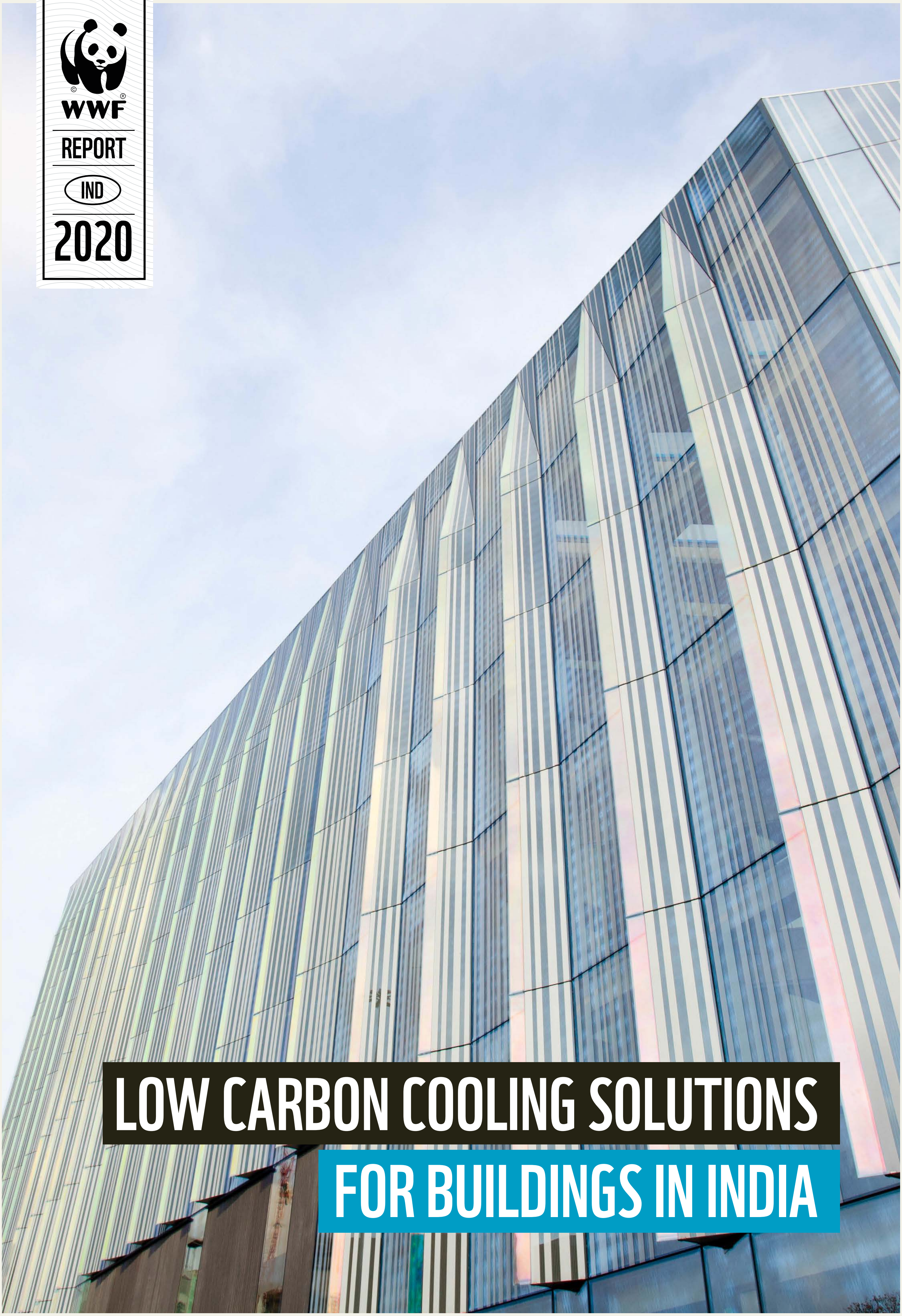
WWF

REPORT

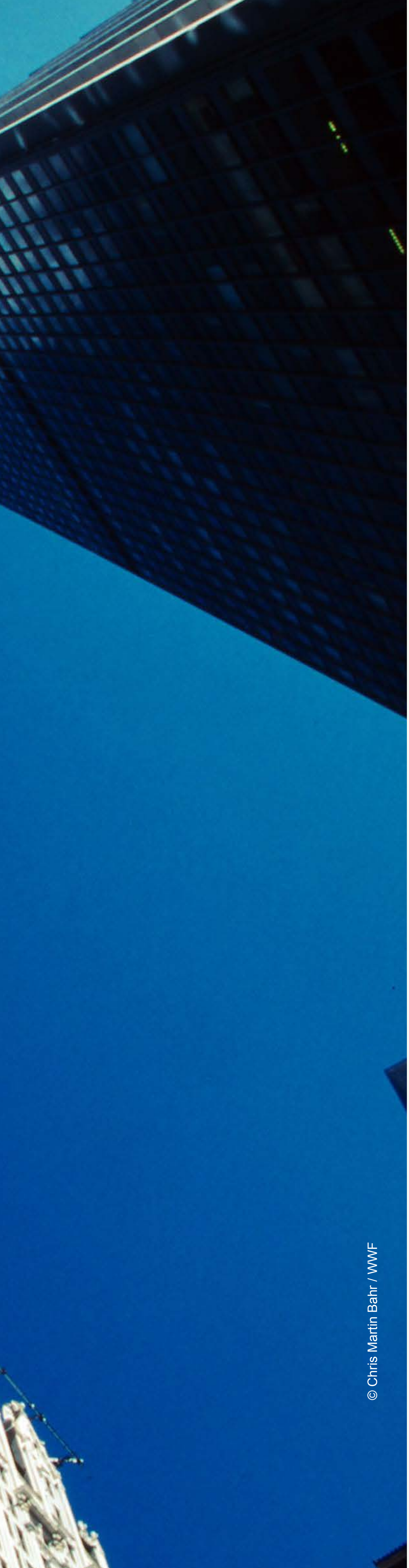
IND

2020



LOW CARBON COOLING SOLUTIONS FOR BUILDINGS IN INDIA

CONTENTS



© Chris Martin Bahr / WWF

ACKNOWLEDGEMENT

Published by WWF-India

Cover Image: **© Global Warming Images / WWF**

Acknowledgements

WWF-India and PwC India are grateful to all experts and specialists for providing insights during the preparation of this report. We would like to thank Dr Anant Shukla (EESL) and Mr Rajeev Chawla (Integrated Association of Micro, Small & Medium Enterprises of India).

We would also like to thank Rehau, Clique Solar, Rosemex Ecotech, Oorja Energy Engineering, Thermax Global, Scanair Engineering, ATE Technologies, Advantek Air Systems Pvt Ltd, SHiFT-Studio for Habitat Futures, Kapsun Resources Corporation, Cool Tech Engineers, Carrier Airconditioning Pvt. Ltd. , Dunham-Bush Ltd., Voltas and Blue Star Ltd for their inputs, deliberations and contributions. The support from WWF-US, and the John D. and Catherine T. MacArthur Foundation is appreciated.

Project Team

PwC India

Amit Kumar, Rajeev Ralhan, Bhaskar Jyoti Nath, Gurraj Bhinder, Ram Joshi, Sorabh Singhal

Dr. Jyotirmay Mathur, MNIT. Jaipur

WWF

WWF-India: Ashwin Jacob, Sakshi Gaur, T. S. Panwar

WWF-US: Catherine Rothacker, Daniel Riley

Design: Creative Curve Communication Pvt. Ltd.

Foreword

India has launched the India Cooling Action Plan (ICAP) in 2019 with an overarching aim to provide sustainable cooling and thermal comfort for all while securing environmental and socio-economic benefits for the society. Setting out a comprehensive, long-term vision, the ICAP has set goals to reduce cooling demand across all sectors by 20-25%, reduce refrigerant demand by 25-30%, and reduce cooling energy requirements by 25-40% by 2037-38. Moreover, it has recognized 'cooling and related areas' as a thrust area of research under national science and technology programme to support development of technological solutions and encourage innovation challenges. According to ICAP, currently India has low access to cooling, which is reflected in the per capita levels of energy consumption for space cooling at 69 kWh compared to global average of 272 kWh. However, as India's population continues to grow and become more affluent, this gap is expected to reduce, creating a need to meet the increasing cooling demand in a sustainable way. Low carbon cooling solutions could play significant role in realizing the goals set by ICAP.

The Bureau of Energy Efficiency (BEE) is playing an active role in promoting energy efficiency in buildings. It has launched the Energy Conservation Building Code (ECBC) in 2017, Eco Niwas Samhita for residential buildings and Star Labeling programme for residential buildings. It recognizes the importance of low carbon cooling solutions in reducing the cooling energy consumption and cooling related direct and indirect GHG emissions.

The Energy Efficiency Services Limited (EESL) is a Super-ESCO with an aim to deliver energy efficiency which is affordable and accessible. It is at the forefront in promoting energy efficiency, in general, and space cooling technologies, in particular, in India. It has successfully implemented energy efficiency projects in various appliance/ technology segments and has one of the world's largest energy efficiency portfolio. EESL's energy efficiency initiatives include programmes such as Unnat Jyoti by Affordable LEDs for All (UJALA), Street Lighting National Programme (SLNP), LED Tube Lights, Energy Efficient Fans, Building Energy Efficiency Programme (BEEP) and Smart Meter National Programme (SMNP) etc. EESL is currently working on various Programmes for space cooling with an objective to promote energy efficiency and reduce direct and indirect emissions due to cooling. These include "Creating and Sustaining Markets for Energy Efficiency", under GEF-6 cycle that focuses on identifying and promoting innovative technologies in air conditioners, motors, public charging infrastructure and tri-generation. Given it's huge savings potential on electricity consumption, peak load demand and GHG emissions, EESL's Super-Efficient Air-conditioner Programme (SEAP) intends to scale up the energy efficiency levels and promote the use of low GWP refrigerants in the Indian air conditioner market. EESL is currently working on a study under the District Cooling (DC) technology with an aim to assess the potential of district cooling in growing Indian cities. The study focuses on comprehensive overview of DC technologies, its various benefits, growth drivers and possible business models. It also discusses the technical, financial, policy and regulatory barriers for implementation of DC and provides recommendations for promotion and scaling up district cooling systems in India.

I congratulate WWF-India and PwC-India on carrying out a comprehensive study on low carbon cooling solutions. The report delves in to understanding the factors driving the demand for space cooling in buildings and estimates the long-term environmental impact of this growing demand under different intervention scenarios. It discusses different low carbon cooling solutions, and the barriers and challenges to their deep penetration. It deliberates on the role of SMEs as technology providers, adopters and innovators in this segment. Finally, the report provides recommendations to expedite the uptake of these solutions, promote research and innovation and develop long-term policy framework for this segment of cooling technologies. This report reinforces the goals set by ICAP in reducing cooling energy requirement and promoting R&D in cooling and related areas.

EESL will continue to promote energy efficiency in cooling in buildings in the country, and support efforts and interventions towards providing sustainable cooling for all.

With best regards,

Saurabh Kumar
Managing Director
Energy Efficiency Services Limited

EXECUTIVE SUMMARY

India's cooling demand is estimated to increase eight-fold from 2018 to 2038; space cooling represents a large proportion of this demand (57 per cent in 2018 and 74 per cent in 2038).[1] Two major factors are contributing to this increase: (1) increasing average air temperatures and more frequent occurrence of extreme heat events and (2) rapid growth in India's building sector. Average air temperatures have increased by 0.61°C per 100 years with a significant increase in maximum temperature of 1°C per 100 years.[2] In addition, extreme heatwaves have become more frequent in the past decade, leading to increased adoption of active cooling system.

The rapid expansion of India's building sector will add more than two billion m² of residential and commercial floor area to the country's building stock in the next two decades (2018 to 2038). Air conditioning use may rise from 8 per cent to 40 per cent in residential buildings and from 26 per cent to 54 per cent in commercial buildings, increasing space cooling demand by 11-fold.[3] This provides an opportunity to increase the share of innovative, low carbon cooling technologies in India's cooling supply mix, which is currently dominated by vapour-compression-based cooling solutions such as RACs (42 per cent).[4] These systems are major contributors to increasing peak electricity demand and associated direct and indirect GHG emissions, leading to global warming. Heat generated by air-cooled condensers also warms local air and contributes to the urban heat island effect.

The government of India has developed the Indian Cooling Action Plan (ICAP) as a transitional driver toward sustainable cooling solutions. This emphasizes a reduction in cooling energy demand by 25-40 per cent and refrigerant demand by 25-30 per cent by 2037-2038 from the baseline value in 2017-2018. India is also a signatory to the Paris Agreement and has pledged to reduce the emission intensity of its GDP by 33-35 per cent by 2030 in its NDC.[5] In order to meet the increasing cooling demand and maintain its commitment to sustainable growth, India must promote low carbon cooling solutions as an alternative to conventional vapour compression-based cooling systems. These solutions would provide acceptable thermal comfort with significantly lower energy and refrigerant requirements, and consequently reduce GHG emissions.

Although many low carbon cooling solutions have emerged in the Indian market over time, their penetration into the cooling supply mix has been notably low. Providing the necessary traction for these technologies requires understanding the reasons behind their slow adoption thus far, from the perspectives of technology providers, designers and end users. This report reviewed the status of the low carbon cooling ecosystem in India, focusing on SMEs and start-ups, to better understand:

- Low carbon cooling technologies currently available in India and their penetration in India's cooling supply mix;
- Their growth drivers and opportunities;
- Role of SMEs in the low carbon cooling segment;
- Challenges faced by actors within this ecosystem and their views on the nature and intensity of efforts required to expand this segment.

It also describes technologies currently in the prototype, pilot or early commercialization stage outside India with the potential to spread into the Indian market.

1 ICAP 2019
2 https://mausam.imd.gov.in/backend/assets/press_release_pdf/Statement_on_Climate_of_India_during_2019.pdf
3 ICAP 2019
4 ICAP 2019
5 https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/India%20First/INDIA%20INDC%20TO%20UNFCCC.pdf

The report first discusses growth in the building sector and the consequent increase in cooling demand, then describes issues with the vapour-compression-based coolingsolutions dominant in the current cooling supply mix. Next, it discusses the need for low carbon cooling solutions to ensure India's commitment to sustainable growth and considers the low carbon cooling ecosystem, its key players, and the pivotal role of SMEs and start-ups.

Chapter 2 defines the approach and methodology used to estimate cooling-related direct and indirect GHG emissions and stakeholder consultations. Chapter 3 expands on the sector-wide analysis of cooling-related emissions, including a discussion of baseline and intervention scenarios and their impact on projected emissions.

Chapter 4 focuses on the status and potential of low carbon cooling solutions in India, briefly discussing the major technologies considered before going into more detail on the role of SMEs as technology providers, innovators and end users, drivers, and opportunities. Chapter 5 discusses technical, financial policy and regulatory barriers. Chapter 6 discusses near and long-term recommendations for scaling up low carbon cooling and expanding the role of SMEs as technology adopters, technology providers and innovators. This chapter also discusses the role of policy makers, investors, academia and R&D institutions.

KEY FINDINGS:

- Current and projected emissions from space cooling are extremely high and must be addressed in line with India's commitment to sustainable growth. Under the BAU scenario, aggregated emissions from building cooling are expected to grow by around one and a half times by 2027, and seven times by 2050, over the 86MtCO_2eq in 2017.
- The current penetration of low carbon cooling technologies in India is noticeably low (0.84 million TR), demonstrating that this segment faces challenges and requires immediate attention and collaborative action from all players within the ecosystem in order to promote growth.

Technical barriers

- Apprehensions and misconceptions regarding low carbon cooling technologies are major barriers faced by technology providers.
- Technology providers find it challenging to identify and hire skilled human resources with technology-specific skillsets. Training and retaining dedicated staff over longer time periods is equally difficult.
- Many technology providers and SMEs particularly pointed toward the lack of mechanisms for business setup, citing similar opportunities available for start-ups.
- The additional time and effort required for designing and integrating low carbon cooling technologies is a major concern for end users and consultants.
- Technology providers feel that R&D in academic and research institutes does not focus on low carbon technology development and there is a dearth of industry-academia research collaborations.
- SMEs lack facilities for new product development and prototype testing that could accommodate low carbon cooling technologies.

Financial barriers

- Higher capital investment requirements discourage technology providers, architects and consultants from pushing for low carbon cooling technologies.
- Fewer alternative business models have been tested in this segment and have not met with notable success (with a few exceptions).
- Few financing products and funding schemes for end users are available in this segment, reducing the adoption of these technologies.

Policy and regulatory barriers

- Technology providers have univocally raised concerns over the absence of a policy environment conducive to upscaling this segment.
- Providers and suppliers have also raised concerns over a lack of dedicated business platforms for B2B meetings and product promotion.
- Many manufacturers have cited an absence of financial support, such as aid or tax benefits, as a major challenge to expansion.

KEY RECOMMENDATIONS

Based on interactions with various stakeholders in the low carbon cooling ecosystem and a comprehensive literature review, this report recommends the following:

Technical

- Inclusion of the low carbon cooling segment as a focus area for state-run and private incubation centres is essential for encouraging innovative technologies and business ideas.
- Development of performance standards and a labelling programme would act as a push-and-pull mechanism driving improved energy efficiency and improved marketing strategies.
- Establishment of specific training and skill-development programmes under government initiatives could help the sector develop a specialized work force and generate employment.
- Development of national and international industry-academia knowledge partnerships would foster innovation, cross learning and best practices while training future workers and generating employment opportunities.

Financial

- Developing and promoting financial incentives to end users could increase the adoption of these technologies.
- Greater emphasis on funding mechanisms and technical assistance would promote local manufacturing in India.

Policy and regulatory

- An inclusive policy environment would be conducive to the long-term growth of this segment, including effective promotion and implementation of such policies.

- Establishing dedicated B2B forums for the low carbon cooling segment could be beneficial for all players, especially the SMEs acting in dual roles as technology providers and adopters.
- Promotional activities and the recognition of achievers and innovators could increase the visibility of these technologies among potential end users, architects and consultants while building confidence.

In conclusion, low carbon cooling technologies are vital for the provision of sustainable cooling throughout India; SMEs that act as technology providers, innovators and end users are key players in this ecosystem. Developing this segment requires collaborative efforts from all stakeholders and players to build a conducive business environment, create funding opportunities, promote innovation, and design an inclusive and effective policy framework for the ecosystem to rely on. This report is intended to stimulate the growth of this segment by providing confidence and assurances to potential end users and consultants considering these technologies as well as a roadmap for future development.

LIST OF FIGURES

ABBREVIATIONS

AC	Air conditioning
B2B	Business to Business
BAU	Business as Usual
BEE	Bureau of Energy Efficiency
BMS	Building Management System
CAGR	Compound Annual Growth Rate
CCHP	Combined Cooling, Heating and Power
CFM	Cubic Feet per Minute
CO_2	Carbon Dioxide
COP	Coefficient of Performance
CST	Concentrated Solar Technology
DG	Diesel Generator
DCS	District Cooling System
DEC	Direct Evaporative Cooling
DOAS	Dedicated Outdoor Air System
DX	Direct Expansion
ECBC	Energy Conservation Building Code
ECBC-R	Energy Conservation Building Code for Residential Buildings
EER	Energy Efficiency Ratio
EPC	Energy Performance Contracting
ESCO	Energy Service Company
EU	European Union
EWT	Entering Water Temperature
GEF	Global Environment Facility
GHG	Greenhouse Gas
GSHP	Ground Source Heat Pumps
GWP	Global Warming Potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbons
HDPE	High Density Polyethylene
HFC	Hydrofluorocarbons
HFO	Hydrofluoro-Olefins
HPMP	HCFC Phase-out Management Plan
ICAP	India Cooling Action Plan
IDEC	Indirect and Direct Evaporative Cooling
IEC	Indirect Evaporative Cooling
IIM	Indian Institute of Management
IIT	Indian Institute of Technology
IMD	Indian Meteorological Department

INVENT	Innovative Solutions for Technology Development
IPCC	Intergovernmental Panel on Climate Change
IPLV	Integrated Part Load Value
IREDA	Indian Renewable Energy Development Agency
ISEER	Indian Seasonal Energy Efficiency Ratio
ISHRAE	Indian Society of Heating, Refrigerating and Air Conditioning Engineers
LEED	Leadership in Energy and Environmental Design
LiBr	Lithium Bromide
LPG	Liquefied Petroleum Gas
MCE	Magnetocaloric Effect
M-Cycle	Maisotsenko Cycle
MNRE	Ministry of New and Renewable Energy
MSME	Micro, Small and Medium sized Enterprise
Mt	Million tonnes
NGO	Non-Governmental Organization
NIDHI	National Initiative for Development and Harnessing Innovation
NSTEDB	National Science and Technology Entrepreneurship Development Board
ODP	Ozone Depleting Potential
OEM	Original Equipment Manufacturer
PEX	Crosslinked Polyethylene
PNG	Piped Natural Gas
PV	Photo Voltaic
R&D	Research and Development
RAC	Room Air Conditioners
RH	Relative Humidity
SEZ	Special Economic Zone
SIDBI	Small Industrial Development Bank of India
SME	Small- and Medium-sized Enterprise
SHGC	Solar Heat Gain Coefficient
SWHEs	Surface Water Heat Exchangers
TABS	Thermally Active Building System
TR	Tonnes of Refrigeration
UNDP	United Nations Development Programme
VAM	Vapour Absorption Machines
VRF	Variable Refrigerant Flow
WSHP	Water Source Heat Pump
WWR	Window to Wall Ratio
YOY	Year on Year

1. INTRODUCTION

1.1. IMPORTANCE OF LOW CARBON COOLING SOLUTIONS

India's cooling demand is projected to increase roughly eight-fold by 2037-2038 over the 2017-2018 baseline.[6] Space cooling for buildings, which accounted for 57 per cent of total cooling demand in 2017-2018, is projected to increase 11-fold during this period, reaching 75 per cent of total cooling demand in 2037-2038.[7] This increase can be attributed to two major trends: (1) year-on-year increases in average summer temperatures and increasing occurrence of extreme heat events and (2) growth in the building sector.

Climate-change-induced global warming has had a significant impact on annual mean land-surface air temperatures in India. According to the Indian Meteorological Department (IMD), the average temperature in 2019 was 0.36ºC above average (1981-2010), making 2019 the seventh warmest year since 1901.[8] Average and daily peak temperatures have risen and extreme heat events have become more frequent, leading to increased mortality during heat waves.[9] During the warmest recorded year (2016), the mean air temperature exceeded the average by 0.71ºC. In addition, 11 of the 15 warmest years on record (1901-2019) occurred from 2005 to 2019.[10] In urban areas, increasing air temperatures are coupled with the urban heat island effect, increasing the situation's severity.[11] This has led to an ongoing increase in cooling demand.

Figure 1: Annual mean land-surface air-temperature anomaly over India from 1901-2019. The dotted line shows the linear trend in the time series. The solid blue line represents the sub-decadal time scale variation smoothed with binomial filter (Source: IMD, 2019)

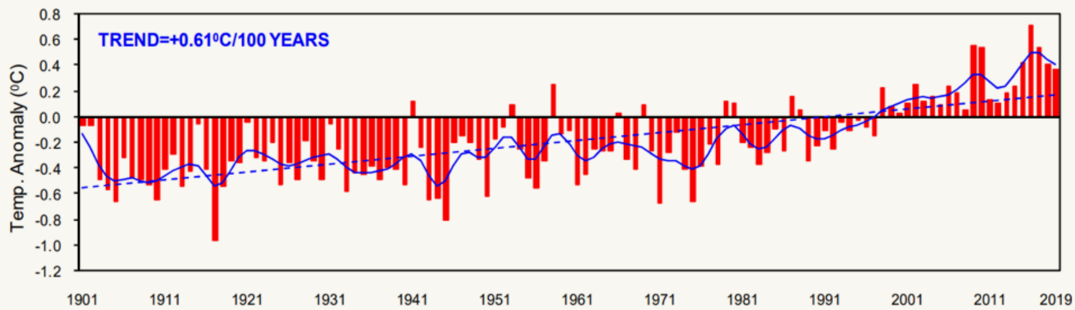
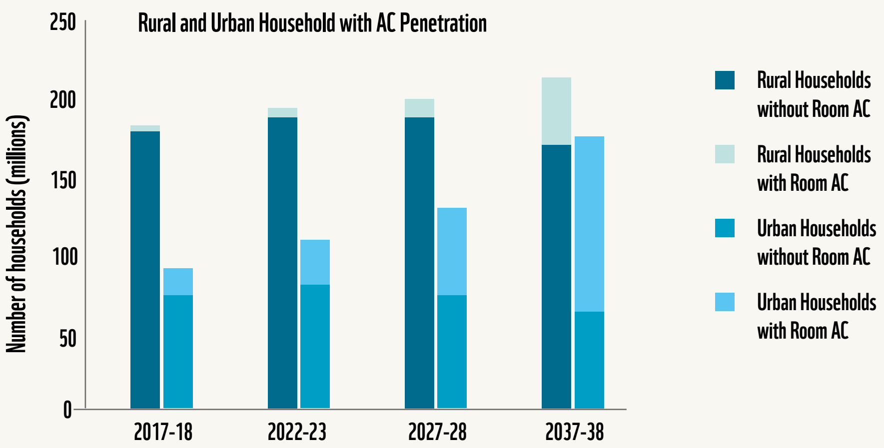
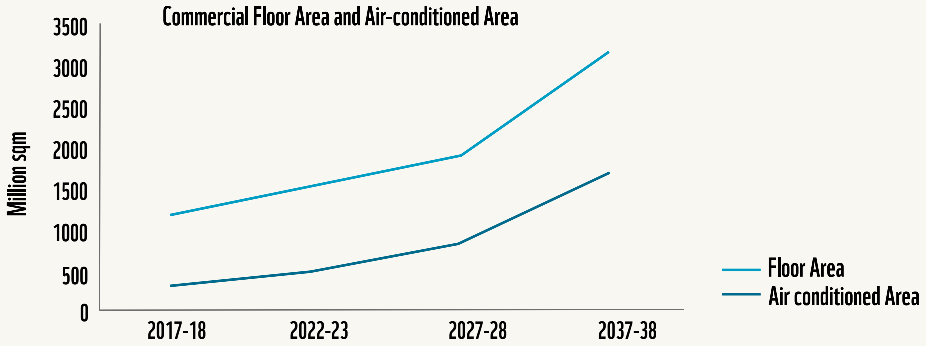


Figure 2: Projected penetration of air conditioning into rural and urban households (Source: ICAP, 2019)



6 ICAP 2019
7 ICAP 2019
8 https://mausam.imd.gov.in/backend/assets/press_release_pdf/Statement_on_Climate_of_India_during_2019.pdf
9 https://www.ctc-n.org/sites/d8uat.ctc-n.org/files/resources/roadmap_for_urban_heatwave_warning.pdf
10 ICAP 2019
11 https://www.wri.org/blog/2019/10/buildings-are-hidden-source-indian-cities-extreme-heat#:~:text=India%20is%20ground%20zero%20for%20extreme%20heat.&text=The%20urban%20heat%20island%20effect,concentrated%20human%20activity%20and%20construction.

Figure 3: Projected increase in total and air-conditioned commercial floor area in India (Source: ICAP, 2019)



The unprecedented expansion of India's building sector means that residential building stock is projected to increase from 272 million households (over 15 billion m^2) in 2017-2018 to 386 million (over 28 billion m^2) by 2037-2038. Similarly, the commercial building sector is projected to increase from 1.2 billion m^2 in 2017-2018 to 3.1 billion m^2 in 2037-38.[12] Electricity consumption in buildings accounts for more than 31 per cent of India's electricity consumption.[13] Buildings consumed 343TWh in 2017, of which HVAC-related consumption in residential and commercial buildings was 95TWh and 74TWh, respectively.[14] This is projected to grow at a CAGR of 5-7.8 per cent for residential buildings and 7.6-10.1 per cent for commercial buildings through 2030.[15] Space cooling is a major end use in Indian buildings, due to its predominantly warm and humid weather conditions. The current penetration of air conditioning in residential and commercial buildings is projected to increase from 8 per cent to 40 percent and from 26 per cent to 54 per cent, respectively, by 2037-2038.[16] This can be attributed to an increase in disposable income and, more importantly, an increasing need for cooling as temperatures rise.

Understanding and recognizing cooling as a necessity and major energy-consuming end use, India has developed the ICAP, which aims "to provide sustainable cooling and thermal comfort for all while securing environmental and socio-economic benefits for the society". ICAP emphasizes reducing cooling energy requirements by 25-40 per cent and refrigerant demand by 25-30 per cent by 2037-2038, against the 2017-2018 baseline.

Vapour-compression-based cooling solutions dominate the present supply mix used to meet cooling demand. These require considerably higher starting power than their average running power consumption; such momentary surges raise the burden on already-stressed electricity grids, leading to blackouts and burnouts. They also contribute to increasing electricity consumption, which causes indirect GHG emissions as most power generation in India is coal-based.

These systems also increase refrigerant demand, which is associated with GWP and ODP. The GWP value quantifies the direct GHG emissions caused by a refrigerant when released into the atmosphere. Although the implementation of the Montreal Protocol regulated the use of refrigerants causing ozone depletion, the rate of increase in demand for high-GWP refrigerants outpaces the rate at which the air-conditioning industry is transitioning to more environmentally friendly alternatives. According to the Global Cooling Prize report, the direct and indirect GHG emissions from RACs alone could contribute to a 0.5°C increase in global warming by 2100. Thus, meeting India's cooling demand through conventional technologies could pose a major challenge to its ambitious target of becoming a US$5 trillion economy while maintaining its commitment to ICAP targets.

12 http://iess2047.gov.in
13 https://niti.gov.in/sites/default/files/energy/ECBC_report.pdf
14 http://iess2047.gov.in
15 https://www.brookings.edu/wp-content/uploads/2018/10/The-future-of-Indian-electricity-demand.pdf
16 ICAP 2019

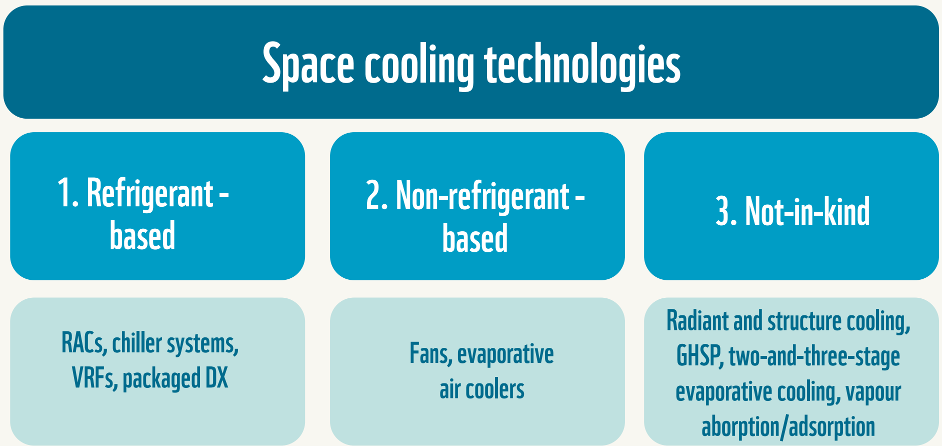
In addition, air-cooled compressors used in split RACs (very common in the cooling supply mix), VRFs and chillers expel heat directly into the outside air, increasing the local air temperature and further increasing cooling demand, producing a vicious cycle. This is also a major contributor to the urban heat island effect that increases the severity of extreme heat events in urban areas.

To reduce mortality rates due to extreme heat events and increasing average temperatures, provide thermal comfort to all, and ensure sustainable growth, it is imperative for India to promote and scale up innovative low carbon cooling solutions as an alternative to conventional appliances using vapour compression. These low carbon solutions would provide acceptable thermal comfort at significantly lower energy and refrigerant requirements, thereby decreasing both direct and indirect GHG emissions.

1.2. OVERVIEW OF INDIA'S RAC MARKET

India's cooling supply mix comprises refrigerant-based, non-refrigerant-based and not-in-kind technologies as shown in Figure 4.

Figure 4: Classification of space cooling technologies in India



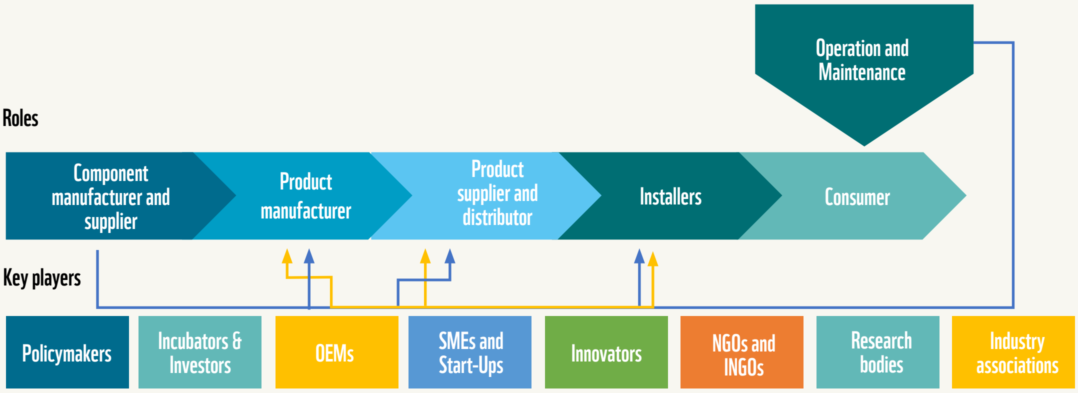
Category 1 (refrigerant-based technologies) is most commonly used for space cooling, with a nationwide installed capacity of ~66 million TR in 2017-2018.[17] This segment comprises vapour-compression-based technologies including RACs, chillers, VRFs and packaged DX systems. These are the major contributors to space-cooling-related direct and indirect GHG emissions. The current refrigerants used in this segment, HFCs, have zero ozone depletion potential. However, when released into the atmosphere, they have significant GWP. The growing international emphasis on climate change mitigation has stimulated interest in a new generation of low-GWP-based refrigerants such as hydrocarbons and HFOs. The suppliers of refrigerant-based technologies are predominantly large corporations or OEMs with standard products for each capacity range and application type; little or no customization is possible in these products.

Category 2 (non-refrigerant-based technologies) includes fans and evaporative air coolers. These are not considered further in this report because they do not offer humidity control (and therefore cannot replace technologies in category 1) and are non-refrigerant and non-compression-based technologies with inherently low carbon emissions relative to categories 1 and 3.

Category 3 (not-in-kind technologies) predominantly comprises non-refrigerant-based technologies including structure cooling, evaporative cooling, GSHPs, vapour absorption and desiccant cooling (along with refrigerant-based radiant cooling), with a total installed capacity of 0.84 million TR in 2017-2018. These technologies are mostly customizable cooling solutions specific to a particular application, and are the primary focus of this report.

17 ICAP 2019

Figure 5: Low carbon cooling ecosystem: Roles and players

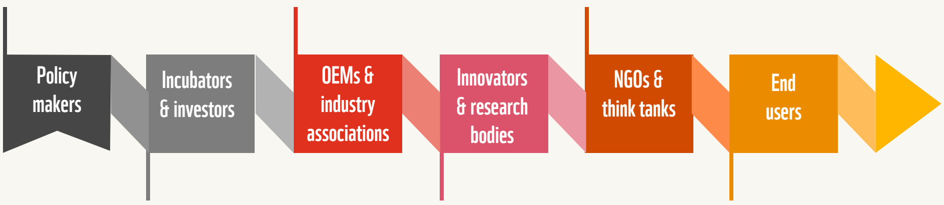


The blue line suggests various roles that SMEs play e.g. Component and Product manufacturer, installers, consumers and operation and maintenance.

Similarly, OEMs, marked by yellow lines, show their involvement as Product manufacturers, Suppliers and distributors, and Installers.

Although this category has been present in India for over a decade, its share in the cooling supply mix is low as it faces several challenges. Overcoming the existing challenges to increase penetration into the marketplace will require contributions from all actors in the low carbon cooling ecosystem (Figure 5).

The low carbon cooling ecosystem consists of multiple actors: policy makers, incubators & investors, OEMs, innovators, NGOs/think tanks, research bodies, industry associations and end users. SMEs and start-ups are heavily represented in this ecosystem and play multiple roles. For example, of the total number of technology providers consulted for this report, more than 60 per cent belonged to the SME sector. This can be attributed to the nascent stage of low carbon cooling solutions in India and the tendency of SMEs to be dynamic, adaptable and innovative with



regard to technology and business models, prudent, and robust, such that they can address specific market needs and challenges. They play many different roles in the low carbon cooling supply chain, including designer, consultant, manufacturer, technology integrator, installer, operator, adopter and end user. SMEs and start-ups also act as technology and business innovators and disrupters. Overall, SMEs and start-ups drive innovation and enhance efficiency by bringing innovative products and alternative business plans to the low carbon cooling segment. This report is focused on understanding the status of different low carbon cooling technologies in India, the current market and opportunities, growth drivers of this segment, and challenges faced by technology providers. Particular focus was placed on SMEs and start-ups in order to understand their perspective on the expansion of this segment.

2. STUDY APPROACH AND METHODOLOGY

2.1. APPROACH

Given the multidimensional nature of this report, the project team adopted an open, adaptive and consultative approach to cover its various aspects at a pan-India level, primarily focusing on SMEs engaged in low carbon cooling technologies. The key objectives were to:

- Collect inventory/sales data for various cooling equipment (for emission calculations);
- Project growth for cooling equipment through 2050 and estimate associated emissions;
- Assess various low carbon cooling solutions available in India and determine their suitability, applicability and growth potential in the Indian cooling ecosystem;
- Consult various SMEs and start-ups serving as suppliers, providers or integrators of low carbon cooling solutions and gather their perspectives on barriers and growth drivers for these technologies in the future;
- Explore the role of SMEs and start-ups in providing innovative technological and business models for scaling up low carbon cooling solutions.

Both quantitative and qualitative research approaches were adopted. Quantitative research primarily involved deriving GHG emissions from space-cooling applications under different scenarios, while both qualitative and quantitative methods were used to analyse the barriers and challenges, growth drivers and roles of SMEs and start-ups in order to determine suitable recommendations.

2.2. SUPPLY AND DEMAND SCENARIO

2.2.1. Primary research

In order to understand the low carbon cooling sector and achieve the report's objectives, the project team conducted semi-structured stakeholder consultations with technology providers including OEMs, SMEs and start-ups, architects and designers, and academia. These consultations were designed to understand the design, technological and financial aspects of every technology, related policies and regulations.

2.2.2. Secondary research

A literature review was conducted to assess current and projected emissions from cooling in buildings, including publicly available studies carried out by government bodies, research institutions and NGOs. Data on key assumptions, timeframes, technology coverage and resultant emissions was collated and compared. The project team also conducted research to understand the global context of these technologies in order to harmonize global and Indian best practices. Literature reviewed for this purpose included academic papers, government policy documents and reports, and studies published by research bodies, NGOs and the industry.

3. EMISSIONS FROM SPACE COOLING IN INDIAN BUILDINGS

As refrigerant-based cooling equipment dominates the space cooling segment in the Indian building sector, calculating the current and projected energy consumption and emissions from different cooling equipment formed the first necessary step. This also provided an opportunity to review the current status of refrigerant-based cooling equipment along with its future growth trajectory (in terms of efficiency and refrigerant use), climate impacts and the potential effects of innovation in the low carbon cooling segment.

This section estimates direct and indirect emissions in different scenarios along with the impact of adopting low carbon cooling solutions that provide thermal comfort at significantly lower energy and refrigerant requirements as well as lower GHG emissions.

3.1. INPUTS FOR EMISSION CALCULATION

The projected emissions from space cooling in India considered both direct and indirect emissions from various equipment types used in the residential and commercial building sectors, including:

- Specification of relevant equipment type along with current and projected cooling load for each;
- Development of emission scenarios considering BAU projection and possible improvements including various policy initiatives, technology improvements, and improved service and maintenance practices.

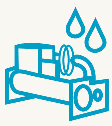
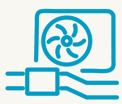
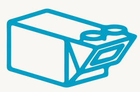
This analysis sought to identify key intervention areas, resultant energy savings and potential GHG emissions for each equipment type.

3.1.1. Equipment type

Direct GHG emissions occur due to refrigerant leakage from equipment during manufacture, operation and disposal, while indirect GHG emissions occur via energy consumption during operation.

The end-use equipment types considered for this analysis were restricted to refrigerant-based cooling equipment in the building sector and had significant impact on thermal cooling in the built environment of both commercial and residential buildings; these were as follows:

Table 1: Refrigerant-based cooling systems assessed

			
RACs Both window and split units.[18]	**Chillers** All types of chiller systems including scroll, centrifugal and screw.	**VRF/VRV systems** Units used in commercial and residential buildings with varied exposure and load across the building.	**Packaged DX systems** Both ducted and packaged systems for commercial and residential air-conditioning segments.

18 Excluding other RAC types such as portable ACs, since their market share was marginal (less than 1 per cent).

3.1.2. Emission scenarios

To establish the impact of cooling equipment and project GHG emissions, three scenarios were considered: (1) BAU scenario, (2) Intervention scenario and (3) Low carbon scenario.

BAU scenario

This scenario considers impacts due to minimum compliance with policies such as building laws (e.g. ECBC) and compulsory equipment labelling programmes by BEE. The key considerations were:

- Efficiency improvements in technologies assessed using BEE's star labelling programme for RACs and voluntary labelling program for chillers along with minimum ECBC compliance requirements for equipment efficiency;
- Foreseeable industry trends on refrigerant transition under the Montreal Protocol and its amendments;
- Continuation of current servicing levels and refrigerant recovery practices.

Intervention scenario

This scenario considered the impacts of aggressive interventions (both political and technological) and more than minimal compliance with building laws and compulsory equipment labelling programmes. The key considerations were:

- A more aggressive transition from current refrigerants to low-GWP and natural refrigerants;
- Technological improvement (primarily efficiency) in air-conditioning equipment;
- Reduction in cooling demand and operational hours through building sector efficiency improvements via stricter adoption of ECBC (e.g. adoption of ECBC+ and Super ECBC);
- Better operation and maintenance practices and improved recovery of refrigerant at the end-of-life stage.

Low carbon scenario

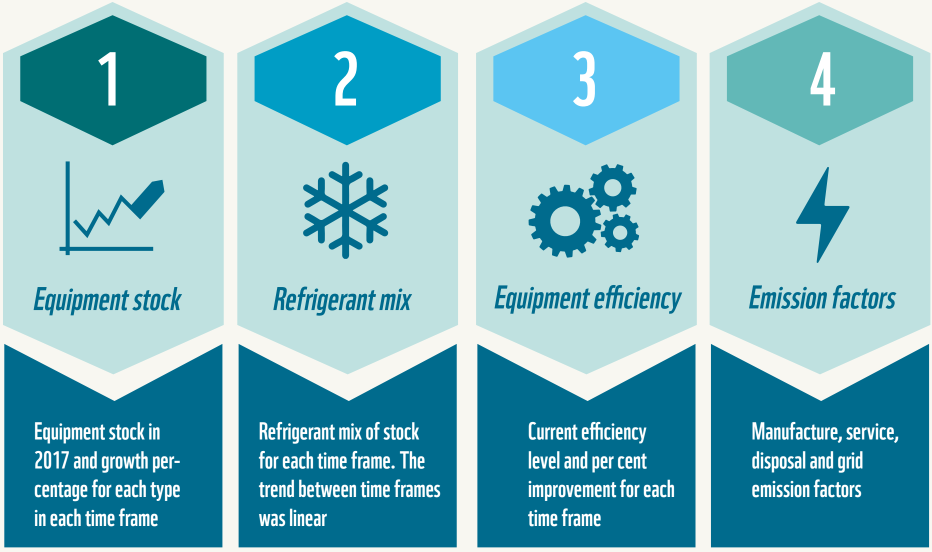
This scenario considered the impacts of the intervention scenario along with higher penetration of low carbon cooling technologies (primarily the non-refrigerant-based technologies identified in this report). All other factors matched the intervention scenario. Most of the low carbon cooling technologies listed in this report act as a support to, or replacement for, the primary cooling systems conventionally installed in the building sector. Therefore, the effects of their penetration on cooling load, overall equipment efficiency and refrigerant demand were suitably accommodated in the GHG emission projection.

3.1.3. Input parameters

Although the full analysis went into more detail regarding the inputs and assumptions considered for each equipment type in each scenario, the emission projection methodology was primarily based on the following input parameters.

The total projection time (2017 to 2050) was divided into three periods (2017-2027, 2027-2037 and 2037-2050) for correlation purposes as most published research and reports used these time frames for equipment stock and sales projections.

Figure 6:
Inputs to the emissions calculation model



The data were gathered through consultations with stakeholders including OEMs, industry experts, associations and government bodies along with in-depth study of literature available in the public domain. Based on these data, some assumptions were made in order to estimate emissions. A "bottom-up" approach was followed to calculate emissions for the forecast period using the revised IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1997); the detailed methodology is discussed in Annexure 1.

Equipment stock

The equipment stock value was determined by reviewing reports available in the public domain and consultation with industry experts. The baseline and projected stock for each equipment type is presented in Annexure 2. Key points include:

- The RAC stock in 2017 was 39 million units with an average capacity of 1.4TR, as given in the BEE report. This was projected to undergo a considerable increase, with a CAGR of 15 per cent for the next decade, 10 per cent from 2027 to 2037 and 8-10 per cent from 2037 to 2050.
- The chiller stock in 2017 was 5 million TR including scroll, screw and centrifugal types, with a projected CAGR of 5-12 per cent through 2050 (for different types of chillers), reaching 130 million TR.
- The VRF stock in 2017 was 2.3 million TR, with a projected steady CAGR of 15 per cent through 2050. The packaged DX stock in 2017 was 4.6 million TR, with a projected CAGR of 5 per cent through 2050.
- The percentage share of total equipment stock for all types in the residential and commercial sectors is given in Figure 9.

Figure 7:
Projected RAC stock

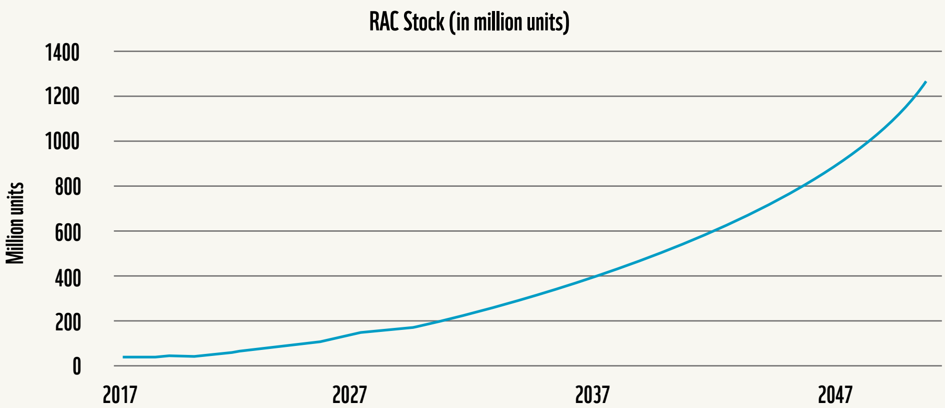


Figure 8:
Projected chiller, VRV and packaged DX stock

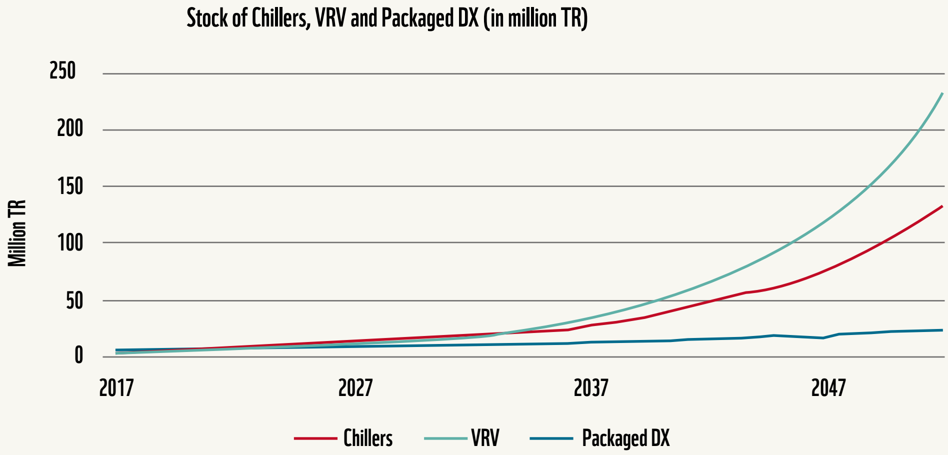
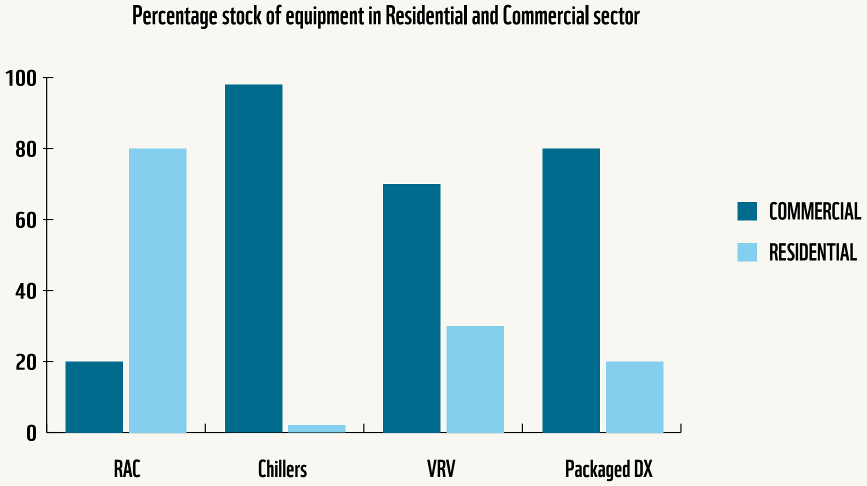


Figure 9:
Percentage stock of equipment types in the residential and commercial sectors



Refrigerant mix

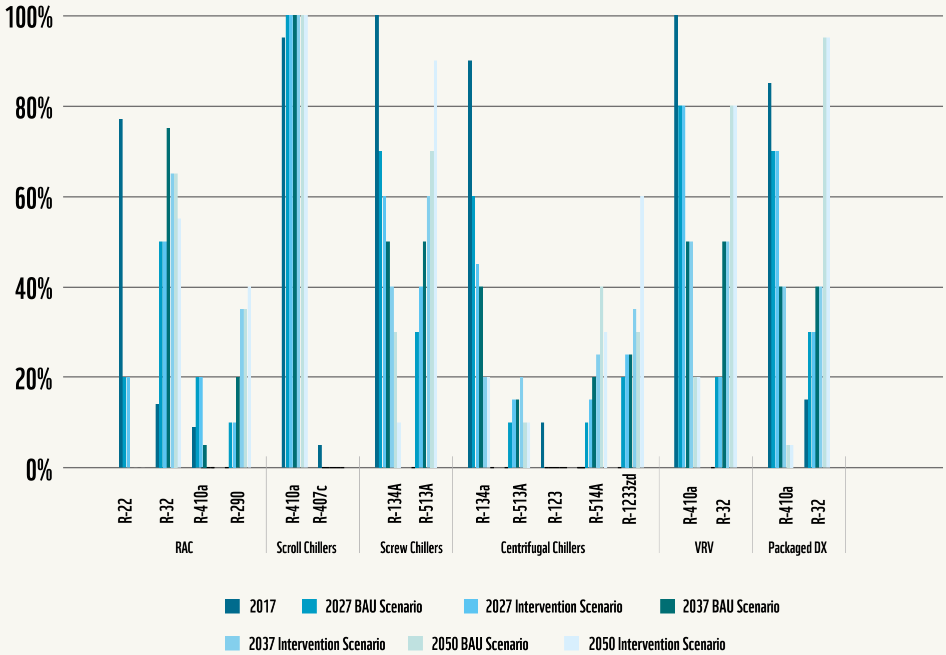
Refrigerant type and GWP at different time frames are critical parameters for the estimation of direct emissions. The refrigerant mix used in these projections was guided by the implementation of Montreal Protocol and the Kigali Amendment, which focused on HCFC phaseouts and HFC phasedowns. Details of this analysis are presented in Annexure 2. Key points include:

- In the RAC sector, a significant share of total equipment stock currently uses HCFC (i.e. R-22) and it is expected that HFC (i.e. R-32) will dominate the sector (65 per cent of total share) by 2050 under the BAU scenario. However, with the implementation of the Kigali Amendment, which considers HFCs to be controlled substances, hydrocarbon-based refrigerants with low GWP (such as R-290) are projected to achieve greater penetration in future; this was considered in the intervention scenario.

- Chillers will experience a more assertive HCFC phaseout and will adopt low-GWP refrigerants (such as R-513A and R-514A). Chillers will also experience more penetration of HFO (R-1233zd); with further policy interventions and market adoption, this could rise to 60 per cent by 2050 in the intervention scenario.

- R-410a is the most common alternative for HCFC in both VRV and packaged DX. With more determined phasedowns of high-GWP refrigerants, R-32 was considered a more relevant option for replacing R-410a in both the BAU and intervention scenarios. However, aggressive penetration of R-32 was considered in the intervention scenario.

Figure 10: Share of refrigerant mix for each equipment type



Equipment efficiency

Cooling equipment in the building sector provides a unique opportunity to optimize cooling demand through improved energy efficiency, as considered under different scenarios:

- For RAC, an efficiency improvement of 3 per cent was considered YOY through 2037, as per the BEE's labelling programme. No further improvement in efficiency beyond 2037 was considered, since this efficiency threshold is difficult to surpass under current technology advancements. Under the intervention scenario, the efficiency level was considered the same as the values were already stringent, but an annual 20 per cent kWh reduction was included to account for stricter adoption of ECBC codes that will reduce the run hours and cooling load.

- The baseline IPLV[19] for chillers in 2017 was set as 1.1IKW/TR for scroll, 1.05IKW/TR for screw and 0.9IKW/TR for centrifugal. An annual IPLC improvement of 0.15 per cent (YOY) was considered for all chiller types. This efficiency growth was in line with the minimum requirements of the ECBC. Under the intervention scenario, no improvement in IPLV at the equipment level was considered since the baseline figures and YOY efficiency improvements were already considered stringent. However, a 20 per cent reduction in IPLV was included from 2018 onward due to strict adoption of ECBC codes (reducing the run hours and building load).

- The COP of a VRF/VRV unit varies from 1.1-0.5IKW/TR, depending on the load conditions and ambient temperature. An average value of 0.81IKW/TR was considered for emission estimations with no YOY improvement in the efficiency level under the BAU scenario. Under the intervention scenario, no improvement

19 The IPLV is representative of the complete plantroom level efficiency figure, consisting of both high-side and low-side equipment.

in the IKW/TR at the equipment level was considered since the baseline value was stringent. However, a 10 per cent reduction in IKW/TR was considered from 2027 onward due to technological advancements.

- An average value of 1.25IKW/TR was considered for packaged DX in 2017 for both the BAU and intervention scenarios. This value was in line with the minimum ECBC requirement. In 2027, values of 1.09IKW/TR and 1.03IKW/TR were considered under the BAU and intervention scenarios, respectively, in line with minimum efficiency requirements under the current ECBC+ and super ECBC. From 2027 onward, a 1 per cent YOY efficiency improvement was considered, based on input from OEMs, for both the BAU and intervention scenarios.

Details of the efficiency level in both the BAU and intervention scenarios for all equipment types are given in Annexure 2.

Manufacture, operation and disposal emission factors

Under the BAU scenario, for all equipment types, refrigerant leakage was set as 1-2 per cent[20] during manufacture, 2-10 per cent during operation and 50-100 per cent during disposal. The high leakage during operation can be attributed to maintenance services provided by informal service sector. Additionally, at the end-of-life stage, equipment is often not disposed of through proper channels (including manufacturer or authorized e-waste handlers) and recovery of refrigerant is not a common practice. Therefore, the disposal emission factor was on the high side. For RAC, VRV and packaged DX, the disposal emission factor was considered to be 100 per cent for the entire projection period under the BAU scenario. However, chillers have better recovery practices and their disposal emission factor was set to 50 per cent from 2017-2050.

Under the intervention scenario, improved servicing practices, leakage reduction and better recovery of refrigerant upon disposal were considered, leading to improvements in the emission factor over time. Details of these factors are given in Annexure 2.

Grid emission factor

The weighted average grid emission factor (net electricity generation basis) of 0.82tCO_2/MWh for 2017 was determined from Central Electricity Authority (CEA) CO_2 Baseline Database for the Indian Power Sector – User Guide V10.[21] CEA also projected weighted average grid emission factors (based on gross electricity generation) for 2021-2022 and 2026-2027 of 0.604tCO_2/MWh and 0.524tCO_2/MWh, respectively. This projection considered electricity generation from all sources, including increased generation from renewable energy sources. With an increasing share of non-fossil-fuel-based generation in the total electricity mix and assuming India was on track to meet its NDC goals, reductions in the grid emission factor were considered for the entire projection period. The reduction through 2026-2027 was in line with CEA's projection. Following 2026-2027, a YOY reduction of 2.8 per cent was derived from reductions estimated for 2021-2026 by CEA.

3.2. ANALYSIS

This section presents the key analysis results for each equipment type, based on the above scenarios; full details and assumptions are given in Annexure 2.

3.2.1. Energy demand

The projected increase in space cooling demand will have a significant impact on energy consumption from cooling equipment. Under the BAU and intervention scenarios:

20 IPCC 1997
21 http://www.cea.nic.in/reports/others/thermal/tpece/cdm_co2/user_guide_ver13.pdf

- Total energy consumption from end-use cooling equipment is likely to increase three-fold by 2027 and fifteen-fold by 2050, growing from 84TWh in 2017 to ~200TWh in 2027 to ~1500TWh under the BAU scenario (Figure 11).
- RACs will continue to dominate the total cooling energy demand (Figure 12), representing 64 per cent in 2017 and 72 per cent in 2027.
- Chillers and VRVs, representing a substantial 22 per cent of the nationwide cooling energy consumption, will grow to 45 per cent by 2050. This requires a significant emphasis on improving the energy efficiency of these equipment types, especially due to their usage in the commercial building sector.
- Packaged DXs represented only 14 per cent of overall cooling energy consumption in 2017; their relative share will drop continuously and reach 2 per cent in 2050.
- RACs and chillers showed a significant in energy consumption saving potential of ~20 per cent by 2050 in the intervention scenario.

Figure 11: Overall energy consumption of each equipment type in the BAU and intervention scenarios

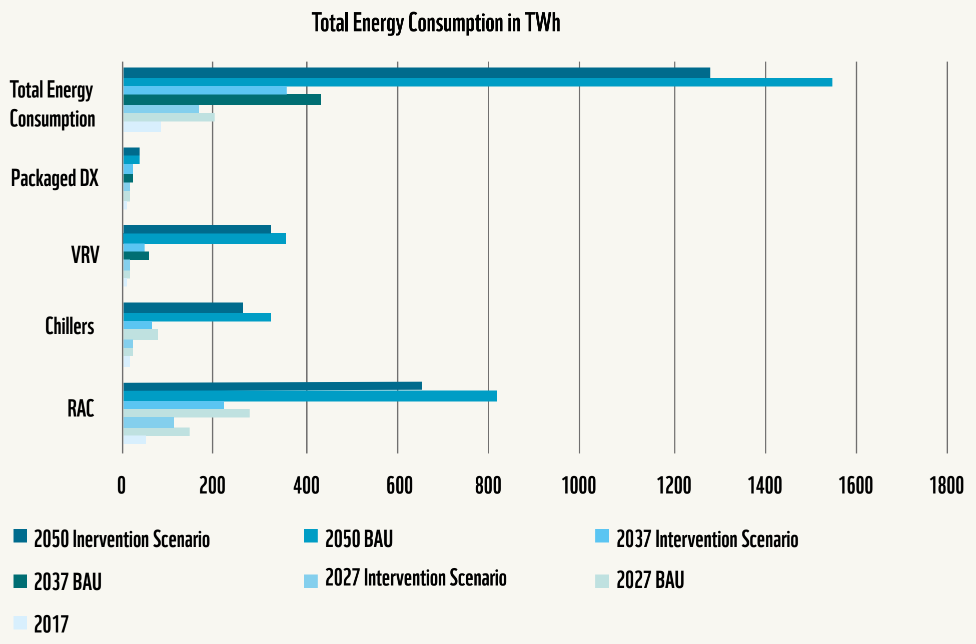


Figure 12: Annual energy consumption for each equipment type in the BAU and intervention scenarios

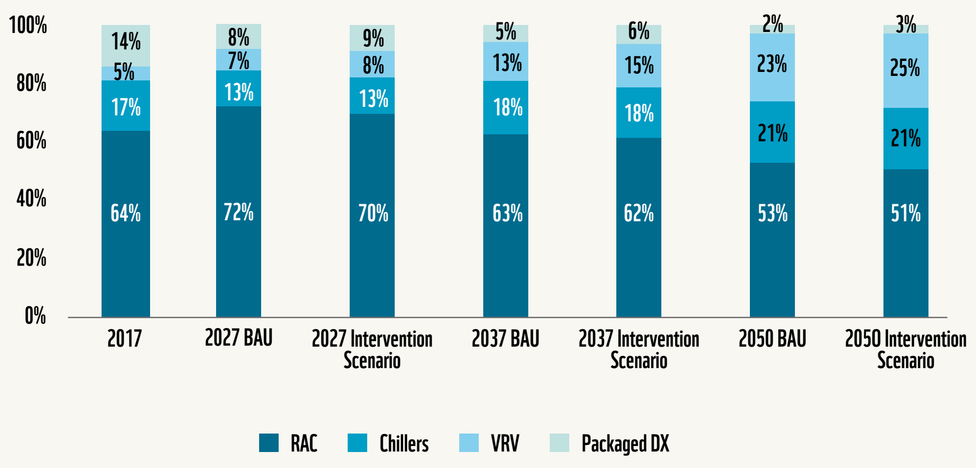
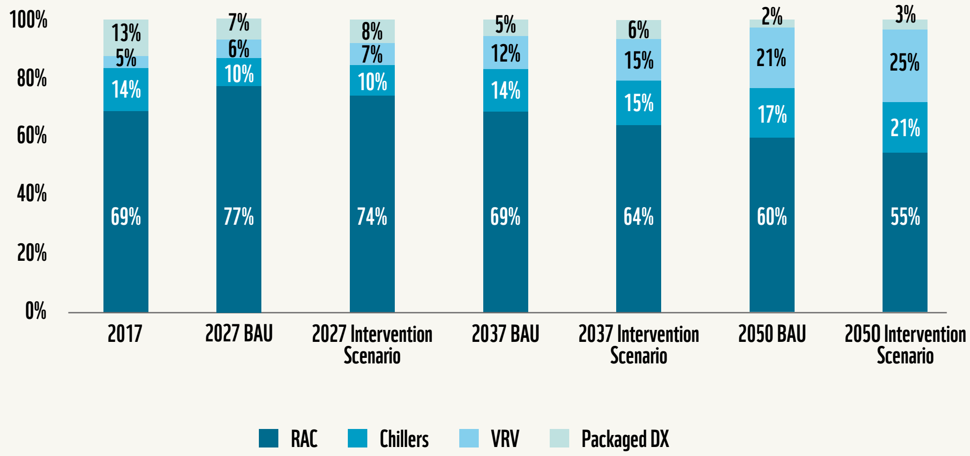


Figure 13:
Annual emissions from each equipment type in the BAU and intervention scenarios

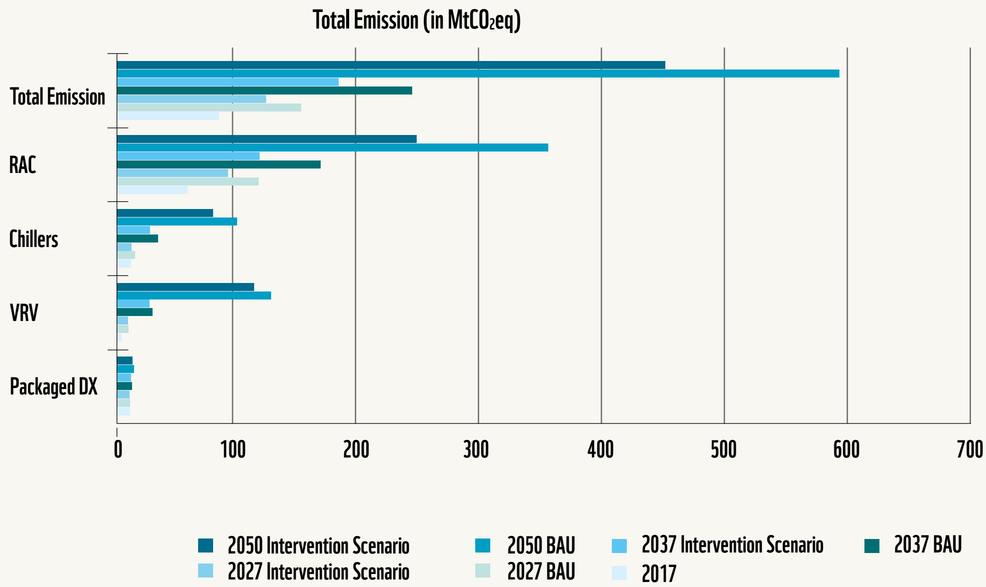


Emission projection

The projected refrigerant mix and increase in energy consumption for space cooling by 2050 in the BAU scenario inevitably resulted in sizeable increases in direct and indirect emissions. The intervention scenario provided an opportunity to focus on low-GWP refrigerants and improvements to refrigerant recovery practices to reduce the impact of direct emissions from cooling equipment. The results of the analysis for both direct and indirect emissions are given in Figure 14.

- The aggregated emissions from cooling equipment was projected to grow by one-and-a-half-fold by 2027 and seven-fold by 2050, over the 86MtCO_2eq in 2017, under the BAU scenario. An overall reduction in GHG emissions of ~19 per cent in 2027, ~25 per cent in 2037 and ~25 per cent in 2050 was predicted under the intervention scenario.

Figure 14:
Total emissions (MtCO_2eq) for each equipment type in the BAU and intervention scenarios



- The RAC sector was the largest contributor to total emissions in 2017 (69 per cent) and was projected constitute the dominant share through 2050 (~60 per cent) under the BAU scenario due to its increasing penetration into household and commercial building.

- Chillers and VRVs contributed ~20 per cent of overall emissions in 2017 and were projected to increase to ~40 per cent in 2050 under the BAU scenario.

- Packaged DXs had the least impact on overall emissions at 13 per cent in 2017; these were projected to decline to 2 per cent in 2050 under the BAU scenario.
- The percentage of total emissions in the residential and commercial sector for each equipment type is given in Figure 15.

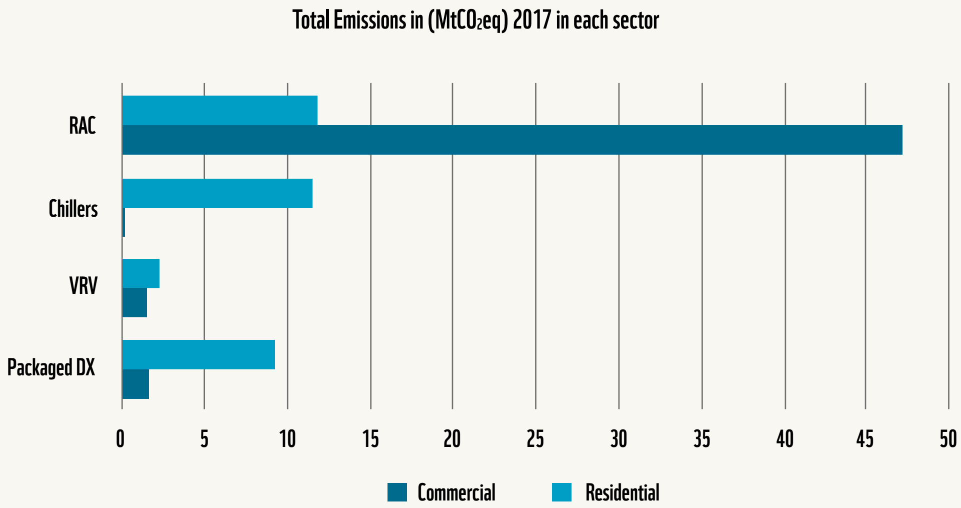


Figure 15: Total emissions ($MtCO_2eq$) for each equipment type by sector in 2017

Low carbon cooling technologies will proliferate over time, resulting in reduced energy consumption and emissions. The low carbon scenario considered the impacts of penetration of low carbon cooling technologies (primarily the non-refrigerant-based types identified in this report). The assumptions used to project overall emissions under the low carbon scenario included:

- Low-carbon cooling technologies primarily consisted of structure cooling, radiant cooling, geothermal cooling, IDEC and renewable-energy-based VAMs.
- Based on ICAP, low carbon cooling solutions in India were responsible for ~0.22 per cent (excluding VAM) of total cooling load in 2017-2018. However, the market share of these solutions will grow (Figure 16). Under low carbon scenario 1, these solutions will provide ~15 per cent of total cooling load by 2050. With better promotion and immediate actions from various stakeholders, including contributions from SMEs, the penetration of these solutions could reach 5 per cent, 10 per cent and 20 per cent by 2027, 2037 and 2050, respectively (low carbon scenario 2).

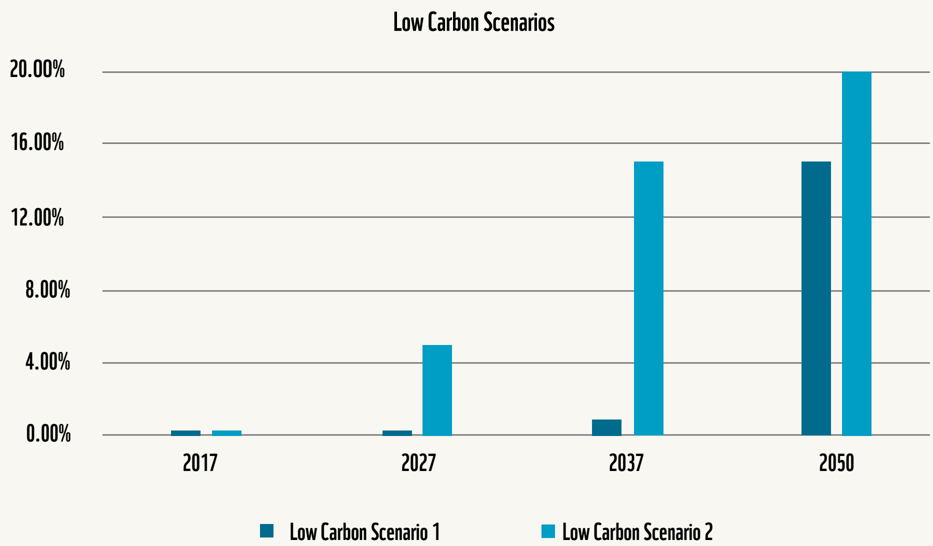
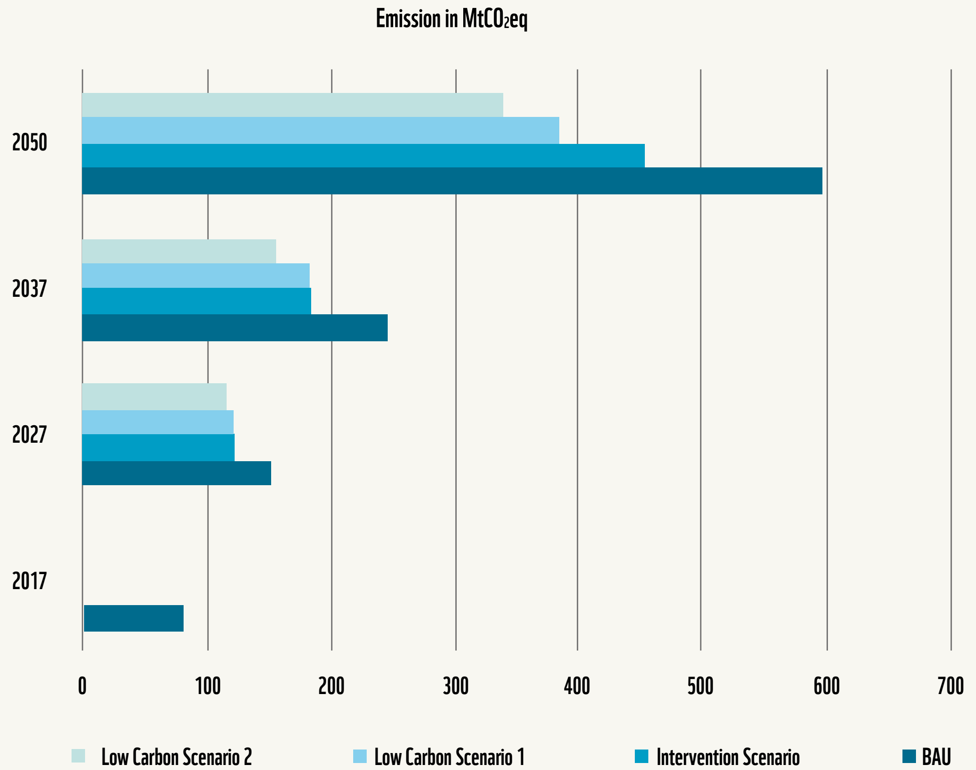


Figure 16: Projected penetration rate of low carbon cooling scenarios

GHG emission projections under the BAU, intervention and low carbon scenarios are compared in Figure 17. Low carbon scenario 1 would result in reductions in GHG emissions of ~35 per cent and 15 per cent in 2050 over the BAU and intervention scenarios, respectively. This scenario was most effective as it included the penetration of low carbon cooling technologies, offsetting the stock of conventional cooling by 15 per cent and lowering peak load demands (in addition to obvious reductions in GHG emissions). The penetration of innovative and low carbon cooling solutions is therefore important for the sustainable growth of the Indian economy.

Figure 17: Total emissions ($MtCO_2eq$) for each scenario



4. LOW CARBON COOLING SOLUTIONS FOR BUILDINGS: CURRENT STATUS

The preceding analysis indicated the importance of low carbon cooling technologies for reducing energy use and direct and indirect GHG emissions associated with space cooling. ICAP prioritizes the development and commercialization of these technologies to reduce the energy and carbon footprint of active cooling; ECBC also encourages the use of these technologies. Thus, the importance and impact of low carbon cooling technologies is well acknowledged and documented. However, the penetration and growth rate of these technologies is low and there is a dearth of research focusing on understanding the underlying reasons. This chapter focuses on the low carbon cooling ecosystem in India, attempting to identify the key technologies available, major providers and adopters, important drivers of the market, and current and future opportunities. Based on stakeholder consultations, it also elaborates the challenges faced by technology providers and their experience with end users, designers, skilled technicians and policy makers.

4.1. LOW CARBON COOLING SOLUTIONS IN INDIA

This section assesses low carbon cooling solutions that provide an acceptable range of thermal conditions, have been present in the market for at least a decade, offer significant energy and emissions savings, are scalable, attract adopters from multiple sectors and could significantly replace conventional cooling technologies. Such technologies included low-GWP refrigerant-based technologies, radiant and structure cooling, GSHPs, evaporative cooling and vapour absorption cooling. The primary focus was on their status in India and examples of successful installations. These technologies are discussed in greater detail in Annexure 3.

4.1.1. Low-GWP refrigerant-based technologies

Efficiency levels of refrigerant-based technologies have been evolving due to regulations such as BEE standards and labelling programmes, which have been raising efficiency levels in the RAC sector since 2009. A voluntary labelling program for chillers was also introduced by BEE in 2018 and is expected to become mandatory shortly. A labelling programme for VRVs and packaged DXs will also be launched soon as their standards are already in place. Refrigerant use in such equipment has largely been regulated by the Montreal Protocol and its subsequent Kigali Amendment, to which India is a signatory.

Some key developments in India with respect to refrigerant-based technologies in the last 3-4 years include:

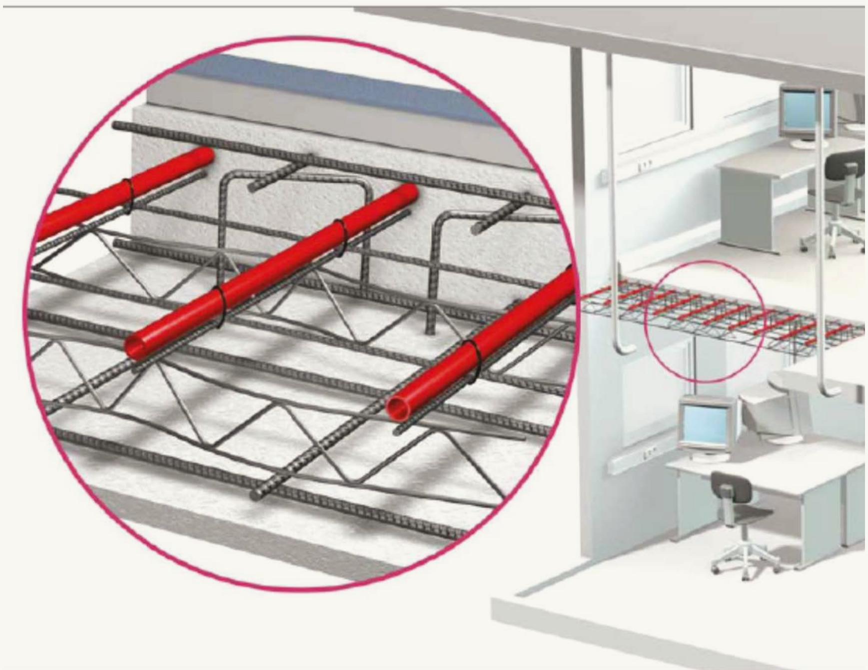
- HFO-based chillers. The large chiller segment (screw and centrifugal types) has predominantly been R-134a-based (see Chapter 3). Although HFCs such as R-134a have provided a safe cooling option (compared to their HCFC predecessors) due to an ODP of zero, their GWP is quite high. HFOs have negligible GWP (0-1) and are an excellent substitute for the widely used R134a (GWP of 1,300). The system efficiency of HFO-based chillers is ~10-15 per cent higher than HFC-based chillers, but their initial cost is also higher. Major chiller manufacturers in India have started promoting HFO-based chillers within the last two years and their market penetration within India is set to increase steadily as their initial cost becomes comparable with their HFC-based counterparts.

- HC-based RACs. The RAC market has transitioned from high-GWP, medium-ODP HCFC-based refrigerants such as R-22 to zero-ODP, medium-GWP HFCs such as R-32. The emerging refrigerants in this market are HC-based (such as R-290) and have an ODP of zero and very low GWP. These units are commercially available, despite some concerns over safety due to higher flammability than HFCs. However, from an emissions perspective, these are the best available option.

4.1.2. Radiant and structure cooling

Radiant cooling is a hydronic system that circulates chilled water through PEX pipes embedded in the floor or ceiling, or through copper pipes embedded in ceiling panels. Water passing through these pipes first cools the floor/ceiling surface, which then cools the enclosed space through radiation. This is different from conventional forced-air systems, in which cool air is circulated through the space to remove internal heat and provide comfort. The heat-transfer medium is water, whose thermal conductivity is ~24 times higher than air, such that equivalent cooling can be provided at a much lower energy expenditure.

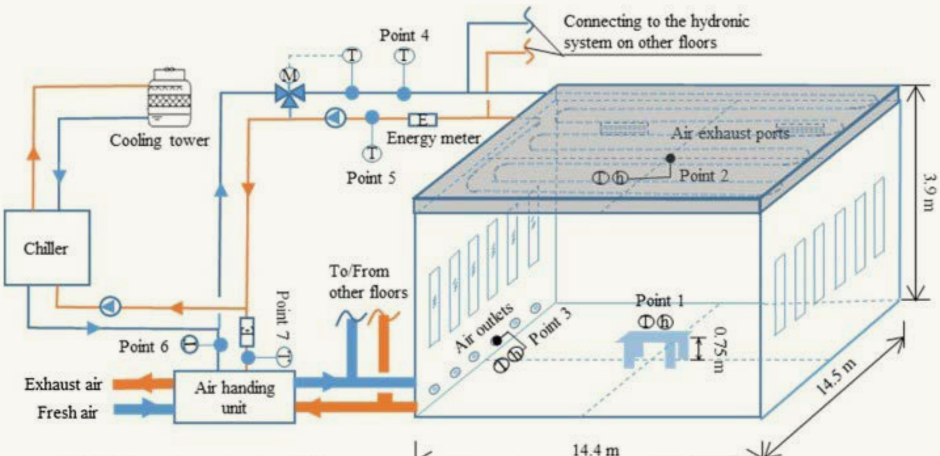
Figure 18: Example of radiant cooling, in which PEX pipes embedded in a concrete slab transfer chilled water to provide interior cooling (Source: Rehau)



Maximizing the effects of radiant cooling requires improving the envelope's thermal efficiency via increased insulation and airtightness to reduce conduction and radiation gains into the space. This reduces the magnitude and frequency of envelope peak loads. Structurally embedded radiant cooling systems can generally handle sensible loads of 35-50W/m^2. In areas of high direct solar gains on radiant surfaces, this capacity can be increased to 75-95W/m^2.[22] The use of radiant panels can increase this to 60-100W/m^2 or even higher. Radiant systems usually absorb 60-70 per cent of the space's sensible heat load. The remaining 30-40 per cent (mainly instantaneous in nature) and the latent load must be removed by a relatively small forced-air system, which may be based on chilled water, VRFs or a unitary system. The same forced-air system can be used to meet fresh-air ventilation requirements, as can a DOAS.

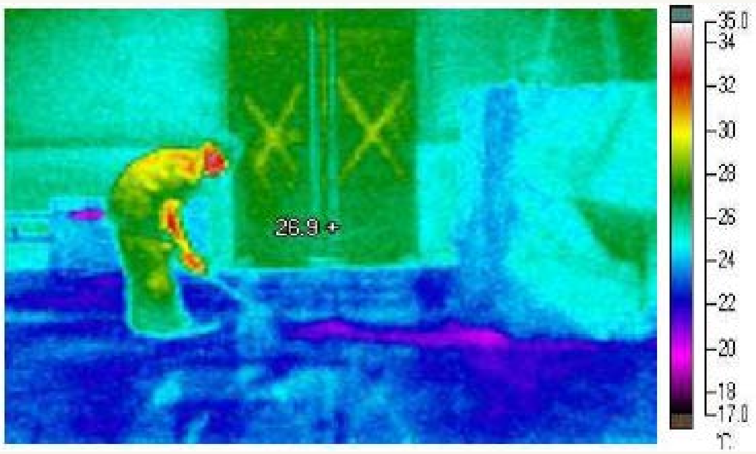
22 https://azaranstore.com/download/articles/238%20Radiant%20Cooling%20Design%20Manual.pdf

Figure 19: Operational schematic of a radiant cooling system with DOAS (Source: Hu and Niu, 2017)



Another important consideration is the control logic of operating radiant cooling systems, which can be manual, automatic or time functioning. However, BMS integration is preferred for smooth operation. The risk of condensation on the radiant surface is one major concern; this can be avoided by modulating the supply water temperature such that the surface temperature is always higher than the highest dew-point temperature in the conditioned zones. Other methods for avoiding condensation include shutting down the chilled water supply whenever the difference between zone air temperature and dew-point temperature approaches 2.5°C and setting a lower threshold for the radiant surface temperature (19°C) and room air temperature (25°C).[23]

Figure 20: Surface temperatures following radiant installation (Source: Rehau)



Structure cooling is an innovative low-energy variant based on the principles of radiant cooling. In this system, water chilled by a two-stage cooling tower to 20-26°C is passed through pipes embedded in the concrete core. This system is essentially a pre-cooling system that reduces the size of primary cooling systems and is suitable where adaptive thermal comfort is acceptable. This system can be used in places with high cooling loads such as malls, hospitals, offices, colleges and semi-open spaces such as transit hubs. The system is very energy efficient, consuming 0.03-0.05kW/TR compared to a conventional system consuming 0.7-1.1kW/TR[24] or even more.

23 Hu and Niu (2017), Operation Dynamics of Building with Radiant Cooling System based on Beijing Weather, Energy and Buildings

24 Stakeholder consultations with Oorja Energy Engineering

Indian Context[25]

Total installed capacity: 18,000TR[26]

Suitable building typology: Offices, commercial, institutional, hotels, defence installations

Capital investment: Radiant cooling with supplemental systems and DOAS: ₹120,000-150,000/TR; structure cooling: ₹40,000-50,000/TR

Annual operational savings: 30-50%

Payback period: Radiant cooling: 3-4 years; Structure cooling: 1-1.5 years

Government policies: No existing policies for these technologies

Radiant cooling is a market-tested and mature technology in India. More than 400,000m² of built-up area is currently served by this technology with an installed capacity of 18,000TR.[27] Radiant cooling is preferred for buildings with >1,000m² floor space, including commercial, institutional, and hotel properties, though its penetration in the residential sector is negligible. Two variants of this technology are available: concrete-core and radiant panels. Structure cooling is rapidly gaining attraction and presently serves >60,000m². It is being adopted in industrial and semi-open spaces such as schools and public buildings due to its cost viability and ability to provide thermal comfort within an acceptable range. Radiant cooling is generally installed in hot and dry climates, though the availability of advanced controls has made it technically feasible in warm and humid conditions as well.

Capital investment for radiant cooling combined with supplemental systems and/or DOAS is ₹120,000-150,000/TR compared to ₹75,000-85,000/TR for a conventional chilled-water system and ₹50,000/TR for VRF. Installations in India have achieved operational energy savings of 30-50 per cent with a payback period of three to four years. Structure cooling offers better economic advantages and payback within one to one and a half years. These systems are marketed on an upfront investment model; ESCO or "Pay-as-you-save" models have yet to be tested. The technology is provided mostly by global players involved in the design, manufacturing and installation of complete systems. SMEs and start-ups active in this segment are involved in design and system integration and depend on either imported or domestic supply of the system's key element (PEX pipes for chilled water). SMEs are also leading R&D in technology innovation and efficiency improvements. Structure cooling is one such innovation, based on the principle of radiant cooling, and has notable potential in semi-open spaces and public buildings.

Case studies

1. Institute of Rural Research and Development, Gurgaon (Installer: Rehau)

This 3,500m² LEED Platinum office building is India's first radiant-cooled structure. Its concrete-core radiant cooling was installed with a forced-air system for comfort cooling and ventilation; ceiling fans enhance the perceived thermal comfort. The radiant area is 1,120m² with 8,000m of PEX-a piping. Additional investments in energy

25 Stakeholder consultation with Rehau and Oorja Energy Engineering
26 ICAP 2019
27 ICAP 2019

efficiency cost ₹15/m² in 2012. Although the capital cost was relatively high, the project realized 35-40 per cent savings in operational energy use and a payback period of one and a half years. The project also features an efficient envelope, night-time cooling, a high-efficiency chiller and air supply in the occupied zone. The building provides better thermal comfort with no hot spots, excellent indoor air quality and good daylighting.

2. Jaquar Global Headquarters, Manesar (Installer: Rehau)

Jaquar Group, a leading sanitary ware manufacturer, developed a net zero energy campus spread over 12 acres that houses their manufacturing facility and business development office. The facility uses a radiant cooling system with 120,000m of piping. The system provides 181TR of the total cooling load of 422TR. Compared to a conventional system, the radiant cooling system uses 30 per cent less energy. The system handles diverse loads by serving both offices and the manufacturing plant, demonstrating the versatility and robustness of the system. The site also generates power through solar PV.

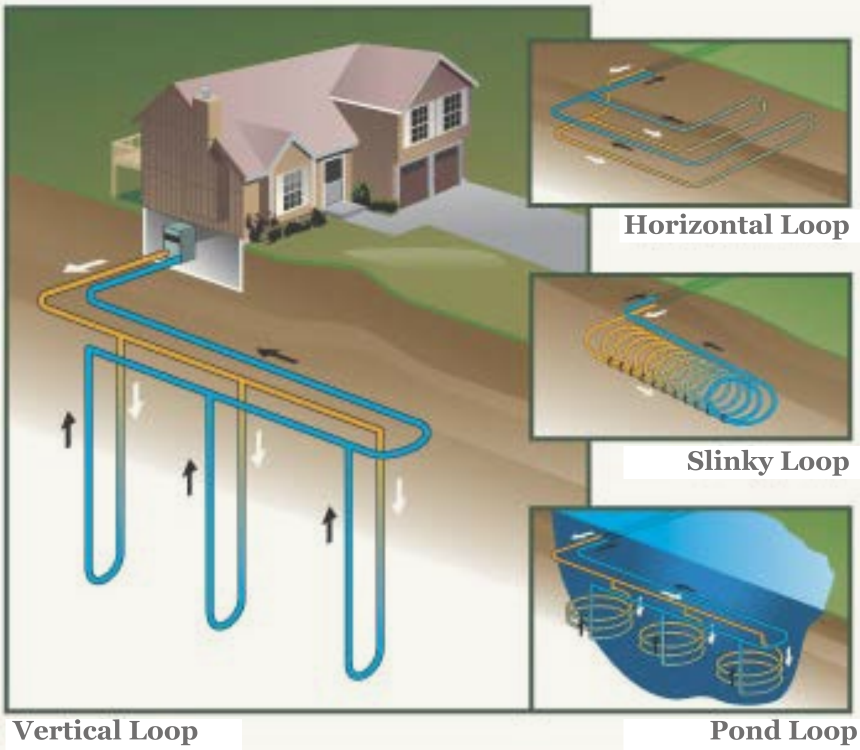
3. School of Architecture, Vellore Institute of Technology, Vellore
(Installer: Oorja Energy Engineering)

The VIT School of Architecture sought a low-energy solution to meet its cooling requirement. Its 10,000m² area would have required an air-conditioning installation of at least 500TR, but the school adopted structure cooling instead. Network of pipes were embedded in the concrete structure; these were connected to a two-stage cooling tower rather than a chiller. The system provides an internal temperature range of 26-30°C. The building is naturally ventilated and ceiling fans enhance thermal comfort. The structure cooling used here yielded > 80% energy savings and paid for itself within one year.

4.1.3. Ground source heat pumps (GSHPs)

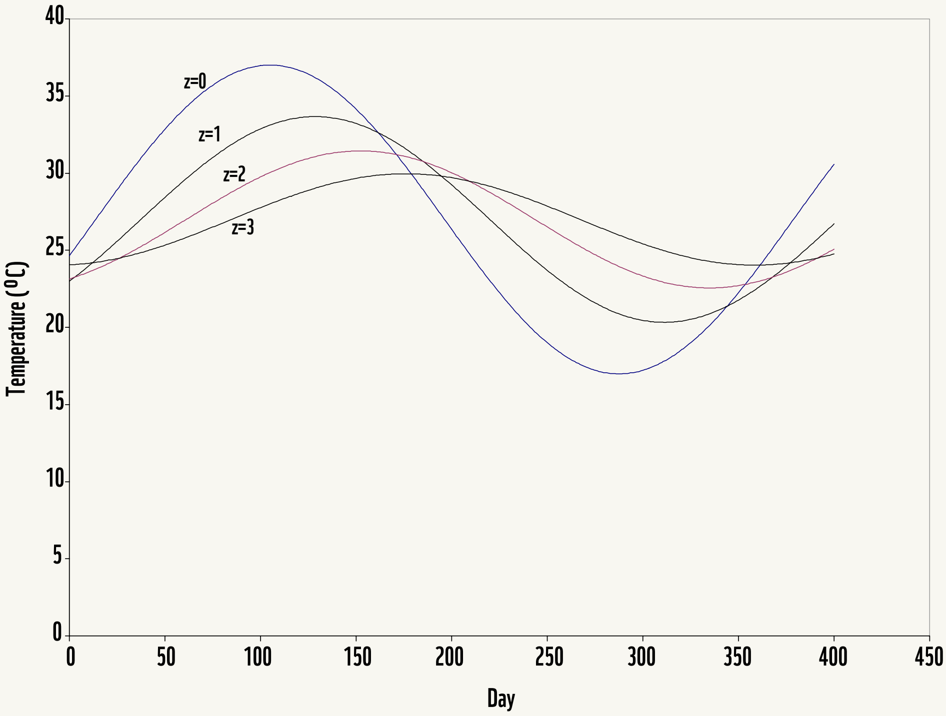
As temperatures within the earth remain relatively stable compared to seasonal changes in ambient air, GSHPs use water-to-water or water-to-air approaches to treat this stable thermal environment as a heat source in the heating season and a heat sink in the cooling season. GSHPs are primarily classified as vertical or horizontal based on the layout of the earth loop. SWHE installations are possible where surface water is available (such as pools, lakes, rivers or seas), although the latter is uncommon due to strong currents, tidal influences and wave action. SWHEs can be either open loop or closed loop.

Figure 21: GSHP loop configurations (Source: NREL)



Depending on the heat pump used, these systems are classified as air source, water source or ground source (geothermal). Temperatures within the earth remain stable compared to the ambient air temperature which changes based on seasonal variation. Ground temperatures below six metres remain approximately equal to the annual mean air temperature at that surface location. GSHPs use this stable thermal environment as a heat source in the heating season and a heat sink in the cooling season.

Figure 22: Ground temperature as a function of time and depth for Ahnedabad, India (Source: Girja Sharan & Jadhav Ratan, 2002)



z denotes depth below the surface in meters

Decision-making for GSHP installation involves considerations such as the building's HVAC load, subsurface conditions, land availability, underground utility location, local rules and regulations, and requirements for future expansion. As for any energy efficiency intervention, it is advisable to reduce the building HVAC load by improving envelope efficiency and optimizing internal heat loads. Subsurface conditions are especially important as soil type and thermal conductivity affects the design and sizing of the GSHP installation. For example, dense soil (such as clay) has higher thermal conductivity than loose, sandy soil; the latter would require more land or deeper vertical penetration.[28]

Figure 23: Drilling of test hole and pressure testing of individual U-tubes at SASE, Manali (Source: Curtis et. al., 2015)

GSHP performance is most dependent on the EWT. It is important to establish a low, consistent range of EWT for maximum year-round GSHP efficiency. As EWT is a function of subsurface and groundwater parameters, one of the first steps in a feasibility study involves assessing the minimum and maximum EWT value. This requires a thermal response test to determine the average thermal conductivity throughout the depth of the tested zone and to ascertain ground temperatures and thermal diffusivity. It is also important to estimate the location of and depth to bedrock and ground water, as encountering and drilling through bedrock can significantly affect the economic viability of vertical installations. Design decisions with respect to the type and length of the earth loop, the depth, number and spacing of vertical bore holes, and the overall area required of area are based on the findings of the feasibility study.

Indian Context[29]

Total installed capacity: ~15,000TR[30]

Suitable building typology: Industrial (manufacturing, fisheries, horticulture, aquaponics), institutional, commercial, hospitals and SMEs (mainly hotels)

Capital investment: ₹35,000-50,000/TR for horizontal installation and ₹100,000-150,000/TR for vertical installation

Annual operational savings: 35-40%

Payback period: 1-3 years

Government policies: The MNRE is providing financial incentives to the private and public sectors for stand-alone GSHP projects with more than 100TR capacity as well as district-cooling-scale applications.

GSHP technology is still at the nascent stage of penetration in the Indian cooling market. Although it is mature and has been present in India since the 2010s, its growth rate has been very slow. Its ability to provide consistent thermal conditions has attracted specific segments of end users, including industrial (manufacturing, fisheries, horticulture, aquaponics), institutional, commercial, hospitals, and SMEs (mainly hotels).

28 Hillesheim and Mosey (2014), Technical Feasibility Study for Deployment of Ground-Source Heat Pump Systems: Portsmouth Naval Shipyard— Kittery, Maine, National Renewable Energy Laboratory
29 Stakeholder consultations with Rosemex Ecotech and Scanair Engineering
30 Stakeholder consultations with various technology installers

GSHP technology is still at the nascent stage of penetration in the Indian cooling market. Although it is mature and has been present in India since the 2010s, its growth rate has been very slow. Its ability to provide consistent thermal conditions has attracted specific segments of end users, including industrial (manufacturing, fisheries, horticulture, aquaponics), institutional, commercial, hospitals, and SMEs (mainly hotels). GSHPs are easy to integrate into new and retrofitted projects, if appropriate land is available. Retrofit applications used to improve the efficiency and performance of existing air-cooled condensers is rising. Existing installations of GSHPs in India range from 30-500TR per installation. This technology is robust in terms of its performance across different climate zones. Across India, GSHPs operate at 0.44-0.53kW/TR, compared to chiller and cooling tower configurations operating at 1.11-1.27kW/TR.

The capital investment required for GSHP installation ranges from ₹35,000-50,000/TR for horizontal installation and ₹100,000-150,000/TR for vertical installation, depending on subsurface conditions. The cost increases significantly when bedrock is encountered within the required depth. Installations in India have realized savings of 35-40 per cent and payback within one to three years. The technology has mainly been offered on an upfront investment model, while the “pay-as-you-save” model has been offered by start-ups and SMEs. Conventional business practices are dominant due to smaller margin of profit. This technology segment is dominated by SMEs and start-ups, who provide design consultation, system integration and installation. Similar to radiant cooling, these players are dependent on imported supply of HDPE pipes. Start-ups are also active in R&D in this segment with regard to the harmonization of global best practices and innovative business models. SMEs are also major adopters of GHSP, particularly the horticulture and aquaculture industry.

The MNRE provides financial incentives in the private and public sectors for stand-alone GSHP projects with >100TR capacity as well as district-cooling-scale applications:

- For closed-loop systems, a subsidy of 30 per cent of the project cost is provided with maximum support of ₹50,000/TR for the first $100MW_t$ ($1MW_t$ = 284.4TR), ₹30,000/TR for the next $200MW_t$ and ₹10,000/TR thereafter.

- For open-loop systems, 25 per cent of the project cost is subsidized with maximum support of ₹15,000/TR for the first $300MW_t$, ₹10,000/TR for the next $200MW_t$ and ₹5,000/TR thereafter.

- For district-cooling-scale applications, the framework provides incentives of 30 per cent of the capital cost up to a maximum of ₹15 million/MW_t subject to a maximum ₹50 million per project, whichever is lower.[31]

Case studies

1. Metro Bhavan, Nagpur (Installer: Rosemex Ecotech)

The head office of MahaMetro (Maharashtra Metro Rail Corporation Limited) is an energy efficient building with rooftop solar PV and a net zero water design. The building is cooled by a horizontal loop GSHP that handles a 175TR cooling load with power

31 http://www.indiaenvironmentportal.org.in/files/file/Draft-Geothermal-frame-work.pdf

consumption of 0.6kW/TR (an equivalent air-cooled chiller would use 1.6kW/TR). The system was installed at an additional cost of ₹22 million and is projected to yield savings of ₹5.1 million of annual operational cost and payback in 3.2 years. Apart from the low operational energy use and low maintenance cost, the building's GSHP also benefits from a long service period (25 years), much higher than that for air-cooled chillers (12-13 years). The system is projected to generate over ₹110 million in its lifetime.

2. **Apollo Cancer Hospital, Hyderabad** (Installer: Geothermal India)

The Apollo Cancer Hospital's 4,000m^2 building uses an open-loop WSHP that is highly energy efficient. The chiller operates at 0.5kW/TR with the entire system operating at 0.84kW/TR. The facility realized energy savings of 44 per cent in operation with an immediate payback. This project was based on an energy performance guarantee in which the capital investment was paid by the installer (an SME) and was repaid from energy cost savings. The project also drew 80 per cent accelerated depreciation tax benefit. The building provides excellent thermal comfort conditions with 90 per cent occupant satisfaction.

3. **Honda Factory, Tapukara** (Installer: Rosemex Ecotech)

This is Honda's largest manufacturing facility in the world for diesel engines and manual gearboxes, with an annual generation capacity of 120,000 units and a daily capacity of 490 units. It is an energy efficient and net zero water development that covers 400 acres. The plant is cooled by a vertical GSHP system than handles the plant's 68TR load and generates 35 per cent savings on energy expenditure (₹1.16 million annual savings).

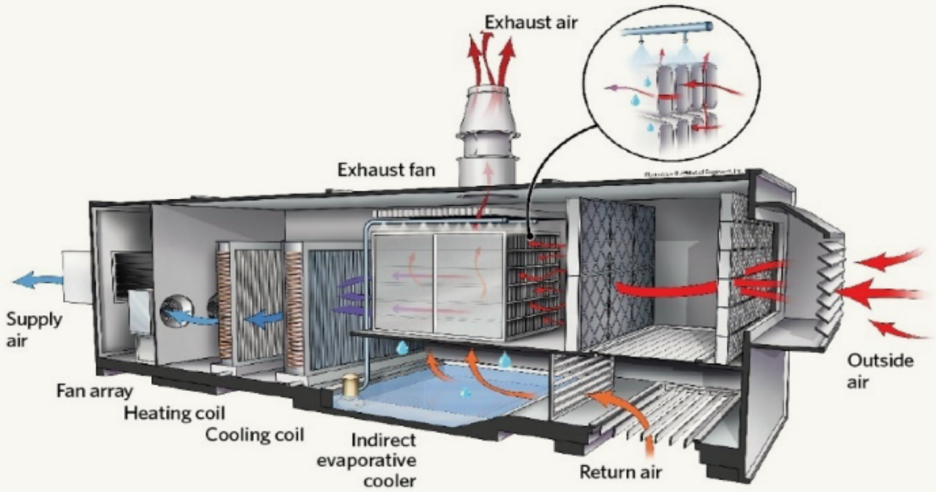
4. **Indira Paryavaran Bhawan, New Delhi** (Installer: Rehau)

This building houses the Ministry of Environment, Forest and Climate Change. Built in 2013, it is India's first net zero energy building.[32] One of the many sustainability features implemented in its construction was a vertical GSHP system consisting of 180 vertical borewells, each 80 m deep and 3 m apart. The system has a combined heat-rejection potential of 160TR and a total cooling demand of 400TR, providing significant savings in energy and water consumption.

4.1.4. Evaporative cooling

Evaporative cooling is based on the principle that water evaporates by absorbing heat from the surroundings. When air is passed over a water surface, evaporation results in the cooling of the air stream. An evaporative cooler draws in outdoor air and passes it through a cooling medium (e.g. soaked pads or a polymer surface). When hot outdoor air is passed through the cooling medium, sensible heat from the air is extracted to evaporate the water flowing through it. Water passing through the cooling media evaporates into the air, reducing its temperature and producing a cooling effect and increasing the air's humidity. Evaporative cooling is most effective in hot and dry climates where water easily evaporates. As air grows more humid, its capacity to absorb further moisture and reduce temperature decreases, reducing the effectiveness of evaporative cooling in warm and humid conditions. Evaporative cooling systems are notably cost-effective as they produce equivalent cooling at one-third the capital cost and have a very low operational cost compared to conventional counterparts. However, their significant water consumption remains a major limiting factor, especially in areas where water is scarce. Depending on the air-water interaction in the cooling media, evaporative cooling systems can be classified into DEC and IEC systems.

Figure 24: Indirect evaporative cooling system (Source: CIBSE)



The performance of an evaporative cooling system is dependent on several critical parameters: the difference in dry-bulb and wet-bulb temperature of outdoor air, efficiency of the cooling media and the flow rate at which air is drawn through the system. Depending on the system efficiency, an evaporative cooler can reduce the outdoor air temperature by 10-15°C, limited to one to three degrees above the wet-bulb temperature. Thus, the higher the difference in dry-bulb and wet-bulb temperatures, the better the performance of the system. The type of cooling media also impacts the effectiveness of evaporative cooling. Materials used for cooling media include wood fibre, cellulose and polymer. Wood fibre pads made of shaved aspen trees have been found to be more effective at temperature reduction, humidity control and saturation efficiency, followed by cellulose pads. Some manufacturers in the SME segment have developed patented polymer products that achieve higher cooling efficiency. Increasing the surface area of the cooling media and thereby the retention time of outdoor air has also increased the system's effectiveness. Cooling efficiency increases with an increase in the flow rate at which air is drawn through the cooling media.

32 https://www.businesstoday.in/magazine/features/cleantech-indira-paryavaran-bhawan-india-first-zero-energy-building/story/222090.html

Evaporative cooling can handle a wide range of cooling requirements, from residential applications of 2,000-3,000CFM to industrial applications of >200,000CFM. Water consumption is another major consideration in arid regions. Evaporative systems are sized by the air flow they can deliver to provide the required comfort level. DEC and IDEC systems range from 1,000-1,500CFM/TR and 600-900CFM/TR, respectively.[33] DEC systems use 7-8LPH/1000CFM and M-cycle-based IDEC systems use 10-12LPH/1000CFM.[34]

Indian Context[35]

Total installed capacity: 100,000TR[36]

Suitable building typology: Offices, commercial, hospitality, industry

Capital investment: ₹5,000-10,000/TR for DEC and ₹25,000-40,000/TR for three-stage IDEC

Annual operational savings: 50-80%

Payback period: 1-2 years

Government policies: No policies exist for this technology

Evaporative coolers are an easily accessible and affordable segment of alternate cooling appliances in India. DEC systems have considerable penetration in the form of desert/swamp coolers. The cooler market size is estimated at ~8 million units sold annually, dominated by the residential sector. IDEC system installation is estimated at 43 million CFM, equivalent to 0.1 million TR of conventional air conditioning in offices, commercial, hospitality and industrial settings. This segment of cooling technology is witnessing steady growth, especially in the industrial sector, and the demand for commercial applications is rising. Unlike other cooling technologies, which are a planned investment, evaporative cooling systems are off-the-shelf, plug-and-play and cheaper solutions.

Evaporative cooling can cater to a wide range of cooling requirements, ranging from residential applications providing 2000-3000CFM to industrial applications providing >200,000CFM. Evaporative coolers have naturally been widely adopted in hot and dry conditions, but IDEC, multi-stage IEC (M-cycle) and three-stage evaporative cooling products are now capable of providing cooling year-round. Several manufacturers in the SME segment are involved in relevant R&D and some have patented high-efficiency cooling media. Such systems have shown good potential to provide cooling at reduced energy use and low environmental impact and have been recognised in global initiatives such as the Global Cooling Prize organized by the government of India and the Rocky Mountain Institute.

Evaporative systems are sized based on the air flow they can deliver; DEC and IDEC systems can provide 1,000-1,500CFM/TR and 600-900CFM/TR, respectively. Water requirements for 25TR DEC and IDEC systems are 420 and 325 LPH, respectively. DEC systems cost ₹5-10/CFM, while three-stage systems require an investment of ₹35-40/CFM. IDEC systems can operate at <50 per cent of the energy requirements of a conventional air-conditioning system, while advanced M-cycle-based systems offer the potential to generate >80 per cent energy savings. Evaporative cooling products are manufactured domestically, so commercial products are available at lower cost per TR compared to conventional systems. This segment is overly represented by SMEs who are involved in end-to-end manufacturing and installation while also driving R&D with regard to high-efficiency improvements.

33 Stakeholder consultations with various technology providers
34 Stakeholder consultations with ATE technologies
35 Stakeholder consultations with ATE technologies and Advantek Air Systems Pvt Ltd
36 ICAP 2019

Case studies

1. St. Mary's School, Pune (Source: ATE Technologies)

This school is a heritage educational institution educating more than 3,000 students annually. The school sought a low-cost, low-energy and low-noise solution to provide thermal comfort inside a 500m² auditorium being added to the existing structure. Conventional air-conditioning solutions required high capital investment and higher operational cost. Hence, the school decided to install an IDEC system with a total capacity of 44,000CFM providing 100% fresh air to the space. The system was able to maintain 26°C during its commissioning in peak summer when the outdoor dry-bulb temperature was 36°C. The system consumes less than half the energy consumed by a conventional air-conditioning system. Post-occupancy evaluation of the auditorium revealed high levels of satisfaction towards thermal comfort and indoor air quality.

2. Amazon Warehouse, Nagpur (Source: ATE Technologies)

Amazon is building fulfilment centres (warehouses) in multiple cities across India. For one such warehouse, it needed a low-cost solution to provide thermal comfort to its employees while maintaining the shelf life of stored products. An IDEC system was selected as it met all the company's criteria. The 7,500m² warehouse is served by multiple IDEC systems with a combined capacity of 200,000CFM. Temperature recordings taken during the peak monsoon season showed an interior-exterior temperature difference of 3-5°C, notable for evaporative cooling in peak monsoon conditions.

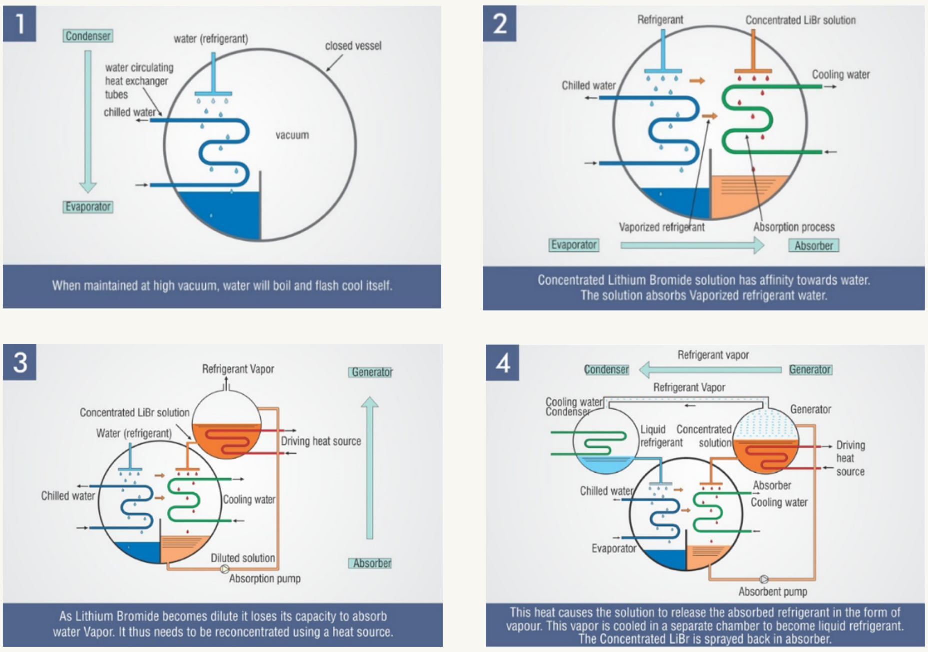
4.1.5. Vapour absorption cooling

Vapour absorption cooling is an alternative to vapour compression cycles. While the latter is electrically driven, VAMs use heat as an energy source to generate chilled water. The absorption works on the principle that a concentrated salt (lithium bromide or ammonia) and water solution can be used to absorb water vapour, which can then be pressurised by a low-power pump. VAMs differ from electrical chillers in several other ways.

Two types of absorption chillers are available: single effect and double effect. The latter is more efficient (COP of 1.2 vs 0.7) but more expensive and complex to operate. Since the operating fuel is heat and not electricity, VAMs can potentially deliver significant energy savings (~95 per cent) over electrical chillers. These sources include:

- District heating used for chilled water generation.
- Waste heat from combined cooling, heating and power (CCHP/trigeneration). CCHP is preferred wherever natural gas is available. However, its cost and environmental effectiveness would depend on the source of electricity grid and relative prices of gas and electricity.
- Direct firing of natural gas, LPG or PNG, or hot water generated by natural gas, biomass or waste heat, with a temperature >1200C. This technique is dependent on the price and availability of fuel. Such systems may be cost-effective at present prices but may become expensive if prices increase in future. Hence, the long-term stability of fuel availability and price is important.
- Heat recovery from industries in SEZs as the source is available at no additional cost.
- Renewable energy sources such as solar thermal or deep geothermal. Solar thermal is viable wherever sufficient land area and capital investment is available. Its cost-effectiveness is higher where the peak demand coincides with the peak availability of solar radiation. Deep geothermal is applicable where suitable high ground temperatures are available.

Figure 25: Operational schematic of a VAM (Source: Thermax Global)



Indian Context[37]

Total installed capacity: 700,000TR[38]

Suitable building typology: Hospitals, hotels, business districts, airports, SME industries such as food and beverages or textiles.

Capital investment: 1.6-1.7 times higher than electric chillers, reducing to 1.15-1.3 times higher for larger applications

Annual operational savings: 40-60%

Payback period: VAM applications: 2-3 years; solar VAM: 5-6 years (3-4 years with subsidy)

Government policies:

- Project run by MNRE, UNDP and GEF from 2012-2017 supporting CST applications for space cooling;
- Project run by MNRE, GEF and UNIDO from 2015-2019 to increase penetration and scaling up of solar energy in the industrial sector.

Integration with CCHP/trigeneration has been the most favoured model for VAM use in India. Its applications are mostly found at smaller scale (200-1000TR) and its true potential in large-scale applications (>10,000TR) is only now being realized with the rise of smart city initiatives, dedicated business districts and SEZs. VAMs have been implemented in hospitals, hotels, business districts, airports, and SME industries such as food and beverages or textiles.

CCHP/trigeneration is the most common application where power is generated on-site using gas or steam turbines. Such applications are most common in the commercial sector, such as hospitals and hotels. Gas-fired turbines are preferred to generate the power and heat; the resultant waste steam is used to fire the VAMs. VAMs combined with electrical chillers are the preferred cooling system in such applications as this increases the cost feasibility of the system. Moreover, smart city initiatives mean that steam generation from waste (the waste-to-energy concept) used to run turbines for power generation is also being considered as an option.

In the industrial sector, VAMs are operated by waste heat from industrial processes and biomass. Prolonged power outages and poor power quality have been the key drivers for setting up VAM-based trigeneration systems. Even for industries that are not opting for trigeneration, the availability of free cooling is a major factor in decision-making regarding VAM-based cooling.

Some solar VAMs were installed from 2006 to 2015 in industries, commercial kitchens, and institutions; these were mainly CST-based. SMEs are acting as R&D drivers and manufacturers of this technology through patented products (such as concentrated solar discs), although the manufacturing and installation of VAMs themselves is limited to global players. CST-based VAMs incur a significantly higher investment, usually four times higher than a conventional system. The major cost component is the concentrated solar discs used for steam generation. Therefore, this technology is struggling for penetration within the VAM segment.

Solar thermal VAMs share some percentage of these installations. Unlike CST, the steam is generated using patented, sophisticated solar heat collectors that are engineered to operate even in diffused or non-incident sunlight. These heat collectors absorb thermal heat through conduction, convection and radiation and can be operated year-round, regardless of seasonal variations. Compared to solar PV, solar thermal collectors have

37 Stakeholder consultations with Thermax Global, Clique Solar and Blue Star Technologies
38 ICAP 2019

considerably higher efficiency (~60 per cent), making them more cost-effective than solar PV VAMs. Payback is more than four years for 150-300TR systems, two and a half to three years for 500-1,000TR systems and even lower for larger installations.[39] The longer payback period can be attributed to the fact that key elements (e.g. solar thermal collectors) and entire systems are imported, which significantly increases the capital investment. High capital investment is the major barrier faced by the technology apart from the presence of very few players, which makes the market non-competitive. Stakeholder consultations revealed that a few start-ups had entered the market in the past but were unsuccessful.

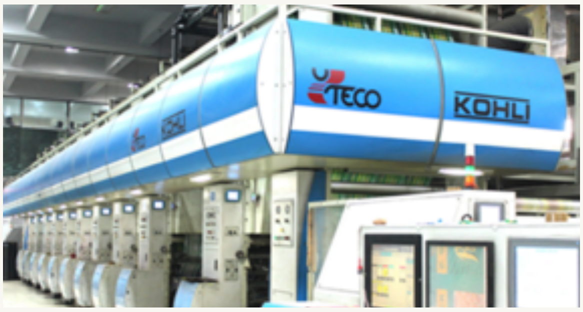
Several programmes have been run for upscaling CST and its applications (included cooling). One such project was run by MNRE, UNDP and GEF from 2012-2017, supporting CST applications for space cooling, community cooking and industrial applications with a 30 per cent subsidy and 80 per cent accelerated depreciation. Another such project was run by MNRE, GEF and UNIDO from 2015-2019 to increase the penetration and scaling up of solar energy in the industrial sector. UNIDO, in partnership with IREDA, provided financial support for CST applications where the project developer's contribution would be 25 per cent and MNRE's contribution would be 30 per cent of the benchmark cost and accelerated depreciation. Currently, there is no financial aid available for solar cooling applications.

Case studies

1. Solar VAM installation at Muni Seva Ashram, Vadodara (Installer: Sunrise CSP India Pvt Ltd)

Kailash Hospital is a low-energy development. Prior to the integration of solar thermal, cooling was provided by a 600TR VAM run by steam generated through a biomass boiler. The facility used solar-based cooking in its kitchen and hence did a pilot installation of 100TR CSP cooling consisting of 3.5 rows with 50 pairs of Scheffler dishes and a total collector area of 1,250m^2 with automatic east-west tracking and manual north-south tracking. A biomass boiler is used as a backup system for non-daylight operation. The initial investment in the 100TR CSP system was ₹12.5 million, of which ₹5 million was provided by MNRE while the rest was borne by the facility. This cost did not include the backup boiler and VAM.

2. Kanodia Technoplast Trigeneration Plant, Haryana (Installer: Clarke Energy)



Kanodia Technoplast, a leading integrated flexible packaging manufacturer, has set up a gas-based trigeneration plant for its manufacturing facility. As the region faces severe power cuts on regular basis, a trigeneration system is a step towards securing uninterrupted power for industrial processes.

39 Stakeholder consultation with Blue Star Technologies

The plant consists of a natural gas engine that generates 1.415MWe of electrical output. The electrical and thermal efficiency of the system is 42 and 44 per cent, respectively, and the total efficiency is 86 per cent (an equivalent coal-based power plant would reach only 30-33 per cent). The engine also generates 400,000kcal of thermal output, which is used to generate 200TR of cooling using VAM. The industrial facility benefits from the constant supply of high-quality power, savings in energy costs and reduced GHG emissions.

3. DLF Cyber City, Haryana

This is India's largest integrated business district with a captive cogeneration system owned and operated by DLF itself. The system consists of a 140MW gas turbine for generating power; the waste heat is supplied to VAMs to generate 78,000TR of cooling. The system operates at 85 per cent efficiency, savings of 53 per cent over a conventional coal-based electricity generation plant. The system also helped DLF reduce their peak power demand by 100MW and save 36,000tCO_2 annually.

4.2. COMPARATIVE ANALYSIS OF LOW CARBON COOLING TECHNOLOGIES

This section compares low carbon cooling technologies based on technical, financial and environmental parameters in order to evaluate their relative value and facilitate decision-making for architects, designers, consultants and end users.

Parameters	Radiant cooling	Structure cooling	GSHPs	Evaporative cooling (2-stage or higher)	Vapour absorption cooling
Feasible range of cooling	100-1,000TR	100-1,000TR	5-1,000TR	5-1,000TR	250-1,000TR (Multiple unit for larger applications)
Capital investment per TR	Comparable to conventional air conditioning	Lower than conventional air conditioning	Comparable to conventional air conditioning	Lower than conventional air conditioning	Significantly higher than conventional air conditioning
Energy and indirect emission savings potential over conventional air conditioning	30-50%	>50%	35-40%	50-80%	40-60%
Product life	>30 years	>30 years	>30 years	15-30 years	15-30 years

Parameters	Radiant cooling	Structure cooling	GSHPs	Evaporative cooling (2-stage or higher)	Vapour absorption cooling
Commercial availability & total installed capacity in India	Available, 18,000TR	Available, 4,600TR	Available, ~15,000TR	Available, 100,000TR	Available, 700,000TR
Major R&D opportunities	Opportunity in piping	Opportunity in piping	Almost saturated	Opportunity in increasing number of heat exchanges and developing smaller-capacity products	Opportunity in increasing collector efficiency
Ease of integration (time and effort required for adaptation)	Case specific, would require some design deliberations	Case specific, would require some design deliberations	Detailed feasibility study required	Availability of installation-ready products	Case specific, would require some technical deliberations
Controllability of thermal comfort (degree of control offered over thermal comfort conditions)	Offers good control over required temperature and RH	Requires shift in thermal and RH setpoints towards higher range	Offers good control over required temperature and RH	Requires shift in thermal and RH setpoints towards higher range	Offers good control over required temperature and RH
Suitability to different climatic conditions	Supplemental system needed year-round	Supplemental system needed year-round	Suitable across all conditions	Supplemental system needed for certain times of year	Suitable across all conditions
Dependence on refrigerants	At least 30-40% dependent on refrigerant	100% refrigerant-free	100% refrigerant-free	100% refrigerant-free	100% refrigerant-free

4.3. SMES AS TECHNOLOGY PROVIDERS AND ADOPTERS

4.3.1. Role as technology provider and innovator

Most of the technology providers interviewed provided complete technology solutions, from design and consultation through manufacturing, installation and maintenance. The design and sizing of low carbon cooling solutions involves specialized calculations and simulations which are performed on customized, and at times patented, computational tools. Thus, most SMEs acting as technology providers are involved in the custom design of such systems and are involved in the overall design process along with HVAC consultants and the rest of the design team. This also means that, unlike conventional cooling solutions which are readily available off-the-shelf, low carbon cooling solutions are customized based on project needs. This role may be extended for certain technologies such as GSHPs, which involve extensive field testing and feasibility analyses. For technologies such as evaporative cooling, SMEs are active in manufacturing the complete product and in installation. For other technologies such as radiant and structure cooling and GSHPs, they act as technology integrators. Key elements such as piping for radiant systems and HDPE pipes for GSHPs are either imported or manufactured domestically. Technology providers are responsible for integrating the end product and its installation. GSHPs require extensive field testing and pre-feasibility studies, expanding the role of the SMEs and start-ups providing this technology. For certain technologies such as solar VAM, SMEs are involved in the design and manufacturing of the solar concentrators that generate steam for the VAM.

The contribution of SMEs to low carbon cooling R&D and innovation is also significant. For instance, SMEs working in the evaporative cooling segment are developing high-efficiency evaporative coolers that can provide the equivalent cooling of a conventional appliance but with much lower energy and water consumption. The solar concentrators used in solar VAMs may also be patented by SMEs. GSHP start-ups are working on loop placement and effective use of underground aquifers to maximize system performance. The low-cost and low-energy variant of the radiant and structure cooling approaches is influenced by SMEs active in this segment. Technology providers other than SMEs are also active in R&D within their respective fields. Technology providers and manufacturer of PEX pipes are involved in materials research for improving thermal performance while increasing cost-effectiveness. Global players and market leaders in the conventional cooling segment are providing patented and innovative solar-heat-collector-based cooling products that are more energy efficient than conventional systems and increase the feasibility of solar cooling as a concept. Start-ups are also introducing innovative business models to increase the uptake of low carbon cooling solutions. GSHPs are offered on ESCO or “pay-as-you-save” models and have successful installations in operation.

4.3.2. Role as technology adopter

SMEs have been adopting low carbon cooling solutions in ways that become part of their mainstream operations. For example, the aquaponics and hydroponics industries are adopting GSHPs to provide reasonably controlled and stable year-round environments; increasing the adoption by this segment by 40 per cent. VAMs are gaining traction in industrial applications such as food and beverages, textiles and packaging where waste steam is being used as fuel for VAM operation and the resulting cooling is free. Industrial storage facilities are adopting evaporative coolers as they provide the acceptable thermal conditions required for maintaining the shelf life of stored goods at a much lower operational cost. Radiant cooling panels and structure cooling are increasingly being adopted in warehouses. Hotels in the SME segment are increasingly adopting radiant cooling and GSHPs.

Outside of the SME segment, low carbon cooling solutions are being adopted in offices, hospitals, institutional buildings, retail spaces and business districts. Radiant cooling is being adopted by offices and retail spaces due to enhanced thermal comfort at a lower operating cost and longer system service life. GSHPs and solar air conditioning are being adopted by hospitals and large-scale kitchens to meet their year-round requirements for cooling and hot water. Institutional buildings are adopting evaporative cooling and structure cooling due to the low capital requirements and operating costs. Business districts are using VAMs through trigeneration to generate on-site power and cooling as a secondary product.

4.4. DRIVERS AND OPPORTUNITIES

4.4.1. Drivers

The growth of low carbon cooling in India is primarily driven by operational energy savings and associated life-cycle costs. Designers and technology providers consulted for this report stated that an easy-to-implement, less-disruptive low carbon cooling technology had a higher chance of adoption by end users. These technologies would provide reasonable thermal comfort at 30-40 per cent less energy expenditure and have a payback period of two to three years. Architects practicing sustainable architecture in India for the past two to three decades have observed a change in the mindset of end users, shifting towards sustainability by design. According to them, this paradigm shift toward low-energy design as the right thing to do is also one of the drivers of sustainable design and the integration of low carbon cooling. Corporate sustainability commitments are another key driver for the adoption of low carbon cooling as industries adopt these solutions in their manufacturing facilities via sustainability initiatives.[40] The green building market in India is growing at a significant rate and is projected to exceed 100 million m^2 by 2022.[41] Low carbon cooling solutions could help achieve significant energy savings, so end users aspiring to achieve green ratings are increasingly opting for these technologies to achieve additional credits for their green building submission. Low carbon cooling solutions are also being adopted for semi-open public spaces where it would not be cost-effective to provide comfort via conventional cooling solutions.

In addition, some technology-specific drivers are spurring the growth of low carbon cooling solutions. Radiant cooling is preferred due to enhanced thermal comfort, longer service life, lower maintenance, increased reliability in areas prone to power outages, and increased freedom of architectural layout. Structure cooling is being adopted for semi-open public spaces where the range of required thermal comfort is broad and cooling is required at low capital investments and energy expenditures.

The growth in GSHPs can be attributed to the year-round stability of cooling output at increased energy efficiency, longer service period, availability of financial incentives from the government and indirect benefits for certain end users.

Evaporative cooling comes at much lower cost and provides ease of integration due to its off-the-shelf readiness. These coolers are most commonly adopted where the range of comfort conditions are not very stringent, such as industry shop floors and workshops. Operational savings, ease of integration and scalability are other drivers identified by technology providers.

VAMs have a niche segment of end users split between those generating waste heat (used for VAM operation) and those requiring hot water or steam (deploying localized trigeneration plants). The latter are also dependent on DGs and boilers for their operation and are opting for reliable energy systems.

4.4.2. Opportunities

Growth in cooling demand

The rapid expansion of the building sector in India provides excellent opportunities for large-scale deployment of low carbon cooling solutions and the consequent expansion of the SME and start-up ecosystem active in this segment.

Growth in the residential sector is headed by several nationwide initiatives such as Pradhan Mantri Awas Yojana for urban and rural India, and similar initiatives at the state level. Consequently, residential air-conditioned areas are expected to increase. According to ICAP, ~8 per cent of current households have RACs; this is expected to rise to 21 per cent and 40 per cent in 2027-2028 and 2037-2038, respectively.

Growth in the commercial sector is attributed to rise of the service industry, increased urbanization and increased demand for office and commercial space. The commercial and retail building footprint is expanding with global retailers setting up new stores in Tier II cities. Luxury hotel chains are planning more than 40 new hotels in the next 5-10 years. As a result, the commercial air-conditioning area is set to increase from 26 per cent to 54 per cent by 2037-2038.

40 Stakeholder consultation with Studio SHIFT
41 https://api.anarock.com/uploads/research/Go%20Green%20-%20The%20Mantra%20for%20Sustainable%20Living.pdf

100 smart cities under the Smart Cities Mission are at the planning and development stage for promoting smart and renewable technologies at the city scale. The infrastructure sector is also expected to expand, with 100 new airports, transit hubs and ports being developed following the sustainable development agenda.

Existing policy initiatives

Although the ECBC 2017 is voluntary, it is expected to become mandatory in the near future. The code awards ECBC+ and Super ECBC status to buildings using low carbon cooling solutions to meet 50 per cent and 90 per cent of their cooling requirements, respectively. This would provide a considerable boost to these technologies, and the opportunities for scaling up low carbon cooling solutions along with the growing building sector are immense.

In addition, an ambitious target of 175GW of renewable installed capacity[42] by 2022 is considered one a key mitigation strategy under India's NDC, providing an opportunity to increase the share of renewable energy in the cooling sector and provide balancing services to the power sector.

HFC phase-down under the Kigali Amendment

The Kigali Amendment to the Montreal Protocol takes responsibility for the phase-down of HFC production and consumption and allows countries to align mitigation actions in the refrigeration and air-conditioning sectors. The amendment also combines the HFC phase-down with effective energy efficiency policies in the sector, providing opportunities for SMEs and other actors to scale up actions with respect to low carbon cooling solutions.

42 This includes 100GW from solar, 60GW from wind, 10GW from bio-power and 5GW from small hydropower. (https://sustainabledevelopment.un.org/partnership/?p=34566)

5. LOW CARBON COOLING SOLUTIONS FOR BUILDINGS: MAJOR BARRIERS

Although the low carbon cooling solutions discussed in this report have been present in the Indian market for more than a decade (some even longer), growth has been very slow. The 2017 installed capacity was only 0.84 million TR, while the dominant conventional cooling technology had an installed capacity of ~66 million TR.[43] Having identified the potential of low carbon cooling systems to reduce energy consumption and associated direct and indirect GHG emissions, along with their broader benefits, ease of integration and potential for scaling up, it is imperative to understand the barriers faced by technology providers to increasing their market penetration. After discussion with stakeholders, these barriers were classified as technical, financial, and policy and regulatory barriers.

5.1. TECHNICAL BARRIERS

Apprehensions and misconceptions

These relate to issues with user expectations, performance shortcomings of the technologies and R&D. One barrier that all technology providers univocally agreed upon was apprehension regarding cooling performance in peak conditions and a tendency to compare this with conventional systems. This was particularly applicable to radiant, structure and evaporative cooling. Technology providers attributed this to a general lack of awareness among designers and consultants regarding ongoing technological improvements in the low carbon cooling segment. Technology providers believed that the systems available now are much improved, with control logic able to provide acceptable thermal comfort year-round. Technology providers also described similar concerns regarding safety issues for systems such as radiant cooling and suggested that technology upgrades have eliminated the probability of accidents.

Technology integration

The time and effort required for design integration and installation was described as a major challenge by most technology providers. Although these technologies provide longer service life, the additional initial effort is seen as a deal-breaker by many end users. Technologies such as GSHPs require extensive field study and analysis to assess installation feasibility. Technology providers believed that the initial testing and risk of failure, added cost for excavation and drilling, and additional land requirements were among the major barriers for deeper penetration of this technology. Technologies such as solar cooling faced issues related to partial availability (daytime only), requiring the end user to invest in a supplemental system that added to the capital and operational expenditure. Consequently, despite major technological upgrades and innovations, this has been difficult to scale up.

Technical knowledge and skilled human resources

Stakeholders identified the lack of technical knowledge and skill sets required among consultants for designing and appraising low carbon cooling solutions as another big

43 ICAP 2019

barrier. Technology providers believed that this is leading low carbon cooling solutions to be considered as secondary choices or not at all. Many respondents also cited a lack of skilled human resources for installation, operation and maintenance as a barrier. Therefore, many respondents have expended significant effort in identifying and training their human resources, requiring technical supervision and financial investment.

Research and innovation

Another barrier that most of the stakeholders agreed with was the absence of R&D and innovation at the sector level. Although almost all stakeholders were involved in some R&D at an individual level, they also identified a lack of academia-industry R&D partnerships and international collaborations that could upgrade the current state of technology. Some providers also highlighted the need for technical assistance from the relevant ministries and other state-funded technical bodies. The need for testing infrastructure for new and innovative products was equally stressed.

Environment for domestic manufacturing

Many technology integrators relied on imports of key technological elements. Although this did not pose a current challenge, many believed that these could be manufactured domestically, making the end product more cost competitive. Challenges envisaged in this process were the requirement for proper technical environments, establishment of relevant quality standards and codes, audits, supporting physical infrastructure and extensive patent registration process (where applicable).

Institutional framework for technical support and mentoring

Industry associations identified a dearth of sustainable institutional frameworks that could guide, and provide technical support to, aspiring SMEs and entrepreneurs. The stakeholders mentioned that such institutions are generally set up as part of technical or financial programmes but are not extended beyond the timeframe of the programme. As a result, many innovative solutions and business ideas fail to obtain the support needed to be converted into successful businesses.

5.2. FINANCIAL BARRIERS

Capital investment

The biggest financial barrier faced by technology providers was upfront investment. Most low carbon cooling solutions require at least 20-30 per cent additional investment per TR over conventional systems. Although the energy savings are significant and these systems pay themselves back within three to four years, the higher investment remains a barrier that technology providers feel is difficult to overcome. Architects and designers practicing sustainable architecture and advocating low carbon cooling solutions have observed that incremental increases in energy savings at corresponding increases in capital investment do not appeal to end users; 20-30 per cent is generally the limit of acceptable additional expenditure.[44] Especially for technologies such as solar VAMs, where the initial investment could be as high as four times the cost of conventional systems, technology providers themselves are reluctant to market the system without any availability of significant financial aid. Some technologies are (or have been) funded by MNRE in collaboration with various international agencies, their impact on space cooling in buildings has not been highly effective. Technology providers also felt that the benefits of economies of scale have yet to be realized through mass implementation, which would emphasize the potential reduction in capital investment and increase in associated energy savings.

44 Stakeholder consultation with Studio SHIFT

Funding for SMEs

The unavailability of financial aid was considered a significant barrier by some SMEs. The manufacturing and integration of these technologies is a capital-intensive process and the lack of focused financial aid could become a barrier for some providers. Many respondents mentioned the absence of start-up-style funding mechanisms for SMEs involved in this segment. For example, equity funding of start-ups is common due to their willingness to share the ownership of intellectual property and patents with investors. SMEs, on the other hand, prefer to retain their intellectual property and proprietary technology, presenting a barrier to equity funding. Many respondents also highlighted the lack of strategic and CSR funding in this segment, believing that this could help financially, bring more confidence to the technology and promote knowledge transfer.

Alternative business models

Start-ups have been experimenting with different business models such as "pay-as-you-save", but have not been able to scale up their product penetration in this manner. SMEs are reluctant to adopt such models, citing narrow profit margins as the major barrier. Many SMEs expressed a need to finance projects adopting low carbon cooling solutions using the EPC model through ESCOs. Similar programmes have been successfully launched for energy efficiency upgrades in existing buildings. SMEs argued that such programmes could make a significant difference, considering the volume of new buildings under construction.

5.3. POLICY AND REGULATORY BARRIERS

Policy environment

Technology providers felt that there is a general lack of government programmes promoting low carbon cooling solutions, citing different policies and programmes run in developed countries for this purpose. These programmes mostly sponsored and increased the visibility of the technology along with providing incentives and tax benefits for scaling up purposes. Technology providers identified the lack of such a policy environment as a major shortcoming from the government.

Financial support and incentives

Technology integrators dependent on the import of key elements (in the absence of domestic products) felt the need for a relaxation of import duties as a support instrument. Several SMEs interested in encouraging domestic manufacturing cited challenges including a lack of quality standards as well as technical and dedicated financial support. SMEs also cited a lack of financial support in terms of financial aid or tax benefits as a major challenge to their expansion. Some respondents cited the absence of intervention programmes funded by international agencies and financial institutions, similar to those focused on lighting and renewable energy. Even where such programmes are in place, there are very limited outreach and awareness activities to ensure their uptake and effective implementation. In the absence of such policy support and promotion from the government, technology providers and SMEs especially found it challenging to market their products. There was also a feeling that sponsorship from the government could increase the confidence of consultants and end users in these technologies. Multilateral funding agencies are providing financial support to manufacturers of refrigerant-based cooling solutions that are working on HCFC phaseouts; many respondents highlighted the lack of similar aid to the low carbon cooling segment.

State-sponsored promotion

The low carbon cooling sector lacks state-sponsored B2B platforms that could be used by SMEs, start-ups and major technology providers to promote their products, increase visibility among sector specific end users and increase collaborations for R&D activities. Respondents felt that sectoral events and promotional activities and programmes were focused more on conventional and well-established cooling technologies, underrepresenting the low carbon cooling segment.

6. RECOMMENDATIONS

This report reviewed the market for low carbon cooling solutions in India with a particular focus on not-in-kind technologies, identifying the key players involved and the role of SMEs and start-ups. Stakeholder consultations undertaken with technology providers, architects and designers documented the barriers they faced and their opinions on overcoming them. Defining the details of these technical, financial and policy barriers allows for the development and discussion of recommendations for supporting growth in the low carbon cooling technologies segment. This section presents a set of near- and long-term actions required to scale up this segment, including inputs and suggestions provided by technology providers, SMEs and designers. These also highlight the role of key players in the low carbon cooling ecosystem, including policy makers, innovators, funding agencies, industry associations and research bodies. The near-term recommendations relate to effective actions that can be achieved within one to three years, while the long-term recommendations have the potential for high impact but require deliberations and efforts from multiple stakeholders and hence are more time intensive.

6.1. NEAR-TERM RECOMMENDATIONS

Establishment of B2B forums for the low carbon cooling sector

The stakeholder consultations revealed the key players in the low carbon cooling market and the role of SMEs as technology providers and adopters. However, one major barrier identified was the absence of a conducive business environment for identifying potential adopters and marketing low carbon cooling products. The establishment of B2B forums could help address this barrier. Such forums are generally attended by market leaders, innovators, providers and potential adopters who are primarily aware of the technologies and products, providing a centralized platform for business-related activities. It is essential that such forums be dedicated to low carbon cooling technologies and separated from the conventional cooling segment, in order to give them much-needed highlight and visibility. Industry leaders and associations, along with NGOs and international organisations, could play an active role in the establishment of such forums.

Development of funding mechanisms to promote local manufacturing in India

Many SMEs dependent on the import of key elements have demonstrated a willingness to enter into domestic manufacturing and thus reduce dependency on external factors. This is a much-needed step and should be encouraged. However, these SMEs have expressed concerns regarding the capital-intensive nature of setting up manufacturing facilities. These entities could be provided support under the "Make in India" and "Atma Nirbhar Bharat" initiatives with required technical and financial assistance. Additionally, SIDBI has established several lines of credit with major national and international financial institutions for green financing; these could fund SMEs operating in the low carbon cooling segment. These include the SIDBI-KfW Innovation Finance Programme, UNIDO's Promoting Energy Efficiency and Renewable Energy in Selected MSME Clusters, GEF-World Bank Financing Energy Efficiency with SIDBI and BEE, SIDBI-JICA Energy Saving Line, SIDBI-AfD Energy Efficiency Credit Line and SIDBI-KfW Energy Efficiency Credit Line.[45]

Establishment of government training programmes for skill development

A lack of skilled human resources was identified as a major barrier by many stakeholders. This puts an additional strain on technology providers to identify and

45 https://d2391rlyg4hwoh.cloudfront.net/downloads/clean_e__innovation_ecosystem.pdf

train a workforce with specialized skills. The government of India already runs skill-enhancement programmes such as "Pradhan Mantri Kaushal Vikas Yojana" that provide youth with access to industry-relevant training. Such programmes could also be used to develop technical skills required for the integration, installation, operation and maintenance of low carbon cooling solutions. Industry leaders, associations (such as ISHRAE), practitioners, construction professionals and academics could work together to develop relevant training programmes.

Establishment of research collaborations between industry, academia and research bodies

R&D in the low carbon cooling industry is still localized at the individual firm level. Although some innovative products and business ideas have emerged from this process, there is immense potential to scale up these efforts by establishing relationships between industry, academia and research institutions for joint research and pilot demonstrations. This could be extended to international research institutions and industries to integrate global research experience and best practices. Such initiatives would promote information exchange and would validate novel research, thus increasing market confidence in the technology. An added benefit would be the development of graduates with industry-relevant and market-ready skills and knowledge, thus contributing to the knowledge and worker pool. Another outcome from such collaborations could be specialized testing and verification facilities for new and innovative low carbon cooling technologies, which are sorely needed to spur innovation in this segment.

Development of an incubation ecosystem

Many SMEs and start-ups are developing innovative products for the low carbon cooling market. In order to continue this trend and support the conversion of such ideas into successful businesses, it is important to providing support in the form of technical assistance and mentoring, financial assistance, brand building and innovation rewards. Institutional frameworks for technical support, mentoring and the vetting of innovative products could also be set up at the industry level. Such institutions could play an active role in supporting aspiring SMEs and start-ups by providing necessary guarantees and recommendations for fundraising. Low carbon cooling technologies could also be added as a focus area in programmes such as the NIDHI and academic incubators set up by major institutions such as IIM, IIT, NSTEDB, INVENT and similar programmes developed by private industry, CSRs, NGOs and independent incubators. Reward programmes such as the Global Cooling Prize and Climate Solver have also been successful.

Promotional activities for low carbon cooling

Technology providers cited unawareness and unfamiliarity toward low carbon solutions as a major barrier to market penetration. Governments, NGOs and industry associations can play an active role in organising events where technology providers can showcase their products and innovations, using this platform for business and marketing purposes. Such events would help end users become better informed about these technologies and how they could meet project requirements. Similar activities in the green building sector have attracted notable traction from market players and could have a similar impact on the low carbon cooling sector. Stakeholder consultations also revealed the need for pilot demonstrations to showcase the mass implementation of low carbon cooling technologies, emphasizing the role of organizations such as Ozone Cell and EESL as partners in such initiatives.

6.2. LONG-TERM RECOMMENDATIONS

Policy and regulatory support for long-term growth

Stakeholders identified the lack of a strong policy environment for low carbon cooling technologies that would be conducive to building a long-term vision and guidelines for the growth of this sector. Countries such as the Sweden, France, Germany, Switzerland, China, South Korea have policies and regulatory frameworks for GSHP technology. Under these policies, end users are offered financial incentives, tax rebates and technical assistance to increase market penetration.[46] The USA is leading R&D in evaporative cooling technology and has introduced innovative policies and financial programmes to increase market penetration. Countries like the USA, China and Japan have major focus on District Energy systems.[47] South Korea provides financial incentives for using high COP VAMs,[48] increasing R&D and sales of high-efficiency VAMs over electric chillers. Similar policy programmes should be developed in India, with a focus on increasing the adoption of low carbon cooling technologies among end users. Inclusion of these technologies in the ECBC 2017 and rewarding utilization is a step in the right direction and similar actions are recommended from policymakers and decision-makers. Policies providing technical assistance, financial support, tax rebates, extra FAR and accelerated depreciation could show positive outcomes and are recommended.

Development of standards and labelling programmes

Performance benchmarking through standards and labelling programmes have helped achieve energy efficiency in conventional cooling technologies, and similar programmes could be launched for low carbon cooling technologies. This would validate the performance of these technologies, which the stakeholders believed was an urgent need for this segment. This would also spur efficiency improvements and innovations in this segment and make the market more competitive. As performance labels have a positive impact on sales and uptake of products, such programmes could expand the market. The BEE has developed performance labels for more than 21 appliances, including RACs, chillers and VRFs (under development), and is also responsible for their periodic revision and upgrade. Similar programmes could be developed for low carbon cooling technologies.

Establishment of financial support programmes

MNRE has been active in launching financial support programmes in association with national and international agencies including GEF, UNIDO, UNDP and IREDA. One financing scheme focuses on promoting GSHP installation, funding GSHP projects with >100TR capacity through subsidies of 30 per cent of project cost for closed-loop systems. However, as this scheme is only applicable to relatively large installations, it excludes most residential and small-scale installations. Similar financial plans could be implemented for installations with lower installed capacity. Several programmes have focused on upscaling CST with space cooling, providing subsidies, accelerated depreciation and soft loans, but there is currently no financial aid available for solar cooling applications. All stakeholders consulted agreed that high initial cost was a major barrier to market penetration, creating a significant need for the development of financing schemes for all low carbon cooling technologies and improved communication about such programmes. This report focused on understanding India's cooling landscape, space-cooling-related direct and indirect carbon emissions, and the role of low carbon cooling technologies in reducing these emissions. It also reviewed low carbon cooling technologies, identified key players, and assessed the challenges faced in increasing the penetration of these technologies and the actions that can be taken to promote and spur the growth of this segment.

The project team reviewed the growth of space cooling demand, problems associated with the current cooling mix, and established the current status and projections for related direct and indirect carbon emissions under BAU and different intervention scenarios. This exercise established the importance of increased penetration of low carbon cooling in lowering emissions in the near- and long-term run. ww

46 https://www1.eere.energy.gov/geothermal/pdfs/gshp_overview.pdf
47 https://www.eesi.org/papers/view/fact-sheet-combined-heat-and-power#4
48 Stakeholder consultation with Thermax Global

7. CONCLUSION

The report also conducted a comprehensive review of low carbon cooling technologies in India. The project team reviewed the low carbon cooling ecosystem and the technologies available in the market through a literature review and numerous stakeholder consultations with technology providers, architects and designers, industry associations, ESCOs, research institutions and policy makers. The literature review was conducted to understand the technologies, technology trends, current status of R&D and global best practices. Stakeholder consultations were conducted to understand practical aspects of the technologies, challenges faced by technology providers at the industry level and views of other players in the ecosystem. These discussions highlighted the prominent role of SMEs and start-ups as technology providers and innovators as well as adopters and end users leading the growth of this segment. The consultations also shed light on major technical, financial, policy, and regulatory barriers and challenges. These included high capital investment, low technical awareness and skill, lack of financial incentives and support, lack of strong policy frameworks and limited focus on R&D.

As an outcome of these discussions and the review of global best practices, the project team put forward several recommendations to promote the growth of these technologies. In the near term, the report recommends developing industry-academia research collaborations, an incubational ecosystem, performance standards, labelling programmes, B2B forums, promotional activities, and training programmes. In the long term, the report recommends the development of a strong policy framework for long-term growth, financing instruments to promote domestic manufacturing, and financial programmes to implement these technologies at a larger scale. These recommendations are in line with ICAP goals and focus areas. This report is intended to develop confidence in these technologies among architects, consultants and end users, boost research and innovation and serve as a foundational study for the development of technical and financial programmes and policies in the future.

ANNEXURES

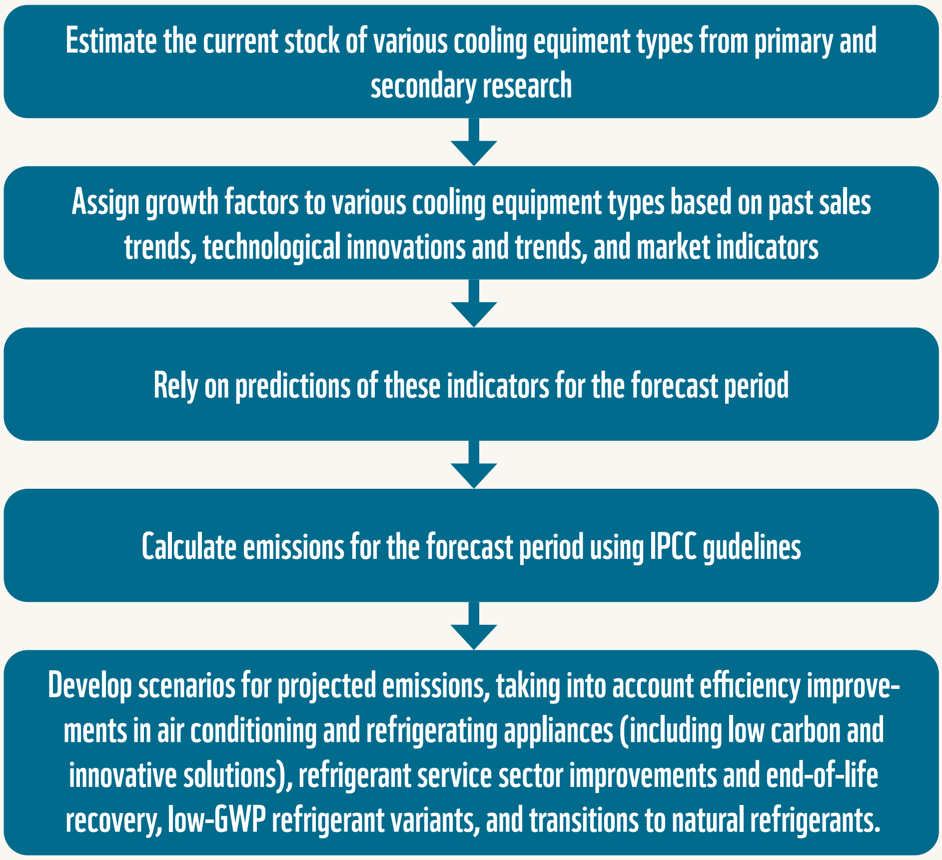
8. ANNEXURE - 1

8.1. EMISSION ESTIMATION METHODOLOGY

The emission inventory covered GHG emissions from total current and projected future emissions (through 2050) for comfort cooling equipment in buildings (RACs, VRV/VRFs, packaged DXs and chiller systems) and included both direct and indirect emissions.

The figure below depicts the methodology employed to assess current and projected emissions through 2050:

Figure 26: Methodology followed for estimation of emissions related to cooling



The calculation method used to derive emissions followed the IPCC Revised Guidelines for National Greenhouse Gas Inventories (IPCC 1997). Emission estimates were prepared in a consistent manner using Tier 2 methodology based on stock data for appliances. The current stock was derived from historic sales figures while future growth trends and dynamics were assumed when determining future stock. Emissions were calculated for each appliance type based on critical technical parameters with respect to both direct and indirect emissions.

The following equations were used to calculate emissions from cooling equipment in India:

Total emissions = $E_{(Direct,t)}$ (Direct emissions) + $E_{(CO2,ind,j)}$ (Indirect emissions)

Direct emissions

Tier 2 methodology calculated direct emissions for individual refrigerants on the basis of emissions during system assembly, operation and disposal, taking current service and recovery practices into account.

$$E_{(Direct,t)}=E_{(assembly,t)}+E_{(operation,t)}+E_{(disposal,t)}$$

where: $E_{(assembly,t)}=E_{(ch\ arg\ ed,t)}\times(k/100)$, $E_{(operation,t)}=E_{(stock,t)}\times(x/100)$, $E_{(disposal,t)}=Ei_{(ch\ arg\ e\ (t-n)\ )}\times Q$

$E_{assesmbly,t}$: direct emissions (CO_2eq) of units t during assembly

$E_{operation,t}$: direct emissions (CO_2eq) of units t during operation

$E_{disposal,\ t}$: direct emissions (CO_2eq) of units t during disposal

$E_{charged,t}$: amount of refrigerant charged into new systems in year t

k: assembly losses by per cent of amount charged

$E_{stock,}$: amount of refrigerant stocked in existing systems in year t

x: annual leakage rate by per cent total refrigerant charge in the stock

$E_{charge(t-n)}$: amount of refrigerants initially charged into new systems installed in year (t-n)

Q:- amount of refrigerants emitted at system disposal by per cent quantity of chemical originally charged into the system

Indirect emissions

$$E_{(CO2,ind,j)}=n_{(stock,j)}\times(CPj/COPj)\times RT_j\times EFelectr$$

where

$E_{co2,ind,j}$: indirect emissions (CO_2eq) of units j

$n_{\ stock,\ j}$ - stock of units j

CP_j : cooling capacity of unit j

COP_j : coefficient of performance of unit j

RT_j: average annual runtime hours of unit j

EF_{electr} : emission factor of electricity

9. ANNEXURE - 2

9.1. PARAMETERS, ASSUMPTIONS AND RESULTS FOR RAC EMISSION PROJECTIONS

<table>
<tr><th>Parameter</th><th>Details</th><th>Remarks</th></tr>
<tr><td>Projection time period (baseline to final year)</td><td>2017-2050</td><td></td></tr>
<tr><td>Stock (2017)</td><td>39 million units</td><td>Stock data followed the ICAP and BEE report (2017). As the most popular unit size was 1.5TR, this was used to convert the stock to TR for the emissions calculations.</td></tr>
<tr><td>Stock growth factors</td><td>
<table>
<tr><th></th><th>2017-2027</th><th>2027-2037</th><th>2037-2050</th></tr>
<tr><td>% growth</td><td>15%</td><td>10%</td><td>8-10%</td></tr>
</table>
</td><td>Projected RAC sector growth for 2017-2027 and 2027-2037 was in line with the ICAP and BEE report. For 2037-2050, the growth factor will decline or remain the same because penetration will have reached a saturation point.</td></tr>
<tr><td>Refrigerant mix in stock</td><td>
<table>
<tr><th colspan="5">BAU scenario</th></tr>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>R-22</td><td>77%</td><td>20%</td><td>0%</td><td>0%</td></tr>
<tr><td>R-32</td><td>14%</td><td>50%</td><td>75%</td><td>65%</td></tr>
<tr><td>R-410a</td><td>9%</td><td>20%</td><td>5%</td><td>0%</td></tr>
<tr><td>R290</td><td>0%</td><td>10%</td><td>20%</td><td>35%</td></tr>
</table>
<table>
<tr><th colspan="5">Intervention scenario</th></tr>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>R-22</td><td>77%</td><td>20%</td><td>0%</td><td>0%</td></tr>
<tr><td>R-32</td><td>14%</td><td>50%</td><td>65%</td><td>55%</td></tr>
<tr><td>R-410a</td><td>9%</td><td>20%</td><td>%</td><td>0%</td></tr>
<tr><td>R290</td><td>0%</td><td>10%</td><td>35%</td><td>45%</td></tr>
</table>
</td><td>BAU scenario: The refrigerant mix of the stock for 2017 and 2027 was taken from the BEE report. Post-2027, the refrigerant mix was based on market trends and estimates provided by sector experts, primarily driven by HCFC phaseout management plans and HFC phasedowns under the Montreal Protocol.

Intervention scenario: The refrigerant mix of the stock for 2017 and 2027 was taken from the BEE report. Post-2027, an aggressive penetration of R290-based RACs was assumed, primarily driven by global markets.</td></tr>
<tr><td>Efficiency factors</td><td>
<table>
<tr><th colspan="3">BAU scenario</th></tr>
<tr><td>ISEER</td><td>Equivalent kWh/year</td><td>Efficiency improvement YOY</td></tr>
<tr><td>3.2</td><td>1,200</td><td>3% improvement through 2037-2038</td></tr>
</table>
<table>
<tr><th colspan="3">Intervention scenario</th></tr>
<tr><td>ISEER</td><td>Equivalent kWh/year</td><td>Efficiency improvement YOY</td></tr>
<tr><td>3.2</td><td>960</td><td>20% reduction in annual consumption</td></tr>
</table>
</td><td>BAU scenario: The baseline ISEER for 2017 was taken from the BEE report. An efficiency improvement of 3% YOY was in line with the BEE's labelling program and the minimum ECBC requirements. Post-2038, improvements in the sector will be driven mostly by refrigerant shifts.

Intervention scenario: The baseline ISEER and YOY improvement were the same as in the BAU scenario, since this is regulated by BEE. However, the annual KWH reduction of 20% considered the adoption of ECBC codes that would reduce the run hours and cooling load</td></tr>
</table>

<table>
<tr><td>Lifespan</td><td>10 years</td><td>In line with the BEE report</td></tr>
<tr><td>Charge rate</td><td>0.21kg/kW</td><td>In line with the BEE report</td></tr>
<tr><td>Grid Carbon Factor (tCO_2eq/MWh)</td><td>
<table>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>Emission factor</td><td>0.82</td><td>0.59</td><td>0.43</td><td>0.3</td></tr>
</table>
</td><td>See section 3.1.3</td></tr>
<tr><td>Annual run hours</td><td>1600hrs</td><td>As defined in the BEE report</td></tr>
<tr><td>Emission factors</td><td>
<table>
<tr><th colspan="5">BAU scenario</th></tr>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>Manufacture</td><td>2%</td><td>2%</td><td>2%</td><td>2%</td></tr>
<tr><td>Service</td><td>10%</td><td>10%</td><td>10%</td><td>10%</td></tr>
<tr><td>Disposal</td><td>100%</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table>
<table>
<tr><th colspan="5">Intervention scenario</th></tr>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>Manufacture</td><td>2%</td><td>2%</td><td>2%</td><td>2%</td></tr>
<tr><td>Service</td><td>10%</td><td>5%</td><td>5%</td><td>5%</td></tr>
<tr><td>Disposal</td><td>100%</td><td>80%</td><td>70%</td><td>60%</td></tr>
</table>
</td><td>BAU scenario: The manufacture emission factors were based on discussions with OEMs and industry information. The disposal and service emission factors followed the BEE report.

Intervention scenario: Best estimates received from industry experts based on improved practices in the service sector and the disposal and recovery of refrigerants at end-of-life.</td></tr>
</table>

	2017	2027 BAU	2027 Intervention	2037 BAU	2037 Intervention	2050 BAU	2050 Intervention
Stock (million units)	39	157		410		1,254	
Indirect emissions ($MtCO_2e$)	44.1	82	65.6	118.3	94.7	245.6	196.4
Direct emissions ($MtCO_2e$)	14.9	36.3	27.3	52.4	24.7	115.6	54.7
Total emissions ($MtCO_2e$)	59	118.3	92.9	170.5	119.3	361.2	251.1

9.2. PARAMETERS, ASSUMPTIONS AND RESULTS FOR CHILLER EMISSION PROJECTIONS

<table>
<tr><th>Parameter</th><th>Details</th><th>Remarks</th></tr>
<tr><td>Projection time period (baseline to final year)</td><td>2017-2050</td><td></td></tr>
<tr><td>Stock (2017)</td><td>
<table>
<tr><td>Scroll</td><td>0.4 Mn TR</td></tr>
<tr><td>Screw</td><td>3.8 Mn TR</td></tr>
<tr><td>Centrifugal</td><td>0.8 Mn TR</td></tr>
</table>
</td><td>Stock data followed the ICAP and BEE report (2017).</td></tr>
<tr><td>Stock growth factors</td><td>
<table>
<tr><th></th><th>2017-2027</th><th>2027-2037</th><th>2037-2050</th></tr>
<tr><td>Scroll</td><td>5%</td><td>5%</td><td>5%</td></tr>
<tr><td>Screw</td><td>7%</td><td>12%</td><td>12%</td></tr>
<tr><td>Centrifugal</td><td>10%</td><td>12%</td><td>12%</td></tr>
</table>
</td><td>Growth factors through 2027 followed the BEE report. Growth factors from 2027-2037 followed ICAP. The same factors were used for 2037-2050 considering the same growth trend in commercial buildings.</td></tr>
<tr><td>Refrigerant mix in stock</td><td>
<table>
<tr><th colspan="6">BAU scenario</th></tr>
<tr><th></th><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td rowspan="2">Scroll</td><td>R-410</td><td>95%</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td>R-407C</td><td>5%</td><td>0%</td><td>0%</td><td>0%</td></tr>
<tr><td rowspan="2">Screw</td><td>R-134A</td><td>100%</td><td>70%</td><td>50%</td><td>30%</td></tr>
<tr><td>R-513A</td><td>0%</td><td>30%</td><td>50%</td><td>70%</td></tr>
<tr><td rowspan="5">Centrifugal</td><td>R-134a</td><td>90%</td><td>60%</td><td>40%</td><td>20%</td></tr>
<tr><td>R-513A</td><td>0%</td><td>10%</td><td>15%</td><td>10%</td></tr>
<tr><td>R-123</td><td>10%</td><td>0%</td><td>0%</td><td>0%</td></tr>
<tr><td>R-514A</td><td>0%</td><td>10%</td><td>20%</td><td>40%</td></tr>
<tr><td>R-1233zd</td><td>0%</td><td>20%</td><td>25%</td><td>30%</td></tr>
</table>

<table>
<tr><th colspan="6">Intervention scenario</th></tr>
<tr><th></th><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td rowspan="2">Scroll</td><td>R-410</td><td>95%</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td>R-407C</td><td>5%</td><td>0%</td><td>0%</td><td>0%</td></tr>
<tr><td rowspan="2">Screw</td><td>R-134A</td><td>100%</td><td>60%</td><td>40%</td><td>10</td></tr>
<tr><td>R-513A</td><td>0%</td><td>40%</td><td>60%</td><td>90%</td></tr>
<tr><td rowspan="5">Centrifugal</td><td>R-134a</td><td>90%</td><td>45%</td><td>20%</td><td>0%</td></tr>
<tr><td>R-513A</td><td>0%</td><td>15%</td><td>20%</td><td>10%</td></tr>
<tr><td>R-123</td><td>10%</td><td>0%</td><td>0%</td><td>0%</td></tr>
<tr><td>R-514A</td><td>0%</td><td>15%</td><td>25%</td><td>30%</td></tr>
<tr><td>R-1233zd</td><td>0%</td><td>25%</td><td>35%</td><td>60%</td></tr>
</table>
</td><td>BAU scenario - The refrigerant mix of the stock for 2017 and 2027 was taken from the BEE report. Post-2027, the refrigerant mix was based on market trends and estimates provided by sector experts, primarily driven by HCFC phaseout management plans and HFC phasedowns under the Montreal Protocol.

Intervention scenario: The refrigerant mix of the stock for 2017 and 2027 was taken from the BEE report. Post-2027, an aggressive penetration of HFO-based chillers was assumed, primarily driven by global markets.</td></tr>
</table>

<table>
<tr><td>Efficiency factors</td><td>
<table>
<tr><th colspan="3">BAU scenario</th></tr>
<tr><td></td><td>IPLV in IKW/TR (Av. value of total stock)</td><td>Efficiency improvement YOY</td></tr>
<tr><td>Scroll</td><td>1.1</td><td>0.15% improvement through 2050</td></tr>
<tr><td>Screw</td><td>1.05</td><td>0.15% improvement through 2050</td></tr>
<tr><td>Centrifugal</td><td>0.9</td><td>0.15% improvement through 2050</td></tr>
<tr><td colspan="3">IPLV includes both high-side and low-side consumption</td></tr>
</table>
<table>
<tr><th colspan="3">Intervention scenario</th></tr>
<tr><td></td><td>IPLV in IKW/TR (Av. value of total stock)</td><td>Efficiency improvement YOY</td></tr>
<tr><td>Scroll</td><td>1.1</td><td>0.15% improvement through 2050</td></tr>
<tr><td>Screw</td><td>1.05</td><td>0.15% improvement through 2050</td></tr>
<tr><td>Centrifugal</td><td>0.9</td><td>0.15% improvement through 2050</td></tr>
<tr><td colspan="3">IPLV includes both high-side and low-side consumption</td></tr>
</table>
</td><td>BAU scenario: The annual improvement in IPLV for all chillers was in line with ECBC minimum requirements.

Intervention Scenario - No improvement in IPLV at the equipment level was considered since the baseline figures and YOY efficiency improvements were considered stringent. However, a reduction of 20% in IPLV was considered from 2018 onward due to strict adoption of ECBC codes (reducing the run hours and building load).</td></tr>
<tr><td>Lifespan</td><td>15 years</td><td>Based on discussions with various OEMs</td></tr>
<tr><td>Charge rate</td><td>0.28kg/kW</td><td>In line with BEE data</td></tr>
<tr><td>Grid Carbon Factor (tCO_2eq/MWh)</td><td>
<table>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>Emission factor</td><td>0.82</td><td>0.59</td><td>0.43</td><td>0.3</td></tr>
</table>
</td><td>See section 3.1.3</td></tr>
<tr><td>Annual run hours</td><td>2,568</td><td>In line with the BEE report</td></tr>
<tr><td>Emission factors</td><td>
<table>
<tr><th></th><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td rowspan="3">Scroll, Screw, Centrifugal</td><td>Manufacture</td><td>1%</td><td>1%</td><td>1%</td><td>1%</td></tr>
<tr><td>Service</td><td>2%</td><td>2%</td><td>2%</td><td>2%</td></tr>
<tr><td>Disposal</td><td>50%</td><td>50%</td><td>50%</td><td>50%</td></tr>
</table>
<table>
<tr><th></th><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td rowspan="3">Scroll, Screw, Centrifugal</td><td>Manufacture</td><td>1%</td><td>1%</td><td>1%</td><td>1%</td></tr>
<tr><td>Service</td><td>2%</td><td>1%</td><td>1%</td><td>1%</td></tr>
<tr><td>Disposal</td><td>50%</td><td>5%</td><td>5%</td><td>5%</td></tr>
</table>
</td><td>BAU scenario: The manufacture emission factors were based on our discussions with OEMs and industry information. The disposal and service emission factors followed the BEE report.

Intervention scenario: With improved practices in the service sector and disposal/recovery of refrigerant at end-of-life, these are the best estimates received from industry experts.</td></tr>
</table>

<table>
<tr><th></th><th>2017</th><th>2027 BAU</th><th>2027 Intervention</th><th>2037 BAU</th><th>2037 Intervention</th><th>2050 BAU</th><th>2050 Intervention</th></tr>
<tr><td>Stock (million TR)</td><td>5</td><td colspan="2">10.2</td><td colspan="2">30.7</td><td colspan="2">131</td></tr>
<tr><td>Indirect emissions ($MtCO_2e$)</td><td>11.6</td><td>15</td><td>12</td><td>33.6</td><td>26.9</td><td>98.2</td><td>78.6</td></tr>
<tr><td>Direct emissions ($MtCO_2e$)</td><td>0.21</td><td>0.35</td><td>0.32</td><td>0.84</td><td>0.73</td><td>2.6</td><td>1.9</td></tr>
<tr><td>Total emissions ($MtCO_2e$)</td><td>11.8</td><td>15.3</td><td>12.3</td><td>34.4</td><td>27.6</td><td>100.7</td><td>80.5</td></tr>
</table>

9.3. PARAMETERS, ASSUMPTIONS AND RESULTS FOR VRV/VRF EMISSION PROJECTIONS

<table>
<tr><th>Parameter</th><th>Details</th><th>Remarks</th></tr>
<tr><td>Projection time period (baseline to final year)</td><td>2017-2050</td><td></td></tr>
<tr><td>Stock</td><td>2.3 Mn TR</td><td>Stock data followed the ICAP and BEE report (2017).</td></tr>
<tr><td>Stock growth factors</td><td><table><tr><th>Year</th><th>2017-2027</th><th>2028-2038</th><th>2039-2050</th></tr><tr><td>% growth</td><td>15%</td><td>15%</td><td>15%</td></tr></table></td><td>The projected VRF/VRV sector growth in the first decade was in line with ICAP and BEE data. The growth factor for 2027-2038 was in line with ICAP. The growth factor for 2037-2050 will reduce or remain the same as the last decade because penetration will have reached a saturation point.</td></tr>
<tr><td>Refrigerant mix in stock</td><td><table><tr><th colspan="5">BAU and intervention scenarios</th></tr><tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr><tr><td>R-410a</td><td>100%</td><td>80%</td><td>50%</td><td>20%</td></tr><tr><td>R-32</td><td>0%</td><td>20%</td><td>50%</td><td>80%</td></tr></table></td><td>Although the VRF/VRV market was entirely R-410a in 2017, manufacturers have introduced R-32 units in other countries. In both scenarios, penetration of R-32 was considered as the only low-GWP option in this segment in the foreseeable future.</td></tr>
<tr><td>Efficiency factors</td><td><table><tr><th colspan="3">BAU scenario</th></tr><tr><td></td><td>2017</td><td>Efficiency improvement YOY</td></tr><tr><td>IKW/TR</td><td>0.81</td><td>No improvement considered</td></tr></table><table><tr><th colspan="3">Intervention scenario</th></tr><tr><th></th><th>2017</th><th>2027 onward</th></tr><tr><td>IKW/TR</td><td>0.81</td><td>0.73</td></tr></table></td><td>BAU and intervention scenarios: The COP of a VRF / VRV unit varies from 0.5-1.1IKW/TR, depending on load conditions and ambient temperature. An average value of 0.81IKW/TR was used for estimation with no YOY improvement in efficiency. Under the intervention scenario, no improvement in IKW/TR at the equipment level was considered since the baseline figure was stringent. However, a 10% reduction in IKW/TR was considered from 2027 onward due to technological advances.</td></tr>
<tr><td>Lifespan</td><td>15 years</td><td>Based on discussions with various OEMs</td></tr>
<tr><td>Charge rate</td><td>0.23kg/kW</td><td>In line with the BEE report</td></tr>
<tr><td>Grid Carbon Factor (tCO_2eq/MWh)</td><td><table><tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr><tr><td>Emission factor</td><td>0.82</td><td>0.59</td><td>0.43</td><td>0.3</td></tr></table></td><td>See section 3.1.3</td></tr>
<tr><td>Annual run hours</td><td>1920 hours</td><td>As defined in the BEE report</td></tr>
<tr><td>Emission factors</td><td><table><tr><th colspan="5">BAU scenario</th></tr><tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr><tr><td>Manufacture</td><td>2%</td><td>2%</td><td>2%</td><td>2%</td></tr><tr><td>Service</td><td>5%</td><td>5%</td><td>5%</td><td>5%</td></tr><tr><td>Disposal</td><td>100%</td><td>100%</td><td>100%</td><td>100%</td></tr></table><table><tr><th colspan="5">Intervention scenario</th></tr><tr><td></td><td>2017</td><td>2027</td><td>2037</td><td>2050</td></tr><tr><td>Manufacture</td><td>2%</td><td>2%</td><td>2%</td><td>2%</td></tr><tr><td>Service</td><td>5%</td><td>5%</td><td>5%</td><td>5%</td></tr><tr><td>Disposal</td><td>100%</td><td>90%</td><td>80%</td><td>70%</td></tr></table></td><td>BAU scenario: The manufacture emission factors were based on discussions with OEMs and industry information. The disposal and service emission factors followed the BEE report.

Intervention scenario: Best estimates received from industry experts based on improved practices in the service sector and the disposal and recovery of refrigerants at end-of-life.</td></tr>
</table>

	2017	2027 BAU	2027 Intervention	2037 BAU	2037 Intervention	2050 BAU	2050 Intervention
Stock (million TR)	2.3	9.3		37.6		231.1	
Indirect emissions ($MtCO_2e$)	3.4	8.3	7.6	25.2	22.7	108.1	97.4
Direct emissions ($MtCO_2e$)	0.5	1.6	1.6	4.9	4.7	21.3	17.7
Total emissions ($MtCO_2e$)	3.8	9.8	9.2	30.1	27.4	129.3	115.1

9.4. PARAMETERS, ASSUMPTIONS AND RESULTS FOR PACKAGED DX EMISSION PROJECTIONS

<table>
<tr><th>S.No.</th><th>Parameter</th><th>Details</th><th>Remarks</th></tr>
<tr><td>1</td><td>Projection time period (baseline to final year)</td><td>2017-2050</td><td></td></tr>
<tr><td>2</td><td>Stock</td><td>4.6 Mn TR</td><td>Stock data following the ICAP and BEE report (2017).</td></tr>
<tr><td>3</td><td>Stock growth factors</td><td><table><tr><th>Year</th><th>2017-2027</th><th>2028-2038</th><th>2039-2050</th></tr><tr><td>% growth</td><td>5%</td><td>5%</td><td>5%</td></tr></table></td><td>Projected packaged DX sector growth through 2038 was in line with the ICAP and BEE report. For 2037-2050, the growth factor will decline or remain the same because penetration will have reached a saturation point.</td></tr>
<tr><td>4</td><td>Refrigerant mix in stock</td><td><table><tr><th colspan="5">BAU and intervention scenarios</th></tr><tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr><tr><td>R-410a</td><td>85%</td><td>70%</td><td>40%</td><td>5%</td></tr><tr><td>R-32</td><td>15%</td><td>30%</td><td>60%</td><td>95%</td></tr></table></td><td>Although the packaged DX market was entirely R-410a in 2017, in both scenarios penetration of R-32 was considered as the only low-GWP option in this segment in the foreseeable future.</td></tr>
<tr><td>5</td><td>Efficiency factors</td><td><table><tr><th colspan="5">BAU scenario</th></tr><tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr><tr><td>IKW/TR (Av. value of total stock)</td><td>1.25</td><td>1.09</td><td>0.99</td><td>0.87</td></tr></table>
<table><tr><th colspan="5">Intervention scenario</th></tr><tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr><tr><td>IKW/TR (Av. value of total stock)</td><td>1.25</td><td>1.03</td><td>0.93</td><td>0.81</td></tr></table></td><td>The average IKW/TR value in 2017 for both scenarios was in line with minimum ECBC requirements. The 2027 values were in line with minimum efficiency requirements under current ECBC+ and super ECBC standards. Post-2027, a 1% YOY efficiency improvement was considered based on inputs received from OEMs for both scenarios.</td></tr>
<tr><td>6</td><td>Lifespan</td><td>15 years</td><td>Based on discussions with OEMs</td></tr>
<tr><td>7</td><td>Charge rate</td><td>0.26kg/kW</td><td>In line with the BEE report</td></tr>
<tr><td>8</td><td>Grid Carbon Factor (tCO_2eq/MWh)</td><td><table><tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr><tr><td>Emission factor</td><td>0.82</td><td>0.59</td><td>0.43</td><td>0.3</td></tr></table></td><td>See section 3.1.3</td></tr>
<tr><td>9</td><td>Annual run hours</td><td>1920 hours</td><td>As defined in the BEE report</td></tr>
</table>

<table>
<tr>
<td>10</td>
<td>Emission factors</td>
<td>
<table>
<tr><th colspan="5">BAU scenario</th></tr>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>Manufacture</td><td>2%</td><td>2%</td><td>2%</td><td>2%</td></tr>
<tr><td>Service</td><td>5%</td><td>5%</td><td>5%</td><td>5%</td></tr>
<tr><td>Disposal</td><td>100%</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table>
<table>
<tr><th colspan="5">Intervention scenario</th></tr>
<tr><th></th><th>2017</th><th>2027</th><th>2037</th><th>2050</th></tr>
<tr><td>Manufacture</td><td>2%</td><td>2%</td><td>2%</td><td>2%</td></tr>
<tr><td>Service</td><td>5%</td><td>5%</td><td>5%</td><td>5%</td></tr>
<tr><td>Disposal</td><td>100%</td><td>90%</td><td>80%</td><td>70%</td></tr>
</table>
</td>
<td>Based on information received from OEMs</td>
</tr>
</table>

	2017	2027 BAU	2027 Intervention	2037 BAU	2037 Intervention	2050 BAU	2050 Intervention
Stock (million TR)	4.6	7.5		12.2		23	
Indirect emissions ($MtCO_2e$)	9.4	8.9	8.4	10	9.4	11.5	10.7
Direct emissions ($MtCO_2e$)	1.4	1.9	1.9	2.3	2.2	2.6	2.2
Total emissions ($MtCO_2e$)	10.8	10.8	10.3	12.2	11.6	14.1	12.9

10. ANNEXURE - 3

10.1. PASSIVE DESIGN STRATEGIES

Passive building design uses natural resources (e.g. sun, wind, microclimate or water) to provide thermal and visual comfort inside the building. Increasing the ability of the building skin to provide thermal comfort can reduce or eliminate the requirement for active cooling systems. This chapter discusses passive design strategies and their impact on building energy use.

1. Mass and orientation

Building mass and orientation play important roles in minimizing solar heat gains and reducing cooling demand. For a cooling-dominated region such as India, building designers can reduce conduction and radiation heat gains by minimizing surface-to-volume ratio and perimeter-to-area ratio; this can reduce solar heat gains by 20-40 per cent.[49] It is advisable to orient buildings with their longer axis parallel to, or within 0-30° of, a south to north axis; this can reduce cooling energy consumption by 15-25 per cent.[50]

2. Window-wall ratio

The window to wall ratio (WWR) is the ratio of total window area to total wall area. A high WWR increases the amount of internal daylight and external views, at the risk of increased glare and cooling requirements. A low WWR provides savings on cooling energy use but reduces available daylight. Previous research has suggested an optimum WWR of 20-40 per cent across all orientations (US DOE 2014).[51][52] Energy savings of 15-20 per cent are achievable through WWR optimization.[53]

3. Airtightness

A building's airtightness relates to heat transfer through the building envelope and is an important aspect of passive design. Unwanted and uncontrolled heat transfer reduces envelope efficiency and puts additional load on HVAC systems. Identification of thermal bridges and their treatment at the design stage helps reduce infiltration, as do continuous air barriers. For mechanically ventilated buildings, it is recommended to maintain an airtightness of less than 3m3/h.m2.[54] Proper airtightness can reduce HVAC energy consumption by 10 per cent.[55]

4. Insulation

Thermal insulation reduces heat transfer through building elements, thus reducing heating and cooling requirements and enhancing thermal comfort. While all building materials offer some resistance to heat transfer, the conductivity of insulation materials ranges from 0.025-0.04W/m.K , far lower than brick (1.3W/m.K).[56] Apart from reducing heat transfer, continuous insulation also helps increase envelope airtightness. A well-sealed and insulated building envelope can reduce heating and cooling energy requirements by 15 per cent (on average across different climates) and 11 per cent for overall energy use.[57]

49 https://beeindia.gov.in/sites/default/files/Design%20Guideline_Book_0.pdf
50 Alghamy and Azmi, Buildings orientation and it's impact on the electricity consumption, 2017
51 https://www.ashrae.org/technical-resources/aedgs
52 Didwania et. al., Optimization of window-wall ratio for different building types, 2011
53 Chiesa et. al., Parametric Optimization of Window-to-Wall Ratio for Passive Buildings Adopting A Scripting Methodology to Dynamic-Energy Simulation, 2019
54 https://www.planningportal.co.uk/info/200135/approved_documents/74/part_l_-_conservation_of_fuel_and_power/3
55 Klaus and Kubeckova, Airtightness of Energy Efficient Buildings, 2013
56 https://beeindia.gov.in/sites/default/files/BEE_ECBC%202017.pdf
57 https://www.energystar.gov/campaign/seal_insulate/methodology

5. Glazing

~25 per cent of heat transfer in a building occurs through windows via conduction and radiation. Thus, it is advisable to select glass material with lower thermal conductivity and SHGC. Double glazing also allows an increase in WWR to 40-60 percent over 30-40 per cent for single glazing.[58]

6. Cool roofs

Cool roofs use highly reflective paints, sheet coverings or highly reflective tiles to reflect up to 80 per cent of incident solar radiation, yielding a reduction of three to five degrees Celsius in air temperature for top floors. [59] Cool roofs are also beneficial in reducing urban heat islands and improving microclimatic conditions.

7. Shading

Solar shading is an integral part of passive design strategy. It cuts direct solar radiation, reducing the cooling load and improving thermal comfort. Solar shading can be designed in the form of overhangs, fins or a combination of both. Shading design in the form of light shelves also improves the internal distribution of daylight. Shading can reduce cooling requirements by 10-20 per cent, with a maximum benefit in hot and dry climates.[60][61]

8. Natural ventilation

Natural ventilation uses outdoor air to provide thermal comfort during various seasons, depending on the climatic zone; methods include single-sided and cross ventilation, stack ventilation, night purge cooling and a combination of these strategies. Depending on the building type and climatic zone, natural ventilation can reduce cooling requirements by 10-30 per cent.[62] [63]

10.2. RADIANT COOLING

Radiant cooling systems come in two basic variants.

1. Concrete-core radiant systems:

In this system (also known as TABS), PEX-a, b or c (in reducing order of quality) pipes are installed in the concrete slab. These pipes are 16-20mm in diameter and are spaced at 100-200mm depending on the cooling load.[64] The building's thermal inertia provides temporary thermal storage for two to three hours, helping optimize the operation of the chilled water plant and maintaining comfortable conditions during power outages. Generally, the installation is done in ceilings to absorb rising hot air. Installation in floors is considered suitable in the case of high direct solar gains.

58 Didwania et. al., Optimization of window-wall ratio for different building types, 2011
59 https://shaktifoundation.in/wp-content/uploads/2017/06/cool-roofs-manual.pdf
60 Farrar-Nagy et. al., Impacts of Shading and Glazing Combinations on Residential Energy Use in a Hot Dry Climate, 2000
61 Samanta et. al., Evaluation of Impact of Shading Devices on Energy Consumption of Buildings in Tropical Regions, 2014
62 https://www.wbdg.org/resources/natural-ventilation
63 Gonzalez-Lezcano and Hormigos-Jimenez, Energy saving due to natural ventilation in housing blocks in Madrid, 2016
64 Stakeholder consultation with Rehau

Figure 27:
PEX-a pipes embedded along with structural reinforcements (Source: Rehau)

2. Radiant panels:

These specialized panels consist of small, closely spaced PEX tubes embedded in plastic or gypsum that can be easily attached to ceilings or walls. Although more expensive than a concrete-core installation, these offer advantages in retrofit applications. Radiant panels do not provide thermal storage but can respond more rapidly to any instantaneous and unpredictable load.

Figure 28:
Radiant panels (Source: Uponor)

Structure cooling is an innovative low-energy variant of radiant cooling, in which water chilled by a two-stage cooling tower to 20-260C is passed through pipes embedded in the concrete core. This is essentially a pre-cooling system and is used where adaptive thermal comfort is acceptable. The system can be used in places with high cooling load such as malls, hospitals, offices, colleges and semi-open spaces such as transit hubs. The system consumes 0.03-0.05kW/TR compared to a conventional system consuming 1.1kW/TR. [65]

65 Stakeholder consultation with Oorja Energy Engineering

Benefits

1. Energy efficiency

Efficient operating modes: In a radiant cooling system, chilled water passing through the PEX pipes is generally maintained at 12-150C (inlet) and 17-200C (outlet). This allows optimal chiller operation as compared to a conventional forced-air system supplying chilled water at 70C and receiving return water at 120C. The higher flexibility of cool-water operating temperature also allows for the selection of alternative sources of cool water (e.g. cooling towers, fluid coolers, geothermal heat pumps or water bodies).

Lower transport energy usage: Forced-air systems use fans to circulate cooled air to remove internal heat; these account for 30-40 per cent of HVAC energy usage, while radiant systems eliminate the requirement for fans. In addition, the heat-transfer capacity of water is 3,500 times greater than air, so a radiant cooling system provides the same amount of cooling at a lower energy consumption than a forced-air system.

Higher room setpoints: The human body is more sensitive to the mean radiant temperature of a space than the air temperature. Radiant systems inherently provide a lower mean radiant temperature at a higher set-point temperature than a forced-air system, making it is possible for a radiant system to increase the set-point temperature by 2-2.50C and still achieve the same level of thermal comfort.

Lower transmission losses: In addition to direct energy savings, radiant systems also help eliminate losses in transmission that occur in conventional forced-air systems, such as those due to inadequate or poor duct insulation, duct leakage, pressure drops and fan resistance. Distribution in radiant systems occurs by pump. reducing transmission losses significantly. The peak electrical demand is thus reduced as a collective effect of improvement in operational efficiency, higher thermal setpoints, lower fan usage and lower transmission losses.

2. Better thermal comfort

In a typical metabolic setting, the human body transfers more of its sensible heat through radiation. Thus, radiant systems can provide better thermal comfort compared to forced-air systems relying only on convection to provide comfort. Radiant systems reduce surface temperature differentials, in turn reducing thermal stratification and increasing radiant symmetry. These systems also provide a uniform thermal distribution, minimizing drafts and ventilation noise.

3. Reduced operating costs and maintenance

Energy savings translate into reduced operating costs. Structure-embedded PEX pipes are maintenance-free and plant-side maintenance is the same as the forced-air system counterpart. In addition, the reduced size of forced-air systems leads to reduced operating costs and maintenance compared to a 100 per cent forced-air system.

4. Greater architecture flexibility

Structure-embedded radiant systems provide greater flexibility in architectural design and space layout. Reduced size and visibility of ducts, grilles and diffusers also add to the freedom of aesthetic design.

10.3. GROUND SOURCE HEAT PUMPS

GSHPs are classified as vertical or horizontal based on the loop layout used for heat exchange.

1. Vertical GSHPs

Vertical GSHPs involve drilling vertical bore wells and inserting HDPE pipes (20-40mm in diameter) that carry either groundwater (open loop) or a water-antifreeze mixture such as glycol (closed loop) for heat exchange between the surface and lower depths. In the former, the water returns to the ground through a well or surface discharge. This configuration is used where there is an abundance of relatively clean water and local rules and regulations allow such groundwater discharge. There is also a risk of saturation of surrounding aquifers, which may ultimately stop the heat pump's operation.

Figure 29: U-bent pipes before installation (Source: Rosemex Ecotech)

In a closed-loop system, U-bent HDPE pipes carry the water/antifreeze mixture. Since there is no direct use of groundwater, its quality remains unaffected. Vertical GSHPs require 70-100m depth per TR of cooling requirement. The total depth requirement can be achieved by single-well or multiple-well configurations. Depending on the project site and soil strata, land requirement per tonnage varies from 25-40m2 with at least five metres between the bore wells. Generally, vertical installation is more expensive due to additional cost of drilling. The system becomes prohibitively expensive if bedrock is encountered.[66]

2. Horizontal GSHPs

Horizontal GSHPs are closed-loop systems involving HDPE pipes laid out in large pits or trenches in linear or circular fashion to increase the heat exchange, depending on the cooling capacity required. Compared to vertical installations, horizontal GSHP can be installed at a much shallower depth (2-3m below the surface) to minimize seasonal variation in solar irradiation on the subsurface. Land requirements are higher than for vertical GSHPs. Depending on the project specifications and ground conditions, the land requirement per tonnage could range from 120-180m2 for linear loops and 80-120m2 for circular loops. Horizontal installation can be done under parking lots, streets, landfills, playgrounds and green areas. This method is ideal for educational campuses, hospitals and other developments with high land availability.

Figure 30: Horizontal GSHP installation (Source: Energy Saving Trust)Ecotech)

66 Stakeholder consultation with Rosemex Ecotech

3. Surface water heat exchangers

SWHEs are possible where surface water is available in the form of pools, lakes, rivers or seas, although the latter is uncommon due to strong currents, tidal influences and wave action. SWHEs can be either open loop or closed loop. Similar to horizontal GSHPs, the HDPE loops are placed inside a water body at a depth where the water temperate is stable and not influenced by near-surface water temperature and water level. The area required is much lower, generally 5-10m2/TR.9

BENEFITS

1. Increased energy efficiency

The COP of a conventional system decreases with increasing ambient temperature, while the COP of a GSHP is unaffected by changes in ambient conditions. Thus, these systems deliver cooling more efficiently. GSHP systems can operate at 0.44-0.53kW/TR across India, compared to chiller and cooling tower configurations operating at 1.11-1.27kW/TR.[67]

2. Water savings

In a conventional chilled water system, the condenser is cooled by a cooling tower, which requires significant amounts of water replacement on a daily basis due to losses in drift and blowdown. This requirement can be eliminated by GSHPs.

3. Reduction in UHI

Air-cooled condensers reject heat into the ambient air at 60-650C, which increases the UHI potential of the surrounding area and increases the building's HVAC load; GSHPs inherently eliminate this impact.

4. Minimum maintenance and longer lifetime

GSHPs have a very low operational cost (50-70 per cent lower than conventional systems). They have a lifetime of 25 years for interior components and 50 years for the ground loop, while requiring minimum maintenance (reducing the life-cycle cost). GSHPs provide increased reliability and energy security.

5. Ease of integration

GSHPs are easy to integrate with other low carbon technologies. For instance, a water-to-air GSHP configuration can be used for pre-cooling fresh air in DOASs. They can also be used as booster systems for evaporative cooling systems. GSHPs are also preferable for retrofit applications with potential land provisions.

6. Free to low-cost hot water

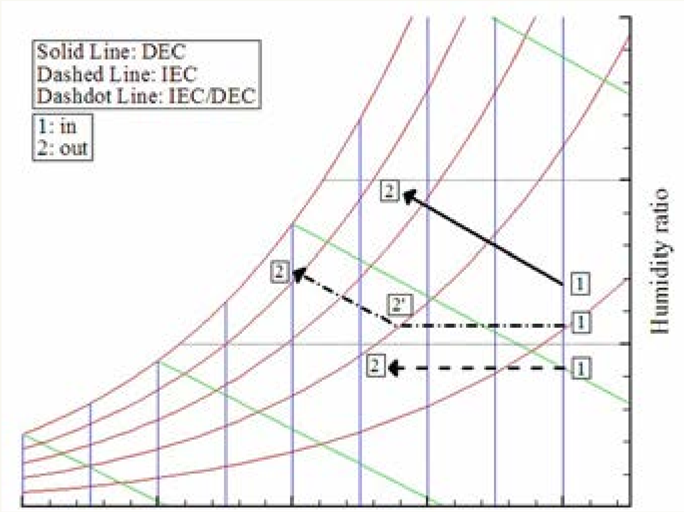
GSHPs are suitable for applications requiring constant hot water, such as hotels, hospitals and kitchens as they generate hot water without any additional energy input. This requires an additional investment for a de-superheater, an additional heat pump or a three-phase heat pump.

10.4. EVAPORATIVE COOLING

Depending on air-water interactions in the cooling media, evaporative cooling systems are classified into DEC and IEC systems.

67 Choudhury. A (2013) HVAC vs Geothermal Heat Pump—Myth & Truth, Open Journal on Energy Efficiency

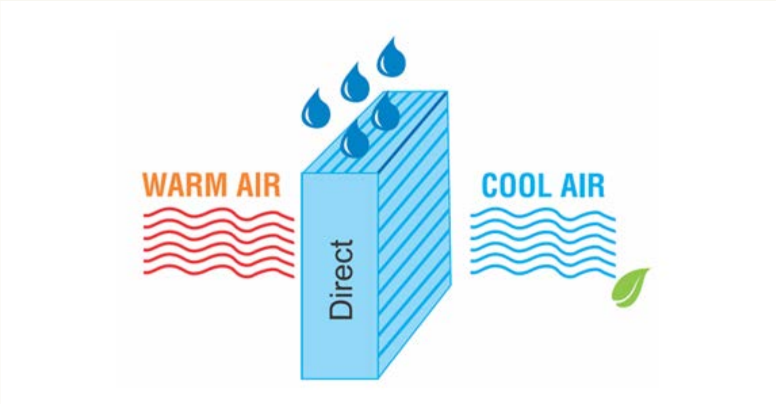
Figure 31: Psychrometrics of DEC, IEC, IDEC and two-stage evaporative cooling systems (Source: Farmahini and Pasdarshahri, 2011)



1. **Direct evaporative cooling**

In this system, outdoor air is passed through soaked cooling media. Water evaporates into the air, thereby increasing its moisture content and reducing its temperature. Theoretically, DEC systems can reduce the temperature of the outdoor air to its wet-bulb temperature by increasing its RH to 100 per cent. However, due to practical limitations, the RH does not reach 100% but falls a few percentage points short. DECs are also referred to as "adiabatic cooling" as the heat exchange occurs only between air and water. Since DEC systems cool the air by adding moisture to it, they are most effective and preferred when outdoor air is hot and dry. The RH of the supply air can get as high as 90 per cent, so the system is well-suited to spaces with very high sensible heat gains and higher RH levels. It would be less advisable for spaces requiring stricter RH control.

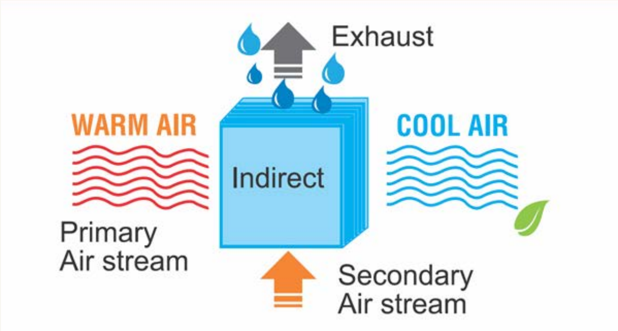
Figure 32: Direct evaporative cooling schematic (Source: ATE Group)



2. **Indirect evaporative cooling**

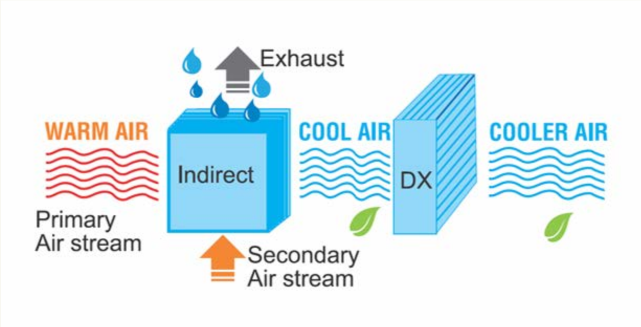
This system alters DEC to mitigate the issue of increased RH. Here, the outdoor air does not come in direct contact with water, but a sensible heat exchanger is used in place of cooling pads. Water is passed in the primary circuit of the heat exchanger, cooling its surface. Outdoor air to be cooled is passed in the secondary circuit, which comes in contact with the cooled surface and is cooled by conduction. In terms of air-moisture balance, this means that the moisture content of the outdoor air remains unchanged and RH increases to a much lower extent than in DEC for an equivalent drop in temperature. Since the cooling is provided through a heat exchanger rather than direct evaporation, its efficiency is much lower (55-70 per cent) compared to DEC (80-95 per cent). However, IECs have wider applicability than DECs.

Figure 33: Indirect evaporative cooling schematic (Source: ATE Group)



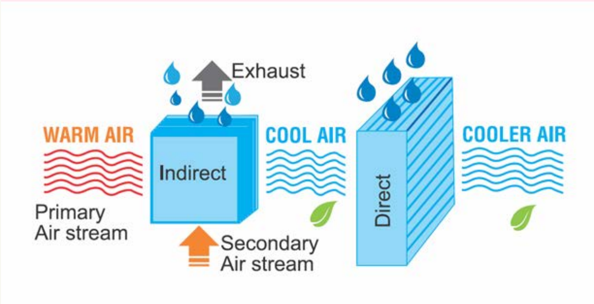
Stage-wise evaporative cooling systems have also been developed to increase the efficiency of evaporative cooling with a controlled increase in RH. These are available as two-stage and three-stage systems. A two-stage evaporative cooling system or IDEC consists of an IEC setup as Stage 1 and DEC as Stage 2. Outdoor air is passed through a heat exchanger in Stage 1, cooling the air at a constant humidity ratio. This air is then passed through water-soaked cooling pads, where it absorbs moisture and its temperature is further reduced, before being supplied to the space. The resultant air is at a much lower temperature with marginal increase in RH. The EER for such systems can range from 25-40. IDECs can reduce the supply air temperature below the wet-bulb temperature of the outdoor air by 3-50C, expanding the applicability of evaporative cooling to much wider climatic conditions and space types. Based on requirements and outdoor conditions, either one of the stages could also be used independently.

Figure 34: Indirect direct evaporative cooling schematic (Source: ATE Group)



Three-stage evaporative cooling systems combine a two-stage system with a conventional cooling coil. The cooling coil (chilled water or direct expansion) is placed downstream of the DEC stage for enhanced temperature and RH control. Its inclusion makes the system viable in monsoon season when cooling is required along with dehumidification.

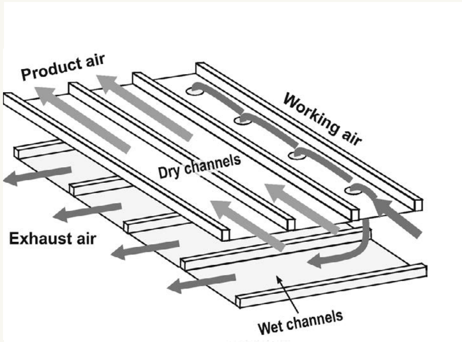
Figure 35: Three-stage evaporative cooling (Source: ATE Group)

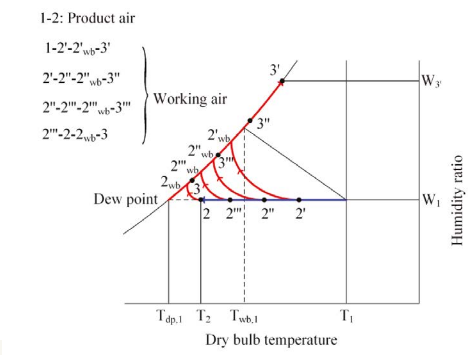


R&D has worked to increase the effectiveness of evaporative cooling. For example, the M-cycle is a multi-stage improvisation over the basic IEC system. Keeping the humidity ratio of the incoming outdoor air constant, it reduces its temperature below wet-bulb temperature and can reduce it to the dew-point temperature, by iterative and progressive heat and mass exchange. Compared to the basic IEC, which uses a single airstream and a sensible heat exchanger, an M-cycle-based IEC system splits the incoming outdoor air into primary/product and secondary/working streams, which are passed through a heat and mass exchanger. The former is passed through dry channels and the latter is passed through wet channels. The cycle simultaneously cools both airstreams at multiple stages. Every stage cools the primary and secondary airstream indirectly and directly, respectively, and resets the input conditions for the next stage. A key feature that enables the resultant air to be cooled to a much lower temperature is the exhaust of moisture at every stage, enabling further cooling. Commercial products based on this psychrometric cycle have been developed and installed successfully across the world. These systems have reported an EER of 45-75 and estimated energy savings of >70% over conventional vapour compression-based cooling systems.[68]

Figure 36: M-cycle schematic (Source: Miyazaki, 2018) *(left)*

Figure 37: M-cycle psychrometrics (Source: Duan et. al., 2017) *(right)*





Benefits

1. 100 per cent refrigerant-free cooling

Evaporative cooling systems work on the principle of water evaporation for cooling, and do not involve any refrigerants. Thus, these system have very low environmental impact compared to their compressor-based counterparts.

2. Low energy consumption

These systems operate at very low energy consumption as the only moving parts are fans and pumps. Thus, depending on the configuration, these systems have an EER of 10-40 for hot and dry conditions.

3. 100 per cent fresh air

Unlike RACs, evaporative cooling systems use 100 per cent filtered outdoor air for cooling. This provides significantly better indoor air quality as indoor contaminants are removed continuously, making these systems suitable for kitchens and hospital wards that require high amounts of fresh air.

4. Cost-effectiveness

These systems' capital investment and operating costs are 50 and 35 per cent lower than conventional systems, respectively.

10.5. VAPOUR ABSORPTION COOLING FOR DISTRICT COOLING

DCSs use hydronic cooling systems to supply cooling at the campus, district or city level. Centralizing the provision of cooling results in energy savings of 40 and 20 per cent compared to air-cooled and water-cooled systems, respectively. As cooling accounts for 40-70 per cent of demand on electricity grids, centralizing cooling reduces strain at the utility level. DCSs also reduce infrastructure costs for individual buildings and incur 20 per cent savings on life-cycle costs.[69]

68 Dean and Metzger (2014) Multistaged Indirect Evaporative Cooler Evaluation, NREL
69 Eveloy and Ayou (2019) Sustainable District Cooling Systems: Status, Challenges, and Future Opportunities, with Emphasis on Cooling-Dominated Regions, Energies

DCSs involve a chilled water plant along with heat rejection, water filtration and treatment, thermal storage, and centralized control systems. The chilled water plant cools water to 4-50C, then pumps it through a network of insulated distribution pipes throughout the area being served. Each building has a separate chilled water loop, meters, valves and pumps. The chilled water is either passed directly into the building's cooling systems or is used to transfer cooling to the building's chilled water loop through a plate heat exchanger. Centralized chilled water returns to the chiller plant at 13-150C and is passed through the filtration and treatment plant. Heat from the return water is rejected in the heat-rejection system (involving air, water, water bodies or the ground) and water is chilled again to be supplied to buildings.

DCSs offer easy integration of different sources for producing chilled water, such as electric chillers, heat-driven chillers, geothermal cooling or free cooling sources such as lakes, rivers, or seas.

This report focuses on two technologies used as components for cooling: vapour absorption and soalr-based cooling.

Principles of VAM operation

The primary reason for focusing on VAMs as a low carbon cooling technology were:

- The primary fuel/input is steam, which is usually available as a by-product in a DCS configuration.
- VAMs reduce refrigerant demand as their operation is refrigerant-free.
- VAMS reduce the peak load requirement and grid stress considerably as their design lowers the required input power and starting torque.

Absorption works on the principle that a concentrated salt (lithium bromide or ammonia) and water solution can be used to absorb water vapour, which can then be pressurized by a low-power pump. VAMs use water as the refrigerant and a lithium bromide (LiBr) solution as the absorbent. The cooling process progresses through stages including refrigerant evaporation, refrigerant absorption by the concentrated LiBr solution, boiling of diluted LiBr solution to generate refrigerant vapour, and condensation of refrigerant vapour. The boiling point of water is directly proportional to pressure; at an absolute pressure of 6mm Hg, the boiling point of water is 3.70C. To change water from liquid to a vapour, it must be heated. The heat required to change the phase of a liquid to vapour is called the latent heat of evaporation. LiBr is similar to common salt (NaCl) and is soluble in water. The LiBr-water solution can absorb water due to its chemical affinity. As the concentration of this solution increases and its temperature decreases, its affinity towards water vapour increases. There is a large difference between the vapour pressure of LiBr and water, meaning that heating the LiBr-water solution will vapourise the water but retain the LiBr, which will become more concentrated.

In addition to fuel, VAMs differ from electric chillers in the following ways:

1. The VAM cycle uses a liquid pump and not a compressor; it is more energy efficient to pump a liquid than to compress a gas.
2. Refrigerants used by VAMs have no associated environmental hazard, ODP or GWP, compared to HCFCs and HFCs.
3. VAMs contain few moving parts, making maintenance requirements very low.
4. The COP of a VAM is much lower than an electric chiller, but the operating cost is also very low, since the working fuel is mostly low-grade waste heat.

There are two types of absorption chillers available, single effect and double effect; the latter is more efficient (COP of 1.2 vs 0.7) but more expensive and complex to operate.

Figure 37: Components and different types of cooling technologies in district energy systems (Source: https://www.districtenergy.ie/images/article_images/IrDEA_Conference_2019_Presentations/Jens_Ole_Hansen.pdf)

Thermal storage

Thermal storage can also be integrated into a district cooling system, where it can decouple cooling demand from the production of cooling energy. Major advantages include:

- Reduced installed chiller capacity as peak demand occurs on the hottest day for only a few hours and stored chilled water can be used to meet this demand;
- Acts as a medium to integrate variable shares of renewable heating/cooling in a DCS;
- Where differential electricity pricing is present, thermal storage can reduce overall operational costs. Chillers benefit from efficiency gains since night-time temperatures are lower. Chillers can be operated at optimal load with the coordinated use of chilled water storage.

Key considerations

DCSs are a significant investment with a larger and longer impact, so decisions involve various stakeholders along with pre-feasibility and detailed feasibility studies. Considerations include:

- Current and future projections of total and peak cooling and power demand. One benefit of DCSs is their economy of scale, which requires large total and peak loads and a potential future increase.
- Density of cooling demand. DCSs are most effective in high-cooling-density regions as more demand is served per length of distribution network.
- Location of cooling centre and distribution network. Ideally, the cooling centre would be located central to the area served or near the cooling source in the case of free cooling.
- Infrastructure costs. DCSs involve major infrastructure costs to set up the chilled water plant and distribution network. This could be easier in greenfield projects, but in brownfield projects, disruption to existing infrastructure should be considered.
- Type of low-side system. This should be considered when assessing DCS feasibility. Existing chilled-water systems are most suitable for integrate with DCSs, but this may not be the case for RACs, split ACs or VRFs.
- Availability and utility cost of fuel, water and electricity. This can be critical for DCSs. For example, the absence of a gas network or a high gas cost could make a trigeneration DCS prohibitively expensive to install and operate.
- Potential revenue from sale of cooling. DCSs can be made feasible if cooling is sold at a competitive or lower cost compared to other systems.

Benefits of DCSs

1. Increased energy efficiency

District cooling benefits from load diversity and flexible capacity during design and installation, utilizing at least 15 per cent less capacity for the same cooling load than combined cooling system distributed in individual buildings. DCSs cater to diverse cooling demands such as offices, commercial establishments, hotels and residences, which peak at different times. They can handle the aggregate peak demand of these diverse loads, in contrast to individual systems designed to meet individual peak demands. In addition, further capacity can be installed as load increases, ensures that DCSs are not disproportionately oversized during initial construction.

2. Energy savings

Aggregated cooling demand can be 25 per cent lower than the sum of individual loads, translating to reduced energy consumption of 40-50 per cent. Energy savings can also be realized through the use of efficient chilled-water systems and heat-rejection systems. Economies of scale can be achieved as larger systems are considerably more energy efficient compared to systems at the individual building level. Integration of thermal storage can reduce strain on utility systems in peak hours and smooth out power requirements during the day.

3. Improved building space utilization

Centralizing cooling at the district level can reduce the plant's space requirements at the individual building level, generally achieving 75 per cent space reductions. Reduced plant room can increase the total usable space, generating additional profit and making DCSs effective for retail, business and industrial zones.

4. Reduced building management expenditure

Since DCSs centralize plant management, individual buildings benefit from simplified building management plans. Requirements for periodic maintenance and replacement of cooling system elements is also eliminated, resulting in cost savings.

5. Improved reliability

DCSs are generally designed with multiple loops to ensure provision of regular and reliable cooling. Some systems also integrate backup systems to provide additional reliability in distribution. Additionally, trigeneration-based DCSs could help avoid expenditures on fossil fuels, generate local tax revenue, create jobs, and defer investments in power generation expenditure.

6. Integration of local renewable sources of energy

DCSs can integrate new waste heat sources and increase the share of renewable energy sources used for cooling, improving the user's overall energy mix and boosting overall system efficiency.

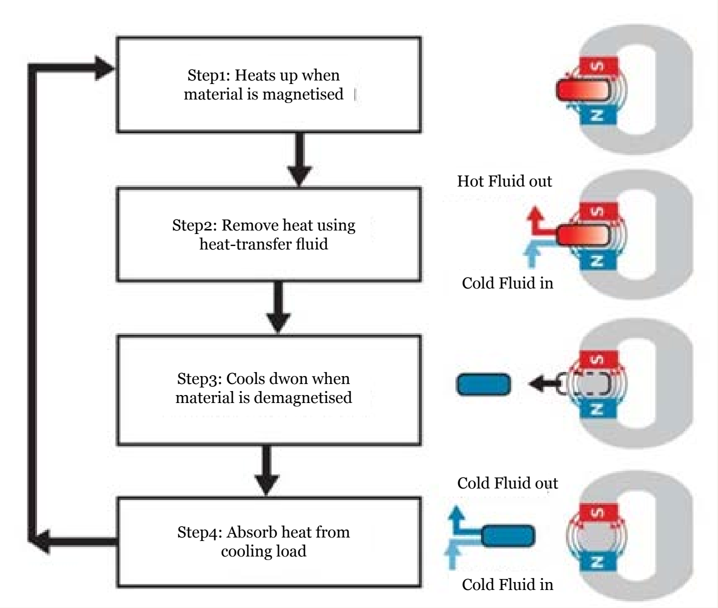
10.6. TECHNOLOGIES UNDER RESEARCH AND DEVELOPMENT

Compression-based technologies are expected to remain the main source of air conditioning in the near future, but certain technologies in the R&D stage could potentially change the landscape of comfort cooling, as outlined below.

10.6.1. Magnetic refrigeration

The principle of magnetic refrigeration is based on the MCE phenomenon. Discovered by Emil Warburg in 1881, this was related to the property of exotic materials (such as gadolinium and dysprosium) that heat up when a magnetic field is applied and cool down when it is removed.

Figure 38: ThermXTM solar thermal collector



The magnetocaloric cycle frequency is typically between one and three hertz, so the rotation speed is slow and therefore very quiet compared to traditional compression systems. According to recent research, MCE may have a significantly higher efficiency (coefficient of performance) than conventional methods, with the potential for 30 per cent energy savings. The main issue is the supply of magnetocaloric materials, which are scarce. Reducing the material content, or identifying new materials, would increase viability.

10.6.2. Cryptocoolers

Andreas Schilling, a physics professor at the University of Zurich, has created a device that could cool a 9g piece of copper from over 1000C to significantly below room temperature without an external power supply. This method uses a Peltier element, which can transform electric currents into temperature differences. Such an element has already been used, in connection with an electric inductor, to create an oscillating heat current in which the flow of heat between two bodies perpetually changed direction. In this scenario, heat also temporarily flows from a cooler to a warmer object, cooling the former even further. This kind of "thermal oscillating circuit" in effect contains a thermal inductor. Schilling's team has not only operated such circuits using an energy source but have now shown for the first time that operation can also be passive, with no external power supply. Thermal oscillations still occur, resulting in heat flowing directly from the cooler copper to a warmer heat bath with a temperature of 220C, without being temporarily transformed into another form of energy. Although the team recorded a difference of only ~20C compared to the ambient temperature, this was mainly due to the performance limitations of the commercial Peltier element used. According to Schilling, it would be theoretically possible to achieve cooling of up to -470C under the same conditions, if the ideal Peltier element – yet to be invented – could be used.

10.6.3. Solar thermal collector

ThermX™ uses an exclusive patented process that places a three-part heat exchanger between the compressor and the condenser. This allows the sun to provide free energy, so the compressor does less work to produce the thermal energy required to meet the delta T requirements for credible subcooling. The collector has a copper or stainless-steel pipe that runs through an evacuated glass tube, so the glass does not come into contact with the refrigerant. The sun's radiation creates heat inside the evacuator tube, as in a thermal flask. This design allows the system to run far less electricity and enhances its overall efficiency.

Figure 39: Magnetic refrigeration schematic

10.6.4. "Smart muscle" cooling

Biomedical applications, like stints for clogged arteries, make use of nickel-titanium's super-elastic properties and shape memory. Professors Stefan Seelecke and. Andreas Schütze of Saarland University used these properties to create a highly efficient, environmentally friendly heating and cooling device that has been referred to as 'smart muscle'. The smart muscle releases heat when stretched and absorbs heat when unloaded. The absorption and release of heat can be used form a cycle like vapour absorption. The device requires an external energy source to do the stretching and unloading but eliminates the need for refrigerants. It has been termed as the most promising alternative to vapour compression technology by the U.S. Department of Energy and the EU Commission.

11. BIBLIOGRAPHY

Alghamry, R. and Azmy, N. 2017. Buildings Orientation and it's Impact on the Electricity Consumption. Al Azhar 14th International Conference (AEIC) on Engineering, Architecture & Technology.

BEE. 2014. Design Guidelines for Energy Efficient Multi-Storey Residential Buildings. Bureau of Energy Efficiency, India.

Chiesa, G., Acquaviva, A., Grosso, M., Bottaccioli, L., Floridia, M., Pristeri, E. and E. Sanna. (2019). Parametric Optimization of Window-to-Wall Ratio for Passive Buildings Adopting A Scripting Methodology to Dynamic-Energy Simulation. Sustainability 11: 3078.

Choudhury, A. 2013. HVAC vs Geothermal Heat Pump—Myth & Truth. Open Journal of Energy Efficiency 2: 42-45.

Dean, J. and Metzger, I. 2014. Multistaged Indirect Evaporative Cooler Evaluation. NREL.

Didwania, S., Garg, V. and J. Mathur. 2011. Optimization of Window-Wall Ratio for Different Building Types. US DOE.

Energy Star. 2020. Methodology for Estimated Energy Savings from Cost-Effective Air Sealing and Insulating. Retrieved from https://www.energystar.gov/campaign/seal_insulate/methodology.

Eveloy, V. and Ayou, D. 2019. Sustainable District Cooling Systems: Status, Challenges, and Future Opportunities, with Emphasis on Cooling-Dominated Regions. Energies 12: 235.

Farrar-Nagy, S., Anderson, R. and P. Reeves. 2000. Impacts of Shading and Glazing Combinations on Residential Energy Use in a Hot Dry Climate. NREL.

González-Lezcano, R. and Hormigos-Jiménez, S. 2016. Energy Saving due to Natural Ventilation in Housing Blocks in Madrid. IOP Conference Series: Materials Science and Engineering.

Hillesheim, M. and Mosey, G. 2014. Technical Feasibility Study for Deployment of Ground-Source Heat Pump Systems: Portsmouth Naval Shipyard - Kittery, Maine. NREL.

HM Government. 2016. Part L2A, The Building Regulations 2010. England

Hu, R. and Niu, J. 2017. Operation Dynamics of Building with Radiant Cooling System based on Beijing Weather. Energy and Buildings 151: 344-357.

Klaus, M. and Kubečková, D. 2013. Airtightness of Energy Efficient Buildings. GSTF International Journal of Engineering Technology 2.

MOEFCC. 2019. India Cooling Action Plan.

Rehau. (n.d.). Radiant cooling. Retrieved from https://www.rehau.com/in-en/radiant-cooling

Samanta, A., Saha, S., Biswas, J. and A. Dutta. 2014. Evaluation of Impact of Shading Devices on Energy Consumption of Buildings in Tropical Regions. Journal of Energy Resources Technology 136: 024503.

Uponor. 2013. Radiant Cooling Design Manual.

US DOE. 2014. Advanced Energy Design Guides: Office Buildings.

Walker, A. (2016). Natural Ventilation. Retrieved from: https://www.wbdg.org/resources/natural-ventilation


इंडियनऑयल
IndianOil
A Maharatna
Company

अहमदाबाद
AHMEDABAD
लिमिटेड
LIMITED
BLUE STAR
RVS

WWF®

LOW CARBON COOLING SOLUTIONS FOR BUILDINGS IN INDIA

IND

WWF

50
YEARS IN INDIA

Working to sustain the natural world for people and wildlife

together possible™ wwfindia.org

WWF-India Secretariat
172-B Lodi Estate
New Delhi 110003
Tel: 011 4150 4814 Fax: 011 4150 4779