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DTC ENGINEERING

REFRIGERATION CLASSIFICATION, PROPERTIES, AND SELECTION

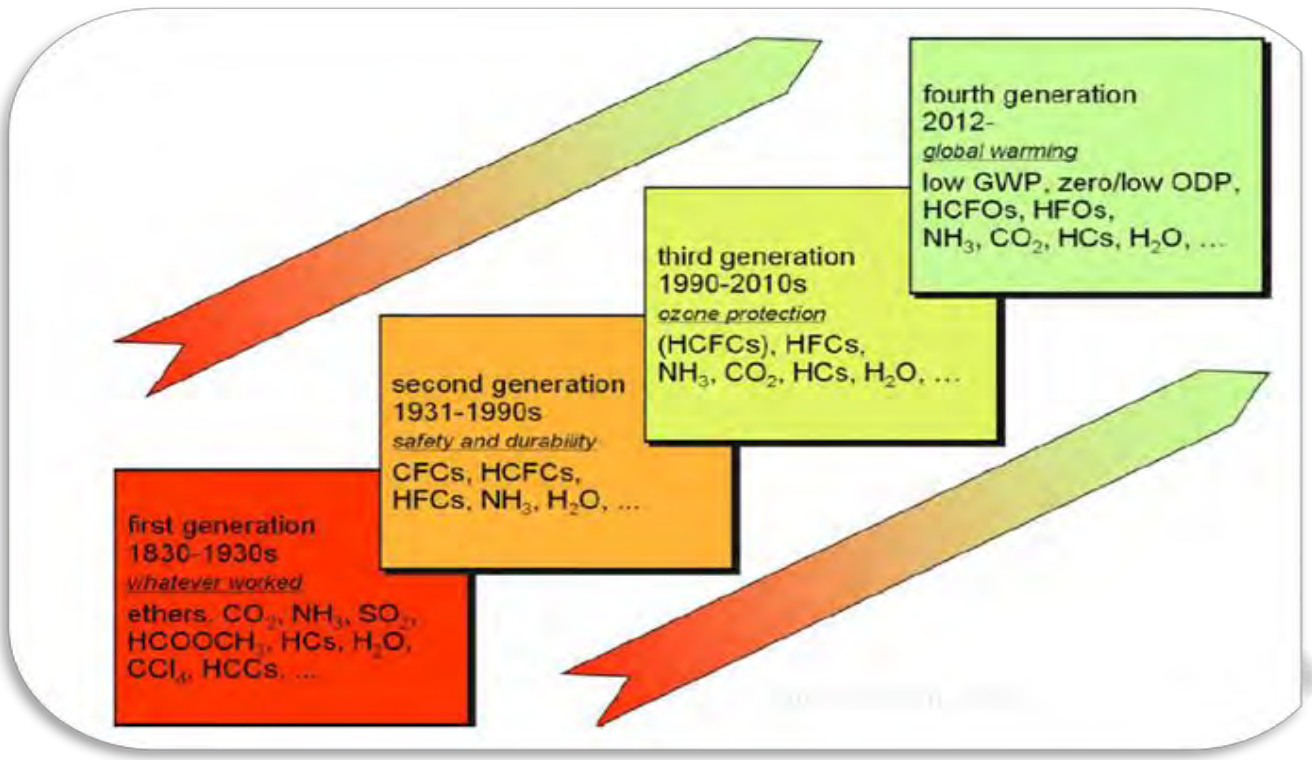

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Table of Contents

REFRIGERATION CLASSIFICATION, PROPERTIES, AND SELECTION

1.0 Introduction to Refrigeration Principles

Since the development of the first refrigerating system, the function of refrigerant as a fluid used for heat transfer has not changed. Today, refrigerants still absorb heat and transfer it at a higher temperature and a higher pressure, usually with a phase change, as was observed in the first system. However, with the evolution and expansion of Industrial refrigeration & HVAC industry, refrigerants have also changed over the years, especially in response to safety and environmental concerns. Now the industry is moving to a new set of refrigerants developed or back to the natural refrigerants. This Engineering Bulletin will describe the benefits and challenges of the refrigerants in the market and discuss the current state as well as changes in the codes, standards and guidelines.

2.0 Changes to Industrial & Commercial Refrigeration & the HVAC

The industry is going through significant changes as public is getting educated on environmental impact, risk of refrigerant releases, regulatory compliance and evaluating the effect of greenhouse gases on climate change. Be aware that refrigerants are only part of the story. In 2013, fluorinated gases, which include HFCs, accounted for ~3% of U.S. greenhouse gas emissions (direct effect), **while carbon dioxide, which is emitted from fossil fuel burning power plants (indirect effect), accounted for 82% of U.S emissions**, as shown in the Figure 1 below [0,3].

To reduce emissions of greenhouse gases there is the need to not only find new low Global Warming Potential(GWP) refrigerants but also to design equipment that is more energy efficient to minimize the consumption of electricity, most of which is generated by burning fossil fuels, leading to the emissions of carbon dioxide. The total electricity consumption of the equipment including that of the compressors, fans, and pumps must be considered.

The appropriate sizing of equipment is important to closely match the capacity to load and avoid excessive compressor cycling. **Any factor that increases energy usage contributes to the indirect effect that equipment operation has on climate change. In other words, selecting low GWP refrigerants with higher energy consumption does not reduce climate change**. In addition, the U.S. Department of Energy is increasing minimum energy efficiency requirements for air conditioning and refrigeration systems [0,2]

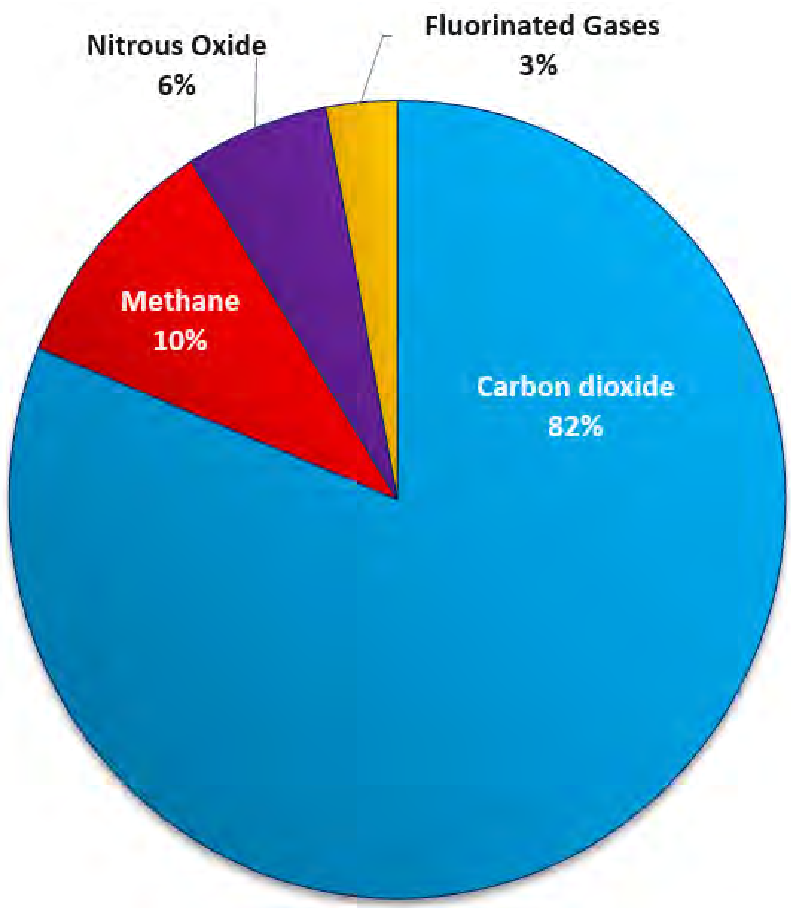


Figure 1: Overview of U.S. Greenhouse Gas Emissions(%) in 2017 [0,3]

(Total Emissions in 2017 = 6,457 Million Metric Tons of CO_2 equivalent. Percentages may not add up to 100% due to independent rounding)

3.0 Historical Perspective

Refrigerants undergo cyclic changes. They consist of substances that ought to be essentially volatile; evaporate and condense at desired temperatures at acceptable pressures. Consequently, the development of refrigerants began as a search for suitable volatile substance [5].

The development of refrigerants can be divided into three specific stages –

1. Refrigerants before the development of CFCs
2. The synthetic fluorocarbon (FC) based refrigerants
3. Refrigerants after the stratospheric ozone layer depletion

3.1 Refrigerants before the Development of CFCs

Water was one of the earliest substances used as refrigerants, although, not in a closed system. It was the first refrigerant to be used in a continuous refrigeration system by William Cullen (1710 – 1790) in 1755. The production of low temperatures by the evaporation of ethyl ether was first observed in 1748 by Williams Cullen while Oliver Evans (1755 -1819) suggested the use of a volatile fluid in a closed cycle to produce ice from water. Ethyl ether, after some developments, was used several years as a refrigerant for ice making. It was gradually replaced by ammonia and carbon dioxide due to its high normal boiling point, toxicity, and flammability.

Carbon dioxide compressor was introduced in 1866, by the T. S. C. Lowe (1832 – 1913). Due to the non-toxic and non-flammable effects of CO_2, it was used mainly for marine refrigeration. It was also used for refrigerating purposes on land. It was used successfully for many years, and then replaced by CFCs. However, it is gradually making a 'comeback' due to the ozone depletion issues associated with CFCs and similar refrigerants.

The introduction of ammonia as a refrigerant was one of the milestone events in history of refrigerants. The first patent for ammonia compressor was granted to David Boyle (1837 – 1891) in 1872. However, Carl von Linde (1842 – 1934) is credited for perfecting the ammonia refrigeration technology and commercialization of ammonia systems. Ammonia is considered one of the most significant refrigerants due to his pioneering efforts. Although ammonia is toxic, incompatible with some common materials, slightly flammable and has a pungent smell; it has remained a formidable refrigerant in the industry due to its other excellent properties.

Sulphur dioxide was introduced as a refrigerant in 1874 by Raoul Pictet (1846 – 1929). Despite its auto-lubricating, non-flammable and flame extinguishing effects, it produces a highly corrosive acid, sulphuric acid (H_2SO_4) in the presence of water vapor. Although the corrosive effect was checked by using airtight sealed compressors, after many years of use in appliances, it was replaced by CFCs.

Other fluids tried and displaced due to different reasons include methyl chloride, ethyl chloride, Isobutane, propane, gasoline, etc.

3.2 Synthetic Fluorocarbon (FC)- based Refrigerants

Due to the hazardous effects associated with the available refrigerants, Thomas Midgley, Jr. alongside his associates, took up the challenge of finding a more suitable refrigerating substance. This search was carried out by a systematic study of the periodic table. After the elimination of the unstable, toxic, and inert gases based on their very low boiling points, and those elements with insufficient volatility, eight potential elements were identified: Carbon, Nitrogen, Oxygen, Sulphur, Hydrogen, Fluorine, Chlorine, and Bromine. These elements were clustered at an intersecting row and column of the periodic table with fluorine at the intersection. From their study, they discovered that flammability decreases from the left to the right for the eight elements; toxicity decreases from the heavy elements at the bottom to the lighter elements on top, and every known refrigerant then was made from the combination of the eight "Midgley" elements. A wide range of refrigerants have been developed by the partial replacement of the hydrogen atoms in hydrocarbons by fluorine and chlorine. Their study showed that the fluorination and chlorination of hydrocarbons can be varied to obtain desired features such as boiling points, reduced toxicity and flammability effects.

The first product of this study was the development of dichlorodifluoromethane (CFC), with the chemical formula CCl_2F_2 in 1930. This refrigerant was obtained by replacing the four Hydrogen atoms of methane (CH_4) with two Chlorine and two Fluorine atoms and was later known as R-12 [0, 5].

With the advent of R-12, the industry had a chemical which was low in toxicity, non-flammable, compatible with mineral oil and very stable. The use of this refrigerant finally led to the development of additional fluorocarbons for specific applications. In time, R-11 (trichlorofluoromethane) became the primary refrigerant in large water-cooled chillers, R-12 in household refrigerators and mobile air conditioning, while R-22 (chlorodifluoromethane) was used in unitary equipment for residential and commercial applications.

Blends of fluorochemicals were also developed for commercial refrigeration such as R-500, which is a mixture of R-12 and R-152a.

In the 1970s, it was found that chlorofluorocarbons (CFCs) were remaining in the atmosphere much longer than anyone expected. The CFCs would eventually be carried up to the lower levels of the stratosphere where they would react with the ozone found there and break down the protective ozone layer that shields the earth from harmful ultraviolet radiation from the sun. As a result of this discovery, the members of the United Nations developed the Montreal Protocol on Substances that Deplete the Ozone Layer, which called for the phase-out of ozone-depleting substances. The halogenated refrigerants (those compounds that include fluorine or chlorine) were divided into three categories based on their ozone depletion potential. The chlorofluorocarbons, such as CFC-11 and CFC-12, with the longest atmospheric lifetime and highest ozone depletion potential were initially phased out, followed by the hydrochlorofluorocarbons such as HCFC-22(R-22) and HCFC-123(R-123).

R-22 was used as an organic & non-toxic competitor of ammonia in industrial refrigeration for many years and there are still a lot of industrial facilities that operate with R-22. Later, in the developed countries, production and consumption of HCFCs was proposed to be reduced 90% from the base level on January 1, 2015 [3]. Production and consumption of HCFCs for use in new equipment will be prohibited on January 1, 2020, with 0.5% of the baseline being allowed for servicing of existing refrigeration and air-conditioning equipment until January 1, 2030. On January 1, 2030, production and consumption of HCFCs will be prohibited. Some nations accelerated this schedule. Developing countries, as defined in Article 5 of the Montreal Protocol, have an additional 10 years to phase out the HCFCs. The actions exercised under the Montreal Protocol have resulted to decrease in the atmospheric abundance of controlled ozone- depleting substances (ODSs) and are aiding the return of the ozone layer toward 1980 levels.

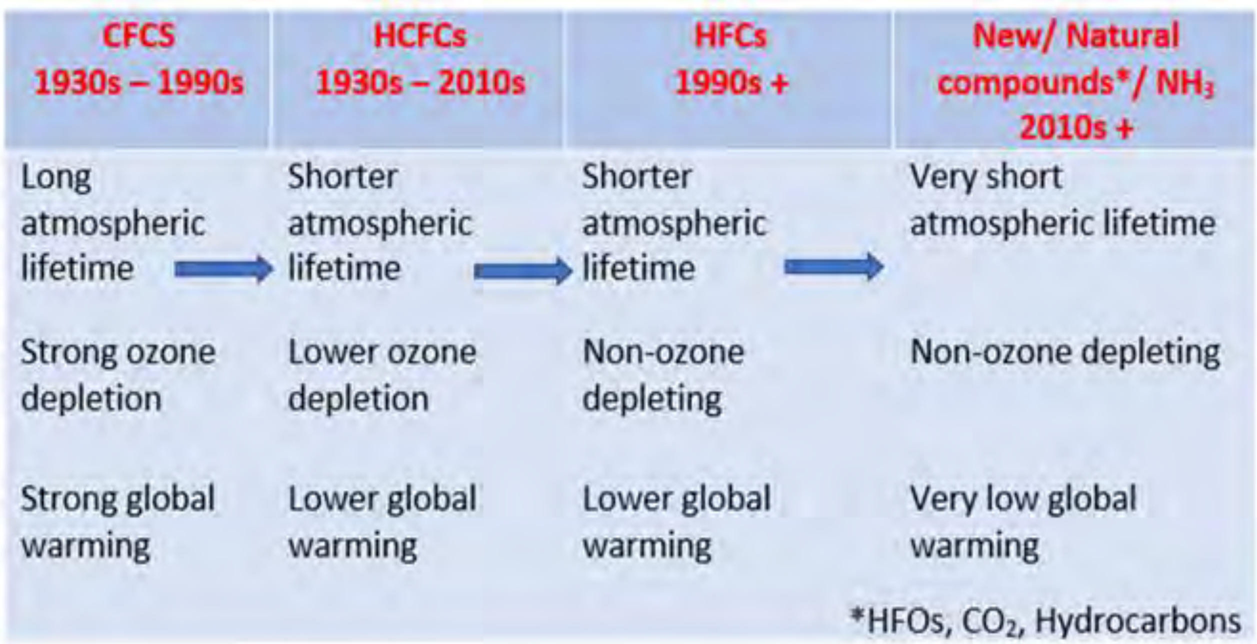
3.3 Refrigerants after the Stratospheric Ozone Layer Depletion

After the discovery of the ozone-layer depleting effect of CFCs, the search for 'safe' refrigerants continued. Safety being defined as not only immediate personal safety issues, such as toxicity and flammability, but also the long-term environmental issues, such as global warming potential and ozone layer depletion. To meet the safety requirements, the replacing refrigerants are expected to be non-ODS, thus the options were limited to the use of either zero ODP synthetic refrigerants or natural substances.

Using the first option, hydrofluorocarbons (HFCs) was introduced. The HVAC industry transitioned to hydrofluorocarbons, such as HFC-134a and HFC-410A, which no not deplete the ozone layer and thus, are not part of the phase-out under the Montreal Protocol.

Although HFCs are non-ozone depleting, but like the replaced CFCs, they are greenhouse gases (so-called because they trap heat in the atmosphere). The Kyoto Protocol, an international agreement linked to the United Nations Framework Convention on Climate Change (UNFCC), specifically identified these refrigerants and called for reductions in emissions of greenhouse gases, including HFCs. Although the Kyoto Protocol has expired, negotiations are underway for a new international agreement to limit greenhouse gases under the UNFCC. Additionally, several proposals have been introduced to revise the existing Montreal Protocol for a global HFC phase-down agreement. In the meantime, some countries and regions are passing regulations limiting the use of HFCs to reduce their emissions of greenhouse gases. Although their use in the future may be limited, HFCs (e.g. HFC-134a, HFC-410A) are not being phased out. The HFCs are the best energy-efficient refrigerants for some applications, and to meet the demand for air conditioning and refrigeration, HFCs will be continually required. The chart in Figure 2 shows the transition in refrigerants since 1930.

The fourth generation of refrigerants consists of hydrocarbons, re-introduction of CO_2, and hydrofluoroolefins (HFOs), which were developed in the last five years. These refrigerants were introduced using the second safety option of using natural refrigerants. They all present the industry with new challenges.



CFCS 1930s – 1990s	HCFCs 1930s – 2010s	HFCs 1990s +	New/ Natural compounds*/ NH_3 2010s +
Long atmospheric lifetime	Shorter atmospheric lifetime	Shorter atmospheric lifetime	Very short atmospheric lifetime
Strong ozone depletion	Lower ozone depletion	Non-ozone depleting	Non-ozone depleting
Strong global warming	Lower global warming	Lower global warming	Very low global warming

*HFOs, CO_2, Hydrocarbons

Figure 2: Chart showing the Evolution of Refrigerants
(Source: Honeywell Company)

4.0 Standards and Codes

The standards of industry play a significant role in worldwide refrigerant regulation and application. Although ASHRAE Standard-34, which defines refrigerant safety classifications has been updated, ASHRAE Standard-15, the equipment safety standard that depends on and refers to these classifications, is yet to be revised. Revisions to ASHRAE Standard-15 are in progress. The equipment safety standard must be amended before any updates to the model codes can be made.

Following is a discussion of some of the changes to these standards and how they will affect the use of refrigerants in the HVAC industry.

4.1 ASHRAE Standard-34, Designation and Safety Classification of Refrigerants

ASHRAE Standard-34 assigns the refrigerant numbers and determines the appropriate safety classification based on toxicity and flammability data.

ASHRAE defines two safety classifications for toxicity: Class A signifies refrigerants that are of lower toxicity and Class B signifies refrigerants that are of higher toxicity. There are three classifications and one sub- classification for flammability. The three primary flammability classes are: Class 1, consists of refrigerants that do not propagate a flame when tested based on the standard; Class 2 is made up of refrigerants that are of lower flammability; while Class 3 is for highly flammable refrigerants, like the hydrocarbons. The safety classification matrix, shown in Figure 3, was recently updated to include a new flammability Subclass 2L, for flammability Class 2 refrigerants that burn very slowly. Some HFOs that have very low global warming potential, are mildly flammable and are classified as A2L. This indicates they are of lower toxicity and have a low burning velocity of ≤ 10 cm/sec. Burning velocity is defined as the rate at which flame front propagates relative to the unburned gas.

Following is a description of some of the low GWP refrigerants and other alternative refrigerants being considered by the industry, along with their ASHRAE Standard-34 classifications and direct GWP values are outlined below.

4.1.1 HFC-32 (Safety Class A2L)

It is a component of R-410A and is being considered as an interim substitute for R-410A in unitary equipment. This mildly flammable refrigerant has a higher vapor pressure than R-410A. With a GWP value of 675, the global warming potential of HFC-32 is lower than that of R-410A (GWP of 2088) but still too high for long term use under current regulatory proposals.

4.1.2 HFO-1234yf (Safety Class A2L)

It was first commercialized as a replacement for HFC-134a in automobile air conditioning. This refrigerant is of lower toxicity and mildly flammable, with a GWP value of 0.31.

4.1.3 HFO-1234ze(E) (Safety Class A2L)

It is being evaluated for use in new chiller applications to replace HFC-134a and is planned for introduction in Europe in 2015. Due to the mildly flammable classification, it is suitable for new chiller applications but cannot be used in existing equipment. This refrigerant has a low GWP value of 0.97.

4.1.4 HFO-1233zd(E) (Safety Class A1)

It is of lower toxicity and non-flammable. This refrigerant was developed for and is being used as a blowing agent for polymer foams. This refrigerant has a GWP value of 1.34 and is also being evaluated for use in new chiller applications as a low-pressure refrigerant that can operate in a vacuum under normal air conditioning conditions. This application would require the use of a purge to remove non-condensable from the closed cycle.

4.1.5 Hydrocarbons

Propane (R-290) with a GWP value of 3.3, and isobutane (R-600a) with a GWP value of 3.0, have very good thermodynamic properties, but are highly flammable and are listed as Safety Class A3. Other than in industrial applications, their use is restricted to hermetically sealed systems with very small charge sizes.

4.1.6 Carbon dioxide (R-744 or CO_2)

It works well in some applications, particularly refrigeration, but its high pressures limit its use elsewhere. Listed as Safety Class A1, carbon dioxide is currently being used in commercial refrigeration systems in northern Europe and in marine container units. The GWP value of carbon dioxide is 1.0.

4.1.7 Ammonia (R-717 or NH_3)

Globally, there is a growing interest in ammonia as a refrigerant, both by itself, and in cascade refrigeration systems with carbon dioxide and other secondary system designs. Regulatory oversight on CFC, HCFC, and other synthetic refrigerants, have re-focused attention on ammonia to emerge as one of the widely used refrigerants that, when released to the atmosphere, does not contribute to ozone depletion and global warming. New technology and equipment are leading to low and reduced ammonia charge designs. The application of these new low charge systems and packages creates an opportunity to use ammonia systems in a broad range of industrial, commercial and indirect space conditioning applications that would not have been considered with traditional designs. These changes will require industry to provide proper recommendations for both design safety and guidance for regulatory and code agencies.

Ammonia is an efficient and popular refrigerant due to its superior thermodynamic properties and low cost. Ammonia is environmentally benign, having zero GWP and zero ODP. It is hazardous when released in large quantities due to its toxicity. However, ammonia does exhibit a unique refrigerant characteristic due to its pungent odor. Persons exposed to an ammonia release will not voluntarily stay near concentrations that are health threatening. Although ammonia will burn in a narrow range of high concentrations, it is difficult to ignite and will not support combustion after the ignition source is withdrawn. Ammonia has an ASHRAE flammability class of 2L, low flammability.

Flammability			
	Higher Flammability	**A3** R-290 Propane R-600a Isobutane	**B3**
	Lower Flammability	**A2** R-152a	**B2**
		A2L* R-32 R-1234yf R-1234ze(E)	**B2L*** R-717 Ammonia
	No Flame Propagation	**A1** R-22 R-134A R-410A R-1233zd(E) R-404A R-407C R-507A R-744 Carbon Dioxide	**B1** R-123
		Lower Toxicity	Higher Toxicity
		Toxicity	
		*A2L and B2L are lower flammability refrigerants with a minimum burning velocity of ≤10 cm/s.	

Figure 3: Safety Classification of Refrigerants (Source: ASHRAE Standard-34, 0)

4.2 ASHRAE Standard-15, Safety Standard for Refrigeration Systems

This standard specifies safe design, construction, installation, and operation of refrigeration systems. This standard reference the safety classifications in ASHRAE Standard-34. The committee responsible for maintaining ASHRAE Standard-15 has established an ad hoc working group to develop revisions to the standard to address the use of mildly flammable refrigerants listed in ASHRAE Standard-34 as A2L. The first draft was circulated for an advisory public review in 2011 to obtain comments from industry representatives outside the committee. The committee is now preparing a revised document, taking into consideration the comments received along with recently completed risk assessments, potential ignition sources, ventilation requirements and leak detector reliability.

Currently, ASHRAE Standard-15-2013 prohibits the use of flammable refrigerants in systems for human comfort where leaked refrigerant will enter the occupied space, as emphasized in sections 7.5.2 and 7.5.3 stated below. Section 7.5.2, Application for Human Comfort stipulates that Group A2, A3, B1, B2 and B3 refrigerants shall not be used in high-probability systems for human comfort while Section 7.5.3, Higher Flammability Refrigerants states that Group A3 and B3 refrigerants shall not be used except where approved by the authority having jurisdiction. Refrigerants listed as A2L in ASHRAE 34 are listed as Class 2 in the International Mechanical Code (IMC) because requirements for the use of Class A2L refrigerants are still in development and its earliest expected appearance in IMC is in 2021. As a result, ASHRAE Standard has no provisions for refrigerants with a flammability classification of 2L, therefore refrigerants in this class must be treated as Class 2 [0].

5.0 Common Category of Refrigerants

Refrigerants in vapor compression refrigeration systems can be classified as pure fluids and mixtures. Pure fluids are further categorized as halogenated hydrocarbons or natural compounds. Early refrigerants used in vapor compression refrigeration applications were halogenated hydrocarbons, predominately made up of chlorofluorocarbons (CFCs), Hydrochloro-fluorocarbons (HCFCs) and Hydrofluorocarbon (HFCs). The different classes of refrigerants are schematically represented in Figure 4 below.

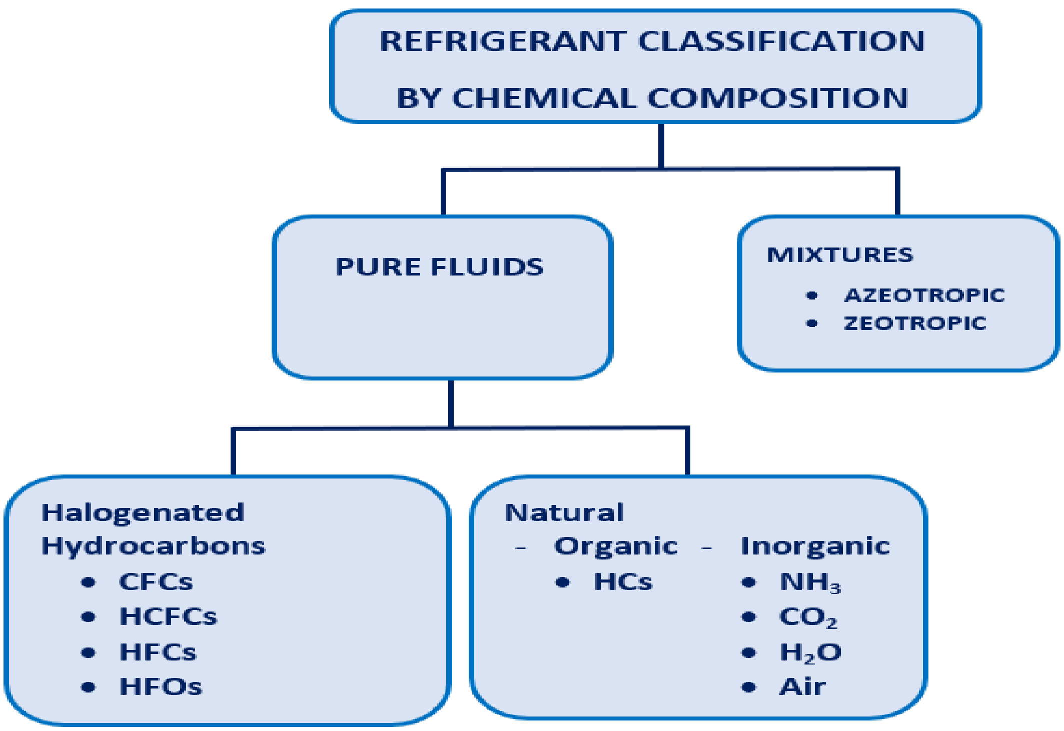


Figure 4: Classification of Refrigeration

5.1 Chlorofluorocarbons (CFCs)

The acronym CFC represents chlorofluorocarbons and refers to the family of refrigerants containing chlorine, fluorine, and carbon. Since they contain **NO** hydrogen, CFCs are chemically very stable, even when released into the atmosphere. They are found to be long-lived in the atmosphere. In the lower atmosphere, the CFC molecules absorb infrared radiation and contribute to atmospheric warming or have very high global warming potential. Once in the upper atmosphere, the CFC molecule breaks down to release chlorine that destroys ozone and, consequently damages the atmospheric ozone layer. Ozone found high up in the atmosphere, called "stratospheric ozone", 6.2 miles or about 33,000 ft (10 km) above earth surface, helps filter out damaging ultraviolet radiation from the sun. The ozone layer acts like a giant sunshade that shields the earth from the sun's harmful ultraviolet radiation.

This phenomenon of Ozone Layer Depletion was first observed in 1974 and was largely attributed to chlorine and bromine containing CFC compounds. Owing to harmful effects of ozone layer depletion on a global level, it has been agreed by the global community (under Montreal Protocol - a landmark International agreement designed to protect the stratospheric ozone layer) to phase out the ozone depleting substances (ODS). The manufacture of CFC refrigerants was discontinued after December 31, 1995.

Prior to the environmental issues of ozone layer depletion, the most widely used CFC refrigerants were: R-11, R-12, R-113, R-114, R-115, etc. Of these, R-11 was primarily used with centrifugal compressors in the air conditioning applications while R-12 was used primarily in commercial industrial refrigeration and cold storage applications in the food and pharmaceutical industries.

5.2 Hydrochloro-fluorocarbons (HCFCs)

Researchers found that modifying the chemical compound of CFCs, by substituting a hydrogen atom for one or more of the chlorine or fluorine atoms, resulted in a significant reduction in the life of the molecule and thus, reduced the negative environmental impact it may have.

This category of refrigerants contains both chlorine and hydrogen. Even though they contain chlorine, which is damaging to the ozone layer, they also contain hydrogen which makes them chemically less stable when they enter the atmosphere. These refrigerants decompose when released in the lower atmosphere so very little ever reaches the ozone layer. HCFCs, therefore, have a lower ozone-depletion potential. The most widely used HCFC refrigerants are: R-22 and R-123. R-22 finds its use in most residential and small commercial air conditioning systems whereas R-123 has wide applications in low pressure centrifugal chillers. HCFC production for use in new equipment in developed countries is mandated to cease in the year 2020 with total halt to manufacturing and importing mandated by year 2030.

5.3 Hydrofluorocarbon (HFC)

HFC refrigerants contain no chlorine. Although these refrigerants have an ozone-depletion potential of zero, they still contribute to the global warming problem. Two HFCs that are replacing CFC-12 and HCFC-22 are HFC-134a (Tetrafluoromethane CF_3CH_2F) and HFC-410A (HFC-32 & HFC-125).

Hydrofluorocarbons (HFCs), are not regulated by international treaty and are considered, at least for the interim, to be the most environmentally benign compounds in HVAC refrigeration systems.

Note that it is the chlorine that makes a substance ozone-depleting; CFCs and HCFCs (partly) are a threat to the ozone layer but HFCs are not.

Generally, all halogenated refrigerants used in refrigeration and air conditioning applications are non-toxic and non-flammable.

6.0 Refrigerant Number Designation

Since many refrigerants exist and have a very complex chemical name, a numbering system has been adopted to designate various refrigerants. From the number, one can obtain some useful information about the type of refrigerant, its chemical composition, molecular weight, etc.

The first step, and one that will provide a valuable way to ascertain the results, is to understand the prefixes CFC, HCFC and HFC.

Prefix	Meaning	Atoms in the Molecule
CFC	Chlorofluorocarbon	Cl, F, C
HCFC	Hydrochlorofluorocarbon	H, Cl, F, C
HFC	Hydrofluorocarbon	H, F, C
HC	Hydrocarbon	H, C
HFO	Hydrofluoroolefins	H, F, C

Compounds used as refrigerants may be described using either the appropriate prefix above or with the prefixes "R-" signifying "Refrigerant". Thus, CFC-12 may also be written as R-12 or Refrigerant 12.

6.1 Decoding the Refrigerant Numbering Scheme

Having understood that prefixes describe the kinds of atoms present in a molecule, the next step is evaluating the number of each type of atom.

7.1.1. The key to the code is to add 90 to the number. The result of this addition yields three digits which represents the number of the carbon, hydrogen, and fluorine atoms respectively. Example, for CFC-12, 90 + 12 yields 102. This indicates there is one carbon, no hydrogen, and two fluorine atoms.

Example 1:

Number of Atoms in Chlorofluorocarbon, CFC-12				
Code = 12	12 + 90 =	**1**	**0**	**2**
		C	**H**	**F**

7.1.2. The remaining bonds not accounted for are occupied by Chlorine atoms. All these refrigerants are saturated, that is, they contain only single bonds. The number of bonds available in a carbon-based molecule is 2C + 2 (i.e. for 1 carbon atom, there are 4 bonds; for 2 carbon atoms there are 6 bonds and for 3 carbon atoms there are 8 bonds).

7.1.3. Chlorine atoms occupy bonds remaining after the F and H atoms have been assigned single bonds. This is illustrated in Example 2 below.

Example 2:

Number of Bonds and Chlorine Atoms in Chlorofluorocarbon, CFC-12				
Code = 12	12 + 90 =	**1**	**0**	**2**
		C	H	**F**
No. of bonds =		(2 * 1) + 2 =	**4 bonds**	
No. of Cl atoms =		4 – (0 + 2) =	**2 atoms**	

7.1.4. A suffix of a lower-case letters a, b, or c indicates increasingly unsymmetrical isomers.

Example 3:

Chemical Formula of HCFC-141b				
Code = 141	141 + 90 =	**2**	**3**	**1**
		C	**H**	**F**
No. of bonds =		(2 * 2) + 2 =	**6 bonds**	
No. of Cl atoms =		6 – (3 + 1) =	**2 atoms**	
$C_2H_3FCl_2$				

The number of chlorine atoms was determined by first ascertaining the total number of bonds and subtracting the number taken up by hydrogen and fluorine atoms.

Consequently, HCFC-141b has 2C, 3H, 1F, and 2Cl or the chemical formula for HCFC -141b is therefore $C_2H_3FCl_2$ as shown in Example 3 above.

Notice that the HCFC designation (**h** ydro **c** hloro **f** luoro **c** arbon) is a good double-check on the decoding; this molecule does, indeed, contain H, Cl, F, and C.

The "**b**" at the end describes how these atoms are arranged; different "isomers" contain the same atoms, but they are arranged differently. The letter designation for isomers is discussed below in another example.

Example 4:

Chemical Formula of HFC-134a				
Code = 134	134 + 90 =	**2**	**2**	**4**

		C	H	F
No. of bonds =		(2 * 2) + 2 =	**6 bonds**	
No. of Cl atoms =		6 – (2 + 4) =	**0**	
		$C_2H_2F_4$		

There are 6 bonds. However, there are no bonds left after F and H, so there are no chlorine atoms. Thus, chemical formula for HFC-134a is $C_2H_2F_4$

Similarly, the prefix is accurately designated, HFC (**h** ydrō **f** luoro **c** arbon), so it contains only H, F, and C, but no chlorine.

Letter "a" stands for isomer, e.g. molecules having same chemical composition but different atomic arrangement. The "a" suffix indicates that the isomer is unbalanced by one atom, giving 1, 1, 1, 2-Tetrafluoroethane. R-134 without the "a" suffix would have a molecular structure of 1, 1, 2, 2-Tetrafluoroethane—a compound not especially effective as a refrigerant.

6.2 Assigning a Chemical Name to the Refrigerant Number

This method of designating a refrigerant by number can be reversed. The following rules apply:

- Let the refrigerant number be X
- From the chemical formula derive a number in order of Carbon, Hydrogen, Fluorine atoms.
- Find X by subtracting 90 from the derived number

Example 5:

Refrigerant number for $CHClF_2$				
Atom	C	H	F	Cl
Number	1	1	2	1
C H F		**1 1 2**		
Refrigerant number, **X** =		112 – 90 = **22**		
Refrigerant can be designated as **HCFC-22**				

Example 6:

Refrigerant number for $CHCl_2CF_3$				
Atom	C	H	F	Cl
Number	2	1	3	2
C H F		**213**		
Refrigerant number, **X** =		213 – 90 = **123**		
Refrigerant can be designated as **CFC-123**				

Note:

Any molecule with only 1C (e.g., CFC-12) will have a 2-digit number, while those with 2C or 3C will have a 3-digit number.

6.3 Inorganic or Natural Refrigerants

Inorganic refrigerants do not deplete the ozone layer and are commonly used in industrial applications. They are designated by number 7 followed by the rounded-off molecular weight of the refrigerant.

For example:

Inorganic/Natural Refrigerant	Molecular Weight	Designation
Ammonia, NH_3	17	**R-717**
Carbon dioxide, CO_2	44	**R-744**
Water, H_2O	18	**R-718**

Ammonia(R-717) is one of the oldest known refrigerants that has very good thermodynamic, thermo-physical and environmental properties. However, it is toxic and not compatible with some common construction materials, such as copper. This incompatibility somewhat limits its application. Other natural refrigerants, for instance, carbon dioxide(R-744) have some specific problems due to their eco-friendliness, they are being studied widely and are likely to play a prominent role in the future. Water(R-718) is used as a refrigerant in the absorption-based refrigeration systems.

6.4 Mixtures

Several refrigerants are made up of blends or chemically prepared mixtures of refrigerants. These are called "Azeotropic" mixtures (designated by 500 series) and "Zeotropic" refrigerants (e.g. non-azeotropic mixtures designated by 400 series).

6.4.1 Azeotropic mixtures

An azeotropic is a mixture of multiple components of volatilities (refrigerants) that do not change volumetric composition or saturation temperature when they evaporate or condense at a constant pressure. In simpler terms azeotropic blends act as single substance, are very stable, i.e., difficult to separate and have a negligible glide. These can be charged in vapor or liquid state. These refrigerants are designated by 500 series.

For example:

A. **R-500**: Mixture of R-12 (73.8 %) and R-152a (26.2%)
B. **R-502**: Mixture of R-22 (48.8 %) and R-115 (51.2%)

C. **R-503**: Mixture of R-23 (40.1 %) and R-13 (59.9%)
D. **R-507a**: Mixture of R-125 (50%) and R-143a (50%)

A near azeotropic is a mixture of refrigerants whose characteristics are near those of an azeotropic. These refrigerants are so named because the change in volumetric composition or saturation temperature is rather small, e.g., 1 - 2°F.

6.4.2 Zeotropic mixtures

Zeotropic or non-azeotropic, including near azeotropic, shows a change in composition due to the difference between liquid and vapor phases, leaks, and the difference between charge and circulation. These can be separated more easily compared to azeotropic mixtures, have some glide and can only be liquid charged.
A shift in composition causes the change in evaporating and condensing temperature/pressure. The difference in dew point, and bubble point during evaporation and condensation is called glide, it is expressed in °F. Near azeotropic has a smaller glide than zeotropic. The midpoint between the dew point and bubble point is often taken as the evaporating and condensing temperature for refrigerant blends. The designated numbers are 400 series.
For example:

A. **R-404a**: Mixture of R-125 (44%), R-143a (52%) and R-134a (4%)
B. **R-407a**: Mixture of R-32 (20%), R-125 (40%) and R-134a (40%)
C. **R-407b**: Mixture of R-32 (10%), R-125 (70%) and R-134a (20%)
D. **R-410a**: Mixture of R-32 (50%) and R-125 (50%)

6.5 Hydrocarbons

Examples of hydrocarbon refrigerants are outlined below.

A. **Propane (C_3H_8)**: R-290
B. **n-butane (C_4H_{10})**: R-600

C. **Iso-butane (C_4H_{10})**: R-600a
D. **Unsaturated Hydrocarbons**: R-1150 (C_2H_4), R-1270 (C_3H_6)

A complete discussion of the number designation and safety classification of the refrigerants is presented in ASHRAE Standard-34-1992.

7.0 REGULATIONS

Environmental concerns about depletion of the Earth's protective stratospheric ozone layer and the effect of CFC on this depletion have resulted in a halt in CFC production since December 31, 1995 and supplies of CFC refrigerant for equipment servicing can ONLY come from recovery, recycling, and reclamation.

On September 16, 1987, the European Economic Community and 24 nations, including the United States, signed a document known as the **Montreal Protocol**. It is an agreement to restrict the production and consumption of CFCs in the 1990s.

The Clean Air Act amendments signed into law in the United States on November 15, 1990 deal with two important issues: the phaseout of CFCs and the prohibition of deliberate venting of CFCs and HCFCs.

In February 1992, President Bush called for an accelerated ban of CFCs in the United States. In late November 1992, representatives of 93 nations meeting in Copenhagen agreed to phase out CFCs beginning January 1, 1996.

While HFCs and PFCs are not ozone-depleting substances, they have been identified as potent greenhouse gases with long atmospheric lifetimes and are part of the six gases included in the **Kyoto Protocol**. The Kyoto Protocol calls for the aggregate emissions of the six gases to be reduced to an average of 5% below 1990 levels in developed countries in the 2008-2012 timeframe. The HCFC production for use in new equipment in developed countries will cease in 2020 with total halt to manufacturing and importing mandated by 2030.

7.1 Implementation of HCFC Refrigerant Phase-out in the United States

Year to be	Clean Air Act Regulations

implemented	
2010	No production and no importing of HCFC R-22 except for use in equipment manufactured prior to January 1, 2010. (Consequently, there will be no production or importing of new refrigeration equipment using R-22. Existing equipment must depend on stockpiles or recycling for refrigerant supplies)
2015	No production and no importing of any HCFC refrigerants except for use in equipment manufactured before January 1, 2020
2020	No production or importing of HCFC R-22. (Since this is the cutoff date for new equipment using HCFC refrigerants other than R-22, this should end the installation of new chillers using R-123).
2030	No production or importing of any HCFC refrigerant. (While it is anticipated that most of the packaged equipment using R-22 will have been replaced by this date, there will still be a significant number of water chillers using R-123 still in operation. These chillers must depend on stockpiles or recycling for refrigerant supplies).

Hydro fluorocarbons (HFCs), are not regulated by international treaty and are considered, at least for the interim, to be the most environmentally benign compounds and are now widely used in HVAC refrigeration systems.

8.0 Recovery, Recycling and Reclamation of Refrigerants

EPA standards for recovery, recycling, and reclamation of refrigerants include the following key guidelines stated below:

8.1 Use of CFC

As of December 31, 1995, CFCs can no longer be legally manufactured or imported into the United States. Supplies of CFC refrigerant for equipment servicing can ONLY come from recovery, recycling, and reclamation.

8.2 Recycling

It is defined as the cleaning of refrigerant for reuse by oil separation, and single, or multiple passes through moisture absorption devices.

8.3 Reclamation

It is defined as processing refrigerant to a level equal to new product specifications as determined by chemical analysis (testing to ARI-700 standards).

8.4 Recovery

This is defined as transferring refrigerant in any condition from a system to a storage container without testing or purifying the refrigerant in any way (according to ARI -740 standards). Recovery of refrigerants is necessary to provide adequate refrigeration supplies for service applications after the production bans, as well as to prevent venting to the atmosphere and the resulting ozone depletion. Since, November 14, 1994, technicians servicing refrigeration hardware must be certified in refrigerant recovery and the sale of CFC and HCFC refrigerants has been restricted to technicians certified in refrigerant recovery.

8.5 Disposal of any Air Conditioning and Refrigeration Equipment

EPA requires recovering the refrigerant before you dispose any air conditioning and refrigeration equipment or any other appliance containing CFC, HCFC, and HFC refrigerants. Venting of substitutes for CFC and HCFC refrigerants, including HFC-134a, is now illegal and mandatory recovery is required for all refrigerants (including HFCs).

8.6 Violation of Clean Air Act

Violation of the Clean Air Act, including the knowing release of refrigerant during the maintenance, service, repair, or disposal of appliances, can result in fines up to $32,500 per day per violation. An award of up to $10,000 may be paid to any person supplying information that leads to a penalty against a technician who is intentionally venting refrigerant.

For information concerning regulations related to stratospheric ozone protection, please visit website: http://www.epa.gov/ or call the EPA Stratospheric Ozone Hotline: 800- 296-1996 (10am-4pm eastern).

9.0 CURRENT REFRIGERANT OPTIONS

Several refrigerants are used in the refrigeration and air conditioning sector that have differing impacts on the environment. The common theme is that they all need to be contained. This is to ensure efficient operation and minimal impact on the environment, i.e., “responsible use”. Based on the HCFC refrigerant phase-out schedule, there will be no production or importing of new refrigeration equipment using R-22 after January 1, 2010. The choices of refrigerants include:

9.1 HFCs (hydrofluorocarbons)

HFCs are the leading candidates for chlorine-free, non-toxic, low to nonflammable refrigerants which may be applied in any of the new installations. The refrigerants in this category which can practically being considered for a large majority of air conditioning applications include R-134a, R-407C and R-410A. Their main characteristics are summarized in the table below.

Summary of the Major Characteristics of R-134a, R-407c and R-410a

Properties	R-134a	R-407c	R-410a
Glide (K)	0	6	0.2
100-year GWP	1300	1530	1730
Pressure @ 50°C bar Abs	13.2	19.6	30.9
Critical Temperature (°C)	101	87	72
Compressor Displacement (%R-22)	54% larger	About same	30% lower
Pressure Drop (%R-22)	~30% higher	About same	~ 30% lower

Evaporator Heat Transfer (%R-22)	~10% lower	~10% lower	~ 35% higher
System Cost	Higher	About same	Potentially lower

9.1.1 R-134a

R -134a has the best theoretical performance and compressors optimized for it give very good COPs. However, due to its lower pressure, about 50% larger displacement is required and this can make any compressor more costly when a larger body or shell size is needed. Also, it needs larger tubing and components resulting in higher system cost.

R-134a has been very successfully used in screw chillers where the short length of pipes minimizes costs associated with larger tubing. R-134a also finds a niche where extra high condensing temperatures are needed and in many transport applications.

9.1.2 R-407c and R-410a

Both R-407c and R-410a are non-azeotropic HFC refrigerant blends. Non-azeotropic blends (400 series) means that they experience a temperature glide during evaporation and condensation. In contrast, a pure refrigerant or an azeotropic (500 series) refrigerant blend has a single boiling point temperature at a given pressure. However, as discussed below R-410a is a near azeotropic refrigerant.

- R-407c has properties close to those of R-22 and is for this reason is seeing extensive use world over. Its glide and heat transfer properties generally penalize the system performance, although counter flow heat exchange can deliver some benefit with plate heat exchangers.

- R-410a looks discouraging at first because of its poor theoretical performance, low critical temperature, high pressure, and non-availability (until recently) of compressors. These factors would seem to indicate a low score on most criteria. However, the refrigerant side heat transfer is about 35% better than with R-22 whereas for the other two it is poorer. The pressure drop effect in equivalent heat exchangers will be approximately 30% less.

9.1.3 R-417a

R-417a is another HFC designed primarily for retrofitting into existing R-22 systems although some OEMs have been considering it for new product. When retrofitted in a system previously optimized for R-22, the heat exchangers become effectively 5 -10% oversized. This will tend to cause an adjustment of evaporating temperature upwards and condensing temperature downwards. It is not surprising that R-417a has been reported to deliver better system COPs than R-22. A major concern is oil return when using mineral oil. Adequate oil return under all commonly encountered conditions is unproven, and users are strongly recommended to verify that proper oil levels are maintained under all conditions if R-417a is to be considered.

9.2 Hydrocarbons (HCs)

HCs have a low global warming potential, are energy efficient, but are highly inflammable. R-290 (propane) is an example. Being inflammable, the charge size is regulated by refrigeration safety standards, which establish maximum allowable charge sizes as a function of the occupancy category and air-conditioned space volume. In practice, for many applications, these charge size constraints preclude the use of flammable refrigerants for direct air conditioning systems.

9.3 Inorganic/Natural Refrigerants

9.3.1 Ammonia (R-717)

It is a non-halocarbon refrigerant and is currently widely used. The advantages of ammonia as a refrigerant are listed below.

A. It is not a contributor to ozone depletion, greenhouse effect, or global warming;
B. It is naturally released into the atmosphere from many sources;
C. It is energy efficient, and
D. It has a pungent odor that gives it a self-alarming property.

Ammonia is widely used in the food processing, cold storage and pharmaceutical industries. However, local-permitting authorities may restrict the use of ammonia due to its toxicity and flammability in some locations. Although, the advent of low charge ammonia system design is promoting the use of ammonia for more commercial applications.

R-717 has the best theoretical COP. In practice, compressor COP tends to be only a few percent better than that of R-22. R-22 has the closest physical properties to ammonia but it is being phased out. System design for the best system COP may result in high cost, particularly when considering necessary items to ensure safety. Ammonia's B2 category makes it suitable only for indirect (chiller) systems.

Within the chiller market, it finds its place mainly in the Screw Chiller sector. Scroll and Reciprocating Chillers are generally smaller size and less able to bear the safety costs and scrolls are not available for R-717.

9.3.2 Carbon dioxide (R-744)

It is a greenhouse gas and very energy efficient but operates at very high-pressure. However, CO_2 is re-emerging as a good natural refrigerant for industrial/commercial refrigeration and specific applications like heat pumps for water heaters. In this case the use of CO_2 is based on an objective assessment of its performance from all the refrigerants available. In contrast, in conventional air-conditioning and refrigeration systems, HFCs remains the optimal solution, which is why it is important to maintain refrigerant choice.

Table in Appendix A provides the suggested replacements for CFCs and HCFCs.

10.0 HISTORY OF THE REFRIGERANT CHOICES

HVAC refrigeration equipment is currently undergoing transition in the use of refrigerants. In the earlier 1990s, R-11 was widely used for centrifugal chillers, R-12 for small and medium-size vapor compression systems, R-22 for all vapor compression systems, and CFC/HCFC blend R-502 for low-temperature vapor compression systems. Because of the phaseout of CFCs and BFCs before 1996 and HCFCs in the early years of the next century, alternative refrigerants have been developed to replace them.

10.1 R-123

It is, an HCFC with ODP of 0.02, to replace R-11. It is a short-term replacement that causes a slight reduction in capacity and efficiency. R-245ca (ODP = 0) may be the long-term alternative to R-11.

10.2 R-134a

It is, an HFC with ODP of 0, to replace R-12 in broad applications. R-134a is not miscible with mineral oil; therefore, a synthetic lubricant of Polyol ester is used.

10.3 R-404a and R-407c

R-404a (R-125/R-134a/R-143a) and R-407c (R-32/R-125/R-134a) are both HFCs near azeotropic with ODP of 0. They are long-term alternatives to R-22. For R-407c, the composition of R-32 in the mixture is usually less than 30% so that the blend will not be flammable. R-407c has a drop of only 1 to 2% in capacity compared with R-22.

10.4 R-507

R-507 (R-125/R-143a), an HFC's azeotropic with ODP of 0, is a long-term alternative to R-502. Synthetic polyol ester lubricant oil will be used for R-507. There is no major performance difference between R-507 and R-502.

10.5 R-402a

R-402a (R-22/R-125/R-290), an HCFC's near azeotropic, is a short-term immediate replacement, and drop-in for R-502. It requires minimum change of existing equipment except for reset of a higher condensing pressure.

11.0 REFRIGERANT SELECTION CRITERIA

The key considerations for any new refrigerant are chemical stability, toxicity, flammability, thermal characteristics, efficiency, ease of detection in the case of leaks, environmental effects, compatibility with system materials, compatibility with lubricants, and cost. In general, the selection of refrigerant for an application is based on the following requirements:

1. Thermodynamic and thermo-physical properties
2. Environmental and safety properties

11.1 Thermodynamic & Thermo-Physical Properties

The requirements that fall under this category are outlined below.

11.1.1 Suction pressure

At a given evaporator temperature, the saturation pressure should be above the atmospheric pressure. This is to prevent the entry of air or moisture into the system and enable ease of leak detection. Higher suction pressure is preferred because it leads to smaller compressor displacement.

11.1.2 Discharge pressure

At a given condenser temperature, the discharge pressure should be as small as possible to allow light-weight construction of compressor, condenser, etc.

11.1.3 Pressure ratio

To ensure high volumetric efficiency and low power consumption, the pressure ratio should be as small as possible.

11.1.4 Latent heat of vaporization

This property should be as large as possible so that the required mass flow rate per unit cooling capacity will be small.

In addition to the above properties, the following properties are also important:

11.1.5 Isentropic index of compression

To ensure the temperature rise during compression is minimal, this property for the refrigerant should be as small as possible.

11.1.6 Liquid specific heat

This property has a direct effect on subcooling. The smaller the specific heat capacity of a refrigerant, the larger the degree of subcooling. Consequently, selecting a refrigerant with low liquid specific heat will ensure larger subcooling effect which will minimize the degree of flash gas production.

11.1.7 Vapor specific heat

To conserve energy, selecting a refrigerant with large vapor specific heat will help to minimize the degree of superheating.

11.1.8 Thermal conductivity

Thermal conductivity in both liquid and vapor phase should be high for higher heat transfer coefficients.

11.1.9 Viscosity

Viscosity should be small in both liquid and vapor phases for smaller frictional pressure drops.

The thermodynamic properties are interrelated and mainly depend on normal boiling point, critical temperature, molecular weight and structure.

The normal boiling point indicates the useful temperature levels as it is directly related to the operating pressures. A high critical temperature yields higher Coefficient of Performance (COP) due to smaller compressor superheat and smaller flash gas losses. On the other hand, since the vapor pressure will be low when critical temperature is high, the volumetric capacity will be lower for refrigerants with high critical temperatures. This, once again, shows a need for trade-off between high COP and high volumetric capacity. It is observed that for most of the refrigerants the ratio of normal boiling point to critical temperature is in the range of 0.6 to 0.7. Thus, the normal boiling point is a good indicator of the critical temperature of the refrigerant.

The important properties such as latent heat of vaporization and specific heat depend on the molecular weight and structure of the molecule. Trouton's rule shows that the latent heat of vaporization will be high for refrigerants having lower molecular weight. The specific heat of refrigerant is related to the structure of the molecule. If specific heat of refrigerant vapor is low, then the shape of the vapor dome will be such that the compression process starting with a saturated point terminates in the superheated zone (i.e. compression process will be dry). However, a small value of vapor specific heat indicates higher degree of superheat. Since vapor and liquid specific heats are also related, a large value of vapor specific heat results in a higher value of liquid specific heat, leading to higher flash gas losses. Studies show that in general the optimum value of molar vapor specific heat lies in the range of 9.5 to 24 Btu/lbmol. °R.

The freezing point of the refrigerant should be lower than the lowest operating temperature of the cycle to prevent blockage of refrigerant pipelines.

11.1.10 Other Desired properties:

A. Evaporating pressure should be higher than atmospheric. Then non condensable gas will not leak into the system.

B. Lower condensing pressure for lighter construction of compressor, condenser, piping, etc.

C. A high thermal conductivity and therefore a high heat transfer coefficient in the evaporator and condenser.

D. Dielectric constant should be compatible with air when the refrigerant is in direct contact with motor windings in hermetic compressors.

E. It should have a critical temperature (temperature above which a gas cannot be liquefied by pressure alone) which is high enough to enable the refrigerant to condense either by cooling water or, preferably, air from the surroundings.

F. It should have a freezing point lower than the lowest operational evaporating temperature.

G. An inert refrigerant that does not react chemically with material will avoid corrosion, erosion, or damage to the system components. Halocarbons are compatible with all containment materials except magnesium alloys. Ammonia, in the presence of moisture, is corrosive to copper and brass.

11.2 Environmental & Safety Properties

Next to thermodynamic and thermo-physical properties, the environmental and safety properties are very important. In fact, at present the environmental friendliness of a refrigerant is a major factor in determining its usefulness. The important environmental and safety properties are outlined below.

11.2.1 Ozone Depletion Potential (ODP)

Ozone depletion potential (ODP) is an index used to compare the relative ozone depletion of various refrigerants. It is defined as the ratio of the rate of ozone depletion of 1 pound of any halocarbon to that of 1 pound of refrigerant R-11. For R-11, ODP = 1.

According to the Montreal protocol, the ODP of refrigerants should be ZERO, i.e., they should be non-ozone depleting substances. Since ODP depends mainly on the presence of chlorine or bromine in the molecules, refrigerants having either chlorine (i.e., CFCs and HCFCs) or bromine cannot be used under the new regulations.

Refrigerants having non-zero ODP have either already been phased-out (e.g. R-11, R-12) or will be phased-out in near-future (e.g. R-22).

Note that the CFC refrigerants have a high ODP; the HCFC refrigerants have a low ODP and the HFC refrigerants have a zero ODP.

11.2.2 Global Warming Potential (GWP)

Like the ODP, Global Warming Potential (GWP) is an index used to compare the global warming effect of a halocarbon refrigerant with the effect of refrigerant R-11.
The GWP is the ratio of warming caused by a refrigerant relative to the warming caused by the same mass of Carbon dioxide. The GWP of CO_2 is 1.0. CFC-11 has a GWP of 5000 while water has a GWP of 0.
Refrigerants should have as low a GWP value as possible to minimize the problem of global warming. Refrigerants with zero ODP but a high value of GWP (e.g. R134a) are likely to be regulated in the future.
The three main advantages of the GWP index over other indices used to evaluate the contribution of halocarbons to global warming include transparency, simplicity, and widespread acceptability.

11.2.3 Total Equivalent Warming Index (TEWI)

The Total Equivalent Warming Impact (TEWI) is a holistic measurement tool for assessing the overall environmental impact of equipment from energy use and refrigerant emissions. It allows the comparison of technologies and provides guidance for targeting improvements in environmental impact. The factor, TEWI, considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming. Naturally, refrigerants with low values of TEWI are more desirable from global warming point of view.

11.2.4 Toxicity

Ideally, refrigerants used in a refrigeration system should be non-toxic. However, all fluids, other than air, can be said to be toxic. This is because they cause suffocation when their concentration is large enough. Thus, toxicity is a relative term which becomes meaningful only when the degree of concentration and time of exposure required to produce harmful effects are specified. Some fluids are toxic even in small concentrations. Some fluids are mildly toxic, i.e., they are dangerous only when the concentration is large, and duration of exposure is long. Other refrigerants such as CFCs and HCFCs are non-toxic when mixed with air in normal condition. However, when they encounter an open flame or an electrical heating element, they decompose and form highly toxic elements (e.g. phosgene-$COCl_2$).

In general, the degree of hazard depends on the:

A. amount of refrigerant used versus total space and total capacity (lbs./ft and/or lbs./TR);
B. type of occupancy;
C. presence of open flames;
D. odor of refrigerant, and
E. maintenance requirement.

Thus, based on toxicity, the usefulness of a refrigerant depends on its specific application.

ANSI/ASHRAE Standard-34-1992 classifies the toxicity of refrigerants as Class A and Class B. Class A refrigerants are of low toxicity. No toxicity was identified when their time-weighted average concentration was less than or equal to 400 ppm, to which workers can be exposed for an 8-hr workday and 40-hr work week without adverse effect. Class B refrigerants are of higher toxicity and produce evidence of toxicity.

11.2.5 Flammability

Refrigerants should preferably be non-flammable and non-explosive. ANSI/ASHRAE Standard-34-1982 classifies the flammability of refrigerants as Class 1, no flame propagation; Class 2, lower flammability; and Class 3, higher flammability.

The safety classification of refrigerants is based on the combination of toxicity and flammability. Newer ASHRAE 34a-1992 standard includes two alphanumeric characters A1, A2, A3, B1, B2, and B3. The capital letter (either A- Non-Toxic or B- Toxic) indicates the toxicity while the numeral (1-non-flammable, 2-slightly-flammable, and 3-highly-flammable) denotes the flammability.

A. Refrigerants belonging to Group A1 (e.g. R-11, R-12, R-22, R-134a, R-744, R-718) are least hazardous, i.e., they have lower toxicity and are nonflammable,
B. Refrigerants belonging to Group B3 (e.g. R-1140) are most hazardous, i.e., they have higher toxicity and are highly flammable.
C. R-123 in the B1 group, has high toxicity and is nonflammable; and R-717 (ammonia) in the B2 group, also has higher toxicity but lower flammability.

For HVAC refrigeration systems, only A1 refrigerants should be considered.

Other important properties include the following:

11.2.6 Chemical stability

The refrigerants should be chemically stable, especially when they are inside the refrigeration system.

11.2.7 Compatibility

The refrigerants should be compatible with common materials of construction (both metals and non-metals).

11.2.8 Miscibility with lubricating oils

Halocarbon refrigerant are generally miscible with lubricant oil and a mixture of a refrigerant and oil helps to lubricate pistons and discharge valves, bearings, and other moving parts of a compressor. Oil should also be returned from the condenser and evaporator back to the compressor for continuous lubrication.

Refrigerants that are completely miscible with oils are easier to handle (e.g. R-12). R-22 is partially miscible. R-134a is hardly miscible with mineral oil; therefore, special precautions should be taken while designing the system to ensure oil return to the compressor. One option is to add synthetic lubricant of Polyol ester to the refrigerant.

11.2.9 Dielectric strength

This is an important property for systems using hermetic compressors. For these systems the refrigerants should have as high a dielectric strength as possible

11.2.10 Ease of leak detection

In the event of leakage of refrigerant from the system, it should be easy to detect the leaks.

11.3 Energy Usage

Ammonia is a natural refrigerant and the most energy efficient refrigerant, as shown in the table below published by IRC ([7). It has been used for many years in a variety of applications due to its high thermal efficiency. Since ammonia is environmentally benign, having zero (GWP) and zero (ODP) characteristics, it is emerging as one of the primary natural refrigerants of choice.

New technology is leading to low and reduced ammonia charge designs. The application of these new low charge systems and packages creates an opportunity to use ammonia in a broad range of new industrial, commercial and indirect space conditioning applications that would not have been considered with traditional designs. These changes will require industry to provide proper recommendations for both design safety and guidance for regulatory and code agencies.

The table below shows the COP of ammonia compared with a wide range of synthetic refrigerants. CO_2 has a very high COP as well and at application below -20°F even higher than ammonia.

Comparative Refrigerant Performance [ref. 7]					
Refrigerant	Chemical formula or Blend	Typical Trade Names [1]	COP[2]	BHP/ton[2]	Sat. Temp (14.7 psia)
R-12	CCl_2F_2	(Phased out)	4.75	0.99	-21.6
R-22	$CHClF_2$	Forane 22, Freon 22, Genetron 22, Arcton 22	4.65	1.02	-41.5
R-134a	CH_2FCF_3	Forane 134a, Suva 134a, Genetron 134a, Klea 134a	4.60	1.02	-14.9
R-404A	R125/143a/124a (44/52/4)	Forane 404A, Suva HP-62, Genetron 404A, FX-70	4.21	1.12	-50.3
R-407C	R32/125/134A (23/25/52)	Suva 900, Klea 66, Klea 407C, AC9000	4.51	1.05	-34.1
R-410A	R32/125 (50/50)	Forane 410A, AZ-20, Puron, Suva 9100, Klea 410A	4.41	1.07	-60.7
R-502	R22/115 (48.8/51.2)	(Phased out)	4.42	1.07	-49.9
R-507	R125/143A (50/50)	Suva 507, AZ-50	4.18	1.13	-52.8
R-717	NH_3	Ammonia	4.77	0.99	-28.0
[1] Property names and their holders: Forane = Atofina, FX = Atofina, Suva = DuPont, Genetron=Honeywell (Allied Signal), AZ = Honeywell (Allied Signal), Klea = ICI. This does not include all possible trade names of these refrigerants.					
[2]Theoretical calculated performance for the U.S. standard cycle of 5°F evaporation and 86°F condensation. (ASHRAE Handbook of Fundamentals, 2001).					

12.0 Summary

The perfect refrigerant does not exist, and no refrigerant is good for every application. Consequently, to come up with the optimum solution for any given application, design system engineers and end users must make an assessment, which balances all consideration at both macro and micro levels.

12.1 Macro Level (multi-facility or corporate level) Assessment

12.1.1 Environmental Acceptability & Regulation Requirements

For example, direct use of ammonia in a food facility is not acceptable in Europe, as a result, the equipment manufacturer and designer use predominantly a secondary refrigerant in the distribution piping and inside the facilities.

However, in the United States, the codes allow the direct use of ammonia inside the food facilities. This flexibility in the code has lent itself to a much wider use of direct ammonia in the United States.

12.1.2 Safety of the people & Risk of release in the facility to the surrounding environment

The degree of required safety and significance of a release has an impact in the selection of a refrigerant. For instance, the direct use of ammonia for comfort cooling is not allowed by the national and local codes. Therefore, there is a significant push back by HVAC designers to use ammonia in commercial cooling application, even in indirect applications.

12.1.3 Performance Characteristics, Economics & Energy Cost

An essential part of this decision is the consideration of competing technology on the markets. Any choice must be guided by regulation and codes, which ensure refrigerants are used responsibly and according to the local laws.

12.1.4 Total Cost of Ownership of Refrigerant

Another basis for the selection of refrigerants is the total cost of ownership over the life cycle of the system, such as:

a. **Regulatory Burden**- this includes how much the compliance with PSM & RMP, or any other regulation will cost the owner. NH_3 is toxic and requires compliance with PSM & RMP over certain Federal threshold of 10,000 lbs.
b. **First Cost Versus Life Cycle Cost** – Most Halocarbon refrigerant for split system have low first cost but higher life cycle cost.
c. **Human Resources**- 24 hours attendance and higher skillset (No certification) is required for ammonia that equates to limited human resources and higher cost.

12.2 Micro Level (more application or site specific) Assessments

12.2.1 Design Constraints

Each design may offer its specific challenges. For instance, a building may not be conducive to roof mounted package system, so the designer has to offer a field erected system that can be built and supported by local contractors.

12.2.2 Size of the system

Size will impact on refrigerant selection from both economics and system charge. System charge will impact local codes & regulation and design & operating requirements. For instance, California OSHA and Mechanical codes require compliance with PSM and RMP for system over 500 pounds of ammonia. This will have an impact on facility owner's decision to use ammonia or any other refrigerants.

12.2.3 Location of the Facility

The location of a new facility, such as proximity to a city center, an airport or a school will have an impact on the selection of a refrigerant.

In final analysis, it is about striking a balance between various factors between codes requirements, safety, economics and other system specific requirements.

APPENDIX A

ASHRAE list of Refrigerants

Number	Chemical Name	Chemical Formula
Refrigerants		
	Methane Series	
11	Trichlorofluoromethane	CCl_3F
12	Dichlorodifluoromethane	CCl_2F_2
12B1	Bromochlorodifluoromethane	$CBrClF_2$
13	Chlorotrifluoromethane	$CClF_3$
13B1	Bromotrifluoromethane	$CBrF_3$
14e	Tetrafluoromethane (Carbon Tetrafluoride)	CF_4
21	Dichlorofluoromethane	$CHCl_2F$
22	Chlorodifluoromethane	$CHClF_2$
23	Trifluoromethane	CHF_3
30	Dichloromethane (Methylene Chloride)	CH_2Cl_2
31	Chlorofluoromethane	CH_2ClF
32	Difluoromethane (Methylene Fluoride)	CH_2F_2
40	Chloromethane (Methyl Chloride)	CH_3Cl
41	Fluoromethane (Methyl Fluoride)	CH_3F
50	Methane	CH_4

Number	Chemical Name	Chemical Formula
	Ethane Series	
113	1,1,2-Trichloro-1,2,2-Trifluoroethane	CCl_2FCClF_2
114	1,2-Dichloro-1,1,2,2-Tetrafluoromethane	$CClF_2CClF_2$
115	Chloropentafluoroethane	$CClF_2CF_3$
116	Hexafluoroethane	CF_3CF_3
123	2,2-Dichloro-1,1,1-Trifluoroethane	$CHCl_2CF_3$
124	2-Chloro-1,1,1,2-Tetrafluoroethane	$CHClFCF_3$
125	Pentafluoroethane	CHF_2CF_3
134a	1,1,1,2-Tetrafluoroethane	CH_2FCF_3
141b	1,1-Dichloro-1-Fluoroethane	CH_3CCl_2F
142b	1-Chloro-1,1-Difluoroethane	CH_3CClF_2
143a	1,1,1-Trifluoroethane	CH_3CF_3
152a	1,1-Difluoroethane	CH_3CHF_2
170	Ethane	CH_3CH_3
	Ethers	
E170	Dimethyl Ether	CH_3OCH_3
	Propane	
218	Octafluoropropane	$CF_3CF_2CF_3$
227ea	1,1,1,2,3,3,3-Heptafluoropropane	CF_3CHFCF_3

Number	Chemical Name	Chemical Formula
236fa	1,1,1,3,3,3-Hexafluoropropane	$CF_3CH_2CF_3$
245fa	1,1,1,3,3-Pentafluoropropane	$CHF_2CH_2CF_3$
290	Propane	$CH_3CH_2CH_3$
	Cyclic Organic Compounds	
C318	Octafluorocyclobutane	$-(CF_2)_4-$
Miscellaneous Organic Compounds		
	Hydrocarbons	
600	Butane	$CH_3CH_2CH_2CH_3$A3
600a	Isobutane	$CH(CH_3)_2CH_3$A3
601	Pentane	$CH_3CH_2CH_2\ CH_2CH_3$
601a	Isopentane	$CH(CH_3)_2CH_2CH_3$
	Oxygen Compounds	
610	Ethyl Ether	$CH_3CH_2OCH_2CH_3$
611	Methyl Formate	$HCOOCH_3$
	Sulfur Compounds	
620	(Reserved for future assignment)	

Number	Chemical Name	Chemical Formula
	Nitrogen Compounds	
630	Methyl Amine	CH_3NH_2
631	Ethyl Amine	$CH_3CH_2(NH_2)$
Inorganic Compounds		
702	Hydrogen	H_2
704	Helium	He
717	Ammonia	NH_3
718	Water	H_2O
720	Neon	Ne
728	Nitrogen	N_2
732	Oxygen	O_2
740	Argon	Ar
744	Carbon Dioxide	CO_2
744A	Nitrous Oxide	N_2O
764	Sulfur Dioxide	SO_2
Unsaturated Organic Compounds		
1130(E)	Trans-1,2-Dichloroethene	CHCl=CHCl
R-1132a	1,1-Difluoroethylene	$CF_2=CH_2$

Number	Chemical Name	Chemical Formula
1150	Ethene (Ethylene)	$CH_2=CH_2$
1233zd(E)	Trans-1-Chloro-3,3,3-Trifluoro-1-Propene	$CF_3CH=CHCl$
R-1224yd(Z)	(Z)-1-Chloro-2,3,3,3-Tetrafluoropropene	$CF_3CF=CHCl$
1234yf	2,3,3,3-Tetrafluoro-1-Propene	$CF_3CF=CH_2$
1234ze(E)	Trans-1,3,3,3-Tetrafluoro-1-Propene	$CF_3CH=CHF$
1270	Propene (Propylene)	$CH_3CH=CH_2$
1336mzz(E)	Trans-1,1,1,4,4,4-Hexafluoro-2-Butene	$CF_3CH=CHCF_3$
1336mzz(Z)	Cis-1,1,1,4,4,4-Hexaflouro-2-Butene	$CF_3CHCHCF_3$

List of Refrigerant Blends

Number	Refrigerant Composition	Mass (%)
	Zeotropes	
400	R-12/114 (must be specified)	(50.0/50.0) (60.0/40.0)
401A	R-22/152a/124	(53.0/13.0/34.0)
401B	R-22/152a/124	(61.0/11.0/28.0)
401C	R-22/152a/124	(33.0/15.0/52.0)
402A	R-125/290/22	(60.0/2.0/38.0)
402B	R-125/290/22	(38.0/2.0/60.0)
403A	R-290/22/218	(5.0/75.0/20.0)

Number	Refrigerant Composition	Mass (%)
403B	R-290/22/218	(5.0/56.0/39.0)
404A	R-125/143a/134a	(44.0/52.0/4.0)
405A	R-22/152a/142b/C318	(45.0/7.0/5.5/42.5)
406A	R-22/600a/142b	(55.0/4.0/41.0)
407A	R-32/125/134a	(20.0/40.0/40.0)
407B	R-32/125/134a	(10.0/70.0/20.0)
407C	R-32/125/134a	(23.0/25.0/52.0)
407D	R-32/125/134a	(15.0/15.0/70.0)
407E	R-32/125/134a	(25.0/15.0/60.0)
407F	R-32/125/134a	(30.0/30.0/40.0)
407G	R-32/125/134a	(2.5/2.5/95.0)
407H	R-32/125/134a	(32.5/15.0/52.5)
407I	R-32/125/134a	(19.5/8.5/72.0)
408A	R-125/143a/22	(7.0/46.0/47.0)
409A	R-22/124/142b	(60.0/25.0/15.0)
409B	R-22/124/142b	(65.0/25.0/10.0)
410A	R-32/125	(50.0/50.0)
410B	R-32/125	(45.0/55.0)
411A	R-1270/22/152a	(1.5/87.5/11.0)
411B	R-1270/22/152a	(3.0/94.0/3.0)
412A	R-22/218/143b	(70.0/5.0/25.0) [k]

Number	Refrigerant Composition	Mass (%)
413A	R-218/134a/600a	(9.0/88.0/3.0)
414A	R-22/124/600a/142b	(51.0/28.5/4.0/16.5)
414B	R-22/124/600a/142b	(50.0/39.0/1.5/9.5)
415A	R-22/152a	(82.0/18.0)
415B	R-22/152a	(25.0/75.0)
416A	R-134a/124/600	(59.0/39.5/1.5)
417A	R-125/134a/600	(46.6/50.0/3.4)
417B	R-125/134a/600	(79.0/18.3/2.7)
417C	R-125/134a/600	(19.5/78.8/1.7)
418A	R-290/22/152a	(1.5/96.0/2.5)
419A	R-125/134a/E170	(77.0/19.0/4.0)
419B	R-125/134a/E170	(48.5/48.0/3.5)
420A	R-134a/142b	(88.0/12.0)
421A	R-125/134a	(58.0/42.0)
421B	R-125/134a	(85.0/15.0)
422A	R-125/134a/600a	(85.1/11.5/3.4)
422B	R-125/134a/600a	(55.0/42.0/3.0)
422C	R-125/134a/600a	(82.0/15.0/3.0)
422D	R-125/134a/600a	(65.1/31.5/3.4)
422E	R-125/134a/600a	(58.0/39.3/2.7)
423A	134a/227ea	(52.5/47.5)

Number	Refrigerant Composition	Mass (%)
424A	R-125/134a/600a/600/601a	(50.5/47.0/0.9/1.0/0.6)
425A	R-32/134a/227ea	(18.5/69.5/12)
426A	R-125/134a/600/601a	(5.1/93.0/1.3/0.6)
427A	R-32/125/143a/134a	(15.0/25.0/10.0/50.0)
428A	R-125/143a/290/600a	(77.5/20.0/0.6/1.9)
429A	R-E170/152a/600a	(60.0/10.0/30.0)
430A	R-152a/600a	(76.0/24.0)
431A	R-290/152a	(71.0/29.0)
432A	R-1270/E170	(80.0/20.0)
433A	R-1270/290	(30.0/70.0)
433B	R-1270/290	(5.0/95.0)
433C	R-1270/290	(25.0/75.0)
434A	R-125/143a/134a/600a	(63.2/18.0/16.0/2.8)
435A	R-E170/152a	(80.0/20.0)
436A	R-290/600a	(56.0/44.0)
436B	R-290/600a	(52.0/48.0)
436C	R-290/600a	(95.0/5.0)
437A	R-125/134a/600/601	(19.5/78.5/1.4/0.6)
438A	R-32/125/134a/600/601a	(8.5/45.0/44.2/1.7/0.6)
439A	R-32/125/600a	(50.0/47.0/3.0)
440A	R-290/134a/152a	(0.6/1.6/97.8)

Number	Refrigerant Composition	Mass (%)
441A	R-170/290/600a/600	(3.1/54.8/6.0/36.1)
442A	R-32/125/134a/152a/227ea	(31.0/31.0/30.0/3.0/5.0)
443A	R-1270/290/600a	(55.0/40.0/5.0)
444A	R-32/152a/1234ze(E)	(12.0/5.0/83.0)
444B	R-32/152a/1234ze(E)	(41.5/10.0/48.5)
445A	R-744/134a/1234ze(E)	(6.0/9.0/85.0)
446A	R-32/1234ze(E)/600	(68.0/29.0/3.0)
446B	R-32/125/1234ze(E)	(68.0/3.5/28.5)
447B	R-32/125/1234ze (E)	(68.0/8.0/24.0)
448A	R-32/125/1234yf/134a/1234ze(E)	(26.0/26.0/20.0/21.0/7.0)
449A	R-32 /125 /1234yf /134a	(24.3/24.7/25.3/25.7)
449B	R-32/125/1234yf/134a	(25.2/24.3/23.2/27.3)
449C	R-32/125/1234yf/134a	(20.0/20.0/31.0/29.0)
450A	R-134a/1234ze(E)	(42.0/58.0)
451A	R-1234yf/134a	(89.8/10.2)
451B	R-1234yf/134a	(88.8/11.2)
452A	R-32/125/1234yf	(11.0/59.0/30.0)
452B	R-32/125/1234yf	(67.0/7.0/26.0)
452C	R-32/125/1234yf	(12.5/61.0/26.5)
453A	R-32/125/134a/227ea/600/601a	(20.0/20.0/53.8/5.0/0.6/0.6)
454A	R-32/1234yf	(35.0/65.0)

Number	Refrigerant Composition	Mass (%)
454B	R-32/1234yf	(68.9/31.1)
454C	R-32/1234yf	(21.5/78.5)
455A	R-744/32/1234yf	(3.0/21.5/75.5)
456A	R-32/134a/1234ze(E)	(6.0/45.0/49.0)
457A	R-32/1234yf/152a	(18.0/70.0/12.0)
458A	R-32/125/134a/227ea/236fa	(20.5/4.0/61.4/13.5/0.6)
459A	R-32/1234yf/1234ze(E)	(68.0/26.0/6.0)
459B	LTR 11: R-32/1234yf/1234ze(E)	(21.0/69.0/10.0)
460A	LTR 10: R-32/125/134a/1234ze(E)	(12.0/52.0/14.0/22.0)
460B	LTR4X10: R-32/125/134a/1234ze(E)	(28.0/25.0/20.0/27.0)
460C	R-32/125/134a/1234ze(E)	(2.5/2.5/46.0/49.0)
461A	R-125/143a/134a/227ea/600a	(55.0/5.0/32.0/5.0/3.0)
462A	R-32/125/143a/134a/600	(9.0/42.0/2.0/44.0/3.0)
463A	R-744/32/125/1234yf/134a	(6.0/36.0/30.0/14.0/14.0)
464A	R-32/125/1234ze(E)/227ea	(27.0/27.0/40.0/6.0)
465A	R-32/290/1234yf	(21.0/7.9/71.1)
Azeotropes		
500	R-12/152a	(73.8/26.2)
501	R-22/12	(75.0/25.0)
502	R-22/115	(48.8/51.2)

Number	Refrigerant Composition	Mass (%)
503	R-23/13	(40.1/59.9)
504	R-32/115	(48.2/51.8)
505	R-12/31	(78.0/22.0)
506	R-31/114	(55.1/44.9)
507A	R-125/143a	(50.0/50.0)
508A	R-23/116	(39.0/61.0)
508B	R-23/116	(46.0/54.0)
509A	R-22/218	(44.0/56.0)
510A	R-E170/600a	(88.0/12.0)
511A	R-290/E170	(95.0/5.0)
512A	R-134a/152a	(5.0/95.0)
513A	R-1234yf/134a	(56.0/44.0)
513B	R-1234yf/134a	(58.5/41.5)
514A	R-1336mzz(Z)/1130(E)	(74.7/25.3)
515A	R-1234ze (E)/227ea	(88.0/12.0)
516A	R-1234yf/134a/152a	(77.5/8.5/14.0)

** This list is not intended to be complete or definitive. Please refer to the latest edition of ASHRAE Standard 34 and all published addenda for complete information on refrigerant designations and safety classifications. For more information on ASHRAE Standard 34 please contact the Assistant Manager of Standards - International or the Manager of Standards at ASHRAE, 1791 Tullie Circle, N.E., Atlanta, GA 30329-2305.*
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Updated 6/10/2019

APPENDIX B

Acceptable Substitutes for CFCs

Substitute (Name used in the Federal register)	Trade Name	Refrigerant being Replaced	Retrofit/ New Uses (R/N)
Evaporative/ Desiccant		all CFCs	N
Cooling			
R-407C	Suva 407C, Klea 407C	502	R, N
R-422C	ICOR XLT1	502	R, N
KDD6	KDD6	12	R, N

APPENDIX C

Acceptable Substitutes for HCFCs

Substitute (Name used in the Federal register	Trade Name	Refrigerant being Replaced	Retrofit/ New Uses (R/N)
HFC-134a		22	N
THR-03		22	N ***NOTE:*** *This determination applies ONLY to window-unit residential air conditioning, and not to central air conditioning systems.*
ISCEON 59, NU-22, R-417a	ISCEON 59, NU-22	22	R, N
R-410a, R-410b	AZ-20,Suva 9100, Puron	22	N
R-407c	Suva 9000, Klea 66	22	R, N
R-507, R-507a	AZ-50	22	R, N
NU-22	NU-22	22	R, N
Ammonia Absorption		22	N
Evaporative/Desiccant Cooling		all HCFCs	N
R-404a	HP62	22	R, N
R-125/134a/600a (28.1/70.0/1.9)		22	R, N
RS-44	RS-44	22	R, N
	Choice		

Substitute (Name used in the Federal register	Trade Name	Refrigerant being Replaced	Retrofit/ New Uses (R/N)
R-421a	R421a	22	R, N
R-422D	ISCEON MO29	22	R, N
R-424a	RS-44	22	R, N
R-125/290/134a/600a (55.0/1.0/42.5/1.5)	ICOR AT- 22	22	R, N
R-422c	ICOR XLT1	22	R, N
R-422b	ICOR XAC1	22	R, N
KDD5, R-438a	ISCEON MO99	22	R, N
R-434a	RS-45	22	R, N
R-125/290/134a/600a (55.0/1.0/42.5/1.5)	ICOR AT- 22	22	R, N
R-422b	XAC1, NU-22B	22	R, N
R-422c	XLT1	22, 402a, 402a, 408a	R, N
R-407a	KLEA 60, KLEA 407A	22, 22 blends including R-401a, R-401b, R-402A, and R-402B	R, N
R-427a	Forane 427a	22	R

APPENDIX D

REFRIGERANTS at 20°F

Refrigerants		Temp.	Pressure	Density	Specific Volume	Enthalpy		Entropy		Specific Heat, c_p		Isentropic exponent (γ)	Viscosity		Thermal Conductivity		Surface Tension	Latent Heat
Name	Identifier	(°F)	(Psig)	lb/ft³ (Liquid)	ft³/lb (Vapor)	Liquid (Btu/lb)	Vapor (Btu/lb)	Liquid (Btu/lb.F)	Vapor (Btu/lb.F)	Liquid (Btu/lb.F)	Vapor (Btu/lb.F)	(or Heat capacity ratio) cp/cv (Vapor)	Liquid (lb/ft.s) x10⁶	Vapor (lb/ft.s) x10⁶	Liquid (Btu/h.ft.°F)	Vap (Btu/h.ft.°F)	lb_f/ft x10³	(Btu/lb)
1,1,1,3,3-Pentafluoropropane	R-245fa	20	-8.97	88.69	6.84	82.354	171.800	0.231	0.418	0.302	0.202	1.101	427.80	6.18	56.64	6.33	1.24	89.446
2,2-Dichloro-1,1,1Trifluoroethan	R-123	20	-11.16	96.27	9.83	83.160	162.272	0.233	0.398	0.235	0.153	1.102	414.26	6.45	49.55	4.26	1.30	79.112
n-Butane	R-600	20	-3.11	37.95	7.44	79.395	247.550	0.225	0.576	0.545	0.384	1.118	145.84	4.44	68.38	7.86	1.07	168.155
2-Chloro-1,1,1,2-Tetrafluoroethane	R-124	20	3.56	90.99	1.96	82.890	153.102	0.232	0.379	0.256	0.172	1.127	255.14	6.92	45.87	5.66	0.93	70.211
Iso-Butane	R-600a	20	3.21	36.72	4.75	79.484	234.476	0.225	0.549	0.537	0.377	1.128	144.19	4.50	58.55	7.91	0.95	154.993
1,1,1,2-Tetrafluoroethane	R-134a	20	18.44	82.19	1.41	82.159	169.674	0.231	0.413	0.316	0.207	1.170	198.55	7.03	54.93	6.33	0.86	87.515
Dichlorodifluoromethane	R-12	20	21.00	88.47	1.11	83.315	150.389	0.233	0.373	0.220	0.147	1.184	179.51	7.04	45.23	4.90	0.87	67.074
Pentafluoroethane	R-125	20	63.65	84.27	0.47	82.423	141.838	0.232	0.355	0.293	0.202	1.196	150.46	7.77	42.03	6.88	0.53	59.415
Propane	R-290	20	41.15	33.55	1.89	78.882	243.948	0.224	0.569	0.584	0.402	1.208	90.41	4.87	63.27	8.68	0.75	165.066
1,1-Difluoroethane	R-152a	20	15.25	60.80	2.43	81.141	216.032	0.229	0.510	0.400	0.253	1.210	160.34	6.00	64.76	6.48	0.97	134.891
1,1,1-Trifluoroethane	R-143a	20	57.95	65.33	0.73	81.741	165.237	0.230	0.404	0.349	0.253	1.245	115.11	6.73	48.16	7.21	0.56	83.497
Propylene	R-1270	20	54.59	34.61	1.58	79.034	245.734	0.225	0.572	0.572	0.379	1.251	85.97	5.11	73.16	8.24	0.74	166.700
Chlorodifluoromethane	R-22	20	43.11	81.39	0.94	82.647	173.048	0.232	0.421	0.275	0.170	1.277	157.72	7.53	56.55	5.19	0.87	90.401
Ammonia	R-717	20	33.52	40.43	5.91	72.771	625.415	0.212	1.364	1.094	0.617	1.384	123.04	5.95	335.21	13.17	2.41	552.645
Difluoromethane	R-32	20	80.04	67.29	0.90	81.021	220.923	0.229	0.520	0.409	0.283	1.437	109.09	7.53	87.04	6.45	0.83	139.902
Ethane	R-170	20	278.92	25.94	0.42	97.082	237.015	0.236	0.527	0.805	0.634	1.694	42.90	6.24	55.56	12.52	0.27	139.933
Trifluoromethane	R-23	20	286.21	67.65	0.17	81.103	145.968	0.229	0.364	0.406	0.351	1.840	69.49	9.55	48.09	9.17	0.26	64.865
Carbon Dioxide	R-744	20	407.28	60.26	0.20	79.176	186.600	0.225	0.449	0.567	0.384	1.936	74.97	9.50	68.52	10.26	0.40	107.424
Ethylene	R-1150	20	494.62	23.15	0.21	118.381	217.096	0.294	0.500	1.122	1.112	3.043	33.38	7.98	52.38	15.70	0.09	98.715

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