# ISHRAE Position Document

on

Refrigerants for Indian Refrigeration and Air Conditioning Industries – Challenges and Responsibilities

2025

ISHRAE

Indian Society of Heating, Refrigerating and Air Conditioning Engineers

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# Contents

# ISHRAE Position Document on Refrigerants for Indian Refrigeration and Air Conditioning Industries – Challenges and Responsibilities

## Introduction

The Refrigeration and Air Conditioning (RAC) applications, in the current era, touch our lives in far-reaching areas in a wide range of fields. They have become essential not only for food security (post-harvest vegetable, fruit, and grain storage, food processing and freezing), health security (healthcare, vaccine and pharmaceutical storage and cryosurgery), financial security, and industrial development (including IT, pharmaceuticals, chemicals, petrochemicals, and many others) but also for human comfort (air conditioning). It is well known that with comfort air conditioning, human productivity increases. Refrigeration and air conditioning are now the backbone of our lifestyle and play an important role in future sustainable development.

Before 1930, refrigerants from known and available chemicals were used and no synthetic fluids were developed. Safety (toxicity and flammability) issues were till then not well understood. Naturally occurring chemicals, including ammonia, carbon dioxide, hydrocarbons, water, and air, were used. The use of naturally occurring refrigerants, also called natural refrigerants, had concerns such as high pressures, toxicity, flammability, corrosion, or lower operating efficiencies.

In 1928, Midgley (1930) discovered that dichlorodifluoromethane (a chlorofluorocarbon or CFC) or CFC-12[1] could be used as a non-toxic and non-flammable refrigerant. A vast number of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), such as CFC-11, CFC-12, HCFC-22, CFC-113, CFC-114, CFC-115, and HCFC-123, were developed in the following decades. These were extensively used as refrigerants. These fluids had many desirable characteristics such as thermal and chemical stability, thermodynamic suitability, lower toxicity, non-flammability, material compatibility, low cost, etc. These fluids were also used as solvents, foam-blowing agents, aerosol propellants, etc. Molina and Rowland (1974) identified CFCs (including HCFCs) as the major source of chlorine radicals in the stratosphere and their link to ozone layer depletion. The stratospheric ozone layer acts as a filter to UV-B radiation. The lethal consequences of its depletion include health hazards on human beings and other living creatures, and other ecological and environmental problems (UNEP, 2014a). The Montreal Protocol in 1987 and its subsequent amendments have changed the landscape of refrigerants. In the past three decades, new environmental criteria have been applied to refrigerant selection, and many new substances and blends are invented, tested, and commercialized. CFCs and HCFCs were largely replaced with hydrofluorocarbons

[1] *ASHRAE designation*

(HFCs), many of which are considered potent greenhouse gases and whose usage is now being restricted due to their relatively high global warming potential (GWP)[2]. In the last decade, hydrofluoroolefins (HFOs) have been introduced, which are non-ozone depleting substances and have ultra-low GWPs. Some of these HFOs are mildly flammable, which has necessitated the revision of safety standards for appliances and systems and their installation to mitigate risks.

## Montreal Protocol

To control the damage to the stratospheric ozone layer depletion, the Montreal Protocol on substances that deplete the ozone layer was adopted in September 1987 and became effective in 1989. The Montreal Protocol specifies some control measures for the reduction and, ultimately, the phase-out of Ozone Depleting Substances (ODSs), including CFCs and HCFCs. The Montreal Protocol embodied "the polluter pays" principle with common but differentiated responsibility and created the Multilateral Fund (MLF) in 1991 for the implementation of the Montreal Protocol based on the contributions made by non-Article 5 countries (developed). The Montreal Protocol also provided a 10-year grace period for Article 5 (developing) countries based on their per capita consumption of Ozone Depleting Substances (ODSs).

India acceded to the Vienna Convention in 1991, ratified the Montreal Protocol in 1992, and followed it up with further ratification of all the subsequent amendments. Indian Ozone Depleting Substances (Regulation) Rules, 2000, under the Environment Protection Act (1986), came into force on 17th July 2000. Accordingly, CFCs were phased out 17 months ahead of their target date of 2010 (MoEF, 2012).

HCFCs have lower Ozone Depletion Potential (ODP[3]), e.g., the ODP of HCFC-22 is just 5% of CFC-12. As per the accelerated Montreal Protocol phase-out schedule, HCFCs must be phased out by 2020 in non-A5 and by 2030 in A5 countries. For A5 countries, 2.5 % of baseline averaged over 10 years (2030-2040) is allowed, if necessary, for servicing of RAC equipment until 2040.

The Government of India has put together a comprehensive roadmap for the HCFC Phase-out Management Plan (HPMP), with concrete goals to meet the schedules. Indian Ozone Depleting Substances (Regulation and Control) Amendment Rules, 2014, came into force on 13th March 2014 (MOEFCC, 2014). As per the amended ODS Regulations, manufacturers of RAC products (excluding compressors) must phase out HCFCs by 1st January 2025. Import of RAC systems containing HCFCs is regulated from 1st July 2015.

With extensive work on alternatives to CFCs and HCFCs, initially, HFCs, which are ozone-friendly with zero ODP, were considered long-term solutions. HFCs were used as alternatives while phasing out CFCs, although these fluids have relatively high GWPs.

## Kyoto Protocol

The global warming due to the greenhouse effect has become another major environmental issue. It is well established that global mean temperatures have increased by more than 0.8°C over the past 100 years. The Intergovernmental Panel on Climate Change (IPCC), agrees that global warming is primarily due to human activity, which has occurred since the industrial revolution. To slow down global warming, the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1994. The Kyoto Protocol, under UNFCCC, which came into effect in 1997, set out more specific and binding commitments to abate the use and emissions of Greenhouse Gases (GHGs), including HFCs. Currently,

[2] *Global Warming Potential (GWP) is the heat trapped on the earth by any greenhouse gas in the atmosphere relative to the heat trapped by the same mass of carbon dioxide. Usually, the time period used to measure the relative impact of a greenhouse gases is 100 years. Carbon dioxide, by definition, has a GWP of 1.*

[3] *The ozone depletion potential (ODP) of a substance or compound is a measure of degradation to the ozone layer relative to CFC-11 (trichlorofluoromethane)*

available HFC options for HCFCs have a very high GWP, typically in the range of 600 to 4000. There is a linkage between the Montreal Protocol and the UNFCCC (Kyoto Protocol) and this was studied by the IPCC (Andersen et al., 2005, and Devotta and Sicars, 2005). CFCs and HCFCs are also GHG but CFCs were phased out and HCFCs are under phase-out under the Montreal Protocol. Therefore, these are not included in the Kyoto Protocol.

The European Union introduced the F-gas Regulation in 2006, which was further revised in March 2024, to contain the growth of the use of HFCs. In Europe, HFCs have already been banned in many new types of equipment where less harmful alternatives are widely available. The EU MAC Directive prohibits the use of fluorinated gases with a global warming potential > 150 in new types of cars and vans introduced from 2011, and in all new cars and vans produced from 2017. Besides bans on new equipment with high GWP refrigerants, service bans were also introduced to reduce the consumption of high GWP refrigerants. For example, from 1st January 2020, the use of fluorinated greenhouse gases with a global warming potential of 2,500 or more to service refrigeration equipment with a charge size ≥40 tonnes of $CO_2$ equivalent was prohibited.

## Kigali Amendment Under the Montreal Protocol

HFC emissions are projected to grow significantly up to 2050, largely due to increasing demand for RAC sectors in developing countries presumed to use high-GWP HFCs, in the absence of global controls. Therefore, it was emphasized that phasing down HFCs, in conjunction with other GHGs, is essential for stabilizing global temperatures.

At the 2015 United Nations Climate Change Conference in Paris, COP 21 or CMP 11, parties agreed to keep the global temperature rise this century well below 2°Celsius above pre-industrial levels. Within a year of this agreement, a historic climate change deal was signed in Kigali, Rwanda. Under the Kigali amendment of the Montreal Protocol, actions to limit the use of HFCs were agreed upon. This amendment will avoid up to 0.5°C increase in global temperature by the end of the century.

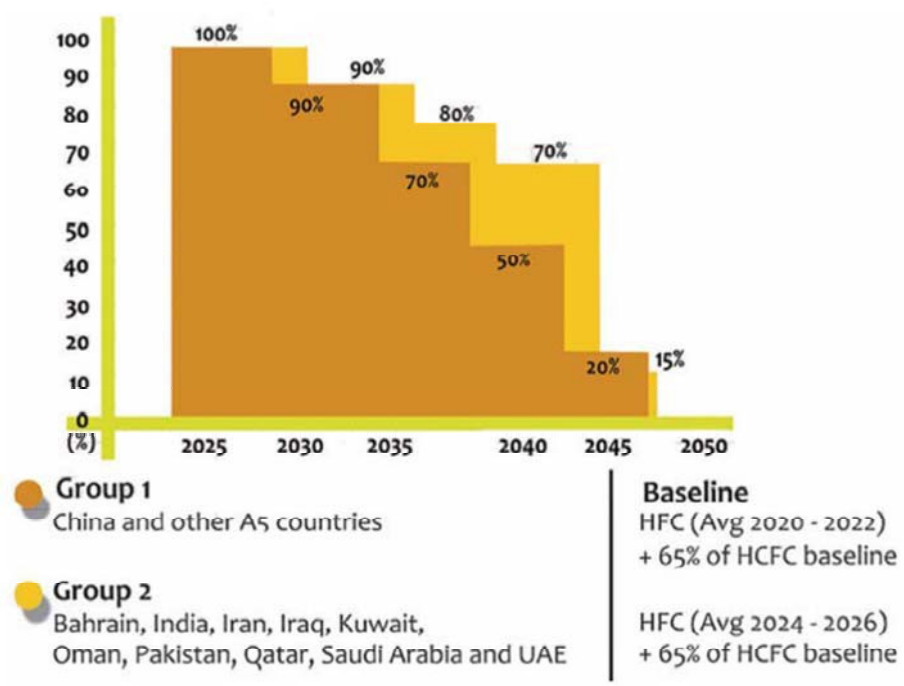


*Figure 1: HFC Phase-down Schedule for Article 5 Countries (ICAP, 2019)*

For the implementation of the Kigali amendment the Montreal Protocol parties were classified into three groups, each with a separate legally binding target phase-down schedule. The first group consists of non-Article 5 countries while Article 5 countries are further sub-divided into two groups. India is in A5 Group 2 and has a delayed freeze and phase-down steps compared with Group 1. The freeze date is four years later (2028 compared with 2024 for A5 Group 1). The Kigali Amendment to the Montreal Protocol for phase down of HFCs lays down a schedule for HFCs which is depicted in *Figure 1*.

India ratified the Kigali Amendment in 2021 (Press Release, GOI). HFC phase down is expected to prevent emission of up to 105 million tonnes of equivalent of greenhouse gases, helping to avoid up to 0.5 degree Celsius of global temperature rise by 2100, while continuing to protect the ozone layer.

One of the goals of ICAP is reduction of refrigerant demand by 25 to 30% by 2037-38. Future refrigerant pathways will include an increased use of low-GWP and natural refrigerants. The progress towards the HFC phase-down targets under the Kigali Amendment will be measured in *tonnes* $CO_2$ *equivalent*. (Kigali Fact Sheet 3, UNEP). To calculate tonnes $CO_2$ equivalent it is necessary to know the GWP of each relevant gas. Tonnes $CO_2$ equivalent is calculated by multiplying the mass of gas (in tonnes) by the GWP of that gas.

For example, tonnes $CO_2$ equivalent of 100 kg of R-404 is calculated as follows:

$CO_2$ equivalent = mass (in tonnes) x GWP

Mass = 100/1000 = 0.1 tonnes

GWP of R-404A = 3922

Hence 100 kg of R-404A is 0.1 x 3922 tonnes $CO_{2e}$

= 392.2 tonnes $CO_{2e}$

## Alternatives to HCFCs and HFCs

The accelerated HCFC phase-out and planned HFC phase-down schedule pose bigger challenges for A5 parties, with multiple dimensions on short-term as well as long-term technology selections (GWP, energy efficiency, cost, etc.) when compared with when CFCs were phased out. Therefore, considerable initiatives have been taken by the RAC industry to identify alternative refrigerants.

The RAC industry is in the midst of a historical technological shift, to comply with very dynamic international environmental protocols and avoid the use of refrigerants that harm the global environment. This has triggered innovative processes leading to new technology and new solutions in a very short term.

Any alternative refrigerant should perform efficiently with reliability within systems but be harmless and benign to the environment, should it leak out of the system. It is well established that HVAC systems account for nearly 40 percent of total global building energy consumption. The contribution to global warming due to fugitive emissions of refrigerants from the equipment varies depending on the application. For large, field-installed commercial refrigeration systems, the direct emissions contribution can be as high as 40% of the total GHG emissions. In contrast, direct GHG emissions contribution can be as low as 1% for factory-sealed systems. On average, around 80% of annual global RAC equipment GHG emissions are indirect and only 20% are direct (UNEP, 2018). Therefore, due consideration should be given for the selection of refrigerants to achieve higher efficiency. To satisfy the environmental and safety regulations, one must address factors such as flammability, toxicity, cost, etc.

### Safety Classification

Flammability and toxicity aspects of refrigerants are covered in ISO standards ISO 5149 and ISO 817, respectively. The Indian standards are IS 16678 and IS 16656, respectively. ASHRAE standards are followed worldwide in consonance with international and national standards, some of which may be equivalent to the ASHRAE standards. ASHRAE Standard 147 deals with the reduction in the release of halogenated refrigerants from AC&R systems.

*Table 1: Environmental, thermodynamic and safety data of select refrigerants*

| Refrigerant | Chemical Formula/ Composition (wt%) | Environmental Parameters | | | Thermodynamic and Safety Parameters | | |
|---|---|---|---|---|---|---|---|
| | | ODP | GWP (AR4 for HFC and AR6 for HFO) | Atmospheric Lifetime, Years | Normal Boiling Point[4], °C | Critical Temp., °C | Safety Classifi■cation |
| CFC-11 | $CCl_3F$ | 1.00 | 4750 | 45 | 23.7 | 198.0 | A1 |
| CFC-12 | $CCl_2F_2$ | 0.82 | 10900 | 100 | -29.8 | 112.0 | A1 |
| HCFC-22 | $CHClF_2$ | 0.04 | 1810 | 11.9 | -40.8 | 96.1 | A1 |
| HCFC-123 | $CF_3CHCl_2$ | 0.01 | 77 | 1.3 | 27.8 | 183.7 | B1 |
| HCFC-142b | $CH_3CF_2Cl$ | 0.06 | 2310 | 17.2 | -9.1 | 137.1 | A2 |
| HFC-23 | $CHF_3$ | 0 | 14800 | 222 | -82.0 | 26.1 | A1 |
| HFC-32 | $CH_2F_2$ | 0 | 675 | 5.2 | -51.7 | 78.1 | A2L |
| HFC-125 | $C_2HF_5$ | 0 | 3500 | 28.2 | -48.1 | 66.0 | A1 |
| HFC-134a | $CH_2FCF_3$ | 0 | 1430 | 13.4 | -26.1 | 101.1 | A1 |
| HFC-143a | $C_2H_3F_3$ | 0 | 4470 | 47.1 | -47.2 | 72.7 | A2 |
| HFC-152a | $C_2H_4F_2$ | 0 | 124 | 1.5 | -24.0 | 113.3 | A2 |
| HFO-1234yf | $CH_2$=CF-$CF_3$ | 0 | <1 | 0.029 | -29.5 | 94.7 | A2L |
| HFO-1234ze(E) | (E)CHF=CH-$CF_3$ | 0 | <1 | 0.045 | -19.0 | 109.4 | A2L |
| HCFO-1233zd(E) | (E)$CF_3$-CH=CClH | 0 | 1 | 0.07 | 18.3 | 165.6 | A1 |
| HFO-1336mzz(Z) | (Z)$CF_3$CH=$CHCF_3$ | 0 | 2 | 0.06 | 33.4 | 171.3 | A1 |
| HC-290 (Propane) | $C_3H_8$ | 0 | 3 | 0.034 | -42.1 | 96.7 | A3 |
| HC-600a (Isobutane) | $C_4H_{10}$ | 0 | 3 | 0.016 | -11.7 | 134.7 | A3 |
| HC-1270 (Propylene) | $C_3H_6$ | 0 | 1.8 | 0.001 | -47.6 | 91.1 | A3 |
| R-717 (Ammonia) | $NH_3$ | 0 | 0 | <0.02 | -33.3 | 132.3 | B2L |
| R-718 (Water) | $H_2O$ | 0 | <1 | ■ | 100.0 | 373.9 | A1 |
| R-744 (Carbon dioxide) | $CO_2$ | 0 | 1 | >50 | | 31.1 | A1 |
| R-404A | R-125/R-143a/R-134a (44/52/4) | 0 | 3922 | ■ | -46.2/-45.5 | 72.1 | A1 |
| R-407A | R-32/R-125/R-134a (20/40/40) | 0 | 2107 | ■ | -45.2/-38.7 | 82.25 | A1 |
| R-407C | R-32/R-125/R-134a (23/25/52) | 0 | 1774 | ■ | -43.6/-36.6 | 86.0 | A1 |
| R-407F | R-32/R-125/R-134a (30/30/40) | 0 | 1824 | ■ | -46.1/-39.7 | 82.60 | A1 |
| R-410A | R-32/R-125 (50/50) | 0 | 2087.5 | ■ | -51.4 | 71.4 | A1 |
| R-422D | R-125/R-134a/R-600a (65.1/31.5/3.4) | 0 | 2729 | ■ | ■43■20/■38■34 | 78.21 | A1 |
| R-438A | R-32/R-125/R-134a/R-600a/R601a (8.5/45/44.2/1.7/0.6) | 0 | 2265 | ■ | -42.33/36.14 | 83.82 | A1 |
| R-448A | R-32/R-125/R-134a/ R-1234yf/R-1234ze(E) (26/26/21/20/7) | 0 | 1386 | ■ | -45.9/-39.8 | 83.6 | A1 |
| R-449A | R-32/R-125/R-134a/ R-1234yf (24.3/24.7/25.3/25.7) | 0 | 1396 | ■ | -46/-39.9 | 81.5 | A1 |
| R-450A | R-134a/R-1234ze(E) (42/58) | 0 | 601 | ■ | -23.4/-22.8 | 104.4 | A1 |
| R-452A | R-32/R-125/R-1234yf (11/59/30) | 0 | 2140 | ■ | -47/-43.2 | 74.9 | A1 |
| R-452B | R-32/R-125/R-1234yf 67/7/26 wt% | 0 | 698 | ■ | -51/-50.3 | 75.7 | A2L |
| R-454A | R-32 /R-1234yf (35/65) | 0 | 238 | ■ | -48.4/-41.6 | 78.9 | A2L |
| R-454B | R-32 /R-1234yf (68.9/31.1) | 0 | 465 | ■ | -50.9/-50 | 76.5 | A2L |
| R-454C | R-32 /R-1234yf (21.5/78.5) | 0 | 146 | ■ | -46/-37.8 | 82.4 | A2L |
| R-455A | R-32/ R-1234yf/R-747 (21.5/75.5/3) | 0 | 146 | ■ | -51.6/-39.1 | 85.6 | A2L |
| R-507A | R-125/R-143a (50/50) | 0 | 3985 | ■ | -46.74 | 70.61 | A1 |
| R-508B | R-23/R-116 (46/54) | 0 | 13396 | ■ | -87.16 | 11.20 | A1 |
| R-513A | R-1234yf/R-134a (56/44) | 0 | 630 | ■ | -29.47 | 94.91 | A1 |
| R-514A | R-1336mzz(Z)/R-1130(E) (47.1/25.3) | 0 | 2 | ■ | 37.85 | 178.1 | B1 |
| R-515B | R-1234ze(E)/R-227ea (91.9/8.9) | 0 | 293 | ■ | -18.80 | 108.9 | A1 |

[4]*Bubble point and dew point temperatures for zeotropic blends*

According to ISO 817, toxicity classification is based on chronic (long-term) measures as follows:

- Class A with OEL ≥ 400 ppm
- Class B with OEL < 400 ppm

where Occupational Exposure Limit (OEL) is the 8-hour time-weighted average (TWA) concentration to which nearly all workers can be repeatedly exposed for a normal 8 h workday and a 40 hour workweek without adverse effect. It is based on the OSHA PEL, ACGIH TLV-TWA, TERA OARS-WEEL, or consistent value.

The flammability classification is based on ASTM E681, *Standard Test Method for Concentration Limits of Flammability of Chemicals (Vapours and Gases)* using a spark ignition source as follows

- Class 1: exhibits no flame propagation,
- Class 2L: exhibits flame propagation when tested at 60°C and 101.3 kPa, LFL > 0.10 kg/m$^3$ and burning velocity ≤ 10 cm/s at 23°C and 101.3 kPa, and heat of combustion < 19 MJ/kg,
- Class 2: exhibits flame propagation when tested at 60°C and 101.3 kPa, LFL > 0.10 kg/m$^3$ at 23°C and 101.3 kPa, and heat of combustion < 19 MJ/kg,
- Class 3: exhibits flame propagation when tested at 60°C and 101.3 kPa, LFL ≤ 0.10 kg/m$^3$ or heat of combustion ≥ 19 MJ/kg,

Where, LFL is the lower flammability limit

*Table 1* presents the environmental, thermodynamic, and safety classification data for some selected refrigerants as per IS 16656 (international equivalent ISO 817). The composition data, normal boiling point, and critical temperature data has been compiled from the AHRI-700 (2019) standard. The atmospheric life, GWP, ODP and safety classification data have been compiled from the UNEP Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (2022). For choosing the transition, retrofitting, or substitution fluid, economical, technical, and ecological criteria should be considered. The transition fluids are basically for the new systems while the retrofitting fluids are for the replacement of the old refrigerants in the existing plants without making major changes. Mixing of refrigerants also enables the use of a refrigerant that would not be acceptable as a pure fluid owing to many technical, health, safety, and environmental limitations such as flammability, GWP, operating envelope, performance, etc.

## Environmental Evaluation of Refrigerants

The following tools are used to assess the environmental sustainability of any RAC system using a chosen refrigerant (UNEP, 2014b).

### Total Equivalent Warming Impact (TEWI)

It is calculated as the sum of greenhouse gas emissions from the direct release of refrigerant from the equipment over the lifetime and indirect use of carbonaceous fuel for generating the electricity to operate the equipment throughout its lifetime.

### Life Cycle Climate Performance (LCCP)

Life Cycle Climate Performance considers the overall environmental performance of a product, providing a framework of "cradle to grave" environmental responsibility. LCCP relates to a defined system and provides a comparative measure rather than one that has any absolute significance. This includes the extraction of raw materials, the manufacture of intermediate products, the manufacture of the substance itself, the phase of use, and waste disposal. For a range of HFC applications, detailed comparisons of LCCP have been made between HFC-based systems and non-HFC based alternative systems/technologies.

There are Guidelines available (IIR, 2016) for calculating LCCP for stationary Air Conditioning, Refrigeration and Heat Pump systems. LCCP is a more comprehensive evaluation than TEWI. It includes all the direct and indirect emissions generated by the system during its lifetime. To do this, in addition to TEWI, LCCP accounts for energy embodied in the product materials, greenhouse gas emissions from chemical manufacturing and end-of-life disposal of the unit. LCCP can also account for minor emission sources that are not accounted for in TEWI such as transportation leakage, manufacturing leakage and refrigerant manufacturing emissions.

Although there have been many attempts and studies using both TEWI and LCCP approaches, there is still no consensus as there are wide variations in the results due to various assumptions made, including energy mix and its $CO_2$ emission (emission factor), leakage rates, performance during the life cycle of systems, recovery and recycling efficiency, destruction efficiency and so on.

## Low GWP Alternative Refrigerants for Various RACHP Sectors

*Table 2* presents some of the currently used and known alternative refrigerants for various sectors of refrigeration, air conditioning and heat pump (RACHP) applications based on global scenarios. The sustainability of refrigeration and air conditioning systems is the key factor in the ultimate choice of alternative refrigerants. Comprehensive details can be found in the UNEP RTOC Report (UNEP, 2022). ISHRAE's assessment is based on the current understanding of the open domain data and is not based on any proprietary or commercial information. The lowest GWP options that meet the requirements of safety, performance in Indian ambient conditions and wide availability of systems and components have been recommended.

Refrigerant selection is a balanced result of several factors which include suitability for the targeted use, availability, cost of the refrigerant and associated equipment and service, energy efficiency rating, safety, ease of use, and environmental issues.

## Heat Pumps

This product segment is growing worldwide. Especially in colder countries in Europe, North America, etc., there are aims and regulations to reduce use of fossil fuels for heating. Heat pumps are a good, energy-efficient alternative. Even in India for industrial/commercial hot water requirements, indigenous developments in application of heat pumps are being undertaken. There are commercial-scale dual-source (air and water) heat pumps that allow the heat pump to select the most efficient heat source/sink on a real-time basis. Heat recovery heat pump systems that allow simultaneous hot water and chilled water generation with a combined COP of 7+ (which is nearly double the efficiency of standalone options) continue to evolve and improve. The challenge of developing solutions that use refrigerants that are less harmful to the environment is being met with vigour. The heat pump systems that use $CO_2$ as their refrigerant can provide 93.3°C (200°F) + fluids. There are options of heat pumps to retrofit legacy hot water heating systems that were designed for 82.2°C (180°F) hot water to a non-fossil fuel heat source.

## HFCs and HFOs

HFC-134a was the most widely used refrigerant across many RACHP sectors across the world. R-410A was the most popular alternative to HCFC-22 in the AC sector. However, given the HFC phase-down program, the long-term future of HFC-134a and R-410A became uncertain and many countries including EU and US have phased out these refrigerants in new systems. These are not yet regulated in India but have been phased out in some of the sub-sectors in new appliances and systems and OEMs may face problems when dealing with exports to some countries.

*Table 2: Low GWP alternative refrigerants for various RAC sectors*

| Sector | Current Refrigerants Used | Alternative Refrigerants* | ISHRAE Assessment of Low GWP options for India (Lowest GWP feasible options that provide high energy efficiency) |
|---|---|---|---|
| **Domestic Refrigeration**<br>Single/double door | R-600a, R-134a | R-600a | R-600a |
| **Commercial Refrigeration**<br>Self-contained units (Display cabinet, water cooler, bottle cooler, visi-coolers, ice cream cabinets, and chest freezers) | R-290, R-22, R-134a, R-404A, R-507 | R-22, R-404A and R-507 replacement options: 407 (A, C and F), R-448A, R-449A, R-454A, R-454C, R-455A<br><br>R-134a replacement options: R-1234yf, R-1234ze(E), R-450A, R-513A, R-515B<br><br>Others: R-290**, R-744 | Non-flammable: R-448A, R-449A, R-513A, R-515B<br>Mildly-flammable: R-1234yf, R-1234ze, R-454A, R-454C, R-455A<br>Flammable: R-290** |
| **Room Air Conditioners**<br>Mini-split and window air conditioners | R-22, R-410A, HFC-32, R-290** | R-32, R-290**, R-452B, R-454B | R-290**, R-32 |
| **Large Air Conditioners**<br>Multi-Split, VRF ACs, ducted, packaged, rooftop | R-22, R-407C, R-410A | R-410A, R-32, R-452B, R-454B | R-410A, R-32, R-452B, R-454B |
| **Mobile AC**<br>Car, Van<br><br>Bus, Truck, Train | R-134a<br><br>R-22, R-134a, R-407C | R-1234yf, R-744<br><br>R-1234yf, R-744, R-450A, R-513A | R-1234yf<br><br>R-1234yf, R-450A, R-513A |
| **Transport Refrigeration**<br>Refrigerated Reefer Containers | R-22, R-134a, R-404A, R-507 | R-404A alternatives: R-448A, R-449A, R-452A<br><br>R-134a alternatives: R-513A | R-452A is an option for both new equipment and retrofit of R-22 and R-404A equipment.<br><br>R-448A and R-449A with liquid injection.<br><br>R-513A |
| **Industrial and Commercial Refrigeration**<br>Direct expansion systems (A1 options only)<br><br>Flooded systems | R-22, R-404A, R-507,R-134a (for medium temperature only)<br><br>R-717, R-22, R-507, R-134a | R-407C, R-407F, R-407H, R-448A, R-449A, R-450A, R-513A, R-515B, R-744 (for low ambient only)<br><br>R-717, R-1234ze(E), R-513A, R-515B, R-744 (for low ambient only) | R-448A, R-449A, R-450A, R-513A, R-515B<br><br>R-717, R-513A, R-515B, R-1234ze(E). |
| **Chillers**<br>Scroll<br><br>Screw<br><br>Centrifugal | R-22, R-407C, R-410A<br><br>R-134a<br><br>R-134a (medium pressure),<br><br>R-123 (low pressure) | R-32, R-452B, R-454B<br><br>R-1234ze, R-515B, R-513A<br><br>R-1234ze, R-515B, R-513A<br><br>R-1233zd, R-514A | R-32, R-454B<br><br>R-1234ze, R-515B, HFO-513A<br><br>Medium pressure: R-1234ze, R-515B, R-513A<br>Low pressure: R-1233zd, R-514A |
| **Commercial Heat Pumps** | R410A<br>R134a | R-454B, R32<br>R-513A, R-515B, R-1234ze | R-454B, R-32<br>R-515B, R-1234ze |
| **Industrial Heat Pumps**<br>Scroll<br>Screw<br>Centrifugal | R-410A, R-134a, $CO_2$*** | R-1234ze, R-515B, R-1233zd | R-1234ze, R-515B, R-1233zd, $CO_2$*** |

* The alternative refrigerant list is limited to options that were commercially adopted in the last 2 decades

** All hydrocarbon refrigerants are Class A3 refrigerants. Special precautions must be taken to avoid any accidents during the manufacture and installation of systems using any flammable refrigerants (A2L, A2 and A3). Therefore, the permissible charge limit per circuit as per IS/IEC 60335-2-40: 2022 is limited to 500 g. The IEC 60335-2-40:2022 is yet to be adopted in India but has adopted IEC 60335-2-40 (2018) version. It may be noted that these are not mandatory in many countries, including India.

*** Transcritical cycle.

Room ACs with HFC-32 are commercially available in many countries, including India. In medium-size DX air-conditioning systems, such as VRF, ducted, and roof-top, A2L options can be used in compliance with IS/IEC 60335-2-40: 2018 and IS-16678: 2018. HFO-1234yf is the most favoured choice for mobile AC and has already been commercialized in non-A5 countries. Its use in other sectors is not yet certain. Since scroll chillers are installed outdoors, A2L replacement options for R-410A such as R-32, R-452B, and R-454B are being adopted. They provide improvement in performance over R-410A. Chillers using HFO-1234ze(E), R-515B, R-513A, R-514A and HFC-1233zd(E) are now commercially available. Lower GWP refrigerants, such as R-407F, R-452A, R-448A, R-449A, R-454C, and R-455A are now widely used for medium to large commercial refrigeration applications.

TFA/PFAS formation after the disintegration of new refrigerants: Some of the breakdown products such as TFAs could be harmful to the environment (concern raised by 5 countries in The European Union) and investigations/research is ongoing. Results are as yet inconclusive.

## Natural Refrigerants

Natural substances existing in our biosphere, e.g., water, ammonia, carbon dioxide, and hydrocarbons, are considered promising alternative refrigerants for some niche areas and applications. However, technologies to use natural refrigerants, in some cases (although commercially available) may be restrictive in some countries owing to safety issues but may bring forward robust and long-term solutions. Some countries in Europe have given special consideration to the use of natural fluids and have taken initiatives to either phase down or reduce the use of HFCs in the RACHP sector using natural fluids.

*Hydrocarbons have zero ODP and ultra low GWP but* are highly flammable (A3) and therefore safety aspects of their applications must be considered during handling, manufacturing, servicing, and disposal of the appliance or systems. The flammability introduces incremental product design requirements to reduce flammability risks. Owing to their excellent thermodynamic efficiency and ultra-low GWPs, HC-600a and HC-290 are being used in domestic and commercial plug-in appliances and systems with appropriate safety codes. In India, HC-290 is being used, to a limited extent, in room ACs, up to 5 kW. However, it is still a greater challenge to use any flammable refrigerants in higher capacity systems, as mini-split systems must be field installed.

*Ammonia (R-717), with zero ODP and Zero GWP,* is a thermodynamically attractive fluid that has been in use for decades in industrial refrigeration and cold storage but is toxic and mildly flammable (B2L) (Pearson, IIF-IIR). Therefore, proper training for service and maintenance is required. With the appropriate application of safety codes in Europe, ammonia has proved itself to be a viable substitute for high GWP refrigerants in direct and indirect systems for commercial, cold storage, and supermarket applications and some exceptional cases for air conditioning using secondary refrigerants.

*Water (R-718)* is a thermodynamically attractive, non-toxic and non-flammable refrigerant and above all is not detrimental to the environment (Pearson, IIF-IIR) . Although water is generally used as a secondary refrigerant, it is also used as a primary refrigerant e.g., sorption systems, steam jet refrigeration. In order to avoid conventional synthetic refrigerants due to climate concerns or flammable or toxic refrigerants for safety concerns, recent advances have made possible to use water as a primary refrigerant in chillers (Pachai, 2016). Although chillers using water have been demonstrated to perform better than conventional refrigerants, these suffer from economics due to relatively large compressor size (compressor suction close to the triple point of water at about 10 mbar) and other system design issues (high pressure ration and low volumetric capacity). Water-based refrigeration systems for industrial refrigeration e.g., mining and air conditioning are being used since 1990 (Eckert et al., 2022). The use of water is usually achieved through binary ice, which is an ideal secondary refrigerant that can be used as a replacement for directly evaporating refrigerants. In ice slurry, the latent heat of fusion is also used and has a rather large cooling capacity and at the same time, behaves very much like water.

*Carbon Dioxide (R-744)* is one of the most promising natural refrigerants with zero ODP, GWP of 1, and an A1 safety class. However, its critical temperature (31.1 °C) is very low and its vapour pressure is relatively very high. Therefore, the refrigeration cycle using $CO_2$ is uniquely operated as a trans-critical cycle and the efficiency of R-744 systems will depend on the ambient temperature. It is widely used for refrigeration in supermarkets in the EU where the ambient is mild (e.g., less than 20 °C) and the resulting COP of the system may be higher than that of R-404A. Its use is also growing in US. However, in warm and hot conditions, such as in India, the efficiency starts to fall and is lower than R-404A. The other development of R-744 systems is in transport air-conditioning, such as in trains and buses, in the EU region. R-744 is also used in the low-temperature cycle in commercial cascade systems.

## Lifecycle Refrigerant Management

Globally, there has been increased awareness and focus on “Lifecycle Refrigerant Management (LRM)”. Policy and practical guidelines, based on a global review, have been presented by Technology and Economic Assessment Panel (TEAP) Task Force (UNEP, 2024). Kumar *et al*. (2023) provides LRM policy guidelines specifically for India. TEAP (UNEP, 2024) report provides a comprehensive overview of LRM challenges, opportunities, and strategies, and to equip stakeholders with the necessary knowledge to address refrigerant management complexities effectively. and establishes the critical importance of LRM to minimise emissions, alongside phasing down HFCs, aimed at a more sustainable RACHP sector.

Every cooling product goes through many phases during its lifecycle such as installation, operation, service maintenance and finally End-of-Life. During each of these phases refrigerant leaks into the atmosphere which could occur due to improper installation or due to leaks in the cooling circuit that have developed over time due to exposure to corrosive environmental conditions. Sometimes, the refrigerant gases are also vented off during servicing or EOL. LRM aims to avoid any release of refrigerant gases into the atmosphere either through leakages or intentional venting. Thus LRM involves focusing on:

- Preventive measures to minimise leakages during installation and operation of the device,
- Recovery of gases during servicing or EOL, and recycling/reclaiming them for reuse or destroying the non-reusable gases.

Selection of material (galvanic factor) can impact the sub systems and components in the HVAC products and systems. The components and sub systems containing refrigerant if impacted due to corrosion has potential to cause leak. The components copper tubes in heat ex-changers, brazing material of copper to copper, copper to brass and copper to steel joints, steel in compressor body, receivers, suction accumulators, stainless steel in plate heat exchangers, brass in various types of valves, stainless steel body of thermostatic or electronic expansion valves, aluminium alloys in microchannel heat exchangers, mild steel shells in shell and tube heat exchanger need to be considered to prevent corrosion that can lead to leaks.

The environment in which the product get installed and operated has to be understood as a first step. In case the application is known in advance, it is possible to build a mitigation strategy say saline atmosphere near seashore or in corrosive chemical environment. In the larger systems like chillers and VRF, wherein the customers are technically aware of the application the design specifications are specified and the manufacturers design the products as per the specifications. However, in most of the cases the environmental conditions are not known at the time of manufacturing as the products such as Room AC are designed for general purpose application. The manufacturers need to design products, select components and select and adopt manufacturing processes to mitigate the corrosion.

## Refrigerant Emission Mitigation

Refrigerant emissions are associated with its handling, fugitive emissions linked to the number of fittings such as valves, flanges, etc., circuit openings linked to filter or oil change, repairs during the system operation, ruptures of safety valves, rupture disc, heat exchanger tubes, and metal recovery during equipment disposal, etc. Therefore, it is imperative to keep the systems leak-tight through trained personnel.

The primary option to mitigate HFC emissions may be the use of alternative non-HFC refrigerants, alternative technologies, recovery, recycling, and possibly destruction. Some of these are not yet cost-effective for developing countries.

## Zero Leakage and Minimum Charge

Non-Article 5 countries are now targeting minimum refrigerant charge and zero leakage during the life cycle of the system. The limitation of refrigerant emissions depends on an efficient recovery policy for end-of-life equipment, careful refrigerant handling by OEM, and efficient leak fixing during operation and maintenance by the service sector. Of these, the service sector has been identified as the primary area in need of improvement. There are concerted efforts globally to train technicians for good service practices towards zero leaks.

Service Sector: As the refrigerant scene is undergoing continued transition, the servicing, operation, and maintenance of different products/systems face multiple challenges. Some of the challenges faced by the service sector are listed below:

(a) At any given time, a technician will have to handle multiple refrigerants such as R-22, R-134a, R-407C, R-410A, R-32, R-404A, R-290, etc.

(b) The product technology is also fast changing, e.g., from fixed to variable speed, which is a challenge for the technician.

(c) In the case of flammable refrigerants, such as R-290, there is a restriction on the amount of refrigerant that can be carried in small cylinders.

(d) Retention of trained technicians is a challenge because of the seasonality of room AC usage.

As the currently used HCFCs and HFCs are mostly non-flammable and non-toxic, service personnel tend to be lax with safety issues. One major task is to train these technicians to change their attitude towards safety and to follow the new and more rigorous safety measures as stringently as possible. Products should be designed to avoid leakage of flammable fluids and most significantly eliminate possible sources of ignition.

## Recovery, Recycling, and Reclamation

For the sake of sustainability, there has been an increasing emphasis on the conservation of refrigerants and the reduction of emissions through recovery, recycling, reclamation, and destruction. More detailed discussion on these topics may be found in the UNEP Report (UNEP, 2014b) and IS/ISO 11650: 1999.

### Recovery

This process removes the refrigerant in any condition from a system for further processing. Refrigerant recovery systems are readily available, including in India. Recovery of refrigerant, especially from systems with relatively large quantities, has become a conventional part of servicing practices in most countries. The main incentive is refrigerant cost savings, besides environmental protection. In non-A5 countries, the regulatory framework is driving the recovery of refrigerants.

### Recycling

This process cleans the extracted refrigerant using oil separators and filter driers to reduce moisture, acidity, and particulate matter. Recycling is usually carried out at the field site. Since the quality of recycled refrigerant cannot be proven by analysis, some restrictions are imposed on the use of recycled refrigerants in some countries. Currently, the MAC industry reuses recycled refrigerant. Refrigerant recovery and recycling equipment have been made available to some OEMs, service stations, and technicians in India, through MLF funding and are being used.

**Reclamation**

This is to reprocess used refrigerants to virgin product specifications. Chemical analysis of the refrigerant is made to ensure that certain specifications are met. Reclamation extends the lifespan of the refrigerant and decreases the dependency on virgin refrigerant. Small portable refrigerant reclamation systems, capable of reclaiming about 80 kg of refrigerant per hour are available, with varying features. Reclamation is typically carried out in a designated facility. Reuse of recovered refrigerant requires adherence to certain good practices. For most refrigerants, there is a lack of affordable field instruments to measure the contaminant levels of recycled refrigerant after processing. Reclamation does require investment, which may only prove viable when the financial return of recovered refrigerant is sufficient. There are a few reclamation centres in India established through MLF funding.

**Destruction**

This process is to transform used refrigerant into benign chemicals in an environmentally responsible manner. There is a worldwide need for the destruction of ODS refrigerants because of the environmental benefits of the avoided emissions. The most common method of destruction is based on incineration. UNEP recognizing the benefits of ODS destruction in an environment-friendly manner, has approved certain processes. There are several approved destruction facilities, in both non-Article 5 and to a limited extent in some Article 5 countries, including India.

## ISHRAE Position on Refrigerants

ISHRAE is committed to the following:

- ISHRAE advocates a responsible selection of refrigerants, which minimize the environmental impact of refrigeration and air conditioning systems, ensure occupational safety, and resulting in low total ownership cost.
- To promote the use of refrigerants with zero ODP and low GWP, wherever suitable alternatives are available.
- For climate change benefits, energy efficiency is a key parameter for any given application.
- Use of flammable and toxic refrigerants mandates special requirements with respect to safety for systems, installations, operation and end of life disposal.
- Conduct a risk assessment for Indian conditions and develop industry guidelines, standards, and codes for the safe adoption of low GWP flammable refrigerants.
- Develop and use advanced design and installation codes, guidelines, and practices to reduce direct refrigerant emissions or follow the international standards as guidelines.
- Develop and use advanced practices and standard operating procedures and guidelines as well as use appropriate tools and trained personnel to minimize refrigerant losses during installation, operation, maintenance, and decommissioning.
- Promote recovery, recycling, reclamation, and destruction through appropriate mechanisms.
- Train personnel and support the student community, through information dissemination and collaborative research, towards responsible use of refrigerants.
- Promote sustainable RAC practices with a holistic approach.

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# About ISHRAE

The Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE) was founded in 1981 at New Delhi by a group of eminent HVAC&R professionals. ISHRAE has over 13,000 HVAC&R professionals as its members today along with 10,000 student members, and operates from 44 Chapters and sub-Chapters spread all over India, with its HQ in Delhi. It is led by a team of elected officers who are members of the Society working on a voluntary basis, collectively called the Board of Governors. In pursuance of its objectives, ISHRAE works in the areas of Research, Standards, Education and Training, and Publication of Technical Books and a Journal. It also organizes world-class annual exhibitions ACREX and REFCOLD, besides hosting technical seminars and conferences. ISHRAE is a responsible and socially-conscious Technical Society.

## Objective

- Advancement of the Arts and Sciences of Heating, Ventilation, Air Conditioning and Refrigeration Engineering and Related Services.
- Continuing education of members and other interested persons in the said sciences through lectures, workshops, product presentations, publications and expositions.
- Rendition of career guidance and financial assistance to students of the said sciences.
- Encouragement of scientific research.

## Activities

**Knowledge Dissemination:** ISHRAE conducts conferences, seminars, exhibitions, workshops, panel discussions and product presentations throughout the country with both national and international participants to discuss, promote and display the state-of-the-art technologies, systems, products and services.

**Books and Publications:** ISHRAE publications help its members and the industry to keep up with technical developments, latest trends and sunrise technologies. ISHRAE publishes Standards, books on fundamentals of various topics, HVAC&R Handbooks and the extremely popular and informative ISHRAE Journal. The latest publication is on Insulation

**Exhibitions cum Conferences:** ISHRAE organises ACREX India, the largest international exposition in South Asia on the Air Conditioning, Refrigeration, Ventilation and Building Services industry. Held annually, ACREX showcases the latest technologies and innovations, and provides a platform for buyer-seller meets for technical and commercial personnel in the HVAC&R field. To serve the interests of the Refrigeration and Cold-chain sector, ISHRAE organises REFCOLD annually. ISHRAE is a member and active supporter of the National Centre for Cold-chain Development (NCCD).

**Education:** ISHRAE is actively engaged in Education and Training, and offers several courses for technical professionals, some with post-examination certification. This helps to bring trained manpower into the HVACR industry.

**Research:** ISHRAE promotes research in the field of HVAC&R technologies. It offers financial support to graduate and post-graduate students to carry out innovative R&D work in technology, systems and processes. ISHRAE partners with the industry, academia and the government to carry out scientific research at Institutes of Excellence associated with ISHRAE.

**Standards:** ISHRAE works in the national interest with various government ministries and departments; for example, in the development of Standards and drafting of the National Building Code for the Bureau of Indian Standards, working on Energy Conservation Building Code with the Bureau of Energy Efficiency, and with the Ozone Cell of the Ministry of Environment, Forest and Climate Change on refrigerant gases. ISHRAE has also developed a pioneering Standard on Indoor Environmental Quality.

**Student Activities:** ISHRAE student chapters in more than 150 engineering colleges encourage students to opt for careers in the HVAC&R industry with industry exposure including factory visits. The K-12 initiative of ISHRAE reaches out to young school children to make them aware of subjects like energy conservation and environmental concerns through drawing competitions, poster designs, quizzes and more, with emphasis on STEM education to inculcate scientific fervour and help them to grow up as responsible citizens.

**Global Reach:** ISHRAE works in close co-operation with other similar societies and organisations, both at national and international levels, for the promotion and development of concepts like health and safety, sustainability, Green buildings, energy efficiency and environmental responsibility, often interacting with UN bodies like UNDP and UNEP.

ISHRAE is indeed looked upon as a repository of technical knowledge in the HVAC&R and Building Services Industry globally by peer organizations and the Government.