

A study of alternative refrigerants for the refrigeration and air conditioning sector in Mauritius

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Abstract. The most frequently used refrigerants in the refrigeration and air conditioning (RAC) sector in Mauritius are currently hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC). However, because of their strong influence on global warming and the impact of HCFCs on the ozone layer, refrigerants such as ammonia (NH₃), carbon dioxide (CO₂) and Hydrocarbons (HC), having minimal impact on the environment, are being considered. So far, HCs have only been safely used in domestic refrigeration. Ammonia has been used mainly for industrial refrigeration whereas CO₂ is still under study. In this paper, a comparative study of the various feasible alternatives is presented in a survey that was undertaken with major stake holders in the field. The retrofitting possibility of existing equipment was assessed and safety issues associated with each refrigerant were analysed. The major setback of hydrocarbons as a widely accepted refrigerant is its flammability which was considered as a major safety hazard by the majority of respondents in the survey and the main advantages are the improved equipment coefficient of performance (COP) and better TEWI factor. This resulted in a 12 % drop in energy consumption. Despite the excellent thermodynamic properties of ammonia, its use has mainly been confined to industrial refrigeration due to its toxicity. In Mauritius, the performance of ammonia in air conditioning is being evaluated on a pilot basis. The major setback of carbon dioxide as a refrigerant is the high operating pressure which is considered a safety hazard. The high initial investment cost and the lack of qualified maintenance technician is also an issue. The use of CO₂ is mainly being considered in the commercial refrigeration sector.

1. Introduction

Mauritius has a mild tropical climate throughout the year and there is relatively little seasonal variation in temperature. January and February are the warmest months with an average day maximum temperature of 29.2 degrees Celsius while July and August are the coolest months with an average night temperatures dropping down to 16.4 degrees Celsius [1]. The average relative humidity which is around 60% in winter period reaches up to 95% in coastal regions during summer [1].

Demand for air conditioning is therefore high in Mauritius especially in summer. Refrigeration is also employed on large scale for processing, storage and transportation of food. The RAC sector in Mauritius will be described in more details in section 3.

Global warming and depletion of the ozone layer are two phenomena directly related to the refrigeration and air conditioning market. CFC's and HCFC's have pervaded the RAC sector since their advent in early 1930's. They gained popularity due to their high stability, very good thermodynamic characteristics and they were not flammable.



CFC's and HCFC's have been widely used in domestic refrigerators, commercial refrigerating equipment, industrial refrigeration, room air conditioning and water chillers. Nonetheless because of increasing environmental issues, their usage in the various sectors has been controlled.

The Montreal Protocol came into force on 1st January 1989 and its objective was to reduce the manufacture of Ozone depleting Substances (ODS) and hence curb down their consumption so as bring down their quantity in the air thereby protecting the environment.

With the Montreal Protocol a program was devised for phasing out the use of CFC's, HCFC's and other ODS by member nations [2, 3]. As per this agreement, small developing countries are grouped under article 5 nations having a consumption of 0.3 kg ODS per individual. As per the agreement, article 5 nations have an obligation to cease using CFCs by the year 2010, while HCFCs must be phased out by the year 2040 [4].

Mauritius has already put a ban on CFC's and use of HCFC's will be stopped in 2025 which is prior of the required schedule for article 5 countries. Import of new equipment that contains HCFC's has also been stopped since 2013.

A new generation of refrigerants, the HFCs, was developed in the 1990's to be used in place of CFC's and HCFC's. HFCs do not contain chlorine atoms; they are thus harmless for the ozone layer. This made them gain rapid popularity in the RAC sector and are widely being used to replace HCFC's. But in spite of having zero ODP, all HFC's have a very high GWP. HFC's can therefore not be considered as good substitutes because their influence on global warming is significantly high [5].

2. Background

Synthetic refrigerants containing halogen atoms are known to be emitted from RAC applications [6]. They were developed from organic gases such ethane and methane by replacing hydrogen atoms with chlorine or fluorine. The group consists of CFC's, HCFC's and HCF's. These substances have been shown to have direct impact on global warming and depletion of ozone layer [7].

2.1. Destruction of the ozone layer

Ozone which occurs naturally in the Earth's atmosphere is an unstable gas with an irritating smell. Ozone occurs 15 to 50 Kilometres above the Earth's surface, when oxygen molecules are broken down by the effect of UV rays. The concentration of ozone varies with altitude, with a peak in the stratosphere about 25-30 km from the Earth's surface. This is known as the ozone layer. The Ozone layer has the important role of filtering harmful UV rays reaching Earth. It therefore protects life on earth.

Molina and Rowland [8] through their research showed that refrigerants that contain chlorine are able to rise up in the atmosphere, where they catalyse destruction of ozone molecules.

2.2. Global warming

Global warming is a phenomenon whereby the mean temperature of the air, oceans and land masses is increasing. Statistics shows that the earth's atmospheric temperature is on the rise, and this has been attributed mostly to human activity, such as usage of RAC equipment running on HCFC's and HFC's with a high GWP.

Global warming occurs due to the fact that infrared emissions emitted by the earth are absorbed by the atmosphere thus raising the overall surface temperature of the globe [9].

The Kyoto agreement was proposed in December 1997 and enforced in 16th February, 2005. Its objective is to curb down release of greenhouse gases such as CO₂ and HFC's which includes R404a, R407c, R410a and R134a.

HCFC's and HFC's are powerful greenhouse gases (GHGs) which contains the fluorine atom. Their effective GWP is thousands of times greater than that of CO₂. Moreover, HFC refrigerants last longer in the atmosphere in comparison to chlorine containing refrigerants. HFCs are thus being controlled under the Kyoto protocol and under European Union regulation No. 517/2008, 2006 [7]. In Mauritius the target is to bring a gradual reduction in HFC's in the forthcoming years.

2.3. Alternatives to HFC refrigerants

Having established that HFC's are hazardous refrigerants for the environment and they are hence facing ban under the EU regulations and under the Kyoto protocol, this section discusses about alternatives refrigerants that have been identified to replace HFC's.

Alternatives that would eventually take the place of halogenated refrigerants would be required to have zero ODP and low GWP. Low toxicity, low price, good chemical stability and good thermal properties would be a definite advantage. Naturally occurring substances like NH₃, HCs and CO₂ could be substitutes to HFCs and HCFCs. Table 1 gives the values of ODP and GWP of frequently used refrigerants.

Table 1. ODP and GWP of common refrigerants (Calm and Hourahan, 2001).

Refrigerant	Group	Atmospheric life	ODP	GWP
R11	CFC	130	1	4000
R12	CFC	130	1	8500
R22	HCFC	15	0.05	1500
R134a	HFC	16	0	1300
R404a	HFC	16	0	3260
R410a	HFC	16	0	1720
R717	NH ₃	-	0	0
R744	CO ₂	-	0	1
R290	HC	<1	0	8
R606a	HC	<1	0	8

2.3.1. Hydrocarbons. P.J. van de Weyde was the first to demonstrate the use of hydrocarbons as a refrigerant in 1866. Hydrocarbons such as Ethane, propane and isobutane were commercially available in the 1920s [11]. However, the substances available at that time were unrefined and contained a significant amount of contaminants. The pressure-temperature correlation was also not satisfactory due to poor technical ability to purify HCs.

At that time refrigeration equipment was not manufactured to the same precision and standards that we have nowadays. So these old systems were not very reliable and leakage of refrigerant was quite high, especially through the seals on the compressor driving shaft, thus giving rise to fire and health hazards. Hence, when synthetic refrigerants were developed in the 1930's, they were very easily accepted at the detriment of HCs due to their chemical stability and very low flammability.

But with the adverse environmental impacts of synthetic refrigerants, HCs made a successful comeback in the mid-1990s [7, 12]. HCs have been extensively used in domestic refrigeration and low capacity commercial refrigeration and air conditioning equipment mainly in Asia and Europe.

Table 2. ODP and GWP of common synthetic and HC Refrigerants [10].

Refrigerant	R12	R22	R134a	R600a	R290
Class	CFC	HCFC	HFC	HC	HC
Atmospheric life	130	15	16	<1	<1
ODP	1.0	0.07	0	0	0
GWP	8500	1700	1300	8	8

In comparison to HCFCs and HFCs, HCs provides zero ODP and very low GWP as shown in table 2. They also offer good efficiency, lower charge sizes, good compatibility with mineral oils, lower compressor discharge temperatures and more efficient heat transfer [13]. But they are highly flammable and this limits their usage in large systems.

The two most commonly used hydrocarbons are isobutane (R600a used in domestic refrigeration) and propane (R290 used in low charge commercial equipment). Hydrocarbons are generally non-toxic.

Hydrocarbons has the advantage of providing an increased efficiency of 14 -20 % in vapour compression systems and since its density is only 40 % that of HFCs the refrigerant charge used is much less [5].

MacLaine-Cross and Leonardi, 1997, stated that if a refrigerator is charged below 50 grams, and the risk of explosion are inexistent. The use of HCs in small commercial equipment and domestic refrigeration is therefore on the rise. HC usage in bigger capacity equipment is limited due to risks of fire and explosion [15].

2.3.2. Ammonia (R717). Ammonia has widely been used in refrigeration equipment for more than a century and has been employed in a large range of industrial activities [16]. It is one of the oldest refrigerants and it is very commonly used in industrial processing and storage of food.

The GWP and ODP of ammonia is zero. Although it is toxic, it has been safely used on a large scale throughout the world in applications such as food processing and air conditioning. Ammonia has also been employed in confined systems in various commercial applications and water chillers [17]. The thermodynamic characteristics of ammonia make it a very efficient refrigerant in vapour compression systems.

Despite the fact that it is very poisonous at relatively low concentrations, fatal accidents resulted from ammonia are not common, because even at very low concentrations it can be easily be identified by its pungent smell. With the introduction of the screw compressors, which overcomes the problem of the high discharge temperature and the advent of plate thermal exchangers operating on volumes of refrigerant, production of simple systems operating on ammonia has been made achievable.

Owing to its environment friendly properties, ammonia is a candidate for much wider use if safety measures and training of technicians are well implemented. The RAC sector especially in Northern Europe is showing new interest in ammonia applications for its market [18].

However, due to its flammability and corrosiveness to skin, its usage in warmer regions which commonly use bigger chillers close to highly populated areas is limited [16]. In Mauritius, only a few minor accidents concerning ammonia have been reported.

2.3.3. Carbon dioxide (R-744). Carbon dioxide was formerly used in refrigeration equipment before the advent of CFCs. But due to the popularity of CFCs, its use was discontinued. However, use of Carbon dioxide is again being considered as refrigerant due to its environment friendly characteristics [19]. The GWP of CO₂ is 1, it does not affect the ozone layer, and it is non-toxic and is not flammable. As CO₂ works at a higher pressure than HFCs, this implies that it needs new operating configurations and parts. Properties such as high density, high latent heat, good conductivity, good cooling capacity per volume and lower value of viscosity make CO₂ an excellent refrigerant [20].

With comparison to other refrigerants, CO₂ has a lower critical point and a higher operating pressure and this poses a major drawback [21]. However, CO₂ can be operated in two different configurations: firstly in the supercritical mode and secondly on the subcritical mode.

Use of CO₂ as refrigerant has found its way in a number of applications including automotive air conditioning and heat pumps [16]. However, the high working pressure of CO₂ implies the redesign of components such as compressors and thermal exchangers and also when it is used as the lower-stage fluid in cascade systems employing common fluids such as HFC, NH₃ or HCs in the higher stage. Cascade systems operating with CO₂ have been used since the last two decades and they have shown rapid development in recent years. Today it is estimated that more than 125–140 such installations are being used in the commercial sector in Europe whereas around 150 are used in agro food processing [16]. In Mauritius, CO₂ is being used in retail applications such as bottle coolers.

3. Survey of refrigerants and equipment used in the RAC sector in Mauritius

A survey was conducted among the major stake holders in the RAC sector to study the types of equipment and refrigerant currently being employed in Mauritius. The RAC sector in Mauritius involves the following uses:

- Domestic refrigeration
- Commercial refrigeration (which includes retail food, cold storage and transport refrigeration)
- Industrial process refrigeration which involves food processing
- Motor vehicle air conditioning (MVAC)
- Domestic and commercial air conditioning (including chillers)

The objective of the survey was to determine,

- Type of equipment currently being used in the RAC sector in Mauritius.
- Refrigerants and refrigerant amounts currently being used in Mauritius.
- Knowledge of the problems associated with the use of HCFCs and HFCs
- Knowledge of technicians about alternative refrigerants to HCFCs and HFCs and proper recovery and retrofitting techniques of refrigerants on the field.
- Emissions of refrigerant from the various sectors.

3.1. Methodology

A survey questionnaire was designed and distributed among the large end-users of refrigeration and air conditioning (RAC) in Mauritius as well as suppliers and contractors in the field. Since it was impossible to contact all companies involved in the field, a sample was made with the major companies/group representing each sector of RAC. In addition, interviews were also carried out with certain respondents to complement information given on the survey questionnaire.

A brief description of each of these sectors is given below in the light of data gathered during the survey.

3.2. Domestic refrigeration sector

In Mauritius, the number of households is increasing with the rising population. It is projected that the number of individual household will increase from 330,000 presently to 420,000 in the year 2020 [1]. 85 % of households have a refrigerator and this figure is likely to rise to 90% or more in 2020 [1].

3.3. Domestic air conditioning

In Mauritius, the domestic air conditioning market is growing rapidly since the late 1990s. The main reason behind this has been the decrease in price of air conditioning units, coming from the south East Asian countries and Egypt which have flooded the market. Air conditioning units for the domestic market are the 'split' unit type. The cooling capacities offered vary from 9,000 BTU to 32,000 BTU. The number of small companies offering domestic air conditioning units for sale, together with an attractive after sales service, has gone up significantly in the recent years. Domestic air conditioning systems for the domestic market are not presently being manufactured in Mauritius.

3.4. Commercial refrigeration sector

Small to large display cabinets are used in the retail food sector such as in supermarkets and retail shops etc, to display foodstuffs offered for sale. In Mauritius, the shopping trend has shifted from small foodstuff stores to super markets and hyper markets. In the last twenty years, we have seen a very rapid growth of groups of supermarkets and hypermarkets. All these together now share the major part of the retail food market in Mauritius. Display cabinets and refrigerated furniture in various size and capacity are used to display frozen and chilled food. Each store is also equipped with a number of cold rooms for their stocks of frozen and food.

3.5. Industrial refrigeration

Industrial refrigeration involves the processing of food such as chicken, fish, meat and ice cream, in mass under a controlled temperature environment. In Mauritius, food processing plants offering a variety of fresh and frozen food are quite widespread and have existed since a relatively long time. For example, the 'Food and Allied Ltd' which specialises in the production of chicken and 'Maurilait Productions Ltd' which produces ice cream and other dairy products have been in operation since the

late 1960s. Other stake holders in this sector are the 'Froids des Mascareignes ltd' involved in production of Seafood, the 'Margarine Industries ltd' and 'Happy World Foods ltd'. This sector also employs an important number of cold rooms for stocking their product prior to distribution in sales outlets. Refrigeration equipment in this sector is often custom designed to suit the needs of the company.

3.6. Commercial air conditioning

In Mauritius, the commercial air conditioning sector embraces primarily large buildings such as offices, hotels and shopping centres. Water chillers are the most widespread equipment for air conditioning large office buildings and hotels, although split units are also widely employed.

With the government policy to increase the number of tourists' arrivals in Mauritius, the number of hotels has known a very rapid growth in recent years. And since all of the luxurious hotels are built on the coast of the island where temperatures is often above 32 °C, air conditioning equipment is extensively used. In the bigger hotels, it is primarily water chillers units that are being used. Smaller hotels opt for split unit air conditioning systems that costs cheaper to install and to maintain. The hotel sector has now become the primary user of commercial air conditioning equipment in Mauritius.

3.7. Motor vehicle air conditioning

The automobile sector in Mauritius has known a very important rise in the last twenty years. The number of motor vehicles (excluding motor cycles and auto cycles) registered in Mauritius were 300 124 in June 2016 out of which 244 401 were cars and dual purpose vehicles [1]. Air conditioning in cars has become popular since the mid-1990s. Air conditioning which was once offered as option in standard cars now forms an integral part of the vehicle. In fact, all new and re-conditioned cars now offered for sale is equipped with air conditioning. This sector was not considered in the survey.

4. Analysis of survey data

4.1. Type of equipment, refrigerants and typical charge size per sector

Table 3 below displays the various types of equipment used in the different RAC sector in Mauritius. Refrigerants currently employed together with the typical charge sizes are also given.

Table 3. Type of equipment, refrigerant and typical charge size.

Sector	Type of equipment used	Refrigerants currently being used	Typical refrigerant charge (kg)
Domestic Refrigeration	Domestic refrigerators	R-134a Hydrocarbons (limited)	0.05 – 0.25
Domestic Air Conditioning	Window and split type air conditioning unit	R-22, R-134a	0.5 – 1.5
Commercial Refrigeration	Display cabinets and refrigerated or chilled furniture. Cold Rooms:	R-134a, R-502, R-404A, R408C, R-22	0.2 – 5 15 - 25
Industrial Food Processing	Large chest freezers and cold rooms	R-502, R-22, Ammonia	5 - 250
Commercial air Conditioning	- Large split type air conditioning units - Water chiller systems	R-22, R-407A, R-134a, R 410a, R407c	1.2 – 2.0 125 – 270
Vehicle Conditioning	Vehicle air conditioning system	R-134a	0.8 – 1.0

● Hotel Sector:

The hotel sector in Mauritius comprises of 116 hotels ranging from 40 to 350 rooms [1] and most of them are located on the coastal regions where temperatures are highest. As such hotels present a high demand for air conditioning.

Hotels where the rooms are clustered in large buildings mainly use chiller units whereas hotels which have individual bungalows mainly use splits air conditioning systems. Smaller hotels with number of rooms ranging from 40 to 75 favour the use of split units as they are easier to maintain. Figure 1 compares the percentage of hotels using chillers, split units and both.

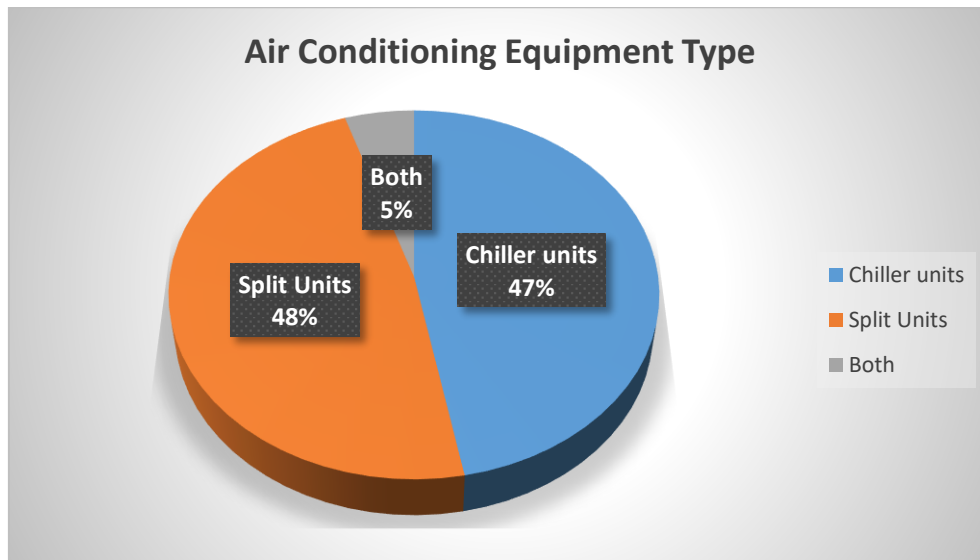


Figure 1. Type of air conditioning equipment in the hotel sector.

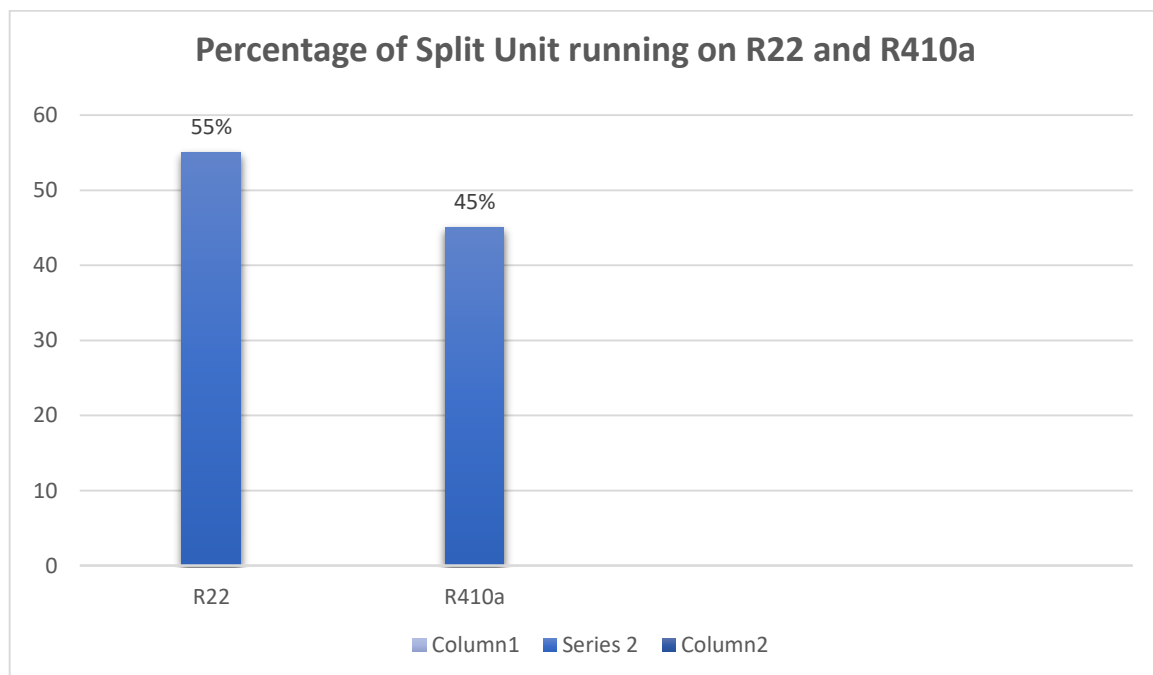


Figure 2. Percentage of split units by type of refrigerant in the hotel sector.

HCFCs, particularly R22, are still being used in the tourism industry, mainly for servicing of RAC equipment. HCFC consumption in the tourism sector accounts for 10 to 15% of the total refrigerants used in Mauritius [22].

An important number of the hotels surveyed have split air conditioners using R22. Figure 2 shows the refrigerant by percentage being used in split units in the hotel sector in Mauritius. It is obvious that with the policy of Mauritian government of shifting to the import of R410a split air conditioner, it may be foreseen that split air conditioner with HCFCs as refrigerant will disappear from the Hotel Sector in the coming 9 years. There is an estimated 3000 split unit room air conditioners in hotels in Mauritius with a stored amount of 3 tons of HCFC 22 [22].

This survey has shown that through renovations and in some cases reconstruction, hotel industry in Mauritius is gradually moving away from HCFCs. However, the import of HCFC's remains significant as shown in figure 3 below for maintenance of existing equipment.

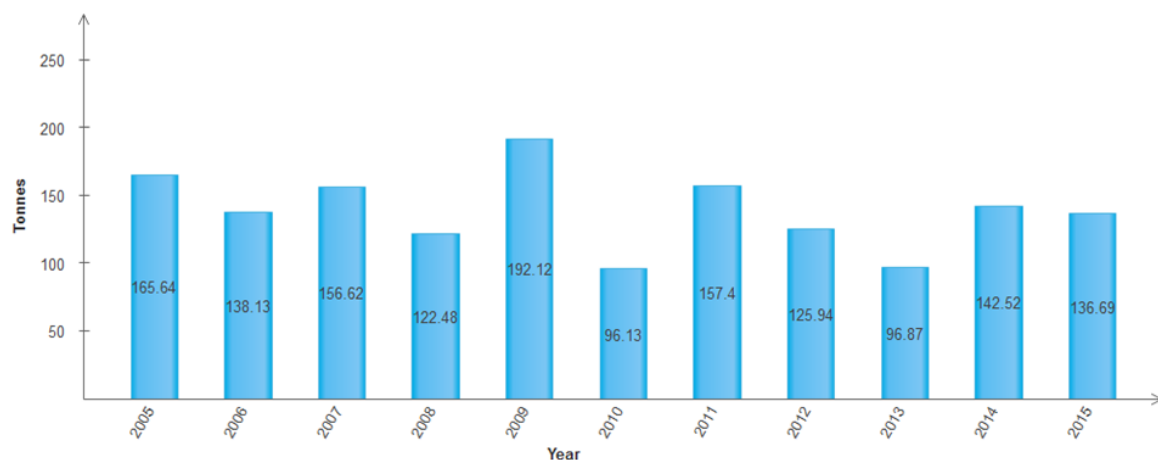


Figure 3. Consumption of HCFC's in the RAC sector in Mauritius (2005-2015) [1].

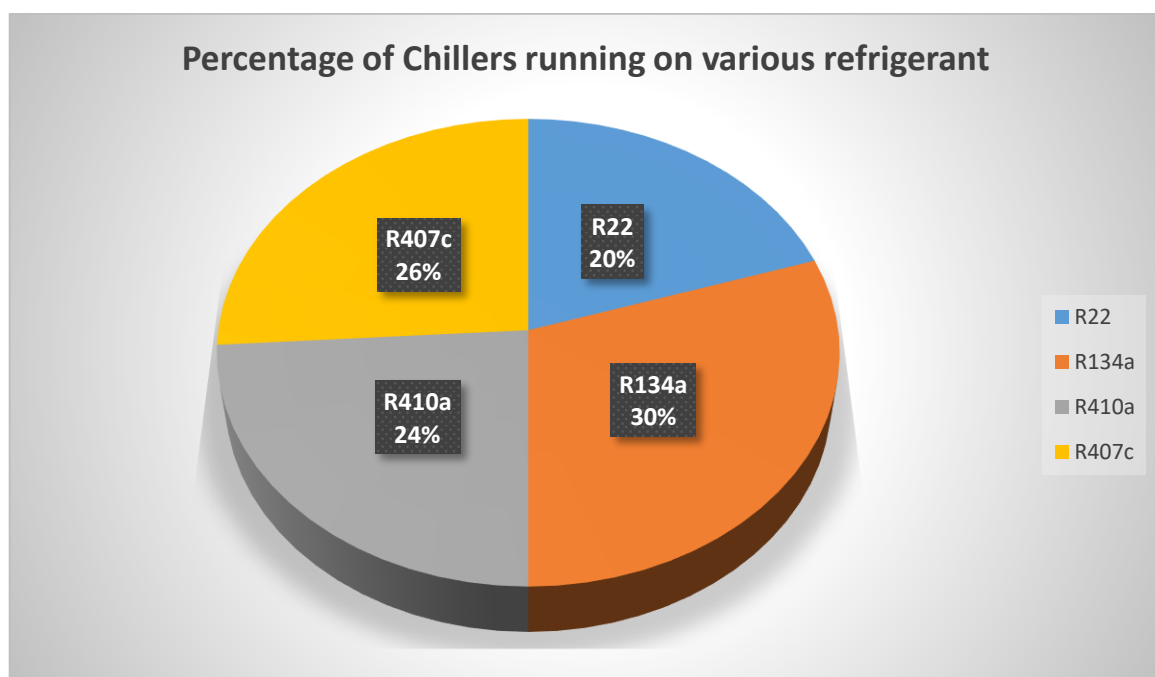


Figure 4. Percentage of chillers by type of refrigerant in the hotel sector.

This is because the commercial and industrial sector is still widely using R22 in existing equipment and they need to purchase this refrigerant for maintenance and repair work on their systems.

- **Chillers:**

Some chillers in the hotel sector still run on R22. The survey identified 15 with an average charge of 50 kg per chiller. Other chillers in this sector are on the HFC namely, R134a, R407c and R410a. Figure 4 shows the percentage of chillers running on each refrigerant.

It is estimated that 750 kg to 1 ton of HCFC 22 are being used in chillers in hotels in Mauritius.

- **Commercial Refrigeration:**

The commercial refrigeration sector consists of hypermarkets and supermarkets. Smaller shops were not considered in this survey. Equipment used are mainly display cabinets and freezers for displaying and selling frozen food and also bottle coolers. All supermarkets have cold rooms for keeping their stocks of perishable foodstuff.

Refrigeration equipment in the surveyed supermarkets in Mauritius operates on R22, R134a and R404a. However, old refrigerator systems working on R22 are gradually being replaced by systems working on HFC refrigerants. Figure 5 gives the percentage of equipment operating on R22, R404a and ammonia.

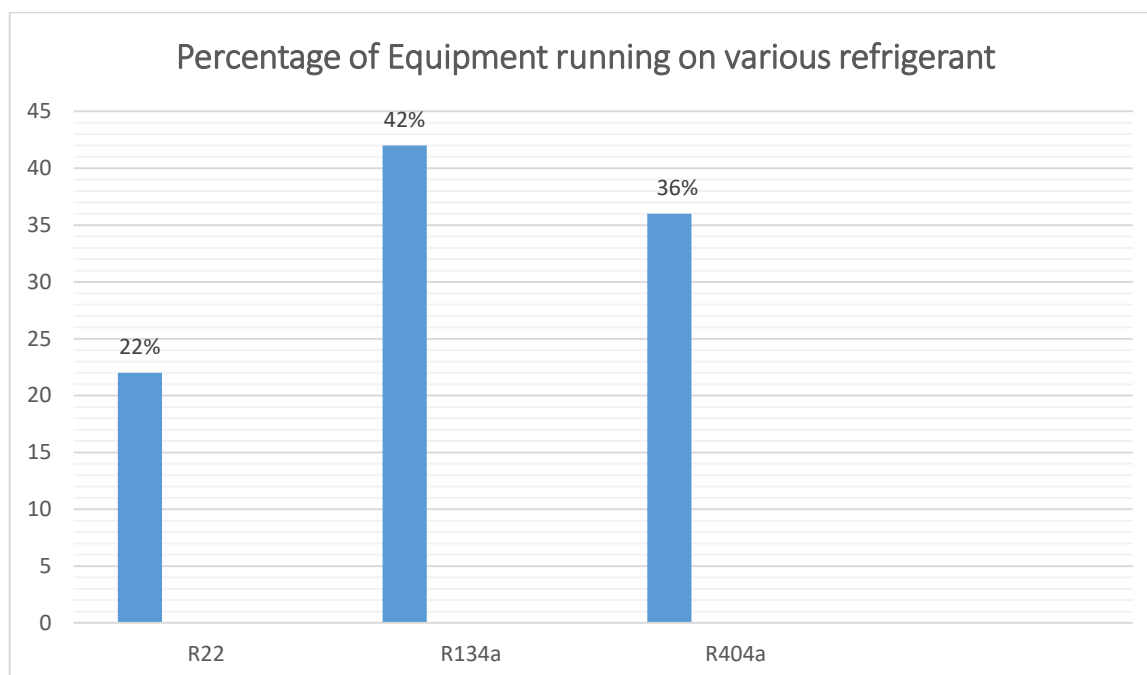


Figure 5. Percentage of equipment by type of refrigerant in the commercial refrigeration sector.

Table 4. Use of R22 in supermarkets in Mauritius.

S/N	Equipment using R22	No of units	Charge per unit (Kg)	Total Charge (kg)
1.	Freezers	34	20	680
2.	Refrigerators	75	5	375
	(Chill Cabinet Unit)	52	10	520
		225	25	5625
3.	Cold room	87	15	1305
		1	250	250
	Total			8755

Source: [22]

Table 4 illustrates an estimated use of HCFC refrigerant (R22) in the supermarkets in Mauritius [20].

- **Industrial Refrigeration:**

This sector employs large cold rooms and blast freezers to rapidly freeze food. The survey showed that three refrigerants namely R22, R404a and R717 are being used. Figure 6 shows the percentage of equipment with their respective operating refrigerants.

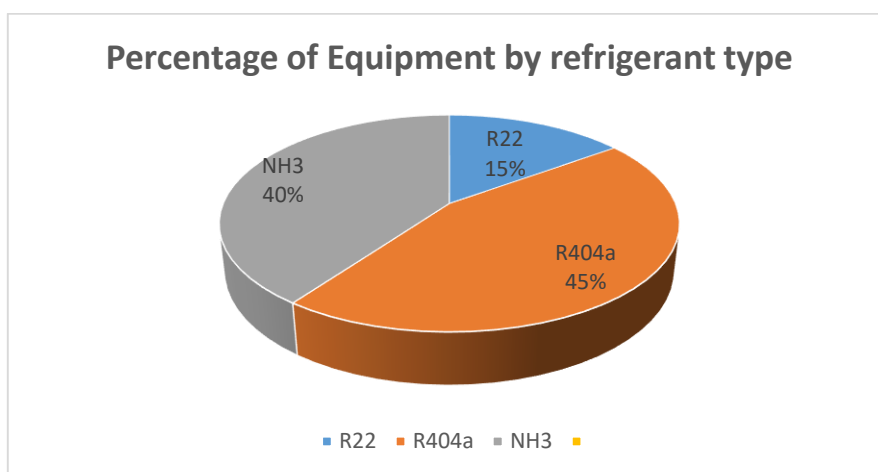


Figure 6. Percentage of equipment by refrigerant type in the industrial refrigeration sector.

4.2. Refrigerant recovery during servicing and disposal of equipment

Table 5 shows the status of refrigerant recovery during maintenance and disposal of equipment.

Table 5. Recovery of refrigerant.

Sector	Recovery of Refrigerant during maintenance
Domestic refrigeration and air conditioning	No
Commercial Refrigeration	Yes
Industrial refrigeration	Yes
Commercial Air conditioning	Yes

4.2.1. Domestic refrigeration/air conditioning sector. In the domestic RAC sector, servicing and repair is done by private mechanics that very often have little knowledge about the theory of refrigeration and air conditioning. They are often trained on the field itself. Out of ignorance, these mechanics most of the times allow the refrigerant to be evacuated in the atmosphere during repair of equipment.

Most of the repair mechanics are also not equipped with a refrigerant recovery unit. The relatively high price of recovery units may be the reason behind this.

At the end of their lifecycle, most domestic refrigerator and air conditioners are scrapped off as solid waste by households. The refrigerant is not recovered at disposal. The same applies to office air conditioners.

Whilst it is not worthwhile to recover the refrigerant for domestic refrigerators as they contain very little refrigerant (50-100 grams in the majority of cases), recovery of refrigerant from air conditioning units can be interesting and economical as the refrigerant can be re-used if recycled.

4.2.2. Commercial/industrial refrigeration and commercial air conditioning sectors. The equipment in these sectors requires mechanics that are more qualified. It is therefore easier to pass information

about environmental aspects of refrigeration and air conditioning. Companies that carry out repairs and maintenance are much better equipped than private mechanics that work for their own. Recovery of refrigerant during repairs in these sectors is therefore much better done. The same thing applies to recovery of refrigerant in equipment completing their lifecycle.

However, three respondents have admitted that they often evacuate important quantities of refrigerant in the atmosphere due to shortage of recovery cylinders.

However, one major impediment to the recovery of refrigerant is that there is no recycling plant for refrigerants in Mauritius. So many companies, after having recovered refrigerants for some time, do not know what to do with them and how to dispose them.

4.3. Consumption of HCF's in Mauritius

Figure 7 shows the variation in the import of HFC's in Mauritius.

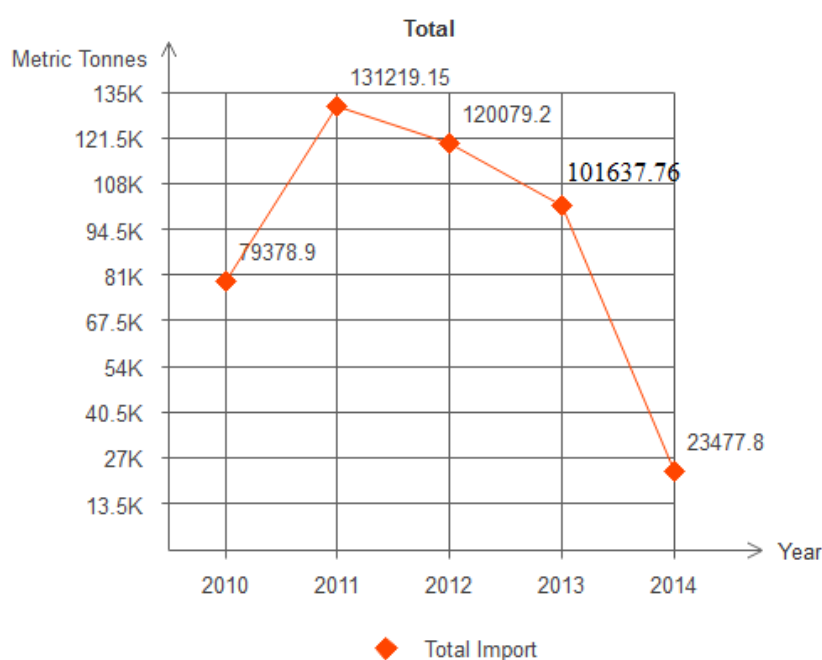


Figure 7. Import of HFC's for the RAC sector in Mauritius, [1].

It should be noted that all import of HFC's is used for charging new equipment and for top-up during maintenance of existing RAC equipment. The graph shows an overall decrease in the import of HFC's in Mauritius. This is an indication that there is less new equipment running on HFC's that is being installed from the period 2011 to 2014. The imported gases in 2014 onwards are thus being used solely for top-up purposes due to leakage in the refrigeration systems.

4.4. Knowledge of alternative refrigerants to HCFCs and HFCs

Most of the respondents were well aware of the problems associated with depletion of the ozone layer and that CFCs and HCFCs were largely responsible for that. However, for many of them ozone depletion and the global warming phenomenon were the same thing and they often mixed issues. But most of them were aware of new replacement refrigerants for CFCs and HCFCs.

Concerning proper retrofitting techniques for new refrigerants many of the technicians were not familiar with the procedures and precautions to be taken. Most of the respondents preferred that the retrofitting be carried out by the representative of the supplier of the equipment.

The proposed replacement refrigerants per sector are presented in table 6 below.

Table 6. Replacement refrigerants per sector.

Sector	Type of equipment used	Refrigerants currently Being used	Replacement refrigerants (post montreal protocol)	Remarks
Domestic Refrigeration	Domestic refrigerators	R-134a Hydrocarbons	R-134a, Hydrocarbons (R-600a)	Hydrocarbons are easily available
Domestic Air Conditioning	Window and split type air conditioning unit	R-22, R-134a	R-407C, R404A, Hydrocarbons	Hydrocarbons are easily available
Commercial Refrigeration	Display cabinets and refrigerated or chilled furniture. Cold Rooms	R-134a, R-502, R-404A, R-22	R-134a, R-404A, Hydrocarbons	Hydrocarbons are easily available
Industrial Food Processing	Large chest freezers and cold rooms	R-22, Ammonia	R-134a, R-404A, R-407A, R-410A, Ammonia, CO ₂ (long term)	CO ₂ require special high pressure piping and equipment
Commercial air Conditioning	- Large split type air conditioning units - Water chiller systems	R-22, 407A, R-134a	R-134a, R-407A, Hydrocarbons	
Vehicle Air Conditioning	Vehicle air conditioning system	R-134a	R-134a, CO ₂ (long term), Hydrocarbons	CO ₂ require special equipment

5. Discussion and recommendations

5.1. Options for retrofitting existing equipment

Small systems operating on R22 have been successfully retrofitted to alternative refrigerants which do not affect the ozone layer, but it is not always possible to replicate the exact operating conditions of R22 and therefore conversions often involve replacing certain components. Therefore prior to any large scale retrofitting of equipment the following should be given due consideration:

- Cost of replacement with a new refrigerant and components which will improve system efficiency,
- The age of the plant,
- The possible hazards due to retrofitting

5.2. Alternative Refrigerants for the RAC sector in Mauritius

It is established that HFC's are not good solutions when considering environmental safety the challenge is to find better alternatives from an energy efficiency and environment point of view. In the survey presented in section 3, it is clear that in Mauritius the focus is now on natural refrigerants such as hydrocarbons and ammonia.

Ammonia which had been employed in large industrial refrigeration applications and food processing industry partly in replacement of the formerly widely used CFC's refrigerant in this sector is now being called upon to be used as a replacement for HCFC's and HFC's. Figures show that ammonia equipment is on the rise. Based on this, it can be safely forecasted that ammonia will become increasingly popular in the long run due to its excellent thermodynamic properties and higher COP with smaller heat exchanger footprints [18].

HC's have also been successfully used in small refrigerator display units in commercial applications but is not popular. Tests conducted recently on domestic AC units and automobile AC units when retrofitted from R22 and R134a respectively showed up to 18% energy efficiency and 12.9% improvement in the COP achieving design temperatures in a shorter time [11]. The only drawback of HC's is their high flammability.

CO₂ as refrigerant is not popular yet in Mauritius. The only few applications has been in soft drinks dispensing machines and bottle coolers. The Ministry of Environment recently donated a CO₂ / ammonia cascade system to the Universite des Mascareignes so that the University can promote CO₂ and ammonia as a safe and efficient refrigerant to the local market.

6. Conclusions

This study shows that in the aftermath of the Montreal protocol which was successfully implemented in Mauritius, HFC refrigerants such as R134a, R404a, R407C and R410 are the predominating refrigerant in the Mauritian RAC sector. HCFC R22 is also being used to a smaller extent in split AC units and large industrial and commercial applications. Survey results show that usage of R22 is slowly declining.

Results of the survey also show that stake holders on the market are well aware of the issue of global warming as related to HFC and HCFC refrigerants and are well acquainted with the fact that natural refrigerants are the alternative solutions. However, the hazards associated with these natural refrigerants such high flammability for HC's, toxicity for NH₃ and high working pressure for CO₂ are posing as barriers in their rapid implementation. Mauritius is also facing a lack of qualified technologists to work with these new technologies especially CO₂. High investment costs for CO₂ and ammonia are also a major setback.

High energy efficiency, good thermodynamic properties together with smaller charges, low price and good COP make HC's an excellent alternative for small and medium refrigeration and air conditioning applications.

NH₃ is well accepted in large industrial refrigeration applications whereas CO₂ is being used on a small scale in bottle coolers and is likely to pick momentum in the coming years in supermarket refrigeration as prices get lower and more technicians acquire adequate training.

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