



Phase-out of high GWP refrigerants in refrigeration systems: Status of process in Colombia

Eliminación de refrigerantes de alto GWP en sistemas de refrigeración: Estado del proceso en Colombia

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ABSTRACT

Keywords:

HFC, low GWP fluids, Colombia, refrigeration systems

This article is intended to draw attention of the community in general to the changes that have taken place in refrigeration and air conditioning industry of the HFC refrigerants currently used. The HFCs are not Ozone-depleting substances, but the some HFCs are greenhouse gases with very high potential for global warming (GWPs). Thus, more than 150 countries sign up the Kigali Amendment in 2016, establishing the decreasing of the production and consumption of the HFCs. This paper briefly describes the problems surrounding the HFCs and summarizes the fluids considered as alternatives for the main HFCs used in refrigeration systems presented in the scientific literature. In addition, the outlook and the current situation of the HFC withdrawal process in Colombia are analyzed.

RESUMEN

Palabras clave:

HFC, fluidos con menor GWP, Colombia, sistemas de refrigeración

Este artículo pretende llamar la atención del público en general sobre los cambios que tendrán los sistemas de refrigeración y aire acondicionado en los fluidos refrigerantes HFCs, usados actualmente. HFCs son alternativas comúnmente usadas para sustancias que destruyen la capa de ozono. Si bien no son sustancias que destruyen la capa de ozono, los HFCs son gases de efecto invernadero, los cuales pueden tener muy altos potenciales de calentamiento global (GWP). Así, más de 150 países firmaron el acuerdo de Kigali en 2016, el cual estableció el fin de la producción y consumo de los HFCs. Este trabajo describe brevemente la problemática que rodea os HFCs e resume los fluidos considerados como alternativas para los principales HFCs usados en los sistemas de refrigeración, presentados en la literatura científica. Adicionalmente, el panorama y la actual situación del proceso de retirada de los HFC en Colombia son analizados.

Introduction

The intensification of the greenhouse effect and emergence of global warming bring severe climate changes to the life on earth. They are caused by the emission of the so-called greenhouse gases. The main one is the carbon dioxide (CO₂). In this way, the greenhouse gas emissions were the main focus of various international agreements in the recent decades. One of the two most important is an

international treaty signed in 1997 in Kyoto, Japan, which is called The Kyoto Protocol. The objective was to warn about the rising of global warming and the greenhouse gases. It was important because this agreement was the first one to establish goals to decrease the greenhouse gases's emission. The Protocol in fact only came into effect from 2015, during the Conference of the Parties, COP-11, in Montreal. Following the same line, the Paris Agreement is an international commitment discussed

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between 195 States with the aim of minimize the consequences of global warming. He was adopted during the COP-21, in Paris, 2015. The objective was to limit the rising of the temperature to 1,5°C above the pre-industrial levels until the end of this century.

There are gases other than the CO₂ that intensify the greenhouse effect, like the hydrofluorocarbons (HFCs) that are commonly used in refrigeration, air-conditioning, insulating foams, and aerosol propellants, being minorly used in solvents and fire protection. The HFCs are synthetic fluids that do not destroy the ozone layer, but these fluids can have fluid capacity of global warming (GWP) to 10.000 times greater than the CO₂ [1]. HFCs were commercialized in the 1990s and its consumption increase quickly. Assuming no new regulation, in 2050, the annual quantity percentage of HFC emissions will be possible to look at equivalent to 12% of CO₂ emissions in the same time period[2].

Therefore, around 200 States came into an agreement to gradually reduce the use and production of HFCs, though the Kigali agreement, after a meeting in October 2016 in Kigali, Ruanda in the benchmark of the Paris Agreement [3]. This agreement established timetable for the withdrawal of the HFCs with the objective to avoid an additional increase of 0,5°C of the global average temperature for the year of 2100 [4].

Table 1 shows the schedule set in the agreement

for Colombia and the majority of the developing countries. Table 1 shows that the production/consumption baseline of high GWP HFCs in 2024 will be the average of the values of the years 2020 to 2023. Then, in the year 2029, the use reduction will begin.

Table I. Schedule to phase-out of HFCs in developing countries

Baseline Calculation	Average production/consumption of HFCs in 2020, 2021, and 2022
Step 1	2029 – 10%
Step 2	2035 – 30%
Step 3	2040 – 50%
Step 4	2045 – 80%

Source: [4].

By the situation described above, the substitution of the high GWP HFCs is necessary and imminent. This paper presents a summary about the new alternative fluids to replace the HFCs. Also, to show how this process already begun in Europe and in the United States and what are the perspectives in Colombia (and Latin America in general).

HFCs refrigerants

The HFCs were the adopted solution to reduce the attack on the ozone layer that is caused by the chlorofluorocarbons fluids (CFC) and the hydrochlorofluorocarbons (HCFC). In 2010, the global consumption of HFC by sector is showed in the figure 1.

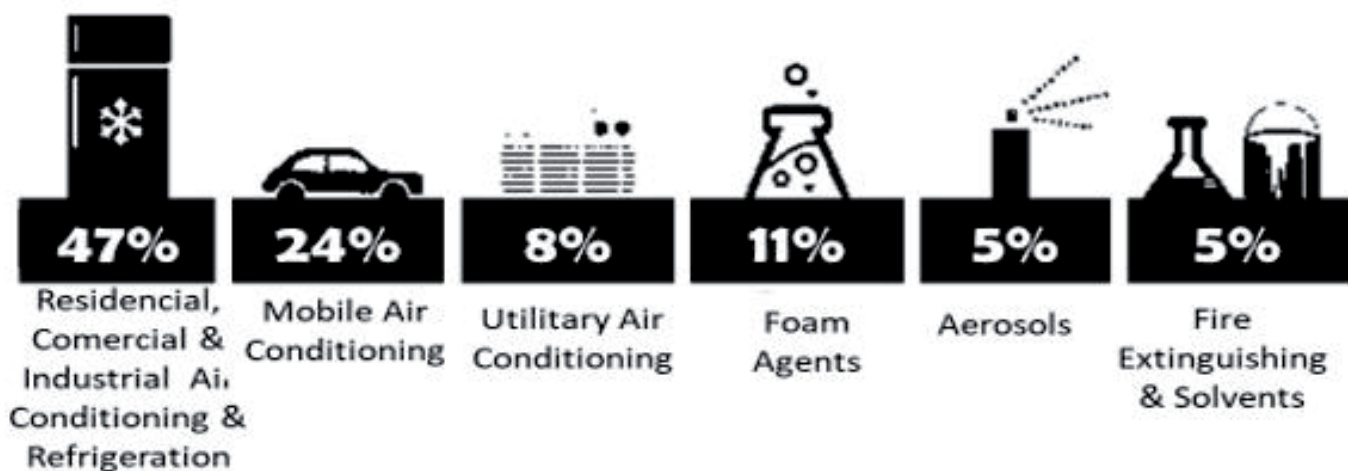


Figure 1. Global consumption of HFC. Source:[5].

The mainly HFCs used in refrigeration and in air conditioning systems are R134a, R404A and R410A [6]. They are non-flammable with a safety classification of A1. In the following, will be described some of the characteristics of these refrigerants.

R134A

R134a has GWP of 1430 and is commonly seen in domestic equipments, medium temperature commercial applications and mobile air conditioning [7]. The R134a is the most HFC abundant and fastest growing.

R404A

R404A has GWP of 3922 and is normally applied in commercial refrigeration for medium and low temperature. [8]. The R404A is a non-azeotropic HFC refrigerant blend of R125, R143a and R134a (52/44/2 %w/w).

R410A

R410A has GWP of 2088 and is frequently found in chillers and air conditioning systems (being them movable or stationary). The R410A is almost an azeotropic refrigerant blend containing R32 and R125 (50/50 %w/w) [9].

Low GWP refrigerants

Historically, the refrigerant fluids have evolved to adjust the operational and environmental needs of each epoch. The first generation of fluids were the natural fluids such as carbon dioxide, sulfur dioxide, methyl chloride and ammonia, used in the beginning of the refrigeration industry. These substances were toxic and dangerous, and rapidly extinguished from the market with the initiation of the CFCs's generation (second generation). The CFCs were created in the 1950s, and their supremacy in the market was questioned in 1980s by the concerns about the depletion of the ozone layer. The HCFC were a transient partial solution to enter the third generation of fluids, known as HFCs. These fluids do not contain chlorine in their composition, it doesn't destroy the ozone layer. However, nowadays they are subject to prohibition discussions because of their

damage effect over the environment. Thus, since around 2010, comes the fourth generation of fluids called low GWP refrigerants, with the objective of reducing global warming.

The main candidates to substitute the HFCs are natural refrigerants fluids like the ammonia, carbon dioxide, hydrocarbons (HFs); pure or blend HFCs with low GWP; and hydrofluoroolefin (HFOs) [10]. In sequence, will be presented the main fluids of each category.

Natural fluids

The CO₂ and the ammonia (NH₃) have been used since the start of vapor compression refrigeration systems. They have a low cost of production and great energy performance. However, lately its application has been restrained to large low temperature systems. The ammonia, besides being toxic, have high condensation temperatures. The CO₂ works at a very high saturation pressure (up until 4 times higher than the commonly used HFCs) and the issues related with transcritical cycles (its critical temperature is 31°C, approx.). In the refrigeration field, the CO₂ and the ammonia are known as R744 and R717, respectively (according to the ASHRAE standard).

R744 has a GWP = 1 and R717 has a GWP = 0. For this reason, they are candidates to substitute the HFC in domestic and commercial applications of medium and low temperature. But for this to happen, a whole line of research and studies have been developed so far but the path does not end [11], [12].

Hydrocarbons

Among the Hydrocarbons, stands out the isobutene (R600a) and the propane (R290) used as refrigerant in domestic refrigerators or in small commercial refrigeration systems. Both fluids have GWP = 3 and high performance, but they are extremely flammable (A3 classification). These hydrocarbons are an alternative to substitute the R134a [13], [14].

Hydrofluoroolefin

Hydrofluoroolefins (HFOs) are organic compounds derived of alkenes (meaning that they have at least one double bond) and halogenated with fluorine. HFOs

are relatively stable compounds in the refrigeration systems, but in the atmosphere are more reactive than the HFC due to his carbon-carbon bond. This reduces their lifetime and GWP and therefore became favorable property concerns on climate changes [15]. The table 1 shows the short life and small GWP of some HFOs compared with the R134a [16].

Table II. Some HFOs properties.

Refrigerant	Chemical formula	Lifetime, days	GWP (100 yr.)
HFC-134a	CH_2FCF_3	4891	1430
HFO-1234yf	$\text{CF}_2\text{CF}=\text{CH}_2$	10.5	<1
HFO-1234ze(E)	Trans- $\text{CF}_3\text{CH}=\text{CHF}$	16.4	<1
HFO-1234ze(Z)	$\text{CF}_3\text{CH}=\text{CHF}(\text{Z})$	10.0	<1

Source: [16].

The Table 2 introduce the most famous and used HFOs. For example, R1234yf has been chosen to substitute the R134a in mobile air conditioning systems (many car manufacturers adopted this refrigerant in nearly 50 models in Europe [17]-[19]); and R1234ze (E) used in chillers [20]. There are more than 20 HFOs considered as refrigerants alternatives [21]. There are also other in fluids study phase such as the R1233zd(E) and the R1123.

One main safety issue related to the HFOs is flammability. A number of HFOs, including the R1234ze (E), are flammable (less than HC), while the others are not, as for instance the R1336mzz (Z) and the R1233zd (E).

It is therefore one main safety issues that are related to HFOs: flammability. A number of HFOs, including R1234yf, R1234ze(E), are flammable, while others are not, as for instance R1336mzz(Z) and R1233zd(E).

Low GWP HFCs

In the section two was mentioned that most of the HFCs have high GWP >1000, and because of this, must be replaced. But, exist some HFCs that have a GWP which is permissible under new regulations and have not been used until now. In this new category there are the R41 (GWP = 166), R32 (GWP = 677), R161(GWP = 4) and R152a (GWP = 138) [22].

R152a is an alternative to R134a because they have similar volumetric cooling capacity and pressure levels similar. Moreover, the energy efficiency, mass flow and vapor density of R152a have values more advantageous than R134a [23]. R32 compared to R410A, has low GWP and a high energy effectiveness [24]. However, R152a and R32 are inflammable (higher than HFOs).

HFC/HFO mixtures

One last category is the HFC/HFO mixture. The goal here is to combine the high performance of the HFCs and the low GWP of the HFO. This way some different mixtures have been suggested as alternative refrigerants to those employed currently. These blends are constituted by CO₂; HFC refrigerants: R32, R125, R152a and R134a; and HFO refrigerants: R1234yf and R1234ze (E). The figure 2 shows these new blends and their composition. For more information in [25], [26].

Discussion

In the previous sections, was made a summary of the alternative fluids to substitute the current HFC (R134a, R404A and R410A) with high potential for global warming as indicated by the Paris Agreement. From experience it can be experienced that a selectin of new refrigerants is not a easy task because all refrigerants have, in some aspect, positive and negative points. Some fluids still are in study and research phases. Others are in a more advanced stage and are produced in commercial scale by companies like Honeyweel and Chermous such as R1234yf, R1234ze(E), R1233zd(E), R448A, R450A, R452A, R452B e R455A.

Some of these fluids already are commercialized in Europe, because were created regulations for the withdrawal of the fluids with high GWP. The EU has imposed limits on a Regulation No 517/2014, where they are briefly listed in Table 3. As can be seen, these limits start at 2015 and finish in 2022, encompass all refrigeration and air conditioning applications [6]. The limits for the GWP of the fluids have different standards in function of the size of the equipment. The smaller and portable systems that exists in more quantity and have a greater risk

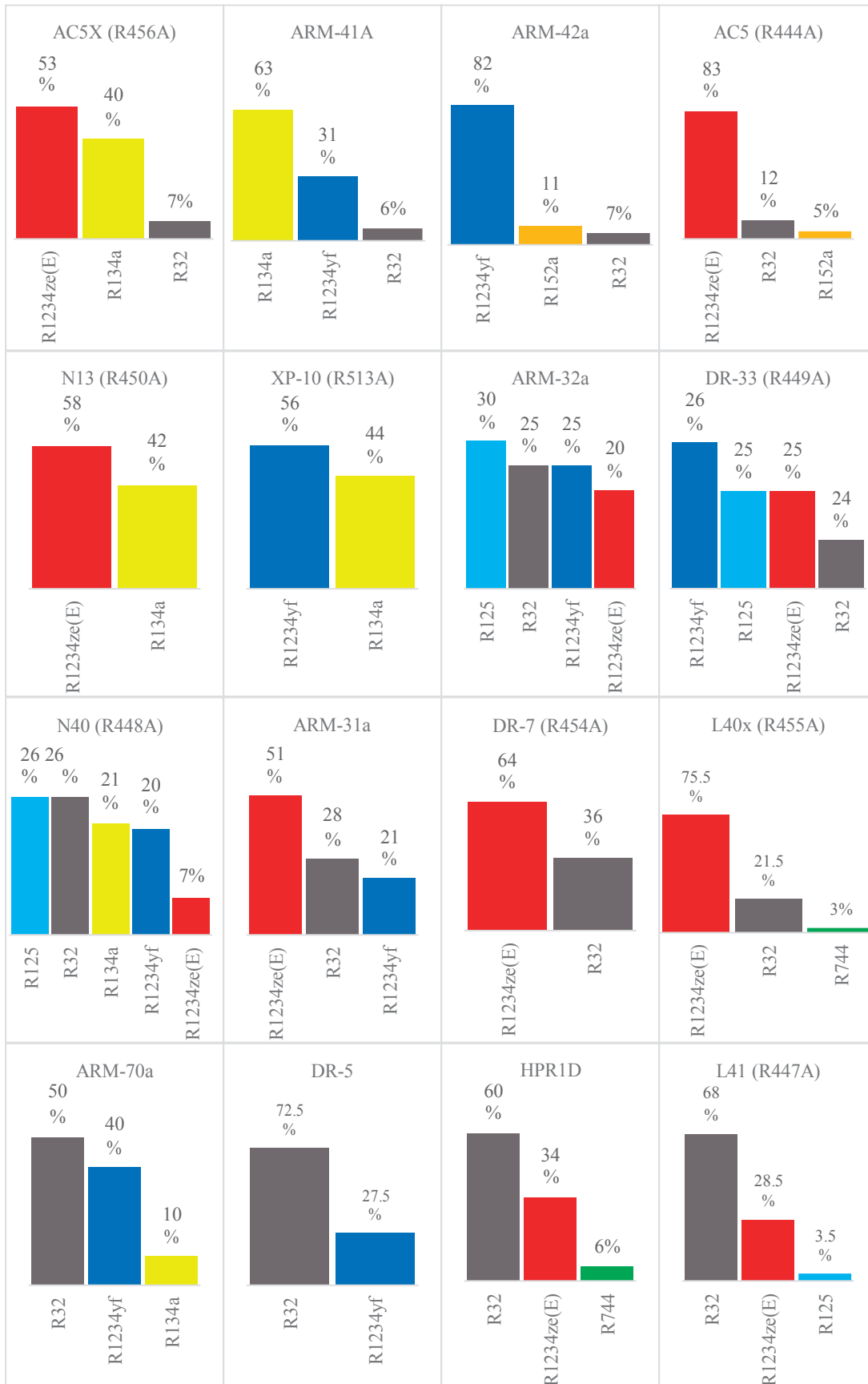


Figure 2. Mass percentage composition of HFC/HFO Mixtures.
Source: [25].

of leaking should have the GWP lower (<150). On the other side, the bigger and statutory commercial systems, the limit of the GWP is higher.

In the United States they are also applying similar regulations. In the Latin America, composed by developing countries, the changes are in smaller stages. In this case, Colombia in 2010, suspend all

the imports and production of CFC, and started the elimination of HFCs with the objective of a total elimination in 2040 [27]. Therefore, currently in Colombia the refrigerant market is shared by the HFCs (R22 and R123) and the HFC (R134a, R404, R407C and R410A).

Table III. Placing on the market prohibitions by the EU Regulation No 517/2014 (Regulation (EU) No 517/20, 2014).

Products and equipment	Date *
Domestic refrigerators and freezers that contain HFCs with GWP \geq 150	2015
Refrigerators and freezers for commercial use (hermetically sealed equipment) that contain HFCs with GWP \geq 2500	2020
Stationary refrigeration equipment, that contains, or whose functioning relies upon, HFCs with GWP \geq 2500 except equipment intended for application designed to cool products to temperature below -50°C	2022
Multipack centralized refrigeration systems for commercial use with a rated capacity \geq 40kW that contains, or whose functioning where fluorinated greenhouse gases with GWP<1500 may be used	2022
Movable room air conditioning equipment (hermetically sealed equipment which is movable between by the end user) that contain HFCs with GWP \geq 150	2020
Single split air-conditioning systems contained less than 3kg of fluorinated greenhouse gases, that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP \geq 750	2025
* January	

Source: [6].

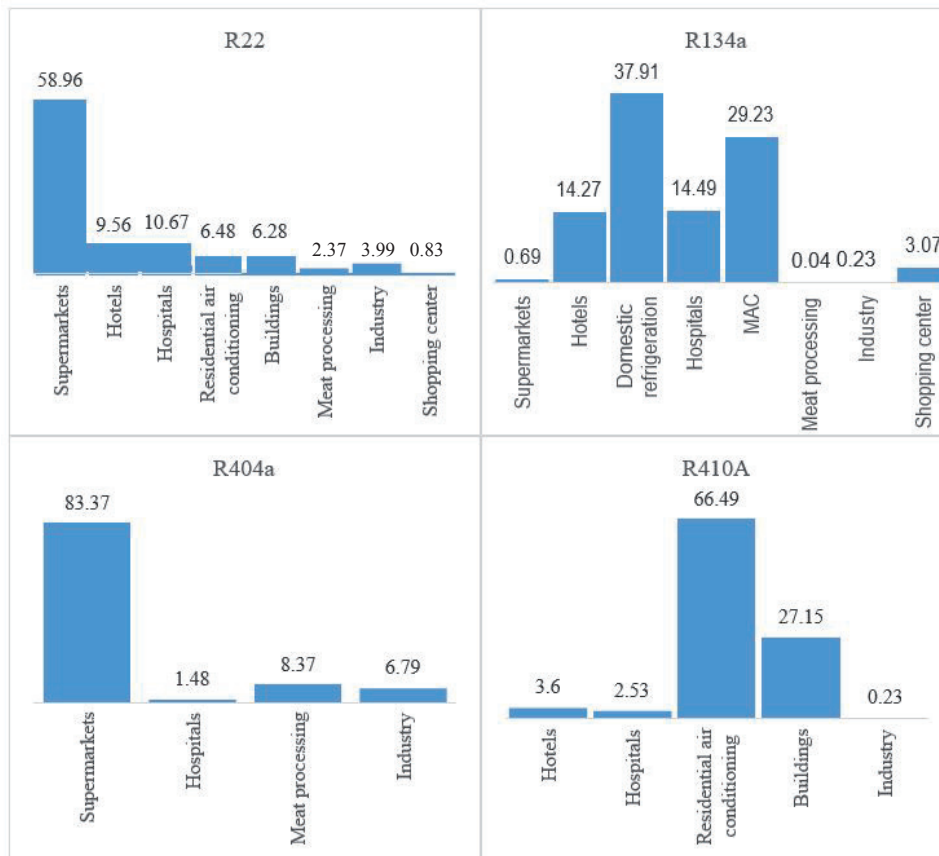


Figure 3. Distribution (%) of the HFCs & HCFCs use in RAC by sector. Source: [28].

In 2012, Colombia started to be part of the Climate and Clean Air Coalition (CCAC), a voluntary partnership among governments, intergovernmental organizations, companies, scientific institutions and civil society organizations have agreed to increase the quality of the air and preserving the climate through measures to minimize short-lived climate-pollutants. Under the HFC Initiative, the CCAC partners are presently giving all the support to the development of HFC inventories and studies to transition away from high- GWP HFCs and reduce HFC leakages.

In 2014 and 2015 was created the Colombian HFC Inventory for the years of 2018 until 2012. This document show details of a market assessment of the consumption of HFCs and the future growth of HFCs in Colombia [28], [29]. The HFCs are commonly used in the refrigeration and air conditioning (RAC) sector. In 2012, this market segment accounted for 98,3% of the total HFC used in the country. The Figures 3-5 show the RAC sub-sectors where the different refrigerant are commonly seen, the total of consumption by sector and the percentage by substance of total RAC use, respectively.

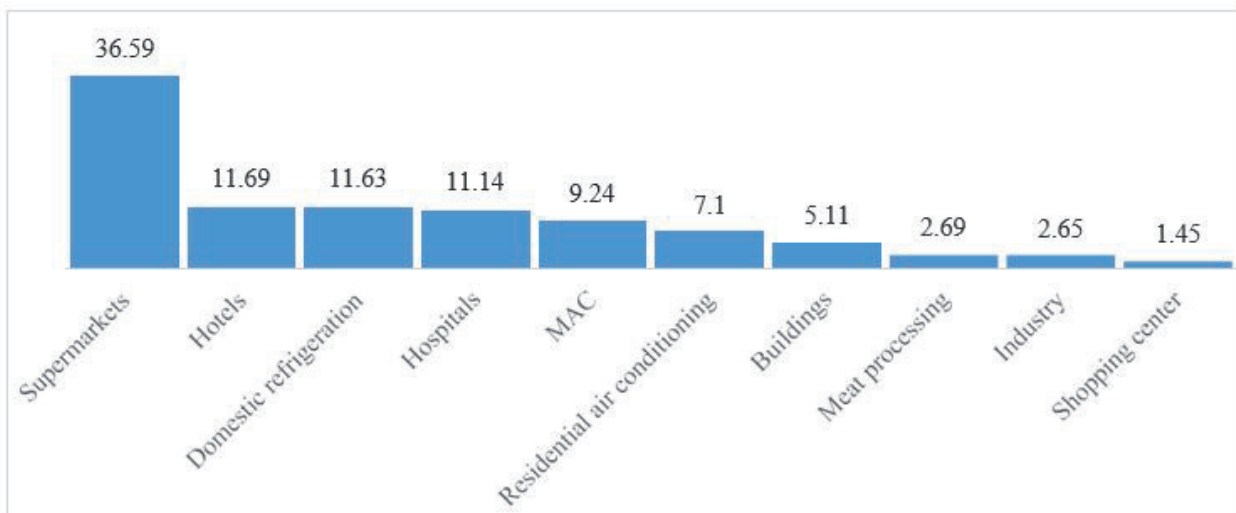


Figure 4. % by refrigerant consumption in each RAC application. Source: [28].

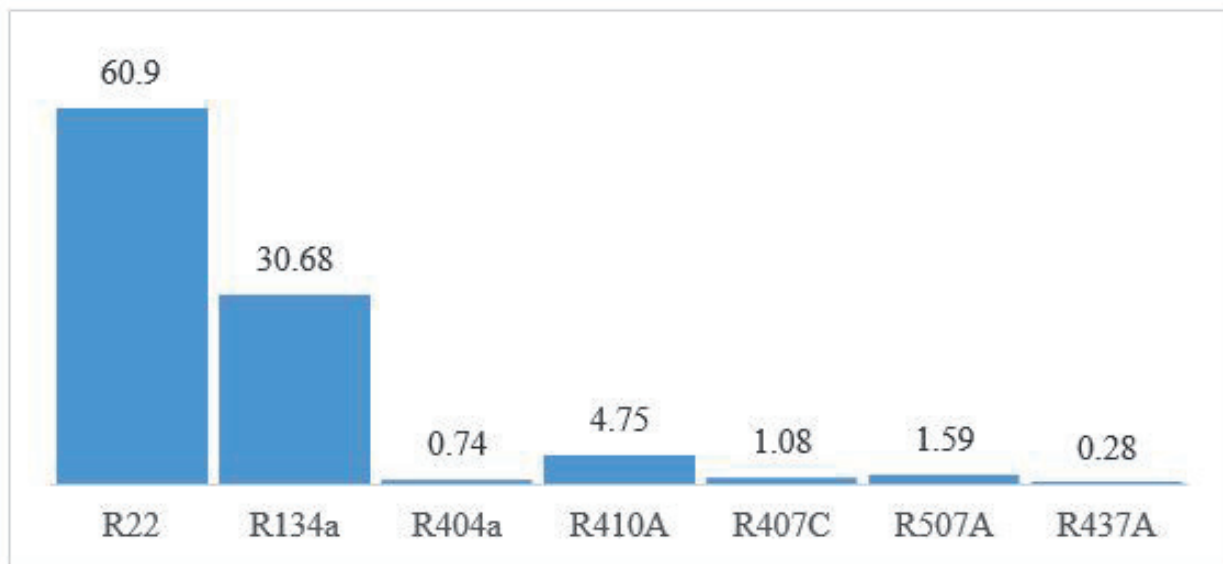


Figure 5. % by refrigerant of total RAC application. Source: [28].

Supermarkets are the sub-sector with the largest use of refrigerant fluids (36.59%). Hotels, hospital, buildings and shopping center, together, have 29.39% of the total use. The residential application (air conditioning, freezer, refrigerator, etc) cover 20.87% of use of refrigerants. The R22 dominates mainly in supermarkets and its process of elimination of the HCFCs still in the its beginnings. The HFCs dominates the rest of the sub-sector. The R134a is the most used HFC, mainly because of its domestic applications (freezers) and automotive (cars). R410 is the most important fluid in residential air conditioning. R404A is also used in supermarkets, but it represents less of 1% of total use.

About HFC consumption, the refrigeration sector in Colombia grew faster and the estimated HFC consumption will triple in 2020 compared to the value in 2012. The HCF fluids mots consumed will R134a and R404A, with 54.4% and 22.2% of the total of the HFC consumption respectively.

Based in this HCFC and HFC inventory, Colombia should start build there policies for the elimination of the high GWP HFC but also needs to rethink the elimination plan for the HCFC, not to be replaced by the same HFCs that were selected in 2010. By policies it is understood that not only legislative (regulations which the companies should meet) and economics actions (financing the companies to implement new and more sustainable systems), but also should stimulate the national scientific community to study the technologies about new refrigerants that are the subject of discussions at an international level. In this sense, Colombia loses a lot for countries like Brazil, Chile and Mexico, which already have universities and research laboratories studying and testing new low GWP refrigerants in refrigeration systems.

The adaptation of the professionals is another aspect that should been taken into account in Colombia with the matter of new policies and refrigerants. In Colombia, it is assumed that the majority of the people that works with refrigeration and air conditioning do not have any formal training. The new equipment will come with inflammable (HC), slightly inflammable (HFOs and HFO/HFC blend) or it will come in high pressure (CO₂). Then, it is

necessary more training programs for the technical staff so they can work more safely during the installation and maintenance [30].

Finally, in Latin America, especially in Colombia, faces a great challenge and must take a definite position to attend the task of developing and transitioning to more efficient, sustainable and clean refrigeration technologies with the assistance of compromised leaderships at all levels of government, the scientific community, manufacturers, companies, consumers and the service providers.

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