INDIAN CHILLER SECTOR
TOWARDS LOW GWP REFRIGERANT TRANSITION

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

SHEETAL
Alliance for Sustainable Habitat, Energy Efficiency and Thermal Comfort for All

INDIAN CHILLER SECTOR **TOWARDS LOW GWP REFRIGERANT TRANSITION**

Mr Ashish Saraswat and Mr Shanmuganathan K

The Energy and Resources Institute
Creating Innovative Solutions for a Sustainable Future

SHEETAL
Alliance for Sustainable Habitat, Energy Efficiency and Thermal Comfort for All

Authors

Mr Ashish Saraswat, Associate Fellow,
Mr Shanmuganathan K*, Associate Fellow, Earth Science & Climate Change (ESCC),
The Energy and Resources Institute (TERI)

Reviewers

Mr R R Rashmi, Distinguished Fellow & Programme Director, Earth Science & Climate Change (ESCC), TERI
Mr Jitendra Bhambure, Advisor Technology- Blue Star Limited

Acknowledgements

We extend our sincere thanks to Mr Sheetal Kulkarni, Sr. General Manager R&D, Blue Star Ltd., Mr Kapil Bhatia, General Manager at Daikin Airconditioning India Pvt. Ltd, Mr Shailendra Chauhan, Senior Manager, Daikin Airconditioning India Pvt. Ltd, Dr Nitin Karwa, Technical Leader – Stationary Refrigeration, Honeywell India Technology Center, Honeywell International Inc., Mr Ramchandran, Director, Eskayem Consultants for sharing their valuable insights and support during the course of the study. We are grateful to Mr R R Rashmi, Distinguished Fellow and Programme Director, Earth Science & Climate Change (ESCC), TERI and Mr Jitendra Bhambure, Advisor Technology- Blue Star Limited for their constant support and guidance throughout the study. We also thank our colleagues Mr Abhishek Kaushik*, Associate Fellow and Area Convener, Centre for Global Environment Research, TERI, Mr Manjeet Singh*, Associate Fellow, TERI and Mr Pradeep Kumar, Senior Fellow, Centre for Research on Sustainable Building Science (CRSBS), Mr Arupendra Nath Mullick, Vice President for their valuable insights and expertise.

We also extend our gratitude to TRANE for sharing the technical details of their case study project using the HFO refrigerant based chiller at India Trade Promotion Organisation (ITPO), Pragati Maidan, New Delhi. The contributions of TRANE greatly complements this report, in comprehending the environmental benefits associated with the HFO refrigerants and its potential benefits in the coming years.

* Was with TERI during the development of the Report

Editorial and Design Team

Rajiv Sharma and Sachin Bhardwaj

Supported by

This work was supported by Children's Investment Fund Foundation (CIFF) under the initiative SHEETAL: Alliance for Sustainable Habitat, Energy Efficiency and Thermal Comfort for All – working towards the opportunity for strategic actions to put forward the sustainable cooling agenda in India. TERI is grateful to CIFF and Honeywell for their support.

Disclaimer

The brief is prepared by The Energy and Resources Institute (TERI) after carefully analysing and processing the data and the information collected from primary and secondary sources. All opinions expressed, as well as omissions and eventual errors are the responsibility of the authors alone.

For more information

Earth Science & Climate Change Division, TERI,
Darbari Seth Block, IHC Complex, Lodhi Road,
New Delhi 110 003, India
Tel.: +91 11 2468 2100 or 2468 2111
Fax: +91 11 2468 2144 or 2468 2145
Email: pmc@teri.res.in
Web: www.teriin.org

MESSAGE

Thermal Comfort is one of the primary considerations for healthy living, sustainable development and India's commitment to climate resilience, and integrating climate friendly technologies with building design & construction is a clear path toward increased energy efficiency in buildings. To this end, Green Rating for Integrated Habitat Assessment (GRIHA) Council has accounted for the requirements of the Energy Conservation Building Code within the GRIHA Rating System, effectively ensuring a shift toward greener building material and envelopes, as well as a reduction in the energy demands of building equipment. India's tropical climate, demanding significant cooling loads, poses a unique challenge in addressing thermal comfort through the minimal and efficient usage of equipment. Vapor compression chillers are usually the equipment of choice in India's commercial building sector, mostly employing environmentally hazardous refrigerants that contribute to climate change. With the introduction of the India Cooling Action Plan, India's policies are converging with that of global economies towards implementing the requirements of the Montreal Protocol and Kigali Amendment. It is therefore high time to invest in the analysis of opportunities for low GWP refrigerants that could ensure a future of environmentally friendly thermal comfort in India.

It is my firm belief that this report could be a building block in India's quest to achieve environmentally friendly cooling. I congratulate the writers, reviewers and stakeholders involved in the inception, evolution and preparation of this report.

Sanjay Seth
Chief Executive Officer
GRIHA Council

TABLE OF **CONTENTS**

ABBREVIATIONS AND ACRONYMS

ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEE	Bureau of Energy Efficiency
BIS	Bureau of Indian Standards
BTU	British thermal unit
CFC	Chlorofluorocarbon
COP	Coefficient of performance
GHG	greenhouse gases
$GtCO_2$	gigatonnes of carbon dioxide
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HCFO	Hydrochlorofluoroolefin
HFC	Hydrofluorocarbon
HFO	Hydrofluoro olefin
HVAC	Heating, ventilation, and air conditioning
ICAP	India Cooling Action Plan
ISHRAE	Indian Society of Heating, Refrigerating and Air-Conditioning Engineers
NECA	National Energy Conservation Awards
ODP	Ozone Depleting Potential
ODS	Ozone Depleting Substances
RAMA	Refrigeration and Air-conditioning Manufacturers Association
VCR	Vapor-compression refrigeration

ABSTRACT

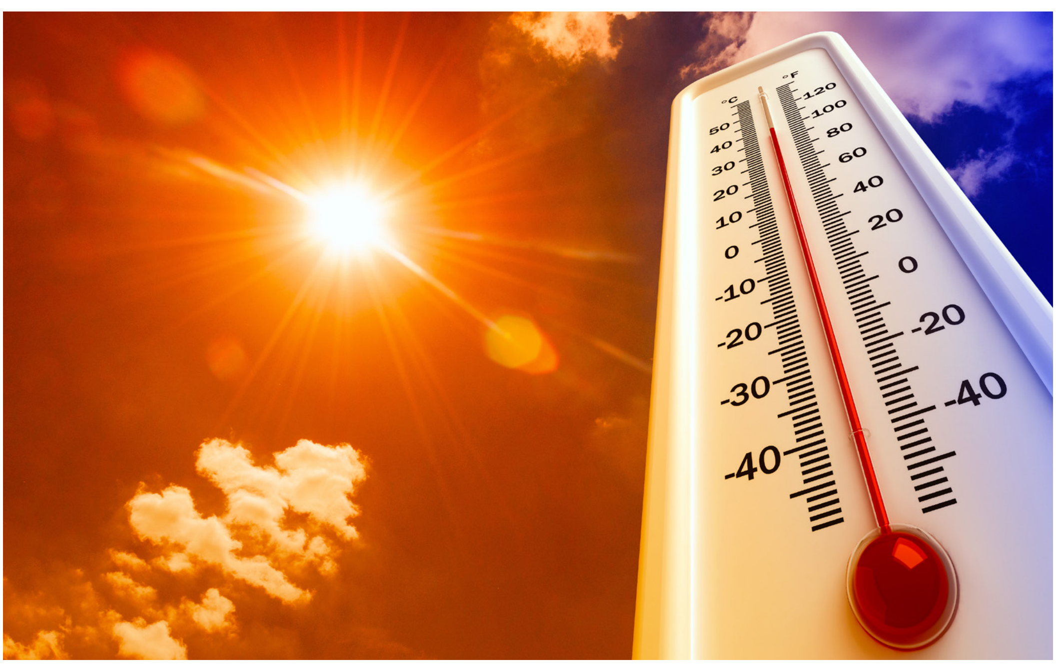
Rising global temperature because of colossal greenhouse gas emissions in the atmosphere is severely affecting the livelihoods of billions of inhabitants, animals, and other species. The persistent rise in temperature has steered the demand for thermal comfort (cooling need) multifold times in recent years and transformed it as a basic need for better productivity and economic development. The continuous growth of cooling, catering to the cross-sectoral needs, has accelerated energy consumption, refrigerant consumption, and its associated greenhouse gases emissions across all nations. However, the efforts of international commitments, national policies, and practices of clean technology solutions are complementing the abatement of increasing energy consumption and its associated greenhouse gas emissions. As the Indian chiller sector moves ahead, abiding the India Cooling Action Plan and the use of refrigerants with low global warming potential are the key towards India's commitments to global climate agendas. The paper aims to present the technology landscaping, challenges and opportunities for holistic integration of low-GWP refrigerants in the chiller sector in India. The study has investigated the different types of chiller technologies and refrigerant options. The study entails the efforts required for the transition of existing chiller sector to low-carbon scenario and adoption of environment friendly refrigerants aligning with India Cooling Action Plan over the next two decades.

Keywords: Space cooling, Chillers, Refrigerants, Next-generation refrigerants, GWP refrigerant

INTRODUCTION

According to World Metrological Organization[1], 2010-2019 was the warmest decade on record, and 2019 was the second warmest year on record after 2016. Facing the challenges of heat, air conditioning has gradually emerged a necessity from being a luxury for a range of applications requiring space cooling over the past few years. In fact, world economies are seeing air conditioning as the integral part of economic development.

Air conditioning, relying heavily on refrigerant-based technologies, are becoming a cause of environmental degradation because refrigerants have ozone depleting potential and global warming potential. India is one of the Asian countries that had a comparatively higher CAGR in space cooling equipment sales in the last decade. Fuelled by rapid growth of cooling equipment, India's peak electricity demand is expected to increase by 45% by 2050 from the baseline scenario of 10% in 2016[2].



1 WMO confirms 2019 as second hottest year on record. Details available at https://public.wmo.int/en/media/press-release/wmo-confirms-2019-second-hottest-year-record.

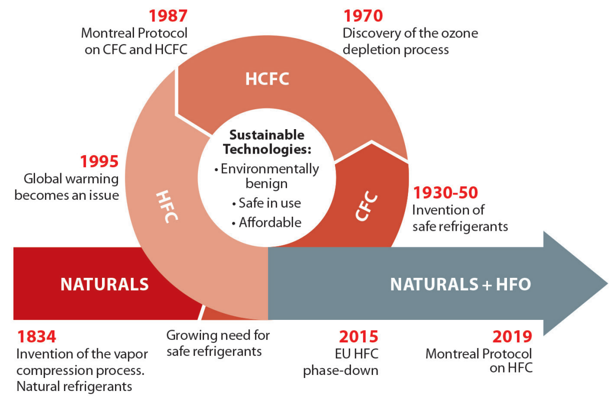
2 International Energy Agency - The future of cooling. Details available at https://www.iea.org/reports/the-future-of-cooling

The accelerated growth of cooling equipment and burden on grid would result in significant increase in greenhouse gas (GHG) emissions. The proportionate use of refrigerants having high ozone depleting potential and global warming potential (GWP) would also significantly contribute to the overall environmental degradation without any corrective measures.

India aligned itself well with Montreal Protocol through (HPMP) Phase Out Management Plan and further gave scope of leap frogging to low GWP options aligning with Kigali Amendments. Followed by phasing out of chlorofluorocarbons (CFCs), India completely phased out 'HCFC141b refrigerant' by 1 January 2020. However, similar proactive steps under the regime of Kigali Amendment would be a challenge due to discrete actions by cooling industry, policymakers, and other stakeholders. Cognizant of this, India rolled out its India Cooling Action Plan (ICAP) in March 2019 in a step to reduce carbon emissions across India's cooling sectors. Details of ICAP are explicated in the later part of the paper. ICAP recognizes chiller as one of important equipment feeding large space cooling loads and expected to grow in future thus requiring immediate attention. Unlike Room Air Conditioner, chillers come with about 25-year lifetime; hence early actions will ensure smooth adoption of low GWP refrigerants as well as lower life cycle climate performance. One way to minimize chiller's direct, indirect, and embodied GHG emissions generated over its lifetime is to adopt higher energy efficiency in chillers alongside integrating the environment-friendly low GWP refrigerants.

Considering the climate impacts of chillers, this report describes the current refrigerant trends, key challenges, opportunities, and possible interventions for India's chiller sector preparing to adopt environment-friendly low-GWP refrigerants.

BACKGROUND



In 1902, Willis Carrier laid the foundation of the modern air conditioning by creating an air conditioning system that countered the problem of water vapours at a Brooklyn-based printing plant. Subsequent cooling technology interventions paved the way for air conditioning to enter into the home cooling needs during 1929 when Frigidaire developed a home compatible cooling system. The increased need for cooling fueled the excessive use of Chlorofluorocarbons (CFCs) and Hydro-chlorofluorocarbons (HCFCs) refrigerants over the last 70–80 years. In the 1980s, CFCs proved to be the key substance that depleted the ozone layer. Thus Vienna convention led by United Nations Environment Programme (UNEP) and the subsequent Montreal Protocol brought the world economies together to protect the depleting ozone layer. The Montreal Protocol is considered to be the most successful environmental treaty that helped in phasing out ozone-depleting substances.

The Protocol established the time guide for phasing out substances that deplete ozone layer. Initially, chemicals with higher ozone depleting potentials, including CFCs and halons, were being targetted for an aggressive phase-out. Later, HCFC refrigerants joined the fleet in 1992 with the phasing out timeline being 2030 for developed countries and 2040 for developing countries, respectively. During that time, Hydrofluorocarbons (HFCs) were being used as an alternative refrigerants to HCFCs based on their lower ODP. Following the Kigali Amendment to Montreal Protocol enforced during 2019, countries were directed to phase-down HFCs by controlling their production and consumption. India falls in the third group of countries[3] (developing countries such as India, Pakistan, Iran, Saudi Arabia) that have to phase out HFCs by 2028 and reduce it to 15% of 2024–26 levels till 2047. Kigali Amendment has an influence on India's whole cooling sector as HFCs are widely used compounds in air conditioning. Taking this cue, the Indian chiller industry, over the years, has shifted from HCFC refrigerants to HFC refrigerants yet the goal to alternative low GWP refrigerants require sizeable efforts.

[3] First group consists of developed countries, e.g. the USA, the UK and the EU whose obligations to phase out HFCs began in 2019; they have to bring it down to 15% of 2012 levels by 2036. The second group consists of countries such as China, Brazil as well as some African countries that will start phasing down by 2024 and reduce it to 20% of 2021 levels by 2045.

Approach and Methodology

The approach and methodology adopted for developing this discussion paper included primary and secondary research. Primary research was conducted through consultation with stakeholders comprising chiller manufactures, architects, HVAC practitioners/consultants, policy makers, and building users/developers. Secondary research included conducting desk review of peer-reviewed journals, publications and scholarly articles pertaining to chillers in the global and Indian market. The details of the methodology is as follows:

Primary research

Primary research for the project was conducted in two stages. In the first stage, interviews were conducted to obtain qualitative data from the industry. These interviews were followed by a second stage where semi-structured interviews with industry experts were conducted to obtain quantitative data. The primary interactions were undertaken with defined stakeholders with the objective of understanding the current market scenario and trends. The information that was sought from the stakeholders included technologies, refrigerants, and barriers.

Secondary research

The secondary research was conducted through literature review, including industry reports, research papers and databases.

Methodology adopted

A market-based evaluation of chillers was carried out that focused on primary-data collection, different market scenarios pertaining to chillers and application sectors. The global and Indian refrigerant market in the context of chillers was analysed. In the next phase, technical performance of chillers with different refrigerants was analysed. Finally, technology, market barriers, and opportunities were evaluated.

1.1 Space Cooling: **Air Conditioning In India**

Globally[4], space cooling accounted for nearly 8.5% (equivalent to about 1 $GtCO_2$ emission) of total electricity consumption in 2019. India would be consuming more than 50% of global energy for space cooling by 2050.

India's space cooling is a mix of refrigerant-based and non-refrigerant-based cooling technologies with the former surpassing the later in terms of superior heat handling capabilities. Like global cooling market, refrigerant-based cooling technologies have a bigger share of vapour compression systems as compared to vapour absorption systems due to attractive techno-commercial benefits. As compared to vapour compression chillers that use compressor, vapour absorption chillers use the collection of waste heat from other processes or equipment to drive a thermodynamic process that allows water to be chilled and distributed for cooling. Air conditioning manufacturers and RAMA estimated that the vapour compression refrigeration systems in India hold approximately 90% share. Depending on application usage and cooling requirements, the commonly employed refrigerant-based cooling technology options in India can be divided between packaged air conditioning and central plant air conditioning.

Air conditioning in India

Packaged Air conditioning

- Window & Portables
- Large packaged and precision control
- Splits system:

  Single and Multi -splits - un-ducted; ducted; cooling only or heat pump; VRF

Central Plant Air conditioing

- Chillers
- Airside products

  Air handling units and fan coils other terminal units

India's residential cooling demand is mostly covered by non-ducted split- (wall mounted) and window- (through the wall) type packaged air conditioning and has a penetration of 7–9%. In the room air conditioner segment, the popular cooling products are split air conditioners, window air conditioners followed by cassette, ducted and tower air conditioners. Portable window air conditioners are still an unattractive segment as past attempts by

[4] OECD/IEA, The Future of Cooling Opportunities for energy-efficient air conditioning Together Secure Sustainable," p. 92, 2018. Details available at https://www.iea.org/reports/cooling

a few air conditioner suppliers have been unsuccessful. County's central plant-based air conditioning demand is mostly fed by chillers; however, growth of airside products and fan coils is low. Chillers in India are primarily used to handle high cooling loads; however, they lack penetration as compared to room air conditioners (Figure 1).

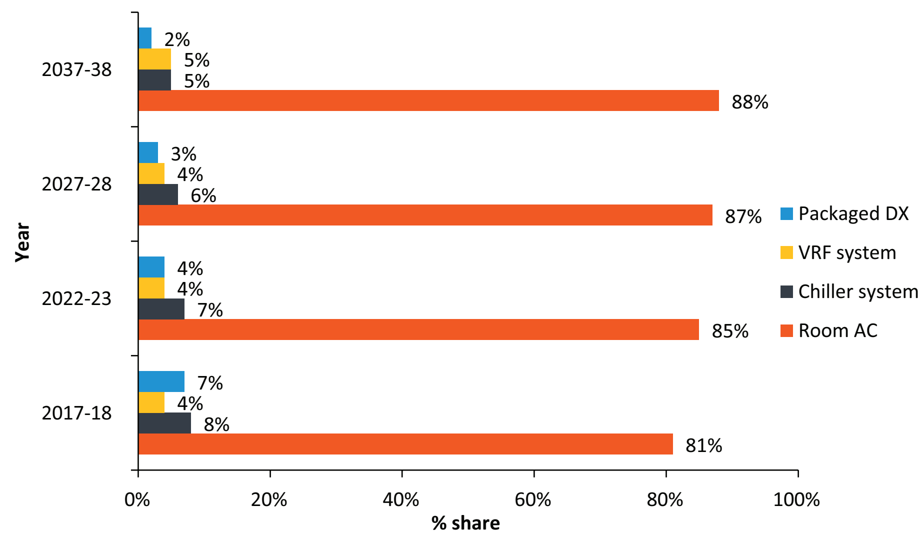


Figure 1: Refrigerant- based equipment stock
Source: India Cooling Action Plan - 2019

1.2 Factors Influencing Architect of **India's Chiller Sector**

In India, currently a diverse nature of factors guides the architecture of the chiller sector. Some factors target refrigerants whereas others target chiller equipment and consumers. The key factors affecting directly or indirectly the refrigerant-based cooling sector are as follows:

Kigali Amendment to the Montreal Protocol: The amendment came into force on 1 January 2019 with the intent to reduce HFC consumptions around the globe and avoid global warming by up to 0.5°C. This could be done by reducing the production and consumption of HFCs as they are potent greenhouse gases. India falls under group 2 of Article 5 countries and thus has a global push to phase down HFCs across applications. The Indian chiller industry is required to align itself with national commitments by reducing HFC consumptions.

India Cooling Action Plan (ICAP): The Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India launched a holistic plan titled the 'India Cooling Action Plan' to strategize its 20 years' action plan aiming to reduce its cooling demand, refrigerant demand and cooling energy requirements. The plan covers chillers as one of the sectors to achieve the targets.

Environmental Impact Assessment (EIA) and Clearance: Introduced in year 2006 by Government of India's Ministry of Environment Forest and Climate Change (MoEFCC), the policy aims to ensure incorporation of necessary environmental safeguards at planning stage in the project cycle to ensure minimal impact on different components of environment. This is a mandatory regime governing all buildings covering the projects with built-up area above 20,000 sq. m.

Energy Conservation Building Code (ECBC): Bureau of Energy Efficiency, Government of India, has laid down the energy performance requirements for cooling equipment in the Energy Conservation Building Code. The code accommodates the minimum efficiency requirements under BEE Standards and Labelling Programme for chillers in commercial buildings.

Standards and Labelling Programme (S&L): Bureau of Energy Efficiency, Government of India, has specified the grades of energy efficiency of refrigerant-based cooling equipment on the scale of Indian Seasonal Energy Efficiency Ratio (ISEER) factor vis-a-vis different capacities of these equipment. The programme provides the energy-efficiency labelling framework for cooling equipment suppliers in India and a choice to Indian customers to higher efficiency product available in the market.

Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE): The ISHRAE is an eminent body working with cooling stakeholders to support developing the standards for cooling equipment. ISHRAE, in consultation with Indian chiller industry and Bureau of Indian Standards, has developed the Indian standard for water cooled vapour absorption chillers.

Main ICAP goals:

- Reduction of cooling demand across sectors by 20% to 25% by year 2037–38
- Reduction of refrigerant demand by 25% to 30% by year 2037–38
- Reduction of cooling energy requirements by 25% to 40% by year 2037–38

Bureau of Indian Standard (BIS): This is the national body developing the standards, marking, quality certifications of cooling equipment. Through its institutional framework, the body ensures to place quality and reliability of cooling equipment. BIS introduced the chiller standard specific to Indian conditions. BIS has rolled out Indian Standard IS 16590: 2017 for water-cooled VCR chillers. BIS has a range of Indian standards applicable to mechanical refrigeration.

Other frameworks: Indian Green Building Council (IGBC) and Green Rating for Integrated Habitat Assessment (GRIHA) are the two other credit-linked frameworks governing India's building sector to award performance grades as per their own institutional frameworks. IGBC has Energy Efficiency Credits for buildings using eco-friendly refrigerants in the facility, thereby minimizing the impact on the ozone layer. GRIHA also specifies that chillers should comply with Energy Conservation Building Codes.

CHILLERS – KEY CONSTITUENT TO **INDIA'S SPACE COOLING**

Principally evolved from the first invention of carrier, chillers are favourite mechanical cooling solutions in hotels, hospitals, retail, data centres, airports, and other similar applications. Vapour compression chiller works with compressors whereas absorption chillers use high temperature heat energy to drive the cooling cycle, for use in commercial and industrial facilities. In India, vapour compression chillers are air-cooled or water-cooled types that are based on the medium used for heat rejection from the condenser to the ambient. Air-cooled chillers use air to cool the condenser whereas water-cooled chillers use water to dissipate heat to atmosphere through a cooling tower. Figure 2 shows a schematic layout of a single-loop water-cooled chiller that produces chilled water for space cooling. The major components of the system are a water-cooled chiller, a cooling tower, and air handling units for conditioning indoor air.

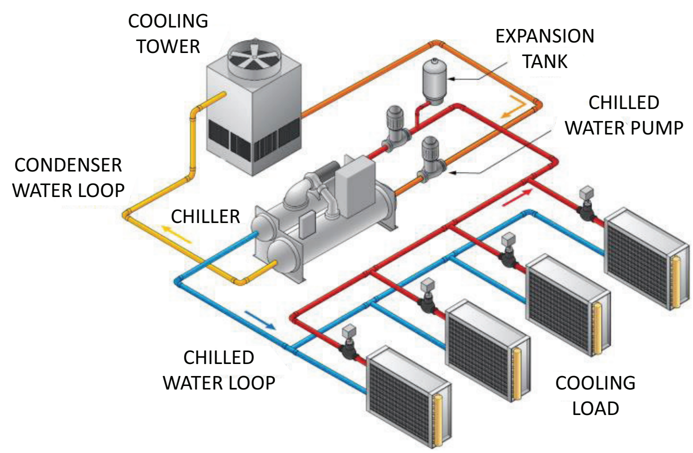


Figure 2: Water cooled chiller system
Source: Deakin-Chiller Application Guide

In the course of evolution, chiller equipment has seen numerous design changes due to different operating conditions, refrigerant usage, and technological advancement in the components. Current chiller systems are highly efficient in comparison to their counterparts that were available during the 1980s. Their efficiency levels have been continuously improving with the use of variable speed drives, DC compressors, oil free technology, falling film and flooded evaporators, high-efficiency heat transfer tubes, DC fan-motor combination fans, refrigerants, etc.

Due to their higher cooling capacities, chillers still remain one of the major power consuming equipment. ICAP highlights that if the electricity consumption of chillers escalates to 65 TWh in 2037–38 from 12.15 TWh in 2017–18, then it will result in more GHG emission.[5]

[5] India Cooling Action Plan - http://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf

2.1 Market Players, **Capacities, and Size**

Driven primarily by infrastructural development, the total market size of chillers stood around 1 million tonne of refrigeration (TR) per year in 2017[6]. In addition, the food processing, pharmaceutical, data centres, electronics, precision machining, plastic and printing industries are fueling the growth of chiller market in the country. The chillers are classified on the basis of type of compressor technology used.

Major market players	Blue Star; Carrier, Daikin, Johnson Controls Inc, Kirloskar, Trane, Thermax and Voltas;

Type	Description
Scroll Chiller	• Driven by scroll compressors, these chillers are used in both air and water coolers. In India, these chillers come with a range less than 150 tonne of refrigeration.
Screw Chiller	• Driven by screw compressors, these chillers are used in both air- and water-cooled and great fit for small to medium cooling loads. In India, the typical capacity range is between 50 and 500 tonne of refrigeration.
Centrifugal Chiller	• Driven by centrifugal compressors to handle medium to large cooling loads, these chillers are mostly used as water cooled. In India, the typical capacity range vary from 300 to 2500 tonne of refrigeration. These are compact in design and provide high cooling capacity.
Reciprocating Chillers	• Comes both as air-cooled and water-cooled reciprocating chillers. These chillers have acutely limited use in the Indian market.

Globally, screw chillers have significant market share as compared to other technologies. In 2017, this share was more than 35%[7]. There is also a slow emerging market for multipurpose chillers for application requiring heating and cooling simultaneously. As per RAMA and other manufacturers, the current total annual market (Figure 3) of VCR chillers in India is around 1.1 million TR, out of which 0.1 million TR market is of scroll chillers with capacities less than 100 TR, 0.6 million TR market is of screw chillers with capacities ranging between 60 and 500 TR, and 0.4 million TR market is of centrifugal chillers with capacities in the range of 400 to 3000 TR.

[6] Details available at https://pib.gov.in/PressReleasePage.aspx?PRID=1546137

[7] Details available at https://pib.gov.in/PressReleasePage.aspx?PRID=1546137

2.2 Market Dynamics

The findings of this section are primarily based on the consultations done with industry players, consultants, consumers, etc. The driving force behind the innovation in Indian chiller market is national energy conservation regulations, policies, and demand from customers. However, factors such as 'Kigali Amendment and ICAP', controlling the usage of high GWP refrigerant usage and 'HVAC / energy conservation consultant' in market are also creating demand for chiller technologies with environment friendly refrigerants.

Choosing a chiller: Chillers in India are offered both as customized and as complete packaged solutions. The selection of a chiller system is generally decided on the basis of required cooling capacity, desired coolant temperature, type of condenser (air- or water-cooled), energy efficiency (Energy Efficiency Ratio (EER) and Integrated Part Load Value (IPLV), and installation environment (indoor or outdoor installations). The capacity tonnes of refrigeration of a typical chiller takes into account the annual/daily cooling load profile with minimum and maximum daily/ monthly cooling load and fluctuations. For the performance of chiller systems, the performance curves for chillers and pump are used by the designer to achieve optimum performance. For packaged systems, the chiller manufacturer facilitates customers to select a combination of compressor, condenser, and cooler, based on the requirement of efficiency and tonnage as well as location that is climate dependent.

The manufacturer also considers other additional parameters such as COP, NPLV, energy efficiency, footprint noise, corrosive resistance, etc. to provide a national standard compliant solution to the customer. The overall life cycle cost, comprising initial investment and operational expenditure of the chiller system, is of utmost priority and considered for different applications except it is demanded by the end customer. HVAC consultants are contractors providing turnkey solutions mainly for commercial buildings.

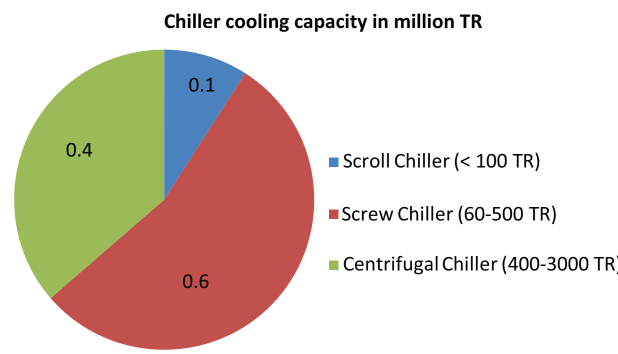


Figure 3: VCR chiller market in India

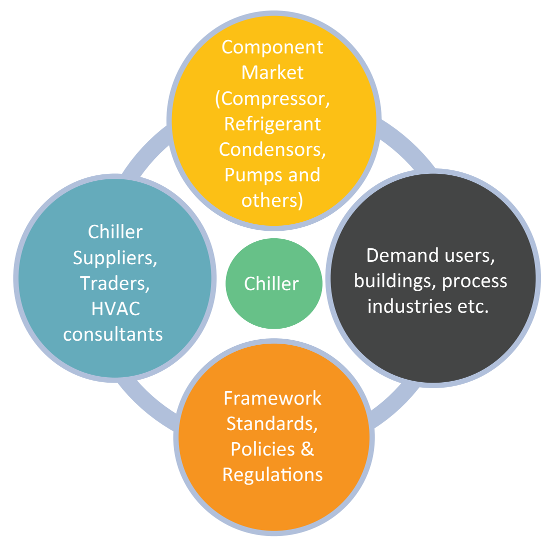
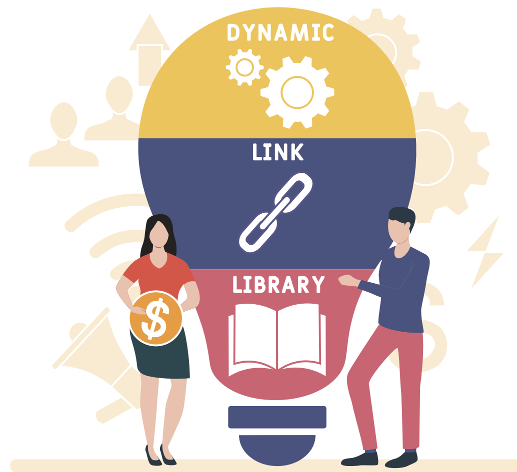


Figure 4: Chiller's market influencers

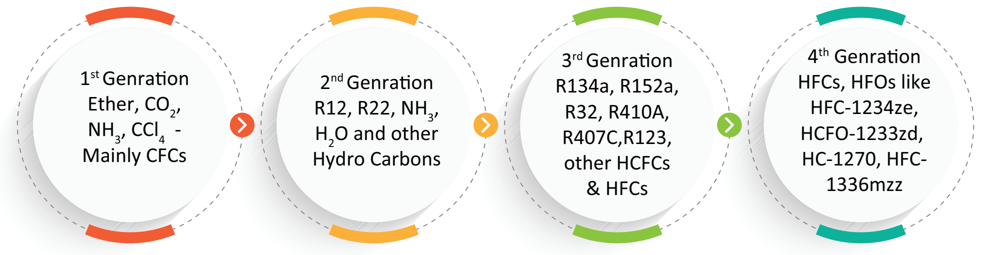
The type of chiller and operating temperature of fluid depends on the type of space cooling required in buildings and process cooling requirements required for industries such as plastic, medical, brewery, laser, dairy, food processing. For commercial air-conditioning in buildings, HVAC consultants play a major role in deciding the type of chiller to be used for a particular facility.



ECBC requires that performance computations in buildings are done according to ASHRAE 90.1 standard and tested as per AHRI 550/560 standards. BEE's star labelling programme provides the level-playing platforms for Indian chiller industry by specifying the energy performance standards. BIS has introduced Indian Standard 16590 to enable chiller suppliers to design chiller systems in compliance with Indian operating conditions under various modes of applications.

PROGRESSION OF **REFRIGERANTS**

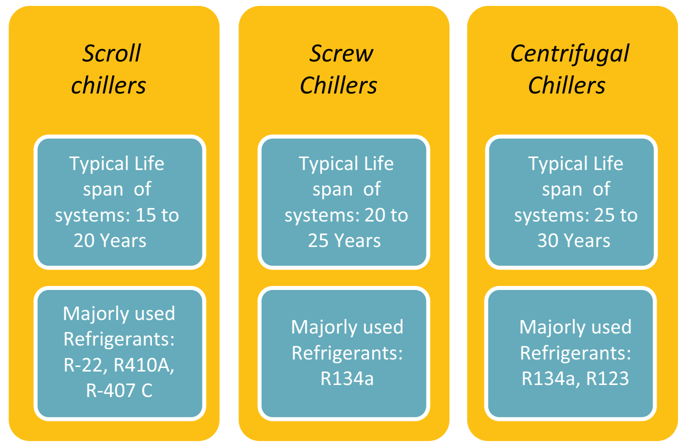
Globally, before the 1970s, the refrigerants used were toxic, such as ammonia and methyl chloride. Later on safer refrigerants based on their specific properties and feasibilities and to a large extent on the type of application's requirement, including CFCs, R22, R502, were used. The biggest driver in this movement was Montreal Protocol as it regulated the use of ozone-depleting substances across the globe. The refrigerants evolved largely based on their ODP and GWP values. ODP (Wuebbles et al., 1983) of a given compound is the count of its effectiveness in removing ozone relative to CFC-11 whereas GWP evaluates the energy absorption of 1 tonne of emitted gas as a factor of emissions of 1 tonne of carbon dioxide (CO_2), over a certain period, usually 100 years. These findings laid the foundations for global- and regional-level co-operations in regulating the use of ozone-depleting and high GWP refrigerants.



3.1 Refrigerant Movement in **Indian Chillers**

The Montreal Protocol in 1987 directed countries to phase out the then widely used CFC refrigerants, thus enabling a complete phase out in developed countries by 1996 and in developing countries by 2010[8] and switching to the next-generation HCFCs refrigerants that minimized ozone depletion.

Followed by the Montreal Protocol, India introduced Ozone Depleting Substances Rules 2000 under Environmental Protection Act 1986, which enabled the phase out of CFCs almost 17 months ahead of the target year of 2010.



Refrigerants used in Indian chillers

Further, Ozone Depleting Substances Amendment Rules 2014 directs the phase out of HCFC refrigerants in RAC products by 1 January 2025.

Current refrigerant movement mostly spans R134a (GWP of 1360 for 100 years), an HFC refrigerant used in centrifugal and screw chillers. Use of R123 (GWP of 79 for 100 years) is very limited in water cooled centrifugal chillers and R123 would be phased out in the country by 2025 as per the Ozone Depleting Substances (Regulation and Control) Amendment Rules, 2014. In scroll chillers, the commonly used refrigerants are R22 (GWP of 1810 for 100 years), R410A (GWP of 2088 for 100 years), and R407A (GWP of 2107 for 100 years). The movement of low GWP refrigerants has been very slow in India with the market presence of R1234ze, R1233zd, R513A, R514A and R515B being acutely lean. The commercial viability of low GWP refrigerants still needs to be explored in terms of component availability, competitive cost, safety, serviceability, sustainability, and other market-linked factors. The alternative low-GWP refrigerants and their characteristics are given in Table 1.

[8] Refrigerants: Market Trends and Supply Chain Assessment Chuck Booten, Scott Nicholson, Margaret Mann National Renewable Energy Laboratory Omar Abdelaziz Oak Ridge National Laboratory. Details available at https://www.nrel.gov/docs/fy20osti/70207.pdf.

Table 1: Alternative refrigerants and its characteristics

Refrigerant	Characteristic	GWP
HFO 1234ze	This low GWP refrigerant is a medium pressure hydrofluoroolefin with an A2L safety classification. It is highly compatible with majority of materials. Interestingly, it is non-flammable below 30°C, so it falls in the PED category 2 (non-flammable fluids) in the EU. R-1234ze is only suitable for new screw and centrifugal chiller designs as it is has lower capacity than R134a. Flammability for handling and storage is almost negligible.	<1
HCFO 1233zd	R1233zd is a low GWP liquid halogenated olefin with an A1 safety classification. Its boiling point is 18.3°C. Centrifugal chillers may attain a same energy efficiency using this refrigerant in place of R123. It has higher capacity and its operating pressure is higher than R-123, so it is only suitable for new designs.	1
HC 1270	A low GWP propylene refrigerant with flammable, non-toxic and good thermodynamic properties. The substance is an alternative to R22 in low- and medium-temperature refrigeration and air-conditioning applications. This requires specific charging and recovery methods due to its flammable nature.	2
R513A	A very low toxic, non-flammable hydrofluoroolefin refrigerant blend alternative to R134a in medium and high temperature refrigeration and chiller applications. The refrigerant falls under A1 safety classification.	631
R514A	A low GWP HFO blend with ASHRAE's B1 toxicity classification. Developed as an alternative to R-123 in low pressure centrifugal chillers for commercial and industrial applications. It is a non-flammable refrigerant suitable for systems and retrofits, which offers an optimal balance of properties, better energy efficiency, and environmental sustainability.	2
R1336mzz (Z)	A HFO with A1 safety classification, it has high critical temperature and is conducive to high condensing temperatures.	9

In terms of transition to low-GWP refrigerant, both refrigerant and chiller industries are at different stages and the market adoption of next-generation low-GWP refrigerants in chiller and component manufacturers is asymmetric.

3.2 Selection Criteria of **Refrigerants in Chillers**

According to ASHRAE terminology, refrigerant is the fluid used for the transfer of heat in a refrigerating system. It absorbs heat at low temperature and low pressure of the fluid and rejects heat at a higher temperature and higher pressure of the fluid and usually involves changes in the phase of the fluid. Refrigerants come with different thermodynamics, physical and chemical, that play a key role in obtaining desired system output (i.e. refrigerating effect) and input (i.e. electrical power consumption). To provide the desired level of cooling output, the compressor (another key energy consumer of a chiller system) combines the refrigerant and regulates its circulation in the chiller system. Aiming at commercial feasibility, the chiller manufacturer mostly chooses the tried and tested options of refrigerants available in the market. In India's chiller sector, commercially matured refrigerants are preferred due to their reliability, easy of availability, performance with highly varied ambient temperatures, serviceability, compressor guarantee for selected refrigerant, and compatibility with other components in the market.

Series of consultations conducted with industry stakeholders and users revealed that the global warming potential is a low priority factor considered by a chiller supplier when selecting the refrigerant, unless there is a specific requirement by a customer or any regulatory obligation (if exists) to use environment friendly refrigerants. Considering the case of buildings, the cost of the refrigerant is a categorical (it may depend on customer's will or supplier's push) consideration as the initial cost of the refrigerant may be less than 5% of the total cost of chiller, which is approximately 4 to 5% of the total cost of building.

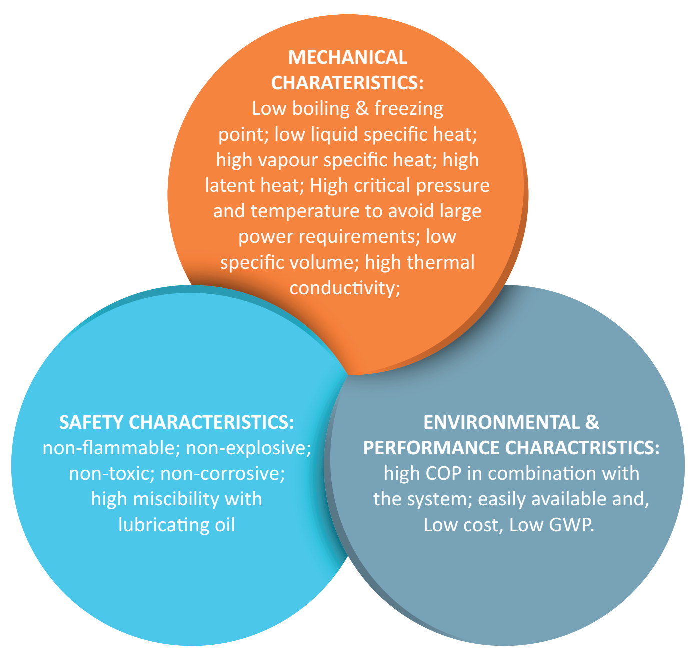
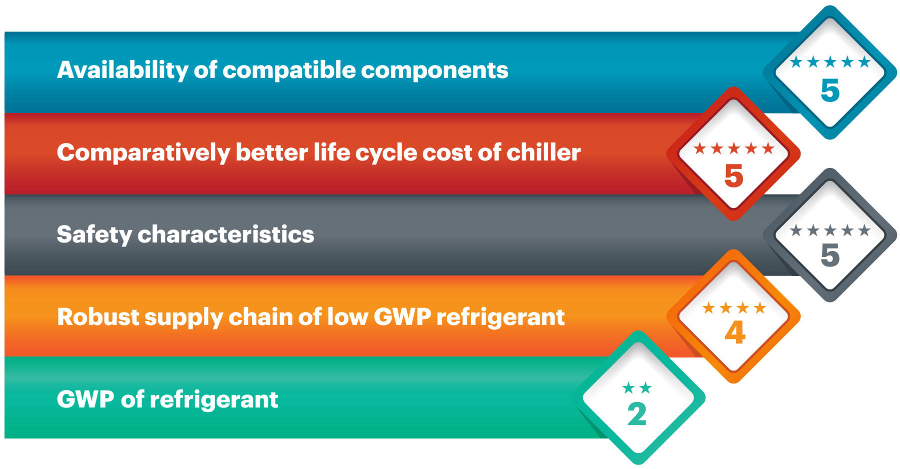


Figure 5: Broad categorization of refrigerant's selection criteria

PRIORITIES OF FACTORS FOR SELECTING REFRIGERANTS IN CHILLERS

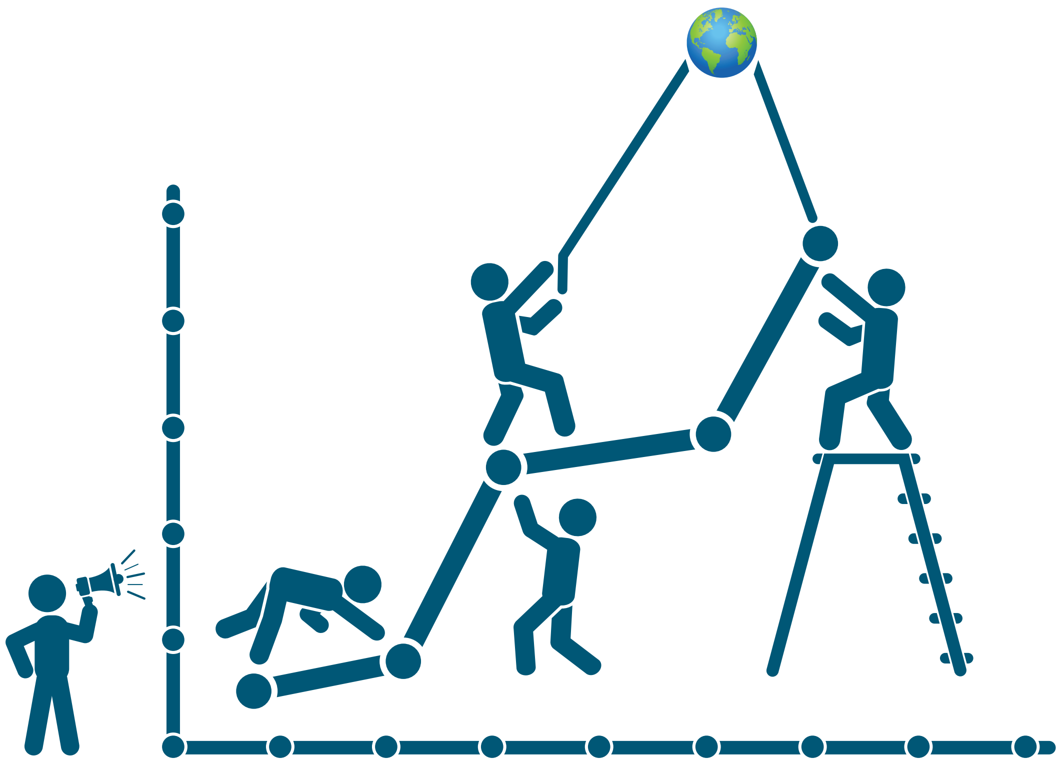


The Indian chiller market is primarily influenced by the HVAC contractors and chiller manufacturers; however, when it comes to new systems, the primary responsibility of the selection of refrigerant lies with the chiller manufacturers who strongly prefer to modify the design of the chiller to obtain the best performance. They discourage change in the refrigerant in the existing (unmodified) chiller system fearing 'unanticipated' performance of the system.

Regarding the customized chiller solutions, component industry (compressors, heat exchangers, etc.) players follow different low-GWP refrigerants owing to different control and pressure levels across applications. Upon further retrospection of the chiller industry, there is hardly any consensus amongst local component manufacturers on a common refrigerant to be followed in a finished chiller product.

3.3 Barriers: Adopting Low **GWP Refrigerants in Chillers**

On the road to embrace low-GWP refrigerant chillers, it is judicious if the barriers are analysed strategically. Under this research work, the barriers are the outcomes secondary literature and rationalized through consultations with various relevant stakeholders including policymakers, associations, consultants, technology providers at pan-India level. From literature review and stakeholder consultations, based on survey questionnaire, we inferred that there are several challenges (technical, capacity and awareness; behavioural; and policy) that impede the uptake of low-GWP refrigerants in the Indian Chiller market. During the course of the study, lack of awareness at technological front, economic viability and the need for capacity building were argued repeatedly as prime reasons for low penetration of low-GWP refrigerants in the Indian market. Exemplifications of each of these barriers are as follows:



Risks pertaining to supply and availability: Experts from HVAC and chiller industry opine that new low-GWP refrigerants (such as HFO 1234ze, HCFO 1233zd, HFO1336mzz) should be sufficiently available in the Indian market for easy, timely, and cost friendly replacements during longer period of use. Lean local supply chain, no clarity on refrigerant alternatives, dependence on imports infused with heavy taxes and duties lead to loss of confidence amongst market players to adopt low-GWP refrigerants. The chiller industry prefers that the refrigerant matures as a technology so that any “next change” in a short span of time can be avoided. While globally there are enough suppliers of HFOs, very few Indian companies manufacture HFOs. For example, Honeywell is the only prominent supplier of HFO 1234ze in India.

Lower readiness of chiller component market: Identical to other vapour compressions systems, chiller is also a highly engineered equipment in which various electro-mechanical components such as heat exchangers and valves are assembled together. The currently available chiller components in the Indian market are designed for optimal performance with control, pressure levels, and other parameters in accordance with commercially matured refrigerants such as R123 and R134a. If these components are simply used with any other low-GWP refrigerant, it may compromise the performance of the packaged (finished product) chiller system. This emerges challenging in terms of local production and just transition within the associated sectors of the low-GWP refrigerant chillers.

Reliance of chiller industry on compressor manufacturers: Compressor is one of the foundational components of a chiller system. It circulates refrigerant in combination with lubrication through the chiller system. In India, most of the chiller suppliers are majorly dependent on imports for low-GWP refrigerant-based compressors. The guarantee commitments offered by the compressor supplier are passed on by chiller supplier to end consumers. To offer vendible chiller packages to customers, chiller suppliers rely on compressor systems tried and tested with new low-GWP refrigerants.

Complexity with installed chiller systems at customer's end: The installed chillers were designed for specific conditions and refrigerants applicable around the time of installations. At this time when Kigali Amendment specifies reduction in the consumption of HFCs, India's efforts to adopt next line of low-GWP refrigerants in chillers will also encompass the existing systems. When considering retrofitting of these existing systems, it is required that unexpected future troubleshooting problems be avoided. Due to additional investments for retrofits, the customer hesitates in replacing these refrigerants in installed systems with low-GWP refrigerants ultimately leading to slower adoption of low-GWP refrigerants.

Challenges of affordability: The current Indian market is less inclined to expand to a new set of refrigerants because of affordability issues from the buyers end. For example, adoption of HFOs, which are 4 to 5 times costlier than currently used HFCs, mostly depends on the specific requirements of customers. Chiller manufacturers generally opt for HFC-based chillers offering similar or slightly lower efficiency of overall system as compared to an equivalent HFO refrigerant-based chiller.

Inadequate proficiency of service technicians and contractors: Refrigerant industry, chiller industry, and consumers (contractors, installers, HVAC consultants) in India are the key pillars for sustainable penetration of low-GWP refrigerants in chillers. On the low-GWP refrigerants side, existing contractors and service technicians are hardly equipped with the knowledge of handling new low GWP refrigerant-based chillers as a result of lack of appropriate training and capacity building.

Feeble financial support: Both customers and chiller manufacturers looking forward to adopt new low-GWP refrigerants in chillers are not getting adequate financial support in India. Manufacturers with their own efforts and funding develop low-GWP refrigerant-based chillers. Johnson Controls Inc. in India has installed a few chiller systems with HFO 1233zd refrigerant.

OPPORTUNITY LEVERS TO ADOPT **LOW-GWP REFRIGERANTS IN INDIAN CHILLERS**

The ICAP estimates that India's cooling demand (tonne of refrigeration) is expected to grow around 3.1 times in 2027 over the baseline, under the BAU scenario. It is also imperative that India's future cooling demand will greatly depend on the increase in urban infrastructure (around 9670 million square meters by 2030). Chillers are a mammoth cooling equipment feeding bulk cooling loads thus share an embracing opportunity in reducing the rising cooling demand. The opportunities for low GWP chillers may be ensured through:

4.1 Investment in **Infrastructure**

The growth of low-GWP refrigerant-based chillers substantially depends on the growth of HVAC systems. As the Indian economy expands, India would face a new era of space cooling needs.[9] A total of INR 57 lakh crore were invested in infrastructure from 2013 to 2019 with the major focus being on power, urban, digital, and railways sub-sectors. The power sector was mainly funded by the government, with little funding from private sector. As per the report of the Task Force by Government of India, a total of INR 111 lakh crore would cover sectors such as energy, airports, urban and railways from 2020–25.

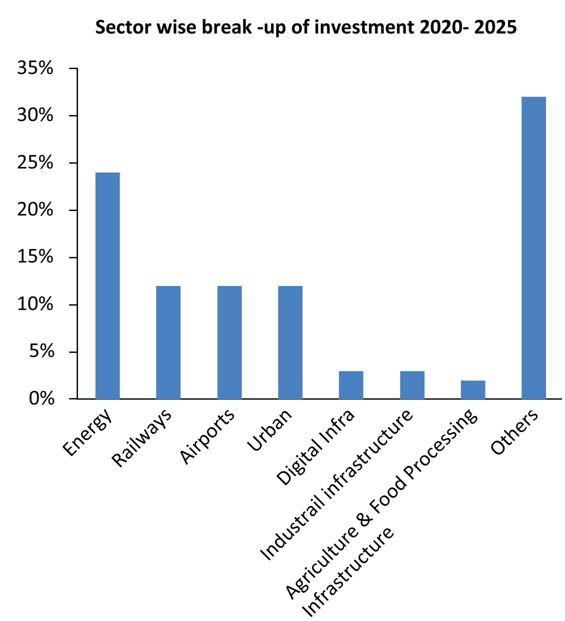


Figure 6: Infrastructure capital expenditure of INR 111 lakh crore during fiscals 2020- 2025

[9] Report of the Task Force Department of Economic Affairs Ministry of Finance Government of India. Details available at https://dea.gov.in/sites/default/files/Report%20of%20the%20Task%20Force%20National%20Infrastructure%20Pipeline%20%28NIP%29%20-%20volume-i_1.pdf

The Indian HVAC market is growing at 9.16% CAGR[10]. Further, a red carpet treatment is expected for industrial chillers in the plastic industry, pharmaceutical formulation, food and beverage processing, paper and cement processing, processes producing milk, meat, fruits and vegetables. Being an agricultural economy, the Indian economy is embarking on a huge potential for cold chain to process perishable produce[13]. A report on "Global Cold Storage Capacity Report[11]" mentioned that India is one of the countries with largest cold store capacity in the world. With more future infrastructural investments, there lies an opportunity for low-GWP chillers.

4.2 Energy-efficiency **Framework**

Adoption of new low-GWP refrigerants in chillers will be synchronous with the pace of optimization of chiller equipment as well as its components. With international and national policies pushing climate-friendly and energy-efficient cooling, there would be an increase in the demand of energy-efficient chillers with low-GWP refrigerants. Global experiments have led toefficiency improvements in chillers' integrating refrigerants of different characteristics; however, these experiments are at the level of manufacturers and limited to specific designs and operating and environmental conditions. In India, penetration of low-GWP chillers is primarily linked with policies and regulations. Government-led policy interventions regulating energy efficiency (BEE) of the chiller systems as well as environment friendly low GWP refrigerant adoption (ICAP) provide opportunity to chiller suppliers to adopt higher efficiency levels integrating low-GWP refrigerants in chillers. BEE has recently developed star ratings for chillers taking the reference of BIS standard for chillers (Table 2). The ratings are grades of Indian Seasonal Energy Efficiency Ratio (ISEER) tested under standard testing conditions. BIS introduced Indian Standard IS 16590: 2017 for chiller as per Indian operating conditions.

[10] Details available at https://acrex.in/uploads/Indian_HVAC_R_Scenario.pdf

[11] Details available at https://www.gcca.org/sites/default/files/2018%20GCCA%20Cold%20Storage%20Capacity%20Report%20final.pdf

Table 2: Minimum Energy Efficiency Requirements for Water & Air Cooled Chillers

Star rating levels for water cooled chillers					
kW of cooling	**1 star**	**2 star**	**3 star**	**4 star**	**5 star**
<260	4.8	5.2	5.6	6.1	6.6
>=260 & <530	5	5.6	6.2	6.8	7.4
>= 530 & <1050	5.5	6.1	6.7	7.4	8.2
>=1050 & <1580	5.8	6.5	7.2	7.9	8.7
>=1580	6	6.7	7.4	8.2	9
Star rating levels for air cooled chillers					
kW of cooling	**1 star**	**2 star**	**3 star**	**4 star**	**5 star**
<260	3	3.3	3.6	4	4.4
>=260	3.1	3.5	3.9	4.3	4.7

The efficiency levels prove to be the pull factors since the total owning cost plays an important role in the Indian chiller market.

Global manufacturers have progressed in this direction by adopting low-GWP refrigerants in chillers. The results show improvements in the efficiency of low-GWP refrigerant-based chillers yet it is hard to establish a direct linkage between refrigerant transition and improvement in efficiency of chiller system.

For example, Mitsubishi Heavy Industries, Ltd. (MHI) improvised its centrifugal chiller using HFO-1233zd(E) as the refrigerant to avoid direct greenhouse gase emissions associated with refrigerant usage. HFO1233zd(E) was adopted as a substitute to HFC134a. It has a volume of refrigerant gas which is about five times as large as that of the conventionally used refrigerant HFC-134a. The improved aerodynamic design with downsized compressors and heat exchangers results in compact design of the chiller and further technology advancements cascades minimal power consumption and averts its associated greenhouse gases emissions. The manufacturer claimed that the replacement of HFO1233zd(E) resulted in 3% improvement with COP in 20 USRT (US Refrigeration Ton chiller) for chilled water temperature 12°C in/7°C out.

To understand industry practices, the data of star-labelled chillers was also studied. Currently, very few chillers in the market are BEE star labelled and none of these chillers use low-GWP refrigerants. However, there are quite a few Indian chiller manufacturers who have commissioned low-GWP chillers in India. Jonhson Controls Inc has installed chillers with R1233zd(E) and Kirloskar Chillers is using R1234ze(E) refrigerant in its new line of chillers manufactured in India. There is a high probability that high energy- efficiency chillers with low-GWP refrigerants would lead to large- scale penetration of such chillers in the Indian market. Though the star-labelling programme does not cover the complete market of chillers in the country, it does cover the major share (VCR chillers).[12]

The programme will bring more than 4000 GWh saving potential with 3.5 million tonne CO_2 reduction in year 2030. Considering a conservative achievement of ICAP target (25% instead of 40%), Figure 7 shows that complying with BEE's star-labelling programme and accommodating low-GWP refrigerants will facilitate India's early transition in the chiller sector even though the Kigali timeline offers enough flexibility to India. Moreover, the current star rating programme is only a push for chiller's efficiency but does not specifically include low-GWP refrigerants.

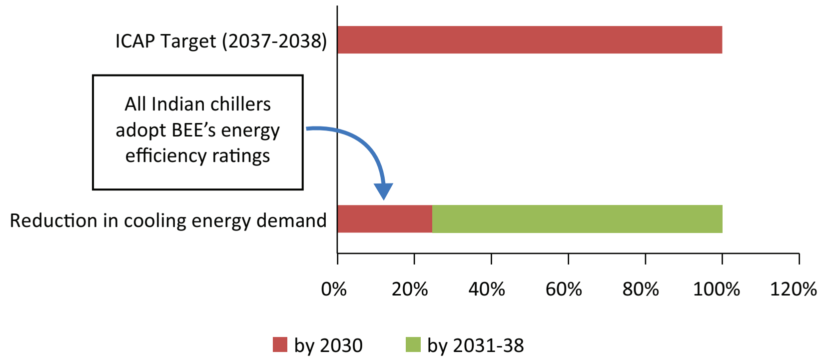


Figure 7: Benefits of mixing low-GWP refrigerants with efficiency

4.3 Energy-efficiency **Framework**

Buildings are key consumers of chillers in India and National frameworks affecting building frameworks such as Energy Conservation Buidling Codess in country are deriving the energy efficiency in country's buildings. The Indian Green Building Council's rating system for Green Service Buildings offers an additional 1 point for a new building that uses zero GWP refrigerant in the building's HVAC equipment. The rating system excludes small HVAC units with less than 0.25 kg of refrigerant.

Further, Energy Conservation Building Codes specifies minimum energy performance standards for chiller systems on the parameters 'COP – Coefficient of Performance measuring efficiency of chillers at 100% load' and 'IPLV – Integrated Part Load Value' measuring

[12] CLASP. Details available at http://indiaatcop24.org/images/presentation/10dec-Session1/1-Enhancing-Energy-Efficiency-in-Space-Cooling-Sector-through-Standard-and-labeling-Program.pdf

efficiency of chillers as a weighted average of full load and part load COP at fixed entering and leaving water condition in the evaporator but different condensing temperatures. ECBC, ECBC Plus, Super ECBC are building codes providing an overwhelming opportunity for energy efficiency in space cooling. However, they lack any credits for low-GWP refrigerant systems.

4.4 District Cooling **Initiatives**

Grounds are gradually building in India to adopt new initiatives such as district cooling which eye on providing more access to cooling with comparatively lower impact on heat island effect and noise levels. This would bring better municipal infrastructure in districts ensuring reliable and robust cooling access.

With threefold increase in building area by 2037, replacing individual room air conditioners with a comprehensive district cooling system would lead to significant reduction in energy requirements as well as CO_2 emissions. Chillers are also seen as the provider of affordable cooling in terms of district cooling initiatives in the country. Benefits such as reduced CO_2 emissions, power demand for cooling, lower cost of cooling to end-users are paving the way for district cooling in India. Already initiated, the district cooling systems in India are DLF Cyber city Gurugram- Haryana (Tri-generation District Cooling with cooling demand of 78,000 refrigeration tonnes), Amaravati Government Complex- Andhra Pradesh (the total cooling capacity is 20,000 TR).

It is estimated that approximately 51 million tonne of refrigeration of the national space cooling demand could theoretically connect to district cooling system. If served by district cooling, it would reduce the need for up to 22 GW of power capacity along with 27 million tonne of annual CO_2 emission reduction[13]. Globally, low-GWP refrigerants are in use for district cooling systems, with HFO-1234ze, HCFO-1233zd or HFO-based refrigerant R-514A. Considering India's climate commitments and tropical conditions, district cooling demand in India provides an opportunity for low-GWP refrigerant-based chillers in India.

[13] Uniindia. Details available at http://www.uniindia.com/news/east/energy-eesl-report/2345745.html

4.5 **Financing Mechanisms**

Low-GWP-based energy-efficient chillers systems require high investments and return risks; thus, financing such projects is the need of the hour. Financial instruments in the form of equity investments, loans or guarantees or other risk-sharing instruments may fulfil this requirement. Energy service companies (ESCOs), offering guaranteed savings against energy-efficiency technologies/services, are the game changers in this context. In India, partial risk sharing facility for energy efficiency is a risk-sharing mechanism that provides a unique investment support for energy-efficient projects. The facility especially works parallel to the energy service performance contracting offered ESCOs. The facility is supported by International Bank for Reconstruction and Development and the Clean Technology Fund (CTF). It supports the loans granted by various Participating Financial Institutions and by Small Industries Development Bank of India as lender.[14] The project has a total outlay of USD 43 million consisting of "Partial Risk Sharing Facility for Energy Efficiency" component of USD 37 million and technical assistance component of USD 6 million. The facility has a coverage of minimum INR 1,000,000 and maximum INR 150,000,000 for a guarantee tenure of 5 years or loan tenure whichever is lower, for eligible sectors such as buildings, MSMEs, and large industries (except power plants).

Apart from this, market-based tradeable mechanism like India's Perform, Achieve and Trade (PAT) may provide a platform for low-GWP refrigerant chillers. PAT sets the specific energy consumption targets for different industries (termed as designated consumers) under identified industry sectors, viz. Thermal Power Plant, Power, Petrochemicals and others. The trading of energy savings is facilitated through ESCerts (energy savings certificates) equivalent to 1 tonne of oil equivalent (toe) of energy savings. These mechanisms can be utilized by process industries reaping energy efficiency as well as environmental benefits.

[14] Details available at http://prsf.sidbi.in/

CASE STUDY 1

India Trade Promotional Organization (ITPO), New Delhi

Project site: India Trade Promotional Organization (ITPO), New Delhi

About Project Site: India Trade Promotional Organization (ITPO) is an iconic and prestigious edifice hosting large national and international exhibitions and conventions in New Delhi, India.

Area: 150 acres

Exhibition space: More than 6, 25, 000 square metres

With the recent technology developments, many facilities in India have started in piloting the low-GWP refrigerants (HFOs) in their utility operations. With its minimal GWP potential, the HFO based refrigerants leaves scanty carbon footprints and also complements for better HVAC systems efficiency. A successful case study of HFO based refrigerant chiller system is presented below with the environmental benefits.

Background

Pragati Maidan located in the heart of the national capital, is currently under renovation to transform it into a world class Integrated Exhibition- cum-Convention Centre (IECC). Contributing to its world class infrastructure construction design, a high efficiency heating, ventilation and air conditioning HVAC) system at state-of-the-art has been deployed by Trane systems. National Building Construction Code (NBCC) is the designated implementing agency in the execution of this prestigious appointment.

The shift towards low GWP footprint

In the initial stages of the design process, the technology provider team convinced HVAC consultant and customers for using new HFO's inline to the Kigali Agreement of the Montreal Protocol and its intended goal of alleviating the GHG emissions associated with refrigerant usages. Environmentally friendly HFO refrigerants, or Hydrofluro-Olefins, are a new class of refrigerants that have a much lessened Global Warming Potential (GWP) compared to the current HFC based refrigerants commonly used in major applications. Recognizing the importance of environmental aspect of cooling, NBCC included HFO based refrigerant as the part of the technical specification in the project tender.

For this prestigious project, Trane has successfully evolved the cooling system integrating HFO. The offered chillers with multistage compressor design, are designed to meet various applications and has helped customers to achieve operational savings while lowering their environmental footprints, without compromising safety, reliability and performance.

Powered by three Series E™ CenTraVac™ large-capacity (1,650TR) chillers with R1233zd (E) along with five CenTraVac (825TR) capacity chillers with R514a refrigerant, the Trane system maintains ambient temperatures at or around 25°C. The CenTraVacTM centrifugal chiller has the lowest total refrigerant emissions rate in the industry. Ensuring user comfort controls with easy-to-navigate touch screens and displays, it allows facility maintenance engineers to monitor the equipment and make adjustments as necessary. The offered CenTraVac series is part of EcoWise portfolio of products designed to lower environmental impact with next-generation, low-GWP refrigerants and high-efficiency operation – consistent with climate commitment to introduce products that reduce greenhouse gas emissions.

Cooling system – basic specifications: Total capacity of the system: 94,75TR comprising:

- 3# 1,650 TR Centrifugal Chillers with HFO1233zd (E)
- 5# 825 TR Centrifugal Chillers with HFO514A
- 2# 200 TR Screw Chillers with R134a

Comparison of R514A / R1233zd (E) and R134a chillers:		
Parameters	**R514A / R1233zd (E)**	**R134a**
Ozone Depletion Potential- (ODP)	0	0
Global Warming Potential (GWP)	2	1,430
Energy efficiency	13.5% over next competitor	Baseline
Low leakage rate	<0.5% per year	estimated 2% per year
Short atmospheric lifetime	26 days	14 years
Phase down date	N.A.	2028~2047 for India

CASE STUDY 2[15]

Waitrose Commercial Refrigeration

There are significant experiment-based evidences available to showcase the benefits of transition of low-GWP refrigerants in chillers yet these benefits are the outcomes of specially optimized chillers (including integral components) for certain applications.

On the front of low-GWP refrigerant chillers, these types of systems are under operations in India but the owners could not reveal the complete details of these facilities due to commercial conflicts. However, one of the below-mentioned international case studies of HFO Chillers installation reveals the benefits of switching to low-GWP refrigerant.

Project site: Waitrose, Bromley South, Bromley, Kent, United Kingdom

Refrigerant transition: The project site is a British supermarket chain having 2,170 square meter store area for groceries and food. The original chiller plant of the store was built in 1996 and uses R404A - an high-GWP HFC refrigerant. As an effort to move away from HFC refrigeration systems, the store installed two 180 kW air-cooled HFO chillers each with two compressors to deliver chilled water. The total cooling capacity of the chillers was 360 kW with 21° C/15° C secondary fluid temperatures using 30% propylene glycol and 35° C air on temperature, split equally between two machines. The new system used reciprocating compressors.

New system: The new chiller systems used non-toxic, mildly flammable HFO1234ze refrigerant with a low- level GWP of 6 as compared to HFCs in general. With an oversized (by around 6%) evaporators as compared to R134a, the refrigerant lines required re-sizing in the gas phase when using HFO1234ze. Spare parts for the system are available. A 22% reduction in energy consumption was identified when comparing the new system with a same-size store in Canterbury (in south-east England) running identical systems using R290 (propane). It was also found that there was a loss of capacity of around 24% compared with R134a across various application conditions. Besides loss of capacity, the new system was able to improvise the overall COP than R134a by absorbing almost 27% less mean power.

Cost and economy: At the time of installation, the capital cost of the new system was approximately 10% more than a propane equivalent. However, the lower cost could be achieved with increasing the production. There was no additional maintenance cost observed when comparing with hydrocarbon systems.

Note: The accuracy of the content and figures is the responsibility of the companies.

[15] The reference of this case study is from the compilation of case studies published as 'Low-GWP Alternatives in Commercial Refrigeration: Propane, CO_2 and HFO Case Studies'– by the United Nations Environment Programme.

WAY FORWARD

- **Government policies:** In India, the adoption of low-GWP refrigerant in chillers largely depends on local demand driven by government-led policies. Country-specific standards (BIS/BEE) available for the design of chillers as per Indian climatic conditions and India's endorsement to Kigali Amendment currently used HFC refrigerants, presents a great future for next-generation refrigerant transition in chillers. However, these standards and timelines capture the performance and HFC usage respectively. It is also a fact that after HFCs, low GWP refrigerants are the future of the chiller sector. Taking the existing references and synching HFC usage timelines, new regulation may be developed covering chiller industry to adopt low-GWP refrigerants in a phased manner across different capacity ranges, applications, etc. This phase-wise movement can help the industry to build resources and gradually move to low-GWP options.
- To address the combined effect of performance and environment, existing standards and ratings for chillers may be revisited to integrate their climate performance. This demand and, in turn, interest in chiller industry may be increased by help of various factors such as identified ministries in India may put efforts to promote low-GWP refrigerant chillers through country-wide awareness campaigns and by setting phase-out targets for high-GWP refrigerants for chillers.
- **Upscale financial mechanisms:** Due to higher cost of new systems and lesser demand, penetration of new technologies is always time consuming, especially in the context of developing countries. Initially, financial instruments can act as financial support to address the objectives of market-linked proliferation of low-GWP refrigerant chillers. Existing financial mechanisms, such as PRSF, takes in to account the energy efficiency and lacks any direct environmental benefits accruing through projects adopting low-GWP refrigerant chillers. In this case too, efficiency compliments important transition of low-GWP refrigerant chillers. Through joint efforts of different ministries, environmental benefits can be integrated in existing financing measures or a dedicated financing instrument to the tune of Partial Risk Security Fund can be developed that would bring a greater endorsement to technology advancements.
- **Synergized industry actions:** Chiller suppliers are heavily dependent on

compressor and other component industry in offering guarantee and service commitments to end consumers, which contribute to the overall cost of equipment. Due to unattractive local demand of new low-GWP refrigerant-based chillers, presently no manufacturer in India makes low-GWP refrigerant-based compressors of any category (screw, scroll and centrifugal) and is dependent on imports that generally use refrigerant trends of their countries. The Indian chiller component industry using different refrigerants brings ambiguity in the final selection of refrigerant for a chiller system. Thus, a synergism between chillers and component industry's actions would bring a smooth implementation of low-GWP refrigerants in chillers.

- **Technology transfer:** The Indian chiller industry's dependence on imported components threatens the delayed adoption of low-GWP refrigerants and a casual approach to 'Make in India' like initiatives. Technology transfer should be on the top priority for the commercial proliferation of new technologies and to do so involving MSMEs would create a bigger database towards self-reliance. Reviewing multilateral fund under Montreal Protocol that supports developing countries, utilizing international climate platforms such as Climate Technology Centre and Network (CTCN), public funded research institutions in India such as Centre for Scientific and Industrial Consultancy (CSIC), Industrial Research & Consultancy Centre (IRCC), Foundation for Innovation and Technology Transfer (FITT), research institutions as well as industries may be strengthened to build in-house capacity.
- **Facilitating industry to market their efforts:** At present R134a, a higher GWP refrigerant, is the widely-used refrigerant in the Indian chiller industry. Very few Indian chiller suppliers are adopting low-GWP refrigerants in chillers. Marketing the efforts of such suppliers may help bring awareness about running practices towards low-GWP refrigerant chillers. There are a number of platforms available to market the best practices of industries, namely Global Cooling Prize, National Energy Conservation Awards by Bureau of Energy Efficiency. Where global cooling prize includes 'prize money' to winners, National Energy Conservation Awards recognizes the efforts of industries, establishments, and organizations for energy efficiency and conservation by them. These kinds of awards may be leveraged to develop interest in the market.
- **Advancing awareness instruments and training:** Lack of awareness on environmental, safety and other associated benefits of low-GWP refrigerant chillers contribute to the demand aggregation gap. Printed information in the form of market-based environmental labelling, covering different climatic requirements of India, should be introduced to enable buyers to identify the benefits of low-GWP refrigerants-based chillers. Current labelling (Star Labelling for chillers) is limited to energy efficiency of chillers

and does not speak specifically on low-GWP refrigerants. Further, target consumer groups may be identified to train them on low-GWP refrigerants and their climate benefits.

- **Resource capacity building:** The present service technicians have the know-how of currently used HFC and HCFC (old installed systems) refrigerants in chillers. Similarly, contractors installing such systems are better tuned to HFC and HCFC refrigerant-based chillers. Integration of next-generation low-GWP refrigerants in chillers requires specific set of servicing skills owing to different mechanical characteristics. India's service technician sector comprises both organized and unorganized sectors. The government of India through MoEFCC and National Skill Development Corporation has facilitated training courses for these service technicians. Leveraging existing trainings specifically for low-GWP chillers, would ready the local resources for low-GWP refrigerant-based chillers.

REFERENCES

"WMO confirms 2019 as second hottest year on record." [Online]. Available: https://public.wmo.int/en/media/press-release/wmo-confirms-2019-second-hottest-year-record.

International Energy Agency - The future of cooling (https://www.iea.org/reports/the-future-of-cooling)

OECD/IEA, "The Future of Cooling Opportunities for energy-efficient air conditioning Together Secure Sustainable," p. 92, 2018.

"HVAC Systems Market Size Worth $208.6 Billion By 2027 | CAGR: 6.1%." [Online]. Available: https://www.grandviewresearch.com/press-release/global-hvac-systems-equipment-market.

Ministry of Environment, Forest & Climate Change (2019). India Cooling Action Plan

Schedule 21 for chillers, Bureau of Energy Efficiency. Available at https://www.beestarlabel.com/Content/Files/Chillers_schedule_21.pdf

Refrigerants: Market Trends and Supply Chain Assessment Chuck Booten, Scott Nicholson, Margaret Mann National Renewable Energy Laboratory Omar Abdelaziz Oak Ridge National Laboratory. Available: https://www.nrel.gov/docs/fy20osti/70207.pdf.

The Indian HVAC&R Growth Story, ISHRAE, ACREX. Available: http://www.acrex.in/uploads/Indian_HVAC_R_Scenario.pdf

Energy Conservation Building Code (2017), Bureau of Energy Efficiency, Ministry of Power

ISHRAE position document on Refrigerants for Indian Refrigeration and Air Conditioning Industries – Challenges and Responsibilities, Indian Society of Heating, Refrigerating and Air Conditioning Engineers

PACE-D Technical Assistance Program HVAC Market Assessment and Transformation Approach for India [12] The Cooling Imperative Forecasting the size and source of future cooling demand. Available: http://www.eiu.com/graphics/marketing/pdf/TheCoolingImperative2019.pdf.

Energy Labelling Requirement, Chillers, Bureau of Energy Efficiency.

Ryosuke Suemitsu, Naoya Miyoshi, Yasushi Hasegawa, Kazuki Wajima, Yoshinori Shirakata, Kenji Ueda "Development of centrifugal chiller and heat pump using low GWP refrigerant". Available: http://hpc2017.org/wp-content/uploads/2017/05/O.3.4.1-Development-of-centrifugal-chiller-and-heat-pump-using-low-GWP-refrigerant.pdf

GRIHA V.2019, A GRIHA Council Publication Volume 1, The Energy and Resources Institute

LEED 2011 For India, Indian Green Buidling Council

Dr. J Sarkar, IIT Varanasi, Selection of Suitable Refrigerant Pair for Cascade System. Available: https://www.coolingindia.in/selection-of-suitable-refrigerant-pair-for-cascade-system/

National Infrastructure Pipeline, Report of the Task Force, Department of Economic Affairs, Ministry of Finance, Government of India, Volume 1.

Mitsubishi Heavy Industries Technical Review Vol. 52 No. 4 (December 2015) "ETI-Z Series" Centrifugal Chiller Applied Low GWP Refrigerant to Contribute to the Prevention of Global Warming. Available: http://www.mhi.co.jp/technology/review/pdf/e524/e524088.pdf.

Summary Report, ATMOsphere 2010, International Workshop on Natural Refrigerants Brussels, Belgium 27 - 28 September 2010; Available: http://hydrocarbons21.com/files/ATMOsphere-report.pdf

Daikin: On the Move to Achieve Zero Energy with Chillers. Available: https://www.daikinindia.com/blog-details/move-achieve-zero-energy-chillers

Nihar Shah, Max Wei, Virginie Letschert, Amol Phadke "Benefits of Energy Efficient and Low-Global Warming Potential Refrigerant Cooling Equipment". Available: https://escholarship.org/content/qt98k072wv/qt98k072wv.pdf

Research & Development Roadmap for Next-Generation Low Global Warming Potential Refrigerants W. Goetzler, T. Sutherland, M. Rassi, J. Burgos November 2014. Available: https://www.energy.gov/sites/prod/files/2014/12/f19/Refrigerants%20Roadmap%20Final%20Report%202014.pdf

Johnson Controls; Refrigerant transition. Available: https://www.johnsoncontrols.com/-/media/jci/insights/2020/white-papers/refrigerant-transition/jci-refrigerant-whitepaper---may-2020.f?la=en&hash=FF1EB262F35D2CED511C18CCAA347DD103C66BFF.pdf

The evolution of the modern chiller. Avaiable: https://www.refrigerationandaircon.co.za/index.php/features/air-conditioning/167-the-evolution-of-the-modern-chiller

Trevor English, "The Engineer Who Invented Air Conditioning: Willis Carrier," Interesting Engineering, 2020. [Online]. Available: https://interestingengineering.com/the-engineer-who-invented-air-conditioning-willis-carrier.