option;
- Refrigerant(s) used for this option;
- A synthesis of the regulation applicable to the option;
- The 6 technical-economical parameters retained allowing to compare this alternative option to the original one:
    - The GWP value;
    - The energy efficiency level, based on the results found in the literature;
    - The volumetric capacity compared to that of the reference;
    - Safety. This criterion is based on the classification of refrigerants according to the Standard NF EN 378 and as a function of their toxicity (A/B) and of their flammability (1/2/2L/3);
    - The cost of the option, not including maintenance;
    - The availability, considering volumes proposed for sale by refrigerant producers according to their policy, and the state of development of the refrigerant.
- A check-up on the benefits of the option based on the literature and the interviews performed with stakeholders in the context of the study. The limitations and benefits can be related, for example, to financial aspects, lack of training, feedback from existing experiences ...
- A multicriteria indicator that graphically represents the 6 technical and economical parameters in order to highlight the advantages and disadvantages of each option. More details are given below.

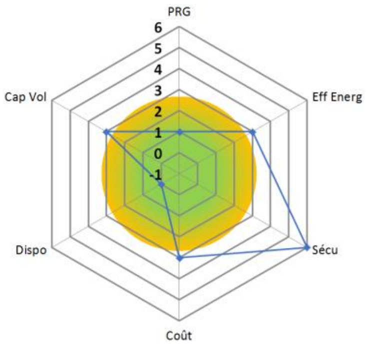


Figure 2-1: Multicriteria Indicator
(radar type)

- The third part entitled “Existing alternative techniques for retrofit” presents the same information as in Part 2

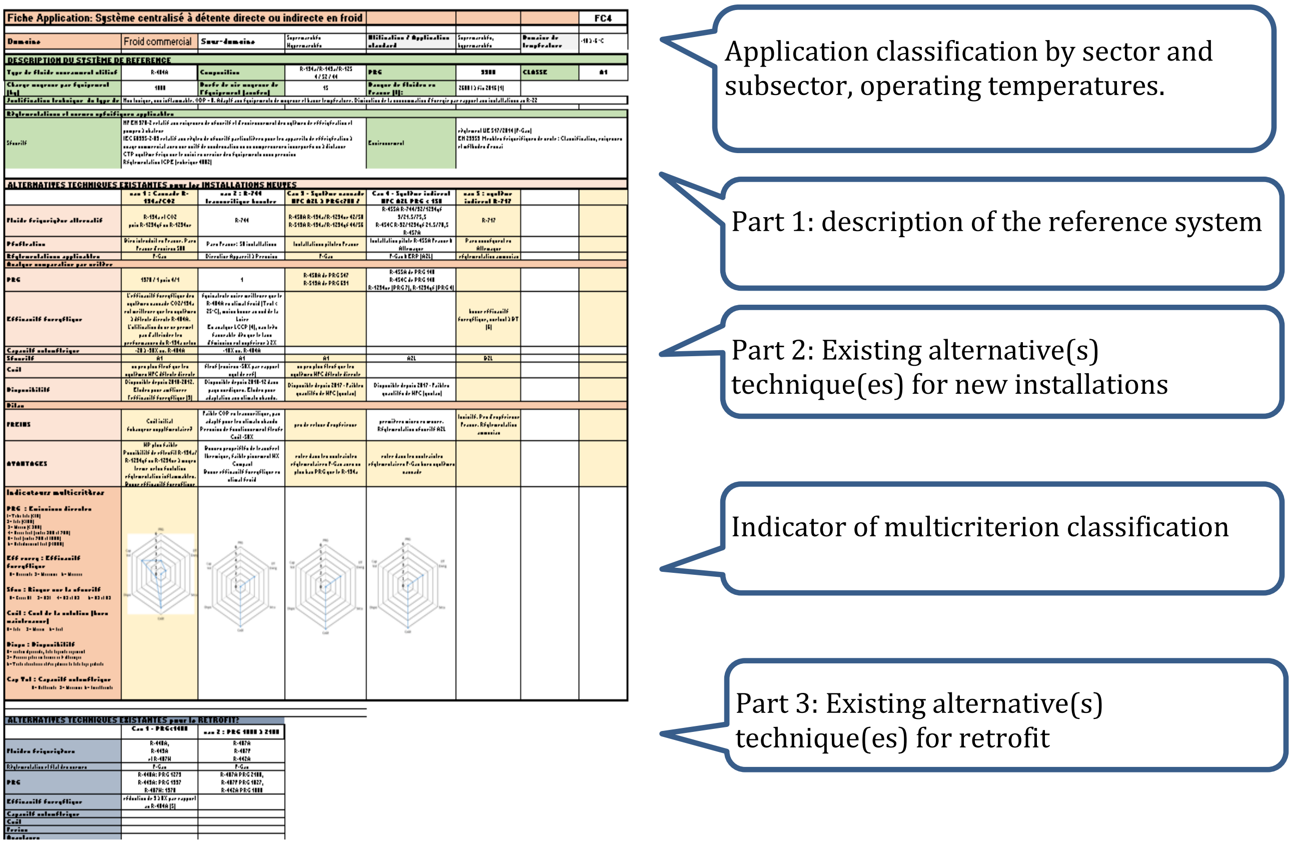


Figure 2-2: Overview of an application summary sheet.

For an application summary sheet, each option is noted using a multicriteria indicator. A score of 0 to 6 is assigned to each of the 6 selected technical and economical parameters. The "0" is the best score that can be awarded, and the "6" the worst. On these "radars" a small surface therefore corresponds to an interesting option. The rating criteria are as follows.

Table 2-1: Notation of criterion.

<table>
<tr><th rowspan="2">Criteria</th><th rowspan="2">Code</th><th colspan="7">Indices</th></tr>
<tr><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td>GWP</td><td>GWP</td><td colspan="2">Very low (<10)</td><td>Low (<150)</td><td>Medium (<300)</td><td>Assez fort (<750)</td><td>High (<1500)</td><td>Very high (>1500)</td></tr>
<tr><td>Energy efficiency</td><td>Energ Eff</td><td colspan="3">Excellent</td><td colspan="2">Medium (<300)</td><td colspan="2">Bad</td></tr>
<tr><td>Safety risk</td><td>Safety</td><td colspan="2">Class A1</td><td colspan="2">Classes A2L and B2L</td><td colspan="2">Classes A2 and B2</td><td>Classes A3 and B3</td></tr>
<tr><td>Option cost</td><td>Cost</td><td colspan="3">Low</td><td colspan="2">Medium</td><td colspan="2">High</td></tr>
<tr><td>Availability</td><td>Avail</td><td colspan="3">Mature option, widely available refrigerant</td><td colspan="2">Several pilots in France or foreign countrieser</td><td colspan="2">Laboratory tests and/or foreseeablerefrigerant shortage</td></tr>
<tr><td>Volumetric capacity</td><td>Vol Cap</td><td colspan="3">Sufficient</td><td colspan="2">Medium</td><td colspan="2">Insufficient</td></tr>
</table>

3 - Regulation and standard state of the art

3.1 Introduction

Refrigeration installations and heat pumps are subject to a binding regulatory and normative framework on safety issues, refrigerants with an environmental impact and the energy efficiency of new equipment.

This chapter addresses all regulations that may impact the choice of refrigerants to replace high-GWP refrigerants:

- EU Regulation n°517/2014 called “F-Gas”,
- Service follow-up of Pressure refrigeration equipment
- Eco-Design Directive,
- NF EN 378 Standard,
- Product Standard.

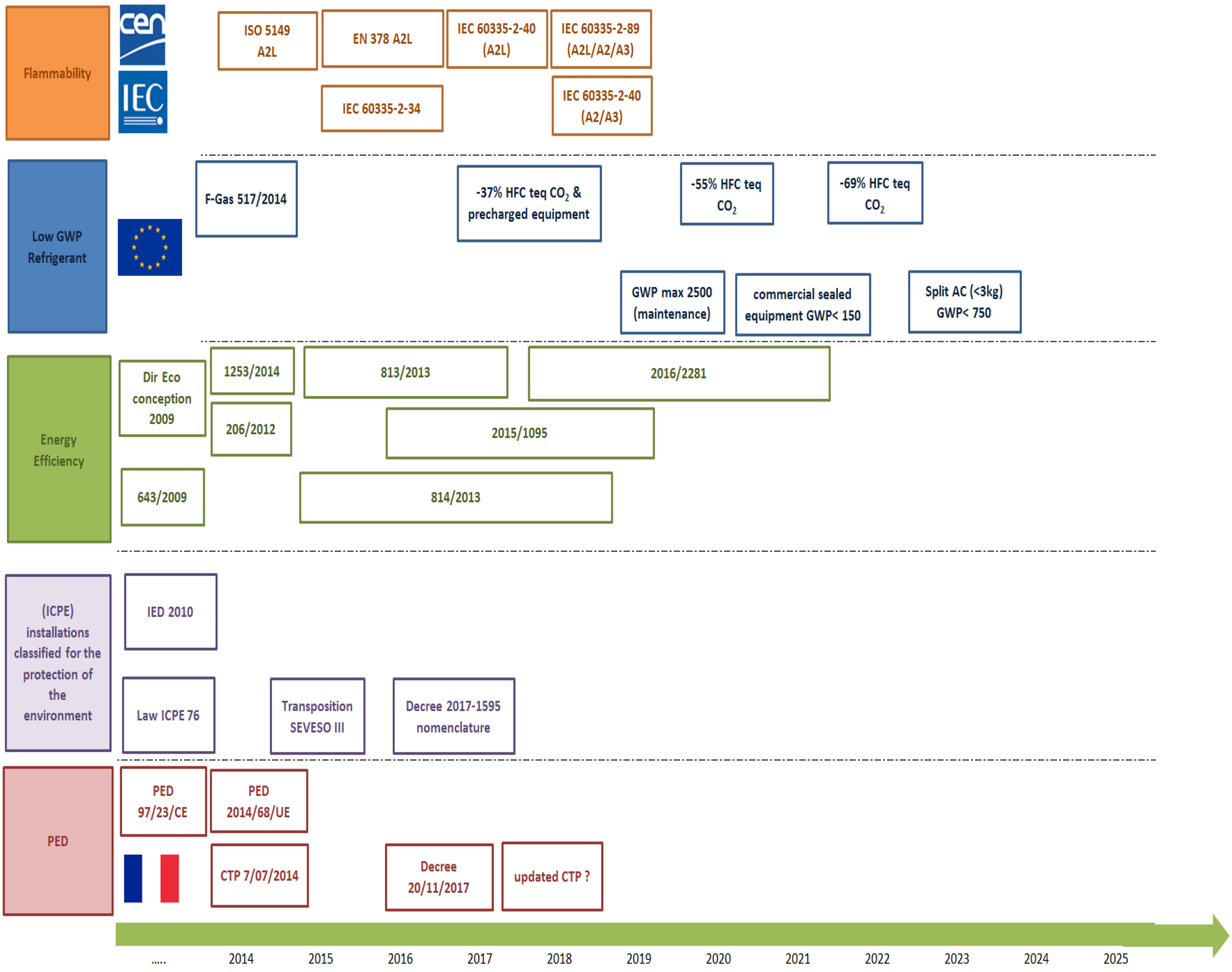


Figure 3-1: Schedule of enter into force of regulations and standards.

3.2 ENVIRONMENT: F-GAS

The regulation (UE) n°517/2014 called « F-Gas » repeals and replaces the previous Regulation (EC) 842/2006, the applicable rules of which are set out in the Environment Code Book V, Title IV, Chapter III, Section 6 and regulate the conditions for placing on the market, use, recovery and destruction of refrigerants used in refrigerating and air conditioning equipment containing more than 2 kg of refrigerant.

The F-Gas European regulation, into force since January 1st 2015, leads to decreasing greenhouse-gas emissions due to the use of fluorinated refrigerants following a progressive schedule until 2030. The objective is ambitious since the aim is to achieve a reduction of 79% of emissions compared to the reference level (2009-2012), see Table 3-6.

Greenhouse-gas emissions are measured in tonnes equivalent CO_2 and are the product of the quantity of fluorinated refrigerant (expressed in kg) by the GWP of the said refrigerant.

For example, for a refrigeration system with a charge equivalent to 5 $TeqCO_2$, the refrigerant quantity varies as shown in Table 3-1.

Table 3-1: Equivalence 5 Teq according to the used refrigerant.

Refrigerant	R-134a – GWP 1430	R-404A – GWP 3922	R-410A – GWP 2088
5 $TeqCO_2$	3.5 kg	1.3 kg	2.4 kg

This diminution of emissions is scheduled according two major axes:

- A progressive reduction of high-GWP halogenated refrigerants (Application of quotas of placing on the market expressed in $TeqCO_2$);
- Sectorial prohibitions, except for military applications, where technical alternatives exist.

Sectorial prohibitions concern the following equipment and uses.

- **Hermetically-sealed equipment**

Table 3-2: Hermetically-sealed equipment

Equipment type	Conditionnality	Prohibition date
Hermetic commercial	GWP≥2500	January 1st 2020
Hermetic commercial	PRP≥150	January 1st 2022

- **Refrigeration equipment**

Table 3-3 : Refrigeration equipment

Equipment type	Conditionality	Prohibition date
Stationary refrigeration equipment	GWP≥2500 (or relies upon) Except application for -50°C	January 1st 2020
Multipack centralized commercial refrigeration systems	Rated capacity ≥ 40 kW GWP ≥ 150 (or relies upon) except cascade primary if GWP < 1500	January 1st 2022

- **Refrigeration equipment**

Table 3-4: Refrigeration equipment.

Equipment type	Conditionality	Prohibition date
Portable room air conditioning (hermetically sealed equipment)	GWP≥150	January 1st 2020
Single-split air-conditioning systems	GWP≥750 (or dependent) Charge < 3 kg	January 1st 2025

- **Service and maintenance**

Table 3-5: Service and maintenance.

Origin of the fluorinated GHG	Conditionality	Prohibition date
Generality	GWP≥2500 Refrigerant charge < 40 TeqCO_2 Except application for -50°C	January 1st 2020
Regenerated fluorinated GHG	GWP≥2500 Existing equipment Ad hoc tag	January 1st 2030
Recycled fluorinated GHG	GWP≥2500 Recovered from the same type of equipment. The undertaker that recovered it or for which it has been recovered Existing equipment Ad hoc tag	January 1st 2030

The table here below presents synthetically the different authorized limits of the F-gas.

Table 3-6: Limits of authorization of the F-gas.

Display cases / stationary refrigeration equipment / centralized commercial systems / movable room air conditioner / single-split air conditioning system.

<table>
<tr><th>Dates on January 1st</th><th>2014</th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th>2020</th><th>2021</th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th></tr>
<tr><td>HFC quantity</td><td colspan="2">100%</td><td colspan="2">93%</td><td colspan="3">63%</td><td colspan="3">45%</td><td colspan="3">31%</td><td colspan="3">24%</td><td>21%</td></tr>
<tr><td rowspan="6">New equipment</td><td>Domestic appliances GWP ≥ 150</td><td colspan="16"></td></tr>
<tr><td colspan="6">Commercial equipment GWP ≥ 2500</td><td colspan="2">GWP ≥ 150</td><td colspan="9"></td></tr>
<tr><td colspan="6">Stationary refrigeration GWP ≥ 2500</td><td colspan="11"></td></tr>
<tr><td colspan="8">Commercial refrigeration > 40 kW and GWP ≥150</td><td colspan="9"></td></tr>
<tr><td colspan="6">Mobile air conditioning GWP ≥ 150</td><td colspan="11"></td></tr>
<tr><td colspan="11">Split system air-conditioning <3 kg HFC, GWP ≥ 750</td><td colspan="6"></td></tr>
<tr><td rowspan="2">Maintenance</td><td colspan="6">GWP ≥ 2500, charge >40 TeqCO2</td><td colspan="11"></td></tr>
<tr><td colspan="16">Regenerated and recycled refrigerants, GWP ≥ 2500</td><td></td></tr>
<tr><td>Labelling</td><td colspan="3">No labelling</td><td colspan="14"></td></tr>
</table>

Phase 2 of the schedule (as of 2018) is very restrictive since it requires both:

- Starting in 2018: Reduction by 37% of HFC quantities put on the market in tonnes of CO_2 equivalent referred to the reference threshold;

- Starting in 2020: Prohibition of the use of HFCs with GWP greater or equal to 2500 except for the maintenance of existing installations with an HFC charge less than 40 tonnes equivalent CO_2

The analysis of the HFC market in 2018 shows the first consequences of the phase down:

- Rapid abandonment of high-GWP refrigerants, including when there is no associated sectorial ban;

- Extension of the effects of the quotas put on the refrigerant market with a GWP greater than 2000 in order to achieve the overall objectives.

The quota management being relative to the quantities placed on the market, this means that only the handling of virgin refrigerant is considered; thus, a system can continue to operate regardless of the refrigerant that circulates there when it is not necessary to handle it.

The handling of high-GWP refrigerants recycled or reclaimed is not considered in sectorial bans, and is not part of the quotas. This means that the handling of recovered refrigerant is possible until 2030.

Fluorinated refrigerants are subject to the regulation relating to installations classified for the protection of the environment (ICPE 4802 heading soon to be replaced by item 1185). The requirements are different depending on whether the refrigerant is used as a refrigerant in a refrigeration system or stored. These requirements are defined in the Ministerial Decree of 4 August 2014.

Accueil | Réglementation | Aide réglementaire | Guides et BREF | Recherche

Autres versions
- Version PDF
- Version imprimable

A propos du document
- Type : Rubrique de la nomenclature
- Date d'entrée en application : 01/06/2015
- Etat : en vigueur

4802. Fabrication, emploi ou stockage de gaz à effet de serre fluorés visés par le règlement (CE) n° 842/2006 ou de substances qui appauvrissent la couche d'ozone visées par le règlement (CE) n° 1005/2009.

4.8 Autres substances et mélanges nommément désignés

(Décret n° 2014-285 du 3 mars 2014, article 4 et Décret n° 2015-1200 du 29 septembre 2015)
Gaz à effet de serre fluorés visés à l'annexe I du règlement (UE) n° 517/2014 relatif aux gaz à effet de serre fluorés et abrogeant le règlement (CE) n° 842/2006 ou substances qui appauvrissent la couche d'ozone visées par le règlement (CE) n° 1005/2009 (fabrication, emploi, stockage).

1. Fabrication, conditionnement et emploi autres que ceux mentionnés au 2 et à l'exclusion du nettoyage à sec de produits textiles visé par la rubrique 2345, du nettoyage, dégraissage, décapage de surfaces visées par la rubrique 2564, de la fabrication en quantité industrielle par transformation chimique ou biologique d'hydrocarbures halogénés visée par la rubrique 3410-f et de l'emploi d'hexafluorure de soufre dans les appareillages de connexion à haute tension. Le volume des équipements susceptibles de contenir des fluides étant	
a) Supérieure à 800 l	(A-1)
b) Supérieure à 80 l, mais inférieure ou égale à 800 l	(D)
2. Emploi dans des équipements clos en exploitation.	
a) Equipements frigorifiques ou climatiques (y compris pompe à chaleur) de capacité unitaire supérieure à 2 kg, la quantité cumulée de fluide susceptible d'être présente dans l'installation étant supérieure ou égale à 300 kg	(DC)
b) Equipements d'extinction, la quantité cumulée de fluide susceptible d'être présente dans l'installation étant supérieure à 200 kg	(D)
3. Stockage de fluides vierges, recyclés ou régénérés, à l'exception du stockage temporaire.	
1. Fluides autres que l'hexafluorure de soufre : la quantité de fluide susceptible d'être présente dans l'installation étant :	
a) En récipient de capacité unitaire supérieure ou égale à 400 l	(D)
b) Supérieure à 1 t et en récipients de capacité unitaire inférieure à 400 l	(D)
2. Cas de l'hexafluorure de soufre : la quantité de fluide susceptible d'être présente dans l'installation étant supérieure à 150 kg quel que soit le conditionnement	(D)

Régime de la déclaration : Arrêté du 04/08/14 relatif aux prescriptions générales applicables aux installations classées pour la protection de l'environnement soumises à déclaration sous la rubrique n° 4802

Figure 3-2: Item ICPE 4802: definition of conditions.

3.3 Safety

3.3.1 NF EN 378

3.3.1.1 Introduction

A standard, by nature of voluntary application, is only necessary if it is referenced in a private contract or if a regulation makes it mandatory.

Published in spring 2017, the new version of the standard NF EN 378 does not derogate to this rule, and updates safety and environmental requirements related to refrigeration systems and heat pumps.

It considers the latest developments generated by regulatory constraints on refrigerants and imposed in particular by the F-Gas.

It incorporates the new classification of refrigerants to which a new category of "slightly flammable" refrigerant has been added and defines the appropriate measures.

The new standard introduces new indexes (RCL, QLAV, QLMV) for the calculation of the limit of the refrigerant charge.

3.3.1.2 Presentation of the standard

The standard applies to both stationary and portable thermodynamic systems of all sizes, including heat pumps, cooling or secondary heating systems, and the locations of these refrigeration systems. It excludes mobile air conditioning. It is structured in 4 parts so as to treat the whole life cycle of a system:

- NF EN 378-1: Basic requirements, definition, classification and selection criteria
- NF EN 378-2: Design, construction, tests, labelling and documentation
- NF EN 378-3: Installation in-situ and protection of people
- NF EN 378-4: Operation, maintenance, repair and recovery.

3.3.1.3 Purpose of the standard

The requirements of the standard are intended to control the inherent dangers of refrigeration systems, in particular those related to the physicochemical characteristics of the used refrigerants, the temperatures and the pressure of operation. Appendix G of Part I lists these potential risks and the CETIM Guide on Standard NF EN 378 is a detailed part of the risk analysis.

The proposed risk mitigation measures are very diverse. They consider all the phases of life of the systems and are addressed to all the actors: manufacturers, installers, maintainers and operators.

Other product standards complement the regulatory and normative framework and are subject to further risk reduction measures. They must be identified, appreciated (thanks to a risk analysis).

The standard considers in its prescriptions several factors and modulates its requirements by relying on various classifications defined here after.

3.3.1.4 Refrigerant classification

The refrigerant safety class is the combination of the toxicity class (A or B) and the flammability class (1, 2L, 2, or 3) presented in the table below. Class 2L refrigerants have a lower combustion speed than Class 2 refrigerants, reducing the likelihood and consequences of ignition.

Table 3-7: Classification of refrigerants as a function of their flammability and toxicity.

Flammability	Toxicity	
	Low	High
Non-flammable	A1	B1
Slightly flammable	A2L	B2L
Moderately flammable	A2	B2
Highly flammable	A3	B3

A list presented in Annex E of the standard NF EN 378-1 specifies the safety class of a large number of refrigerants and also information on their main physico-chemical characteristics.

Table 3-8: Characteristics of refrigerants.

Group of PED refrigerants	Group that allows the characterization of the dangerous nature of a refrigerant under the Pressure Equipment Directive. Group 2 refrigerants correspond to safety classes A1, B1 and some A2Ls. Group 1 refrigerants considered hazardous correspond to safety classes A2, A3, B2L and the majority of A2Ls.
Practical limit (kg/m^3)	Practical limit of a refrigerant: represents the highest level of concentration in an occupied space that does not cause any harmful (acute) effect for the emergency evacuation and does not generate any risk of ignition of the refrigerant. It is used to determine the maximum charge for this refrigerant for a specific application.
ATEL (kg/m^3)	Acute Toxicity Exposure Limit (ATEL): The maximum recommended concentration of refrigerant determined in accordance with NF EN 378 and intended to reduce the risk of acute toxicity to humans in the event of a refrigerant discharge.
ODL (kg/m^3)	Oxygen Deprivation Limit (ODL): The concentration of a refrigerant or other gas that results in insufficient oxygen for normal breathing
LFL (kg/m^3)	Lower Flammability Limit: A minimum concentration of refrigerant capable of propagating a flame in a homogeneous mixture of refrigerant and air
RCL	Refrigerant concentration limit: maximum concentration of refrigerant in the air established to reduce the risks of acute toxicity, asphyxiation and ignition
QLAV	Quantity limit with additional ventilation: density of refrigerant charge which, when exceeded, instantly generates a dangerous situation if the total charge escapes into the occupied space
QLMV	Quantity limit with minimum ventilation: density of refrigerant charge that would result in a concentration equal to RCL in a non-airtight room in the event of a moderately severe refrigerant leak
GWP	Global Warning Potential

Refrigerants used until now in refrigeration and HVAC equipment mainly belong to safety class A1 (R-404A, R-410A, R-134a, R-407C, etc.). However, with F-GAS limiting the use of high-GWP HFCs, the market opens up to alternative refrigerants with lower GWP but higher flammability characteristics. R-32 is an example and its class is A2L. Table 3.10 shows the characteristics of some of these refrigerants.

Table 3-9: Refrigerants commonly used currently.

ASHRAE Classification	R-134a	R-404A	R-407C	R-410A	R-32
Composition	1,1,1,2-Tétrafluoro-ethane	R-125/ R-143a/ R-134a	R-32/ R-125/ R-134a	R-32/ R-125	Difluoro-methane
Safety class	A1	A1	A1	A1	A2L
PED fluid group	2	2	2	2	1
Practical limits	0.25	0.52	0.31	0.44	0.061
ATEL/ODL	0.21	0.52	0.29	0.42	0.30
LFL	NI	NI	NI	NI	0,307
GWP	1430	3922	1774	2088	675

Table 3-10: So-called “natural” refrigerants.

ASHRAE classification	R-290	R-600a	R-717	R-744
Composition	Propane	Isobutane	Ammoniac	CO_2
Safety class	A3	A3	B2L	A1
PED fluid group	1	1	1	2
Practical limit	0.008	0.011	0.00035	0.1
ATEL/ODL	0.09	0.059	0.00022	0.072
LFL	0.038	0.043	0.116	NI
GWP	3	3	0	1

Table 3-11: HFO and HFC-HFO mixtures.

ASHRAE classification	R-1234yf	R-1234ze(E)	R-448A	R-449A	R-452A
Composition	2,3,3,3-tétrafluoroprop-1-ène	Trans-1,3,3,3-tétrafluoroprop-1-ène	R-32/ R-125 / R-1234yf/ R-134a/ R-1234ze(E)	R-32/ R-125/ R-1234yf/ R-134a	R-32/ R-125/ R-1234yf
Safety class	A2L	A2L*	A1	A1	A1
PED fluid group	1	2*	2	2	2
Practical limits	0.058	0.061	0.388	0.357	0.423
ATEL/ODL	0.47	0.28	0.388	0.357	0.423
LFL	0.289	0.303	NI	NI	NI
GWP	4	7	1387	1397	2 140

* In accordance with the ISO 817test conditions, the refrigerant is classified in 2L; however, the PED refrigerant group is 2, based on CLP Regulation (EC) 1272/2008.

3.3.1.5 Classification of occupied places

An incident occurring in an open access area will have more serious consequences than in an area where access is restricted and limited to a few people trained in security measures. The standard classifies areas of occupancy into three categories of access based on the peoples' security that can be directly affected in the event of abnormal operation of the refrigeration system. Security considerations consider the location, the number of potential occupants and the type of people who can enter. This classification is presented in Table 3-12.

Table 3-12: Categories of access based on occupancy.

Access category	General characteristics	Examples
General access a	Rooms, parts of building, buildings: • sleeping facilities are provided • people are limited in their movement • an uncontrolled number of people are present • anyone who has access without personally being aware of the institution's security measures	Public buildings: Hospitals, law courts, supermarkets, schools, concert halls, hotels, restaurants…
Monitored access b	Rooms, parts of building, buildings where only a limited number of people can meet together, some of them being necessarily informed of safety measures of the establishment	Offices or professional spaces, laboratories, factories, etc.…
Restricted Access c	Rooms, parts of building, buildings where have access only authorized persons who are aware of the general and special security measures of the establishment and where the fabrication, processing or storage of equipment or products is done on site	Manufacturing facility (chemical or food), storage, non-public areas in supermarkets …

3.3.1.6 Classification of locations of refrigeration systems

The location of refrigeration systems is also a key factor to consider when assessing the level of risk involved and determining appropriate safety measures. The standard considers in its requirements four classes of locations presented in Table 3-13.

Table 3-13: Classification based on the location refrigeration systems.

Location class	Location of refrigeration systems or parts containing refrigerant
I	Located in a non-occupied space, which means an enclosed space of a building occupied by people for a significant period of time
II	Compressor and pressure vessel (HP side) located in a machinery room or in the open air, the other parts in the occupied space
III	In a machinery room or in the open air. A machinery room being defined as an enclosed space with mechanical ventilation, isolated from accessible and non-accessible areas, intended to contain system components
IV	In a ventilated enclosure (system of specific industrial design)

3.3.1.7 Classification refrigeration systems

The architecture can be different depending on the system and greatly impact the level of risks incurred in case of abnormal operation. The standard classifies the various systems. In particular, it distinguishes direct and indirect systems and specifies the relationship with the location classification.

3.3.1.8 Limitation of refrigerant charges

The quantity of refrigerant contained in the refrigeration system is also critical in case of incident. The standard provides charge restrictions modulated according to the combination of the above-mentioned classification factors and considering the application (comfort or else) for which the system is intended.

This is obviously to avoid, in case of leakage, concentrations that could lead to risks of acute toxicity, asphyxiation or flammability, in any confined space where these refrigerants could escape directly or, under certain circumstances, by means of a heat transfer refrigerant. These provisions affect the choice of the system and the possible locations.

The following tables show the charge limits for Class A1 and A2L refrigerants, respectively.

Table 3-14: Higher-charge limits.

	Flammability data according to ISO 817				Ceiling charge of systems based on flammability In occupied spaces (location classes I and II) According to NF EN 378		
Refrigerant	Classification Iso 817	LFL [kg/m^3]	LFL [%=Vol/Vol]	Vapor density at 25°C kg/m^3	Ceiling 1 Without constraint Base Limit kg	Ceiling 2 Without constraint kg	Ceiling 3 With constraint + safety measure kg
R-32	A2L	0.307	14.41%	2.13	1.84	11.97	59.87
R-1234yf	A2L	0.289	6.2%	4.66	1.73	11.27	56.36
R-1234ze	A2L	0.303	6.5%	4.66	1.82	11.82	59.09
R-143a	A2L	0.282	8.2%	3.44	1.69	11	54.99
R-152a	A2	0.13	4.81%	2.7	0.52	3.38	16.9
R-1270	A2	0.046	2.67%	1.72	0.18	1.2	5.98
R-290	A3	0.038	2.11%	1.8	0.15	0.99	1.5
R-600a	A3	0.043	2.38%	2.38	0.17	1.12	1.5

The charge restriction requirement is determined on the basis of the most stringent allowable charge in the calculations based on toxicity and flammability.

Until now, the computation of the charge limit, especially for A1 refrigerants, was to multiply the volume of the smallest of the rooms, in which the refrigerant could escape, by their practical limit. From now on, the standard makes it possible to base the calculation on new indexes RCL, QLMV and QLAV. These three indexes allow to consider the level of ventilation of premises. A concentration level is accepted beyond the RCL limit (for lowest floor in the basement) or QLMV (for other floors) subject to the implementation of an additional safety measure contributing to the control of the danger in case of leakage. Beyond the QLAV limit, at least two additional measurements are required (additional emergency ventilation, alarms or detectors ...). The standard specifies the characteristics of the additional systems to be implemented.

3.3.1.9 Rules related to the design and realization of refrigeration circuits

The standard reiterates in Part II the requirements of the previous standard on the design and in-situ realization of refrigerant circuits: the nature and type of tubes and fittings, accessories, supporting, location, accessibility etc.

3.3.1.10 Tests and commissioning of the installation

The standard also incorporates from the previous standard various commissioning tests: resistance to pressure, sealing, operation of the safety devices of the complete installation before commissioning.

In this part are also indicated the markings to be made (machines, pipes) and on the technical documentation to be provided and their contents (constitution of the DOE and the descriptive file of pressure equipment in particular)

3.3.1.11 Operation, maintenance, repair and recovery

The requirements for maintenance, recovery, reuse and disposal of refrigeration systems are covered in Part IV of the standard. It specifies the necessary skills for the personnel, the handling and storage modes of the refrigerants.

This part also specifies the points to check during in-operation checks. An amendment has recently been published to specify the frequency of maintenance operations according to the type of equipment and the refrigerant charge of the installation.

3.3.2 IN SERVICE TRACKING OF PRESSURIZED EQUIPMENT

3.3.2.1 Regulatory frame

Directive 97/23 / EC on pressure equipment, known as PED was transposed into French law by Decree 99-1046 of 13 December 1999; it covers the provisions relating to the design, manufacture and conformity assessment of pressure equipment with a maximum allowable pressure greater than 0.5 bar. Equipment which conformity with the directive is certified bears the CE marking.

Directive 97/23 / EC was revised under the name of Directive 2014/68 / EU of the European Parliament and of the Council of 15 May 2014 on the harmonization of the laws of the Member States concerning the availability on the market of pressure equipment. The reshuffle focuses mainly on additional explanations for the Directive.

In its foreword, in (7), it states:

“This Directive should also apply to assemblies composed of several pieces of pressure equipment assembled to constitute an integrated and functional whole. Those assemblies may range from simple assemblies such as pressure cookers to complex assemblies such as water tube boilers. If the manufacturer of an assembly intends to place it on the market and put it into service as an assembly — and not in the form of its constituent non-assembled elements — that assembly should comply with this Directive. However, this Directive should not apply to the assembly of pressure equipment on the site and under the responsibility of a user who is not the manufacturer, as in the case of industrial installations.”

Decree 99-1046 has since been repealed, with effect from January 1st 2018, by Decree No. 2016-1925 of 28 December 2016. This last decree aims to continue the insertion of the "PED" regulation previously implemented by decrees in the Environmental Code (Book V, Title V) within its chapter dedicated to "Products and equipment at risk" (Chapter VII, Articles R557-1 to R557-15).

These provisions are the subject of the new decree of 20 November 2017, whose objective is to maintain the level of safety of the equipment during its operation (Art 17 of the decree) by providing for its installation and commissioning conditions for maintenance, monitoring and control. This new decree, which replaces the amended decree of 15 March 2000, generalizes the implementation of inspection plans that open to operators, who do not have a recognized inspection body (SIR), the possibility of setting up an inspection. based on risk in order to identify, evaluate and materialize events that could compromise the integrity of pressure equipment so as to define the most appropriate frequency, nature and type of control considering the operating conditions and constraints.

The decree leads to operations that are inappropriate for refrigeration systems; the profession has therefore set up a special monitoring protocol through a "Refrigeration System" Technical Workbook, validated by the BSEI decision on July 7, 2014.

3.3.2.2 Vocabulary

- Pressure refrigeration equipment:

They are enclosures (receivers, some heat exchangers, …), piping, safety devices (expansion valves, pressure switches, …) and under pressure devices (valves, filters, …).

- Assembly of pressure refrigeration equipment:

They are several pieces of pressure equipment assembled by a manufacturer (in a factory or on-site) used in refrigeration, air conditioning or heat pump to be an integrated and functional whole.

This assembly has been assessed for compliance with the essential requirements of the PED by a notified body and has a CE marking.

- Refrigeration installation:

Several pressure equipment put together or individually on the market and assembled on site under the responsibility of the operator to constitute a refrigeration system used in refrigeration, air conditioning or as a heat pump.

- Safety devices:

Devices for the protection of pressure equipment against exceeding the permissible limits.

- Pressure devices:

Devices with an operational role and which envelop is under pressure.

3.3.2.3 Classification of equipment

The PED leads to classification of equipment by risk category; these categories are defined by the refrigerant hazard class contained in the PED and by the provisions under which it was designed and manufactured (modules).

There are 4 categories of risk, applicable on the containers and on the pipes, and in a different way on the refrigerants either in liquid or gaseous state.

The risk categories are defined by the maximum allowable pressure (PS), the volume (V) or the diameter (ND) of the equipment.

The PEs have on their nameplate the indication of the modules and / or the indication of the category.

3.3.2.4 Commissioning

Under certain conditions, the commissioning of a PE may force a declaration in the prefecture (Ex: for a group 2 gas container: PS> 4 bars and PS.V> 10,000 bar. Liters).

3.3.2.5 In-service monitoring

In-service monitoring of PEs is governed by the decree of 20 November 2017 and the arrangements described in the Technical Workbook Refrigerant Systems of 7 July 2014.

The Technical Workbook only applies to gaseous refrigerants and for category II. In the event of liquid / vapor mixing, the limit is conditioned by the gas data unless it can be proved that there will never be any gas, this implies its application on all the equipment of a refrigeration installation.

The Notebook includes 5 chapters.

Table 3-15: PED chapters.

<table>
<tr><th colspan="3">A – Generalities applicable to PE</th></tr>
<tr><td>B – Enclosures with specific provisions</td><td>C – PED enclosures</td><td>E - Piping</td></tr>
<tr><td colspan="3">F – Special cases</td></tr>
</table>

It focuses on the following points:

- Initial verification at commissioning

The Initial Verification (IV) is carried out within a period not exceeding 3 months from the date of commissioning (first use by the end user - the transfer of the refrigeration system from the manufacturer to the operator along with a document). Failing this, the date of the final verification test of the fabrication of the container or the piping is taken as a reference for the calculation of the regulatory deadlines mentioned in the following chapters.

It is performed by an authorized person who carries out documentary checks and visual control operations. Furthermore, in the case of an installation, it is also verified the adequacy between the settings of the safety devices and the allowable limits (PS / TS) of the containers they protect.

For a CE assembly this verification was carried out by the manufacturer and the Notified Body as part of the final verification and does not need to be reproduced.

The IV results in a report.

- Periodic inspection (24 or 40 months)

Except specific cases, the periodic exception is carried out with a frequency of 40 months maximum.

It covers documentary checks, visual checks, verification of the condition and operation of the condenser, and verification of safety accessories.

It is performed by an authorized person; it results in a report.

- Periodic requalification

It covers the verification of the performance of previous operations and additional checks, particularly on safety accessories (recalibrating or replacing of valves). The requalification results in a certificate of requalification. This operation can only be carried out by an authorized body.

- Competence of authorized persons and training

The Technical Workbook contains the training program that allows the company manager to empower his staff to follow up PEs in service.

3.3.3 *Safety regulations against fire and panic risks in public buildings (ERP) - Article CH35*

The regulations on safety against fire risks in public buildings are defined by the decree of 25 June 1980 approving the general provisions of the safety regulations against the risk of fire and panic in public buildings (ERP). Article CH35 of this decree is entitled Production, transport and use of cold, sufficiently generic title to include any type of equipment of cold production. Using an old classification of standard NF EN 378/2000, this regulation strictly prohibits the use of flammable refrigerants for the equipment covered by this chapter. This regulation is now obsolete and is the subject of numerous exchanges between the ministry and professionals due to:

- Clarification of the applicable scope of this article, which would apply only to fixed air-conditioning installations and would not apply to commercial refrigeration equipment.
- The evolution of the classification of refrigerants and the introduction of the A2L class not mentioned in the current regulations.

Therefore, regulatory adjustments are necessary to set the rules in CH 35 applicable to air conditioning systems using A2L refrigerants. The lack of recognition of these refrigerants is a barrier to the transition to low-GWP refrigerants. The exclusion of commercial refrigeration equipment from the regulation has led to additional work to establish the acceptable conditions of use of facilities using HCs:

- Guide M fixing the maximum charge in HC (1.5 kg) and the conditions of installation of the hermetic display cases (distance away);
- Ineris study commissioned by the ministry in charge of ecology to confirm the maximum permissible thresholds for class A3 refrigerants in ERPs.

It is therefore expected in the short-term regulatory developments of the CH35 to resolve these issues. In addition, the status of centralized equipment in commercial refrigeration using A2L refrigerants or A3 remains unclear. By excluding it from the scope of the ERP regulation and the current guides and studies, this equipment is in a very uncomfortable legal vacuum for manufacturers.

The AFCE, UNICLIMA and other organizations are actively working with the concerned ministries and INERIS for explicit recognition of A2L refrigerants in the CH35 regulation and the treatment of applications not currently covered in the INERIS report. At the time of the end of the study, there is still no consensus with the industry on the text proposed by the government and the final text is not published yet.

The coherence between the future regulations applicable to the ERP and the Guides (Type Guide M) with the standards applicable to the products will also have to be sought to avoid that the standards are finally more binding than the regulation and place the manufacturers in position of arbitrator.

3.3.4 PRODUCT STANDARDS

3.3.4.1 IEC 60335-2-24: Freezers and refrigerators

This document deals with the safety of refrigerators, freezers, ice makers and ice-cream makers for domestic use or recreational use for camping, caravanning and boating. It also deals with compression devices that use flammable refrigerants.

3.3.4.1.1 Marking and instructions

Compression devices (paragraph 7.1) that use flammable refrigerants must bear the symbol "Warning: risk of fire".

Figure 3-3: Pictogram “Warning; risk of fire”.

Equipment using R-744 in a transcritical refrigeration system must be marked, in essence, with the following warning: "The system contains a refrigerant at high pressure. Do not touch the system. The interview must be done only by qualified persons "

Devices using R-744 in a transcritical refrigeration system must be marked, in essence, with the following warning: "The system contains a refrigerant at high pressure. Do not touch the system. The interview must be done only by qualified persons "

3.3.4.1.2 Constructive provisions

Compression equipment (paragraph 22.103), including enclosures for the protection of a protected cooling system, using flammable refrigerants shall withstand:

- a pressure equal to 3.5 times the saturation vapor pressure of the refrigerant at 70°C for the parts located on the high-pressure side during normal operation;
- a pressure equal to 5 times the saturation vapor pressure of the refrigerant at 20°C for the parts located only on the low-pressure side in normal operation.

Appliances using a transcritical refrigeration system shall have on the high-pressure side of the refrigeration system a safety valve on the compressor or between the compressor and the gas cooler. Between the compressor and the safety valve, no other rupture device or other element other than piping should be found which could cause a pressure drop.

In addition (paragraph 22.106), the refrigerant charge of compression equipment that uses flammable refrigerants in its refrigeration system shall not exceed 150 g per individual refrigeration circuit.

Compression equipment (paragraph 22.109) that uses flammable refrigerants shall be built in such a way that leaking refrigerant does not become so stagnant as to create a fire or explosion hazard in locations outside conservative food compartments where electrical components that produce arcs or sparks are mounted, or in locations where lighting fixtures are mounted.

The surface temperatures that may be exposed to flammable refrigerant leakage shall not exceed the refrigerant ignition temperature specified in Table 3-16, minus 100 K.

In compression equipment (paragraph 22.111) that uses a flammable refrigerant in its cooling system, all possible unintended contact points between uncoated aluminum and copper pipes or between other dissimilar metals shall be protected against galvanic couplings by a concrete means such as the use of sleeves or insulating stops.

3.3.4.2 IEC 60335-2-40: electric heat pumps, air conditioners and dehumidifiers

This document deals with the safety of heat pumps, including heat pumps for domestic hot water, air conditioners and dehumidifiers with hermetic motor compressors, of which the maximum rated voltage is not more than 250 V for single-phase and 600 V units for all other devices.

This standard, which is to be published shortly, is extremely important and we were able to obtain the final draft. This document specifies the rules for the design, installation, marking and maintenance of equipment using 2L and 3 flammable refrigerants. It is currently the most comprehensive document for setting the rules for permissible flammable refrigerant charges flammable according to the volumes of rooms in which these products are installed. The most new and important elements are presented here below.

Markings: equipment containing A3 or 2L flammable refrigerants shall bear the following pictograms on the manufacturer plate

A 3 refrigerant:  Symbol ISO 7010- W021

A2L refrigerant: 

The Annex BB of the standard defines in [kg/m^3] the lower flammability limits in [kg/m^3].

Table 3-16: Refrigerants and their characteristics.

Refrigerant	Refrigerant name	Safety class	Refrigerant ignition temperature [°C]	Refrigerant lower flammability limit [kg/m^3]
R-32	Difluoro-methane	A2L	648	0.307
R-50	Methane	A3	645	0.032
R-143a	1,1,1 - Trifluoroethane	A2L	750	0.282
R-152a	1,1 - Difluoroethane	A2	455	0.13
R-170	Ethane	A3	515	0.038
R-290	Propane	A3	470	0.038
R-600	n-Butane	A3	365	0.038
R-600a	Isobutane	A3	460	0.043
R-1150	Ethylene	A3	425	0.036
R-1270	Propylene	A3	455	0.046
R-142b	1-Chloro -1,1 - Difluoroethane	A2L	750	0.329
R-1234yf	2,3,3,3 - Tetrafluoro - 1 - Propene	A2L	405	0.289
R-1234ze (E)	Trans - 1,3,3,3 - Tetrafluoro - 1 - Propene	A2L	368	0.303

The 25-page Annex GG of the standard defines the charge limits of A3 and A2L refrigerants and requirements for the ventilation and secondary systems.

This standard allows the calculation of the maximum flammable refrigerant charge as a function of the lower flammable limit (see table in Annex BB) and the room volume. The formulas are different for A3 and A2L refrigerants. Specific formulas are used for ventilated and non-ventilated rooms. Equipment built with fans dedicated to the dilution of A2L refrigerants is also defined in case of leakage.

Rules are defined for the secondary systems considering the possibility of leakage of flammable refrigerant via the secondary circuit in case of rupture of tubes or walls of the refrigerant / secondary refrigerant heat exchangers.

Other important rules are defined in the following Annexes

Annex CC: related to transport, marking and storage of equipment using flammable refrigerants

Annex DD: requirements for the operation manual for installation and maintenance of equipment containing flammable refrigerants

Annex FF: Tests for leak simulations

Annex HH: skills of maintenance personnel

Annex JJ: acceptable mode of relay openings to avoid ignition of A2L refrigerants

Annex KK: method of test for ignition of A2L refrigerant by hot surfaces

Annex LL: detection system for A2L refrigerants

Annex MM: test for confirmation of the localization of refrigerant detectors

Annex NN: Flame arrestor verification test of an enclosure containing equipment charged with an A2L refrigerant

3.3.4.3 IEC 60335-2-89: equipment for commercial refrigerating appliances with an incorporated or remote refrigerant unit or compressor

This document addresses the safety of electrical equipment for commercial refrigeration with a built-in compressor or are supplied as two units for assembly into one unit in accordance with the manufacturer's instructions (two-unit system).

Equipment with a charge greater than 150 g of flammable refrigerant in each separate refrigeration circuit are not covered by this standard. For equipment with a charge of more than 150 g of flammable refrigerant in each refrigeration circuit and for the installation, NF EN 378 can be applied.

3.3.4.3.1 Marking and instructions

For equipment using flammable refrigerants, instructions must include information for handling, servicing and disposal of the equipment.

Compression devices (paragraph 7.1) that use flammable refrigerants must bear the symbol "Warning: risk of fire".

Figure 3-4: Pictogram “Warning: Risk of fire”.

Devices using R-744 in a transcritical refrigeration system must be marked, in essence, with the following warning: "The system contains a refrigerant at high pressure. Do not touch the system. Servicing must be done only by qualified personnel".

The instructions for equipment (paragraph 7.12) that use flammable refrigerants shall also include the following warnings:

- WARNING: Keep the ventilation openings free in the enclosure of the appliance or in the mounting structure.
- WARNING: Do no use mechanical devices or other means to accelerate the defrosting process, other than the ones recommended by the manufacturer.
- WARNING: Do not damage the refrigeration circuit.
- WARNING: Do not use electrical devices inside the inside food storage compartments unless they are of the type recommended by the manufacturer.

Instructions for equipment using R-744 in a transcritical refrigeration system must include the following warning:

- WARNING: the refrigeration system is under high pressure. Do not touch. Contact qualified servicing personnel prior disposal.

For appliances intended to be connected to the water supply network for cooling purposes, the instructions shall include information on the maximum allowed temperature of the water supply compatible with safe operation of the appliance

For appliances (paragraph 7.15) that use flammable refrigerants, the marking of the type of flammable refrigerant and the foaming agent of the flammable insulation shall be visible when the moto-compressor is accessed, and, in the case of appliances with a remote refrigerant unit, on piping connections.

The symbol "Warning: risk of fire" must be placed on the nameplate of the unit, near the mention of the type of refrigerant and information on the charge. It must be visible after the installation of the equipment.

3.3.4.3.2 Constructive requirements

Equipment (Paragraph 22.7), including enclosures for the protection of a protected cooling system, that uses flammable refrigerants must withstand:

- a pressure equal to 3.5 times the saturated vapor pressure of the refrigerant at 70°C, or equal to 3.5 times the pressure at the critical temperature if this is less than 70°C, the pressure of the test being rounded up to the nearest 0.5 MPa (5 bar), for parts on the high-pressure side in normal use;
- a pressure equal to 5 times the saturated vapor pressure of the refrigerant at 20 ° C, or equal to 2.5 MPa (25 bar), whichever is greater, the test pressure being rounded to 0.2 MPa (2 bar) higher, for parts only on the low-pressure side in normal use.

Equipment using a transcritical refrigeration system shall have on the high-pressure side of the refrigeration system a safety valve on the compressor or between the compressor and the gas cooler. Between the compressor and the safety valve, no other rupture device or other element other than piping should be found which could cause a pressure drop.

In addition (paragraph 22.105), the refrigerant charge of appliances that use flammable refrigerants in their refrigeration system must not exceed 150 g per separate refrigeration circuit.

Units with a protected refrigeration system (paragraph 22.106) and using flammable refrigerants must be built in such a way as to avoid any risk of fire or explosion if refrigerant leaks from the cooling system.

For compression equipment (paragraph 22.107) with unprotected cooling systems using flammable refrigerants, the electrical components inside the food storage compartments which, under normal or abnormal operating conditions, produce sparks or arcs, and luminaires must be tested and meet the requirements of Appendix BB for Group Food Processes gases or for the refrigerant used.

Temperatures of surfaces (paragraph 22.109) that may be exposed to flammable refrigerant leakage shall not exceed the refrigerant ignition temperature specified in Table 3-16, minus 100 K.

Systems with two assemblies (paragraph 22.114) that use flammable refrigerant shall not be installed using pre-charged refrigerant interconnecting lines.

3.4 ENERGY EFFICIENCY/ECO DESIGN

The European Policy ErP (Energy related Products) aims at improving the energy and environmental efficiency of equipment consuming energy. The EU seeks to achieve the 20-20-20 target, which aims, by 2020, to:

- Reduce CO_2 emissions by 20%
- Reduce by 20% the use of primary energy
- Increase by 20% the share of renewable energies.

It is declined in 2 Directives:

- Ecodesign (or eco-design) 2009/125 / EC: This directive lays down a number of measures to reduce the environmental impact on energy-consuming products throughout their life cycle. It aims at the elimination of the least energy-efficient products on the market.
- Energy labelling (or eco-labelling) 2010/30 / EU: This directive aims to inform consumers and encourage them to buy the most efficient energy-related products with the valuation of their energy classes (A better than G). This is the obligation to display an indication of energy consumption.

The Ecodesign Directive is transcribed into ecodesign regulations specific to each product family described below.

3.4.1 *DOMESTIC REFRIGERATORS AND FREEZERS*

The regulation n°643/2009 establishes eco-design requirements applicable to domestic refrigerators and freezers.

The annual power consumption of products submitted to the present regulations in the European Community has been estimated at 122 TWh in 2005, which is 56 million of tonnes equivalent CO_2. If it is expected that the power consumption of domestic refrigeration appliances decreases by 2020, this decrease should slow down because requirements and energy labelling are obsolete. Thus, it will not be possible to realize energy savings with a good ratio cost-efficiency if no additional measure is introduced to update the eco-design requirements in force.

Table 3-17: Requirements and schedule: Regulation 643/2009.

Equipment type	Standard of tests	July 1st 2010	July 1st 2012	July 1st 2014
Vapor compression refrigeration equipment	NF EN 62552 August 2015 Domestic refrigeration appliances - Characteristics and testing methods	IEE < 55	IEE < 44	IEE < 42
Absorption refrigeration equipment and other types of refrigeration equipment		IEE < 150	IEE < 125	IEE < 110

3.4.2 *AIR CONDITIONERS AND COMFORT FANS*

The regulation 206/2012 established eco-design requirements for air conditioners and comfort fans.

The annual power consumption of air conditioners and comfort fans has been estimated at 30 TWh, within EU, in 2005. It is estimated that it will reach 74 TWh in 2020 if no action is taken.

Since refrigerants are covered by F-Gas Regulation, this Regulation does not lay down any specific requirements for them. However, compensation is provided under the eco-design requirements to encourage market participants to use refrigerants less harmful to the environment. The compensation will have the effect of reducing the minimum energy efficiency requirements for equipment running with low-GWP refrigerants.

The regulation defines a maximum power consumption in minimum standby mode as well as a parameter to measure the energy efficiency of the product (EER, COP) and the target values. Measurements are made using generally a standard harmonized with the directive (EN 14825: 2016 for air conditioners).

Table 3-18: Requirements related to the maximum power consumption in standby and sleep mode for single and dual duct air conditioners and for comfort fans.

Mode	Requirement	January 1st 2013	January 1st 2014
Standby	The power consumption of the equipment for all states corresponding to the "standby" mode must not exceed:	1 W	0.5 W
Sleep mode	The power consumption of the equipment being in any state in which only a function of reactivation is provided, or only a reactivation function associated with a single indication that the reactivation function is activated does not exceed:	1 W	0.5 W
	The power consumption of the equipment in any state in which only the display of an information or a state is ensured, or only the display of information or a state associated with a reactivation function is enabled does not exceed:	2 W	1 W
Availability of the "sleep" mode and / or "off" mode	The equipment is, to the extent that it is compatible with the intended use, provided with a "stop" and / or "standby" mode, and / or another mode in which, when connected to the sector, the applicable requirements for electricity consumption in "off" and / or "standby" mode are met.		

Table 3-19: Requirements and schedule: Regulation 206/2012.

Equipment type	Nominal power	GWP Refrigerant	January 1st 2013		January 1st 2014	
			EER	COP	EER	COP
Single-duct air conditioner	< 6 kW	GWP>150	2.40	1.80	2.60	2.04
	< 6 kW	GWP≤150	2.16	1.62	2.34	1.84
	6kW≤P≤12kW	GWP>150	2.40	1.80	2.60	2.04
	6kW≤P≤12kW	GWP≤150	2.16	1.62	2.34	1.84
Double-duct air conditioner	< 6 kW	GWP>150	2.40	2.36	2.60	2.60
	< 6 kW	GWP≤150	2.16	2.12	2.34	2.34
	6kW≤P≤12kW	GWP>150	2.40	2.36	2.60	2.60
	6kW≤P≤12kW	GWP≤150	2.16	2.12	2.34	2.34

Table 3-20: Requirements and schedule: Regulation 206/2012.

Equipment type	Nominal power	Refrigerant GWP	January 1st 2014	
			SEER	SCOP
Air conditioners except single-duct or double-duct air conditioners	< 6 kW	GWP>150	4.60	3.80
	< 6 kW	GWP≤150	4.14	3.42
	6kW≤P≤12kW	GWP>150	4.30	3.80
	6kW≤P≤12kW	GWP≤150	3.87	3.42

3.4.3 *ROOM HEATING EQUIPMENT AND MIXED HEATING*

The regulation n°813/2013 establishes eco-design requirements for space heaters and mixed heaters.

The annual energy consumption of space heaters and mixed heaters has been estimated at 12089 PJ (around 289 Mtoe) in the EU in 2005, or 698 million tonnes of CO_2 emissions. It is estimated that it will reach 10688 PJ in 2020 if no action is taken. The preparatory study shows that the energy consumption of space heaters and mixed heaters during use can be significantly reduced.

The preparatory study referred to in the Regulation considers that, with regard to space heating devices and mixed heaters, it is not necessary to lay down requirements for the other eco-design parameters referred to in Annex I, Part 1 of Directive 2009/125 / EC. In particular, greenhouse gas emissions from refrigerants used in the current installed base of heat pumps for heating the current European building installed base are not considered significant. The desirability of setting eco-design requirements for such greenhouse gas emissions will be re-evaluated during the review of the regulation.

The regulation defines seasonal energy efficiency and target values. It also defines, for heat pumps only, maximum sound power levels according to the rated thermal power. The measurements are made using generally a standard harmonized with the directive (EN 14825: 2016 for heat pumps).

Table 3-21: Table (Excerpt) of requirements and schedule: Regulation 813/2013

Equipment type	26 Sept. 2015	26 Sept. 2017
Heat pumps and mixed heating by heat pumps, except low-temperature heat pumps:	100%	110%
Low-temperature heat pumps	115%	125%

3.4.4 THERMODYNAMIC WATER HEATERS

Delegated Regulation (EU) No 814/2013 establishes eco-design requirements for water heaters and hot water tanks including thermodynamic water heaters.

Greenhouse-gas emissions from refrigerants used in heat pumps for heating the current European building installed base are not considered significant. The desirability of setting eco-design requirements for above-mentioned greenhouse gas emissions will be re-evaluated during the review of the regulation.

The annual energy consumption of water heaters and hot water tanks was estimated at 2156 PJ (around 51 Mtoe) in the EU in 2005, i.e. 124 million tonnes of CO_2 emissions. It is estimated that it will reach 2243 PJ in 2020 if no action is taken. The annual emissions of nitrogen oxides from water heaters and hot water tanks were estimated at 559 kt SOx equivalent in the Union in 2005. It is estimated that they will reach 603 kt SOx equivalent in 2020 if no action is taken.

The regulation defines a minimum energy efficiency according to the declared tapping profile. The following table lists a number of profiles.

Table 3-22: Table (Excerpt) of requirements and schedule: Regulation 814/2013.

Declared tapping profile	Standard of tests	26 Sept. 2015	26 Sept. 2017	26 Sept. 2018
3XS (7 Liters)	EN 16147	22%	32%	32%
S (36 Liters)		26%	32%	32%
L (130 Liters)		30%	37%	37%
XL (210 Liters)		30%	37%	37%
XXL (300 Liters)		32%	37%	60%
3XL (520 Liters)		32%	37%	64%
4XL (1040 Liters)		32%	38%	64%

3.4.5 *COMMERCIAL REFRIGERATION CABINET, CONDENSING UNITS AND INDUSTRIAL PROCESS COOLERS*

Regulation (EU) 2015/1095 establishes eco-design requirements for commercial refrigeration cabinets, fast cooling and freezing cells, condensing units and industrial chillers (process chillers). They are presented in the tables below.

Regulation (EU) 2015/1094 establishes the requirements for labelling and the provision of other product information relating to commercial refrigerated cabinets.

The annual power consumption of condensing units, industrial coolers and commercial refrigerated cabinets in the Union was estimated at 116.5 terawatt hours (TWh) in 2012, corresponding to 47 million tonnes (Mt) of carbon dioxide (CO_2) emissions. If no specific measure is adopted, annual energy consumption should rise to 134.5 TWh in 2020 and 154.5 TWh in 2030, i.e. 54.5 and 62.5 Mt respectively of CO_2 emissions. The combined effect of Regulation (EU) 2015/1095 and Delegated Regulation (EU) 2015/1094 of the Commission is expected to save 6.3 TWh of power annually by 2020 and 15.6 TWh of power by 2030, compared to the status quo scenario.

For each product, the regulation defines a parameter to measure the energy efficiency of the product (IEE, COP or SEPR) and the target values. The measurements are made using generally a standard harmonized with the directive.

Table 3-23: Requirements and schedule: Regulation 2015/1095.

Equipment type	Standard of tests	July 1st 2016	July 1st 2018	July 1st 2019
Commercial refrigeration cabinets and fast cooling cells	NF EN 16825 (Commercial refrigeration cabinets) EN 17032 (fast cooling cells)	IEE < 115	IEE < 95	IEE < 85

Table 3-24: Requirements and schedule.

Equipment type	Standard of tests	Characteristics	July 1st 2016	July 1st 2018
Condensing units Average operation temperature	EN 13771-2 (Tests) EN 13215 (Efficiency declaration)	0.2 kW≤ Pnom* ≤ 1 kW	COP > 1.20	COP > 1.40
		1 kW≤ Pnom ≤ 5 kW	COP > 1.40	COP > 1.60
		5 kW≤ Pnom ≤ 20 kW	SEPR >2.25	SEPR >2.55
		20 kW≤ Pnom ≤ 50 kW	SEPR >2.35	SEPR >2.65
Condensing units Low operation temperature		0.2 kW≤ Pnom ≤ 1 kW	COP > 0.75	COP > 0.80
		1 kW≤ Pnom ≤ 5 kW	COP > 0.85	COP > 0.95
		5 kW≤ Pnom ≤ 20 kW	SEPR >1.50	SEPR >1.60
		20 kW≤ Pnom ≤ 50 kW	SEPR >1.60	SEPR >1.70

P nom: Nominal cooling capacity

For condensing units to be used with a refrigerant with a GWP lower than 150, COP and SEPR values may be up to 15% less than the requirements by July 1st 2016 and up to 10% less than those required by July 1st 2018.

Table 3-25: Requirements and schedule.

Equipment type	Standard of tests	Characteristics	July 1st 2016	July 1st 2018
Process chillers (air condensation) Average operation temperature	EN 14511-3:2013: "Air-conditioners, chillers and heat pumps with compressor electrically-driven for heating and cooling spaces - Part 3: Method of tests" EN 14825:2016: "Air-conditioners, chillers and heat pumps with compressor electrically-driven for heating and cooling spaces - Tests and determination of characteristics at partial charge and seasonal efficiency calculation "	Pnom ≤ 300 kW	SEPR > 2.24	SEPR > 2.58
		Pnom > 300 kW	SEPR > 2.80	SEPR > 3.22
Process chillers (air condensation) Low operation temperature		Pnom ≤ 200 kW	SEPR > 1.48	SEPR > 1.70
		Pnom > 200 kW	SEPR > 1.60	SEPR > 1.84
Process chillers (water condensation) Average operation temperature		Pnom ≤ 300 kW	SEPR > 2.86	SEPR > 3.29
		Pnom > 300 kW	SEPR > 3.80	SEPR > 4.37
Process chillers (water condensation) Low operation temperature		Pnom ≤ 200 kW	SEPR > 1.82	SEPR > 2.09
		Pnom > 200 kW	SEPR > 2.10	SEPR > 2.42

P nom: Nominal cooling capacity

Concerning process chillers intended for use with a refrigerant with a GWP lower than 150, the SEPR values may be up to 15% lower than the requirements by 1 July 2016 and up to 10% below those required as of July 1st, 2018.

3.4.6 *AIR HEATING AND COOLING PRODUCTS, HIGH-TEMPERATURE PROCESS CHILLERS, AND FAN COIL UNITS*

The regulation (UE) 2016/2281 establishes eco-design requirements for air heating and, cooling products, high-temperature process chillers and fan coil units.

The annual combined energy consumption of air heating appliances, cooling appliances and high-temperature process chillers was estimated at 2,477 PJ (59 Mtoe) in the EU in 2010, representing 107 million tonnes of emissions. of carbon dioxide (CO_2). If no specific measures are taken, the annual energy consumption of air heaters, cooling appliances and high-temperature industrial chillers should rise to 2,534 PJ (60 Mtoe) per year by 2030. Eco-design set out in this Regulation are expected to result in annual energy savings of around 203 PJ (5 Mtoe) by the year 2030, equivalent to 9 million tonnes of carbon dioxide emissions.

Since refrigerants are covered by F-Gas Regulation, this Regulation does not lay down any specific requirements for them.

The regulation defines a minimum seasonal energy efficiency for each type of heating and cooling equipment. For high-temperature industrial chillers, it defines the Seasonal Energy Performance Ratio (SEPR).

Table 3-26: Requirements and schedule: Regulation 2016/2281

Heating/ Cooling	Equipment type	Standard of tests	Power	Minimum Seasonal Energy Efficiency - SEE ηs,h (%)	
				January 1st 2018	January 1st 2021
Heating	Air-air heat pumps electrically driven, except roof heat pumps	EN 14825:2016		133	137
	Roof heat pumps	EN 14825:2016		115	125
	Air-air heat pumps electrically driven by an internal combustion engine	EN 16905-5:2017		120	130
Cooling	Air-water coolers electrically driven	EN 14825:2016	< 400 kW	149	161
			≥ 400 kW	161	179
	Water/glycol water cooler electrically driven		< 400 kW	196	200
			400 kW≤ P < 1500 kW	227	252
			≥ 1500 kW	245	272
	Air/water air conditioners driven by an internal combustion engine	EN 16905-5:2017		144	154
	Air-air air conditioners electrically driven, except rooftops	EN 14825:2016		181	189
	Rooftops			117	138
	Air/air conditioners driven by an internal combustion engine	EN 16905-5:2017		157	167

Concerning multi-split air-conditioners or heat pumps, the manufacturer shall establish the conformity with the Regulation on the basis of measurements and calculations obtained in accordance with Annex III of the Regulation.

Table 3-27: Requirements and schedule: 2016/2281.

<table>
<tr><th rowspan="2">Heating/ Cooling</th><th rowspan="2">Equipment type</th><th rowspan="2">Standard of tests</th><th rowspan="2">Power</th><th colspan="2">Seasonal Energy Efficiency Ratio - SEPR (%)</th></tr>
<tr><th>January 1st 2018</th><th>January 1st 2021</th></tr>
<tr><td rowspan="5">High-temperature process chillers</td><td rowspan="2">Heat-transfer fluid on air condensation side</td><td rowspan="5">EN 14825:2016</td><td>< 400 kW</td><td>4.5</td><td>5.0</td></tr>
<tr><td>≥ 400 kW</td><td>5.0</td><td>5.5</td></tr>
<tr><td rowspan="3">Heat-transfer fluid on water condensation side</td><td>< 400 kW</td><td>6.5</td><td>7.0</td></tr>
<tr><td>400 kW≤ P < 1500 kW</td><td>7.5</td><td>8.0</td></tr>
<tr><td>≥ 1 500 kW</td><td>8.0</td><td>8.5</td></tr>
</table>

The applicable test standard is EN 14511-3: 2013. For each outdoor unit model, a list of recommended combinations with compatible indoor units is included in the technical documentation. The declaration of conformity applies to all combinations indicated in this list. The list of recommended combinations is made available before buying / lease rental / renting an outdoor unit.

3.5 Programs of Voluntary Certification

The EU eco-design regulation requires Member States to implement the prescribed limit values and to monitor the conformity of products placed on the market. Due to the lack of institutions with the necessary technical equipment and expertise in Europe, these oversight mandates of governments are all the more difficult to exercise. To address this issue, a number of voluntary certification schemes have been implemented to transparently certify equipment that meets minimum performance requirements. Voluntary certification also allows prescribers, installers and buyers to select certified products with the assurance that the characteristics announced by the manufacturer are reliable.

3.5.1 ASERCOM

The *ASERCOM*, the European Association of refrigeration component manufacturers, has been developing a refrigeration compressor certification program for around 20 years and has recently developed a program for condensing units. The certification process is done under the responsibility of the manufacturer in relation to a well-defined evaluation program. The technical files are sent to the ASERCOM certification committee, where the likelihood of the results is validated in the presence of an independent notified body. In addition, controls are implemented from equipment purchased in the sales channel and then tested by internal and external laboratories. All data on certified equipment is available on the ASERCOM website.

3.5.2 *CERTICOLD*

Certicold HACCP is a European conformity label of refrigerating equipment. The labelling committee is composed of:

- Government representatives
- Operators or users
- Manufacturers
- Experts in the cold chain

There is a specific program for refrigerated cabinets (stand-alone display cases with hermetically sealed equipment) including:

- Annual audit of manufacturing sites
- Tests carried out by an independent laboratory: Tests of performance, energy consumption, cleanability
- No minimum, display of energy consumption per unit of volume
- Continuous self-checks by the manufacturer
- Production of individual certificates by equipment valid for 3 years.

3.5.3 *EUROVENT*

The aim of the Eurovent certification programs is to create common databases for comparing the technical characteristics of refrigeration and air conditioning equipment. Eurovent certification offers certification programs for a number of equipment listed below:

- Heat exchangers (evaporator, condenser, air cooler, batteries)
- Air conditioners up to 12 kW
- Air-handling units
- Chillers
- Refrigeration display cases

3.6 GUIDES AND RECOMMENDATIONS

3.6.1 *INERIS REPORT, SAFETY STUDY ON THE REPLACEMENT OF REFRIGERANTS*

INERIS (National Institute of Industrial Environment and RISks) is a public institution under the supervision of the Ministry of Environment. It conducts research programs focused on understanding phenomena that may lead to situations of risk or harm to the environment and health.

On December 20, 2017, Ineris released its report "Safety Study on Refrigerant Replacement". This study, commissioned by the Ministry of the Interior, focuses on the use of flammable refrigerants in mechanical vapor compression systems that fulfill the needs of air conditioning (hot or cold) and / or in the production of hot domestic water in Public Buildings. Thermodynamic systems used to maintain the cold chain (refrigerated display cases, cold rooms, laboratories ...) are therefore excluded.

The report is relatively brief because the field of study is very specific. We will therefore try not to paraphrase it but to describe the type of information available in it.

In Chapter 1, Ineris clarifies the scope of the study and recalls some fundamental notions drawn from NF EN 378, in particular the classification of refrigerants according to their flammability and toxicity (see Table 3-28).

Chapter 2 presents the study of various accidents that may lead to the appearance of risks related to the presence of flammable refrigerants. Ineris studies the local newspapers and the scientific literature to better understand the possible origins of an accident, then proposes different approaches to decide on the level of acceptability of the risk. The approach adopted by Ineris is the so-called "deterministic" approach. This approach consists in removing the stakes (Public buildings staff, users such as shoppers or hospital patients, local residents or emergency services such as firefighters in intervention). so that they are not exposed in the event of an accident.

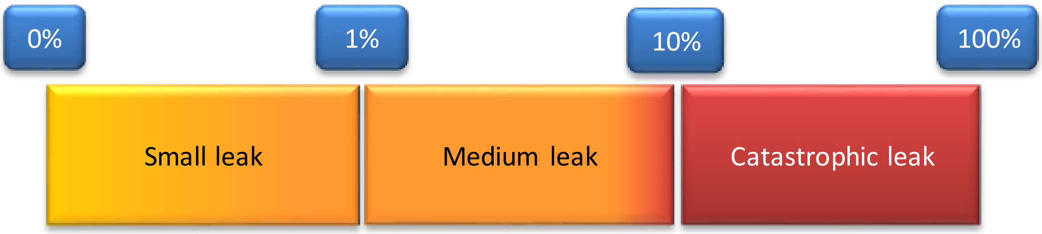


Figure 3-5: Leak typology as a function of leak diameter/piping diameter ratios.

For this study, Ineris defines 3 types of refrigerant leaks that will serve as a reference for the rest of the study. Each type of leak corresponds to leakage diameter / pipe diameter ratios (Figure 3 5).

Ineris then synthesizes the dreaded phenomena of a leak (third Chapter) and their expected effects (thermal, toxic, overpressure, anoxia).

Table 3-28: Dangerous phenomena and expected effects for each class of refrigerants.

		Classification of refrigerants			
Dangerous phenomena	Expected effect	A3	A2	A2L	A1
Torch fire	Thermal	Yes	Yes	Yes	No
Cloud fire	Thermal	Yes	Yes	Yes	No
VCE	Overpressure	Yes	Yes	No	No
Dispersion	Toxic	To see	To see	To see	To see
	Anoxia	Yes	Yes	Yes	Yes

We note that the ignition of an A2L or B2L refrigerant cloud cannot generate VCE because of their low laminar velocity of flame propagation. In fact, these refrigerants have laminar velocity of flame propagation lower than 10 cm / s, a value below which Ineris usually considers that the explosion does not give rise to overpressure. This does not prevent the thermal effects of cloud fire.

As for the toxicity of A-class refrigerants, they have so-called "low" toxicity (no evidence of toxicity for concentrations <400 ppm), which does not necessarily mean that they are not toxic at all. It is therefore not possible to exclude any risk of toxicity associated with the use of these refrigerants.

Based on these findings, in a fourth chapter Ineris proposes additional measures to implement for the use of flammable refrigerants. These measures concern:

- installation rules for:
    - complete systems;
    - parts of the circuit located outdoor;
    - parts located inside the machinery room;
- operation rules;
- maintenance rules;
- Incident response rules (leakage, fire…).

In addition to the study itself, the report proposes in appendix:

- A refrigerant inventory (non-chlorinated) per class;
- An update on the regulatory texts of reference;
- A generic risk analysis for the phases of an installation lifetime:
    - Installation;
    - Use;
    - Maintenance;
    - Intervention of firefighters.
- A study to quantify the effects of a leak with:
    - A reminder of the expected phenomenology (physical mechanisms involved during a leakage of liquid or gaseous refrigerant under pressure);
    - A list of possible dangerous phenomena in the event of a leak;
    - The presentation of the method of quantification of the effects (assumptions made, tools retained information and justification of choice ...);
    - A detail of the values used for the effects (thermal effects thresholds related to a torch fire and a cloud fire, and overpressure effect related to a VCE) and their justification;
    - The presentation of the results of the study:
        - Anoxia risks;
        - Risks related to the ignition of a refrigerant leak.
            - Modeling has been realized for pentane (R-601, class A3), propane (R-290, class A3), R-152a (A2) and R-32 (A2L);
            - The results are given according to whether the refrigerant is in gas phase or two-phase, depending on the saturation temperature (directly related to the pressure) and according to the diameter of the leak;
        - A prioritization of the harmfulness of toxic fumes according to the refrigerant;
        - The risks of formation of flammable pools;
    - The comparison of prescriptions from the Ineris study with those of the GZ;
    - And finally, an example of application of the design rules proposed in the report applied for a hotel according to whether a VRF system is used, or mono-split installed directly in the rooms or a chiller on the roof with indirect exchange.

3.6.2 *GUIDE M*

The General Directorate of Civil Security and Crisis Management (DGSCGC) published on December 27, 2017 its Practical Guide on fire safety in stores and shopping centers. This guide is free and accessible on the website of the Ministry of the Interior.

This book is intended for any person or organization concerned with security in Public Buildings, from the designer to the user and including the administrative authorities. In particular, in the 2.8 datasheet, it clarifies the conditions of use of flammable refrigerants in stand-alone display cases with hermetically sealed equipment installed in stores and shopping centers. Indeed, it was usual, until now, to limit the maximum charge to 150 g for stand-alone operating with A2, A2L or A3 class refrigerants. This was a consensus value and comes from the article CH35 of the safety regulation against fire and panic risks in public buildings. However, there was some doubt as to whether or not this article was applicable to refrigeration systems of display cases.

The DGSCGC Handbook revisits this issue and clarifies it as follows: "Article CH35 of the Fire and Panic Safety Regulation in public buildings specifies the conditions [...] for comfort ventilation". Article CH35 therefore not applicable to refrigeration in food processes, so it is the standard NF EN 378-1 which is put forward by the practical guide.

The calculation method of the maximal charge is detailed in the guide and specifies that: “the authorized maximum charge […] must comply with the following two conditions:

a/Charge per circuit [in kg] <20% of the Lower Explosive Limit or LEI [in kg/m^3] x room volume [in m^3].

b/ Charge per circuit < 1.5 kg if the circuit is located in the ground floor or floors and 1 kg if the circuit is located in the basement accessible to the public.

This LEI is specific to each refrigerant concerned by this guide.

As an example, for propane (R-290), in a 2000 m^3 store on the ground floor, condition (a) gives 20% × 0.038 × 2000 = 15.2 kg. To also comply with condition (b), the charge will be limited to 1.5 kg per circuit. "

It is important to underline that today the limitation of the charge is imposed by circuit, so the number of circuits by store is not limited. Topics remain unresolved, such as the question of the use of A2L refrigerants for air conditioning in Public Buildings, or the use of centralized refrigeration systems that are not covered by the guide M.

3.6.3 *GUIDE NF EN 378*

This guide was developed by the Technical Center for Mechanical Industries (Cetim) with the help of the union of heating, air-conditioning and refrigeration industries (UNICLIMA), AFCE (Alliance refrigeration, air conditioning, environment), AFF (French Refrigeration Association).

It is a guide to the application of the NF EN 378: 2017 standard through the presentation of risk analyses based on a "red line" example and other simpler illustrative examples. It does not replace the standard and focuses on the concept of risk study, which is a fundamental point of the standard NF EN 378 and the European directives (Machines, pressurized equipment...) more generally.

The red line example presents several typologies of refrigeration and air conditioning systems. These are either in a large sales area or in a small food store or in Public Buildings premises.

The “red-line” example is composed of:

- A sales area:
  - Stand-alone display case: location class I,
  - Display case connected to a centralized system: location class II.
- An office zone:
  - Direct air-conditioning system (Variable-refrigerant-flow (VRF) air-conditioning system): location class II.
- A machinery room (refrigeration production):
  - Direct system: location class II (centralized refrigerating system),
  - Indirect system ventilated and closed: location class III (chiller).
- A cold room:
  - Condensing unit: location class II.

Over the entire lifecycle of each of these configurations, the authors chose to address the following cases:

Table 3-29: Case studies.

Examples	Life phase	Refrigerant
Centralized refrigerating system	Design	R-744
Condensing unit	Construction	R-455A
Condensing unit	On-site installation	R-744
Air-conditioning unit (VRF)	On-site installation	R-32
Chiller	On-site installation	R-1234ze(E)
Chiller	Operation	R-1234ze(E)
Display case	Maintenance or repair	R-290
Centralized refrigerating system	Maintenance or repair	R-744
Air-conditioning unit (VRF)	Maintenance or repair	R-32

4 - REFRIGERANT SUBSTITUTES

HFCs that are being replaced are essentially R-134a, R-404A and R 410A that have themselves substituted in the last 20 years CFCs and HCFCs. Substitution by hydrocarbons (R-600a, R-290, R-1270) also began in the 1990s, mainly for domestic refrigeration and more generally for fully-welded small capacity equipment. Ammonia has always been used and has expanded its use in industrial refrigeration, and finally CO_2 has developed into commercial refrigeration and for thermodynamic water heaters. The new substitution refrigerants are HFOs (R-1234yf and R-1234ze (E)) and mixtures of HFO and HFCs, particularly mixtures using R-32.

4.1 OVERALL ANALYSIS OF THE 2016 BANK

In 2016, the HFC bank accounts for 86% of the total refrigerant bank, of which only 1% HFO (R-1234yf and R-1234ze (E)). Non-fluorinated refrigerants (HC, R-744 and R-717) represent 11% of the 2016 bank. Note, however, that the HFC family includes HFC / HFO mixtures, some of which are an alternative to the use of high-GWP HFCs such as R-404A.

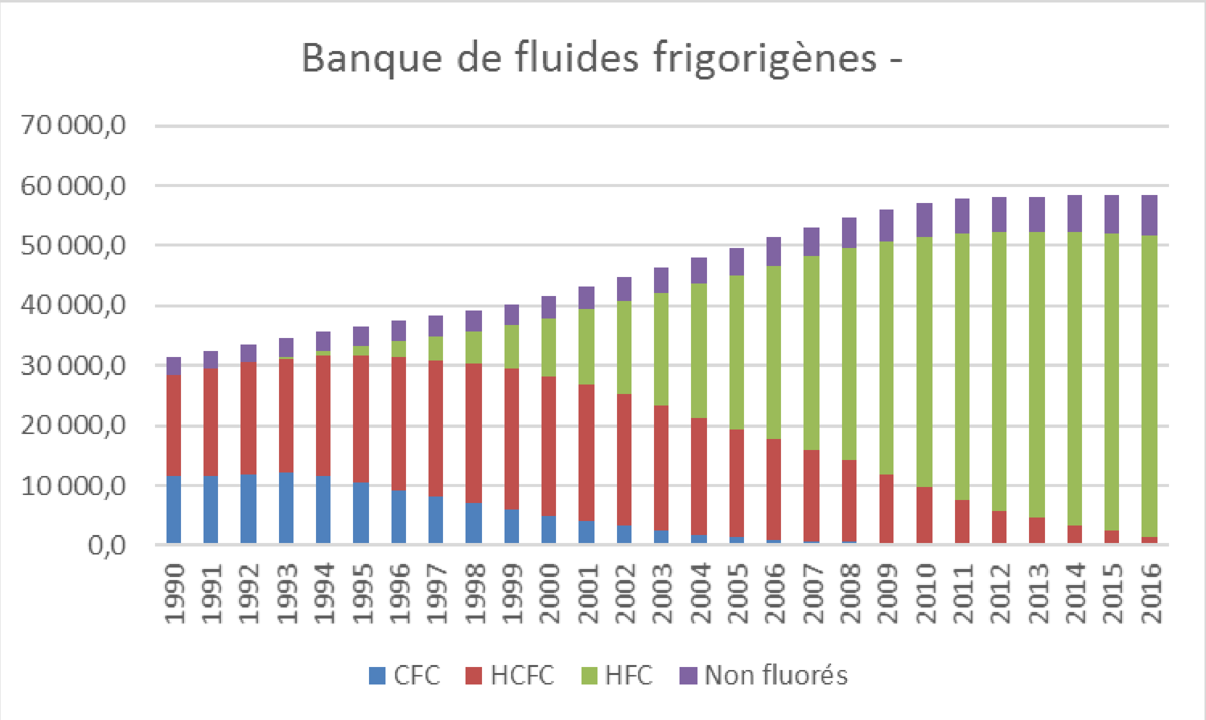


Figure 4-1: Evolution of the refrigerant bank from 1990 to 2016 – all sectors.

Figure 4-2 shows that high-GWP HFCs represent more than 80% of the refrigerant bank in mainland France in 2016. On this graph, the quantities of R-134a from the R-134a / CO_2 cascade systems as well as R-407A and 407F are included in the "high-GWP HFC " family, while they can be considered alternatives to high-GWP HFCs in some sectors intensive users of R-404A.

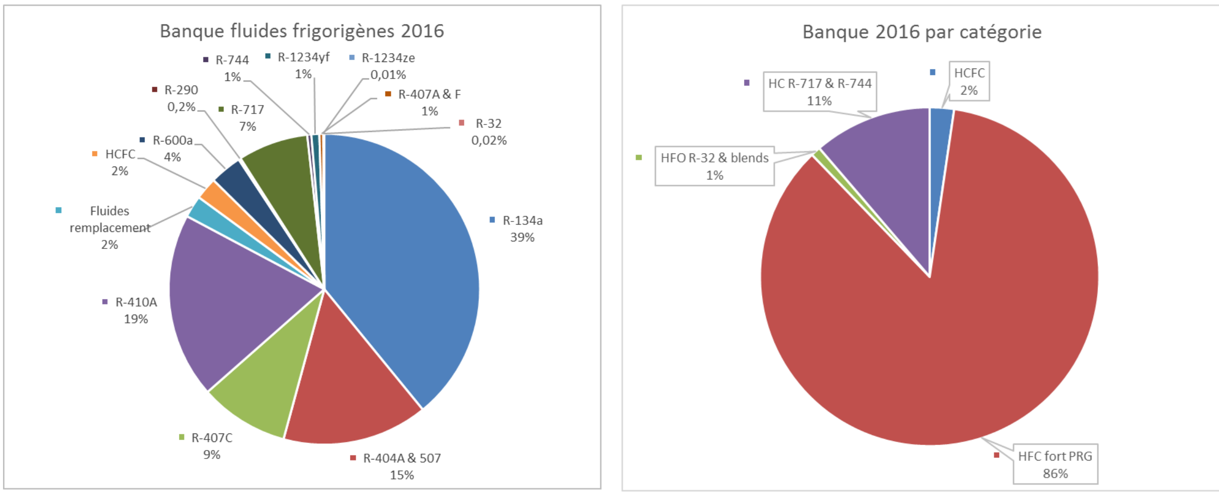


Figure 4-2: 2016 refrigerant bank – all sectors.

Before performing the application-by-application analyzes, we will present the substitutes currently available for each of the 3 refrigerants (R-134a, R-404A and R-410A) by distinguishing between retrofit substitutes and long-term substitutes for new installations or equipment.

For each of these three reference refrigerants, in these sections, we do not detail all applications where these refrigerants can be used but only essential applications where OEM choices are confirmed.

4.2 R-134A AND ITS SUBSTITUTES

R-134a substitutes are different depending on applications and their use started at very different dates.

4.2.1 *REPLACEMENT BY R-600A*

The replacement of R-134a by isobutane (R-600a) started as soon as 1996 and was extremely fast, once the maximum charge of 150 g and safety measures for domestic refrigeration were taken. Technological developments have been made with this refrigerant to meet the energy efficiency thresholds pf the Labelling Directive 94/76 / EC and following. Note that this replacement was made both by a lobbying group such as Green Peace and by the rapid decision of major European manufacturers.

4.2.2 *REPLACEMENT BY R-1234YF*

The main application of R-1234yf to replace R-134a is mobile air conditioning. From 2005 to 2015, many tests, many controversies have surrounded the introduction of R-1234yf to replace R-134a. Comparative tests with CO_2 (R-744) have mobilized all car companies and their Tier 1 suppliers. Given the very high CO_2 pressures, the implementation in mobile air-conditioning ran up against leakage issues for pipes that must withstand not only vibrations but also movements of the motor relatively to the body. These technical difficulties associated with increased costs and the uncertainty of maintenance possibilities in a global market, led to the choice of R-1234yf which, from the point of view of implementation, required minor adaptations without change of component costs. Otherwise, for commercial refrigeration applications, R-1234yf is a refrigerant with thermodynamic characteristics and energy performance very close to or even slightly higher than R-134a.

4.2.3 REPLACEMENT BY R-1234ZE(E)

For centrifugal chillers several manufacturers already sell centrifugal units with R-1234ze (E) to replace R-134a. This replacement assumes specific developments since the volumetric cooling capacity of R-1234ze (E) is slightly more than 10% lower than that of R-134a. It is not a retrofit refrigerant even if it is possible to retrofit a centrifugal unit by agreeing to lose 10 to 15% cooling capacity. Manufacturers who developed the centrifugal units announced gains in energy efficiency of 7 to 10%.

Table 4-1: Data on candidates to R-134a replacement.

Standardized name	Compositions	GWP	Safety Class	T critical and T normal boiling *(glide)*	Vol. capacity relative to R-134a	COP relative to R-134a COP
R-134a	-	1430	A1	TC = 101°C TNe = -26°C	1	1
R-600a	-	3	A3	TC= 134.6°C TNe =-11°C	1	1,1
R-1234yf	-	4	A2L	Tc = 94.7°C TNe= 29.5°C	0.98	1
R-1234ze(E)	-	7	A2L	TC = 109.6°C TNe= -19°C	0.89	1.07
R-451A et B	R-1234yf / R-134a 89.8 /10.2 et 88.8/11.2	149 164	A2L	TC = 95.3°C TNe=-30.8/-30.5°C TNe= -31/-30.6°C	-	-

4.2.4 REPLACEMENT BY R-513A OR R-450A

In applications where the equipment value is high and its long lifetime (typically 10 to 20 years), the retrofit of R-134a can be interesting. This is particularly the case of volumetric chillers. R-513A and R-450A are two refrigerants whose characteristics are shown in Table 4-2, both of which are A1 and whose GWP values are 631 and 603 respectively. Peer-reviewed publications show that those refrigerants are "drop-in" refrigerants and that the energy performances are superior to those of R 134a.

Table 4-2: Characteristics of two refrigerants for the conversion of installations running with R-134a.

Standardized name	Compositions	GWP	Safety Class	T critical and T normal boiling *(glide)*	Vol. capacity relative to R-134a	COP relative to R-134a COP
R-134a	-	1430	A1	TC = 101°C TNe = -26°C	1	1
R-450A	R-134a/1234ze(E) 42/58	603	A1	TC = 102°C TNe= -23.4/-22.6°C	0.91	1.05
R-513A	R--134a /R-1234yf 44/56	631	A1	TC = 97.35°C TNe= --29°C	1.05	1.05

4.3 R-404A AND ITS SUBSTITUTES

Several R-404A replacement refrigerants are already on the market. In Table 4-3, the long-term replacement refrigerants are distinguished, that is to say with a GWP <150. Transition refrigerants, designed for retrofit, are presented in a second step.

- Propane (R-290) is used by a number of stand-alone display case manufacturers, that is, equipment with a fully welded circuit. This trend has developed with the authorized increase of A3 refrigerant charges as defined in standard NF EN 378. The tests conducted by Cemafroid (see Section 13) show a very clear improvement in the energy efficiency of R-290 compared to R-404A.
- R-454C blends and R-455A with a GWP less than 150 are long-term replacements for R-404A from manufacturers of synthetic refrigerants. These refrigerants show test returns with energy efficiency 10% higher than R-404A on refrigerated cabinets. This has to be confirmed for other applications.

Table 4-3: Characteristics of candidate refrigerants to replace R-404A.

Standardized name	Compositions	GWP	Safety Class	T critical and T normal boiling *(glide)*	Vol. capacity relative to R-404A	COP relative to R-404A COP
R-404A	R-125/R-143a/R-134a 44 /52/4	3 922	A1	TC = 72 TNe = -46.2°C	1	1
R-290	-	3	A3	TC = 96.7 °C TNe = -42.4°C	0.98	1.05
R-1270	-	2	A3	TC = 91°C TNe= -47.9°C	1.03	1.07
R-744	-	1	A1	TC= 31°C	-	-
R-454C	R-32/R-1234yf 21.5/78.5	148	A2L	Tc = 90.2°C TNe = -39°C (-50.8/-36°C)	0.9	1.08
R-455A	R-744/ R-32/R-1234yf 3/21.5/75.5	148	A2L	TC = 89.2°C TNe = -40.7°C (-60.9/-38.4°C)	1	1.1

- CO_2 (R-744) replace R-404A
  - either only at the low temperature where it feeds display cases or cold freezing rooms (T <-38°C); its condensation is then ensured between -15 and -20°C on a heat exchanger which is itself cooled by a refrigerant used for the medium temperature. This is a configuration used in commercial refrigeration facilities in hypermarkets.
  - Or at both temperature levels (freezing and fresh products); the operation is then in transcritical cycle. In fact, above 31°C, CO_2 is above its critical point, the high pressure is between 90 and 100 bar and the cooling of CO_2 in the supercritical zone leads to significant energy losses during the low-pressure expansion. These

transcritical systems are used significantly in the Nordic countries and in Germany, but also in France but in supermarkets or mini-markets, where the required cooling capacity is generally lower than 200 kW.

4.3.1 *Transition Refrigerants for the Retrofit of Installations Running with R-404A*

Replacement refrigerants of R-404A used in retrofit are all non-flammable refrigerants (A1). Indeed, it is not possible to retrofit to A3 or A2L flammable refrigerant because the equipment is not designed for. As a result, all intermediate refrigerants include R-125 to neutralize the flammability of A2L components. The GWP of R-125 being 3500, all these refrigerants have a GWP greater than or equal to 1400, which is objectively a GWP gain of more than a factor 2 with respect to R-404A but which is only a transient option to extend the equipment lifetime, in commercial refrigeration, in industrial process refrigeration and in refrigerated transport.

Table 4-4: Data of candidate refrigerants to retrofit R-404A installations.

Standardized name	Compositions	GWP	Safety Class	T critical and T normal boiling *(glide)*	Vol. capacity relative to R-404A	COP relative to R-404A COP
R-404A	R-125/143a/134a (44/52/4)	3922	A1	Tc = 72°C TNe = -46.6/ -45.8°C	1	1
R-407A	R-32/125/134a (20/40/40)	2107	A1	Tc = 90.1°C TNe = -45.2/ -38.7°C	0.81	0.89
R-407F	R-32/125/134a (30/30/40)	1825	A1	Tc = 89.2°C TNe = -46.1/ -39.7°C	1.02	1.07
R-407H	R-32/125/134a (32.5/15/52.5)	1495	A1	TC=86.5°C TNe= -44.6 / -37.6°C	1.01	1.06
R-442A	R-32/125/134a/ 152a/227ca 31/31/30/3/5	1888	A1	TC=82°C TNe= -46.5/ -39.9°C	1.1	1.1
R-448A	R-32/125/1234yf/ 134a/1234ze(E) 26/26/20/21/7	1387	A1	TC = 86.4 °C TNe = -45.9/ -39.8°C	0.83	0.86
R-449A	R-32/125/1234yf/ 134a (24/25/25/26)	1397	A1	TC = 87.4 °C TNe = -46/-39.9°C	0.88	1.05
R-452A	R-32/125/1234yf 11/59/30	2140	A1	TC=76.5°C TNe=-47/-43.2°C	1.02	-
R-452C	R-32/125/1234yf 12.5/61/26.5	2220	A1	TC=75°C TNe=-47.5/ -44.2°C	1.02	-

The table above presents the transition refrigerants on the market for retrofitting R-404A installations. The penetration of each refrigerant depends not only on energy performance, the commercial strength of each synthetic refrigerant production company, but also on the management of the quotas allocated each year by Europe. Before opting for any of these refrigerants, it is still advisable to seek the opinion of the manufacturer of the application or components.

4.4 R-410A AND ITS SUBSTITUTES

For the replacement of R-410A in air conditioning, replacement refrigerants must meet very strict criteria for both volumetric refrigeration capacity and energy efficiency. Air conditioning equipment is sold worldwide, the individual air conditioning market is between 50 and 60 million units per year. Choices of replacement refrigerants are choices that have heavy industrial impacts and are taken for many years.

4.4.1 R-32 AND R-32-BASED MIXTURES

The current trend for large companies is clearly to use replacement refrigerants that have energy performance and volumetric refrigeration capacity equal to or greater than R-410A. As shown in the table below, this is R-32 and mixtures containing more than 65% R-32 (R-452B and R-454B). The first R-32 units are currently marketed in Europe and since 2016 in Japan and Southeast Asia.

4.4.2 R-290

From a thermodynamic point of view, R-290 is more a substitute for R-22 than for R-410A, with a lower volumetric cooling capacity of 10%. From an energy point of view, the properly implemented R-290 has energy efficiency equal to or slightly higher than R-410A. It is marketed in Europe in small "stand-alone" equipment and in individual "splits" air conditioning systems in China and India; however, it is not adopted as a option by major international manufacturers.

Table 4-5: Data of refrigerants to replace R-410A.

Standardized name	Compositions	GWP	Safety Class	T critical and T normal boiling *(glide)*	Vol. capacity relative to R-410A	COP relative to R-410A COP
R-410A	R-32/125 50 /50	2088	A1	TC = 71.4°C. TNe = -51.4°C	1	1
R-290	-	3	A3	TC = 96.7°C. TNe = -42.4°C	0.9	-
R-452B	R-32/125/1234yf 67/7/26	698	A2L	TC = 86.9°C TNe= -59.8/-58.5°C	0.95	1
R-454B	R-32/1234yf 68.9/31.1	466	A2L	TC = 83.2°C TNe = -59.6/-58.5°C	1	1
R-32	-	675	A2L	TC = 86.9°C TNe = -51.7°C	1.12	1.05

4.4.3 BEYOND 2030

The replacement of R-410A by R-32 or mixtures with high R-32 content raises long-term questions because of the GWRP of 675 kg eq. CO_2 of R-32. The publication of Pham, (Pham, 2016) poses the possible tracks or not.

The global substitution of R-32 by R-290 does not appear plausible for safety reasons for split-system equipment and even more so for multi-splits systems.

The substitution by CO_2 raises questions of technological developments and costs that seem insurmountable considering the energy penalty that the transcritical cycle represents for the typical conditions of use of air conditioners, that is to say for outdoor temperatures above 25°C and up to 50°C. It should be noted that both in mobile air conditioning (see Section 9) and for thermodynamic water heaters, European industry and especially Japanese industry have been carrying out R & D efforts for 20 years, which have led in the mobile air-conditioning industry to equipment whose energy performance is known and which is much lower than the minimum required by the Ecodesign Regulation (EU) 2016/2281. Japanese industry has identified the efficient uses of CO2, especially for thermodynamic water heaters (see Section 5). Developments have led to the design and construction of new compressors adapted to CO_2, the replacement of regulators with ejectors, and the design of two-stage injection systems. Despite all these developments, CO_2 does not appear on the AC system market.

Substitution by synthesis refrigerants with GWP <150. The known HFOs (R-1234yf and R 1234ze (E)) cannot be used currently given a volumetric cooling capacity of 40% lower than that of R-410A. Mixtures with GWRP <150 limit the R-32 content to about 20%. Developments of new compressors and circuits for such mixtures are needed.

Publications and technological developments will need to be carefully monitored to identify what will be the new routes for the use of GWP<150 refrigerants suitable for stationary air conditioning systems.

5 - DOMESTIC APPLIANCES (REFRIGERATORS, FREEZERS, THERMODYNAMIC WATER HEATERS)

5.1 DOMESTIC REFRIGERATORS AND FREEZERS

R-600a (isobutane) has established itself as the refrigerant and 95% of domestic refrigerators and freezers sold in Europe are run with this refrigerant. Only large and imported refrigerator-freezers still contain R-134a. The replacement of R-134a with either R-1234yf (Aprea 2016-a) or R-1234ze (E) (Aprea 2016-b) is being studied and tests already show superior efficiency of R-1234ze compared to R-134a. These R & D efforts are likely to take place outside Europe, in the USA, Japan, Korea where the use of R-134a was still significant.

5.1.1 ANALYSIS OF THE 2016 BANK

According to the 2016 refrigerant inventory analysis (*Barrault, 2016*), the domestic refrigeration bank is around 2 600 tonnes in 2016 of which 75% are hydrocarbons. The CFC bank is estimated to have been eradicated in 2013 according to the lifetime assumptions made in the study.

In domestic refrigeration, R-134a is no longer available on the European market since January 1, 2015. The HC-600a was already widely used in France since the 2000s and became marginal, both for refrigerators and freezers, since 2010. Considering an average lifetime of 15 years, the installed base is therefore dominated by R-600a. Since the R-600a volume charge ratio is two to three times lower than that of R-134a, the domestic refrigeration bank still consists of about 25% of R-134a.

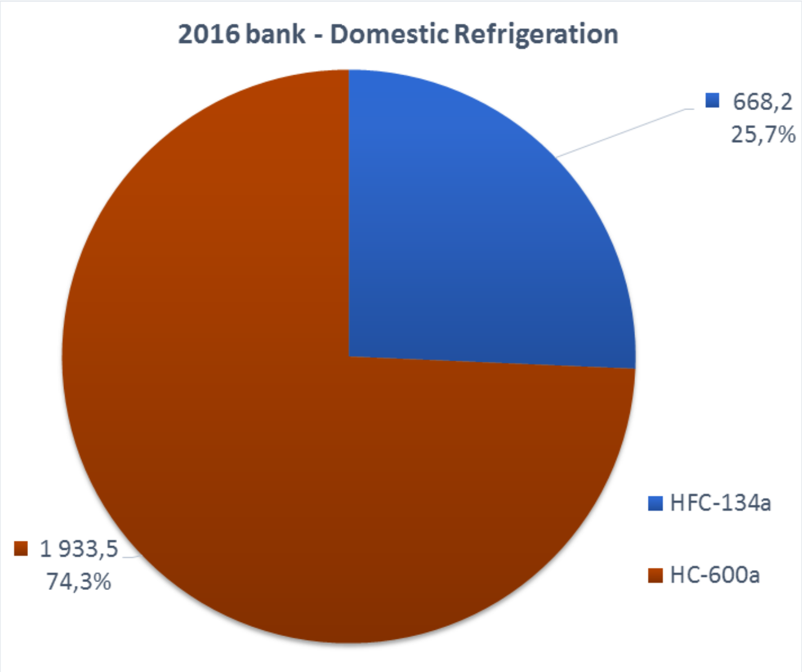


Figure 5-1: Shares of refrigerants used in the domestic refrigeration bank in 2016. (*Barrault 2016*)

5.1.2 *Conclusions*

The transition from R-134a to a low-GWP refrigerant, isobutane, is already done in domestic refrigeration in Europe. The R-600a systems chosen by all major brands have been developed continuously to improve the energy efficiency of refrigerators and freezers. The energy efficiency is very good and no company in Europe is looking to return to A2L refrigerants instead of R-600a because this refrigerant and technological developments can achieve the A ++++ label, which is the highest label of European labelling. R-600a meets the requirements of the regulations. In addition, the risks related to its flammability are limited by the small size of the refrigeration systems of domestic systems that have refrigerant charges of a few tens of grams. The possible new developments where HFO will replace R-134a should only moderately change the distribution of refrigerants in this market.

Table 5-1: Synthesis of alternatives to high-GWP HFCs available for domestic refrigeration.

Reference refrigerant	Alternative Options	+	-
R-134a	HC R-1234yf or R-1234ze	Improved efficiency Energy efficiency equivalent to that of R-134a	A3 A2L

5.2 Thermodynamic water heaters (TWH) on new air or extracted air

5.2.1 *Reference refrigerants*

First thermodynamic water heaters appeared on the French market around 2007-2008. The refrigerant used in this type of equipment until 2016 in France is R-134a. The bank is estimated at less than 200 tons. However, an emerging market for CO_2 exists starting in 2014.

The 2012 Thermal Regulation leads to the stop of the installation of electric resistance water heaters in new buildings. To cope with this radical change in the water heater market, many manufacturers are developing thermodynamic water heaters running on R-134a. The NF EN 16147 performance measurement standard measures the coefficient of performance of these air / water heat pumps at 45°C. Even with these favorable conditions, the average annual COP is at best between 2.4 and 3 (see manufacturer's documentation) for these R-134a water heaters.

5.2.2 *Alternatives*

In Japan, the EcoCute program (Hashimoto, 2006) has enabled the development of thermodynamic water heaters operating with CO_2 and capable of producing hot water between 55 and 70°C. The annual COPs measured on in situ installations show annual values greater than 4, which is quite remarkable. One brand, at least, produces such water heaters adapted to European needs with a COP of the same level but a price much higher than that of water heaters developed with R-134a.

Communications on the replacement of R-134a by R-1234yf or R-1234ze (E) do not yet appear, but from a thermodynamic point of view, those two refrigerants are easily adaptable to water heaters developed with R-134a. The replacement of R-134a with isobutane is not currently announced because the refrigerant charge required for the heating capacity of the water heater is well above 150 g.

However, water heaters with a capacity of between 100 and 300 liters operating with R-290 appear on the French market.

For this application, as for domestic refrigerating appliances, the refrigerant circuits are completely hermetic and the retrofit does not make sense. Only replacement refrigerants in new equipment should be considered.

5.2.3 CONCLUSIONS

CO_2 has a future ahead of it, but the cost of CO_2-powered water heaters is currently limiting the development of its market. The EcoCute program has enabled the development of this market to several million of units, no less than 17 Japanese brands have entered this market, which has allowed an extraordinary R & D work for the development of all the components necessary for the management of CO_2 at high pressure. One of the lessons to be learned from these developments is that Japanese companies that develop heat pumps as well as air-conditioning or refrigeration systems are very familiar with the efficient uses of CO_2, whether in commercial refrigeration or thermodynamic water heaters, and designed and realized the key components of CO_2 implementation. If CO_2 uses are currently limited it is knowingly.

Table 5-2: Synthesis of alternatives to high-GWP HFCs available for TWH.

Reference refrigerant	Alternative Options	+	-
R-134a	CO_2	Better efficiency Feedback from Japan	Expensive
	R-290	Efficiency	Expensive

6 - COMMERCIAL REFRIGERATION

6.1 HERMETICALLY SEALED EQUIPMENT FOR DISPLAY CASES

6.1.1 REFERENCE REFRIGERANTS

Hermetically sealed equipment fitted into refrigerated cabinets (refrigerated display cases, cabinets, freezers, ice cream dispensers, etc.) in convenience stores have historically used R-134a and R-404A and, in the case of vending machines, only R-134a.

6.1.2 ANALYSIS OF EXISTING ALTERNATIVES FOR NEW EQUIPMENT

Since the 2010s, hydrocarbons have been put on the market, via some manufacturers who offer refrigerated display cases, freezers and ice cream dispensers operating with propane (HC-290).

CO_2 also appears in this period in vending machines with the commitment of multinational companies. The literature establishing energy comparisons between different options mainly concern, for this sector, the replacement of R-134a by a pure HFO and the replacement of R-404A by an HFC-HFO mixture. The trends are that R-1234yf provides a cooling capacity and an energy efficiency comparable to R-134a (*Sethi, 2016*). R-1234ze (E) requires larger swept volume compressors to achieve the cooling capacity of R-134a, which has no effect on energy performance. For the replacement of R-404A several HFC-HFO blends are developed. According to (*Sethi, 2016-b*), measurements on freezer or cold room equipment using R-448A (GWP 1387) or R-455A (GWP 148) show an improvement in energy efficiency from 4 to 9% compared to R-404A, depending on the case. According to (Minor, 2016), the R-454C (GWP = 148) is an energy-saving A2L alternative for small charge equipment, to replace R-404A. The tests show a low energy consumption and a good compatibility of materials and oil used.

6.1.3 ANALYSIS OF THE SECTORIAL BANK 2016

The refrigerant historically most used in hermetically sealed equipment is R-134a and, for higher capacities, R-404A with fewer equipment but larger charges. The share of hydrocarbons (R-290 and R-600a) is growing but they have recently appeared on the French market and, because of the equipment lifetime and the low charges involved, their penetration in the bank is estimated at less than 10% in 2016.

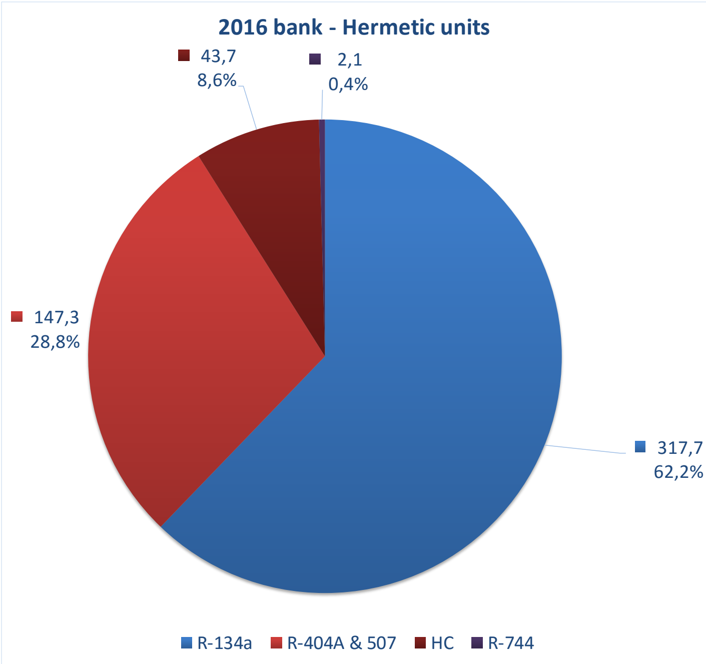


Figure 6-1 – Hermetically sealed equipment (small stores) – 2016 bank.

6.1.4 CONCLUSIONS & PERSPECTIVES

For the segment of hermetically sealed equipment of small stores, the transition from R-134a to hydrocarbon alternatives has begun; R-1234yf is also an energetically feasible option for this type of equipment. Regarding the replacement of R-404A, A2L mixtures (R-454C or R-455A) are proposed, with energy efficiency superior or comparable to that of R-404A according to the articles studied.

Table 6-1 – Synthesis of alternatives to high-GWP HFCs for hermetically sealed equipment for small stores.

Reference refrigerant	Alternative Options	+	-
R-134a	HC R-1234yf CO_2 (vending machines)	Improved efficiency Energy efficiency equivalent to R-134a To be demonstrated	A3 A2L Implementation
R-404A	R-455A Or R-454C	Energy efficiency higher or similar to that of R-404A based on articles studied	A2L

6.2 CONDENSING UNITS

The term "condensing unit" refers to an assembly of components, forming a unit for compressing the low-pressure gases, cooling them in a flow of air to condense them and thereby supplying high-pressure liquid to one or more evaporators. This unit (minimally consisting of a compressor, a condenser and a fan) is suitable for establishments with low-cooling capacity needs such as restaurants, bars, hotels, as well as small sales areas such as specialized food stores and convenience stores. The architecture chosen for these establishments consists in feeding display cases and / or small cold rooms with a condensing unit. These units release their energy in the ambient air (outdoor):

- Either directly if they are located outdoor,
- or via an air duct coupled to a fan driving outdoor air to the condenser and releasing it after it has warmed up.

Food storage temperatures are said medium (between 0°C and 10°C depending on the products) or low (<-18°C).

It should be noted that this is a global market, the choices of refrigerants therefore include a constraint of trivialization of the refrigerant. Several choices can, however, coexist. This is a market that is of great interest to manufacturers of hermetic compressors.

6.2.1 Reference refrigerants

The most common refrigerants so far for these applications are R-134a for medium temperatures and R-404A for medium and / or low temperatures.

6.2.2 Analysis of existing alternatives for new equipment

Today, alternative refrigerants are R-290, R-744, for low temperatures and R-1234yf or le R-1234ze(E) for medium temperatures.

For R-290, some manufacturers offer small cooling capacity condensing units for low-temperature systems to replace R-404A. Mounting an installation on site requires know-how, and thus training (due to the high flammability of propane) that may be missing today.

R-1234yf is proposed by manufacturer of condensing units running previously with R-134a and thus for medium temperatures.

CO_2 is proposed in condensing units of larger cooling capacity by world-leading or smaller manufacturer (*Leong, 2017*).

The lack of training of installers for the design, installation and use of facilities running with those refrigerants was mentioned several times during interviews. Options are already available or under development, but the next step is the availability of competent personnel to handle them.

6.2.3 Analysis of existing alternatives for retrofit of installations

In theory, several refrigerants can replace R-404A and R-134a for retrofit of installations. Manufacturers of condensing units validate certain of them by tests. It is necessary to verify that a refrigerant is indeed validated by the equipment manufacturer prior to proceed a retrofit.

For R-404A, manufacturers of condensing units push for:

- R-407A,
- R-407F,
- R-448A,
- R-449A, and R-452A.

All these refrigerants belong to A1 safety class, such as R-404A. Before proceeding with the replacement of R-404A, the following points must be considered:

- The cooling capacity and the efficiency obtained with these replacement refrigerants may vary; software of manufacturers allow to estimate those efficiencies.
- R-32 being a component of these blends, the discharge temperatures increase (except for R-452A). Thus, the range of use of those refrigerants may be limited.
- The significant temperature glides of those refrigerants.

There is currently no requirement to replace R-134a because its GWP (1430) is below the limit of 2500. However, replacement refrigerants exist, that are:

- R-450A and
- R-513A

Those refrigerants, blends of R-134a and R-1234yf, with no or small temperature glide, allow same operating ranges and present the advantage to have lower GWP than pure R-134a.

6.2.4 *Analysis of the sectorial bank 2016*

Historically, R-404Aa was widely used in condensing units fitted to display cases in small stores and mini markets. Charges can be significant, especially in mini markets and "drive"-type stores, which are also considered in this sector since a few years in the inventory studies (average charge = 200 kg).

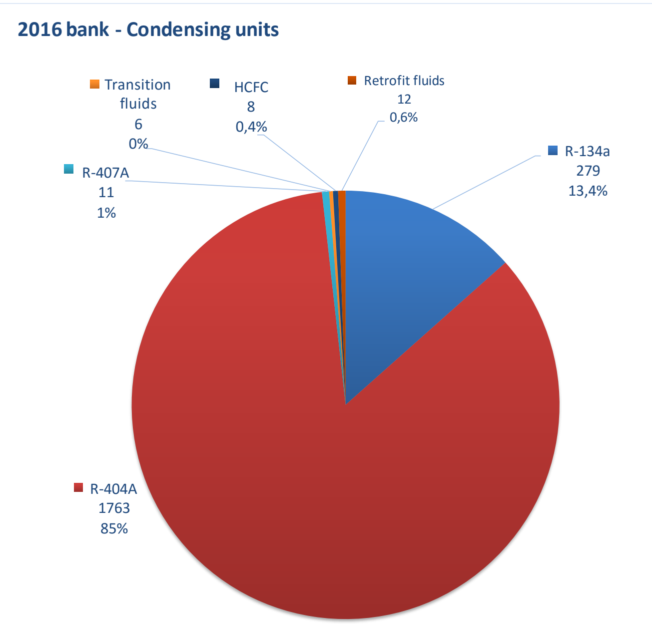


Figure 6-2 – Bank 2016 of condensing units in small stores.

In 2016, alternatives to R-404A and R-134a are therefore not very representative of the bank.

6.2.5 Conclusions and Perspectives

Alternatives to high-GWP refrigerants exist for condensing units. However, products are not all matures and the personnel trained to the use of refrigerants with flammability risks is still insufficient. These findings push some manufacturers to bet on HFOs (R-1234yf or R-1234ze). CO_2 begins to be proposed including by major manufacturers.

As far as energy efficiency is concerned, the condensing-unit manufacturers must, since July 2018, meet the Eco-Design requirements mentioned in Paragraph 3.4.5. For intermediate replacement refrigerants, efficiencies vary with volumetric capacities from -10 to + 10% and for COP compressors the same dispersion is found. For longer-term options for R-134a, HFOs or propane can achieve at least the same energy efficiency as the AHRTI reports have shown. For the long-term replacements of R-404A, systematic results are still lacking.

Table 6-2: Synthesis of alternatives to high-GWP HFCs available for condensing units of small stores.

Reference refrigerants	Alternative options	+	-
R-134a For medium T°	R-1234yf and R-1234ze	Energy efficiency equivalent to R-134a	Technical maturity A2L
R-404A For medium and low T°	R-290 R-744 R-448A, R-449A R-450A, R-513A R-455A, R-454C	Improved energy efficiency (+++) To be demonstrated Energy efficiency equivalent to R-404A	A3 – Installer training Technical maturity Short term, GWP

In the shorter term, some manufacturers have made the choice to develop product lines designed for transition refrigerants such as R-448A or R-449A; the market for such products is limited to a few years due to their GWP close to 1400.

6.3 Direct or Indirect Centralized Systems for Medium and Low Temperature Refrigeration Equipment

Hypermarkets and supermarkets have centralized facilities, with a machine room where two series of refrigeration systems operate, one between -10 and -15°C for the preservation of fresh products (medium temperatures) and the other at around -35 to -38°C for frozen products (low temperatures). Referred to the total cooling capacity installed, the medium-temperature refrigeration typically represents 75% and the low-temperature refrigeration approximately 25%.

In this sector, two types of applications exist:

- Direct or indirect expansion systems in medium-temperature refrigeration systems,

- ➢ Direct or indirect expansion systems in medium and low-temperature refrigeration systems.

Under the F-Gas regulation, this sector is specifically targeted by:

- the ban on the use of refrigerants with GWPs higher than 2500 from 2020 and higher than 150 as of 2022, an exception being granted to cascade-type systems whose primary circuit uses a refrigerant with a GWP lower than 1500. Attention, as noted below in Note 21 of the European Commission's report of 4 August 2017 (*European Commission, 2017*), **the definition of primary circuit is ambiguous.**

"It is important to point out that the 2022 requirement does not allow a simple cascade with e.g. HFC R134a in the primary circuit that also serves the whole medium-temperature cooling requirements while absorbing the heat from a CO_2 circuit for the low temperature. The requirement demands instead that the medium-temperature itself is split into two circuits, where only the primary circuit would be allowed to use HFCs < 1500, such as R134a."

- the ban on the use of virgin refrigerants with a GWP higher than 2500 for the maintenance of existing installations as from 1 January 2020.

This sector is therefore particularly targeted by the regulations, because of the very wide use of HFCs with high GWP and the proven existence of alternatives for new installations.

As a result, whether for new equipment technologies or retrofit opportunities, the proposals offered to this sector are abundant and it is difficult to be exhaustive and to be able to compare all the options between them in terms of total greenhouse-gas emissions. As shown on the following graph, some Life Cycle Climate Performance (LCCP) analyzes exist in the literature but they are based on a large number of assumptions, the whole of which is not always explicit, and some of which, such as the rate of emission of the installation that can have a preponderant impact on the conclusions. For the record, the LCCP (*IIR, 2015*) distinguishes direct emissions (related to the use of the refrigerant during the equipment lifetime) from indirect emissions related to both the energy consumption of the equipment but also those related to the equipment manufacturing, the refrigerant production and the equipment dismantling.

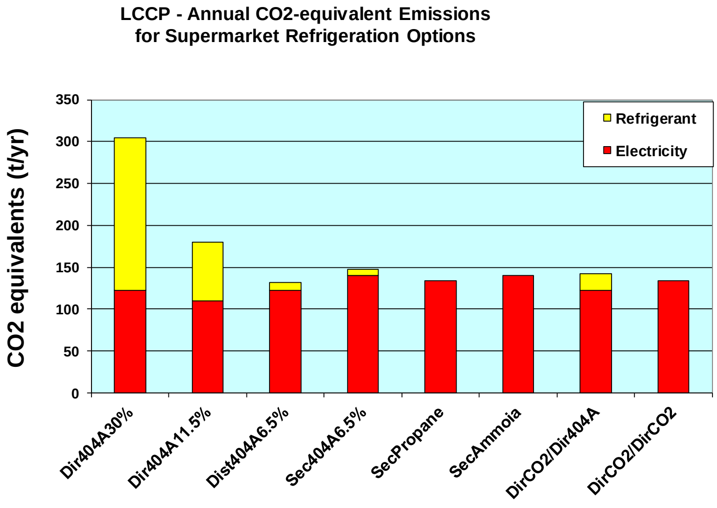


Figure 6-3 – Comparison of the total annual equivalent CO_2 emissions of several types of commercial refrigeration plants (*Bivens, 2002*).

Figure 6-3 shows an example of a comparison of several options used in commercial refrigeration. It is verified in this figure that a refrigerant such as R-404A, with a very high GWP and also a high emission rate, is required for a strong differentiation with respect to the other options for which the energy consumption is both preponderant and of the same order of magnitude.

6.3.1 *REFERENCE REFRIGERANTS*

In this sector, the reference system, dominating the market of new equipment for several years, is the **centralized direct-expansion system using R-404A in low and medium-temperature refrigeration systems** or in medium-temperature refrigeration system alone.

R-404A (GWP = 3922) and R-507 (GWP = 3985) constitute almost all of the new refrigerant market for centralized commercial refrigeration facilities between 2000 and 2009-2010. Depending on the need for medium and low-temperature refrigeration, the supermarket or hypermarket has one or more R-404A racks. The nominal refrigerant charges for installations vary from 200 kg for small supermarkets to almost 3 tonnes for larger hypermarkets.

One of the advantages of R-404A in commercial refrigeration was to be adapted to medium and low-temperature refrigeration and to be used throughout the installation at a competitive cost.

6.3.2 *ANALYSIS OF EXISTING ALTERNATIVES FOR NEW EQUIPMENT*

6.3.2.1 Implemented alternatives

In centralized commercial refrigeration and for new facilities, alternatives to direct expansion systems using R-404A are as follows.

1 – “Cascade” systems using R-134a/CO_2: those systems use R-744 in direct expansion system for low-temperature and indirect expansion system using R-134a (R-134a/heat transfer fluid) for medium temperature. The R-134a/CO_2 cascade system remains today one of the main alternatives to direct or indirect expansion systems in medium and low-temperature refrigeration systems using R-404A. This alternative presents the following advantages:

- Low HFC charge, since it is used only in the primary circuit (150 to 500 kg);
- a cost that has become competitive compared to the reference installations usingR-404A (option existing on the market for several years);
- to be an energy efficient option;
- to be a option accepted by the F-Gas II regulation even after 2022;
- to be a long-term option offering *a priori* possibilities of conversions to HFO (R-1234ze(E) or R-1234yf).

  To be noted: other HFCs are proposed as alternatives to R-134a for cascade systems, with GWP between 1200 and 1500 such as R-448A.

2 – "R-744 transcritical" systems so-called "booster" that use R-744 (CO_2) in both Low-Temperature (LT) and Medium-Temperature (MT) systems. LT compressors act as boosters to go up from the LT stage to the MT stage. These systems had the disadvantage of being expensive and less energy efficient than other options in hot climate. As shown in Figure 6-4 from a European Commission study (*European Commission, 2017*), the trend is to reduce costs and improve energy efficiency.

3 – Cascade systems using an HFC-HFO mixture with GWP near 600: R-450A and R-513A for example, both non-flammables can be used in the primary circuit of a cascade system. This type of installation has already been implemented in hypermarkets in France and meets the post-2022 constraints of the F-Gas regulation (GWP <1500 for the refrigerant used in the primary circuit of a cascade type installation) while limiting the equivalent CO_2 quantities installed compared to R-134a. Without or with a very low temperature glide (1 K for R-450A), these refrigerants could also be considered for the retrofit of existing R-134a / CO_2 cascade-system in commercial refrigeration.

4 – Systems using an HFC-HFO blend with a GWP lower than 150, such as R 455A and R-454C, both A2L, may be used in an indirect or "cascade"-type installation. There are pilot stores, especially in Germany. Some of these mixtures were identified in the previous study *Alternatives to high-GWP HFCs*; they were improved in terms of GWP and recently released after being integrated in ASHRAE 34. These refrigerants, however, have a significant temperature glide that can be problematic for the maintenance of the facilities.

5 – Indirect or cascade type equipment using R-717 (ammonia) as primary refrigerant. This type of alternative option is very unusual in France but used in some countries such as Hungary (*Winter, 2012*). Ammonia, because of its toxicity (B2L), can be used only if confined in machinery rooms and presents strong constraints of usage in terms of safety and installation.

It should be noted that direct or indirect expansion systems using R-134a or an A1 mixture of GWP around 600 are suitable for supermarkets and allowed in new installations until 2022 while meeting the 2020 deadline for maintenance.

Other direct expansion systems using refrigerants with GWP between 1800 and 2500 such as R-407A or R-407F are technically and legally possible alternatives to R-404A but are not proposed as a credible alternative in this study because these options seem inappropriate from the point of view of *phasedown* and available quotas.

It should also be noted that in some countries, shops are starting to use propane / heat transfer fluid systems associated with "stand-alone" equipment (hermetically sealed equipment).

6.3.2.2 Lessons learned

In accordance with Chapter 3 of Article 21 of F-Gas Regulation (EU) No 517/2014 concerning the review of the ban on the use of HFCs with GWP> 150 in new centralized refrigeration equipment (except in "cascade" systems for which the GWP threshold is set at 1500), the European Commission published in August 2017 a report "assessing the prohibition foreseen in Annex III, point 13, and examining in particular the existence of options technically feasible and cost-effective, energy efficient and reliable, capable of replacing the centralized multi-split refrigeration systems referred to in that provision. "(European Commission, 2017). The objective is to verify that the situation of the commercial refrigeration sector is in line with the 2022 deadline.

This report is based on various preliminary studies such as that of Oko-Research (Oko, 2016), which surveyed 150 European companies (response rate 27%) on their use and knowledge in terms of energy costs and energy efficiency of alternatives to high-GWP HFCs in centralized commercial refrigeration.

The conclusions of the European Commission report are that:

- Several alternative technologies to R-404A are widely used in Europe in this sector;
- These can be structured in 3 main categories: transcritical CO_2 installations, indirect centralized systems (including "cascade" systems) and stand-alone systems associated with a chiller using low-GWP refrigerants;

- These options are considered reliable and energy efficient;
- The results of the studies "suggest" that many of these alternatives are or will be cost-competitive in 2022;

It is therefore not necessary to relax the regulatory deadline of 2022.

In the particular case of the "transcritical CO_2" category, the report highlights the reduction of the energy costs and consumptions of this type of installation (Figure 6-4) as well as that of the emission rates, which are now in the same order of magnitude as those of HFC installations. Although the report points out that transcritical CO_2 systems are more suitable for cold or moderate climates, it mentions that:

- According to several case studies cited in (Oko-Research, 2016), successive technological improvements to booster systems (parallel compression, ejectors, secondary coolers) have considerably improved the efficiency of transcritical CO_2 systems compared to HFC / CO_2 direct-cascade systems and HFC systems;
- Their use is increasing even in southern European countries such as Italy, Spain, Portugal and Romania.

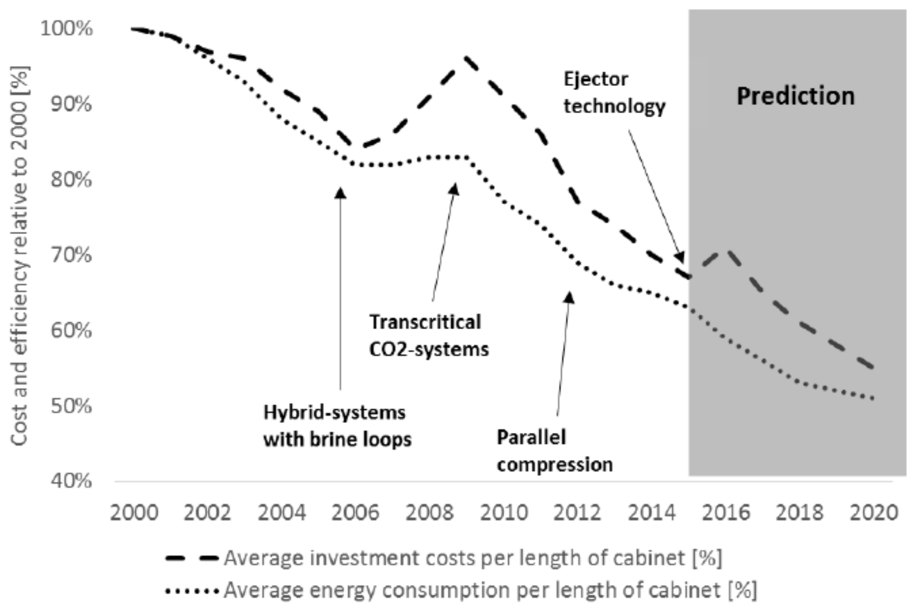


Figure 6-4 – Evolution of costs and energy consumptions of CO_2 systems in commercial refrigeration. Feedback from Switzerland (*European Commission, 2017*).

In terms of cost, the report underlines the initial additional cost of CO_2 technology (particularly high in the case of systems adapted to hot climate countries) is offset by the savings of energy after a few years, according to the Oko-Research survey returns.

In hot climates and large stores, the report highlights the value of indirect-cascade systems R 717 / R-744 that perform well in this type of conditions

In France, the transcritical CO_2 option is indeed used by large commercial chains and clearly displayed by certain brands [1] but without specifying the size of stores for which the transcritical CO_2 systems are adapted. Some installers, specialized in the control of the energy consumptions of refrigerating installations, have been proposing only this option for several years on the French market [2].

In recent years, with the revision of the F-Gas regulation and the implementation of the new regulation, commercial chains have tested and implemented several alternatives to R-404A, whether they are new installations or retrofits. Operators highlight the advantages of each option.

- The R-448A / CO_2 cascade systems present the advantage of a smaller footprint compared to R-134a / CO_2 installations (lower volumetric capacity of R-448A) and, as a result, a lower cost of installation [3];
- The first field tests conducted by the Auchan group on R 450A / CO_2 cascade systems show an improvement in energy efficiency compared to R 134a / CO2 [4];

[1] Position of the Carrefour group, http://www.carrefour.com/fr/content/du-co2-pour-un-froid-plus-propre

[2] Interview of Matthieu Auclerc, EO2S, pour le CITEPA, September 2017.

[3] http://larpf.fr/Archives-article/Fiche/7554/Un-Intermarche-marseillais-s%2592equipe-d%2592une-cascade-R-448A%252FCO2

[4] https://www.hvac-intelligence.fr/actualites-marches/r450a-remplace-r134a-systeme-cascade-co2/ Auchan, 2015, R-450A replaces R-134a in the CO_2 cascade system, communication of HVAC intelligence.

6.3.2.3 Scientific literature data

Numerous articles compare the performance of transcritical CO_2 installations to centralized HFC systems traditionally used in supermarkets and hypermarkets. Encouraging the conclusions of the European report, studies show that the energy efficiency of recent transcritical CO_2 technologies is improved.

- Article by Sawhala & al. (*Sawalha, 2017* and *2015*) comparing 5 commercial refrigeration systems in supermarkets in Sweden, based on field measurements associated with modeling to make comparable experimental situations and to evaluate annual energy consumption show that:
    - Current CO_2 transcritical systems are significantly more efficient than the first systems (COP differences of up to 40%) and provide higher COPs than centralized direct expansion systems using HFCs for outdoor temperatures below 24°C;
    - The energy consumption of recent transcritical CO_2 equipment in supermarkets is about 20% lower than for traditional HFC equipment (R-404A and R-407C);
    - Recent enhancements such as parallel compression or ejector tend to reduce the performance gaps of transcritical CO_2 systems between hot and cold climates and to make the use of transcritical CO_2 systems in hot climates possible.
- According to (*Tsamos, 2017*), comparing 4 CO_2 configurations for commercial refrigeration, the parallel compression system is the most efficient in both warm and moderate climates and allows an improvement of energy efficiency of 5% in hot climate and 3.6% in a moderate climate compared to the reference booster system.

Recent studies are also being carried out to improve the performance of R 134a / CO_2 cascade systems. According to (*Llopis, 2016-b*), the introduction of an (internal heat exchanger, IHX) on the LT CO_2 circuit of an R-134a / CO_2 cascade system increases the overall COP of 3.7% while slightly reducing the cooling capacity.

Articles attempt to realize global comprehensive comparative LCCP analyzes using open access tools such as the tool created by the Oak Ridge National Laboratory and the University of Maryland College Park (http://lccp.umd.edu/ornllccp/) for commercial refrigeration systems in supermarkets and heat pumps. In (*Beshr, 2014*) are compared, using this tool, the environmental impact of 4 supermarkets equipped with direct expansion or cascade systems, and R-404A, R-448A or R-455A (then L-40 of GWP 285) refrigerants, with a transcritical CO_2 system. This tool is coupled with the EnergyPlus software to simulate the hourly performance of the systems. A large number of assumptions are associated with the model, with various sources, which makes the analysis of the article difficult. However, it appears that in terms of energy consumption, the most efficient system is then a composite installation of an indirect system with R-455A as a primary medium temperature refrigerant, combined with a direct expansion system using R-448A. On the other hand, in all cases, it is the transcritical CO_2 system, (let us mention that this article is part of the "traditional" booster model of 2014), which energy consumption is the highest, significantly in hot climates. This article shows that low-GWP HFCs are possible in the primary circuit of a cascade system in order to reduce energy consumption.

6.3.3 ANALYSIS OF EXISTING ALTERNATIVES FOR THE RETROFIT OF INSTALLATIONS

6.3.3.1 Alternatives implemented

For the retrofit of existing equipment using R-404A, the R-407A and F were the most used refrigerants until 2015-16.

Since 2015, when they were not yet available during the assessment carried out for the *Study on Alternatives of 2014*, several blends with a GWP between 1250 and 1500 have been put on the market (R-448A, R-449A, R-407H in particular) to convert equipment using R 404A.

6.3.3.2 Lessons learned

Large companies prefer retrofits from R-404A to R-448A or R-449A for equipment that are too recent and have not yet been amortized.

In Spain, following the introduction of a tax on HFCs, numerous retrofits of R-404A installations were made. Feedback from the Makro chain of wholesalers indicates a gain in energy consumption of plants that have been retrofitted from R-404A to R-448A [6].

Several publications compare the performance of retrofit refrigerants with those of R-404A. Among others, (*Sethi 2016-b*) is interested in converting a supermarket using R-404A to R-448A. The analysis shows a reduction in energy consumption of 9 to 20% depending on the outdoor temperature. In *(Llopis, 2017)*, R-407H is tested in drop-in in a low-temperature direct-expansion system under different operating conditions and for partial and complete drop-ins. Compared to R-404A, the energy consumption is reduced by 7.7% on the compressor and 4.0% on the whole system.

These feedbacks tend to show that retrofit options, in the short term, can be energy efficient alternatives to R-404A and an option to the consequences of phasedown observed in 2017-2018.

[5] Interview of Makro for the RPF, February 2018. End of R-404A: Spanish installations retrofitted to R-448A.

6.3.4 Analysis of the 2016 sectorial bank

R-134a / CO_2 cascade installations are already widely used in France in hyper and supermarkets. From 2010-2011, inventories studies mention their introduction on the French market. The share of these installations in the new market for centralized equipment has increased, as their cost has become rapidly competitive. According to the European Commission's 2017 report, 9,000 stores use transcritical CO_2 systems in Europe in 2016 and the number of these systems has recently increased significantly in France.

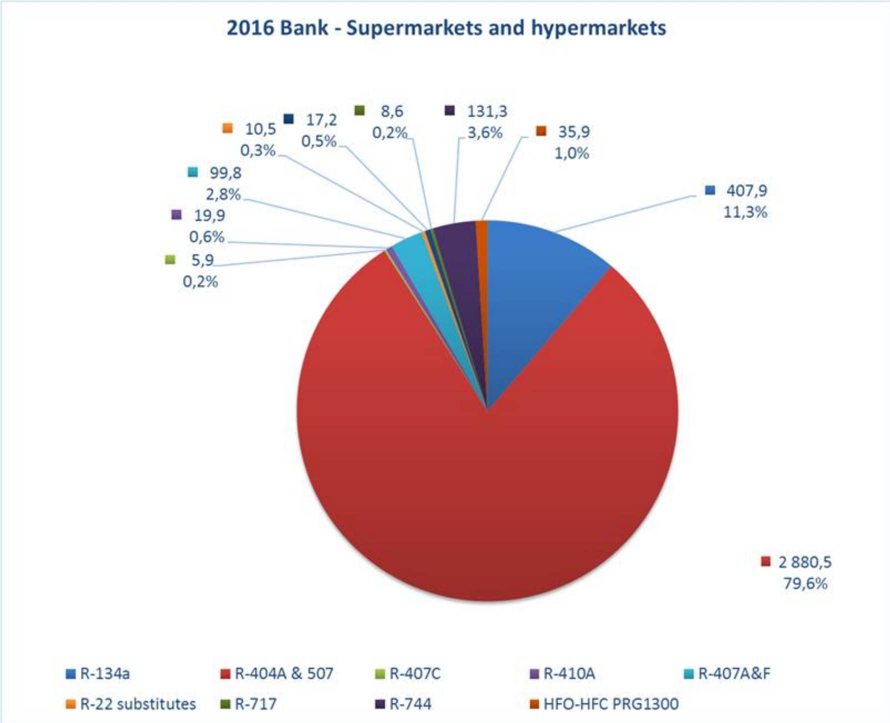


Figure 6-5: Bank of refrigerants used in commercial refrigeration – Centralized systems of super and hypermarkets. (*Barrault, 2016*)

It should be noted that the average quantities of R-744 installed in the HFC / CO_2 or transcritical CO_2 cascade systems are known less precisely than those of HFCs and, in the context of the inventory studies, the CO2 bank presents greater uncertainty.

The 2016 bank is still clearly dominated by R-404A, at nearly 80%, but the decreasing trend, of 8% between 2015 and 2016, will increase and gradually reduce the bank. It is possible that the CO_2 bank is slightly underestimated.

6.3.5 CONCLUSIONS & PERSPECTIVES

Different alternative options to direct expansion systems using R-404A are currently available.

While many papers compare systems using HFC / CO_2 cascade systems to transcritical CO_2 systems, few address indirect systems. Technological developments have been and are being carried out in order to improve the energy efficiency of transcritical CO_2 systems, which up to now have not been able to achieve the performance of R-404A direct expansion equipment for outdoor temperatures above 24 °C. It should be emphasized that, on the one hand, it is necessary to ensure the robustness of the progress made in medium-temperature refrigeration on CO_2 installations and, on the other hand, that some of these technical advances could be adapted to R-134a / CO_2 cascade systems or low-GWP HFC / CO_2 and further improve its efficiency already superior to the reference installations. At the same time, the cost of these options tends to decrease. The upcoming regulatory deadlines for new equipment placed on the market should therefore be honored. Let us underline once again that, what was not obvious at the first reading of Regulation (EU) No 517/2014 is highlighted in the August 2017 report of the European Commission: the primary circuits of cascade systems authorized to be placed on the market after 2022 must use a refrigerant with GWP <1500.

Table 6-3 : Synthesis of alternatives to high-GWP HFCs available for centralized systems in supermarkets and hypermarkets.

Reference refrigerants	Alternative options	+	-
R-404A	Cascade R-134a/CO_2	Competitive cost Efficiency ++ Long term (EU517/2014 & HFO conversion)	Availability R-134a
	Cascade HFC/CO_2 with HFC with GWP around 600	Efficiency equivalent to cascade R-134a/CO_2, A1 Adapted post 2022 and phasedown	
	Cascade NH_3/ CO_2 or indirect NH_3	Efficiency +++ Long term Efficiency ++ Long term	B2L - safety Maintenance & installation Cost Little feedback in commercial refrigeration
	Indirect systems or HFC cascade with GWP < 150	Long-term post 2022 Efficient +	A2L Technical maturity T° glide
	CO_2 transcritical improved booster system	Recent technical developments for hot climate adaptation Improved energy efficiency and cost	Remains expansive Techno cold + to be tested
Retrofits: R-448A & R-449A alternatives efficient with R-404A (4 to 20% gain in energy consumption)			

Finally, with more than 2,500 tonnes of R-404A still present in commercial refrigeration centralized systems, it is the 2020 deadline for the prohibition of the use of new refrigerants of GWP> 2500 for the maintenance of installations that may be a problem for the commercial refrigeration sector. It is likely that short-term retrofit options to GWP <2500 refrigerants need to be implemented. The proposed replacement refrigerants of GWP around 1300 can reduce energy consumption by 4 to 20% depending on the configurations, in the cases studied in the literature.

7 - Air-to-air air conditioning

Air conditioning equipment can be organized in two sub-sectors, based on their cooling capacity: individual air conditioning (< 17,5 kW) and autonomous air conditioning. Table 7-1, from the 2015 inventory report (*Barrault, 2015*), presents data of markets of various equipment categories in 2015.

Note: RTOC and BSRIA reports have respectively 6 and 8 different categories; Here we have 8 categories grouped in 2 sub-sectors names residential and “autonomous”.

Table 7-1: Markets of air-conditioning equipment in France in 2015.

Markets	Residential air conditioning				Autonomous air conditioning				
	Portable**	Window	Split system	Multi split system	VRF	Split & multi split	Roof top	Specific cabinets	Vertical cabinets
2017	70,000*	350*	365,000	120,000	23,000	5,000	1,500*	1,000*	1,000*

* estimated values.
**market data with high uncertainty.

Table 7-2 shows differences in order of magnitude:

- between residential air-conditioning, with equipment sold annually to several hundred thousand units, and stan-alone air conditioning, with a market of around 20,000 units;
- inside the residential air conditioning the market of several hundreds of thousands of units is that of the split systems and the portables of tens of thousands;

On the other hand, DRVs differ from multi-splits by the cooling capacity but present a close design.

These observations on orders of magnitude have the consequence that the ultra-dominant refrigerant is R-410A because splits, multi-splits, VRFs are manufactured by international companies that make choices for all global markets.

R-290, even if it is installed in hundreds of thousands of "portables", remains a niche market as shown in Table 7 2.

Table 7-2: Refrigerants used in the air conditioning sector (*Barrault, 2015*).

Refrigerants	2010	2015
Portables	100% R-410A	90% R-410A, 10% R-290
Windows	100% R-410A	100% R-410A
Mono split	2% R-407C, 98% R-410A	1% R-407C, 94% R-410A, 5% R-32
Multi splits	14% R-407C, 86% R-410A	1% R-407C, 94% R-410A, 5% R-32
Specific cabinets	26% R-407C, 55% R-410A, 19% R-134a	1% R-407C, 99% R-410A
DRV	25% R-407C, 57% R-410A, 18% R-134a	18% R-407C, 65% R-410A, 17% R-134a
Splits and Multi splits	5% R-407C, 95% R-410A	5% R-407C, 95% R-410A
Roof tops	27% R-407C, 73% R-410A	15% R-407C, 85% R-410A
Vertical cabinets	1% R-134a 99% R-410A	1% R-134a 99% R-410A

In this report, air conditioners with hermetically sealed circuit are distinguished because of their characteristic of being able to convert to propane (R-290).

7.1 AIR CONDITIONING USING HERMETICALLY SEALED SYSTEMS

7.1.1 REFERENCE REFRIGERANTS

This segment of air-conditioning with hermetic refrigerant circuit is identified as such because it corresponds a priori to the one that can most easily use hydrocarbons. This segment is however dominated by R-410A because the use of R-290 is currently limited, in Europe, to portable air conditioners with a refrigerant charge of several hundred grams. Several European manufacturers offer such portable air conditioners with the complete circuit entirely manufactured in the factory without connection between the outdoor and the indoor units. The choice of R-290 has not extended to the "windows", whose French market is extremely reduced, which are products that follow the American standards and therefore use R-410A. For the consoles, cooling capacities are several kW and the refrigerant charge is quickly beyond the normalized limits (NF EN 378 and EN 335-2-40), hence again the use of R-410A.

7.1.2 SECTORIAL BANK 2016

R-290 started to be introduced in portable-type appliances as of 2005. The bank of hydrocarbons is slowly growing and represents about 3% of the refrigerant bank of this sector.

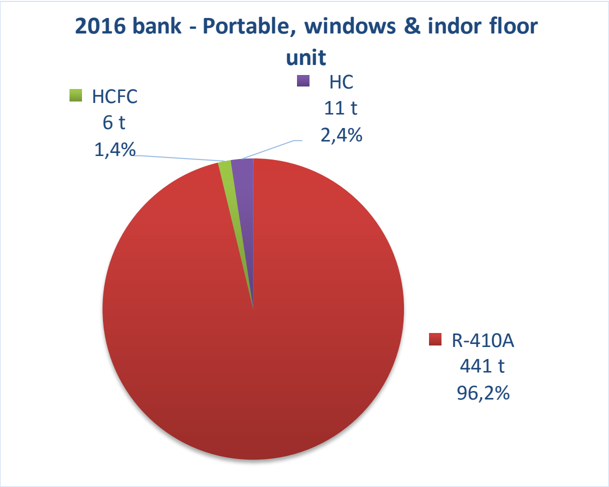


Figure 7-1: Bank 2016 – Hermetic air-conditioning systems.

7.2 SPLIT OR MULTI-SPLIT SYSTEMS (P<17.5 KW)

The split and multi-split systems are manufactured in large series and the retrofit does not make sense, nor the R-410A towards the R-32, nor towards the R-290, for obvious safety reasons and also for thermodynamic reasons on the pressure levels, discharge temperature or volumetric capacity. The substitution of R-410A only arises for new equipment with a system that integrates the thermodynamic and safety properties of the replacement refrigerant. For units operating on R-407C the interest of replacement refrigerants A1 is irrelevant because GWPs are very slightly different and, for long-term replacements, mixtures A2L will be found but not proposed in retrofit for safety conditions.

7.2.1 REFERENCE REFRIGERANT

Table 7-2 shows the R-410A dominance for split and multi-split systems, R-407C representing a very small share and is only used by manufacturers addressing very specific markets of relatively modest size. All major international manufacturers sell equipment using R-410A.

7.2.2 *ANALYSIS OF EXISTING ALTERNATIVES FOR NEW EQUIPMENT*

Currently, R-32 is the alternative refrigerant to R-410A used in split or multi-split systems commercialized in Europe. We note the introduction, by at least three Japanese firms well established in Europe, of split and multi split systems operating with R-32. According to (*Mota-Babiloni, 2017*), R-32 presents three advantages over R-410A: the reduction of the GWP is combined with the charge reduction and the energy efficiency improvement. However, its discharge temperature requires technical optimization of the systems.

The use of R-290 in split systems appears in India and China but these split systems are not marketed in Europe and will have to follow the product standard EN 60335-2-40 whose summary of the 2017 version is presented in Section 3.3.4.2. In (*Lee, 2016*), an LCCP analysis of 4 low-GWP blends is compared to those of R-32, R-290 and R-410A. It is shown that R-32 and R-290 achieve the best reduction in total CO_2 equivalent emissions compared to those blends.

Long-term replacement refrigerants of R-407C are not specifically communicated because
R-407C was chosen to continue operating product lines designed for R-22. It can be stated, however, that these product lines can work with GWP <150 mixtures of R 454C or R-455A designed to replace R-404A.

7.2.3 *ANALYSIS OF THE SECTORIAL BANK 2016*

The bank of this sector taken from the 2016 refrigerant inventory report 2016 shows the dominance of R-410A, with almost 80% of the equipment fleet.

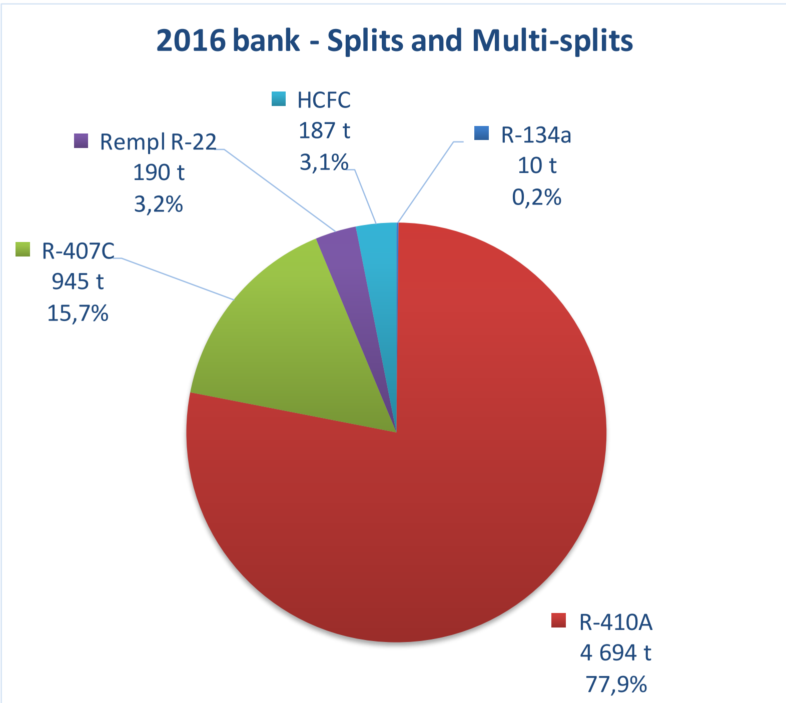


Figure 7-2: Bank 2016 –Split and multi-split systems.

7.3 MULTI-SPLITS P>17.5 KW, DRV SYSTEMS AND ROOFTOPS

7.3.1 REFERENCE REFRIGERANT

Multi-split systems with capacity above 17.5 kW, as well as DRVs, operate mainly on R-410A. As mentioned earlier, R-407C is found in equipment that was designed for R-22. For rooftops, the compactness of equipment is a little less important, resulting in a share of R-407C in the range of 15%. However, we note that the technical developments made for R-410A lead to an energy efficiency that can be higher than that of R-407C units hence the dominance of R-410A also in the segment of rooftops.

7.3.2 ANALYSIS OF EXISTING ALTERNATIVES FOR NEW EQUIPMENT

The long-term alternatives for this equipment of significant cooling capacity are A2L alternatives; there is no reference to the use of R-290 for such cooling capacities. As for the lower cooling capacity units, there are already multi-split or DRV systems marketed with R-32. Replacement refrigerants of the R-452B or R-454B type are not currently advertised in these market segments. The ORNL report (*Abdelaziz, 2016*) on the low-GWP alternatives for rooftops shows that the proposed alternatives, with GWP between 450 and 750, provide better efficiency than
R-410A. However, the substitutes studied have a GWP greater than 250.

7.3.3 ANALYSIS OF EXISTING ALTERNATIVES FOR INSTALLATION RETROFITS

As mentioned in the previous section, the retrofit of multi-split systems running with R-410A will not be done with A2L refrigerants. For rooftops using R-407C, retrofit with A2L refrigerants does not seem plausible and non-flammable alternatives (A1) do not present attractive GWP compared to R-407C.

7.3.4 ANALYSIS OF THE 2016 SECTORIAL BANK

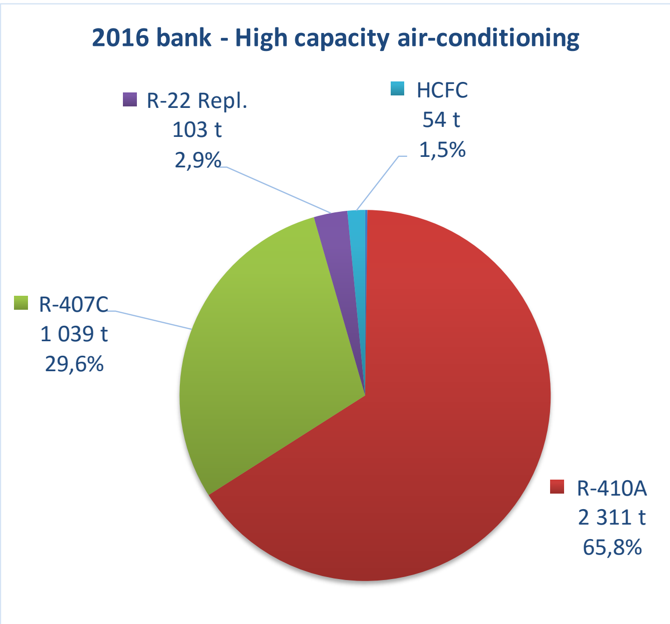


Figure 7-3: Bank 2016 –Multi-splits systems, DRVs and rooftops.

The bank of this equipment fleet reflects the dominant use of R-410A and a significant R-407C bank.

7.4 AIR-TO-AIR AIR CONDITIONING CONCLUSION

The replacement of R-410A by R-32 has been the subject of very significant development work of Japanese manufacturers of split or multi-split systems on both the reliability by the control of the discharge temperature and for the energy efficiency which is improved by 7 to 10%.

As with other applications where hydrocarbons are used, the propane correctly used has an energy efficiency at least equal to R-410A, but its volumetric cooling capacity is at least 15% lower than that of R-410A.

Table 7-3: Synthesis of alternatives to high-GWP HFCs available for air-air conditioning systems.

Reference refrigerants	Alternative Options	+	-
R-410A (hermetic)	HC	Improved efficiency	A3
R-410A (split or multi-split P<17.5 kW)	R-32	Improved efficiency	A2L
R-407C (split or multi-split (P<17.5 kW)	R-454C or R-455A	Equivalent efficiency	A2L
R-410A (multi-split >17.5 kW, VRVs and Rooftops)	R-32	Equivalent efficiency	A2L

8 - HEAT PUMPS

Heat pumps (PAC) can be grouped into four families:

- geothermal heat pumps that draw heat from the ground or water from a ground water via a network of heat exchangers or boreholes;
- aerothermal heat pumps that draw it directly from the ambient air;
- thermodynamic water heaters, treated in household equipment (Section 5.2);
- reversible air conditioners (split or multi-split or VRF), treated in the section of high cooling capacity air conditioning equipment and constitute a very large number of systems operating in heat pumps during the heating season.

Heat pumps considered in this section are the heat pumps that will deliver their heat on a water circuit which avoids the double counting of reversible air conditioners. Ground / floor, ground / water, water / water and heat-transfer fluid / water HPs constitute geothermal heat pumps.

HPs delivering heat to the water circuit can have the thermodynamic system outdoor and only a heat-transfer fluid circuit transfers heat to the interior of the house, making it easier to use flammable refrigerants or moderately flammable. Here again the safety rules are explained in IEC 60 335-2-40 (see Section 3.3.4.1).

Table 8-1: Market of residential heat pumps.

HP	2010	2017
Air/ water	53,854	79,617
Water/water, Floor/ground and Ground/water	8,957	2,005

The heat pump market data is taken from UNICLIMA data. It can be seen that:

- more than 95% of the market is composed of air / water heat pumps that are easier to install and less expensive, and
- less than 5% of water / water or ground / water heat pumps.

8.1 REFERENCE REFRIGERANTS

According to the 2016 inventory study (*Barrault, 2016*), the predominantly used refrigerant in the different types of HPs is R-410A, R-407C occupies 50% of the water / water and ground / water HP sector. Propane (R-290) is starting to be used but currently represents only about 10% of the market.

8.2 ALTERNATIVES FOR NEW EQUIPMENT

As explained above, the alternatives for R-410A are mainly:

- R-32 which is already proposed by several Japanese brands (the interviews conducted for this study confirm this), which is of course facilitated by the fact that the heat is distributed by a water circuit. Some manufacturers plan to produce only HPs using R-32 in the coming years;
- R-290 is already on the market and will probably see its use expand, supported by European firms. The positioning of medium-sized manufacturers is not yet explicit. In the interviews conducted for this study, manufacturers have announced plans to develop systems that use this refrigerant, and some already offer this type of product.

Several studies compare the performance of HPs based on the refrigerant used. We can cite in particular (*Makhnatcha, 2014*), who is interested in a 30-kW air / water heat pump. The results show that R-290 and R-1270 are more energy efficient than R-410A.

For R-407C, switching to R-454C or R-455A refrigerants makes sense for OEMs manufacturing these heat pumps because their GWP is less than 150, but it is still too early to see such an evolution. R-290 can also be an option.

Note on industrial heat pumps

Depending on the temperature level, candidates for the future are R-1234ze (E) and R-1233zd (E). The critical temperatures of these two refrigerants are respectively 109.4°C and 165.6°C, which allows specialized manufacturers to offer heat pumps with higher temperature levels, provided that the lubrication problems are correctly handled.

8.3 ANALYSIS OF THE 2016 SECTORIAL BANK

The air / water HPs largely dominate the residential HP market and mainly use R-410A, which explains that it dominates the bank of this sector. The alternative refrigerant in 2016 is propane, which represents less than 3% of the bank.

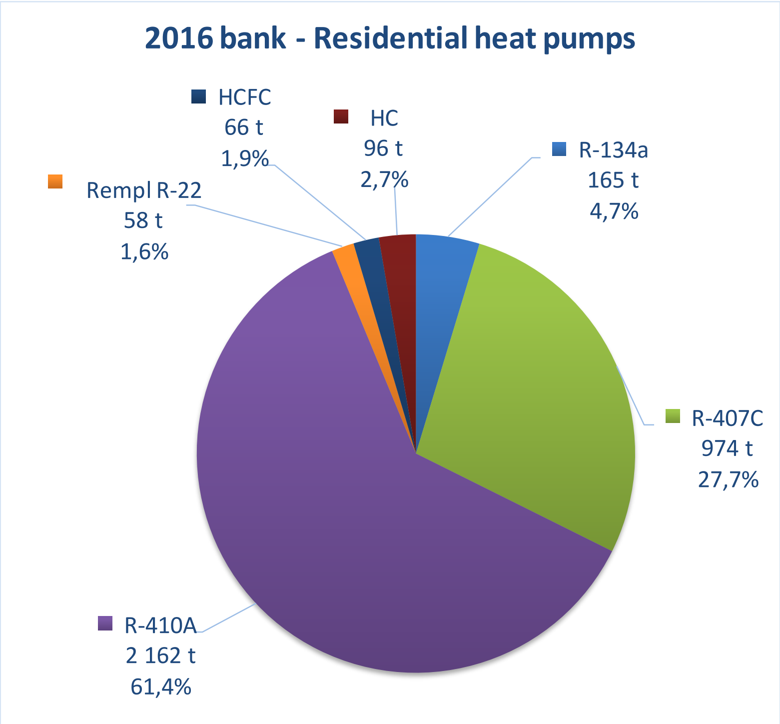


Figure 8-1: Sharing of refrigerants used in HPs and represented in the 2016 bank (air / water, water / water, ground / water & ground / ground).

8.4 Conclusions & perspectives

This sector of water heat pumps follows a priori the same tendencies as the sector of air conditioning. The unknowns are just as strong for the medium term except for the replacement of R 407C where there are A2L mixtures of GWP lower than 150 and where propane can find easier developments than in air-to-air air conditioning. According to the referenced publications, hydrocarbons (A3) are energy efficient alternatives for the replacement of R-410A.

Table 8-2: Synthesis of alternatives to high-GWP HFCs available for heat pumps.

Reference refrigerants	Alternative options	+	-
R-410A	R32 R-290 and R-1270	Good efficiency Improved efficiency	A2L A3
R-407C	R-454C or R-455A	Equivalent efficiency	A2L
R-410A (industrial HPs)	R-1234ze R-1233zd	Good efficiency Improved efficiency A1	Lower cooling volumetric capacity HCFO

9 - Mobile air conditioning (mobile air conditioning system)

9.1.1 *Reference refrigerants*

Since 1994, R-134a has been the only refrigerant used in automotive air conditioning for passenger cars, light commercial vehicles and commercial vehicles. The air conditioning of trains, buses and trams first used R-22 systems and then R-407C or R 134a systems.

9.1.2 *Alternatives for new equipment*

9.1.2.1 10 years of R-1234yf and CO_2 evaluation

Car manufacturers have a strategic interest in a unique and worldwide refrigerant to be used in vehicle air conditioning systems. This banalization makes it possible to maintain a strong pressure on the price of air-conditioning systems offered by Tier 1 equipment manufacturers.

The technical controversy over the choice of R-134a replacement refrigerant between R-1234yf and CO_2 mobilized R & D for all automotive groups for 10 years. Under the auspices of Society of Automotive Engineers (SAE), annual tests were conducted in extreme weather conditions in Phoenix, Arizona for cooling and in winter in Salfenden, Austria to evaluate heat pump performance. From a performance point of view, the tests showed that CO_2 performance could be equivalent in cooling mode and, tendentially better, in heat pump mode. Japanese manufacturers have both developed high-performance CO_2 and R-1234yf systems, and have shown that concerning the reliability and leakage at the rotating joint, CO_2 could hardly become a global choice. From there, R-1234yf became the reference refrigerant in automotive air conditioning despite strong resistance from German firms. European manufacturers have delayed as long as possible the transition to R-1234yf because of the sales price of this refrigerant.

Studies such as (*Papasavva, 2014*) have shown that, placed in a global context, R 1234yf is a better alternative than CO_2, (Figure 9-1) considering all direct and indirect emissions during the life cycle (LCCP) of the vehicle and the refrigerant, even if CO_2 showed slightly better performance in cold or temperate climate.

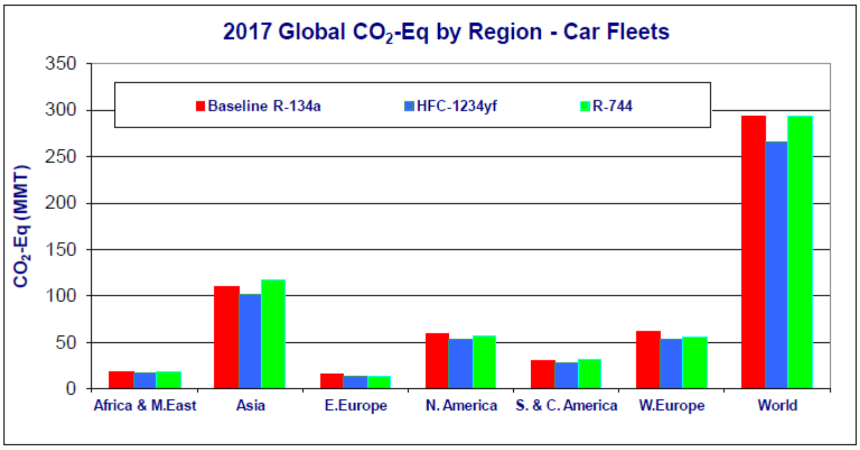


Figure 9-1: Evaluation of total equivalent CO_2 emissions (direct + indirect LCCP meaning) of fleets of mobile air conditioners assuming the implementation of alternatives to all new vehicles as of 2011 (Source: Papasavva, 2014).

9.1.2.2 Implemented alternative

The Directive 2006/40 / EC, said Directive MAC, banned since January 1st 2017 the commercialization on the European market of private vehicles whose air-conditioning system uses a refrigerant of GWP> 150. The Directive provided for a gradual introduction of the alternative to R-134a, from 2011 to 2017. Reconciliations were made, as part of the 2016 inventory study (*Barrault, 2016*), between the markets declared at the ADEME Observatory and the demand for refrigerants derived from inventories based on a progressive penetration of R-1234yf into the European market. Significant differences showed that the introduction of R-1234yf was much slower than expected and initially communicated. The 2017 deadline has been respected and, currently, the private vehicles put on the French market all use R-1234yf. However, given the price difference between R-1234yf and R-134a, the majority of manufacturers favored the use of R-134a over that of R-1234yf over the period 2011-2016, by limiting the number of new platforms.

It should be recalled that commercial vehicles, trucks, buses and trains are currently not covered by the MAC Directive. The disadvantage of R-1234yf for these other applications is currently the refrigerant cost.

9.1.3 ANALYSIS OF THE 2016 SECTORIAL BANK

Given the slow introduction of R-1234yf in the automotive market over the period 2011-2016, its share of the refrigerant bank in 2016 is low, estimated at only 3%.

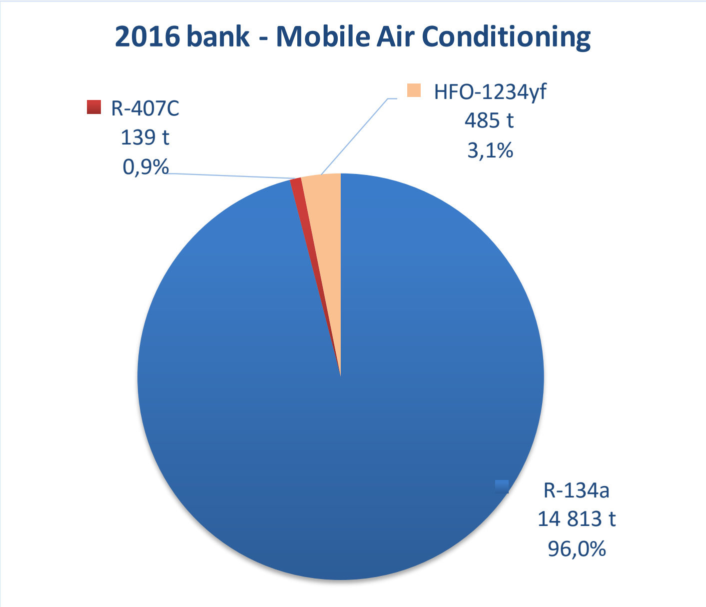


Figure 9-2: Sharing of refrigerants of the mobile air-conditioning sector. 2016 bank.

9.1.4 CONCLUSIONS & PERSPECTIVES

Once the strategic choice is made, it is unlikely that there is a step back; not to forget that, worldwide, R-134a is still significantly dominant, the European regulation being an exception at the global level.

Table 9-1: Synthesis of alternatives to high-GWP HFCs for mobile air-conditioning.

Reference refrigerants	Alternative options	+	-
R-134a	R-1234yf	Equivalent efficiency	A2L
	CO_2	GWP =1 Equivalent efficiency	Reliability High pressure, Increased risk of leakage on the rotating joint

10 - Chillers

According to inventory studies, chillers with a large centrifugal compressor is a small market compared to chillers with volumetric compressors (Table 10-1). In the coming years, the Turbocor "revolution" will have to be considered with the commercialization of centrifugal units of medium cooling capacity (250 to 700 kW).

Table 10-1: French market of chillers (*Barrault, 2015*)

Markets	2000	2005	2010	2015
All cooling capacities	9,830	13,510	7,380	6,424
Centrifugal compressors	49	53	56	50

As shown on Table 10-2, refrigerants used are dependent on the compressor technology: centrifugal or volumetric, and involved cooling capacities. Centrifugal chillers represent a global market and so are chillers with screw compressors. Small size chillers are manufactured by a large number of enterprises, of all sizes, and more local markets.

Table 10-2: Refrigerants used on the market of new chillers 2010-2015 (*Barrault, 2015*)

Refrigerants used	2010	2015
Chillers P < 50 kW	R-407C (31%) R-410A (69%)	R-407C (5%) R-410A (95%)
Chillers 50 < P < 350 kW	R-407C (45%) R-410A (53%) R-717 (2%)	R-407C (5%) R-410A (94%) R-717 (1%)
Chillers P > 350 kW	R-407C (22,5%) R-410A (25,5%) R-134a (50%) R-717 (2%)	R-407C (10%) R-410A (49%) R-134a (40%) R-717 (1%)
Centrifugal compressors	R-134a (100%)	R-134a (95%) R-1234ze(E) (5%)

10.1 Centrifugal chillers

10.1.1 Reference refrigerants

In Europe, the centrifugal market is essentially operating with R-134a. In the rest of the world the market is shared between R-134a and R-123, R-123 allowing the realization of equipment that does not fall under the Pressure Equipment Directive or equivalent regulations outside Europe.

10.1.2 ANALYSIS OF EXISTING ALTERNATIVES FOR NEW CENTRIFUGAL CHILLERS

Alternatives implemented

R-1234ze (E) was launched on the centrifugal chiller market in France in 2015 [1]. The tests were carried out quickly by the manufacturers and the energy efficiency of R 1234ze (E) compared to R-134a is 5 to 10% higher (*Kasai, 2013*). This is the typical case where the alternative has many advantages: GWP in the range of 1, price equivalent to R-134a, improved energy efficiency and very low flammability.

Likewise, **R-1233zd (E)**, which is an HCFO (it remains a chlorine but its effect on ozone is extremely low ODP = 0.00034) has also imposed itself very quickly on the market of new equipment due to a COP higher than that of R-123, a lack of flammability and a very acceptable price [2]. It should be noted, however, that the German environment agency UBA asked the European Commission in August 2017 that this refrigerant be banned from use because it is an HCFO even if its ODP is insignificant.

[1] Carrier sees future in R-1234ze https://www.coolingpost.com/world-news/carrier-sees-future-in-r1234ze/

[2] York chiller heralds adoption of R-1233zd https://www.coolingpost.com/world-news/york-chiller-heralds-adoption-r1233zd/

10.1.3 ANALYSIS OF EXISTING ALTERNATIVES FOR THE RETROFIT OF CHILLERS

Centrifugal chillers are generally equipment with a cooling capacity of more than 1 MW, up to 10 MW and more, and their lifetime is in the tens of years due to regular maintenance. The question of retrofit therefore arises. Tests have been carried out in particular in the framework of the AHRI studies, to replace R-134a by R-1234ze (E) in retrofit. We can conclude that it is necessary to change the lubricant, to check the conditions of use of a refrigerant A2L even if the flammability of this refrigerant is extremely low and to accept a loss of refrigerating capacity of the order of 10% for an improved energy efficiency by around 5%.

R-513A (R-1234yf/134a; 56/44) with a GWP of 631 and R-450A (R-134a/1234ze(E); 42/58) with a GWP of 603 are refrigerants presented as drop-in; their results are presented for volumetric chillers (see Section 102).

10.1.4 ANALYSIS OF THE 2016 SECTORIAL BANK

The first centrifugal chillers using the recently launched R-1234ze (E), the bank of this sector is mainly composed of the reference refrigerant, R-134a, more than 90%. It should be noted that the HCFC bank is not yet completely eradicated and a share is constituted by transition refrigerants to replace R-22 (R-422D in particular).

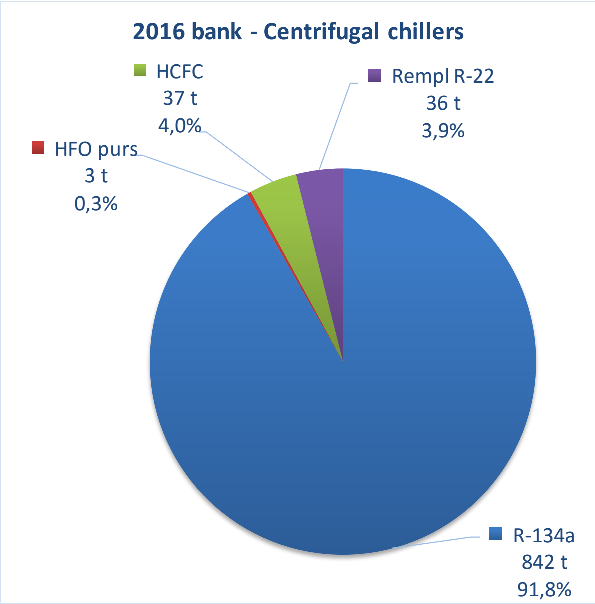


Figure 10-1: 2016 bank of centrifugal chillers.

Conclusions & perspectives

For centrifugal chillers, long-term options exist, the rate of change from R-134a to HFOs will depend on the allocation of allowances attributed to refrigerant manufacturers, the containment quality of centrifugal chillers, and the availability of recycled R-134a. All of these conditions should lead to a progressive smooth phase out of R-134a.

Table 10-3: Synthesis of high-GWP HFC alternatives available for centrifugal chillers.

Reference refrigerants	Alternative options	+	-
R-134a	R-1234ze	Improved efficiency from 5 to 10% compared to R-134a	A2L
R-123	R-1233zd	Good efficiency, A1	HCFO

10.2 Volumetric chillers

As shown in Table 10-1, the annual market of volumetric chillers varies from 6,000 to 13,000 units depending on the year. Cooling capacities are strongly variable and applications include industrial and commercial refrigeration as well as air conditioning in commercial buildings.

10.2.1 Reference refrigerants

Table 10-4, excerpt from the 2015 inventory report, shows a significant change towards R-410A; historically, R-407C was used by OEMs because volumetric chillers operated previously with R-22. It is also noted that with the increase in the cooling capacity, R-134a, which is not used for cooling capacities below 350 kW, appears significantly in volumetric screw-type chillers, which indicates that from this power threshold, the additional cost associated with the size of the compressor is cancelled.

Table 10-4: Refrigerants used on the market of new volumetric chillers in 2010 and 2016 according to (*Barrault, 2015*).

Refrigerants used	2010	2016
Chillers P < 50 kW	R-407C (31%) R-410A (69%)	R-407C (5%) R-410A (95%)
Chillers 50 < P < 350 kW	R-407C (45%) R-410A (53%) R-717 (2%)	R-407C (5%) R-410A (94%) R-717 (1%)
Chillers P > 350 kW	R-407C (22,5%) R-410A (25,5%) R-134a (50%) R-717 (2%)	R-407C (10%) R-410A (49%) R-134a (40%) R-717 (1%)

10.2.2 Analysis of existing alternatives for new volumetric chillers

Given the distribution of coldness by a coolant circuit, chillers present limits for the use of A2L refrigerants, ammonia or A3, which are greatly enlarged, resulting in a very wide variety of technical options and difficulty to obtain a clear vision on what will be the distribution of refrigerants with low GWP on the future market.

For small sizes (some refrigerating kW), chillers using **R-290** are already available on the market and are commercialized by international brands [1]. As already mentioned for propane, its energy efficiency is usually higher and even much higher than that of the replaced HFC.

For chillers of several tens of kW refrigerating capacity running with R-410A, chillers operating with **R-32** are already available on the European market with an improved energy efficiency [2].

In the same range of refrigerating capacity, chillers using **ammonia** (R-717) operate with coated compressors especially designed for ammonia; here again no difficulty to obtain high energy efficiency.

For chillers with refrigerating capacity higher than 250 kW, and often with screw compressors, the same option as centrifugal compressors applies, which is the replacement of R-134a by **R-1234ze**; the offer is already available from several international brands.

According to a major manufacturer in the industry, the post-R-410A evolution could take place in two phases: first with R-32-based mixtures and then, in the medium term, with R-32 or R-32. 452B (GWP 698).

Will R-407C be replace by refrigerants such as R-455A or R-454C? It is plausible but still too early to say.

[1] Tecumseh. Technical Bulletin Hydrocarbons.

[2] Daikin applied launches first R-32 chiller series. http://www.acrjournal.uk/uk/daikin-applied-launches-first-r32-chiller-series

[3] York chillers compatible with R-513A https://www.coolingpost.com/world-news/york-chillers-compatible-with-r513a/

10.2.3 Analysis of existing alternatives for the retrofit of volumetric chillers

The retrofit of volumetric chillers running with R-134a by two refrigerants either R-513A or R-450A, both of them A1 safety refrigerants with GWP of 631 and 603 respectively, is already claimed by OEMs of screw-type volumetric chillers as a drop-in refrigerant [4].

Otherwise the retrofit from R-134a to R-1234ze (E) is also possible both because of the very low flammability of R-1234ze (E) and the fact that the loss of about 10% of the refrigerating capacity with higher COP can be considered acceptable by the end user.

4.2.4 Analysis of the 2016 sectorial bank

As shown by the 2016 bank, R-410A is the mostly used refrigerant in the sector of volumetric chillers, all refrigerant capacities combined. However, even though it is gradually being replaced by R-410A, R-407C has also been heavily used, and so its bank is significant.

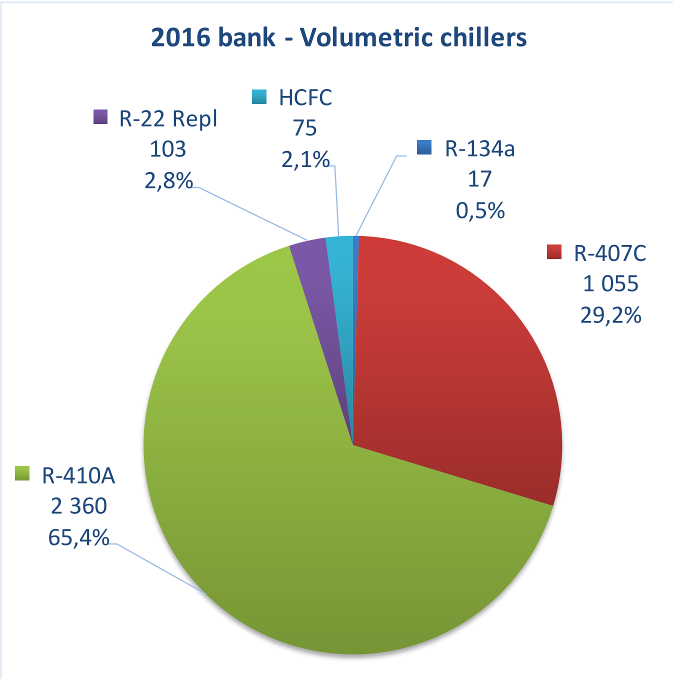


Figure 10-2: 2016 bank – Volumetric chillers.

10.2.4 Conclusions & perspectives

For new equipment, volumetric chillers operating with R-134a will likely follow the same development as centrifugal chillers, which is a change from R-134a to R-1234ze(E), of which efficiencies are improved.

Evaluation is more complex for chillers operating with alternative piston-type compressors or Scroll compressors. The need for a refrigerant with a high volumetric refrigeration capacity is proven but with greater flexibility than for air / air conditioners. Pure A2L refrigerants (R-32) and blends (R-455A, R-454C, among others) refrigerants will be used in new equipment. Propane will be used for small refrigerating capacities without knowing what market share will be taken. Ammonia may also be used but it is not currently being adopted by international companies.

Table 10-5: Synthesis of alternatives to high-GWP HFCs available for volumetric chillers.

Reference refrigerants	Alternative options	+	-
R-410A P < 50kW	R-290	Improved energy efficiency	A3
R-410A 50 <P < 350kW	R-32 NH_3	Improved efficiency Improved efficiency	A2L B2L
R-410A P > 350kW	R-1234ze	Good efficiency	A2L

The efficiency of the retrofit from R-134a to R-513A or le R-450A is proven. The uncertainty on the amplitude of these retrofits depends on the allocation of quotas associated to the F-gas Regulation.

11 - REFRIGERATION IN FOOD PROCESSES

The so-called "industrial refrigeration" includes very diverse refrigeration systems whose characteristics must be recalled. We resume below the introduction of the previous report on alternative refrigerants, written in 2014 for the AFCE.

In food processes and industrial processes, there are four main categories of refrigeration needs:

- cold storage (medium or low temperatures),
- process cooling (medium temperatures),
- freezing in processes (low temperatures),
- room conditioning (medium or low temperatures).

To satisfy these needs, installations can present different system architectures:

- direct expansion systems adapted to various ranges of refrigerating capacities, from centralized systems with independent machinery room and refrigerant circulation in a direct expansion system;
- indirect systems using heat transfer fluid or CO_2 as coolant, the thermodynamic system containing the refrigerant cooling itself the heat transfer refrigerant.
- cascade systems with two distinct refrigerants, one adapted to the high temperature, for example R-134a, the other to the low temperature such as CO_2, the "high-temperature" refrigerant condensing the low-temperature refrigerant by evaporation into an evaporator-condenser;
- two-stage systems (booster) using the same refrigerant at both temperature stages;
- systems with recirculation by pump feeding high-refrigerating-capacity evaporators and operating essentially at low temperature; these systems require pure refrigerants or quasi azeotropic refrigerants;
- systems with flooded evaporators such as milk tanks;
- chillers.

The choice of installation depends on:

- the operating temperature level,
- the required refrigerating capacity (itself being as a function of the production),
- the cooling mode of the condenser (air, water, cooling tower, etc.)
- the desired energy efficiency,
- the budget.

In France, in terms of installations, the food processing industry represents:

- about 720 refrigerated warehouses, i.e. 15 million m^2 [DEV12];
- 13,500 enterprises of which 2,500 in the meat industry, 1,250 in the milk industry, 300 in the fish industry, 1,350 the fabrication of bakery and pastry products and 2,600 in the production of beverages [PAN12];
- 170,000 milk tanks are installed on dairy farms.

11.1 ANALYSIS OF THE 2016 SECTORIAL BANK

As shown on Figure 11-1, refrigeration in food processes is strongly user of R-404A and R-717 (ammonia). Some easiness in the French regulation concerning installations using ammonia, then the implementation of the F-Gas regulation reinforced the already strong tendency of ammonia usage in this type of installation.

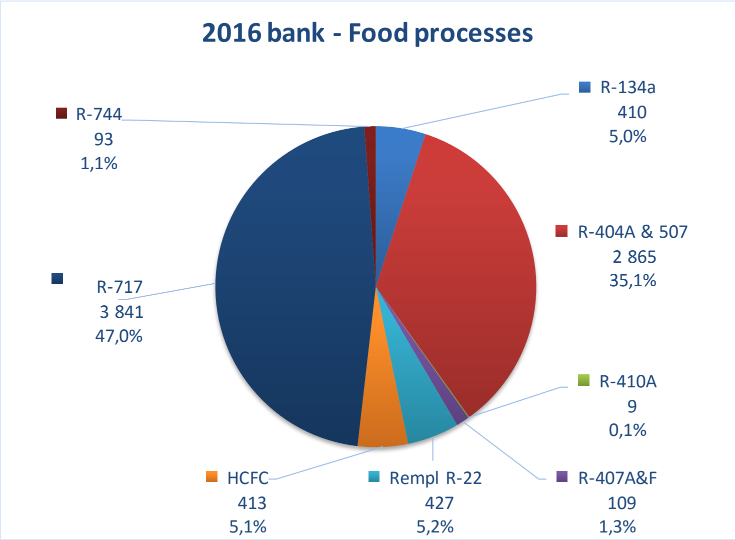


Figure 11-1: Sharing of refrigerants used in the food-process refrigeration, 2016 bank.

The vision of the bank will simplify the analysis in front of the technical expansion described above and that we will analyze by type of structure: direct expansion or pump feeding.

11.2 Direct expansion system, low temperatures or medium and low temperatures

These systems have a similar design to systems installed in large hypermarkets. Typical cooling capacities range from 100 kW to 1 MW. The circuits are relatively short, the expansion devices are thermostatic. If the refrigeration requirement is mainly for medium temperatures, as for dairy and cheese factories, R-134a or R-404A systems will often be found. However, companies have environmental policies of their own and can choose ammonia also in medium-temperature refrigeration alone.

When refrigerating needs are both for medium and low temperatures, and that systems are still direct expansion refrigeration systems, the same options as in commercial refrigeration will be possible.

Case of the cooling systems of the milk tanks: The documentary analysis of the technical offer (for example that of Charriau [1]) shows that the evaporators of the milk tanks are evaporators with direct expansion system using R-404A controlled by thermostatic expansion valves. So, they are non-flooded evaporators that are the same options in new or retrofit as those presented in this section.

[1] http://charriau.com/en/new-bulk-milk-coolers/new-elliptical-tanks

11.2.1 Reference refrigerants

The reference refrigerants are ammonia, R-404A, and R-134a. The lower the cooling capacity, the more R-134a and R-404A are the working refrigerants. Ammonia requires circuits in steel or stainless steel because this refrigerant is not compatible with copper. Air / ammonia evaporators are more expensive because they are not mass produced, but for condensation, evaporative condensers are at acceptable costs from a certain size.

When the cooling needs exist at both temperature levels and in direct expansion, cascade architectures can be found: CO_2 at low temperature and ammonia or R-134a for medium temperatures.

11.2.2 *ANALYSIS OF EXISTING ALTERNATIVES FOR NEW DIRECT EXPANSION EQUIPMENT*

For new installations, choices depend on the required refrigerating capacity and on temperature levels: medium only or medium and low.

For installations operating with R-134a, depending on the safety choices made by the user company, long-term options are available:

1) ammonia,
2) R-1234yf or le 1234ze(E).

All these replacement refrigerants adequately implemented present an energy efficiency equal or higher to that of R-134a.

For installations running with R-404A where *a priori* one can think that needs exist at low temperature, long-term options are known:

3) Either ammonia for all temperature levels;
4) Either ammonia for medium temperature and CO_2 for low temperature. Here again, significant energy gains exist when a cascade system is implemented with CO_2 at the low temperature and ammonia for medium temperature;
5) Either replacement of R-404A by R-455A or R-454C of which measured energy efficiencies are higher than that of R-404A according to first feedbacks.

11.2.3 *ANALYSIS OF EXISTING ALTERNATIVES FOR THE RETROFIT OF DIRECT EXPANSION SYSTEMS*

For retrofit of R-134a installations, R-513A or R-450A refrigerants are possible options with no major change but with GWPs around 600, improved energy efficiency and a slightly higher volumetric capacity with R-513A, which is about 10% lower for R-450A. The retrofit to R-1234yf or R-1234ze (E) is also technically possible but not presented currently.

The retrofit refrigerants for R-404A are very numerous with GWP ranging from 1400 to 2200, and 8 of them are mentioned in Section 4.3. These transition refrigerants can also be used for installations still operating with R-22.

The effective availability of these transition refrigerants depends on the commercial policy of their producers, as well as on their quotas expressed in CO_2 equivalent put on the market. Hence the fear of possible shortage of such refrigerants for the retrofit of facilities operating at R-404A. The use of recycled R-404A, which is permitted out of its original refrigeration system, provides flexibility for the operation of R-404A systems. Especially since recycled R-404A is out of quota.

11.2.4 *CONCLUSIONS & PERSPECTIVES*

Long-term options exist for all direct-expansion systems in industrial refrigeration and they are as diverse as the options used currently. This variety is based on the safety and environment policies defined by each end-user.

Retrofit options exist for R-134a and R404A. Given the relatively high GWP of R-404A replacement transition refrigerants, there is uncertainty about the effective availability of refrigerants in sufficient quantity for retrofits.

Table 11-1: Synthesis of alternatives to high-GWP HFCs for the sector of food processes.

Reference refrigerants	Alternative options	+	-
R-134a	Pure HFO NH_3	Improved efficiency Improved efficiency	A2L B2L, material compatibility, safety
R-404A	NH_3 NH_3/CO_2 Blends HFC-HFO PRP < 150 (R-454C, R-455A)	Feedback ++ efficiency + efficiency	B2L B2L A2L

11.3 System with flooded evaporator – medium temperatures or low and medium temperatures

Flooded evaporators are fed by pump and correspond to large size installations typical of refrigerated warehouses and the food-process industry with centralized machinery room. The use of pump feed is suitable for very large installations with liquid refrigerant supply lines over long distances to obtain an efficient heat exchange in the evaporators.

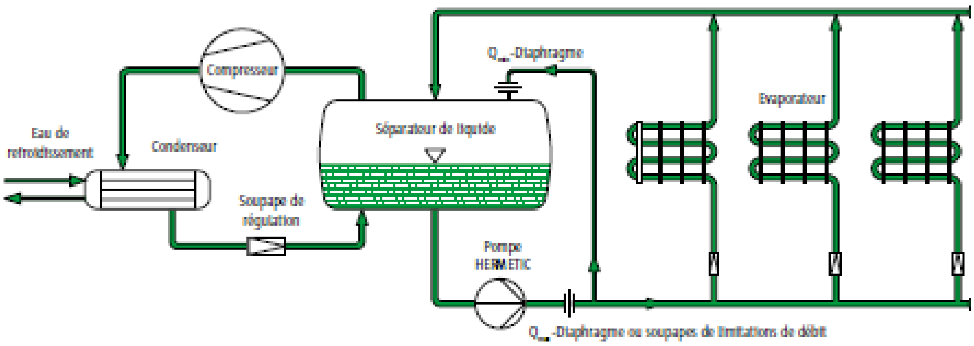


Figure 11-2: Principle lay-out of the feeding of flooded evaporators (*documentation Hermetic*)

As shown on Figure 11-1, the pump is connected to a receiver that ensures the liquid refrigerant feeding; this receiver is also used as a liquid-vapor separator, so that only vapor goes back to the compression system. The recirculation flow, i.e. the mass of evaporated liquid to the total mass, varies typically from 4 to 8, which is only 12 to 25% of the evaporated refrigerant; this guarantees an excellent heat exchange at the evaporator, which is so called flooded.

The receiver causes difficulty for blends with temperature glide because the vapor composition is different from the liquid composition and, in the long run, two different refrigerants circulate in the compression system and in the evaporators. Hence the need to use pure refrigerants or azeotropic blends, or very slightly zeotropic blends such as R-404A.

11.3.1 Reference refrigerants for pump-powered systems

Reference refrigerants for such systems are ammonia, R404A, and historically, R-22. CO_2 can also be used in this way at low temperature but the pressure is much higher. Such systems contain refrigerant charges of several tonnes.

11.3.2 Analysis of existing alternatives for new equipment

For new equipment, and it has been established for more than a decade, there are cascade systems with CO_2 at the low temperature and ammonia at the medium temperature. There are also systems running with ammonia only but refrigerant quantities can be considered too significant hence the interest to used CO_2 at the low temperature.

Currently, there is no mixture with low GWP and low temperature glide suitable for this type of installation. The use of coolant such as Tyfoxit, which presents an acceptable pressure drop even at -40°C, can become a way of using blends with temperature glide in indirect systems, medium and low-temperature systems in the industry.

11.3.3 Analysis of existing alternatives FOR THE retrofit of installations

Similarly, to R-22 replacement, R-404A retrofits are not possible currently for this type of installations. Their design requires the use of a quasi-zeotropic refrigerant with temperature glide superior to 1°C.

11.3.4 Conclusions & perspectives

Long-term options using ammonia or ammonia in CO_2 cascade are available, energy efficient, and are validated but the market. HFO-based options are lacking for the low temperature.

12 - REFRIGERATED TRANSPORT

In order to comply with the cold chain and the regulatory temperatures imposed by the hygiene package, the fleet of transport vehicles consists of vans and small vehicles (payload <3.5 tonnes), trucks and carriers (> 3.5 tons), trailers and semi-trailers (20 to 24 tonnes).

12.1 REFRIGERATION UNIT CHARACTERISTICS

Most of transport vehicles with controlled temperature in France (89%) use a vapor compression-refrigeration unit and ventilated evaporator. Eutectic groups, used mainly for distribution of packaged frozen food by light vehicles with wickets represent less than 2.5% of the French fleet. Cryogenics represents less than 0.2% of the fleet.

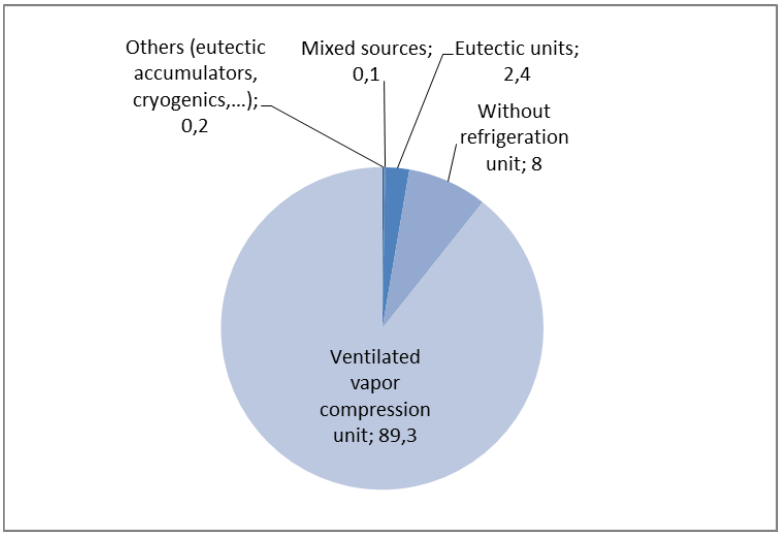


Figure 12-1: Typology of refrigeration technologies of the fleet with controlled temperature, France 2017

Pulley-engine type refrigeration units are small equipment mounted on vans and other light commercial vehicles. The compressor is driven by the main engine of the vehicle. Split-type units are autonomous systems directly mounted under the chassis or on the insulated trailer. Refrigeration units are autonomous systems, almost integrated into the front of a trailer. Generally, they are of high capacity and are rather designed for long-distance transport.

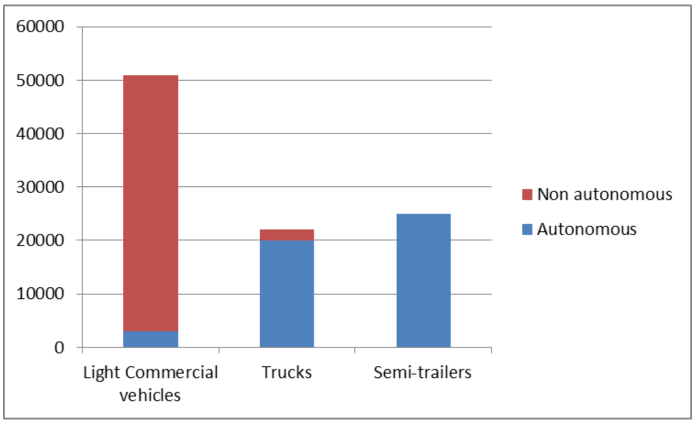


Figure 12-2: Autonomy of the refrigeration unit, France 2017.

12.2 Reference refrigerants

12.2.1.1 Refrigerant type

Currently, R-134a is the refrigerant used for refrigerating capacities below 3,500 W. Beyond, R-404A is the selected refrigerant. R-404A is also used in small systems, pulley-engine type, for simplicity of maintenance.

The rather difficult conditions of use of this equipment involve a fairly high refrigerant leakage rate.

12.2.1.2 Refrigerant charge

Typical technical data of the different types of refrigeration unit are presented in the table below.

Table 12-1: Average charges per type of vehicle.

Technology	Refrigeration capacity (at -20°C)	Average charges (kg)
Pulley-engine	500 à 3,000W	1.6
Splits	2,500 à 5,500W	4
Stand-alone units	6,000 à 10,000W	7

12.2.2 Analysis of existing alternatives for new equipment

12.2.2.1 Implemented alternatives

In the short term, all manufacturers offer compression systems with R-452A as an alternative refrigerant to R-404A.

Comparative tests carried out by the Cemafroid allowed to validate efficiencies of R-452A units.

But these HFCs are also concerned by the reduction of uses imposed by the F-Gas. Different refrigeration technologies exist that do not need compression systems using high-GWP HFC. They are summarized here after.

- The use of refrigerated vehicles with cold storage: these vehicles are usually used to transport frozen products such as ice-creams and are generally equipped with a wicket. They are often poorly adapted to long-distance transport and their use is dedicated to the urban environment. The main difficulties specific to this technology are the payload affected by the weight of the cold storage (eutectic) as well as the complementary means necessary to freeze the eutectics (often a device which itself has a compression group).
- The use of cryogenics in direct or indirect expansion system: appeared fifteen years ago, these devices offer the advantage of silent vehicle well suited to urban deliveries. Their use for long-distance transport is less suitable because of the lack of a nitrogen or liquid CO_2 supply network. Direct expansion systems where nitrogen is released into the box present safety problems, monitored by automations integrated in vehicles. These systems cannot be used to transport certain products: live crustaceans for example.
- Vehicles with CO_2 compression: This technology is now available on the market. This is probably the most credible alternative for refrigerated vehicles because restrictions of use are low or non-existent. The technology must however be adapted for very different European climates. The weight of the group is also an obstacle to its development.

12.2.3 Analysis of existing alternatives for the retrofit of refrigerated vehicles

12.2.3.1 Implemented alternatives

Alternative options for retrofits are identical to that of new vehicles, namely mainly R-452A.

12.2.4 Analysis of the 2016 sectorial bank

As mentioned previously, Figure 13-2 demonstrates that, starting in 2018, the market is moving from R-404A to R-452A for new vehicles.

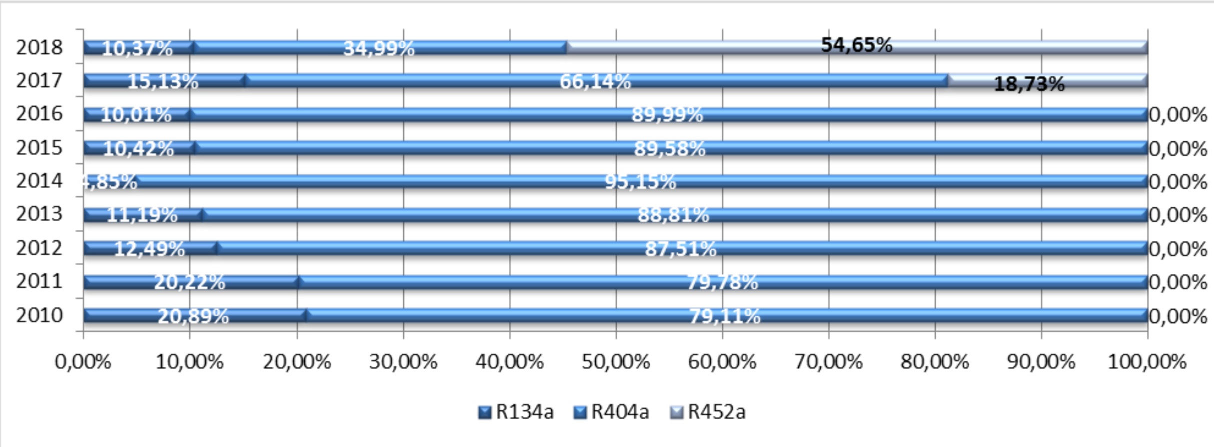


Figure 12-3: Synthesis of ATP attestations delivered for new vehicles per type of refrigerant.

On the other hand, there is still very few retrofit from R-404A to R-452A. Only 2.15% of the vehicles in service are retrofitted.

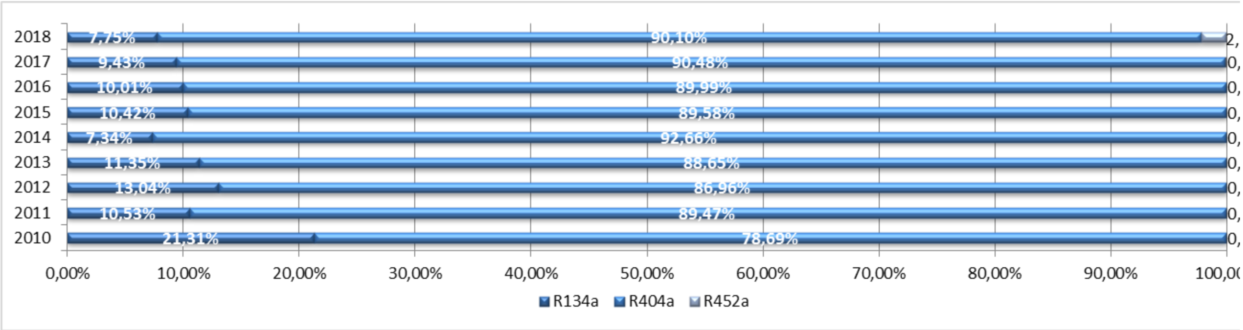


Figure 12-4: Synthesis of ATP attestations delivered for vehicles in service per type of refrigerant.

Overall, the refrigerant bank is still dominated by R-404A. R-452A, non-existent in 2016, is quickly gaining shares in the global bank. The illustrations below show the refrigerant bank in the refrigerated transport units in 2017 and 2018 (Cemafroid data).

Table 12-2: Refrigerant quantity per year and per refrigerant type.

Refrigerants	Refrigerant quantity (kg) 2017	Refrigerant quantity (kg) 2018
R-134a	11,417	11,160
R-404A	356,183	338,391
R-452A	13,990	381,68
Others (R-410A and R-507A)	9,958	103,40
Total	391,548	398,059

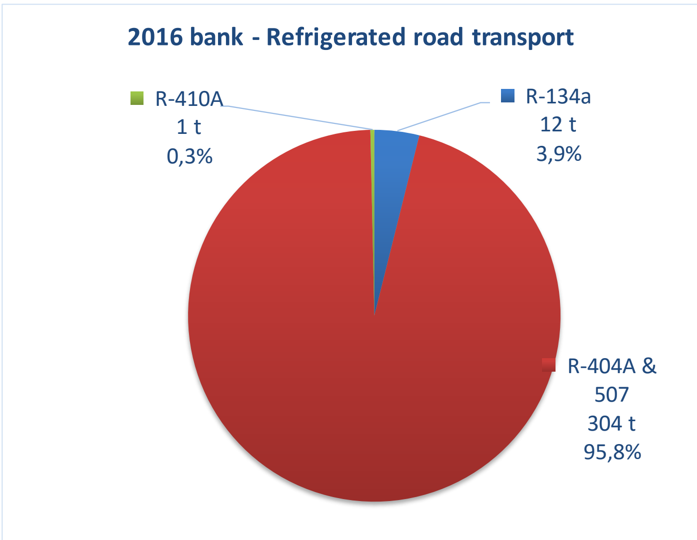


Figure 12-5: Sharing of refrigerant banks in refrigerated transport in 2016 (*Barrault, 2016*), before R-542A introduction.

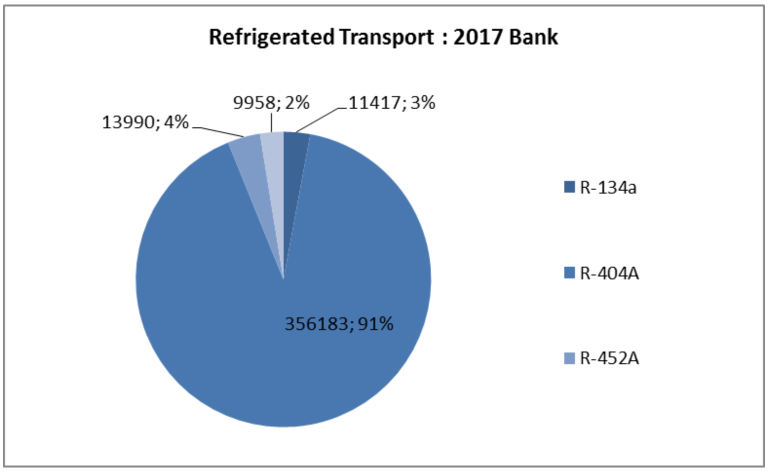


Figure 12-6: Sharing of refrigerant banks in refrigerated transport in 2017 (source Cemafroid) and in 2016 (source Inventories 2016, before R-542A introduction).

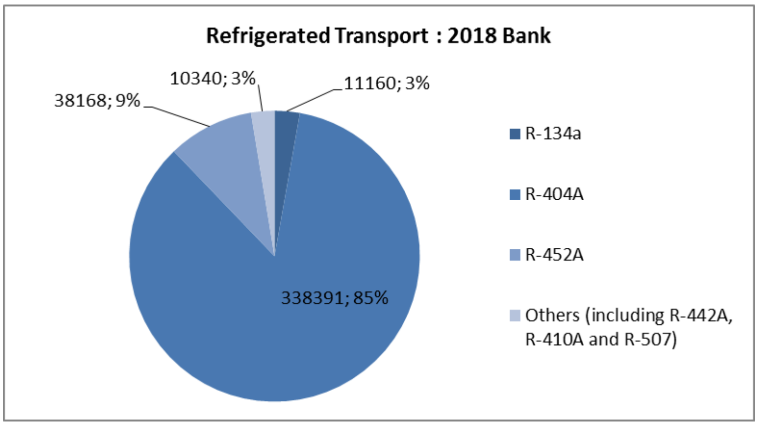


Figure 12-7: Sharing of refrigerant banks in refrigerated transport in 2018.

12.2.5 *Conclusions & perspectives*

R-404A refrigeration units are no longer relevant today. Options using R-452A are very short-term alternatives, waiting for virtuous and sustainable options.

With a view to reducing the environmental impact of refrigerated transport, the choice of CO_2 (R-744) as a refrigerant seems interesting. To try it would be relevant even if the cost of such a option remains 30 to 50% more expensive than a R 404A unit, because the market is not mature enough.

Table 12-3: Synthesis of alternatives to high-GWP HFCs available for refrigerated transport.

Reference refrigerants	Alternative options	+	-
R-404A	R-452A CO_2	Similar efficiency Low GWP	Still high GWP Still under development, high cost and significant weight Maintenance (international transport)

13 - SYNTHESIS OF IMPLEMENTED CASE STUDIES FOR NEW OPTIONS AND FEEDBACK

13.1 RETROFIT IN HYPERMARKETS

This case study relates to a retrofit operation of the medium temperature unit of a 5,300 m² hypermarket implanted in Aude (11) where R-442A is chosen as a substitute to R-404A. The objective of this study is to measure the impact of the retrofit on the operation and on the GHG emissions of the refrigeration unit of this store. The refrigeration unit is instrumented a week before retrofit and dis-instrumented one week later.

No physical items were changed during the refrigerant replacement operations. However, after the study, the nozzles of the expanders were replaced. It is for this reason that in this chapter the substitution operations of the R-404A are referred to as "retrofit" and not "drop-in".

13.1.1 INSTRUMENTATION

For expertise, mobile measurement and data recording means are used. Three types of measuring instruments were used:

- Calibrated temperature loggers programmed to record the measured temperature every 4 minutes.

Figure 13-1: Temperature recorder.

- Humidity and temperature recorders programmed to record the relative humidity and the temperature measured every 4 minutes.
- Power analyzer, which measures and records the various properties of the three-phase electrical network (voltage, current and phase shift). This device measures the active power and the energy absorbed by the entire system thanks to the ampere-metric clamps and the voltage measurements.

Figure 13-2 : Temperature and humidity recorder.

Figure 13-3: Power analyzer.

13.1.2 *COMPARISON RELIABILITY*

The studied system never works in continuous regime which prevents to compare power pre / post retrofit cooling capacity. The parameter studied is therefore the energy consumption which integrates powers and allows to compare directly two identical periods (for example several days of operation). This total consumption also depends on the demand in cooling capacity.

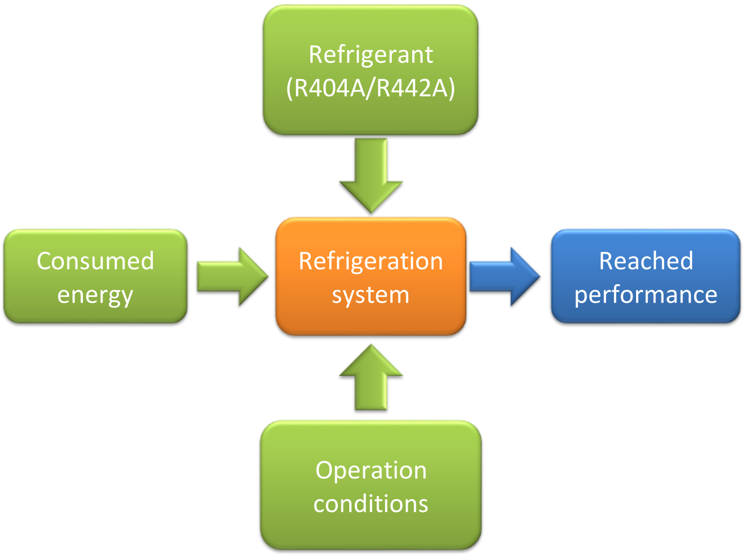


Figure 13-4: Inputs/outputs of the refrigerating system.

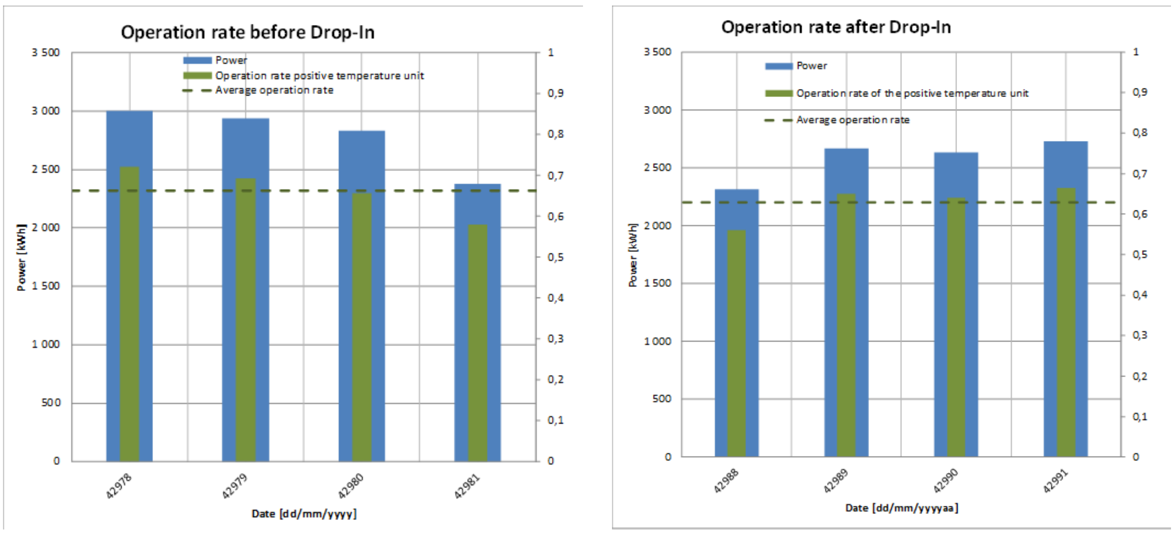


Figure 13-5: Daily energy consumption compared to the operation rate of the medium-temperature refrigeration unit before and after retrofit. In blue the daily energy consumption in kWh (left axis. In green the operation rate (right axis).

13.1.3 ANALYSIS OF RESULTS

13.1.3.1 Compressor operation ratio

This comparison shows a decrease of the daily operation ratio of the unit from 66% to 63% at the retrofit time.

13.1.3.2 Analysis of the energy consumption of the installation

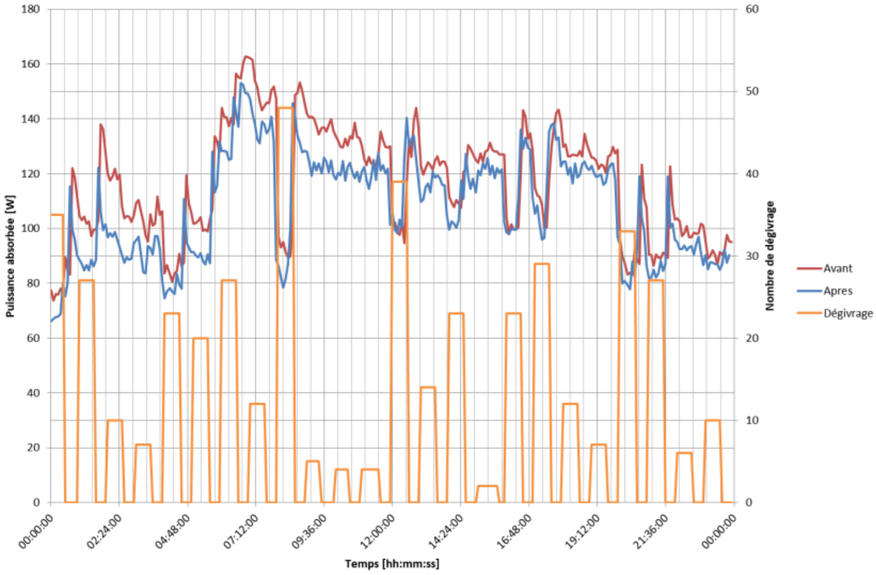


Figure 13-6: Evolution of the absorbed power compared to defrosting schedules of the medium and low-temperature refrigeration units.

The curves are relatively similar because they are closely related to the defrosting cycles and the times of the day. The analysis of the average daily consumption indicates a decrease of 6.5% of the daily consumption.

13.1.4 CONCLUSION OF THE CASE STUDY

The comparison before/after retrofit shows that:

- The operating time of the installation is reduced by 3% compared to the initial situation;
- The energy consumption is 6.5% lower compared to the initial situation.

This case study allowed to validate that with relatively simple means, it is possible to compare efficiencies of an installations after refrigerant change.

13.2 Controlled temperature transport

13.2.1 Introduction

Thee Cemafroid compared test reports of several transport groups to determine the impact of refrigerant change (R-404A / R-452A) in terms of delivered refrigerating capacity and COP.

13.2.2 The test standard

The International Agreement on the Transport of Perishable Foods (ATP) defines the test method for measuring the refrigerating capacities of refrigeration units in different operating regimes. Associated energy consumptions are also measured at these operating conditions, whether they are electricity, fuel (diesel), cryogenic devices or the torque provided by a hydraulic device. The measurement of air flows can be performed simultaneously. These tests require a controlled atmosphere generally at + 30°C for tests responding to ATP but also at + 38°C or + 43°C for maritime containers for example.

The maximum heating power acceptable by the unit by adding the thermal losses of the test bench gives its power at a given temperature. Measurements can also be carried out at partial charge, for example according to the European standard for testing units EN 16440-1.

13.2.3 Test means

Cemafroid's official ATP test station, recognized by the United Nations, is testing new and in-service temperature-controlled transport units. The "climatic tunnels" make it possible in particular to determine the envelope isotherms, the refrigerating capacity and consumption of refrigerating transport units, and the efficiency of refrigeration equipment.

The climatic tunnel in which tests are carried out must meet the ATP requirements:

• Horizontal air blowing

• Air velocity between 1 and 2 m / s at 10cm from the walls of the body

• Temperature control (spatial homogeneity and temporal stability)

Figure 13-7: Climatic tunnel for testing of refrigeration units for refrigerated transport.

13.2.4 *Results*

Tests are ranked in 3 categories according to the group type:

- "Pulley-motor"
- Units intended for trucks
- Unit intended for semi-trailers

In total, the results of 70 tests are compiled in order to know the impact on the cooling capacity and the COP of the R-404A replacement by R-452A.

The following figures show the evolution of unit efficiency when replacing R-404A by R-452A.

The represented values are min and max values of variations of the COP and refrigerating capacity by temperature level compared to R-404A.

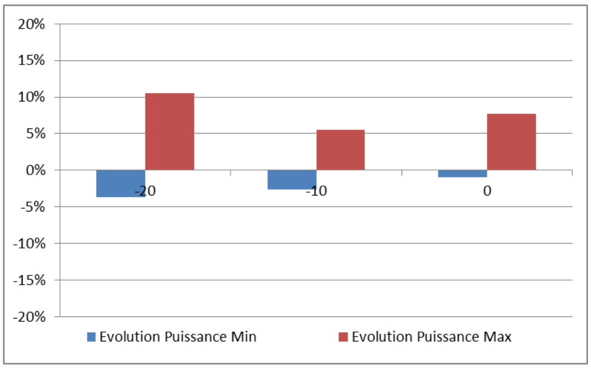


Figure 13-8: Evolution of refrigerating capacities of units when replacing R-404A by R-452A.

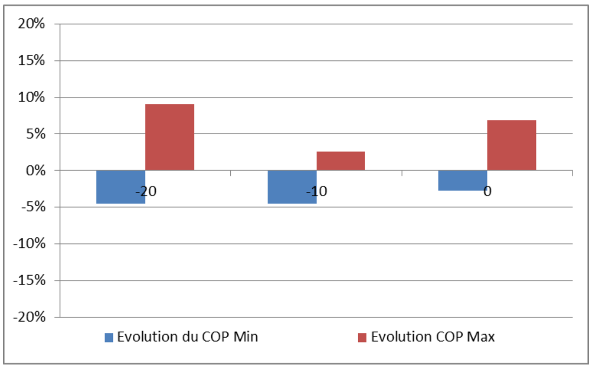


Figure 13-9: Evolution of COPs of units when replacing R-404A by R-452A.

It shows that the use of R-452A is an alternative with efficiencies slightly higher than R-404A at 0°C and slightly lower to R-404A at low temperature.

13.3 Efficiency of stand-alone display cases with hermetically-sealed unit

13.3.1 *Introduction*

Two series of stand-alone display cases have been tested in the Cemafroid laboratory to compare efficiencies of display cases using R-404A and R-290. Display cases were very similar, with the same dimensions and the same surface of presentation.

13.3.2 *The standard of test*

The performance of display cases is measured according to the international standard EN ISO 23953. This standard specifies the construction requirements, characteristics and performance of refrigerated display cabinets used for the sale and presentation of foodstuffs. It also specifies the test conditions and methods for checking that the requirements have been met, as well as the classification of the display cases, their marking and the list of their characteristics to be declared by the manufacturer.

Tests must comply with the following procedure:

- Instrumentation by thermocouple at the heart of tests packs
- Measurement of the input power absorbed by the display case
- Stabilized operation during 24 hours
- Door opening during 12 hours, each door is opened:
    - 6 times per hour for frozen applications
    - 10 times per hour for refrigerated applications
- Turn off the lights and / or installation of the night blind for 12 hours.

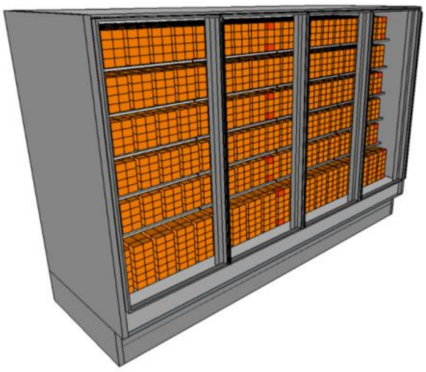


Figure 13-10: Charge plan of a display case.

13.3.3 TEST MEANS

The climatic room in which tests are performed must meet the standard requirements:

- Horizontal air blowing
- Air velocity between 0.1 and 0.2 m / s ±10%
- Material choice (light grey) to reduce the emissivity of walls
- Lighting 600±100 lx
- Control temperature
- Hygrometry control

Figure 13-11: Climatic test room for refrigerated display case.

The room allows the simulation of all ambiance classes defined in the standard and in particular class 3 (25°C, 60% HR) in the one where all tests were carried out.

13.3.4 RESULTS

Results presented concern:

- the respect of the display case conservation class
- the energy consumption

The temperature class is associated to each display case as a function of maximum and minimum temperatures of test packs during the test.

Table 13-1: Temperature classes.

Class	Highest temperature of the hottest pack °C	Lowest temperature of the coldest pack °C	Highest minimum temperature °C
L1	-15		-18
L2	-12		-18
L3	-12		-15
M0	+4	-1	
M*	+6	-1	
M1	+5	-1	
M2	+7	-1	
H1	+10	+1	
H2	+10	-1	

Temperature classes generally targeted by manufacturers are M1 class for medium-temperature display cases and L1 for low-temperature display cases.

The energy consumption of a display cases is appreciated according to the following parameters:

- DRC: Daily refrigeration consumption [kWh/24h]
- DCA: Daily consumption of display case accessories [kWh/24h]
- TEC: Daily consumption of the display case (REC+DEC) [kWh/24h]
- SEC: Daily consumption by square meter of display area [kWh/m^2.24h]

The display area being the same for each series of display cases, the following table presents only the overall consumption of display cases.

Table 13-2: Comparison of daily energy consumptions of stand-alone display cases.

(R-404A / R-290)

Display case	Application	TEC R-404A [kWh/24h]	TEC R-290 [kWh/24h]	Difference [%]
1	Medium temperature	5.7	4.1	28%
2	Medium temperature	6.1	4.5	26%
3	Medium temperature	8.2	6.23	24%
4	Low temperature	17.2	14.7	15%
5	Low temperature	23.9	22	8%

Tests in standardized conditions demonstrate a clear difference in energy consumption in favor of display cases running with R-290. The difference is more significant for medium-temperature display cases (about 26% referred to a display case running with R-404) than for low temperatures (about 12% referred to a display case running with R-404).

In addition, R-404A and R-290 display cases meet the temperature class (M1 for medium temperatures and L1 for low temperatures).

14 - STATUS OF TRAINING PROGRAMS ON ALTERNATIVES

The implementation of alternatives to high-GWP HFCs faces two major issues:

- Development adequate training programs to acquire specific skills in the use of refrigerant substitutes
- The current regulations leave little space for the use of alternatives.

The objective of this section is to define the training needs for the use of alternatives to high GWP alternatives.

14.1 INTRODUCTION

The F-Gas implementation allowed to increase skills of technicians working in the refrigeration sector, especially on key topics such as the containment of installations and handling of refrigerants (refrigerant charge and recovery).

The search for alternative options to the use of high-GWP refrigerants has led to the use of refrigerants with very different characteristics. Indeed, the use of natural refrigerants imposes a specific know-how (CO_2 operating pressures and ammonia toxicity), the same goes for the use of highly flammable hydrocarbons. The design of the installation is affected, as well as the refrigerant handling, maintenance and use of the system. Ammonia is corrosive, moderately toxic, so it imposes other constraints. Flammable refrigerants such as hydrocarbons and, to a lesser extent, HFOs, impose other rules. Precautions may be related to safety, environmental protection or maintenance of plant performances.

In addition, the technology of the installations has considerably evolved to meet the requirements of rationalization of the energy consumption, with a significant use of the digital communication tools.

Forward-looking management of jobs and skills (GPEC) must be a priority of the sector to sustain the profession of refrigeration by relying on existing diplomas, certificates or professional titles and the updating of the Employment / Activities / Competencies Frameworks (REAC) of the Ministry of Labor.

Modeled on the requirements of the F-Gas, the standards must evolve to integrate the new skills and knowledge required to handle alternative refrigerants:

o AMCVC: HVAC Maintenance Agent (Lvlv)

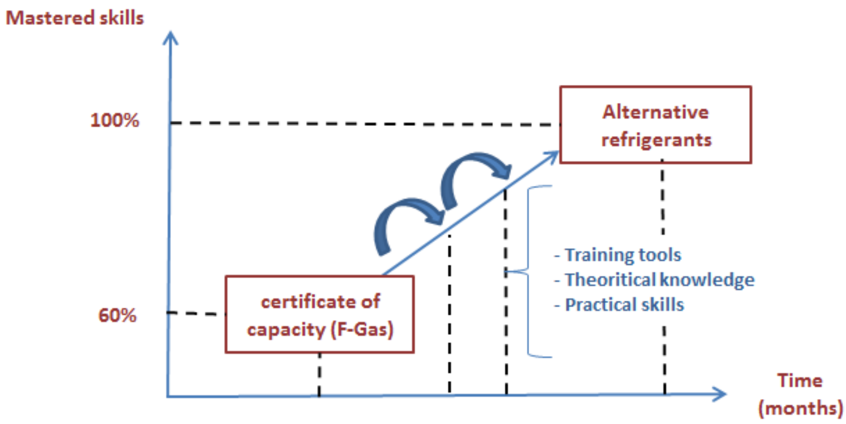
o TMCVC: HVAC Maintenance Technician (Lvl IV)

o TSMEC: Higher Technician of Maintenance in Climatic Equipment (Niv III)

- **Refrigeration sector:**
  - MDF: Refrigeration Repairer (Niv V)
  - TIFCC: Technician of Intervention in Commercial Refrigeration and Air Conditioning (Niv IV)
  - TIFI: Technician of Intervention in Industrial Refrigeration (Niv IV)
  - TIFECP: Technician for Cold Intervention and Pro Kitchen Equipment (Niv IV)

- **Air-conditioning sector:**
  - MDC: Air Conditioning Troubleshooter (Niv V)
  - TICCSER: Tech Installer Heating, Air conditioning, Sanitary, Renewable Energy (Niv IV)
  - AMECC: Maintenance Agent in Climatic Comfort Equipment (Niv V)
  - TMECC: Maintenance Technician in Climatic Comfort Equipment (Niv IV)
- **HVAC sector:**
  - AMCVC : Maintenance Agent HVAC (Niv V)
  - TMCVC : Maintenance Agent HVAC (Niv IV)
  - TSMEC: Higher Technician of Maintenance in Climatic Equipment (Niv III)

Table 14-1: Synoptic of development of competencies.



14.2 EUROPEAN REGULATION FOR TRAINING

The European Union has published a report on the availability of training on handling of alternatives to HFC refrigerants to meet the requirements of Article 21 (6) of the F-Gas Regulation which reads as follows: "on 1 January 2017 at the latest, the Commission publishes a report examining the Union legislation on the training of physical persons in the safe handling of alternative refrigerants to replace or reduce the use of fluorinated greenhouse gases and submit , where appropriate, a legislative proposal to the European Parliament and the Council to amend the relevant Union legislation."

In addition to F-Gas, a number of European directives aim to guarantee the safe handling of equipment, which implicitly imposes, for refrigeration equipment, that the personnel be trained in the handling of alternative refrigerants:

- Directive 2014/68/UE on pressurized equipment
- Directive 2014/34/UE on explosive atmospheres (ATEX 95)
- Directive 99/92/CE concerning the minimum requirements to improve the safety and health protection of workers who may be exposed to the risk of explosive atmospheres
- Directive-cadre 89/391/CEE on the safety and health at work
- Directive 2014/35/UE low tension
- Directive 2014/30/UE Electro-magnetic compatibility
- Directive 2006/42/CE machine

All these documents are directives and leave the Member States a certain margin of appreciation in the implementation. Unlike F-Gas, these directives do not provide for any particular European minimum requirements for alternative HFC refrigerants or any mandatory certification system. Employers are obliged to maintain a register of trained personnel, but no role has been defined at European level for refrigeration certification bodies. The lack of a

European certification requirement may suggest that there is no binding requirement for training on HFC substitutes, which is not the case at all.

In addition, it is important to note that prescriptive requirements for training and skills are detailed in two EN standards that apply to refrigeration:

- EN378-4
- EN 13313

In conclusion, the report states that a number of European directives already require the provision of adequate training to personnel working with alternative refrigerants. A binding requirement also requires employers to provide training for staff to guard against occupational safety and health risks.

14.3 KEY COMPETENCIES RELATED TO REFRIGERANTS SUBJECTED TO F-GAS

Operators must obtain a **certificate of capacity** issued by an approved body for each of its establishments handling halogenated refrigerants. The certificate of capacity shall be issued for a maximum period of five years after verification by the recognized organization that the operator fulfills the conditions of expected professional capacity and possesses the appropriate tools.

The regulatory tools presented below must be periodically verified.

Table 14-2: Synoptic of the training course.

Activity category	Mandatory tool
Category I	Charge and recovery station according to Standard NF EN 35421.
	Recovery cylinders for each refrigerant type.
	Leak detector according to Standard NF EN 14624.
	Flexible connexions with flap.
	Pressure gaujes. electronic thermometers and precision scale 5%.
	Marking tools.
Category II	Charge and recovery station according to Standard NF EN 35421.
	Recovery cylinders for each refrigerant type.
	Leak detector according to Standard NF EN 14624.
	Flexible connexions with valve.
	Pressure gaujes. electronic thermometers and precision scale 5%.
	Marking tools.
Category III	Charge and recovery station according to Standard NF EN 35421.
	Recovery cylinders for each refrigerant type.
	Pressure gaujes. electronic thermometers and precision scale 5%.
Category IV	Leak detector according to Standard NF EN 14624.
	Pressure gaujes and thermometer.
Category V	Compact charge and recovery station or in separate elements.
	Leak detector adapted to mobile air conditioning systems.
	Thermometer and precision scale 5%.
	Updated table of refrigerant and lubricant charges of vehicles.

The certificate of capacity specifies the types of equipment on which the operator can intervene as well as the types of activities that he can exercise. Operators **shall declare** to the body which issued them the capacity certificate, each year n for the calendar year n-1, the quantities of HFC refrigerant that were **acquired, charged, recovered and sold**. This declaration also mentions the inventory status on January 1 and December 31 of the previous calendar year.

The **persons** who carry out the responsibility of the operator hold a **certificate of aptitude** issued by a certified body, corresponding to the **types of activities** carried out and the **types of equipment** used. In summary, this corresponds to:

Table 14-3: Certificate of aptitude required by domain and by activity.

	Refrigeration		Air conditioning		Heat pump		Mobile air conditioning and vehicles	
	All	<2 kg	All	<2 kg	All	<2 kg	All	<2 kg
Leak tightness control	I, II	I, II, IV	I, II	I, II, IV	I, II	I, II, IV	V	V
Servicing	I	I, II	I	I, II	I	I, II	V	V
Maintenance	I	I, II	I	I, II	I	I, II	V	V
Installation	I	I, II	I	I, II	I	I, II	V	V
Recovery	I	I, II, III	I	I, II, III	I	I, II, III	V	V

Today, the number of professionals with a certificate of capacity is estimated to 72,000 people in France, including 27,000 in category 1 and 37,000 in category V.

The professional skills corresponding to the types of activities carried out, the types of equipment used and the conditions of issue of the aptitude certificate are specified by the decree of 29 February 2016 of the Ministry of the Environment, Energy and the sea. The decree defines the skills, practical know-how (practical test) and knowledge (theoretical test) necessary to obtain the attestation of aptitude.

Since January 1st 2015, in addition to technical knowledge and practical training on fluorinated greenhouse gases, certified technicians must also have "information on relevant technologies to replace fluorinated greenhouse gases or to reduce their use and safe handling." The aim is to provide technicians who are trained in the handling of fluorinated greenhouse gases with some general information on the properties of alternative refrigerants (i.e. CO_2, ammonia, hydrocarbons and HFOs) and the characteristics of equipment designed to use them. The Regulation does not lay down more specific training requirements for alternative refrigerants (which are not fluorinated greenhouse gases), as these do not fall within its scope.

14.4 Key competencies related to flammables refrigerants

Flammable refrigerants are hydrocarbons (A3) but also low flammable refrigerants (A2L) for which no qualification is required. For obvious safety reasons, refrigeration technicians handling flammable refrigerants must acquire knowledge of good handling practices for these refrigerants, charge limits (NF EN 378), drafting of risk analysis (NF EN 378) and ATEX regulations (mechanical and electrical). Refrigeration technicians must also know the specific tools for interventions on hydrocarbon refrigerants (manifold and explosion-proof transfer unit).

14.5 Key competencies related to high-pressure refrigerants

The term high-pressure refrigerant concerns essentially CO_2, for which no qualification is required. However, the refrigeration technicians involved in CO_2 installations must know the specificities of this particular refrigerant recalled below:

- Thermodynamic properties unsuitable for traditional uses
- Low-temperature limitation (triple point -56.6°C)

• Critical temperature +310C; 73.6 bars (for comparison R-404A at 72.1°C, 37.3 bars) so no condensation above the critical point

• Traditional single and double-stage applications require transcritical compressor operation

• Very high discharge pressure

• Component design

• Problem of oil return.

For refrigerant operating at pressures higher than 85 bars, the knowledge of PED and CTP are essential when handling CO_2.

14.6 KEY COMPETENCIES RELATED TO TOXIC REFRIGERANTS

The term toxic refrigerant concerns essentially ammonia. The decree of 16 July 1997 requires operators to ensure professional qualification and specific safety training for its personnel. The staff may be assigned to conduct or monitor refrigeration facilities (subject to Item 4735) or likely to operate on them (Article 54).

This training includes exercises to become familiar with the wearing of the breathing apparatus (ARICO) and the rules of safety of the installation in case of leakage.

In addition, refrigeration technicians must acquire knowledge on risk analysis drafting (NF EN 378).

If the use of ammonia extends to non-ICPE facilities, the responders to the facility should be trained in the handling of this refrigerant.

14.7 KEY COMPETENCIES RELATED TO HFC/HFO BLENDS

Most of the low-GWP refrigerants offered are refrigerant mixtures with a higher or lower temperature glide. In particular, the selection of compressors and evaporators is no longer based on the evaporation temperature (at constant pressure) but on the average of the temperatures (evaporator inlet - end of evaporation). This parameter is to be taken into account in the equipment selection software as part of the new plant design. Specifiers and specialized BE staff need to be trained to consider temperature glides in installation designs.

In addition, refrigeration technicians must acquire knowledge on risk analysis drafting (NF EN 378) because of their low flammability.

14.8 Synthesis

The following table is a synthesis of needs in terms of practical know-how (Practical: P) and knowledge (Theory: T).

Key thematic	**HFC**	**HC (A3)**	**CO_2**	**NH_3**	**A2L***
Technical knowledge	Included in the certificate of aptitude	Technical specificities (P, T) Charge limit (T)	Technical specificities (P, T)	Technical specificities (P, T)	Technical specificities (P, T) Charge limit (T)
Tightness	Included in the certificate of aptitude	No particular specificities	No particular specificities	No particular specificities	No particular specificities
Tools	Included in the certificate of aptitude	Specific manometer Precision balance Long flexible to degas out of confined space é	Specific manometer (P) Specific detector (P)	Specific detector (P)	Specific transfer group (P)
Recovery	Included in the certificate of aptitude	No regulatory obligation	No regulatory obligation	Recovery mandatory by a trained person (Decree of 16 July 1997)	No particular specificities
ATEX	No	A3	Non	B2L	A2L*
PED / in service follow up PE	According to pressure level				
Individual protection equipment	Yes (oxygen detector) (P)	Yes (HC detector) (P)	Yes (oxygen detector) (P)	ARICO mandatory (P, T)	Yes (oxygen detector) (P)
NF EN 378 (safety)	Yes				

* Class A2L not yet recognized by the French regulation on fire risks.

14.9 Directory of available training programs

The AFF has written a report entitled: "**Training in the handling of refrigerants called" Natural ", the state of needs**" This report addresses the topic of training / development of skills for the use of CO_2, NH_3 and hydrocarbons. Training needs and the existing supply are detailed for each technology. The theoretical and / or practical aspect is also considered.

You will find below a list of these organizations as well as their contact details. Moreover, the programs of some trainings are in Annex 1.

Table 14-4: Training-center information.

Organisme	Adresse	Numéro de téléphone	Site internet
AFPA	Plusieurs centres de recherche sur le territoire métropolitain	/	https://www.afpa.fr/
Association de la Providence	146 Boulevard de Saint-Quentin, 80094 Amiens	03 22 33 77 77	http://www.la-providence.net/
Axima (GdF Suez)	Lille, Lyon, Marseille, Nantes, Strasbourg	03 88 19 19 41	https://engie-axima.fr/refrigeration/
Cemafroid	5 Avenue des Prés, 94260 Fresnes	01 49 84 84 84	http://www.cemafroid.fr/formation.htm
CFI Orly	5 Place de la Gare des Saules, 94310 Orly	01 41 76 00 70	https://www.cfi-formations.fr/
Coprotec	12 Impasse Montgolfier, 68127 Sainte-Croix-en-Plaine (Colmar)	03 69 28 89 00	http://www.coprotec.net/
Costic	Batiment 16, 102 Route de Limours, 78470 Saint-Rémy-lès-Chevreuse	01 30 85 20 10	https://www.costic.com/
INSA Lyon	20 Avenue Albert Einstein, 69100 Villeurbanne (Lyon)	04 72 43 83 83	https://www.insa-lyon.fr/
Institut Emmanuel d'Alzon	11 Rue Sainte-Perpétue, 30000 Nîmes	04 66 04 93 00	https://www.dalzon.com
Institut Français du froid Industriel	EPN01 292 Rue saint Martin 75141 Paris cedex 03	01 40 27 21 65	http://iffi.cnam.fr/formation-et-recherche-en-froid-industriel-climatisation-refrigeration-851197.kjsp
Johnson Controls	5, rue de l'hôtellerie Bat "Bel Air 3" 44 470 Carquefou	02 40 30 63 62	http://www.johnsoncontrols.com/fr_fr/buildings/our-solutions/training
Lezin Henri	Chemin de Ceinture, 82000 Montauban	05 67 21 09 22	www.lezin-formation.com/
Lycée Cantau	1 Allée de Cantau, 64600 Anglet	05 59 58 06 06	http://www.lycee-cantau.net/
Lycée Édouard Branly	2 Rue de la Porte Gayole, 62200 Boulogne-sur-Mer	03 21 99 68 00	http://lycee-branly.org/
Lycée Jean-Mermoz	717 Avenue Jean Mermoz, 34000 Montpellier	04 67 20 60 00	http://www.lycee-mermoz.net
Lycée Lafontaine des eaux	8 Prom. de la Fontaine des Eaux, 22100 Dinan	02 96 87 10 00	http://www.lycees-dinan.fr/
Lycée La Martinière Monplaisir	41 Rue Antoine Lumière, 69008 Lyon	04 78 78 31 00	http://www.lamartinieremonplaisir.org/
Lycée Maximilien Perret / GRETA MTI	Place San Benedetto del Tronto 94140 Alfortville (Paris)	01 43 53 52 30	http://www.maxp.fr/
Matal Formation	40 Rue de la Poste, 44840 Les Sorinières (Nantes)	02 40 84 54 96	http://www.matal-formation.fr/
Profroid	178 Rue du Fauge, 13400 Aubagne	04 42 18 05 00	http://www.profroid.com/profroid/cms/7339/formations.dhtml
Pyc Formation	6/18, place de la chapelle 75018 Paris	01 53 26 48 00	http://www.pyc.fr/
Université de Rouen-Normandie	1 Rue Thomas Becket, 76130 Mont-Saint-Aignan	02 35 14 60 00	http://www.univ-rouen.fr/
Université Grenoble Alpes	621 Avenue Centrale, 38400 Saint-Martin-d'Hères (Grenoble)	04 57 42 21 42	https://www.univ-grenoble-alpes.fr/

References

Abdelaziz O [et al.] Alternative refrigerant evaluation for high ambient temperature environments: R-22 and R-410A alternatives for rooftop air conditioners [Report]. - [s.l.] : Oak Ridge National Laboratory for US Department of Energy, 2016.

Ademe Base carbone, Documentation des facteurs d'émissions de la Base Carbone [Report]. - [s.l.] : Ademe, 2017.

AFCE Alternatives aux HFC à fort GWP dans les applications de réfrigération et de climatisation [Report]. - [s.l.] : AFCE, 2014.

AFF Formation à la manipulation des fluides dits « naturels » CO2, NH3, HC Etat des lieux et des besoins [Report]. - [s.l.] : AFF, 2014.

Ansar N [et al.] PROJET ICE-TEA: INNOVATION POUR UNE CHAMBRE D'ESSAI THERMIQUE A EFFICACITE AMELIOREE [Report]. - [s.l.] : Ademe, 2015.

Aprea C [et al.] HFO-1234ze as Drop-in Replacement for R-134a in Domestic Refrigerators: An environmental Impact Analysis [Report]. - [s.l.] : Energy Procedia 101, 2016. - pp. 964-971.

Aprea C, Greco A and Maiorino A An experimental investigation on the substitution of HFC-134a with HFO-1234yf in a domestic refrigerator [Report]. - [s.l.] : Therm. Eng 106, 2016. - pp. 959-967.

Arrighi M [et al.] Environmental impacts of carbon dioxide and dry ice production [Report]. - [s.l.] : EIGA, 2010.

Barrault S, Zoughaib A and Clodic D Inventaire des émissions de fluides frigorigènes – France et DOM COM - Année 2016 - Rapport Final [Report]. - 2016.

Barrault Stéphanie and Clodic Denis Inventaire des émissions de fluides frigorigènes – France et DOM COM - Année 2016 - Rapport Final [Report]. - 2015.

Bella B and Leportier Régis Glide Effect on Performance [Report]. - [s.l.] : Asercom, 2016.

Beshr M [et al.] A comparative study on the environmental impact of supermarket refrigeration systems using low GWP refrigerants [Report]. - Hangzhou, China : 11th IIR Gustav Lorentzen Conference on Natural Refrigerants, 2014.

Bitzer Bitzer Software 6.8 [Report]. - 2018.

Bitzer Refrigerant report 13th edition A-501-13 [Report].

Bivens D Safeguarding the Ozone Layer and the Global Climate System: Issues Related to Hydrofluorocarbons and Perfluorocarbons: Refrigeration [Report]. - [s.l.] : IPCC-TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System, 2005.

Chassecot M Residentiel and light Commercial AC [Report]. - [s.l.] : Shecco, 2017.

Chemours Product Information (Chemour) [Report]. - [s.l.] : Chemour, 2016.

Commision Européenne Rapport de la commission concernant la disponibilité pour le personnel d'entretien de formations à la manipulation sans danger de technologie respectueuse du climat remplacant les gaz à effet de serre fluorés oou en réduisant l'utilsation. [Report]. - 2016.

Danfoss Refrigerants from a Danfoss Perspective [Report]. - [s.l.] : Danfoss, 2018.

Devin Eric Les entrepôts et leur activité en 2012. Observation et Statistiques. Chiffres et statistiques. [Report]. - [s.l.] : Commissariat Général au Développement Durable, N° 334, 2012.

Divers Analysis of scientific literature [Report]. - [s.l.] : Divers, 1997-2002.

Du L, Meszler D and Minjares R HFC-134a Phase-out in the chineese light-duty motor vehicule sector [Report]. - [s.l.] : ICCT, 2016.

Emerson Transition des fluides frigorigènes en application du Règlement F-Gaz 517/2014 Quelques options ratiques sur la voie des systèmes CVACR de demain [Report]. - [s.l.] : Emerson, 2016.

Emerson Copeland Selection software 7.16 [Report]. - 2018.

European Commission Report from the Commission of 4.8.2017 assessing the 2022 requirement to avoid highly global warming Hydrofluorocarbons in some commercial refrigeration systems [Report]. - 2017.

Fukuda S [et al.] Low GWP refrigerant R1324ze€ and R1234ze(Z) for high temperature heat pumps [Report]. - [s.l.] : International Journal of Refrigeration, 2013.

Grenelle Environnement Chauffe-eau thermodynamiques en habitat individuels - Conception et dimensionnement [Report]. - [s.l.] : Règles de l'art Grenelle environnement 2012, 2015.

Hashimoto K Technology and Market Development of CO2 Heat Pump Water Heaters (ECO CUTE) in Japan [Report]. - [s.l.] : IEA Heat Pump Centre Newsletter. Vol 24. N°3, 2006.

Hickman K Reference List for low GWP Refrigerant testing [Report]. - [s.l.] : AHRI Low GWP AREP, 2013.

Hughes J and Shah S Testing of Low GWP Replacements for R-410A in Stationary Air Conditioning [Report]. - [s.l.] : Chemours / Internat R andAC Conference, 2016.

IIF Guideline for Life Cycle Climate Performance [Report]. - [s.l.] : IIF, 2015.

IIR Guideline for Life Cycle Climate Performance [Report]. - [s.l.] : IIF, 2015.

IIR Les progrès du froid dans les supermarchés [Report]. - [s.l.] : IIR Information, 2018.

Ineris Rapport Ineris: Etude de sécurité sur le remplacement des fluides frigorigènes [Report]. - [s.l.] : Ineris, 2017.

IPCC IPCC Fifth Assessment report [Report]. - [s.l.] : UNEP, 2014.

IPCC IPCC Fourth Assesssment report [Report]. - [s.l.] : UNEP, 2007.

Kamada T, Haikawa T and Taira S Research on Optimization of Heat exchanger in Heat pump using R32 and HFO-mixed Refrigerant [Report]. - [s.l.] : Purdue University, International Refrigeration and Air Conditioning Conference, 2016.

Kasai Kazushige and Johnson Phillip System Drop-in Test of R134a Alternative Fluids R-1234ze(E) and D4Y in a 200 RT Air-Cooled Screw Chiller [Report]. - 2013.

Kujak S and Shultz K Compositional Fractionation Studies of R410A Alternative R452B or DR55 and Their Impact on Flammability Behavior and Safety Implications [Report]. - [s.l.] : Purdue University, International Refrigeration and Air Conditioning Conference, 2016.

KWT Pompes à chaleur jusqu'à 2000 kW [Report]. - 2015.

Lee H [et al.] LCCP evaluation on various vapor compression cycle options and low GWP refrigerants [Report]. - [s.l.] : International Journal of Refrigeration, 2016.

Leong CC The first CO2 refrigerant-based condensing unit to Jaya Grocer in Malaysia [Report]. - [s.l.] : Asia Atmosphere, 2017.

Llopis R [et al.] R-407H as drop-in of R-404A. Experimental analysis in a low temperature direct expansion commercial refrigeration system [Report]. - [s.l.] : International Journal of Refrigeration, 2017. - pp. 11-23.

Maina P and Huan Z A review of carbon dioxyde as a refrigerant in refrigeration technology [Report]. - [s.l.] : South african journal of science, 2015.

Makhnatch P and Khodabandeh R The role of environmental metrics (GWP, TEWI, LCCP) in the selection of low GWP refrigerant. [Report]. - [s.l.] : The 6th International Conference on Applied Energy – ICAE2014, 2014.

Ministère de l'intérieur Guide M:Guide pratique relatif à la sécurité incendie dans les magasins de venteet les centres commerciaux [Report]. - [s.l.] : Ministère de l'intérieur, 2017.

Minor B, Shah S and Simoni L Testing of HFO Refrigerant with less than 150 GWP in a commercial freezer [Report]. - [s.l.] : 16th International Refrigeration and Air Conditioning Conference at Purdue, 2016.

Mota-Babiloni A, Makhnatch P and Khodabandeh R Recent investigations in HFCs substitution with lower GWP synthetic alternatives: focus on energetic performance and environmental impact [Report]. - [s.l.] : International Journal of Refrigeration, 2017.

Öko-Recherche Availability of alternatives to HFCs in commercial refrigeration in the EU [Report]. - 2016.

Pan Xuexin Panorama des industries agroalimentaires, édition 2012. [Report]. - [s.l.] : Ministère de l'agriculture, de l'agroalimentaire et de la forêt., 2012.

Papasavva Stella and Moonaw William Comparison between HFC-134a and Alternative Refrigerants in Mobile Air Conditioners using the GREEN-MAC-LCCP© Model [Report]. - [s.l.] : Purdue University, International Refrigeration and Air Conditioning Conference, 2014.

Pham Hung and Rajendran Rajan R32 And HFOs As Low-GWP Refrigerants For Air Conditioning [Report]. - [s.l.] : International Refrigeration and Air Conditioning Conference at Purdue, 2012.

Rajendran R Recent Development in refrigerants for air-conditioning and refrigerant system [Report]. - [s.l.] : Emerson, 1997-2000.

Rajendran R Refrigerant Update [Report]. - [s.l.] : Emerson, 2011.

RPF Rétrofit et fluides frigorigènes à glissement de température élevé [Report]. - [s.l.] : RPF, 2018.

RPF Sans stage, la profession se met en danger! [Report]. - [s.l.] : RPF n°1061, Décembre 2017, 2017.

Sawalha S [et al.] Field measurements of supermarket refrigeration systems. Part I: Analysis of CO2 trans-critical refrigeration systems. [Report]. - [s.l.] : Applied Thermal Engineering 87, 2015. - pp. 633-674.

Sawalha S [et al.] Field measurements of supermarket refrigeration systems. Part II : Analysis of HFC refrigeration systems and comparison to CO2 trans-critical. [Report]. - [s.l.] : Applied Thermal Engineering 111, 2017. - pp. 170-182.

Sethi A and Yana Motta S Low GWP Refrigerants for Air Conditioning and Chiller Applications [Report]. - [s.l.] : Purdue University, International Refrigeration and Air Conditioning Conference, 2016.

Sethi A, Pottker Gérald and Yana Motta S Experimental evaluation and field trial of low global potential R-404A replacements for commercial refrigeration. Science and Technology for the built Environment [Report]. - [s.l.] : International Journal of Refrigeration, 2016. - pp. 1175-1184.

Sethi A, Vera Becerra E and Yana Motta S Low GWP R-134a replacements for small refrigeration (plug-in) applications [Report]. - [s.l.] : International Journal of Refrigeration, 2016. - pp. 64-72.

Shah S Testing of HFO Refrigerant With Less Than 150 GWP in a Commercial Freezer [Report]. - [s.l.] : Chemours 16th Internat R and AC at Purdue, 2016.

Shecco F-Gas Regulation is shaking up the HVAC and R industry [Report]. - [s.l.] : Shec co, 2016.

Sutherland G and Burgos R Research and Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants [Report]. - [s.l.] : US Department of Energy, 2014.

Tecumseh Selection Program V4 [Report]. - 2018.

Timmermans J Refrigerant and cooling n renovation buildings [Report]. - [s.l.] : Daikin, 2017.

Tournus Equipement FLUIDE Réfrigérant R455A, GWP inférieur à 150 Amélioration des performances Sécurité [Report]. - [s.l.] : Tournus Equipement, 2017.

Tsamos K. M [et al.] Energy analysis of alternative CO2 refrigeration system configurations for retail food applications in moderate and warm climates [Report]. - [s.l.] : Energy conversion and Management 150, 2017. - pp. 822-829.

UNEP 2014 Report of the refrigeration, air contditioning and heat pumps technical options commitee [Report]. - [s.l.] : UNEP, 2014.

Winter J Success with NH3/CO2 Cascade [Report]. - [s.l.] : Eurammon symposium, 2012.

ANNEX 1

EXISTING TRAINING PROGRAMS

The list of training organizations and modules is not exhaustive. There are other organizations offering training on the topics of alternative refrigerants to high-GWP refrigerants. We focused on the training provided in France.

In addition, some of the organizations listed below offer several trainings on the same topics. Some will for example focus on the design of CO_2 installations, others will focus on maintenance. All the existing modules are not reproduced below, since this is an overview of the existing possibilities as well as the types of training offered (practical / theoretical, short / long ...)

The programs presented are subject to change. They are available on the websites of the training organizations.

Organizations	Topic	Training Program	Duration
AFPA	NH_3	Intervenir sur une installation à l'ammoniac (NH_3) en toute sécurité	3 jours
AFPA	CO_2	Intervenir sur une installation au CO_2 en toute sécurité	2 jours
AFPA	Hydrocarbures	Manipuler des fluides frigorigènes hydrocarbures en toute sécurité	1 jour
Axima Réfrigération	CO_2	Conduite et manipulation des installations CO_2	2 jours
Axima Réfrigération	NH_3	Conduite et manipulation des installations NH_3	2 jours
Cemafroid	NH_3	MG3 - Savoir conduire une installation à l'ammoniac (NH_3-R717)	7h
Cemafroid	CO_2	MG4 - Savoir conduire une installation au CO_2	7h
Cemafroid	Hydrocarbures	MG2 : Fluides « Naturels et alternatives au HFC	7h
CFI Orly	Hydrocarbures	FR36 – Manipuler des fluides frigorigènes propane et isobutane (R290 et R600a)	8h
CFI Orly	CO_2	FRC02-1 Manipuler des installations au CO2 sub et transcritiques	14h
Coprotec	CO_2 et NH_3	T110-07 - Formation sur la réglementation des fluides naturels dans les installations de climatisation CO_2et Ammoniac	7h
Johnson Controls	CO_2	Conduite et manipulation des installations CO_2	2 jours
Johnson Controls	NH_3	Habilitation Ammoniac NH_3	2 jours
Johnson Controls	Hydrocarbures	Manipulation fluides frigorigènes R290, R600a	2 jours
Matal Formation	NH_3	Perfectionnement et sécurité, qualification spécifique ammoniac (NH_3)	3,5 jours
Matal Formation	CO_2	Perfectionnement, sécurité, maintenance, optimisation (tous fluides), habilitation fluides fluorés	1 jour

Organizations	Topic	Training Program	Duration
Profroid	CO_2	Formations pratiques	Plusieurs jours
Profroid	CO_2	Formations théoriques	Plusieurs jours
Pyc Formation	CO_2	Les fondamentaux du CO_2 : de la théorie aux cas pratiques	7h
Pyc Formation	CO_2	Manipuler les installations CO_2 en subcritique, transcritique et booster	7h
Pyc Formation	Hydrocarbures	Hydrocarbures R290 et R600a : comment les utiliser en réfrigération ?	7h
Pyc Formation	Hydrocarbures	Hydrocarbures : les manipuler et intervenir en toute sécurité	7h