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Demand Analysis for Cooling by Sector in India in 2027

Study by:

Alliance for an Energy Efficient Economy

On behalf of:

igef Indo-German Energy Forum

सत्यमेव जयते

GOVERNMENT OF INDIA
MINISTRY OF POWER

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Ministry of Road Transport and Highways (MoRTH)
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Version
New Delhi, October 2018 (Update from previous version of January 2018)

Note to the Reader: The analysis presented in this report is based on the latest production data of star labelled aplliances. New information became available per the latest production data of star labelled appliances published by BEE in May 2018 for RACs, domestic-type refrigerators and ceiling fans. New trends emerged from the revised dataset - particularly, the RAC analysis presented in this edition has been significantly revised.

This Edition also incorporates latest intelligence and expert inputs gathered from stakeholders during on-going discussions pertaining to the future of cooling in India. Most of the revisions focus on the Space Cooling in Buildings, Refrigeration and Cold-chain sectors.

Key findings

1

Cooling energy demand of India to double until 2027

The aggregated nationwide cooling energy demand in terms of primary energy is expected to grow around 2.2 times in 2027 over the 2017 baseline, and the cooling demand in terms of tonnes of refrigeration is expected to grow around 3.1 times in 2027 over the 2017 baseline, under the business as usual scenario.

2

Around 25 GW of new coal capacity can be avoided by energy efficiency in cooling

The 2027 Improved Scenario suggests that, even with the known strategies and technologies (that is, not factoring in game-changers), there is potential to reduce the aggregated growth in energy demand by 17%, and the resulting emissions, by 20%. Energy savings of ~20 mtoe can been leveraged between 2027 (BAU) and 2027 (Improved) – of this over 90% (i.e. ~100 TWh) will be electricity savings. This translates to capacity avoidance of ~25 GW, or around 50 power plants of 500 MW capacity each. Emissions reduction of ~100 mtCO2e can been achieved between 2027 (BAU) and 2027 (Improved).

3

57% of all Indian energy demand for cooling comes from buildings

Relative share of cooling energy demand for all sectors remains more or less the same in years 2017 and 2027. Building sector (Space Cooling) continues to dominate, with an approximately 57% share of the entire cooling energy demand, with Refrigeration as the next largest contributor at ~25% in 2027.

4

Energy demand from fans and air coolers is higher than from ACs

Given the dominant share of the building sector, it is worth highlighting the significant presence of non-refrigerant based cooling from fans and air coolers –consuming more energy in 2027 than all the commercial systems (chillers, VRF and DX) combined. This makes a strong case for realigning focus to include a greater emphasis on energy efficiency of fans and air coolers that will continue to be very pervasive, particularly in the residential sector in India.

5

Significant energy and emission savings through improvement in servicing practices of cooling devices and refrigerants

Improvements in operations, maintenance and servicing practices (including the refrigeration service sector) - an aspect that tends to get less attention in the discussions about cooling - will bring marked savings in the 2027 energy consumption and emissions, across multiple sectors.

Foreword from BEE

अभय बाकरे, आईआरएसईई
महानिदेशक
ABHAY BAKRE, IRSEE
Director General

सत्यमेव जयते

ENERGY IS LIFE
CONSERVE IT

ऊर्जा दक्षता ब्यूरो
(भारत सरकार, विद्युत मंत्रालय)
BUREAU OF ENERGY EFFICIENCY
(Government of India, Ministry of Power)

FOREWORD

India has made a commitment to reduce its energy use by 33-35% through its Nationally Determined Contributions under the COP21 Agreement. Building energy use, specifically managing the cooling energy demand efficiently offers one of the biggest opportunities for the country. Access to cooling should be the hallmarks of any modern society due to its implications on the health, productivity and quality of life.

Bureau of Energy and Efficiency (BEE), through the Standards and Labelling program & the Energy Conservation and Building Code(ECBC), is already at the forefront of disseminating the importance of cooling and air conditioning. While there are minimum performance standards for commercial buildings, room & split air conditioners, BEE is in the process of launching the ECBC for residential buildings with focus on enhancing thermal comfort through improvements in envelope design and construction.

Against this backdrop, it is imperative to estimate the cooling demand for the entire country in a realistic manner. The analysis presented in the report is an outcome of series of structured interviews with domain experts and organizations and would act as a comprehensive reference for stakeholders.

I would like to commend & congratulate IGEF and AEEE for putting together this assignment in a timebound and professional manner.

I hope this publication will be useful to the policy makers, academia, private sector and other key stakeholders.

14.05.2018

Abakre 14.5.18
(Abhay Bakre)

स्वहित एवं राष्ट्रहित में ऊर्जा बचाएँ Save Energy for Benefit of Self and Nation

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Preface

Shri Abhay Bakre, Director General, Bureau of Energy Efficiency, Ministry of Power (MoP), Government of India and Dr. Georg Maue, Head General Issues of Energy Efficiency at German Federal Ministry for Economic Affairs and Energy (BMWi), initiated the project to analyse the cooling demand by sector in India in 2027 as an activity under the Indo-German Energy Forum.

The Alliance for an Energy Efficient Economy (AEEE) had been identified to carry out this first-of-its-kind comprehensive overview of the nationwide cooling demand.

The main objective was to determine the growth in cooling demand in India by 2027 in order to calculate the future energy consumption and CO2e emissions for all relevant cooling sectors.

The second objective was to identify the key intervention areas with the highest potential for energy savings and for emission reduction. Based on energy efficiency strategies, changes in technologies and refrigerants, improved servicing of technologies and leakage reduction, improved labelling programs, awareness measures about comfort temperatures and many other measures, an improved scenario for the development of the cooling sector in India had to be identified.

The 5 key findings of this analysis shall serve as a basis for further intensified dialogue on the energy efficiency potential and realistic emission reductions of the cooling sector in India.
It is this promotion of dialogue on relevant energy issues which Honourable Prime Minister of India and the Chancellor of Germany requested to intensify by founding the Indo-German Energy Forum in 2006.

Dr. Winfried Damm
Indo-German Energy Forum Support Office

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List of Abbreviations

AC	:	Air-conditioner
AHU	:	Air handling unit
AT&C	:	losses Aggregate Transmission & Commercial losses
BAU	:	Business-as-usual
BEE	:	Bureau of Energy Efficiency
BSRIA	:	Building Services Research & Information Association
CEEW	:	Council on Energy, Environment and Water
DC	:	Direct cool
DMI	:	Directorate of Marketing and Inspection
DX	:	Direct expansion
ECBC	:	Energy Conservation Building Code
EE	:	Energy Efficiency
EER	:	Energy efficiency ratio
FF	:	Frostfree
GWP	:	Global Warming Potential
HCFC	:	Hydrochlorofluorocarbons
HDV	:	Heavy Duty Vehicles
HFC	:	Hydrofluorocarbon
HFO	:	Hydrofluoroolefin
HPMP	:	HCFC Phase-out Management Plan
HVAC	:	Heating, Ventilation, and Air-conditioning
HVAC&R	:	Heating, Ventilation, Air-conditioning &Refrigeration
ISEER	:	Indian Seasonal Energy Efficiency Ratio
ISHRAE	:	Indian Society of Heating Refrigerating and Air Conditioning
LDV	:	Light Duty Vehicles
MAC	:	Mobile air-conditioning
MoEFCC	:	Ministry of Environment, Forest and Climate Change
MoFPI	:	Ministry of Food Processing Industries
MoRTH	:	Ministry of Road Transport and Highways
MoSPI	:	Ministry of Statistics and Programme Implementation
MT	:	Metric tonne
mtoe	:	Million ton of oil equivalent
mtCO2e	:	Million ton of CO2 equivalent
NCCD	:	National Centre for Cold Chain Development
NHB	:	National Horticulture Board
NHM	:	National Horticulture Mission
ODP	:	Ozone Depletion Potential
O&M	:	Operation & Maintenance
RAC	:	Room airconditioner
SIAM	:	Society of Indian Automobile Manufactures
TR	:	Ton of refrigeration
Twh	:	Terawatt hour
VAM	:	Vapour absorption machine
VRF	:	Variable refrigerant flow

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Executive summary

Introduction

Cooling has become vitally important to many aspects of modern life. From providing thermal comfort in our homes and offices to keeping our food, cars, medicines, industry and scientific instruments cool, the demand for cooling in all its forms is rapidly growing.

Globally, as well as nationally, there is the much-needed recognition for cooling as a social imperative and as a developmental priority. India, which currently has one of the lowest access to cooling across the world, is poised for rapid and significant growth in cooling demand. While this growth is in alignment with India's economic and social development, and the hot and humid climate conditions, it comes with adverse impacts in the form of significant additional power generation capacity, peak load impacts, and an enormous carbon footprint through both direct and indirect emissions.

The criticality of addressing India's space cooling challenge cannot be overstated, particularly against the backdrop of two recent international climate change agreements: the Paris Agreement (2015) wherein India, through its Nationally Determined Contribution (NDC), has committed to significantly reduce its emissions intensity; and the Kigali Amendment to the Montreal Protocol (2016) wherein India has committed to stop production and freeze the consumption of HFCs by 2028. As the nation is at an inflection-point of cooling growth, now is the critical window of opportunity to grasp the extent of this growth and to proactively manage it in order to neutralize its impacts. This sets the backdrop and the need for the study: Demand Analysis for Cooling by Sector in India in 2027.

About the Report

This report presents a first-of-its-kind comprehensive overview of the nationwide cooling demand in India. The term 'cooling' in the context of this report implies both air conditioning, ventilation and refrigeration. The primary focus is, the preparation of demand analysis for cooling by sector in India in 2027, which includes -

a) Specifying relevant segments and assessing their current cooling demand

b) Prediction of two different scenarios (business as usual (BAU) versus Improved Scenario) for the cooling demand of each identified sector until 2027

The study seeks to identify key intervention areas and the resultant energy savings and emissions reduction potential in each sector. The intervention areas include, but are not limited to, energy efficiency strategies, changes in technologies and refrigerants, stringent equipment labelling programs, capacity building and improved standards of the servicing sector/technicians, behavioural adaptations such as adaptive thermal comfort standards, and enhanced public awareness.

During the inception of this study, the Government of India announced plans to develop an India Cooling Action Plan (ICAP) that provides a future outlook on how cooling demand in India will evolve and grow and what strategies and actions are needed to develop a robust eco-system to promote sustainable and smart cooling strategies, as well as to meet India's global and national climate change commitments. The heightened government and industry activity around the development and imminent release of the ICAP lends significant importance to this well-timed study that informs the cooling landscape in multiple sectors over the next 10 years.

Scope and Methodology

This project is intended as an analytical study that builds upon a thorough understanding of the best available industry knowledge. It is essentially a synthesis report, drawing from multiple credible sources, and utilizing the latest data available from the government's database (Bureau of Energy Efficiency database), to derive our best estimate of future projections. Much of the effort has been directed at doing a “bottom up” analysis that requires a sound understanding and knowledge of the domain; the project team believes that this will complement any top down econometric analysis that may be carried out in future.

The scope of this project is limited to the next ten-year outlook, in terms of the growth in cooling demand, that is, the energy required for air-conditioning and refrigeration, as well as the possible interventions to neutralize the impacts of this growth. As such it should be noted that:

The interventions considered in the Improved Scenario are limited to what can be feasibly implemented and leveraged within the 10-year timeframe.

- The interventions considered in the Improved Scenario are limited to what can be feasibly implemented and leveraged within the 10-year time frame.
- The discussion of potential savings in this study is limited to the possible reductions in energy consumption and in emissions; a more micro-level analysis covering the cost-benefit assessment and the technical and financial potential falls outside the scope of this study, and could be addressed with more detailed modelling.
- While some of the growth parameters - such as GDP, growth in building stock, growth in purchasing power - are not explicitly stated in the report, these are very much implicit and factored in the sales projections data gathered from market intelligence reports and calibrated with secondary research and information gathered from structured interviews conducted with domain experts. Should a detailed modelling or econometric analysis be carried out in future, such parameters should become part of the key input variables.
- As agreed during the project inception meetings, because the focus of this project is to identify and isolate the improvement potential through energy efficiency and other demand-side interventions, the estimated electric energy consumption factors in the demand side only and does not include the supply side factors such as AT&C losses and future improvements in AT&C and average emission factor of grids over the next 10 years.

Sector	Sub-sector	Description
Space Cooling in Buildings	RAC, chiller system, VRF systems, packaged DX, Fan, and air cooler	Refrigerant and non-refrigerant based space cooling for comfort cooling in residential & commercial buildings, and cooling requirements for data centres & server rooms
Mobile Air-Conditioning	Passenger LDV, passenger HDV, and railway	Air-conditioning for comfort cooling of commuters in cars, buses and railways
Refrigeration	Domestic-type refrigerator, standalone unit, vending machine, remote condensing unit, water cooler, super/hyper market systems	Refrigeration or cooling of perishable food products, medicines or drinking water for domestic and commercial applications
Cold Chain	Cold storage, pack house and ripening chamber, reefer vehicle	Refrigeration of perishable products during packaging, ripening, storage and transportation
Industrial Process Cooling	Industrial AC (non-ammonia), process and milk chiller (ammonia)	Air-conditioning or refrigeration needs in dairy, pharmaceutical, textile, chemical, plastic, brewery, beverages, food processing, detergent industries

The report has tried to plug some of the information gaps through a multi-source methodology adopted by the AEEE team, which triangulates inputs from: existing government databases, market intelligence reports, secondary research sourced from other reliable sources, and interviews with subject matter experts. The five sectors, and the respective sub-sectors that are covered in this report are presented in table below.

While the report goes into more details about the inputs and assumptions behind each scenario, broadly, the 2027 BAU projections in our analysis are based upon multiple parameters, such as:

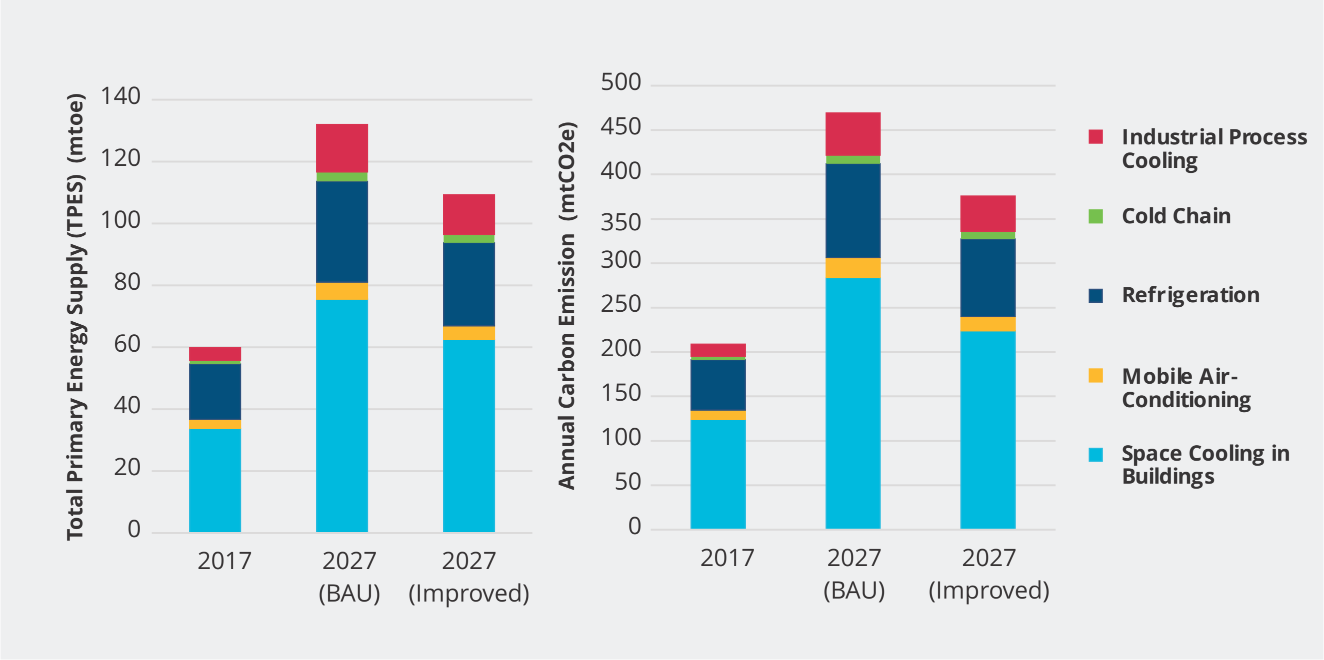
- Sales projections from market intelligence reports, which factor in population growth, urbanization,

residential and commercial building stock growth, GDP growth, and market adoption profiles
- Planned efficiency improvements in technologies such as: BEE's ISSER-based star labelling programme for RACs; BEE's voluntary fan efficiency norms, BEE's fuel efficiency norms for passengers LDVs
- Planned reduction in cooling demand where applicable; such as through prevalentor soon to be launched building energy codes
- Efficacy of refrigerants used in the cooling and refrigeration systems
- Foreseeable industry trends over the next decade, as gathered from field experts Similarly, the typical key parameters for the development of the 2027 Improved Scenario are:
- Building sector efficiency improvements from the adoption of existing ECBC-Commercial and upcoming ECBC-Residential code which is likely to reduce the need for active air-conditioning demand
- Technology improvements primarily captured through efficiency improvements of air-conditioning and refrigerating appliances and equipment
- Better O&M practices
- Refrigerant service sector improvements and end-of-life recovery
- Low GWP refrigerant variants – transition from HCFC and/or HFC to natural refrigerants

Because the scope of the study is until year 2027, the discussion of the Improved Scenario is limited to this 10-year time frame. It is worth point out that, while there are some evolving and imminent technologies and trends on the radar – such as e-Mobility, district cooling, and others - the market or industry experts are not yet ready to quantify their impacts within the 10-year time frame of this study. Hence, such trends are not factored into the calculations, but are discussed briefly in Chapter 7 of the report.

Aggregated Results and Conclusion:

The aggregated results for cooling energy consumption and the total emissions are tabulated below and represented in the bar-graphs.



Note: A constant primary energy conversion efficiency as per IESS Level 2 for 2017 has been assumed for all scenarios. However, the reduction in T&D losses and increased share of renewable mix shall impact the cooling related primary energy supply in future years.

	Annual Energy Consumption (mtoe)				Annual Carbon Emission (mtCO2e)			
	2017	2027 BAU	2027 Improved	Saving Potential	2017	2027 BAU	2027 Improved	Saving Potential
Space Cooling in Buildings	33.8	75.6	62.5	17%	124	284	224	21%
Mobile Air-Conditioning	3	5.5	4.4	20%	10.8	22.6	16.1	29%
Refrigeration	17.8	32.5	26.9	17%	56.6	105.4	87.2	17%
Cold Chain	1.2	3	2.7	10%	4.1	9.7	8.6	11%
Industrial Process Cooling	4.1	15.3	12.8	16%	13.2	47.6	39.6	17%
Total	59.8	131.9	109.3	17%	208.7	469.3	375.5	20%

The key takeaways of the study are:

The aggregated nationwide cooling energy demand in terms of primary energy is expected to grow around 2.2 times in 2027 over the 2017 baseline, and the cooling demand in terms of tonnes of refrigeration is expected to grow around 3.1 times in 2027 over the 2017 baseline, under the business as usual scenario.

- The 2027 Improved Scenario suggests that, even with the known strategies and technologies (that is, not factoring in game-changers), there is potential to reduce the aggregated growth in energy demand by 17%, and the resulting emissions, by 20%. Energy savings of ~20 mtoe can been leveraged between 2027 (BAU) and 2027 (Improved) – of this over 90% (i.e. ~100 TWh) will be electricity savings. This translates to capacity avoidance of ~25 GW, or around 50 power plants of 500 MW capacity each. Emissions reduction of ~100 mtCO2e can been achieved between 2027 (BAU) and 2027 (Improved).
- Relative share of cooling energy demand for all sectors remains more or less the same in years 2017 and 2027. Building sector (Space Cooling) continues to dominate, with an approximately 57% share of the entire cooling energy demand, with Refrigeration as the next largest contributor at ~25% in 2027.
- Given the dominant share of the building sector, it is worth highlighting the significant presence of non-refrigerant based cooling from fans and air coolers – consuming more energy in 2027 than all the commercial systems (chillers, VRF and DX) combined. This makes a strong case for realigning focus to include a greater emphasis on energy efficiency of fans and air coolers that will continue to be very pervasive, particularly in the residential sector in India.
- Improvements in operations, maintenance and servicing practices (including the refrigeration service sector) - an aspect that tends to get less attention in the discussions about cooling - will bring marked savings in the 2027 energy consumption and emissions, across multiple sectors.

Future Recommendations:

We propose some overarching recommendations that we feel are fundamental in nature. In addition, we recommend some specific actions grouped under three intervention areas as summarized in the table below.

Address space cooling in the building sector as a priority area for intervention

Given this dominance, both in consumption and the potential for improvement, this sector warrants increased attention and hence a significant portion of the policy, technology and market-based interventions will have to be directed at space cooling as a priority. In the light of significant increase (1.5-2X) in building area by 2027 (from 2017), it is important to reinforce the need to build in strategies and interventions to reduce the cooling demand itself. Role of building energy code is increasingly important in this regard.

Ensure that best available technology (BAT) is brought to the Indian market

Keeping in view the criticality of what is at stake, India should push to bring the best available technology to the Indian market. Technological developments are typically led by large manufacturing hubs and larger companies with significant R&D budgets and talent. Indian policy makers and industry stakeholders should jointly keep an eye on the manufacturers, particularly the innovators be it in the field of refrigerants or energy efficiency and explore how can our policies and market encourage and attract these innovative manufacturers to develop or bring the best available technology to India.

Leverage global best practices and existing knowledge for India's benefit

The policy makers should closely monitor what other regions/countries are practising in terms of policies and technology pathways along with market based instruments, and leverage this knowledge towards India's benefit.

Recommended actions grouped under key intervention areas:

Technology Interventions	Market Transformation through Policy & Other Interventions	Operational Interventions
Standards and Labelling programs	Migration towards energy efficient building practices	Institutionalizing effective O&M practices
Government incentives to accelerate MEPS	User awareness towards importance of low-energy and low-impact cooling practices	Capacity building and improvements in the refrigerant servicing sector
Support of collaborative R&D ecosystem - low energy cooling & low-carbon refrigerants	Demand response opportunities	Migration towards controls-based equipment

Endnote:

The information and analysis presented in this report is a result of gathering, calibrating, and processing the best available data by reaching out to various industry organisations, manufacturers, and industry and subject matter experts during this project. While we have relied on expert inputs to fill the information-gaps, we do not always know the basis of the assumptions behind the information received, or the limitations with these assumptions. Hence, we present this report as a macro-level view based on the best available data within the framework of limits and limitations, and it should be viewed as such. The analysis and outputs can be further improved with a formal peer review, outside the project's time constraints.

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Introduction

With rapid urbanization, rising temperatures and growing aspirations, India's cooling needs are growing at an exponential pace. Both the air-conditioning and the refrigeration segments are projected to at least double in the next decade. While this growth is in alignment with India's economic and social development, it comes with significant impacts in the form of significant additional power generation capacity, peak load impacts, and an enormous carbon footprint through both direct and indirect emissions.

The criticality of addressing India's space cooling challenge cannot be overstated, particularly against the backdrop of two recent international climate change agreements. First is the Paris Agreement (2015) within the United Nations Framework Convention on Climate Change (UNFCCC), wherein India, through its Nationally Determined Contribution (NDC), has committed to significantly reduce its emissions intensity. Second is the Kigali Amendment to the Montreal Protocol (2016) wherein India has committed to stop production and freeze the consumption of HFCs by 2028. This will have to be achieved within the overarching framework of sustainable development,and India's right to grow and develop in a sustainable manner considering that it is the largest country that will undergo rapid economic growth and urbanisation in the next 20-30 years.

To assess the growth of cooling by sector in India in 2027, this first-of-its-kind comprehensive overview of the nationwide cooling demand considers the following tasks:

- Specify relevant sectors and sub-sectors and assess their current cooling demand
- Predicttwo different scenarios (business as usual (BAU) v/s Improved Scenario) for the cooling demand of each identified sector until 2027

For each of the identified sectors, the study aims to determine the growth in cooling by 2027, in terms ofthe energy required to meet this cooling demand, and the resulting CO2e emissions. Secondly, the project seeks to identify key intervention areas to neutralize the impacts of the projected growth, and determines the extent of energy savings and emissions reduction possible in each sector through a combination of strategies such as buildingenergy efficiency, advancements in equipment efficiency and refrigerants, improved servicing of technologies and leakage reduction, improved labelling programs, adaptive thermal comfort, and enhanced public awareness.

1. Approach and Methodology

1.1 Overarching Approach

Being a multi-sectoral project, the team realized the need for a flexible methodology to adapt to the unique aspects and data availability in each respective sector. However, the underlying approach for the overall project remains consistent and is characterised by:

- Multiple input sources
- Bottom up analysis and top-down validations to the extent data allowed
- Assumptions based on expert inputs

1.1.1 Framing the Project Scope

Given the short duration of the original project, this study was not intended as a modelling exercise, but rather as an analytical study that builds upon a thorough understanding of the best available industry knowledge. We have essentially performed a synthesis exercise, utilizing the best available information, filling in the data gaps and triangulating with the growth data available in government's database (BEE database), to come up with a future growth range. A lot of effort has been put into doing a thorough “bottom up” analysis that requires significant technical expertise and a sound understanding and knowledge of on-the-ground realities. We feel that this approach will add significant value to any top down econometric analysis that may be carried out in future.

- The scope of this project is limited to the next ten-year outlook, in terms of the growth in the cooling energy demand, as well as the possible improvements through interventions. As such it should be noted that:
- The interventions considered in the Improved Scenario are limited to what can be feasibly implemented and leveraged within the 10-year time frame of this project.
- The short duration of the study limits the discussion of potential savings to simply the possible reductions in energy consumption and in emissions; a more micro-level analysis covering the cost-benefit assessment and the technical and financial potential falls outside the scope and could be addressed with more detailed modelling.
- While some of the growth parameters - such as GDP, growth in building stock, growth in purchasing power - are not explicitly stated in the report, these are very much implicit and factored in the sales projections data gathered from market intelligence reports, and calibrated with secondary research and information gathered from structured interviews conducted with domain and industry experts.Should a detailed modelling or econometric analysis be carried out in future, such parameters should be part of the key input variables.
- As agreed during the project inception meetings, because the focus of this project is to identify and isolate improvement potential through energy efficiency and other demand-side interventions, the estimated electric energy consumption factors in the demand side only and does not include the supply side AT&C losses and future improvements in AT&C and average emission factor of grids over the next 10 years.

The report has tried to plug some of the information gaps through the methodology adopted by the AEEE team. The step-by-step methodology followed under this project is as follows:

1.1.2 Project Inception

The project started with a meeting with the IGEF team and other stakeholders wherein the methodology was discussed in detailed, and deliberations were made to refine the various steps for achieving the outcomes. The project team discussed the scope of activities, data collection and analysis approach and the time schedule for the project. It was realized that the data availability would be one of the biggest challenges in this study and econometric modelling for the future projections would not be possible in such a short duration of the project, and therefore secondary research and an analytical approach will be used. Further, it was decided that considering the subject matter expertise available within the AEEE team and its network, a bottom up approach will add significant value to any top down econometric analysis that may be carried out in future.

1.1.3 Defining the Sectors

One of the early tasks was to establish a framework of sectors and sub-sectors in discussion with the IGEF team. We identified five broad sectors and outlined respective sub-sectors within each. Data sources, data availability and limitations with respect to each of the sub-sectors were discussed with the IGEF team. It was agreed that sub-sectors that are either not significant enough in size (i.e., consumption), or have significant limitations in terms of data availability may not fall within the project's timeline. The five sectors, and the respective sub-sectors that are covered in this report are presented in Table 1.1.

Table 1.1 Sectors and Sub-sectors

Sector	Sub-sector	Description
Space Cooling in Buildings	RAC, chiller system, VRF systems, packaged DX, Fan, and air cooler	Refrigerant and non-refrigerant based space cooling for comfort cooling in residential & commercial buildings and cooling requirements for data centres & server rooms
Mobile Air-Conditioning	Passenger LDV, passenger HDV, and railway	Air-conditioning for comfort cooling of commuters in cars, buses and railways
Refrigeration	Domestic-type refrigerator, standalone unit, vending machine, remote condensing unit, water cooler, supermarket & hypermarket	Refrigeration or cooling of perishable food products, medicines or drinking water for domestic and commercial applications
Cold Chain	Cold storage, pack house and ripening chamber, reefer vehicle	Refrigeration of perishable food products during packaging, ripening, storage and transportation
Industrial Process Cooling	Industrial AC (non-ammonia), process and milk chiller (ammonia)	Air-conditioning or refrigeration requirements in dairy, pharmaceutical, textile, chemical, plastic, brewery, beverages, food processing, detergent industries

1.1.4 Data Research

The team adopted various strategies to collect the relevant data from multiple sources, as highlighted in Figure 1.1. Given the short project timeline, it was established during the proposal stage that the data collection exercise shall be based upon secondary research which shall include various sources such as government database where applicable, market intelligence reports, manufacturers' product brochures, and articles from leading journals.Essentially three parallel methods were utilized to source and triangulate the data and cover the data-gaps.

A) Government databases: Two government resources have been key in informing the inputs and assumptions behind the analysis. These are:

- Bureau of Energy Efficiency database for production volumes and energy efficiency levels for Room Air-Conditioners and ceiling fans.
- India Energy Security Scenarios (IESS), NITI

Aayog's energy model which includes impacts of GDP, population, per-capital income, urbanization, and % penetration of cooling appliances.

B) Desk research: Extensive desk research was conducted by reviewing industry reports, sales report from manufacturers and reports published by peer groups (listed below in 'C'). The operating efficiencies for certain end-uses was gathered from synthesising the respective rated efficiencies from BEE's Standards & Labelling programme, where available. For other end-uses inputs from industry experts were solicited and incorporated.

C) Stakeholder inputs: The success of this project could not be possible without interactions with the stakeholders. The project team identified multi-sectoral experts and conducted interviews to discuss the project objectives, obtain data and later discuss the results and analysis. An indicative list of stakeholders who have been directly consulted, or their data utilized, for this project is as follows:

- Bureau of Energy Efficiency (BEE)
- Indian Society for Heating, Ventilation and Air Conditioning (ISHRAE)
- Refrigeration and Air Conditioning Manufacturer's Association (RAMA)
- National Centre for Cold-chain Development (NCCD)
- Association of Ammonia Refrigeration (AAR)
- Service sector consultants
- Equipment manufacturers for various sectors such as Daikin, Trane, Godrej, UTC, Subros, TATA Motorserts
- HVAC design consultants
- Service sector consultants
- Recognized subject matter experts
- Peer groups such as Council for Energy, Environment & Water (CEEW), Prayas (Energy Group), cBalance, CLASP and NRDC

This list is indicative only and a more exhaustive list of the various stakeholder organizations and/or individuals consulted during this project is presented in the Acknowledgement.

A questionnaire-based approach was also adopted to reach out to multiple subject matter experts to address specific data gaps. This was typically followed-up by one-to-one interactions with the respective stakeholders. The discussion broadly focussed on validation of data, addressing data gaps, and validating the accuracy of assumptions made to fill the data gaps. These discussions have helped tremendously in informing the assumptions made by the team, and in refining our analysis.

AEEE also leveraged its in-house database, drawing particularly from:

- AEEE commercial building database- commercial sector stock modelling exercise where existing built-up areas and energy consumption patterns for different kind of buildings are estimated.
- AEEE Residential RAC Survey– a first-of-its-kind dataset derived from a nationwide survey of nearly 1000 households aiming to understand the usage patterns of room ACs in residences. This data informed aspects such as annual run hours, number of RACs in an urban household, typical setpoint temperature maintained in residences, most typical capacity and star ratings installed.

1.1.5 Data Analysis and Output 'Scenarios'

The raw data obtained from sources was filtered out to remove the outliers and a detailed analysis was conducted. The numerical analysis performed involved the estimation of following key indicators for each sector: installed capacity, annual energy consumption, indirect emissions, direct emissions, and annual total emissions. The results were obtained for three different scenarios: 2017 (Existing), 2027 Business-as-Usual (BAU), and 2027 Improved Scenarios. While each of the five sectors had their unique nuances due to data variability, the main underlying parameters that are typical to the development of the scenarios are as follows:

2017 existing stock estimation. The primary inputs for this bottom-up analysis are

- Sales data from industry reports
- Any available stock information: such as Bureau of Energy Efficiency database for production volumes and energy efficiency levels for Room Air-Conditioners and ceiling fans; and published peer-group reports
- Equipment efficiency levels from BEE's S&L database where applicable
- Equipment replacement rate

The bottom-up analysis is supplemented with a top-down validation to the extent data allows.

Cooling energy consumption. To calculate the energy consumption for the current and future years, the following parameters are applied to the stock information:

- Deployed capacity
- Current level of technology efficiency
- Average annual utilization rate
- Stand-by capacity or diversity factor as applicable

Emissions. To calculate the total emissions for the current and future years, the following parameters are applied to the stock information:

- Refrigerant mix in use
- Charge rate
- Operational leakages and end-of-life emissions
- Existing level of equipment O&M practices
- Current standards of refrigerants-related servicing
- Indirect emissions from the respective fuel

2027 projection. These numbers are based on multiple parameters:

- Sales projections from market intelligence reports, which factor in population growth, urbanization, residential and commercial building stock growth, GDP growth, and market adoption profiles
- Planned efficiency of technologies such as
  - BEE's ISSER-based star labelling programme for RACs
  - BEE's voluntary fan efficiency norms
  - BEE's fuel efficiency norms for passengers LDVs
- Planned reduction in cooling demand where applicable; such as through prevalent (ECBC-Commercial) or soon to be launched building energy codes (ECBC-Residential)
- Efficacy of refrigerants used in the cooling and refrigeration systems
- Foreseeable industry trends over the next decade, as gathered from field experts

2027 Improved Scenario. The key parameters for the development of this scenario are:

- Building sector efficiency improvements from the adoption of existing ECBC-Commercial and upcoming ECBC-Residential code which is likely to reduce the need for active air-conditioning demand
- Technology improvements primarily captured through efficiency improvements of air-conditioning and refrigerating appliances and equipment
- Better O&M practices
- Refrigerant service sector improvements and end-of-life recovery
- Low GWP refrigerant variants – transition to HFC to natural refrigerants

It is worth point out that, while there are some evolving and imminent technologies and trends on the radar – such as e-Mobility, district cooling, and others - the market or industry experts are not yet ready to predict and quantify their impacts within the 10-year time frame of this study. Hence, such trends are not factored into the analysis, but are discussed briefly in Chapter 7 of the report.

1.1.6 Use of Assumptions to Plug Information Gaps

There has been wide variability in the availability of data for different sectors, therefore certain assumptions have been made while making the sectoral projections. The assumptions have been typically considered and formulated by the AEEE technical team, after discussions with the sector experts, or are based on existing literature. The set of assumptions, and their basis, has been discussed separately in each sector-specific chapter.

As an important step, we have sought validation of the analysis from subject matter experts at a sector level (or sub-sector level where applicable). We have been able to achieve this validation, at varying degrees of granularity, for all the sectors except for the Refrigeration sector.

1.1.7 Periodic Review Meetings

The team has conducted periodic review meetings with IGEF team to discuss the analysis carried out for the sectoral estimation of cooling demand and projections for 2027. The comments and suggestions received have been incorporated in the analysis.

1.2 Important Notes on the Outputs

1.2.1 Output Units

Where the fuel consumed is electricity, the sector wide results are presented in terawatt hour (TWh) units. This is done to isolate the electricity impact of the cooling energy demand. For all other fuels, the sector wide consumption units are indicated in terms of tonne of oil equivalent (toe). For the overall aggregation of consumption, the common unit used is toe. The emissions are always indicated in terms of CO2 equivalent.

1.2.2 Demand Side Electric Energy

Because the focus of the project is to identify improvement potential through energy efficiency and other demand-side interventions, the electric energy consumption estimated for the sectors is on the demand side only and does not include the AT&C losses (sum of technical or T&D loss, commercial losses and shortage due to non-realization of total billed amount because of theft, metering issues etc.). The AT&C improvements planned over the next 10 years will add further to the improvements in the energy consumption and indirect emissions projected under the Improved Scenario.

1.3 Endnote

The information and analysis presented in this report is a result of gathering, calibrating, and processing the best available data. The primary mode of information gathering is secondary research, and we have relied on expert inputs to fill the information-gaps. Hence, we present this report as a macro-level view based on the best available data within the framework of limits and limitations, and it should be viewed as such.

While AEEE has tried to reach out to various industry organisations, manufacturers, industry and subject matter experts during this project, the analysis and outputs can be further improved with a formal peer review, outside the project's time constraints, as well as by seeking comments from some of the key industry associations - such as RAMA, NCCD, SIAM and industry experts - to further validate the numbers.

2. Space Cooling in Buildings

2.1 Scope

This sector addresses cooling demand as it relates to thermal comfort in the built environment, including both residential and commercial buildings. The following end-use technologies are covered in the cooling demand analysis:

- **Room air conditioners (RACs) -** The analysis presented in this report is limited to RACs of un-ducted single split (fixed-speed and inverter types) and window/through-the-wall (fixed speed type) configurations. It precludes all other configurations like various cassette, floor standing, corner and ceiling/floor RACs – market intelligence suggests that un-ducted single split and window configurations dominate the packaged and central plant market, 78.3% and 17.1% by volume in 2015; although cassette type configurations are growing in sales, the preponderance of window and split configurations is likely to continue into the next decade.
- **Chiller systems -** Air-conditioning systems utilised in commercial buildings, excluding RACs, can be classified into three major segments – chiller system, packaged direct expansion (DX), and variable refrigerant flow (VRF) system. Chiller systems which are also called central (chilled-water) air-conditioning systems are the preferred choice for large commercial buildings like hotels, hospitals, malls and office complexes. Other than the chiller itself which is the largest energy guzzling component, the system comprises various auxiliaries including chilled water pumps, condenser water pumps, cooling tower fans, air handling units, and fan coil units. All types of chillers, both air-cooled and water-cooled, including centrifugal, screw, and scroll compressor types, with and without variable speed drive are considered in this analysis
- **VRF -** The analysis covers VRF systems used in high-rise commercial buildings, which have varying exposure and loads across the building.
- **Packaged DX -** This analysis covers ducted and packaged systems which include rooftop and indoor packaged units in commercial air-conditioning segment. Packaged DX units were typically installed to cater to small to medium buildings to avoid the complexities associated with chiller systems.
- **Fans -** This analysis covers ceiling, pedestal, table and wall-mounted fans. Exhaust fans used more to ventilate rather than to cool, and industrial fans have been precluded from this discussion.
- **Air coolers -** This analysis addresses residential-type air coolers, although they might find application in commercial spaces too. This does not however address large industrial air coolers.

2.2 Sectoral Results

The key results have been tabulated in Table 2.1.

Table 2.1 Space Cooling in Buildings– Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Annual energy consumption (TWh)	126	281	233	17%
Total emissions (mtCO_2e)	124	284	224	21%

- The overall energy consumption for the Building Sector more than doubles in the next decade, growing from around 126 TWh in 2017 to around 281TWh in year 2027.
- The total emissions are also projected to double between year 2017 and 2027.
- The Building Sector shows a significant improvement potential, with a possibility of up to17% reduction in consumption and up to 21% reduction in emissions through demand-side interventions.
- RACs, dominating the building sector cooling energy consumption at 38%, will show the most growth in the next decade, utilizing 50% of the sector wide cooling energy consumption in 2027.
- The non-refrigerant based cooling technologies, fans and air-coolers together, represent a significant 40% of the current sector wide cooling energy consumption. While their relative share drops in 2027, they will still represent a substantial portion of the sector's cooling energy consumption at 30% - more than that of the commercial cooling systems combined (chillers, VRF, DX). This makes a strong case for greater emphasis on energy efficiency of fans and air coolers that will continue to be very pervasive, particularly in the residential sector in India.
- Within the Building Sector, chiller systems show the maximum saving potential in 2027, at around 30% reduction potential in both energy consumption and total emissions.
- While multiple factors contribute to the Improved Scenario (as detailed in the chapter), the main drivers are: ISEER improvements will cause maximum energy savings in RACs, followed closely by energy efficient building practices; better O&M practices bring the maximum positive impacts in chiller systems.
- In the light of significant increase (1.5-2X) in building area by 2027 (from 2017), it is important to reinforce the need for interventions to reduce the cooling demand itself. Given that a large part of the building stock and cooling stock is yet to come, now is the critical window to leverage the positive impacts of ECBC 2017 and the upcoming ECBC-R.

The 2017 and 2027 scenarios for energy consumption and emissions are highlights in the following charts.

Figure 2.1 Space Cooling in Buildings – 2017 Annual Energy Consumption

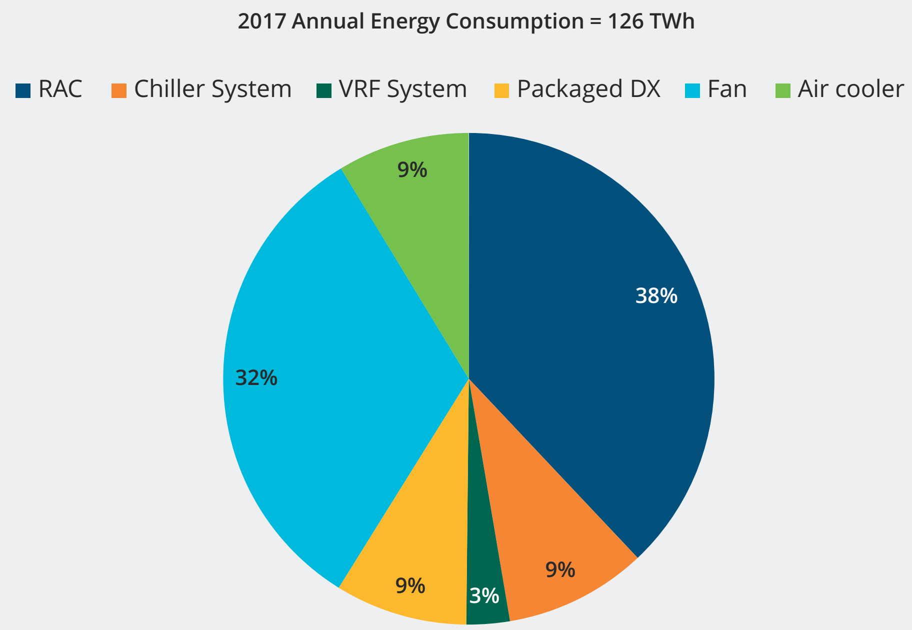


Figure 2.2 Space Cooling in Buildings– 2017 Annual Carbon Emission

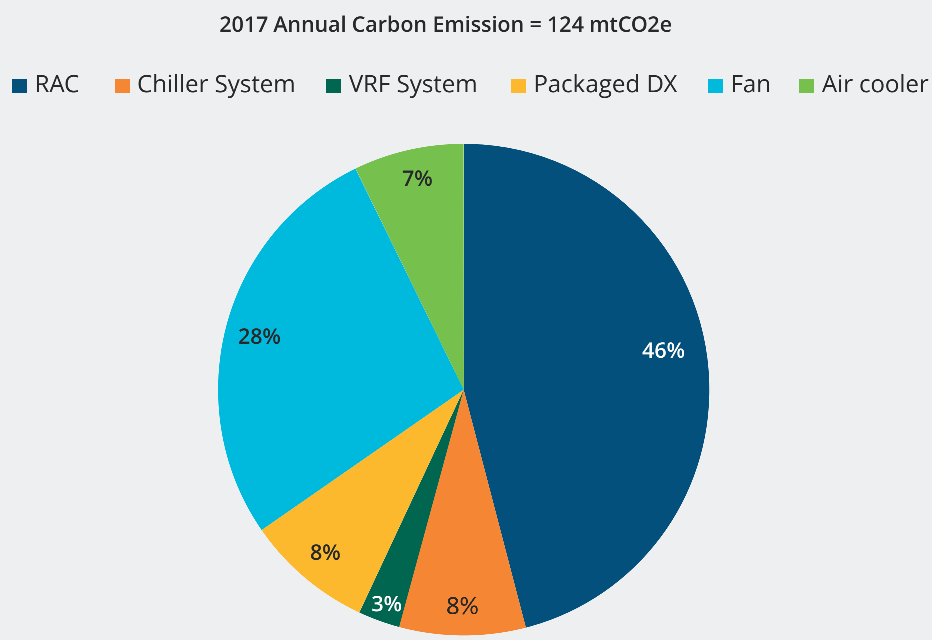


Figure 2.3 Space Cooling in Buildings– A Comparison of the Annual Energy Consumption in 2017, 2027 (BAU) and 2027 (Improved) Scenarios

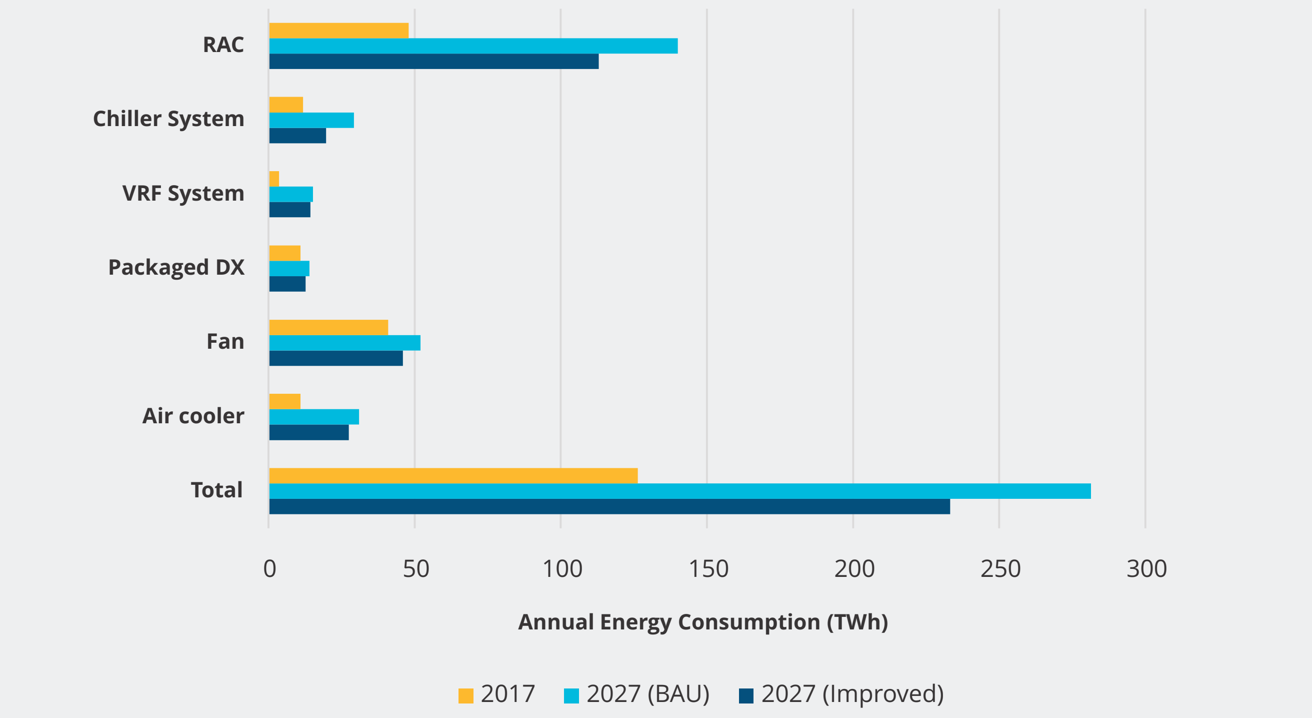
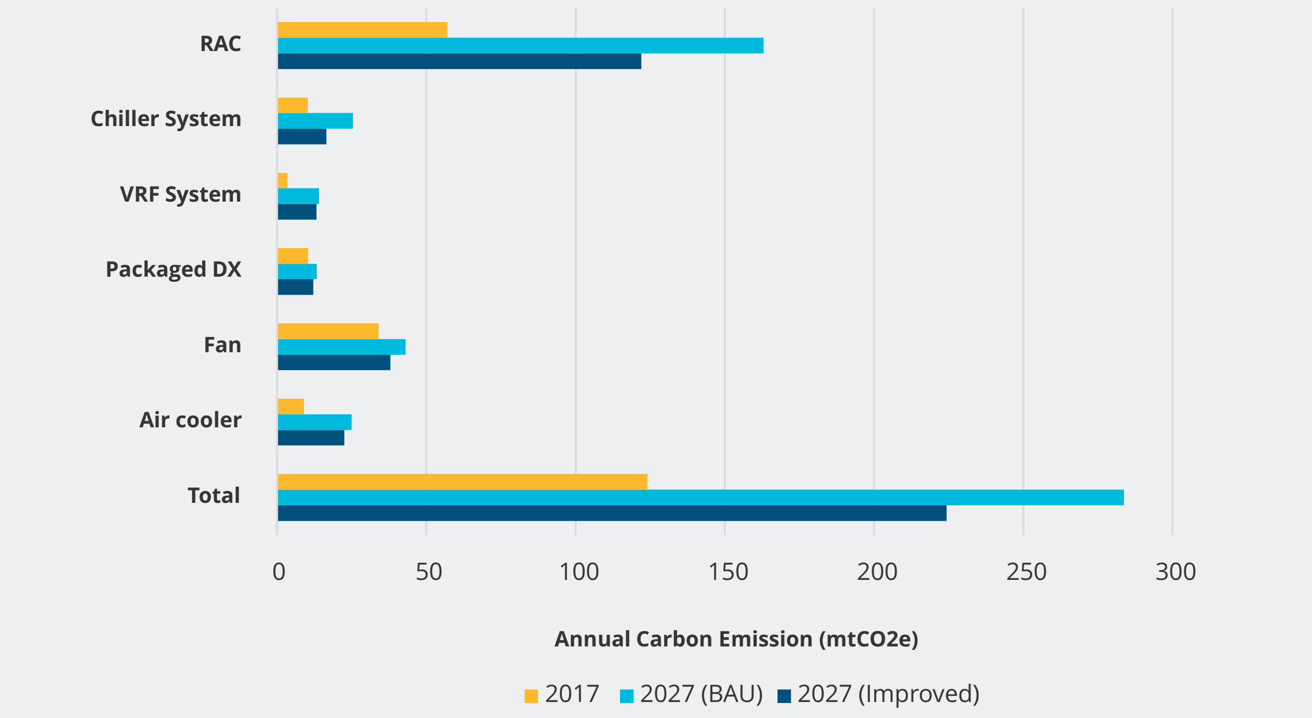


Figure 2.4 Space Cooling in Buildings– A Comparison of the Annual Carbon Emission in 2017, 2027 (BAU) and 2027 (Improved) Scenarios



2.3 Sectoral Deep Dive

2.3.1 Room Air Conditioner (RAC)

2.3.1.1 Overview of the Analysis

The starting point of the analysis i.e. the RAC stock information was realised though a bottom-up approach using sales data mentioned in industry reports and production data published by BEE – this was verified during stakeholder consultations. Typical tonnage, BEE star-rating and EER (or ISEER) values were then applied on the RAC stock. The deployed capacity and annual run hours were used to obtain the annual energy consumption - this was extended to indirect carbon emissions using the grid carbon factor of 0.82 tCO2e/MWh. The estimated annual energy consumption of currently available RAC models is in close alignment with the estimates per BEE Search & Compare.The direct carbon emissions were estimated as a function of the refrigerant mix and the refrigerants' GWP values, typical charge and leakage rates and standard RAC servicing practices. Table 2.2 presents the key inputs and assumptions underlying the RAC analysis, citing their respective sources and basis. As a general protocol, the various assumptions were validated by subject matter experts including industry associations, government agencies, think-tanks and manufacturers. An independent nation-wide surveyto map the use of domestic RACs carried out in 2017 by AEEE was used to corroborate several parameters like tonnage, BEE star-rating and annual run-time.

Table 2.2 RAC – Key Inputs and Assumptions

<table>
<tr><th></th><th colspan="2">2017</th><th colspan="2">2027 (BAU)</th><th colspan="2">2027 (Improved)</th></tr>
<tr><td rowspan="2">Stock (million units)</td><td colspan="2">39</td><td colspan="2">170</td><td colspan="2"></td></tr>
<tr><td colspan="6">The current and future RAC stock were estimated using BEE data described above and the following underlying assumptions:
● BEE production data can be used as a proxy for RAC sales.
● RAC life = 10 years
●RAC sales will grow at a CAGR of 15% in the coming decade</td></tr>
<tr><td rowspan="2">Tonnage (TR)</td><td colspan="6">1.4</td></tr>
<tr><td colspan="6">Per a recent AEEE survey of approximately 1000 households using air-conditioning, RACs of 1.5 TR is the most popular consumer choice, at 61% of the data-set. A weighted average TR of 1.4 TR was used in this analysis.</td></tr>
<tr><td rowspan="4">BEE star-rating</td><td></td><td>1 star</td><td>2 star</td><td>3 star</td><td>4 star</td><td>5 star</td></tr>
<tr><td>Fixed-speed</td><td>4%</td><td>23%</td><td>48%</td><td>4%</td><td>21%</td></tr>
<tr><td>Inverter</td><td>0%</td><td>0%</td><td>74%</td><td>11%</td><td>14%</td></tr>
<tr><td colspan="6">BEE publishes RAC production (or sales) by star rating. The table above captures the average consumer preference for different star-rated fixed-speed and inverter RACs.</td></tr>
<tr><td rowspan="2">Technology</td><td colspan="2">Fixed-speed: 90%
Inverter: 10%</td><td colspan="4">Fixed-speed: 10%
Inverter: 90%</td></tr>
<tr><td colspan="6">Considering the trends in the uptake of fixed-speed and inverter RACs observed in the past few years and similar trends observed in other geographies, it is anticipated that the share of fixed-speed RACs in the future RAC stock will decline rapidly.</td></tr>
</table>

	2017	2027 (BAU)	2027 (Improved)
ISEER (kWh/kWh) (The ISEER mentioned here is the weighted efficiency level of 1.5 TR split RACs, adjusted by the consumer preference in RAC star rating.)	3.2 ISEER	4.8 ISEER	5.9 ISEER
	BEE revises the MEPS of RACs every 2-3 years. If these revisions in RAC efficiency levels is annualised, a steady growth of 3% p.a. can be observed.	It has been assumed that RAC ISEER will continue to be ratcheted at 3% p.a. in the BAU scenario.	RAC efficiency levels may be ratcheted up annualised to 5-6% p.a. based on the current technology available and feedback received from BEE. Technology already available in the Indian market is promising and supports this intervention.
Annual run-time (hour)	1600		1440
	There will be variations in RAC usage depending on the climate and type of use. Nevertheless, this analysis has been carried out using an annual runtime of 1600 hours, per BEE inputs, to obtain a broad estimate of the annual energy consumption towards RACs.		Building energy efficiency manifest in climate-appropriate building design and construction, furthered primarily through more stringent building codes and a higher level of compliance will result in reduced RAC runtime – per conservative estimate, a 10% reduction in RAC run-time is possible.
Refrigerant mix installed (approximations)	77% R22, 14% R32 and 9% R410A (R290 under 1%)	50% R32, 20% R22, 20% R410A, 10% R290	70% R32, 15% R22, 15% R290
	Determined through India's HCFC phase-out schedule, refrigerant preferences of key market players, refrigerants used in top selling models and expert interviews.		An aggressive HCFC phase out schedule and a greater presence of the lower GWP HFC and R290 is assumed.
Refrigerant charge rate[8] (kg/kW)	0.21		
	Determined through expert inputs from peer group of HVAC professionals.		
Annual operational refrigerant leakage rate	10%		
	Cited in CEEW (2015) and vetted by industry experts		
Refrigerant recovery at recharging and end-of-life	0%		15%
	Cited in CEEW (2015) and vetted by industry experts		This is our best estimate based on inputs from industry peers

2.3.1.2 Results and Discussion

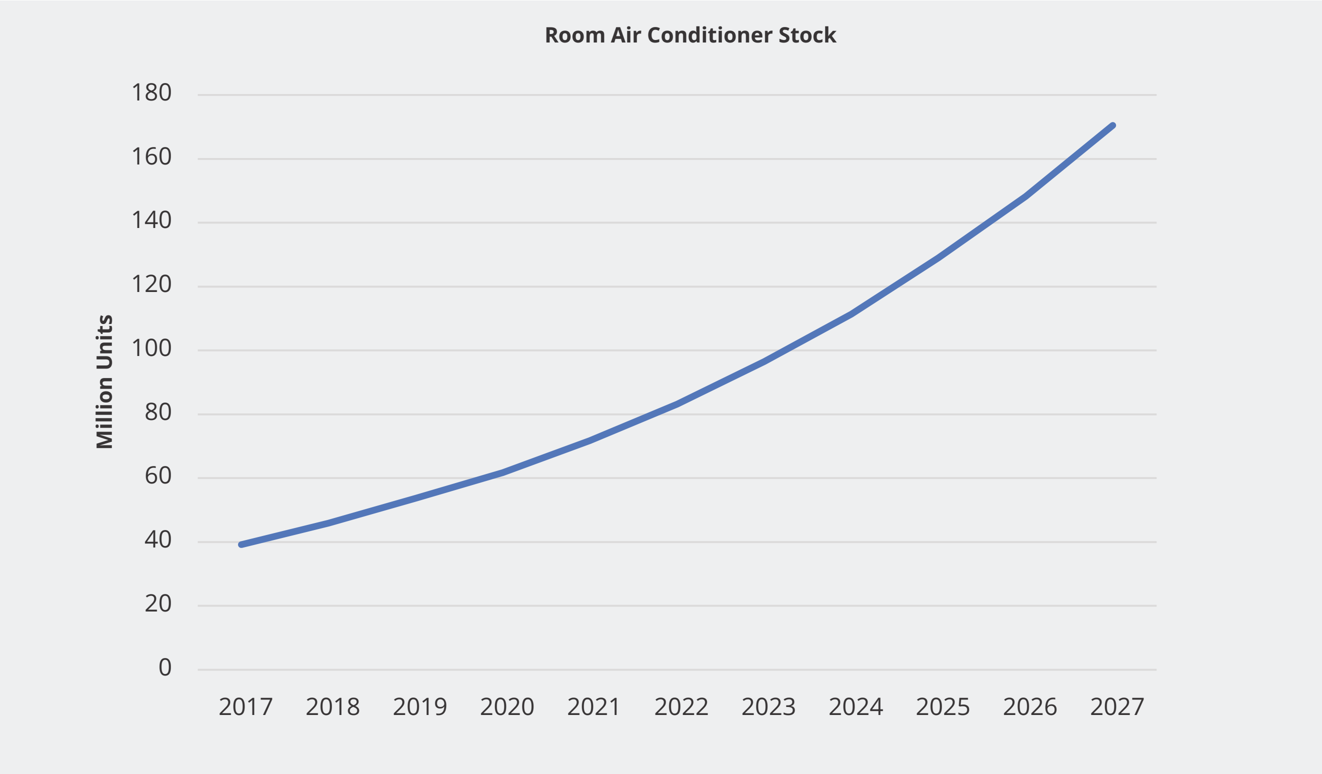
The key results have been tabulated in Table 2.3.

Table 2.3 RAC – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Installed capacity (million TR)	55	238	238	
Annual energy consumption (TWh)	48	140	113	19%
Indirect emissions (mtCO_2e)	39	114	93	
Direct emissions (mtCO_2e)	18	49	29	
Total emissions (mtCO_2e)	57	163	122	25%

- It is important to highlight here the various levers that can be pulled to reduce the carbon footprint of RACs in 2027 – these have been duly incorporated in the 2027 improved scenario. The primary ones with the most meaningful impact are:
  - Envelope improvements in upcoming buildings that should reduce the need for active space cooling: While the envisioned reduction in the total installed capacity is not large, more significant reduction manifests in terms of reduction in run hours, which could be around 10% per our analysis, in the next decade. The key contributors in this are ECBC, the upcoming ECBC-R, and an overall shift towards energy efficient building practices and adaptive thermal comfort strategies
  - The RAC market is expected to see a greater proliferation of inverter RACs in the coming years. This will have a positive bearing on the annual energy consumption of the overall RAC sector. Industry experts suggest inverter RACs' energy performance is 20-30% better than that of comparable fixed-speed RACs.
  - Ratcheting up the ISEER of RACs at 5-6% improvement per year: As the analysis confirms, equipment efficiency can have the strongest impact in the intervention scenario in terms of reducing the energy consumption from RACs.
  - An aggressive HCFC phase-out schedule towards a more climate-friendly refrigerant mix, including an increased penetration of the natural refrigerant R290: It is noteworthy that while our Improved Scenario assumes a moderate penetration of R290 at 15%, a more aggressive shift towards this low GWP refrigerant in the next decade is very much within the realm of possibility with the appropriate policy support from the government.
- Other factors contributing towards the Improved Scenario are:
  - Replacement of refrigerant-based cooling with alternate low energy and climate-appropriate cooling technologies.
  - Improvements in servicing and maintenance practices, to better manage and reduce refrigerant losses during recharge and end-of-life. This considers ESSCI's (Electronics Sector Skills Council of India) planned certification system for service technicians in the RAC-Sector in India.

Figure 2.5 RAC – Stock Projection



2.3.2 Chiller System

2.3.2.1 Overview of the Analysis

The existing stock information has been arrived at by gathering two key pieces of information - chiller sales data and the estimate of the historical installed base. Chiller sales data, sourced from various market intelligence reports (BSRIA Chiller Report, 6Wresearch) across different types of technologies has been aggregated from 2011 onwards. The estimation of installed base in 2010 was made based upon consultations with industry experts and published research reports,. The data on estimated market size of different types of chillers in India in 2017 was also gathered from RAMA. It was observed from BSRIA chiller report that roughly one-sixth of the total annual chiller sales goes into replacing old existing chillers. The future growth in the chiller market in the next decade, which in turn is driven by growth in the retail, hospitality and infrastructure projects has also been forecasted based on market growth projections by RAMA. The operating efficiencies of chillers and auxiliaries were estimated based upon consultations with HVAC industry peers working in the realms of designing, commissioning, retro-commissioning and retrofitting HVAC systems. For estimating future improvements in efficiency, domain expertise from national and international industry champions was tapped. The penetration of high efficiency chiller systems has a huge bearing on effective compliance with ECBC-2017 norms for commercial buildings which is currently at low level of enforcement across states. The operating hours were estimated and validated by HVAC experts in the O&M space, based upon the mix of daytime and 24-hour operating buildings which in turn was arrived from market intelligence reports. In terms of refrigerant mix, the chiller industry is already on track to phase-out HCFCs and is thus heavily dependent on HFCs. Although prototypes with low GWP (and high efficiency) refrigerants are commercially available and offered by many manufacturers, still the penetration is negligible as on date. The forecast of future mix of refrigerants across different chiller technologies has been made based upon consultations with HVAC industry experts and major chiller manufacturers operating in India. To quantify the refrigerant leakages during operation and end of life emissions, extensive consultations were held with experts in the O&M industry looking after different portfolio of commercial buildings in India. In terms of refrigerant leakage during operation, chillers have least emissions compared to other systems. Practices to recover and reclaim refrigerants after end of life are also in place in the chiller industry, although there is significant scope for improvement.

Table 2.4 Chiller System - Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million TR)	Screw: 3.8 Scroll: 0.4 Centrifugal: 0.8 Total: 5.0	Screw: 8.2 Scroll: 1.2 Centrifugal: 4.7 Total: 14.0	Screw: 8.2 Scroll: 1.2 Centrifugal: 4.7 Total: 14.0
	Assimilated using sales data acquired from BSRIA reports and published research by CEEW.	Chiller sales forecast has been assumed based upon inputs from industry experts. Per RAMA the CAGR across different typologies in the next 10 years is estimates to be - Centrifugal: 9 to 10% Screw: 7% Scroll: 3 to 5%	Although the overall demand shall remain the same but from 2023 onwards scroll chillers are assumed to be gradually replaced by Screw type chillers owing to their better efficiencies.
Unit Tonnage (TR[15])	Screw: 60 to 570 Scroll: 16 to 60 Centrifugal: 100 to >710		
	From BSRIA chiller report		
Overall Plant IPLV (kW/TR)	Centrifugal: 0.9 to 1.05 Screw: 1.05 to 1.10 Scroll: 1.10 to 1.15	Centrifugal: 0.8 to 0.9 Screw: 0.90 to 0.95 Scroll: 0.95 to 1.00	Centrifugal: 0.65 to 0.70 Screw: 0.70 to 0.75 Scroll: 0.75 to 0.80
	The overall operating efficiency of the chiller plant including both high side (chiller, chilled water pumps, condenser water pumps, cooling tower) and low side equipment (air handling units, fan coil units) were estimated based upon consultations with HVAC industry peers. The operating efficiencies of different types of chillers have been estimated based upon minimum efficiency standards prescribed in ECBC 2017. Minimum ECBC compliance requirements of IPLV have been considered for the 2017 efficiency levels of chillers.	EECBC+ requirements have been considered by 2027. The minimum energy performance improvement trends of ASHRAE Standard 90.1 from 2004 onwards (2004, 2007, 2010, 2013, 2016) were also studied. It was observed from the past trends that the minimum efficiency requirements of chillers as specified by ASHRAE 90.1 would be at par with ECBC+ requirements by 2027.	For estimating the further improvements in efficiency of chillers, Super ECBC requirements have been considered by 2027. Improvements in operating efficiencies from 2023 onwards have been considered owing to higher penetration of building automation and energy management systems. Retro-commissioning and retrofitting are considered to improve the operating efficiencies of the entire existing stock to the tune of average operating efficiencies of the new stock from 2023 onwards
Annual run-time (hour)	2568		
	Based upon 70:30 mix of daytime versus 24-hour buildings in commercial stock, sourced from BSRIA; inputs from experts in HVAC O&M.		

Refrigerant mix installed	Screw: 100% R134A Scroll: 95% R410A, 5% R407C Centrifugal: 90% R134A, 10% R123	Screw: 70% R134A, 30% R513A Scroll: 100% R410A Centrifugal: 60% R134A, 10% R513A, 10% R514A, 20% R1233zd	Screw: 60% R134A, 40% R513A Centrifugal: 45% R134A, 15% R513A, 15% R514A, 25% R1233zd
	Determined through India's HCFC phase out schedule, refrigerant preferences of key market players, refrigerants used in top selling models and expert interviews	An aggressive HCFC phase out schedule and HFC phase down	An aggressive HFC phase down with higher penetration of low GWP (high efficiency) refrigerants.
Charge rate (kg/kW)	0.28		
	Determined through expert inputs from peer group of HVAC professionals.		
Annual operational refrigerant leakage rate	2%		1%
	Determined through expert inputs from peer group of HVAC professionals.		Assuming lower operational leakages in the future stock due to better technology in chillers and improved O&M practices
Refrigerant recovery at end-of-life	Full charge is recovered from 50% of the scrapped chillers		Full charge is recovered from 90% of the scrapped chillers
	Determined through expert inputs experts in HVAC O&M		Assuming better refrigerant management practices.

2.3.2.2 Results and Discussion

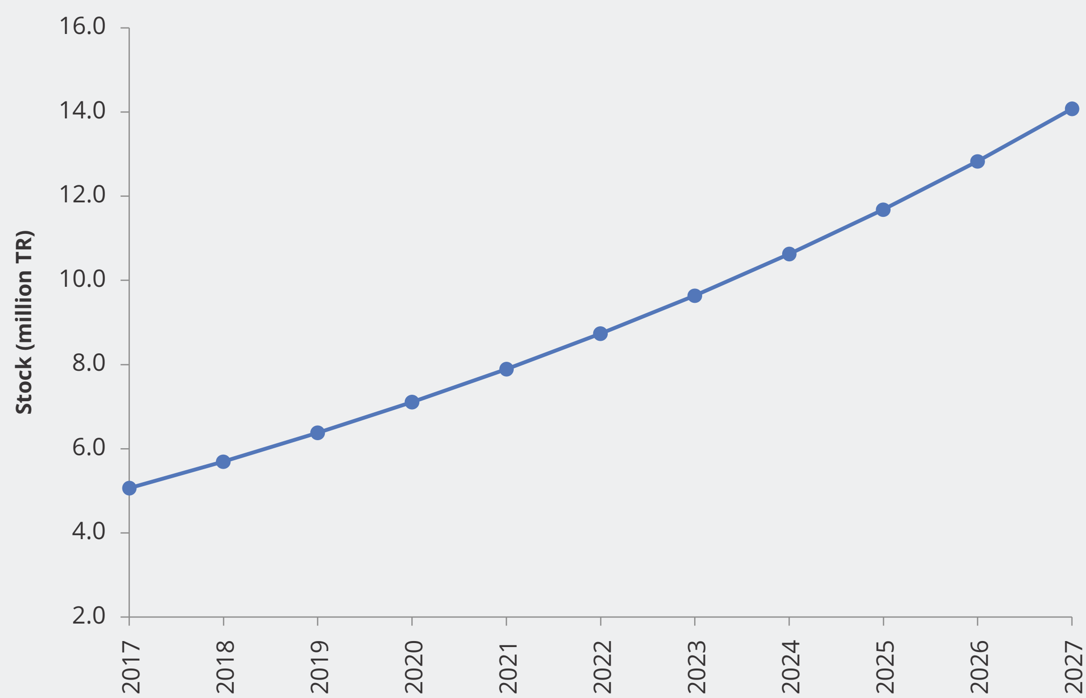
The key results have been tabulated in Table 2.5.

Table 2.5 Chiller System – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Installed capacity (million TR)	5.0	14.0	14.0	
Annual energy consumption (TWh)	11.8	29.2	19.7	32%
Indirect emissions (mtCO_2e)	9.6	23.9	16.1	
Direct emissions (mtCO_2e)	0.7	1.5	0.4	
Total emissions (mtCO_2e)	10.3	25.4	16.5	35%

- With the advent of technology and combination of national and international best practices, significant scope for improvement lies in the chiller systems. The 2027- Improved Scenario has been developed considering determined effort towards this endeavour from all concerned stakeholders. The most important levers being:
  - Better O&M practices with focus on two important aspects:
    - **I.** HVAC O&M being a specialist's job, is better handled by trained HVAC engineers and technicians rather than generalists.
    - **ii.** Utilisation of the Internet of Things (IoT) in day to day operations
  - Higher penetration of Building Automation/Management Systems in upcoming medium to large constructions.
  - Higher penetration of BEE star rated chillers (currently under voluntary scheme) and other HVAC system auxiliaries like pumps (chilled / condenser water) and fans (cooling tower, AHU).
- Stringent uptake of ECBC-2017 with more buildings crossing the minimum ECBC compliance and even achieving ECBC+ and Super ECBC requirements.
- Retro-commissioning of existing HVAC systems to plug the inefficiencies due to poor O&M practices
- Retrofitting old and inefficient HVAC systems with new efficient & right-sized equipment
- Aggressive phase-down of HFCs with low GWP alternatives (phase-out of HCFC is already on track in the Chiller industry)
- Improvements in chiller technology as well as O&M practices to further reduce operating and end of life refrigerant leakages.

Figure 2.6 RAC – Stock Projection



2.3.3 VRF System

2.3.3.1 Overview of the Analysis

VRF systems have been gaining wide acceptability and popularity in India due to various advantages such as high energy efficiency, quick installation, ease of operation and the flexibility of choosing a wide range of indoor units for several applications. While the residential air-conditioning market is moving towards inverter split air-conditioners, the commercial segment is showing a strong shift towards VRF systems. The sales and stock numbers were estimated using data obtained from various published research reports, market intelligence reports, interactions with industry experts and manufacturers. Per RAMA, the market size of VRF systems in 2017 is estimated to be around 0.44 million TR. Based on their absolute capacity, VRF systems are classified into mini VRF and large systems with large systems being dominant in the commercial market. The energy efficiency and annual operating hours were then employed to calculate the total energy consumption.

Table 2.6 VRF System - Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million TR)	2.3	9.7	9.7
	Estimated using sales data gathered from BSRIA, CEEW, RAMA; an annual replacement factor of 5% was considered	HVAC industry experts suggest that the VRF market will grow at a CAGR of at least 15% in the next decade, an annual growth rate of 15% is also forecasted by BSRIA	
Tonnage (TR)	Mini VRF – 5 Large VRF - 11	Mini VRF – 5 Large VRF - 11	
	As per BSRIA, also validated from HVAC industry experts		
Efficiency (kW/TR)	0.81	0.81	0.73
	The rated efficiency of VRF systems ranges from 0.8 to 1.1 kW/TR depending upon equipment size. Per ECBC (2017), the minimum efficiency requirement for VRF systems (< 40 kW) is 0.81 kW/TR. In BAU this efficiency of 0.81 kW/TR is assumed until 2027, assuming a higher degree of code compliance in commercial buildings in the next decade.		A 10% improvement in 2027 is considered over the 2017 baseline level in improved scenario with various technological advancement in the near future
Annual run-time (hour)	1920		
	Assuming day-time application in commercial buildings		
Refrigerant mix installed	100% R410A	100% R410A	80% R410A, 20% R32
	All VRF models available in Indian market use R410A refrigerant; also validated through expert interviews		Interaction with manufacturers suggest that alternate refrigerant like R32 may be used in next decade
Charge rate (kg/kW)	0.23		
	Determined through expert inputs from peer group of HVAC professionals.		

Annual operational refrigerant leakage	5%
	Determined through inputs from HVAC industry experts
Recovery at recharging and end-of-life	0%
	Determined through inputs from HVAC industry experts

2.3.3.2 Results and Discussion

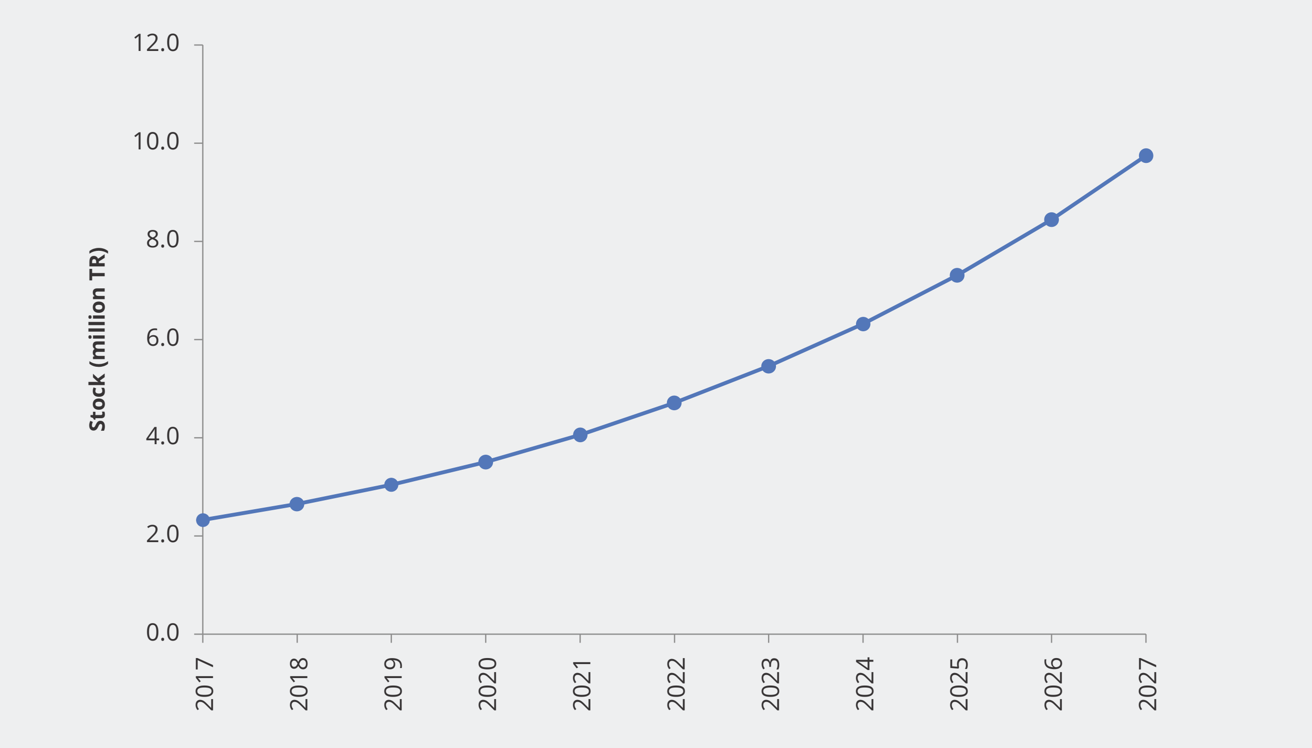
The key results have been tabulated in Table 2.7.

Table 2.7 VRF Systems – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Installed capacity (million TR)	2.3	9.7	9.7	
Annual energy consumption (TWh)	3.6	15.2	14.3	6%
Indirect emissions (mtCO_2e)	3.0	12.4	11.7	
Direct emissions (mtCO_2e)	0.4	1.6	1.5	
Total emissions (mtCO_2e)	3.4	14.0	13.2	6%

- Savings of 6% in energy consumption is possible by improving the efficiency of the system by 10% in the next decade. Further, with the possible development of MEPS for VRF by BEE and the higher uptake of ECBC+ and SuperECBC in buildings, energy savings will be much higher.
- The initial cost of a VRF system is higher than other comparable systems, but they offer much better energy efficiency. The actual energy performance of VRF systems is compromised due to poor O&M practices – regular maintenance of filters, cooling coils, shading the outdoor unit and ensuring good airflow around the outdoor unit for heat rejection is recommended.

Figure 2.7 VRF System – Stock Projection



2.3.4 Packaged DX

2.3.4.1 Overview of the Analysis

The stock and sales data for packaged DX systems were gathered from various published research reports and stakeholder interactions. Per RAMA, the market size of packaged DX systems in 2017is around 0.6 million TR and will grow at a CAGR of 5% in the next decade. There is minimal growth in ducted and small packaged DX; per market intelligence reports, rooftop DX market is very small. Also, growth of indoor packaged unit is decreasing, as VRFs continue to grow. An annual replacement factor of 10% was assumed to calculate the stock numbers. The average TR and operating efficiency determined through inputs from HVAC industry experts were then employed to find the total energy consumption of the unit.

Table 2.8 Packaged DX – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million TR)	4.6	6.7	6.4
	Estimated using sales data from RAMA, BSRIA, CEEW; an annual replacement factor of 10% was assumed	Per RAMA, sales will grow at a CAGR of 5% in the next decade. In the improved scenario, the growth of packaged DX market is assumed to decline from 5% to 2% from 2022-2027. This decline is expected due to the popularity and faster adoption of VRF systems.	
Unit Tonnage (TR)	5 to 20		
	From BSRIA World Air Conditioning Report		

Efficiency (kW/TR)	1.25	1.09	1.03
	Per ECBC (2017), the minimum efficiency requirement for an air-cooled packaged DX system (< 10.5 kW) is 1.25 kW/TR. In BAU, it is estimated that by 2027 the efficiency of packaged DX will reach 1.09 kW/TR, which the minimum efficiency requirement for an ECBC+ compliant is building i.e. an energy efficiency improvement of 13% over 2017 baseline level. This is in line with trends in ASHRAE standards of minimum cooling efficiency for packaged AC.		Per ECBC (2017), the minimum efficiency requirement for an air-cooled packaged DX system (< 10.5 kW) for SuperECBC complaint building is 1.03 kW/TR. It is assumed that by 2027, the efficiency of packaged DX systems will reach 1.03 kW/TR due to advancements in compressor technology.
Annual run-time (hour)	1920		
	Assumed based on day-time application in buildings		
Refrigerant mix installed	85% R410A, 15% R32		70% R410A, 30% R32
	Determined through inputs from HVAC experts and refrigerant used by top manufacturers		Increased use of alternate refrigerant in future
Charge rate (kg/kW)	0.26		
	Determined through expert inputs from peer group of HVAC professionals.		
Annual operational refrigerant leakage	5%		
	Determined through inputs from HVAC industry experts		
Recovery at recharging and end-of-life	0%		
	Determined through inputs from HVAC industry experts		

2.3.4.2 Results and Discussion

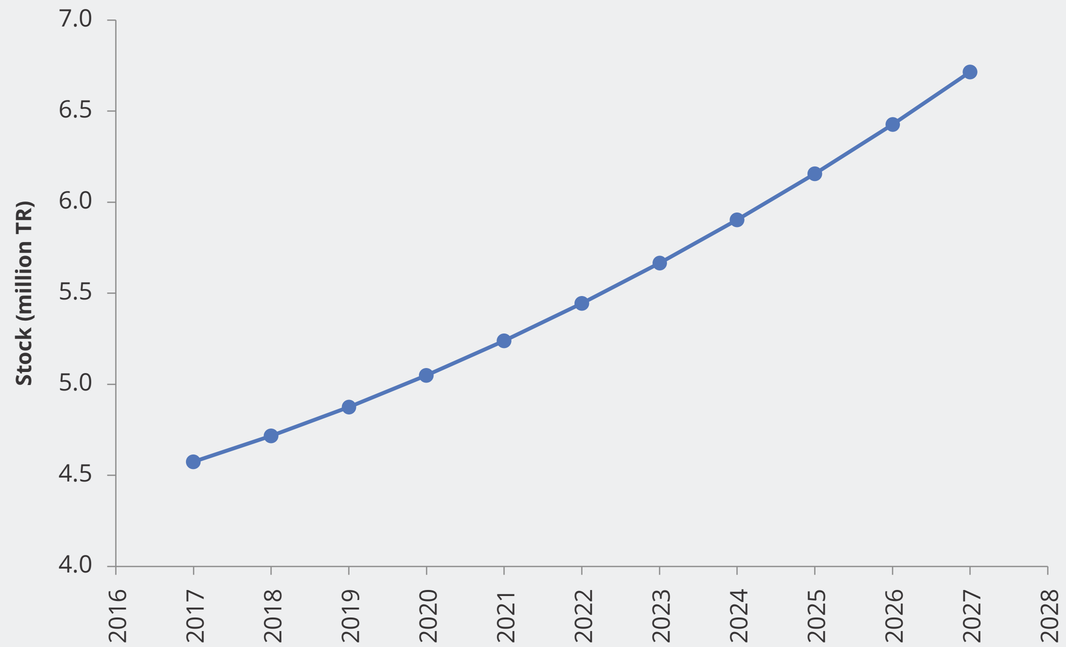
The key results have been tabulated in Table 2.9.

Table 2.9 Packaged DX – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Installed capacity (million TR)	4.6	6.7	6.4	
Annual energy consumption (TWh)	11.0	14.0	12.7	9%
Indirect emissions (mtCO_2e)	9.0	11.5	10.4	
Direct emissions (mtCO_2e)	1.4	1.8	1.7	
Total emissions (mtCO_2e)	10.4	13.3	12.1	9%

- Owing to the declining market share of Packaged DX, the manufactures do not have much interest in them, although advancement in technology with energy efficient compressors with microprocessor controllers and better maintenance practices can reduce the indirect emissions in 2027 by a small margin.

Figure 2.8 Packaged DX – Stock Projection



2.3.5 Fan

2.3.5.1 Overview of the Analysis

The fan stock number was realised using a combination of techniques – household information, fan penetration, fan sales, and export. This stock was then split into an EE fan stock, comprising BEE star-rated ceiling fans only, and a non-energy efficient stock comprising ceiling, pedestal and wall-mounted fans. Typical input wattages for such appliances and typical usage hours were then plugged in to obtain the annual energy consumption. This was used to finally calculate the carbon emissions from fan use.

Table 2.10 Fan – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Total stock (million units)	458	646	
	Estimated using household information, fan penetration, number of fans per household and their residential and commercial application. These data points were extrapolated and adapted from Census (2011), NSSO (2012), Prayas Energy Group (2010) and IESS 2047		

	2017	2027 (BAU)	2027 (Improved)
BEE star-rated ceiling fans	Per BEE published data, the production of BEE star-rated ceiling fans has been steadily increasing at approximately 30%. In the BAU scenario, it has been assumed that this market trend will continue into the next decade. With the growing uptake of star-rated fans, the overall energy efficiency of the surviving stock in use will continue to improve. Per Prayas Energy Group (2010), the non-star-rated stock will comprise ceiling fans and smaller fans in the ratio of 80:20 approximately.		Per inputs from BEE, it is likely that star rating for ceiling fans will be made mandatory 2019 onwards – this input has been incorporated such that all ceiling fans sold 2019 onwards will be energy efficient compared to the regular fans that pervade the Indian market today. If BEE star-labelling for ceiling is made mandatory, as is already being planned, it will have a significant bearing on the annual energy consumption of fans.
Input wattage	The following input wattages have been assigned to the various types of star-rated and regular fans based on a market survey of the fan products of the top fan manufacturers of India. It is acknowledged that the 2017 fan stock will have a small number of super energy efficient BLDC fans – however, this has not been incorporated into the analysis due to lack of verifiable data. It is however anticipated that their number is not large enough to have a significant bearing on the results. Average input wattage of a star-rated ceiling fan = 50 W Average input wattage of a regular ceiling fan = 75 W Average input wattage of a regular table/pedestal/wall fan = 50 W		
Utilisation factor	80% Since no meaningful insight could be gained into this either through literature or through stakeholder consultation, this is our best estimate based on our observation		
Annual run-time (hour)	1600 Per Prayas (Energy Group)		

2.3.5.2 Results and Discussion

The key results have been tabulated in Table 2.11.

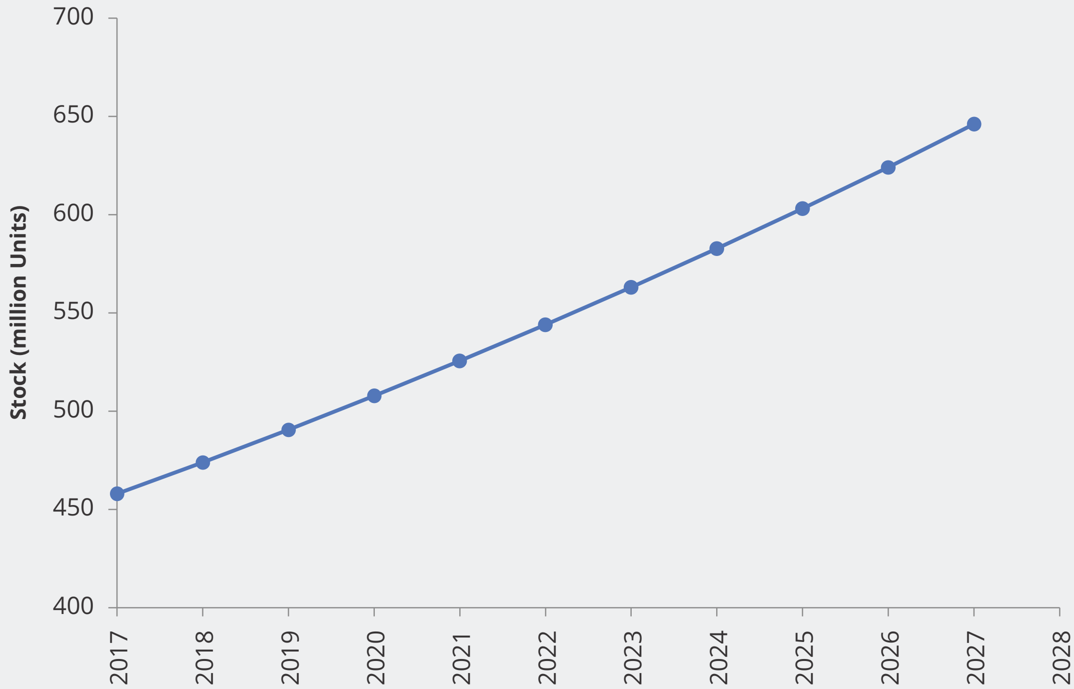
Table 2.11 Fan – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Annual energy consumption (TWh)	41	52	46	12%
Total emissions ($mtCO_2e$)	34	43	38	12%

- This analysis brings into light the enormity of energy consumption from fan use and presents a compelling case on why fans should be an appliance in focus alongside RACs.
- Energy saving of 12% is possible from the use of fans in the medium term from ratcheting-up the market share of efficient fans. One definitive way of achieving this is to upgrade ceiling fans from the voluntary to the mandatory phase of BEE star-

rating in the next 1 year. In this analysis, the average input wattage of efficient fans has not been stepped up. A step-up in the energy efficiency of ceiling fans from 50W to 35W is possible and should be viewed as conservative since super energy efficient BLDC fans of 35 W are already available in the market today.

Figure 2.9 Fan – Stock Projection



2.3.6 Air Cooler

2.3.6.1 Overview of the Analysis

The stock number was estimated using household penetration of air coolers and other sporadically available data points. A typical input wattage and hours of use was inputted across the entire stock to obtain the annual energy consumption – this number was used to arrive at the emission numbers.

We found this sub-sector to be a fairly unorganized, in terms of data availability as well as the proliferation of privately fabricated home-grown variety air coolers. As such, verifiable data, especially for future projection has been hard to come by.

Table 2.12 Air Cooler – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million)	55		
	The stock number was estimated using household penetration of air coolers, and other available data points from industry sources i.e. air cooler sales, the split between the organised and unorganised air cooler sectors (currently 30% vs 70%, respectively) and typical equipment lifetime (5 to 10 years depending on equipment quality).		
Stock characteristics	Per industry input, air coolers of 500-1000 CFM are most widely used in residential and similar applications.		

	2017	2027 (BAU)	2027 (Improved)
Operational characteristics	55		
	● The annual runtime was assumed to be 1200 hours distributed among months from March to October; the maximum utilisation of air coolers will occur in the first half (less humid) of the summer season. Since no meaningful insight could be gained into the stock redundancy either through literature or through stakeholder consultation, it is assumed to be 80-90%. ● It is worth pointing out that air coolers are water-guzzling appliances. This can become a serious limitation in water-stressed regions of India. However, air cooling consumes roughly 10-20% of the electricity consumed by air-conditioning – the air cooler industry argues that the water consumed by power plants to produce the excess electricity directed towards air-conditioners would easily offset the water consumed by air coolers. Hence, while air coolers will deplete locally available water (i.e. at the site of their deployment), a more holistic assessment may provide a contrasting perspective. ● The cooling effectiveness of air coolers is seriously constrained by dryness of the ambient air; as such the performance of air coolers will vary significantly between climate zones (hot & dry and composite vs warm & humid) and seasons (low, medium and high relative humidity). Air coolers also need adequate ventilation to function well in humid conditions.		
Stock characteristics	Per industry experts, air coolers typically consume 0.2 to 0.3 kWh.		10-20% energy savings is possible, with more and more air coolers being fitted with energy efficient fans and pumps. In other words, market forces will need to influence consumer behaviour to shift consumer choice towards better quality air coolers manufactured by the organised sector, rather than indigenously manufactured ones. However, for India, where price-sensitivity will continue to play a key role at least in the foreseeable future, the cost-benefit equation will remain the key driver for the consumers while purchasing air coolers. Government policy, like a mandatory MEPS, will also help in the transformation of the air cooler industry towards more energy-efficient air coolers.

2.3.6.2 Results and Discussion

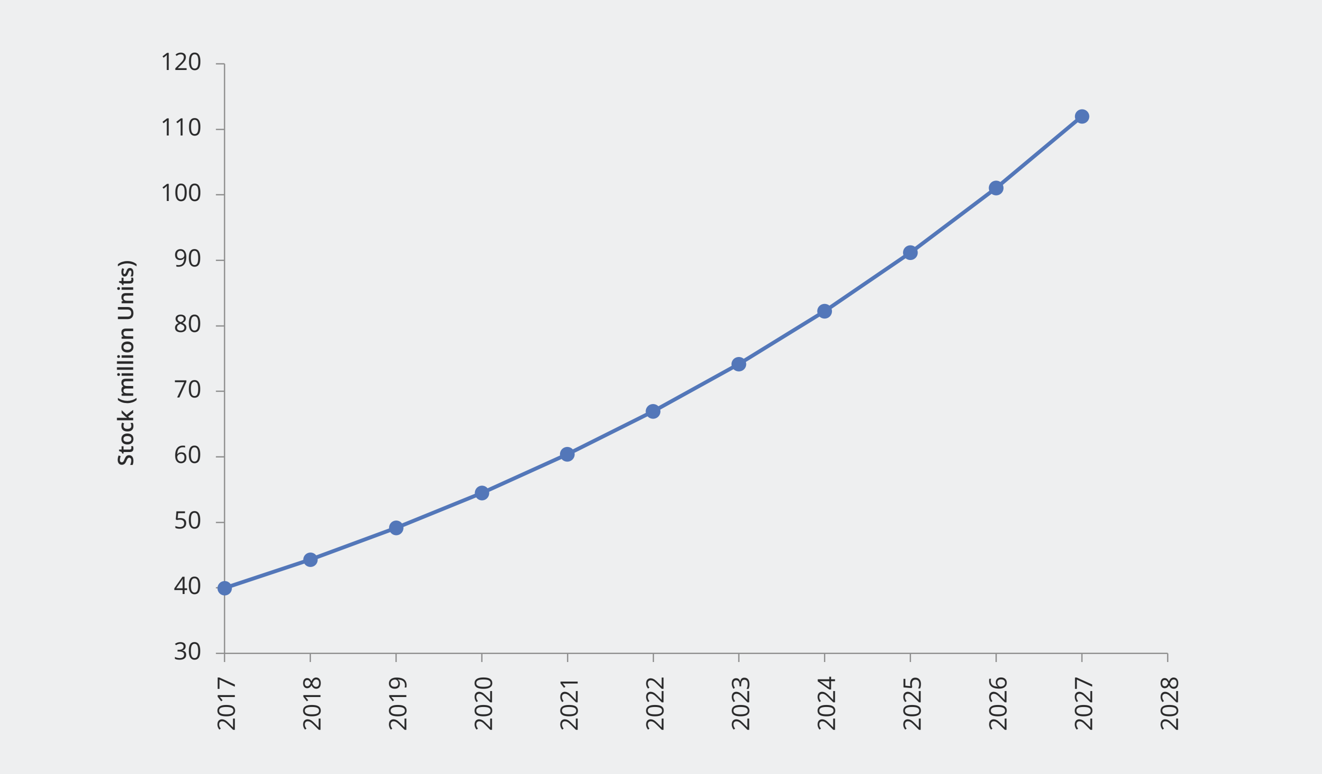
The key results have been tabulated in Table 2.13.

Table 2.13 Air Cooler – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Annual energy consumption (TWh)	11	31	27.5	11%
Total emissions (mtCO2e)(mtCO$_2$e)	9	25	22.5	11%

Innovative air cooler technologies can play an important role in displacing air-conditioning in the next decade or so, especially for some specific climate types and applications. One such technology is a two-stage evaporative cooler which the manufacturer claims is cost-effective and climate appropriate, designed specifically for India's needs specifically.

Figure 2.10 Air Cooler – Stock Projection



2.4 Endnote

- The commercial building sector is fairly non-homogenous with multiple building types. To accommodate within the short timeframe of this study, we have taken an aggregated look at the commercial sector. While this aggregated view serves well for the macro nature of this study, however, outside the time-bounds of the project, we recommend a deeper look specifically at the defence sector. This sector has very unique needs in terms of energy demand, and we feel that the cooling discussion may be better informed by a deeper dive to understand and quantify the cooling needs in the defence sector.

3. Mobile Air-conditioning

3.1 Scope

- The analysis of passenger light duty vehicles (LDV) covers cars, jeeps, and taxis for public and private use. The Indian automotive sector is likely to witness a greater penetration of electric vehicles in the next decade or so – expectedly, this will have a bearing on the energy used for air-conditioning, however, the industry experts couldn't fully quantify this.
- The study of passenger heavy duty vehicles (HDV) addresses air-conditioned buses only.
- In the railways sector, the annual energy consumption for cooling, from air-conditioned passenger coaches, is quite small as compared to other sectors of cooling described in this report – therefore, a brief overview of the analysis has been presented.
- Air-conditioning in city-level metro transit systems could not be included within the project timeline.

3.2 Sectoral Results

The key results have been tabulated in Table 3.1.

Table 3.1 Mobile Air-Conditioning – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Annual energy consumption (mtoe)	3.0	5.5	4.4	20%
Total emissions (mtCO_2e)	10.8	22.6	16.1	29%

- The MAC sector is projected to double in terms of energy consumption as well as total emissions within the next decade.
- The stock of air-conditioned passenger LDV and HDV is likely to double by 2027 (over 2017 baseline) – however, the ensuing carbon footprint can be avoided from doubling from a wide range of interventions, namely, improved fuel efficiency, efficient MAC system, lower GWP refrigerants, lower operational refrigerant leakage and better MAC servicing practice.
- 20% energy savings is possible between BAU and Improved Scenarios primarily due to efficient MAC system and improved fuel efficiency. The LDV industry is already on a path of improved fuel efficiency, per BEE LDV standards; in fact, one car manufacturer indicated that the industry is well ahead of government norms – hence, there a small room for improvement in fuel efficiency, which has been accounted for in the Improved Scenario. Manufacturers also suggested that fuel efficiency of AC buses is also on a rise, albeit not as steep as in cars.
- 29% carbon savingsis possible between BAU and Improved Scenarios. Majority of these savings will come from the mitigation of direct emissions through better MAC servicing and maintenance practices, and recovery at end of life. The results call the MAC servicing sector to action to cause a deeper decarbonisation of MACs.

Figure 3.1 Mobile Air-Conditioning – 2017 Annual Energy Consumption

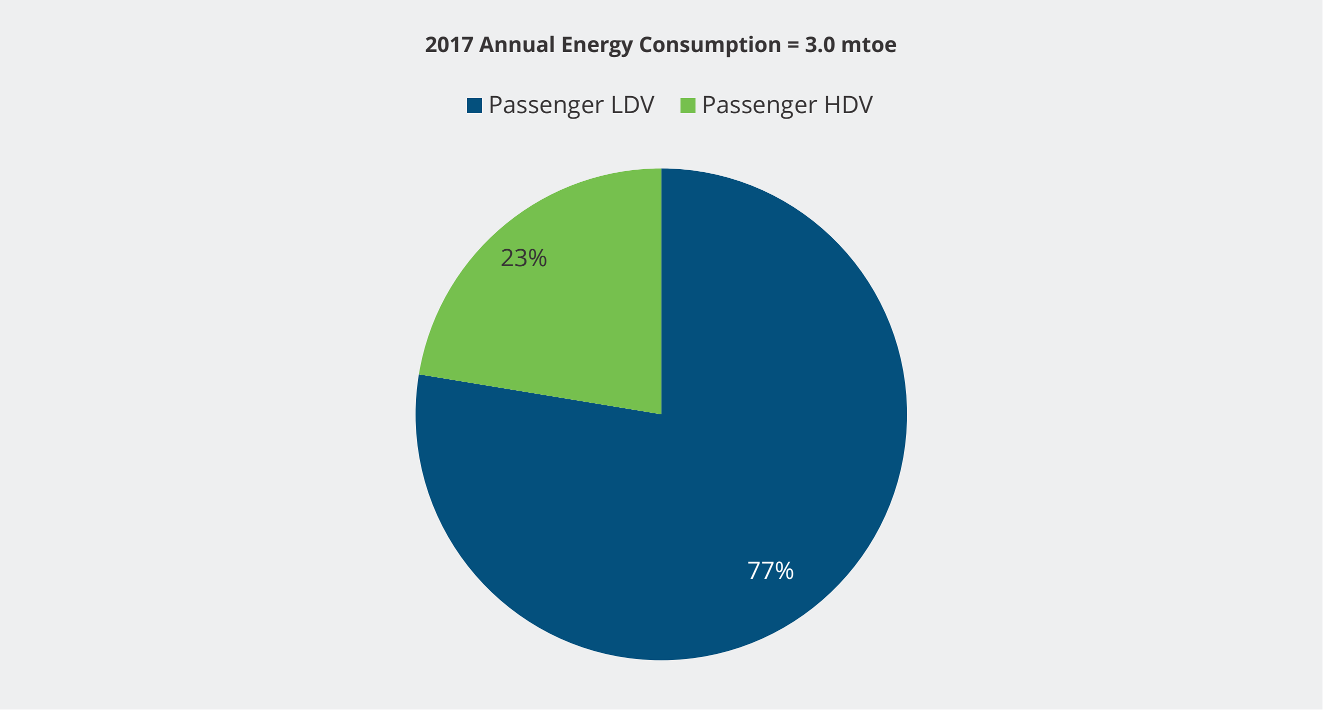


Figure 3.2 Air-Conditioning – 2017 Annual Carbon Emission

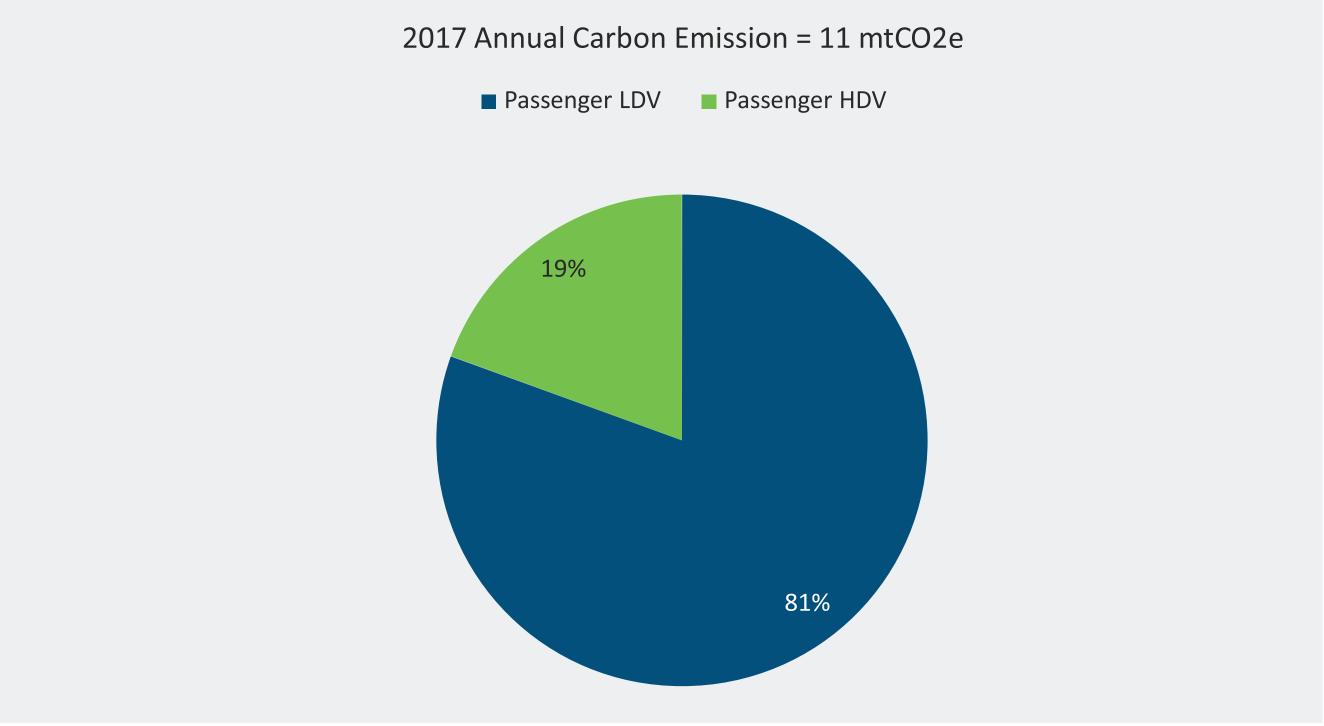


Figure 3.3 Mobile Air-Conditioning – A Comparison of the Annual Energy Consumption in 2017, 2027 (BAU) and 2027 (Improved) Scenarios

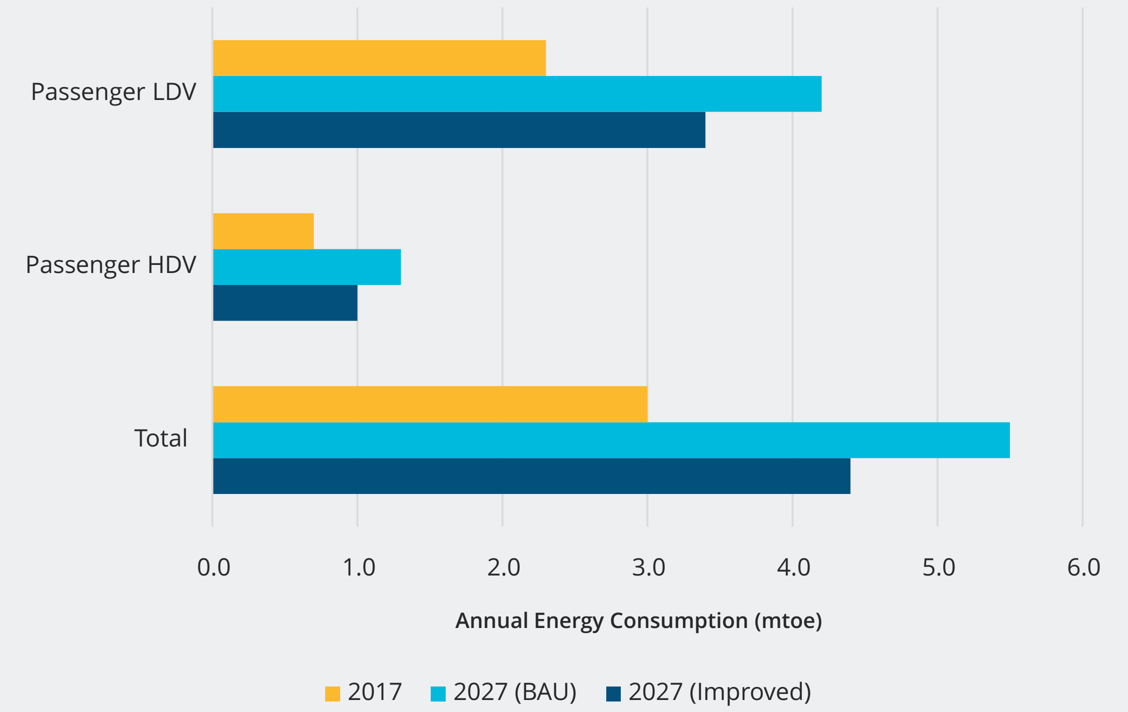
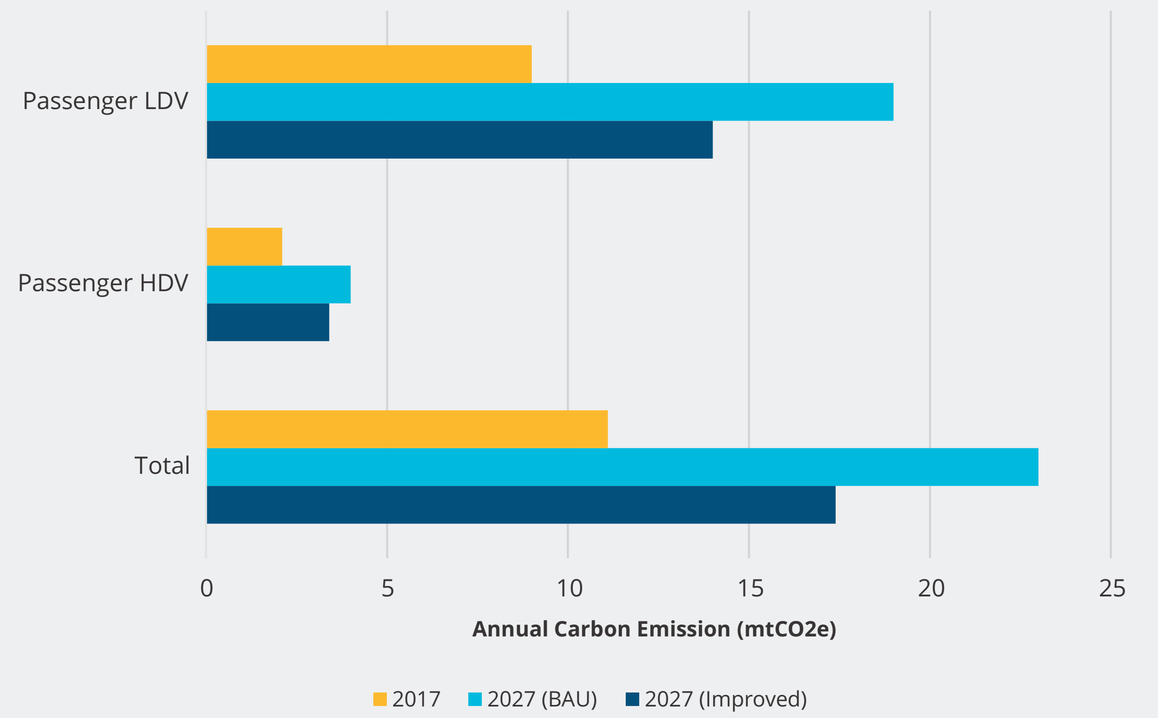


Figure 3.4 Mobile Air-Conditioning – A Comparison of the Annual Carbon Emission in 2017, 2027 (BAU) and 2027 (Improved) Scenarios



3.3 Sectoral Deep Dive

3.3.1 Passenger Light Duty Vehicle (LDV)

3.3.1.1 Overview of the Analysis

The 2017 stock was estimated using data published by MoRTH and the growth trends reported by SIAM. Market intelligence indicates that more than 95% of the 2015 stock was air-conditioned and almost all passenger cars sold thereafter were fitted with MACs. Typical annual distances travelled by passenger vehicles with air-conditioning switched on, and BEE fuel efficiency norms for LDV were used to arrive at the total fuel consumption – of this about 15-20% goes into air conditioning. The indirect carbon emissions were calculated using an emission factor of petrol and diesel. To estimate direct emissions, refrigerant charge and leakage rates during operation, servicing and end of life were employed. The key inputs and assumptions are given in below Table 3.2.

Table 3.2 Passenger LDV – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million)	32	65	
	Estimated using MoRTH data of registered cars, jeeps and taxis and sales data; based on CPCB, MoEFCC, a 4% annual replacement factor was assumed[23]	Based on historical and current trends, an annual growth rate of 8% in sales was assumed between now and 2027[24]	
Annual distance travelled with AC ON (km)	7840		
	The weighted average annual distance travelled by private and public vehicles was estimated to be 11,200 km – a climatic distribution was applied on this to determine that 70% of the total distance travelled was with AC ON; some car manufacturers suggest that this share could be as high 90% since MACs are used for humidity control at low ambient temperatures.		
Fuel efficiency with AC OFF (km/l)	13-15	15-17 (new sales)	17-20 (new sales)
	BEE mandatory fuel efficiency norms[25]; a 20% deterioration was applied to replicate real conditions		The EU has set a CO_2 emission target of 95 g/km; the average weight of Indian cars is lower than that of cars in the EU, and India can achieve a relaxed target of 105g/km by 2020 per CSE[26]; a 10% deterioration was applied to replicate real conditions.
Fuel consumed by MAC	15% of total fuel consumption is for AC		13.5% of total fuel consumption
	Determined through interactions with industry experts and secondary research (NREL); this is in the range of 15-20% i.e. 15% in moderate climatic conditions and 20% in hot climate		Per industry inputs, the efficiency of MAC system can be improved by 8-10% in next 10 years

	2017	2027 (BAU)	2027 (Improved)
	32	65	
Refrigerant mix installed	100% R134A		92% R134A, 4% R1234yf, 2% R152A, 2% R744
	R134A is used across the entire spectrum after the successful phase out of CFCs		Interactions with automobile industry expert suggest that 2020 onwards, the MAC sector may see an increase in the use of low GWP refrigerants. R744 may percolate to the Indian market as some European manufacturers are already utilizing it; however the market share is difficult to predict just yet.
Charge rate (g/car)	500		
	Estimated using the average refrigerant charge of top selling cars in India; Experts indicate that for smaller cars this charge is 300-400 g, whereas for bigger cars it is in the range of 500-800g		
Annual operational refrigerant leakage as share of refrigerant charge	10%		5%
	Industry expert inputs indicate that 40-60 g of gas leaks each year		With more efficient leak proof joints and hoses, it is possible to reduce refrigerant leakage to as low as 15 g/year
Refrigerant Recovery at servicing, end of life recovery	50%, 0%		80%, 30%
	Determined through inputs from automobile industry professionals		Assuming very feasible good servicing practices

3.3.1.2 Results and Discussion

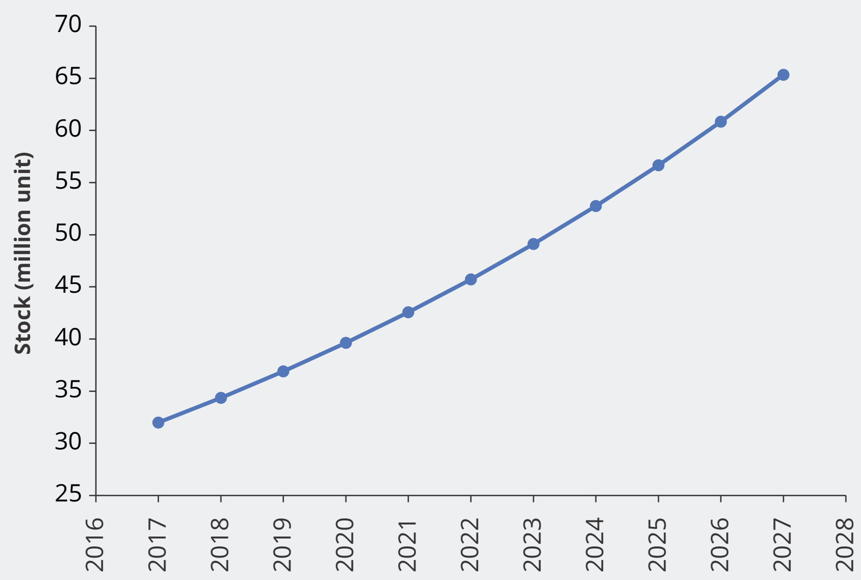
The key results have been tabulated in Table 3.3.

Table 3.3 Passenger LDV – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Annual energy consumption (mtoe)	2.3	4.2	3.4	19%
Indirect emissions ($mtCO_2e$)	6.4	11.7	9.5	
Direct emissions ($mtCO_2e$)	2.3	6.9	3.5	
Total emissions ($mtCO_2e$)	8.7	18.6	13.0	30%

- New fuel efficiency norms published by BEE for the next decade or so will see improvements in engine efficiency, transmission efficiency, vehicle weight and size, alternate fuels, and the rolling resistance of tyres – this will have a positive bearing on the carbon emissions from MACs. Some stakeholders have also indicated that the industry is well beyond government norms.
- HFO-1234yf is already used in North America, Europe, Japan, and China. Indian car manufacturers could follow an aggressive trend towards adopting these low GWP variants, as a first step towards HFC phase down. From an energy efficiency perspective, R152A (mildly flammable) is better than R134A whereas R1234yf (mildly flammable) is worse than R134A. Experts suggest CO2 will need pressurised piping for use
- Good servicing practices and awareness is vital in reducing direct emissions. Topping up is standard practice in MAC servicing and should be fully adhered to in India too.

Figure 3.5 Passenger LDV – Stock Projection



3.3.2 Passenger Heavy Duty Vehicle (HDV)

3.3.2.1 Overview of the Analysis

The 2015 stock and sales numbers were obtained by data put forth by MoRTH and SIAM. The MAC community approximates that the penetration of AC buses was 8-10% in 2015[27]. The key inputs and basis of assumptions is given in below Table 3.4.

Table 3.4 Passenger HDV – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million)	0.2	0.4	
	Estimated using MoRTH and SIAM data; AC bus penetration of 10% in 2015	Sales of AC buses is estimated to grow at 15% p.a.[28]	

	2017	2027 (BAU)	2027 (Improved)
Annual distance travelled with AC ON (km)	1,05,000		
	Sourced from CEEW (2015)		
Fuel efficiency with AC OFF (km/l)	3-4	4-5 (new sales)	4-6 (new sales)
	Estimated using the weighted average of fuel efficiency of AC buses in India; one bus manufacturer suggested the following fuel efficiency range: 5-7 for mini buses, 3-4 for medium/standard size buses, 2-3 for premium (or large) buses		Japan set a fuel efficiency target of 6.3km/l for buses in 2015, India can formulate fuel efficiency standards for HDVs by 2020; a 10% relaxed target w.r.t. global targets is assumed – this should be viewed as a modest assumption
Fuel consumed by MAC	15% of total fuel consumption is for AC		13.5% of the total fuel consumption is for AC
	Determined through interactions with automobile manufacturers		8-10% efficiency improvement in MAC system is considered per industry inputs in next 10 years
Refrigerant mix installed	95% R134A 5% R407C		96% R134A, 2% R1234yf, 1% R152A, 1% R744
	Buses in India majorly use R134A; industry experts suggest that some buses use R407C		Assumption based on the advent of low GWP refrigerants, a step towards HFC phase out. It is possible that R744 may percolate to the Indian market as some European manufacturers are already utilizing it; however the market share is difficult to predict just yet.
Charge rate (kg/bus)	5		
	Weighted average applied based on interactions with automobile experts; the charge rate range is: 2.5-3 for mini, 3.5-4.5 for medium, 6-9 for standard and 9-11for premium buses		
Annual operational refrigerant leakage as share of charge	10%		5%
	Determined through inputs from automobile industry professionals		Improvement is possible by reducing lengths of pipes, number of joints and leak proof hoses
Refrigerant recovery at servicing and end of life	50%, 0%		80%, 30%
	Based on inputs from industry experts		Assuming better recycle and recovery practices in the MAC servicing sector

3.3.2.2 Results and Discussion

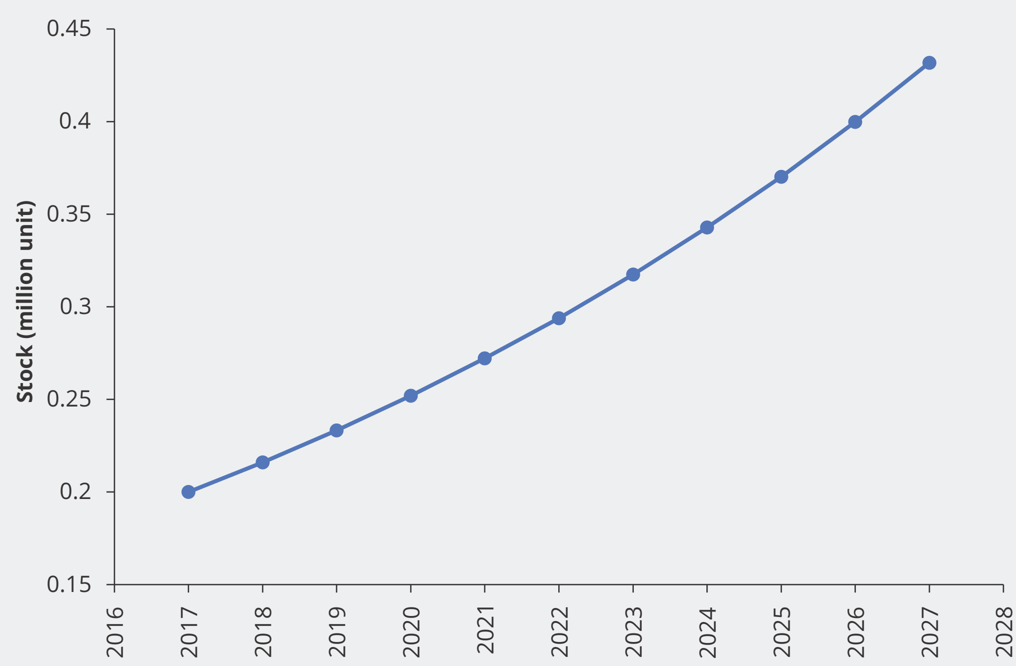
The key results have been tabulated in Table 3.5.

Table 3.5 Passenger HDV – Key Results

	2017	2027 (BAU)	2027 (Improved)	Savings Potential in 2027
Annual energy consumption (mtoe)	0.7	1.3	1.0	23%
Indirect emissions ($mtCO_2e$)	2.0	3.7	2.9	
Direct emissions ($mtCO_2e$)	0.1	0.3	0.2	
Total emissions ($mtCO_2e$)	2.1	4.0	3.1	23%

- India should fast track implementing fuel efficiency standards for HDV which will drive manufacturers to improve the fuel efficiency. Per ICCT, 20-25% fuel reduction is possible by improving rolling resistance and auxiliary loads, optimizing driver behaviour, improved engine and transmission efficiencies and reducing vehicle weight.
- The leakage rate can be reduced by leak testing with soap solutions, using Recovery and Recycling (R&R) machines, good servicing practices, consumer and technician awareness, and regular servicing of equipment[31].

Figure 3.6 Passenger HDV – Stock Projection



3.3.3 Railway

The 2017 stock (non-AC and AC) of railway coaches comprises approximately 55,000 passenger coaches – this was extrapolated from the railway statistics published by MoSPI using a 3% annual growth as has been observed in 2003-14. CEEW cites that the share of AC coaches increased from 5% in 1990 to 13% in 2010 – based on this trend, it was assumed that 20% of the current stock is air-conditioned. A capacity of 10 TR of air-conditioning is typically installed/coach that works at 80% part-load. It is assumed that the EER at this part-load is 1. Using the average distance travelled and the average speed of AC trains, it was concluded that a passenger coach would use air-conditioning for 12 hours/day – assuming a coach plies for 300 days/year, air-conditioning in passenger coaches would consume about 3 TWh of energy. If business is carried out as usual, this metric would double by 2027. Passenger coaches use two types of AC systems – conventional and roof-mounted. Adequate data related to refrigerant leakage in railways could not be gathered within the project time line and has been reserved for investigation in a future project.

4. Refrigeration

4.1 Scope

- Refrigeration is broadly classified into domestic and commercial sectors.
- Domestic refrigeration includes domestic-type refrigerators such as those found in homes – however, they might find application in commercial setups too like hotels, retail, and hospitals. It covers frost-free (FF) and the more recent direct-cool (DC) technology types.
- This analysis on commercial sector pertain to Stand-alone, Vending machines, Remote condenser units, Water coolers, Super markets and Hyper markets systems.

4.2 Sectoral Results

The key results have been tabulated in Table 4.1.

Table 4.1 Refrigeration– Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Annual energy consumption (TWh)	66.5	120.5176	100.3	17%
Total emissions (mtCO_2e)	56.6	105.4	87.2	17%

- R-744 (CO2) is a suitable alternate refrigerant for deployment in Supermarkets which would help mitigate substantial direct emissions.
- Research promotion of R-744 for penetration in deep freezers, visi-coolers - which to a large extent are high GWPrefrigerant driven. Deterioration of energy performance during the lifetime of refrigerators is huge and needs to be addressed. Domestic refrigerators are already covered under BEE's mandatory star rating but even that cannot address the deterioration of energy performance during the equipment lifecycle.
- Significant energy saving of up to 17% is possible between BAU and Improved Scenarios; equal proportion of carbon savings - 17% is possible between BAU and Improved Scenarios. Majority of these savings will come from the mitigation of indirect emissions through operational energy efficiency improvements.

Figure 4.1 Refrigeration – 2017 Annual Energy Consumption

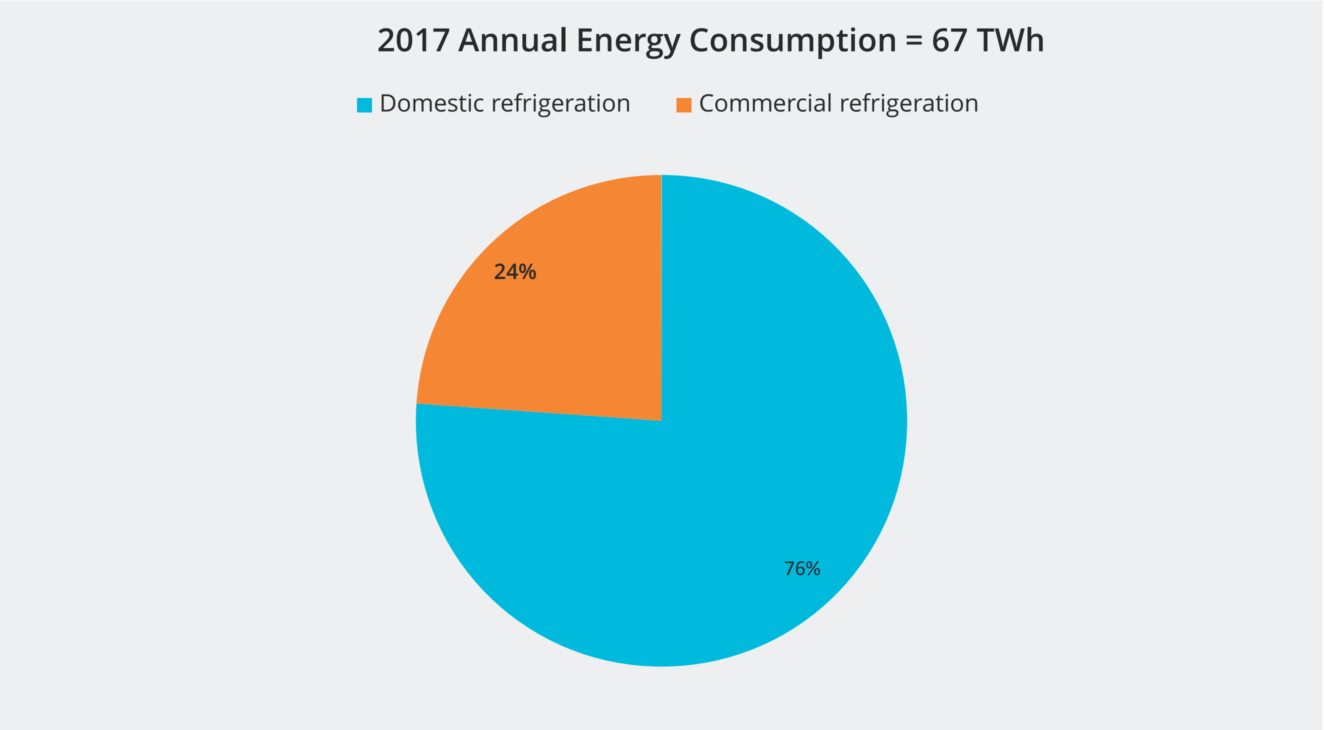


Figure 4.2 Refrigeration – 2017 Annual Carbon Emission

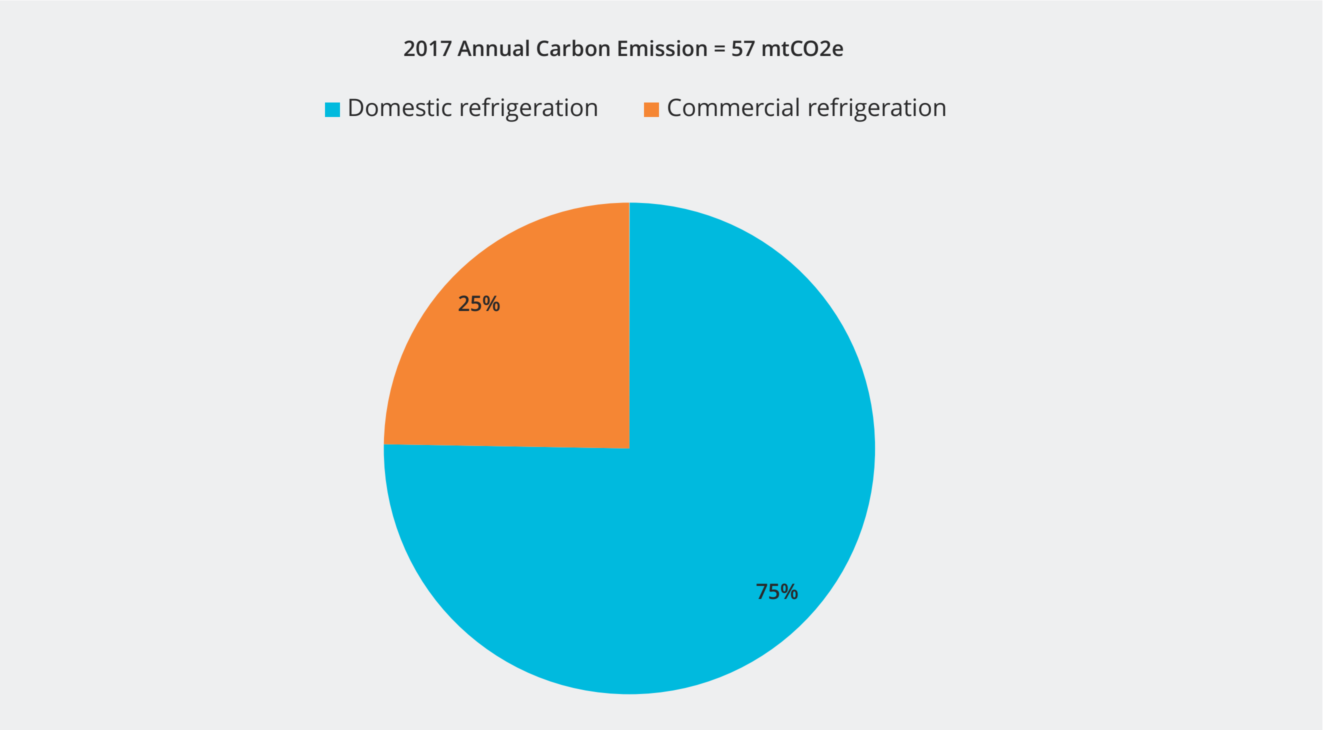


Figure 4.3 Refrigeration– A Comparison of the Annual Energy Consumption in 2017, 2027 (BAU) and 2027 (Improved) Scenarios

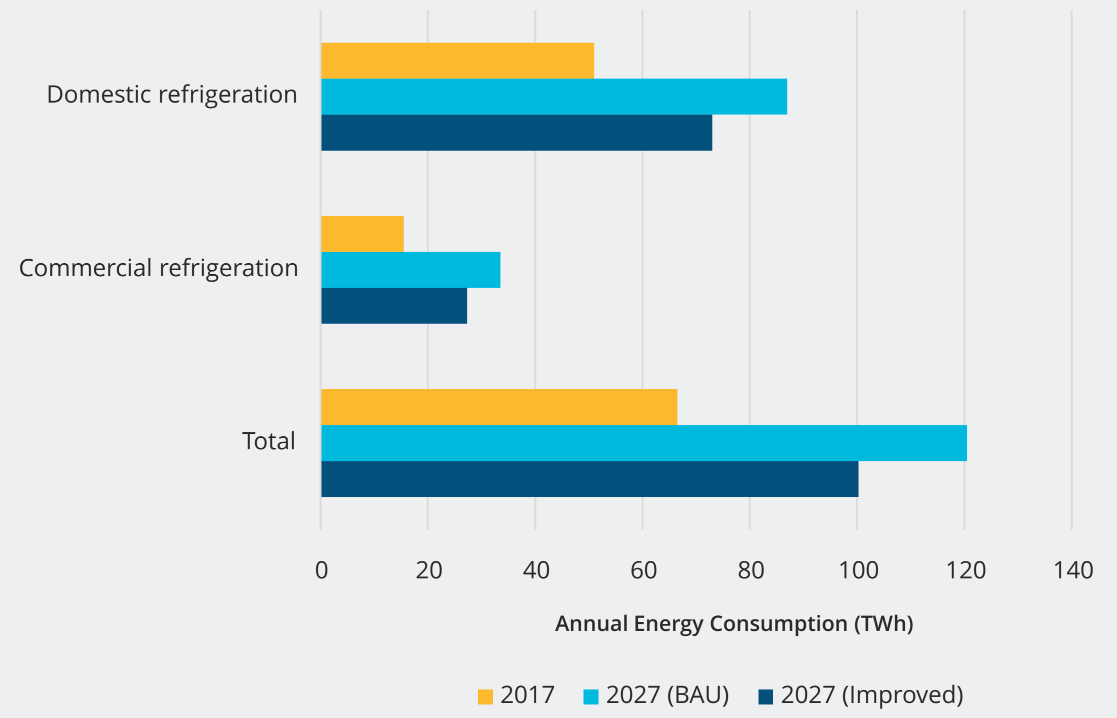
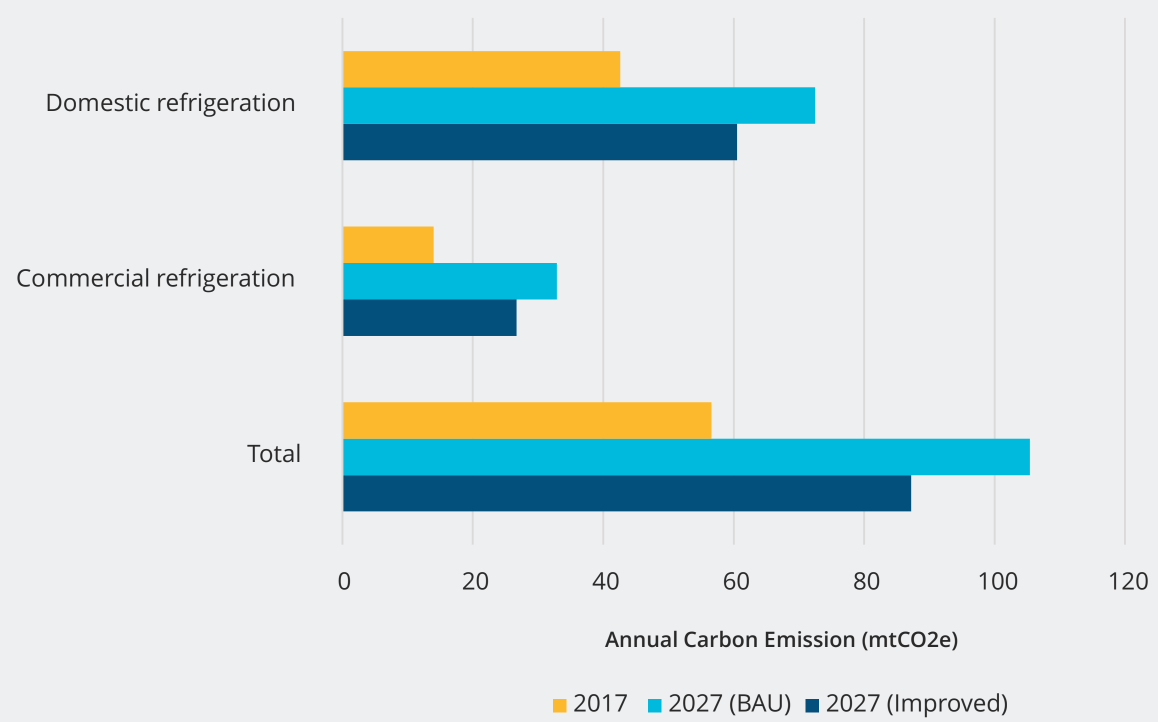


Figure 4.4 Refrigeration– A Comparison of the Annual Carbon Emission in 2017, 2027 (BAU) and 2027 (Improved) Scenarios



4.3 Sectoral Deep Dive

4.3.1 Domestic-type refrigerators

4.3.1.1 Overview of the Analysis

The sales and stock data were estimated using a combination of information published by BEE and sales information gathered from published sources(CEEW 2015). This stock is categorised by technology, that is, direct cool (DC) and frost-free refrigerators (FF), and by BEE star-rating which has been mandatory for FF refrigerators since 2009 and for DC refrigerators since 2016.

Typical unit annual energy consumptions sourced from BEE were used to estimate the annual energy consumption of domestic-type refrigerators and their indirect carbon footprint. Table 4.2 summarises the key inputs and assumptions used in this analysis.

Table 4.2 Domestic-type refrigerators – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million)	100	168	
	Arrived at using BEE domestic refrigerators production data	Based on the historical trends in growth rate, the domestic refrigerator sales are expected to continue at a steady growth rate of 5-6% over the next 10 years. The life of domestic refrigerators is assumed to be 10 years.	
Unit annual energy consumption (kWh)	400-600	400-600	400-600
	Weighted average of different star ratings adapted from BEE Search and Compare, BEE (2010) and CEEW(2015); BEE published data reveals the following consumer choice patterns: DC:FF = 80:20, 3* refrigerators are most preferred		In the improved scenario the increase in equipment efficiency is considered in line with the BEE startlabel up-gradation over the past years for frost free and direct cool refrigerator. This efficiency improvement can be achieved by ratcheting up the efficiency level by 1 star every 2-3 years till 2027.
Refrigerant mix installed	70% R134A, 30% R600A	50% R134A, 50% R600A	70% R600A, 30% R134A
	Per expert inputs		
Charge rate (kg/kW)	0.15		
	Per CEEW (2015)		
Annual operational refrigerant leakage	1%		
	Per CEEW (2015)		
Recovery at end-of-life	0%		
	Per CEEW (2015)		

4.3.1.2 Results and Discussion

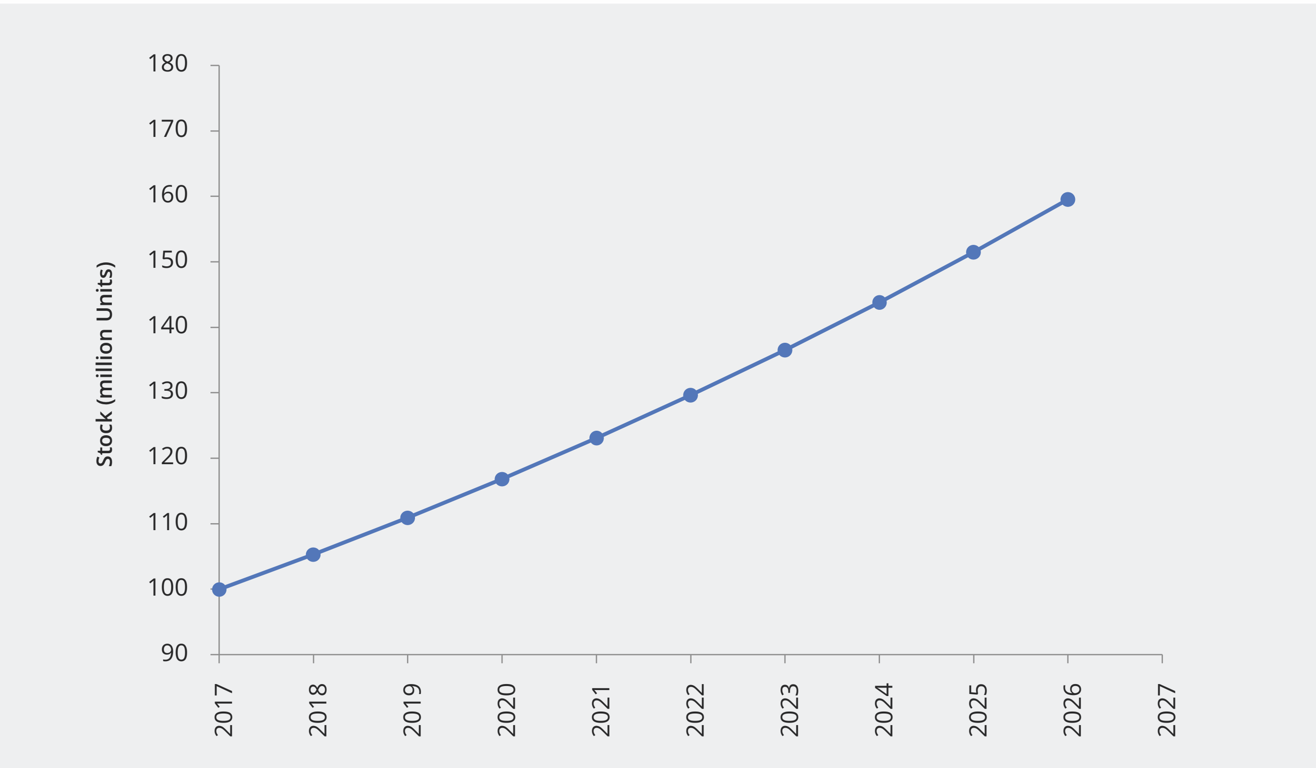
The key results have been tabulated in Table 4.3.

Table 4.3 Domestic-type refrigerators – Key Results

	2017	2027 (BAU)	2027 (Improved)	Savings Potential in 2027
Annual energy consumption (TWh)	51.0	87.0	73.0	16%
Indirect emissions (mtCO_2e)	41.8	71.3	59.8	
Direct emissions (mtCO_2e)	0.8	1.2	0.7	
Total emissions (mtCO_2e)	42.6	72.5	60.5	17%

- The energy impact of operating obsolete refrigerators is often underestimated or overlooked. Replacing inefficient refrigerators will be an important factor in optimizing the energy consumption of the overall refrigerator stock.
- Energy and Carbon savings will be primarily through energy efficiency improvements and then by switching over to R600A. It is also noteworthy that 50% of all new refrigerators worldwide are already running on R600A; with the right policy support from the government it is very possible to bring about a more aggressive shift towards R600A which has a low GWP of only 3.
- Energy saving of up to 16% is possible between BAU and improved scenarios, primarily owing to equipment efficiency improvement, increased consumer awareness and uptake of efficient (star-rated) appliances, and replacement of existing inefficient appliances.

Figure 4.5 Domestic-type refrigerators – Stock Projection



4.3.2 Commercial Refrigeration

4.3.2.1 Overview of the Analysis

The commercial refrigeration sector forms a significant part of the food and beverage retail market. There has been a remarkable growth in products offered in this sector suiting the precise cooling requirements. It primarily consists of deep freezers (glass top or hard top), visi-coolers, remote condensing units, water coolers, super markets and hyper markets systems. Remote condenser units could either be display type employed by large retails shops or non-display for storage of additional refrigerated goods. Non-display units have racks of condensing units placed in a small machinery room away from the display area. Centralised systems (where compressor racks are installed in a machine room and involve lengthy piping) used in supermarkets and hypermarkets are not very prevalent in India now but are likely to grow in the future.

Data was gathered from various published reports,,, interactions with industry experts and manufacturers to estimate the sales and stock data for all commercial refrigeration systems. Per RAMA, the market size of deep freezers, visi-coolers, remote condensing units and waters coolers in 2017-18 is estimated to be around 0.6 million units, 0.3 million units, 0.04 million units and 0.2 million units respectively. Visi-cooler segment is likely to decline in the next decade due to the declining sales trends in the soft drink market. The refrigerant base compositions, operational leakages and running hours for all these units were corroborated from HPMP and consultations with various stakeholders, domain and field experts.

Table 4.4 Commercial Refrigeration - Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million TR)	Deep Freezer –3.4 Visi-cooler –3.2 Remote condensing unit - 0.2 Water cooler - 1.5 Supermarket system - 0.05 Hypermarket system - 0.01 Total – 8.3	Deep Freezer –11.1 Visi-cooler –2.4 Remote condensing unit - 0.6 Water cooler - 2.5 Supermarket system – 0.22 Hypermarket system – 0.03 Total – 16.8	
	Assimilated using sales data acquired from published research by CEEW and cBalance	The main factors for growth in this commercial refrigeration sector will be commercial space growth, cold chain, GDP growth and technological changes in the future. The CAGR for these equipment was estimated using inputs from RAMA – Deep Freezer: 12% to 15% Visi-cooler: -2% to -8% Remote condensing unit: 10% to 15% Water cooler: 5% Supermarket and hypermarket system: 15%	
Unit Tonnage (kW)	Deep Freezer - <1 kW Visi-cooler - <1 kW Remote condensing unit - 1 to 20 kW Water cooler - <2 kW Supermarket system - 60 to 100 kW Hypermarket system - 100 to 200 kW		
	Collated from CEEW, C-Balance and domain expert interaction		

<table>
<tr><th></th><th>2017</th><th>2027 (BAU)</th><th>2027 (Improved)</th></tr>
<tr><td rowspan="2">System Efficiency (kW/TR)</td><td colspan="2">Deep freezers, Visi-coolers, Remote condensing units and water coolers - 0.8 to 0.9

Supermarket and Hypermarket systems - 1.0 to 1.2</td><td>Deep freezers, Visi-coolers, Remote condensing units and water coolers:
0.65 to 0.7
Supermarket and Hypermarket systems – 0.8 to 0.9</td></tr>
<tr><td colspan="2">Manufacturer consultation and domain expert interaction.</td><td>15 to 20% efficiency improvement in 2027 over the 2017 baseline is considered owing to –
BEE star rating for commercial refrigeration equipment's, advanced compressor technology, efficient evaporator and condenser fan motors, Retro-commissioning of existing commercial systems to plug the inefficiencies due to poor O&M practices in the future.</td></tr>
<tr><td rowspan="2">Annual run-time (hour)</td><td colspan="3">6000</td></tr>
<tr><td colspan="3">Determined through stakeholders and domain experts</td></tr>
<tr><td rowspan="2">Refrigerant mix installed</td><td>Deep freezer
65% R134A, 20% R404A, 5% R744, 10% R407A/R410A

Visi-cooler
70% R134A, 20%R404A, 10% R407A/R410A

Remote condensing unit 70% R134A, 20% R404A, 5% R744, 5% R407A/R410A

Water cooler
70% R134A, 20% R404A, 5% R744, 5% R407A/410A

Supermarket and hypermarket system
70% R404A, 30% R407A/R410A</td><td>Deep freezer
50% R134A, 10% R404A, 10% R744, 30% R407A/R410A

Visi-cooler
60% R134A, 5% R404A, 35% R407A/R410A

Remote condensing unit 60% R134A, 5% R404A, 10% R744, 25% R407A/R410A

Water cooler
60% R134A, 5% 404A, 10% R744, 25% R407A/R410A

Supermarket and Hypermarket system
50% R404A, 10% R744, 40% R407A/R410A</td><td>Deep freezer
50% R134A, 5% 404A, 15% R744, 30% R407A/R410A

Visi-cooler
60% R134A, 5% R404A, 10% R744, 25% R407A/R410A
Remote condensing unit 55% R134A, 5% 404A, 15% R744, 25% R407A/R410A

Water cooler
50% R134A, 5% 404A, 15% R744, 25% R407A/R410A

Supermarket and hyper market
30% R404A, 15% R744, 55% R407A/R410A</td></tr>
<tr><td>Determined through refrigerant preferences of key market players, refrigerants used in top selling models and expert interviews</td><td colspan="2">An aggressive HFC phase down with higher penetration of low GWP (high efficiency) refrigerants and inclination towards natural refrigerants like R744..</td></tr>
</table>

	2017	2027 (BAU)	2027 (Improved)
Charge rate (kg/unit)	Deep freezer - 0.3 Visi-cooler - 0.3 Remote condensing unit - 3 Water cooler - 0.6 Supermarket system - 200 Hypermarket system - 380		
	Determined through domain expert inputs, publications from CEEW and cBalance.		
Annual operational refrigerant leakage	5%		2%
	Determined through expert inputs from peer group of HVAC professionals.		Assuming lower operational leakages in the future stock due to technological advancements and improved O&M practices
Recovery at end-of-life	0%		
	Determined through interaction with field and domain experts		

4.3.2.2 Results and Discussion

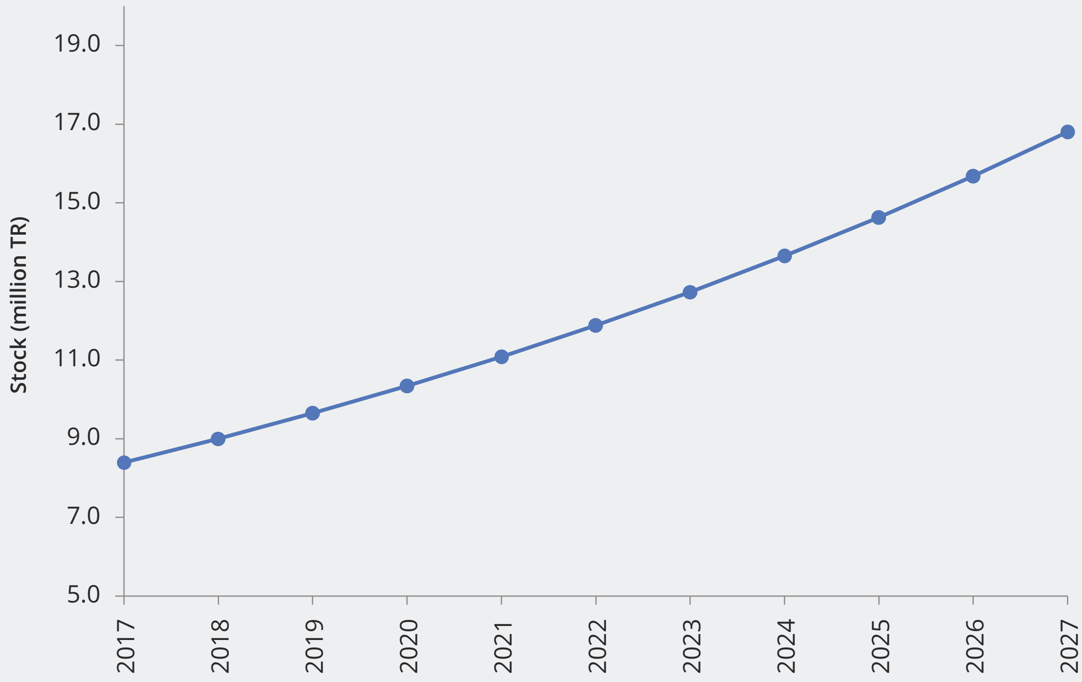
The key results have been tabulated in Table 4.5.

Table 4.5 Commercial Refrigeration – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Annual energy consumption (TWh)	15.5	33.5	27.3	19%
Indirect emissions (mtCO_2e)	12.7	27.4	22.3	
Direct emissions (mtCO_2e)	1.3	5.5	4.4	
Total emissions (mtCO_2e)	14.0	32.9	26.7	19%

- All the commercial refrigeration system apart from supermarket and hypermarket systems almost share proportion of total energy consumption at present, but in the next decade deep freezers will dominate the market with upto 50% of the total energy consumption.
- The direct emissions are minimal (<5%) across all the sectors except for super markets and hyper markets. Direct emissions in latter sectors are upto 50% due to high operational leakages upto 25%. Technological advancements in energy efficiency and arresting operational leakages would help mitigate significant carbon emissions. India foresees adoption of R744 (GWP-1) in these sectors which can minimise the direct emissions.
- Energy saving of up to 16% is possible by 2027 primarily due to efficiency improvement and the proposed introduction of BEE star rating for commercial refrigeration. This amounts to around 6TWh of electricity saving.

Figure 4.6 Commercial refrigeration – Stock Projection



5. Cold Chain

5.1 Scope

- Cold-chain in India is broadly classified into cold storages, pack-houses, ripening chambers, and reefer vehicles.
- The present analysis on cold storages is undertaken considering conventional vapour compressor units alone as they have principal share over the vapour-absorption systems. Also, technologies like zero energy cooling chambers (ZECC), Solar based cold storages are not considered owing to their nascent phase.
- The study on reefer vehicles is limited to road reefer transport and does not include railway reefers and air/marine cargo and the present analysis is carried out considering diesel engine driven refrigerated vehicles without differentiating as s elf-drive and direct-drive vehicles.

5.2 Sectoral Results

The key results have been summarized in Table 5.1.

Table 5.1 Cold Chain – Key Results

	2017	2027 (BAU)	2027 (Improved)	Savings Potential in 2027
Annual energy consumption (mtoe)	0.45	1.56	1.4	10%
Total emissions (mtCO_2e)	4.1	9.7	8.6	11%

- Analysis showcases the dominance of cold storages over other cold-chain sub-sectors in terms of energy consumption and Ammonia (R-717) is the heavily adopted refrigerant in this sector.
- Although, Ammonia is a natural refrigerant and is heavily employed in majority of large cold storages. It is classified as B2L indicating toxicity evidence. Hence emphasis on promoting and mandating PPE (Personal Protective Equipment) is necessary.
- Reefer vehicles incur refrigerant operational leakage rates up to 10%, hence emphasis on reducing these leakage rates is imperative to realise significant reduction in carbon emissions.
- Solar cooling of reefer vehicles along with Eutectics/PCM (phase change materials), Magnetic refrigeration system (MRS) are promising technological advancements.
- HCFC still continues as a dominant refrigerant in pack-houses and ripening-chambers and there is scope for transition to Low GWP HFC or natural refrigerants.
- Promotion of low-energy and sustainable cooling technologies like Geothermal cooling, Solar cooling, MRS can help mitigate substantial carbon emissions.

Figure 5.1 Cold-chain – 2017 Annual Energy Consumption

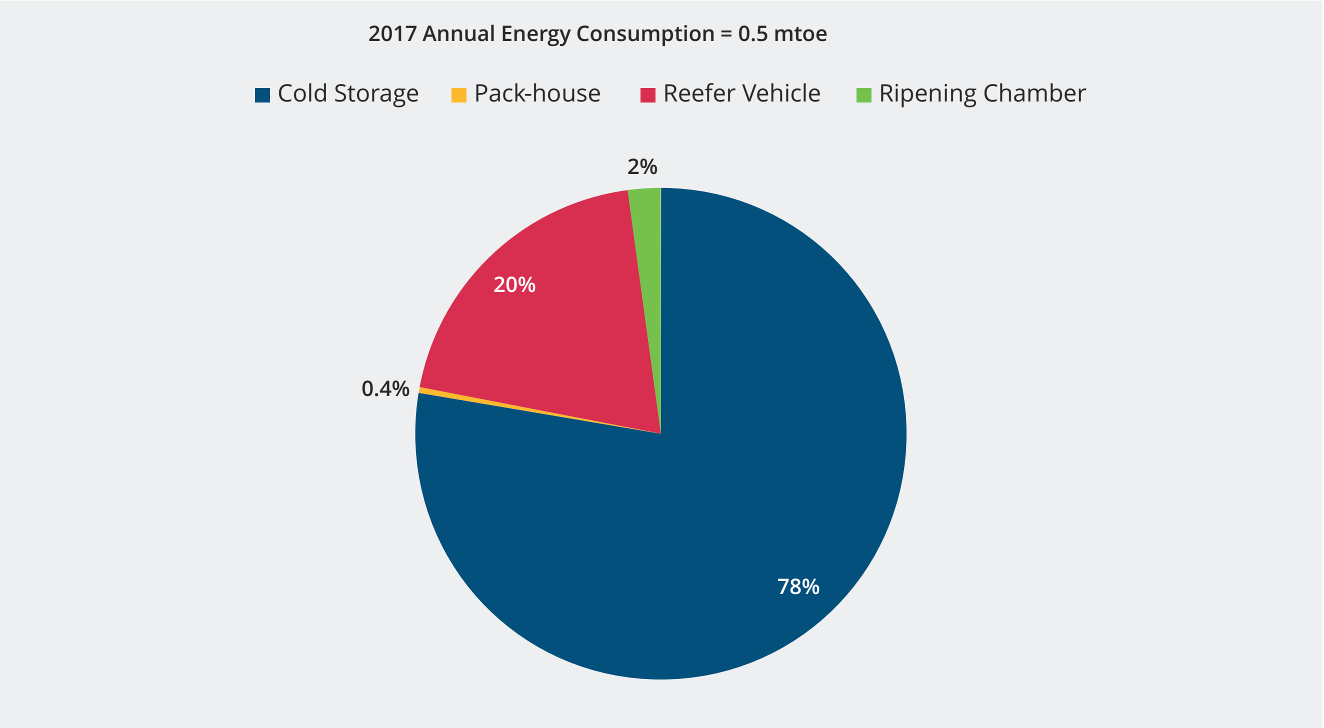


Figure 5.2 Cold-chain – 2017 Annual Carbon Emission

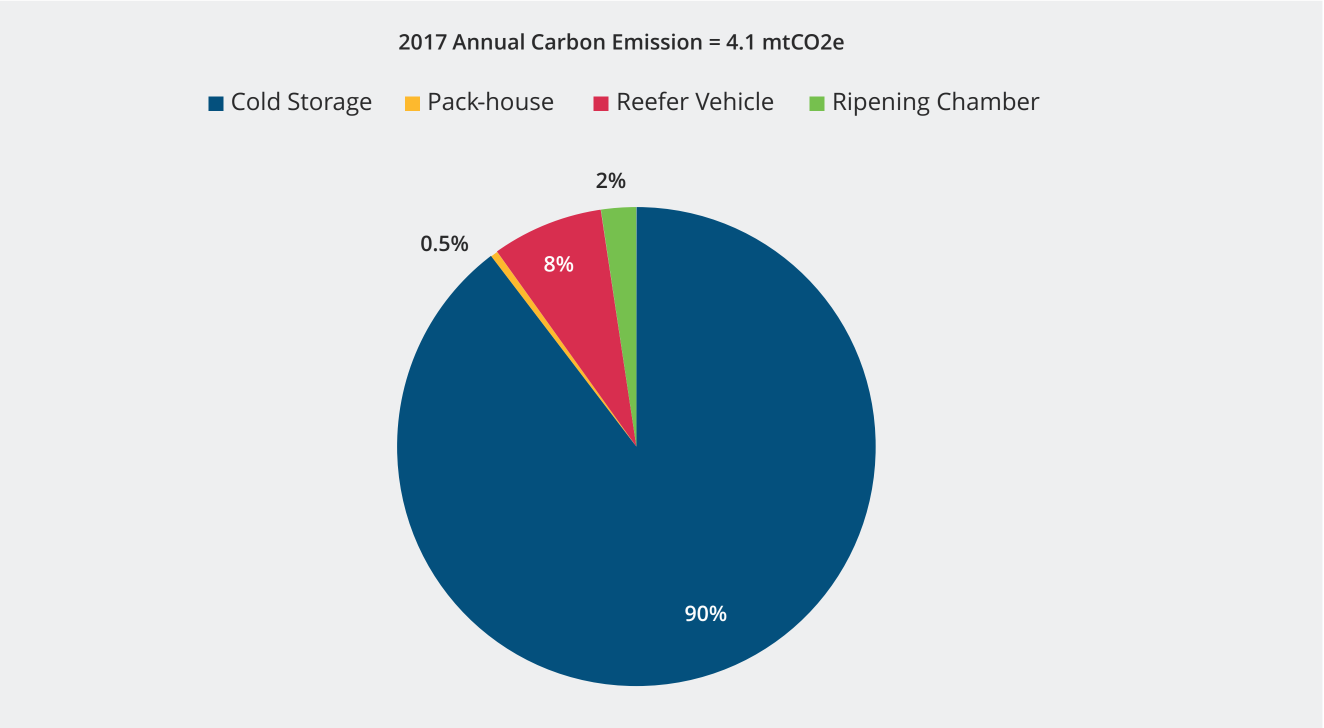


Figure 5.3 -chain – A Comparison of the Annual Energy Consumption in 2017, 2027 (BAU) and 2027 (Improved) Scenarios

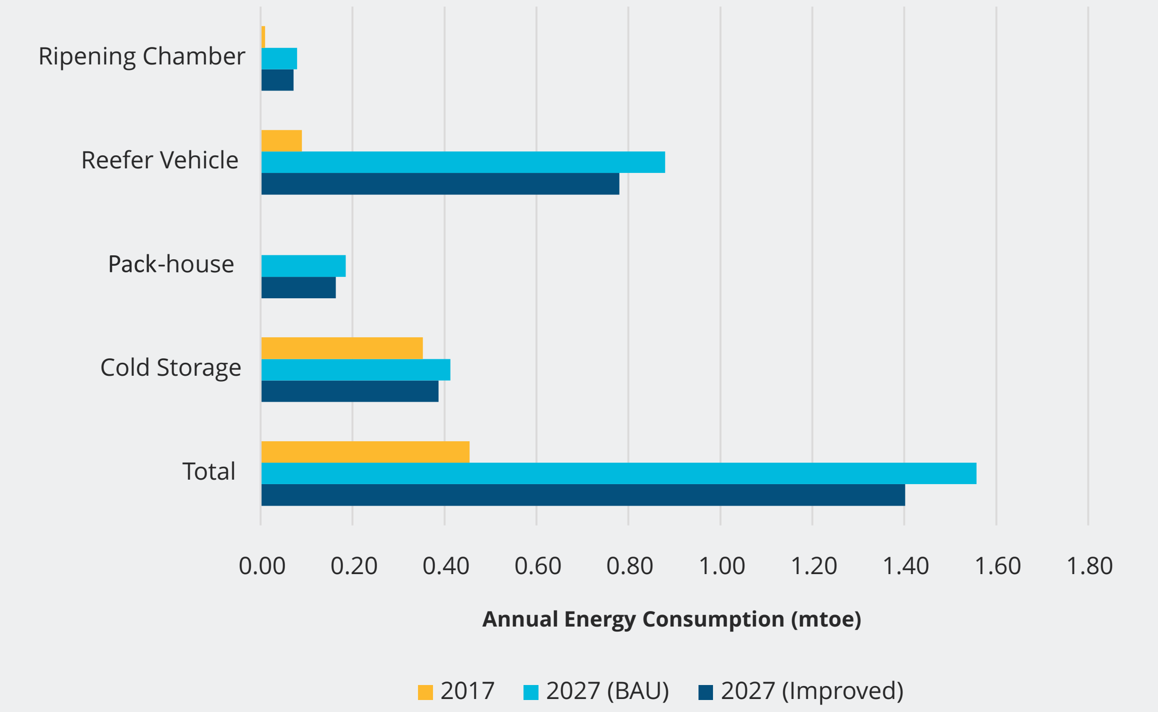
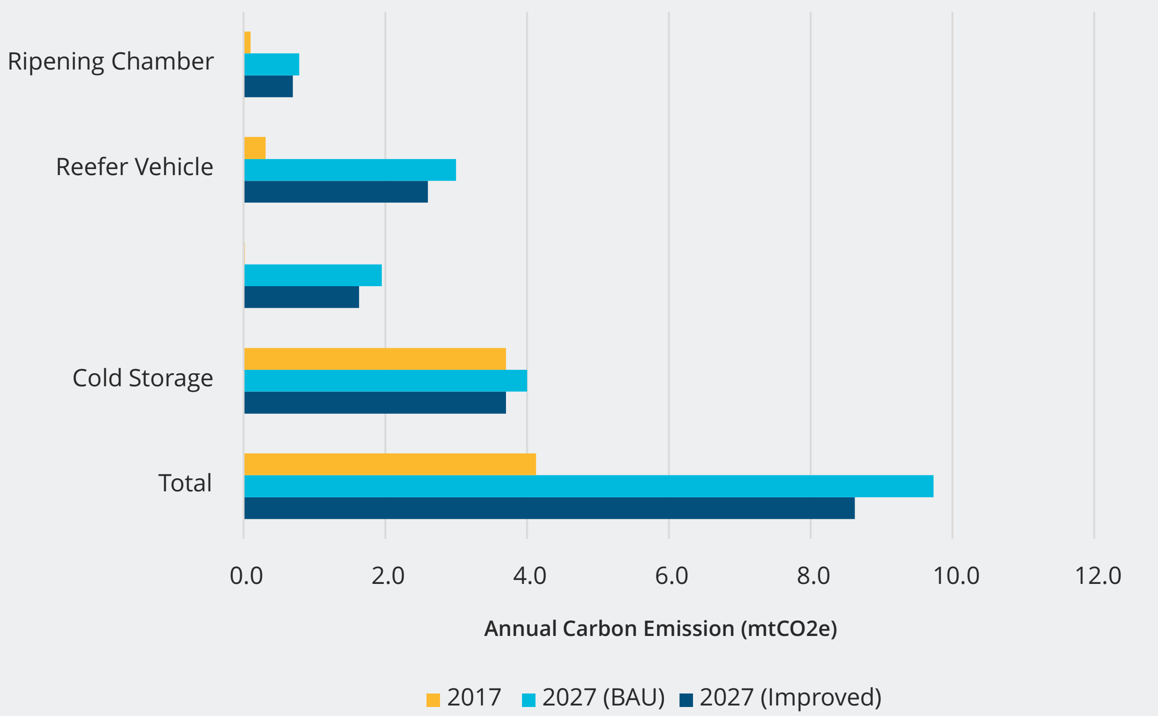


Figure 5.4 Cold-chain– A Comparison of the Annual Carbon Emission in 2017, 2027 (BAU) and 2027 (Improved) Scenarios



5.3 Sectoral Deep Dive

5.3.1 Cold Storage

5.3.1.1 Overview of the Analysis

A typical cold storage facility comprises a highly insulated static refrigerated chamber designed to store perishable products to essentially increase their longevity. Based on the duration of the produce storage they are broadly classified in to Bulk and Hub.

Cold storage (Bulk) is an environment-controlled warehousing space with multiple chambers intended for bulk storage of perishable produce and is seen as an independent refrigerated warehouse, and not part of an integrated cold-chain described earlier. The space is designed for long duration storage of a specific produce so as to build an inventory buffer which will serve to smoothen the episodic production by stabilising & sustaining the supply lines. These are normally constructed in areas close to producing areas (farm-gate) to facilitate quick access to farmers, for a selective set of crops only.

Cold storage (Hub), is an environment-controlled warehousing space functioning as a distribution hub and very much an integral part of the cold-chain. It is designed for short-term handling of produce so as to serve as a distribution logistics platform for marketable packaged produce and ready to retail produce. Cold storage (Hubs) are key to effective distribution of perishable produce and are essential for maintaining the integrity of the cold-chain. These are normally constructed close to consumption centres, built at the front-end linked to source points with refrigerated transport.

The existing stock number of cold storages was collated from various sources- DMI (Directorate of Marketing and Inspection), MoFPI (Ministry of Food Processing Industries), NHM (National Horticulture Mission) NHB (National Horticulture Board) and NCCD (National Centre for Cold-chain Development). Per NCCD, a bulk cold storage unit of volumetric size is, on an average, equal to 5000 MT holding capacity. The holding capacity in tonnes is effectively a measure of space, and the system standards by NCCD describe the unit conversion: 1 MT of space is taken as equivalent to 3.4 m3 of volumetric capacity for all products uniformly. Majority of the bulk cold storages in India are set up to store potatoes and chillies. The historical trends in the past 3 years indicate that around 1 million MT of cold-chain capacity is created every year. A trend has recently been observed where a significant slowdown has been observed in the recent past and it is likely that cold storage capacities may be significantly lower if the recent trends continue in the future. Further, incentives to modernise the existing cold storages result in annual retrofitting of 5% to 10% of existing cold storages. The annual run hour time was obtained from DFI Volume-III which helped in computing the indirect emissions. The energy efficiency of the equipment, refrigerant charge rate was corroborated from various field experts. Interactions with various stakeholders and domain experts along with market intelligence reports helped predict the current refrigerant break-up and its possible trends in the next decade. Majority of these trends developed in milieu of rapid HCFC phase out management plan (HPMP). The operational leakage and end of life emissions were obtained from various field experts and stakeholders that informed the direct emissions. The key inputs and assumptions are summarised in Table 5.2.

Table 5.2 Cold storage – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (Million MT)	35	45	45
	Collated from NHM, NHB, MoFPI, NCCD;	The 2027 stock is estimated by assessing the historical growth trends; 5% of the existing is retrofitted	The stock would be in tandem with BAU except for improved technology
Average storage capacity (MT)	5000	5000	
	Per NCCD		
Cooling capacity (kW)	273		
	The cooling capacity of a cold storage varies between 228 to 402 kW. Further, it is observed that the mean cooling capacity of urban cold storages is high, as most of these cold storages fall under hub category which have higher handling capacities.		

	2017	2027 (BAU)	2027 (Improved)
Efficiency (kW/TR)	1.5	1 to 1.5	
	Cold storages are broadly classified into diffuser type, bunker type and fin coil type. Fin coil systems are more energy efficient and have percolated into the Indian market. Per stakeholder interaction, it is estimated that all new cold storage installations are equipped with fin coil systems.	The overall operating efficiency of these systems is likely to improve owing to significant number of diffuser and bunker cooling systems which are being replaced with fin coil systems.	
Annual operating hours	5100		
	A typical cold storage unit runs for 16 to 18 hours per day on grid power. The annual operating hours of both hub and bulk cold storages have been derived considering their annual operating cycles and holding cycles2. Diesel powered generators are also used across the country for cold storage operations and the average consumption of diesel per cold storage is around 16,000 to 18,000 litres per year.		
Refrigerant mix installed	5% R- 134a 10% R-22 10% R-404a 75% R-717	5% R- 134a 10% R-404a 85% R-717	5% R- 134a 5% R-404a 90% R-717
	Contemplated through refrigerant preferences of key market players, refrigerants used in top selling models and domain expert interviews	R-717 would be a potential market driver as its profitable for large-scale applications and has zero GWP.	An aggressive HCFC phase out schedule and inclination towards increased adoption of R-717
Charge rate (kg/kW)	2.5		
	Majority of the cold storages deploy ammonia as refrigerant which has a relatively high charge rate.[41]		
Annual operational refrigerant leakage	2% to 5%		
	Determined through domain expert inputs and stakeholder interaction.		
Recovery at recharging and end-of-life	0%		
	Determined through domain expert inputs and stakeholder interaction.		

5.3.1.2 Results and Discussion

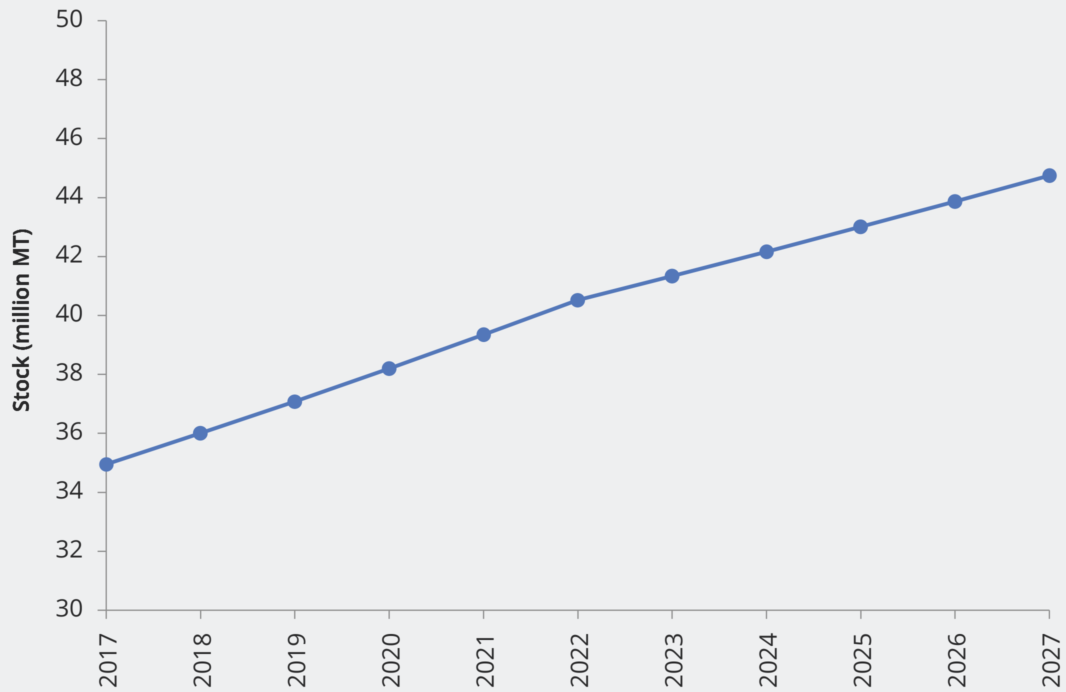
The key results have been tabulated in Table 5.3.

Table 5.3 Cold storage – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Stock (million MT)	35	45		
Annual energy consumption (TWh)	4.1	4.8	4.5	6%
Indirect emissions (mtCO_2e)	3.4	3.9	3.7	
Direct emissions (mtCO_2e)	0.3	0.12	0.04	
Total emissions (mtCO_2e)	3.7	4	3.7	8%

- The results highlight the dominance of indirect emissions over the direct emissions. This is primarily due to heavy adoption of R-717 (zero GWP) refrigerant in the prevailing stock (>70%). Although R-717 (ammonia) is toxic the trend still subsists as there is very limited human exposure in cold storages. Research explorations have captivated Geothermal cooling, Solar cooling, Liquified Natural gas cooling, Magnetic Refrigeration System as promising future technologies
- It is inferred that most of the carbon savings in 2027 could be realized purely due to technological advancements and improving energy efficiency of the equipment:
    - Improved insulation- Upgrading the insulation in peripheral and intermediary walls, roofs and floor of cold-chain facilities would ensure a superior thermal barrier resulting in energy loss reduction.
- Technological advancements- Use of variable frequency drives (VFD), compressor efficiency improvements, etc.
- Automation and PLC- A programmed logic controller consists of a pre-programmed software, physical refrigeration control and various sensors that help in optimizing the system operation.
- Retrofitting and re-commissioning: Retro-fitting of existing diffuser and bunker cooling systems with fin-coil or other efficient cooling systems.

Figure 5.5 Cold Storage – Stock Projection



5.3.2 Packhouse & Ripening chamber

5.3.2.1 Overview of the Analysis

A typical pack-house consists of various operations namely sorting, grading, washing, drying, weighing, packaging, pre-cooling and staging, among others. The role of refrigeration comes in during pre-cooling and staging processes. The entire set of activities is also known as preconditioning the produce for market connectivity.

A precooling unit is a specialized cooling system designed to rapidly remove field heat from freshly harvested produce and thereby prepares the cargo for subsequent travel in the cold-chain. A precooling unit can be in the form of forced-air cooling, hydro cooling, vacuum cooling, room cooling and icing.

A cold staging unit is an insulated and refrigerated chamber which serves as a transient staging space and is a necessary attachment to a Pre-Cooling Unit. Appended to pre-coolers, a staging cold room frees the pre-cooler space for the sequential batch of incoming freshly harvested produce.

The existing stock number of pack-houses was collated from various sources- NCCD, APEDA (Agricultural and Processed Food Products Export Development Authority) and NHB (National Horticulture Board). The typical storage capacity of each unit is drawn from NCCD. Under the Doubling Farmers Income (DFI) mission, there will be a push to build approx. 22000 pack-houses/GrAMs by 2023, and further its predicted that the pack-houses would, grow at a 10% CAGR in the subsequent years. which will include assembly & collection centres for post-harvest handling, short term storage and transportation. It is observed that R-22 still is a dominant refrigerant in this sector but future pack-houses is likely to deploy HFC based refrigerants. The charge rate was corroborated in from various field experts which helped in computing the Indirect emissions. Interactions with various stakeholders and domain experts along with market intelligence reports helped predict the current refrigerant break-up and its possible trends in the next decade. Majority of these trends developed in milieu of rapid HCFC phase out management plan (HPMP). The operational leakage and end of life emissions were obtained from various field experts and stakeholders. The key inputs and basis of assumptions are given in below Table 5.4.

Table 5.4 Pack-house – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Number of Pack-houses	500	52000	
	Collated from APEDA, NCCD, NHB;	Under the Doubling Farmers Income (DFI) mission, there will be a push to build approx. 22000 pack-houses by 2023, and further its predicted that the pack-houses would, grow at a 10% CAGR.	
Average storage capacity (MT) of Pack-house	30	30	
	Nominal average size as stated in NCCD; Inclusive of a throughput of 16 MT/day and two staging rooms of 15 MT each		
Efficiency (kW/TR)	Pre-cooler system - 2.2 to 2.5 cold room (staging) system - 1 to 1.5	2 to 2.3	
	Per interaction with Stakeholder and domain experts'	The efficiency values are inclusive of both pre-cooler and staging rooms, improvement has been considered with technological advancements in future	
Operating hours	2160		
	Derived by considering the annual operating cycles as mentioned in Volume III of DFI. NCCD states three batches a day throughput (16 MT/day) and a typical batch requires 6 operating hours that translates to 18 hrs/day		
Refrigerant mix installed	R-134a- 35% R-404a- 35% R-22 - 30%	R-134a- 70% R-404a- 25% R-22 - 5%	R-134a- 75% R-404a- 20% R-744 - 5%
	Contemplated through refrigerant preferences of key market players, and stakeholder, domain expert interviews.	R-134a would foresee a steep rise. R-22 persists as many of these units are established in rural areas.	An aggressive HCFC phase out schedule. and inclination towards adoption of natural refrigerants.
Refrigerant charge (kg)	35		
	Per NCCD, charge for a typical pack-house is around 35 kg of which pre-cooler unit constitutes 25 kg whilst staging cold room constitutes upto 10 kg.		
Annual operational refrigerant leakage	5%	2%	
	Determined through domain expert inputs and stakeholder interaction.		
Recovery at recharging and end-of-life	0%		
	Determined through domain expert inputs and stakeholder interaction.		

5.3.2.2 Results and Discussion

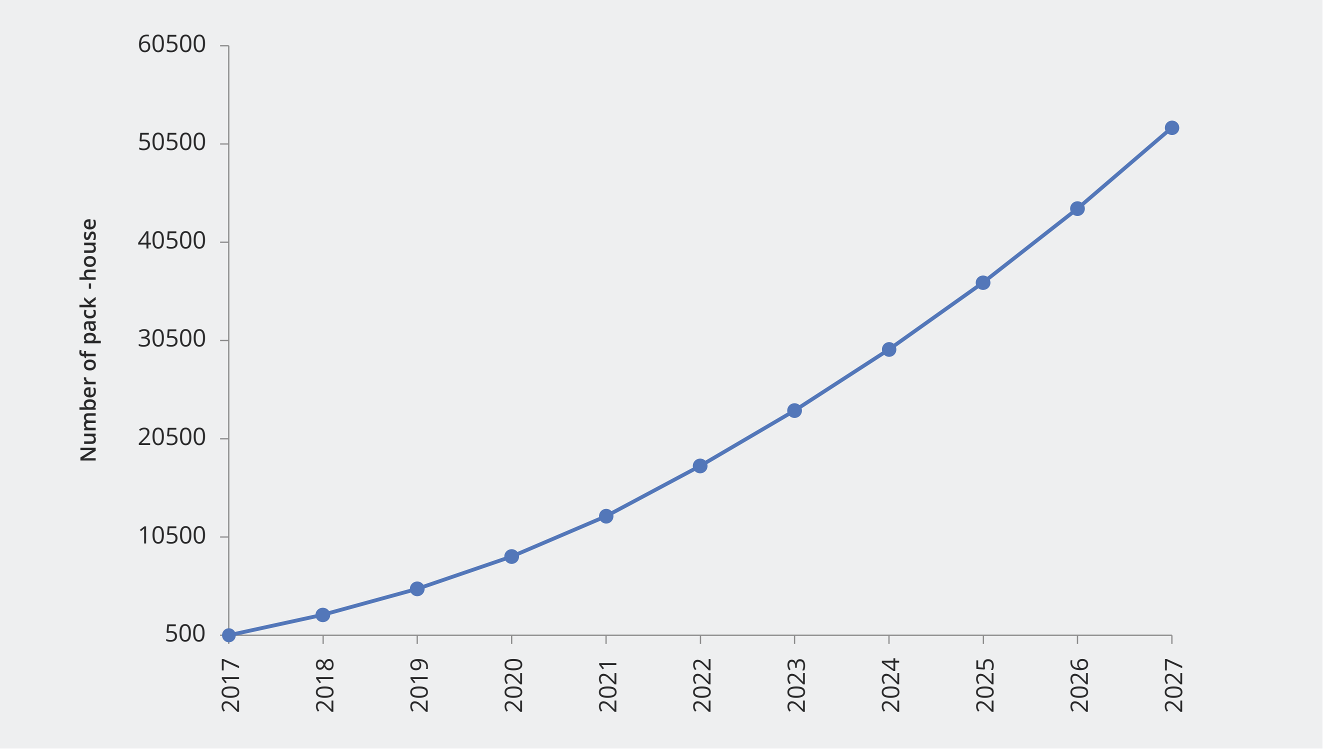
The key results have been tabulated in Table 5.5.

Table 5.5 Pack-house – Key Results

	2017	2027 (BAU)	2027 (Improved)	Saving Potential in 2027
Installed capacity (million TR)	500	52000	0.4	
Annual energy consumption (TWh)	0.002	2.15	1900	12%
Indirect emissions (mtCO_2e)	0.018	1.76	1.56	
Direct emissions (mtCO_2e	0.002	0.19	0.07	
Total emissions (mtCO_2e)	0.02	1.95	1.63	16%

- The rapid HPMP would result in substantial reductions in direct emissions due to limited R-22 share in the future scenario. R-744 (carbon dioxide) is a promising alternative refrigerant and is already in application in the cold-chain sector in other parts of the world. Its full-scale implementation and penetration should be explored after addressing concerns about high pressure piping and use at high ambient temperatures.

Figure 5.6 Number of pack-houses



5.3.3 Reefer Vehicles

5.3.3.1 Overview of the Analysis

NCCD defines reefer vehicles as road transport vehicles with a fixed insulated body equipped with active refrigeration designed for environment-controlled carriage of products. The existing number of road reefer transportation vehicles was obtained from various sources - NCCD, CEEW and domain expert interviews. It is estimated that 800 to 1000 road reefer transportation vehicles are added each year. The growth of reefer vehicles is in direct proportion with the growth of pack-houses.

NCCD provides the operating distance and speed of a regular reefer which helps predict the annual distance (km) plied by the reefers. There are many methods to derive the indirect emissions of refrigerated reefer trucks. Tassouet al (2009) in his study enumerated the refrigeration fuel consumption for various reefer vehicles. The operational leakage rates stated fall in the bandwidth suggested by IPCC (2005). Annual fuel consumption of the reefer vehicles was deduced considering the annual operating cycles to estimate the ID emissions. The refrigerant break-up, replacement factor rate, operational leakage and end of life emissions values were contemplated from various domain experts and stakeholders. The key inputs and basis of assumptions are given in below Table 5.6.

Table 5.6 Reefer Vehicles – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (Units)	13,500	140,000	
	Collated from NCCD, Manufacturer consultation, CEEW. It is estimated that the sales of these vehicles grow at a CAGR of 12%. Furthermore, the DFI mission would necessitate 2 reefer vehicles for every GrAM/pack-house that will be set up.		
Average storage capacity (MT)	10		
	Per Industry and domain experts, it is estimated that a typical reefer vehicle has a holding capacity of 10 MT and is equipped with a 3.6 to 5 kW refrigerating unit.		
Annual diesel consumption (million litres) for cooling	105	1050	950
	The annual distance plied by the reefer vehicles have been estimated per NCCD and stakeholder interaction considering 4 days of active transit in a week. The reefer vehicles traverse at an average speed of 30 km/hr for 15 hours in a day.		
Fuel Consumption (l/hr)	2.2 to 2.5		
	The fuel consumption to cater to the cooling requirements of the reefer vehicles is determined based on manufacturers' input.		a 10 to 15% reduction in fuel consumption is considered in the next 10 years.
Refrigerant charge/ unit (kg)	2.0		
	Per manufacturers' input, a reefer vehicle of 10MT holding size has a refrigerant charge of 1.8-2.1 kg. Hence the average is assumed.		
Operational leakage	10%	5%	3%
	IPCC (2005), Stakeholder consultation. 2.67 kg CO2 / litre is considered as diesel emission factor.	IPCC (2005), Manufacturer consultation; Few leading market players claim products with only 2.5% operational leakage as of 2017.	It is assumed that the technology diffuses amongst the peer market players which entails rapid penetration of minimum leakage reefer vehicles.

	2017	2027 (BAU)	2027 (Improved)
Refrigerant base	R-134a - 35% R-404a - 40% R-22 - 20% R-407/R410a - 5%	R-134a - 50% R-404a - 30% R-22 - 5% R-407/R410a - 15%	R-134a - 55% R-404a - 30% R-744 - 5% R-407/R410a - 10%
	Stakeholder consultation, HPMP and interviews with domain experts.	Established based on consultation with stakeholder and domain experts R-134a and R-404a are dominant due to their extensive usage in fresh and frozen products respectively. HPMP ensures steady decline of R-22 while there is a trend in adoption of natural refrigerants like R-744.	
Recovery at recharging and end-of-life	0%		
	Determined through domain expert inputs, stakeholder interaction and consultation with major market players.		

5.3.3.2 Results and Discussion

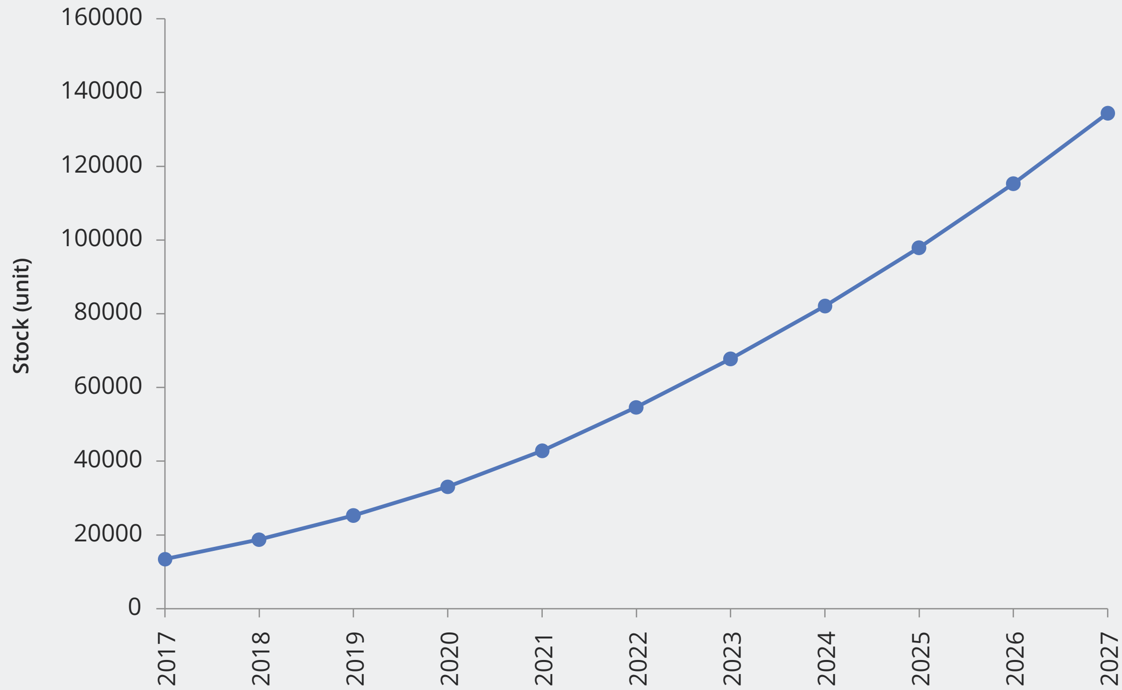
The key results have been tabulated in Table 5.7.

Table 5.7 Reefer Vehicles – Key Results

	2017	2027 (BAU)	2027 (Improved)	Savings Potential in 2027
Number of Reefer Vehicles	13,500	1,40,000		
Annual energy consumption (mtoe)	0.09	0.88	0.78	11%
Indirect emissions ($mtCO_2e$)	0.3	2.9	2.5	
Direct emissions ($mtCO_2e$)	0.01	0.11	0.07	
Total emissions ($mtCO_2e$)	0.31	3	2.6	13%

- It is observed that direct emissions have a significant share in the total emissions in reefer vehicles unlike the stationary refrigeration systems. This is due to exposure of reefer vehicles to harsh environments and operating conditions resulting in higher operational leakages. Improved technological advancements in terms of mileage and minimal operational leakages are the key reasons that attribute to significant energy savings in the improved scenario.
- Alternate reefer cooling technologies viz absorption, adsorption and thermo-electric are not adopted in reefer vehicles owing to very low COPs. However, recent studies indicate solar energy driven systems as a promising alternative technology.
- Few technologies like Stirling cycle powered systems, magnetic refrigeration and eutectics are in their embryonic stage and would soon transform as a cutting-edge technology that could offset significant carbon emissions.

Figure 5.7 Reefer vehicles – Stock Projection



5.3.4 Ripening Chamber

5.3.4.1 Overview of the Analysis

Ripening chamber consists of a series of chambers and is a front-end facility in the cold-chain, designed to function for controlled and hygienic ripening of certain fresh produce. In India, these are used extensively for ripening bananas and climacteric fruits like mangoes and papayas on commercial scale. The chambers may also be used for avocadoes, tomatoes, pears, and for de-greening purposes with some citrus fruit.

Table 5.8 Ripening chamber – Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Number of ripening chambers	1000	9500	
	Collated from APEDA, NCCD, NHB;	The 2027 stock is accrued by employing a CAGR-35% - Market intelligence reports and several incentives from GoI expedite the growth.	
Average storage capacity (MT) of ripening chamber	40	40	
	Considering four chambers of 10MT as stated by NCCD		
Efficiency (kW/TR)	1.5 to 2	1.2 to 1.7	
	Stakeholder and domain expert interaction	Technological advancements are likely to improve the efficiency	

	2017	2027 (BAU)	2027 (Improved)
Operating hours	4500		
	The annual operating hours have been estimated considering the annual operating cycles and seasonal produce and demand for the facilities.		
Refrigerant mix installed	R-134a- 35% R-404a- 35% R-22 - 30%	R-134a- 35% R-404a- 35% R-22 - 30%	R-134a- 35% R-404a- 35% R-22 - 30%
	Contemplated through refrigerant preferences of key market players, and stakeholder, domain expert interviews.	R-134a would foresee a steep rise. R-22 persists as many of these units are established in rural areas.	An aggressive HCFC phase out schedule and inclination towards adoption of natural refrigerant.
Refrigerant charge per ripening chamber (kg)	24		
	Per NCCD, a typical ripening chamber consists of 4 chambers and charge for each chamber is around 6 kg.		
Annual operational refrigerant leakage	2 to 5%		
	Determined through domain expert inputs and stakeholder interaction.		
Recovery at recharging and end-of-life	0%		
	Determined through domain expert inputs and stakeholder interaction.		

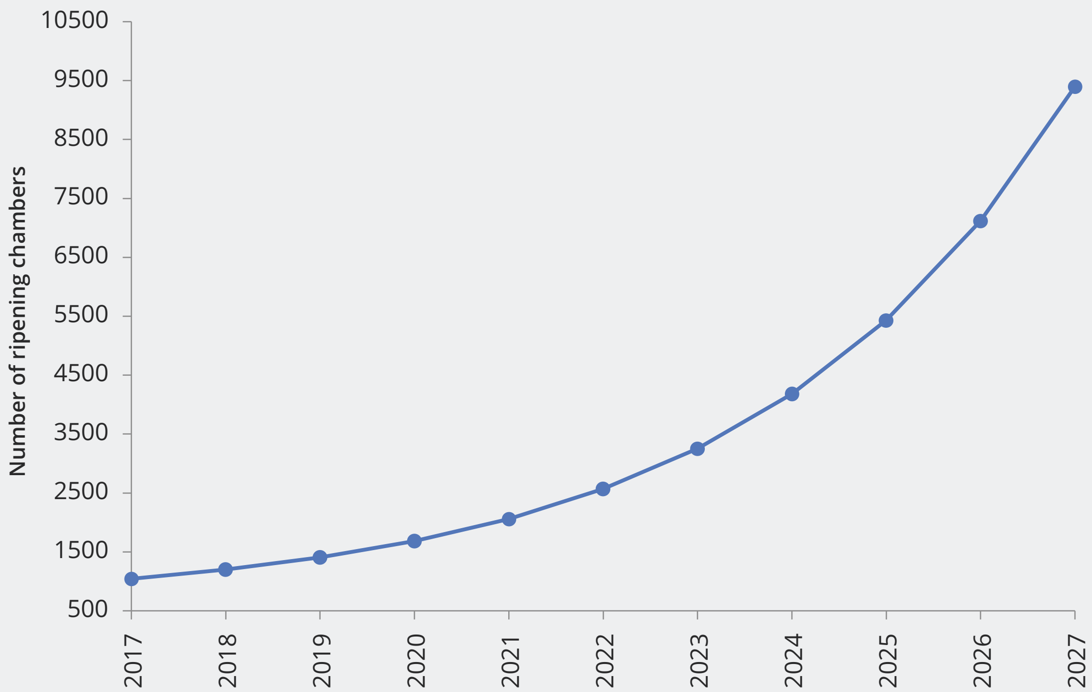
5.3.4.2 Results and Discussion

The key results have been tabulated in Table 5.7.

Table 5.9 Ripening chamber – Key Results

	2017	2027 (BAU)	2027 (Improved)	Savings Potential in 2027
Number of ripening units	1000	9500		
Annual energy consumption (TWh)	0.114	0.925	0.835	10%
Indirect emissions (mtCO2e)	0.095	0.76	0.685	
Direct emissions (mtCO2e)	0.003	0.025	0.01	
Total emissions (mtCO$_2$e)	0.098	0.785	0.695	11%

Figure 5.8 Number of ripening chambers



6. Industrial Process Cooling

6.1 Scope

The section includes chillers used for industrial air conditioning or process cooling for following applications- including, but not limited to, pharmaceutical and textile industries to maintain the desired humidity levels, ammonia-based milk chillers used in the dairy industry and process chillers used in chemical, plastic, brewery, beverages, food processing, detergent industries. The analysis also covers non-electric vapour absorption machines which are used in industries where waste heat is available.

6.2 Sectoral Results

The key results have been tabulated in Table 6.1.

Table 6.1 Industrial Process Cooling – Key Results

	2017	2027 (BAU)	2027 (Improved)	Savings Potential in 2027
Annual energy consumption (TWh)	15.7	57.6	48.2	16%
Total emissions (mtCO_2e)	13.2	47.6	39.6	17%

- This sector sees the most aggressive growth in cooling energy demand and carbon emission at nearly 3.5 times from 2017 baseline.
- Industrial sector requires both air conditioning and refrigeration for various processes and applications. The annual energy consumption of industrial process cooling alone (without cold storage) is more than that of chiller systems utilized for air-conditioning in commercial buildings in 2017. Although the installed base of commercial building chillers is more than that of the industrial process chillers but due to the all-weather operation of industrial process cooling its energy consumption is higher. Unlike commercial building chillers, industrial process chillers are designed to operate in harsh environmental conditions.
- The emissions from this sector are predominantly indirect emissions from energy use. Zero GWP alternatives like Ammonia and VAM are already in use in the industrial sector. Ammonia systems does not contribute to any ozone depletion or global warming impact and cost 10-20% less to install than systems using alternative industrial refrigerants, but their application especially for bigger installations has raised safety concerns due to the associated toxicity.
- Industrial sector studies pertaining to some industries indicate that leakages of refrigerant can reduce a system's efficiency by 40%.[46]

Figure 6.1 Industrial Process Cooling – 2017 Annual Energy Consumption

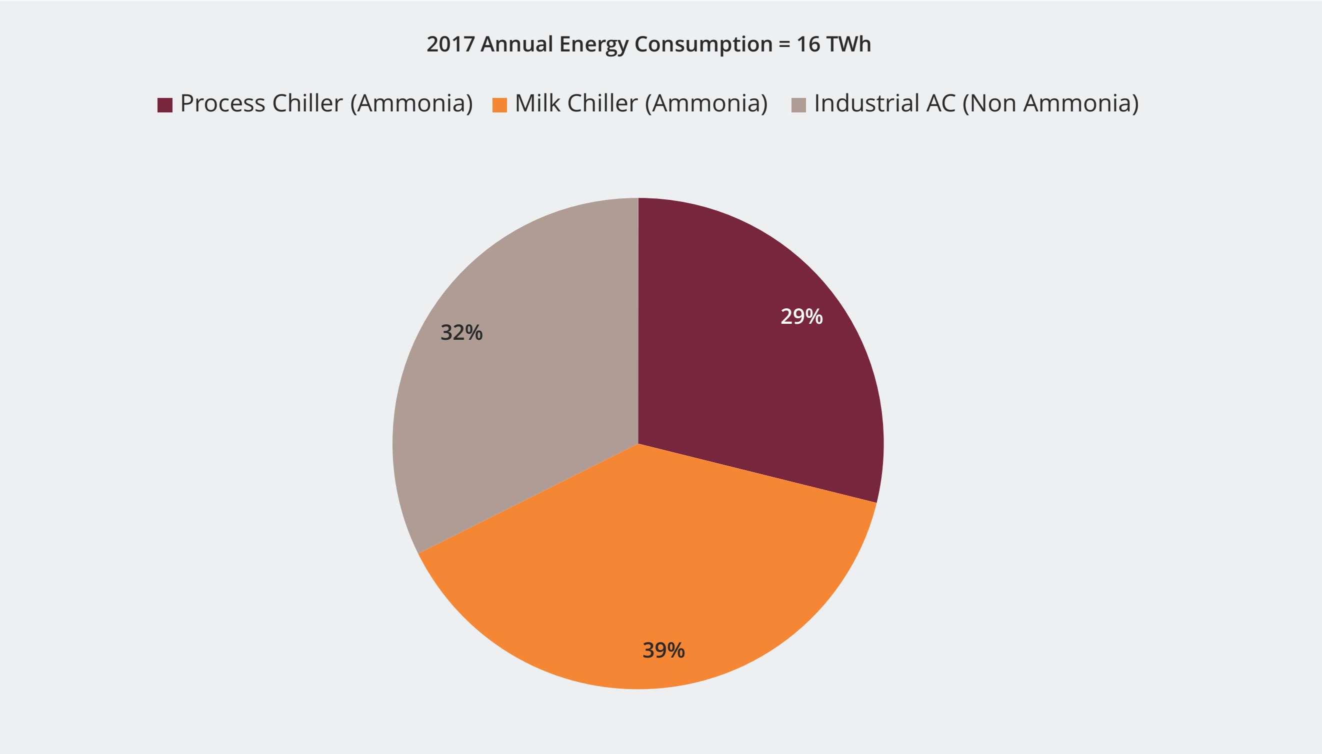


Figure 6.2 Industrial Process Cooling – 2017 Annual Carbon Emission

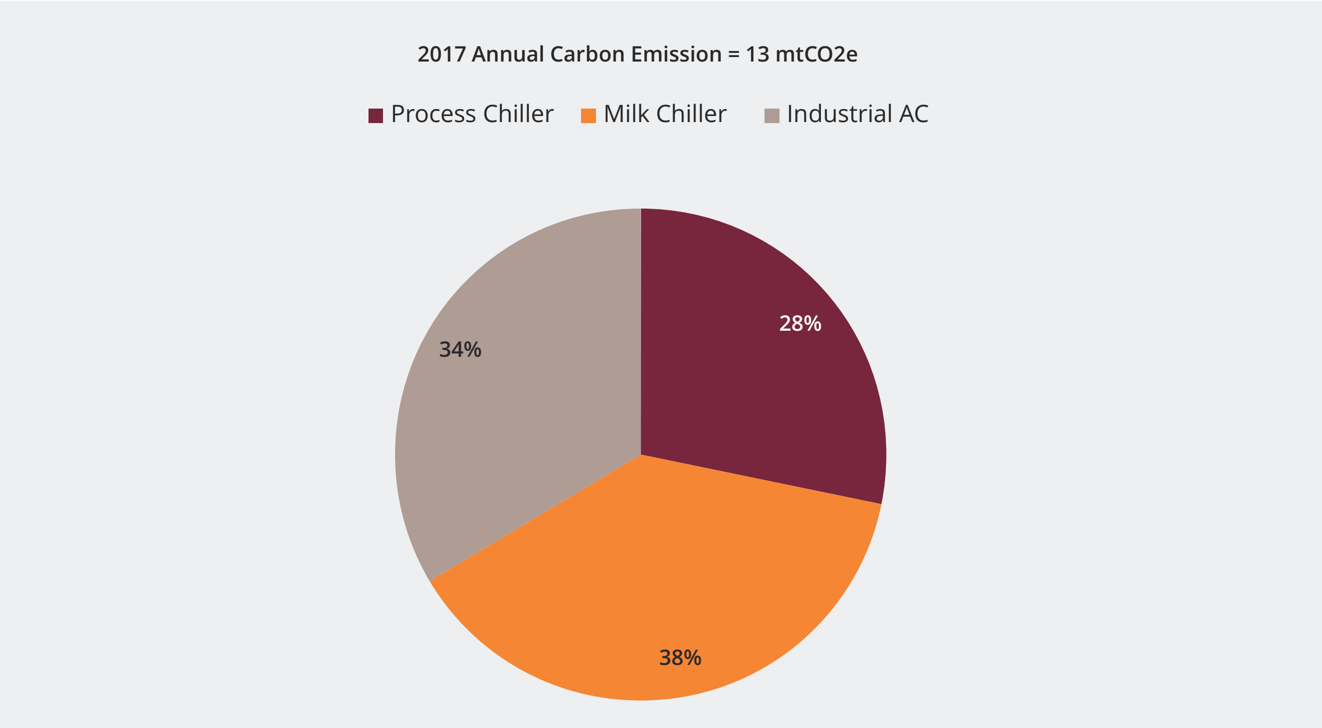


Figure 6.3 Industrial Process Cooling – A Comparison of the Annual Energy Consumption in 2017, 2027 (BAU) and 2027 (Improved) Scenarios

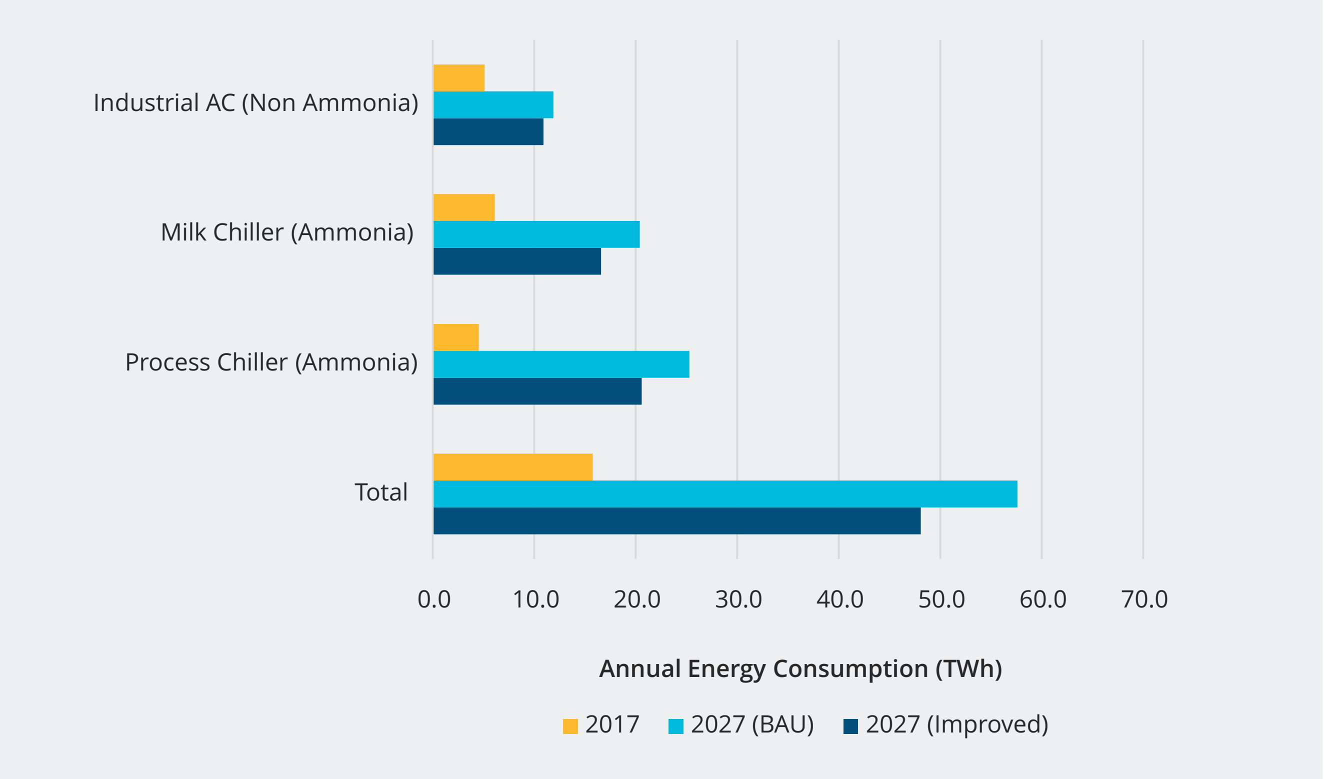
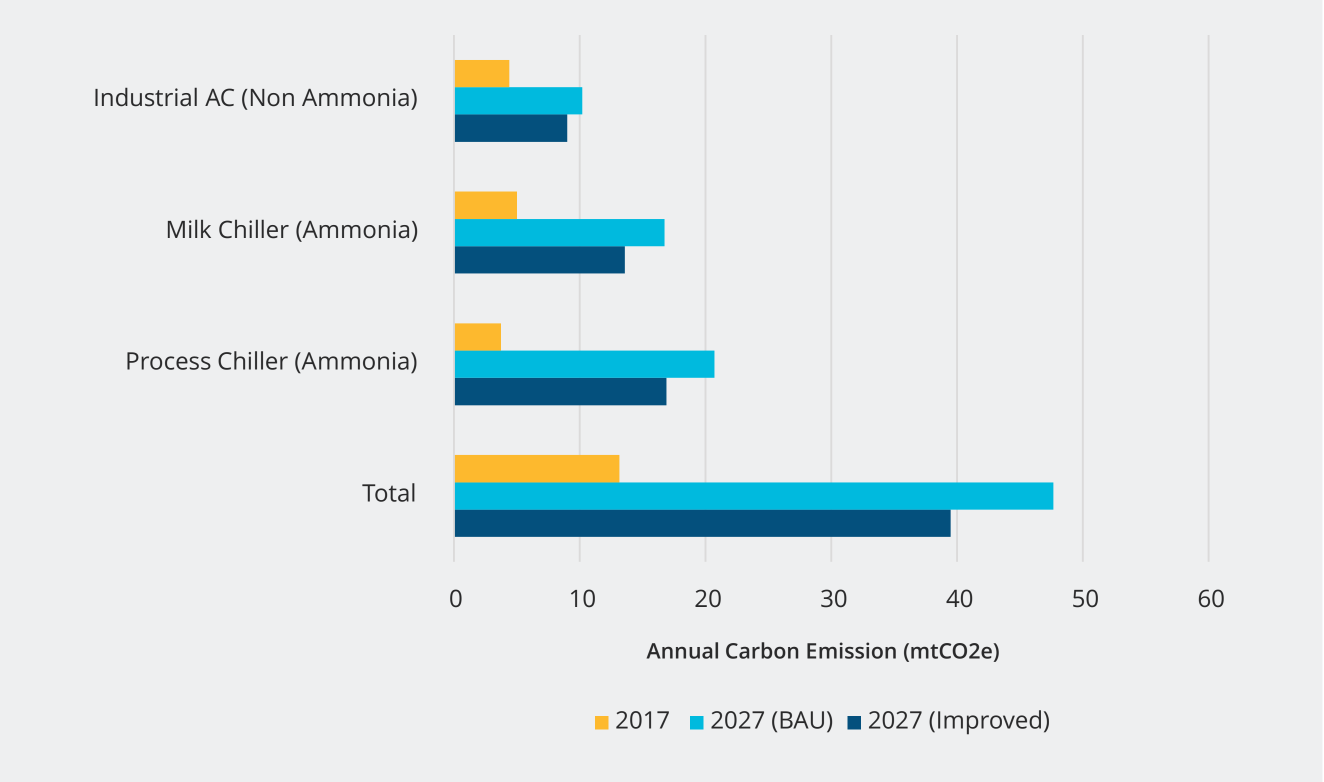


Figure 6.4 Industrial Process Cooling – A Comparison of the Annual Carbon Emission in 2017, 2027 (BAU) and 2027 (Improved) Scenarios



6.3 Sectoral Deep Dive

6.3.1 Overview of the Analysis

Data gathered from market intelligence report (BSRIA 2016), published research reports (cBalance 2016) and expert interviews with industry associations were used to estimate the present stock information. The installed base comprises of different type of chillers based on size, compressor type & drive, heat rejection method and refrigerants employed. Industrial chillers are broadly divided into two segments- 1) ammonia-based milk & process chillers and 2) non-ammonia chillers including absorption. Ammonia with zero ODP and GWP (compatible with reciprocating and screw compressors) is a widely preferred refrigerant in the sector, although its application requires caution due to the associated toxicity. The operating efficiency of the system and operating hours were determined through interaction with industry experts, which were then utilised to estimate the total energy consumption. The direct emissions for non-ammonia-based chillers were calculated by employing refrigerant charge and leakage rates during operation, servicing and end of life of the unit. The sector still accounted for 2% of the total HCFC consumption in 2015 (MoEFCC. (2017).

Table 6.2 Industrial Process cooling - Key Inputs and Assumptions

	2017	2027 (BAU)	2027 (Improved)
Stock (million TR)	Reciprocating: 0.1 Screw: 0.9 Scroll: 0.2 Centrifugal: 0.2 Ammonia: 1.2 VAM: 0.5 Total: 3.0	Reciprocating: 0.2 Screw: 1.9 Scroll: 0.4 Centrifugal: 1.0 Ammonia: 5.8 VAM: 1.0 Total: 10.4	
	Estimated using sales data obtained from BSRIA and cBalance report	Based on sales data up to 2020 from BSRIA and cBalance report and assuming the same growth rate till 2027, reciprocating and scroll chillers will have negligible sales by 2027	
Unit Tonnage (TR)	Reciprocating: 30 to 200 Screw: 60 to 570 Scroll: 16 to 60 Centrifugal: 100 to >710 Ammonia: 20 to 1000 VAM: 30 to >710		
	From BSRIA chiller report and interaction with industry associations		
System Efficiency (kW/TR)	Reciprocating: 1.7-1.8 Centrifugal: 0.9 to 1.05 Screw: 1.05 to 1.10 Scroll: 1.10 to 1.15 Ammonia: 1.5-1.7 VAM: 0.03-0.04	Reciprocating: 1.6-1.7 Centrifugal: 0.8 to 0.9 Screw: 0.90 to 0.95 Scroll: 0.95 to 1.00 Ammonia: 1.2-1.5 VAM: 0.03	Reciprocating: 1.5-1.7 Centrifugal: 0.65 to 0.70 Screw: 0.70 to 0.75 Scroll: 0.75 to 0.80 Ammonia: 1.2-1.5 VAM: 0.03
	Based on interaction with industry experts, the overall system efficiency during operation was considered	Efficiency improvement has been assumed owing primarily due to advancements in technology in next decade with advanced compressors, better O& M practices and regular servicing of the system	

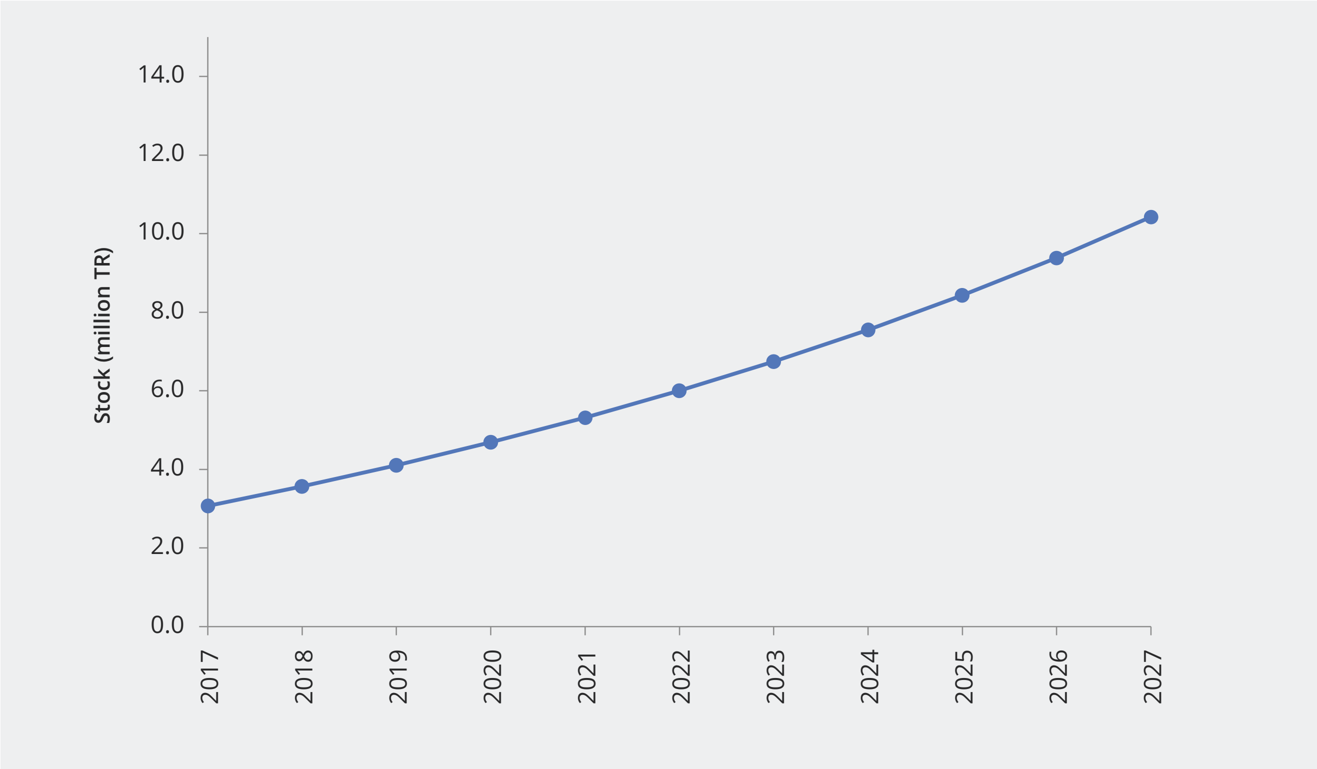
	2017	2027 (BAU)	2027 (Improved)
Annual run-time (hour)	8000 for milk chillers 4080 for industrial air conditioning and process chillers		
	Determined through industry expert inputs experts		
Refrigerant mix installed	Reciprocating: 100% R22 Screw: 100% R134A Scroll: 95% R410A, 5% R407C Centrifugal: 90% R134A, 10% R123 R717 in Milk and process chillers	Reciprocating: 100% R22 Screw: 70% R134A, 30% R513A Scroll: 100% R410A Centrifugal: 60% R134A, 10% R513A, 10% R514A, 20% R1233zd R717 in Milk and process chillers	Reciprocating: 100% R22 Screw: 60% R134A, 40% R513A Centrifugal: 45% R134A, 15% R513A, 15% R514A, 25% R1233zd R717 in Milk and process chillers
	Determined by refrigerant preferences of key market players, refrigerants used in top selling models and expert interviews	An aggressive HCFC phase out schedule and HFC phase down	An aggressive HFC phase down with higher penetration of low GWP refrigerants.
Charge rate (kg/kW)	0.28		
	Determined through expert inputs from peer group of industry professionals.		
Annual operational refrigerant leakage	2%		1%
	Determined through expert inputs from peer group of industry professionals.		Assuming lower operational leakages in the future stock due to better technology in improved O&M practices
Recovery at end-of-life	Full charge is recovered from 50% of the scrapped chillers		Full charge is recovered from 90% of the scrapped chillers
	Determined through industry expert inputs experts		Assuming better refrigerant management practices.

6.3.2 Results and Discussion

The key results have been tabulated in Section 6.1.

- For industrial air conditioning application, similar improvement opportunities can be adopted as mentioned in Chapter 2 (Chiller System), Section 2.3.2.2. The most important ones being:
  - Better O&M practices with the utilisation of Internet of Things (IoT) in day to day operations
  - Higher penetration of high efficiency chillers and other HVAC system auxiliaries like pumps and fans.
  - Retro-commissioning of existing HVAC systems to plug the inefficiencies due to poor O&M practices
- Retrofitting old and inefficient HVAC systems with new efficient & right-sized equipment
- Aggressive phase-down of HFCs with low GWP alternatives
- Improvements in chiller technology as well as O&M practices to further reduce operating and end of life refrigerant leakages.
- Integration of renewable sources of energy like Concentrated Solar Power with Absorption air conditioning.
- Greater system integration by use of heat pumps, heat recovery units and trigeneration.

Figure 6.5 Industrial Process Cooling – Stock Projection



7. Aggregated Results

7.1 Discussion of Results

The key aggregated results have been encapsulated in Tables 7.1 and &.2.

Table 7.1 Annual Energy Consumption (mtoe)

	2017	2027 (BAU)	2027 (Improved)	Saving Potential
Space Cooling in Buildings	33.8	75.6	62.5	17%
Mobile Air-Conditioning	3	5.5	4.4	20%
Refrigeration	17.8	32.5	26.9	17%
Cold Chain	1.2	3	2.7	10%
Industrial Process Cooling	4.1	15.3	12.8	16%
Total	59.8	131.9	109.3	17%

Table 7.2 Annual Carbon Emission (mtCO_2e)

	2017	2027 (BAU)	2027 (Improved)	Saving Potential
Space Cooling in Buildings	124	284	224	21%
Mobile Air-Conditioning	10.8	22.6	16.1	29%
Refrigeration	56.6	105.4	87.2	17%
Cold Chain	4.1	9.7	8.6	11%
Industrial Process Cooling	13.2	47.6	39.6	17%
Total	208.7	469.3	375.5	20%

- The aggregated nationwide cooling energy demand in terms of primary energy is expected to grow around 2.2 times in 2027 over the 2017 baseline, and the cooling demand in terms of tonnes of refrigeration is expected to grow around 3.1 times in 2027 over the 2017 baseline, under the business as usual scenario.
- The 2027 Improved Scenario suggests that, even with the known strategies and technologies (that is, not factoring in game-changers), there is potential to reduce the aggregated growth in energy demand by 17%, and the resulting emissions, by 20%. Energy savings of ~20 mtoe can been leveraged between 2027 (BAU) and 2027 (Improved) – of this over 90% (i.e. ~100 TWh) will be electricity savings. This translates to capacity avoidance of ~25 GW, or around 50 power plants of 500 MW capacity each. Emissions reduction of ~100 mtCO2e can been achieved between 2027 (BAU) and 2027 (Improved).
- Relative share of cooling energy demand for all sectors remains more or less the same in years 2017 and 2027. Building sector (Space Cooling) continues to dominate, with an approximately 57% share of the entire cooling energy demand, with Refrigeration as the next largest contributor at ~25% in 2027.
- Given the dominant share of the building sector, it is worth highlighting the significant presence of non-refrigerant based cooling from fans and air coolers – consuming more energy in 2027 than all the commercial systems (chillers, VRF and DX) combined. This makes a strong case for realigning focus to include a greater emphasis on energy

efficiency of fans and air coolers that will continue to be very pervasive, particularly in the residential sector in India.

- Improvements in operations, maintenance and servicing practices (including the refrigeration service sector) – an aspect that tends to get less attention in the discussions about cooling – will bring marked savings in the 2027 energy consumption and emissions, across multiple sectors.

Figure 7.1 2017 Installed Cooling Capacity (Sector-wise)

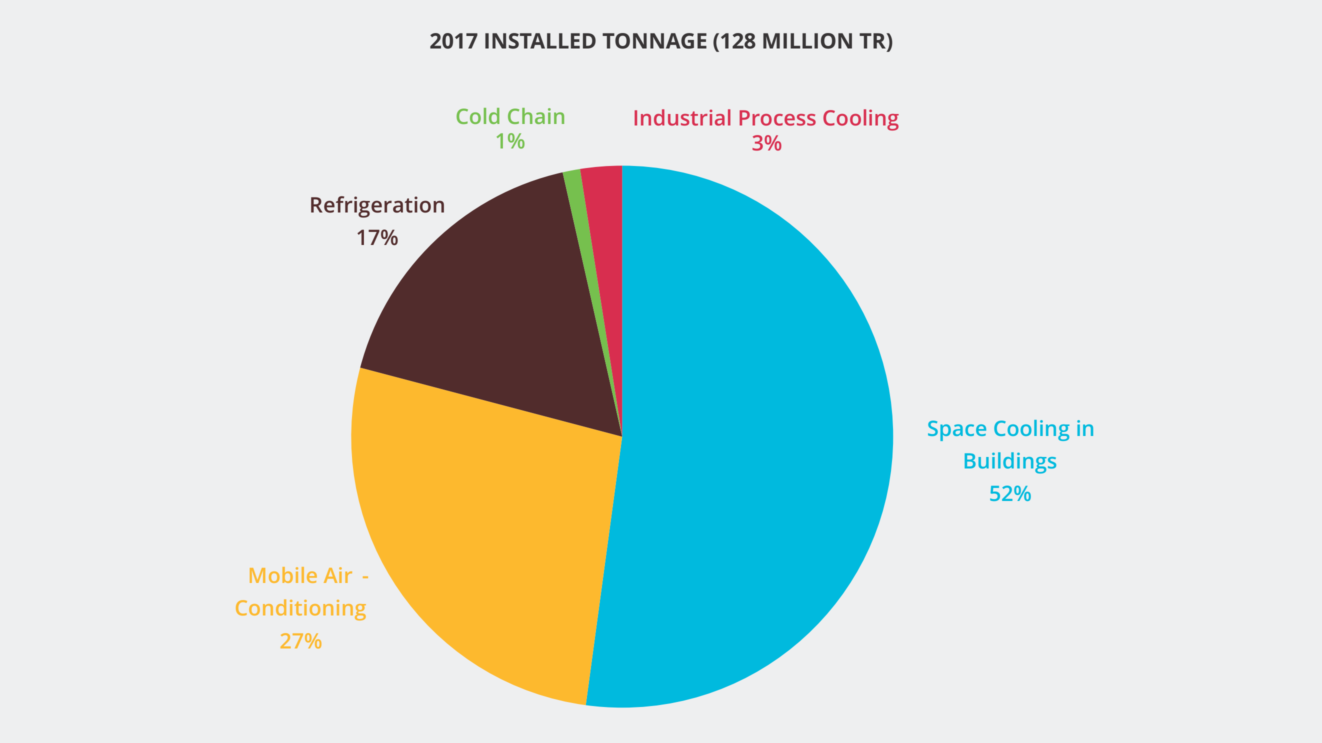


Figure 7.2 2027 Installed Cooling Capacity (Sector-wise)

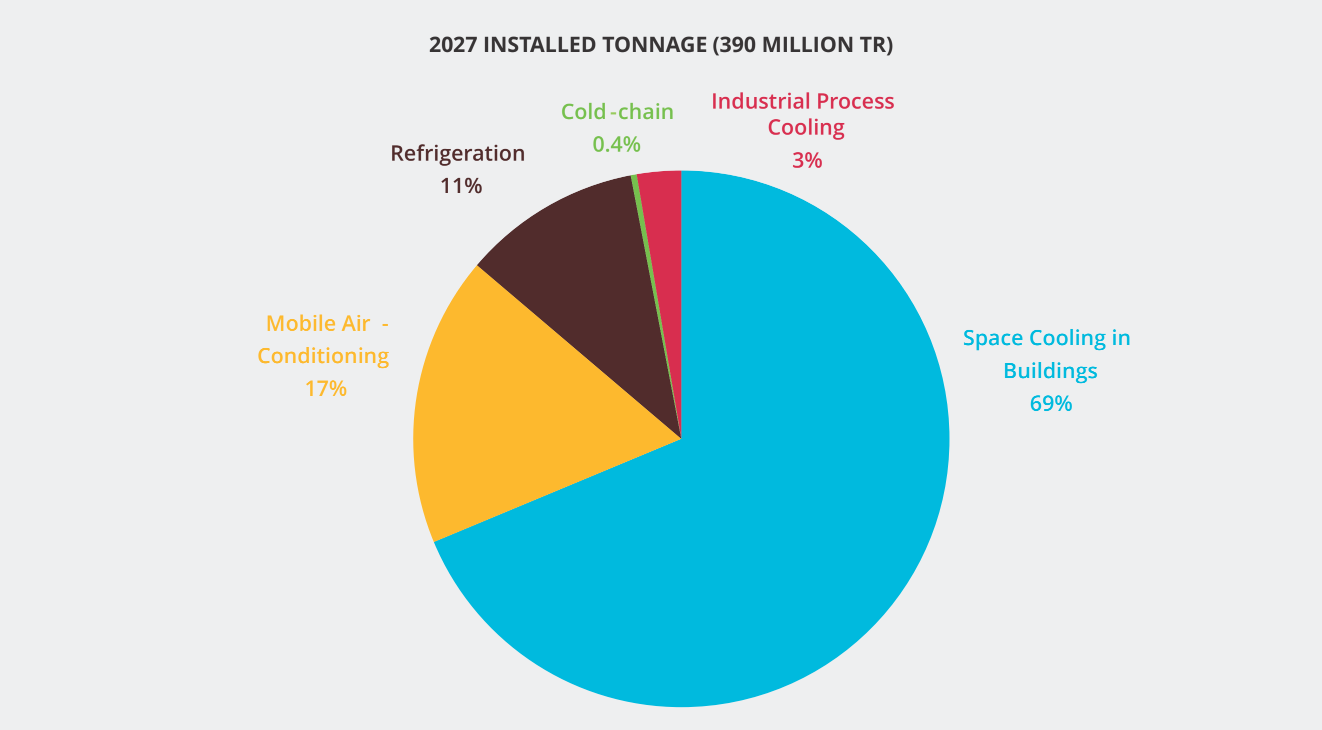
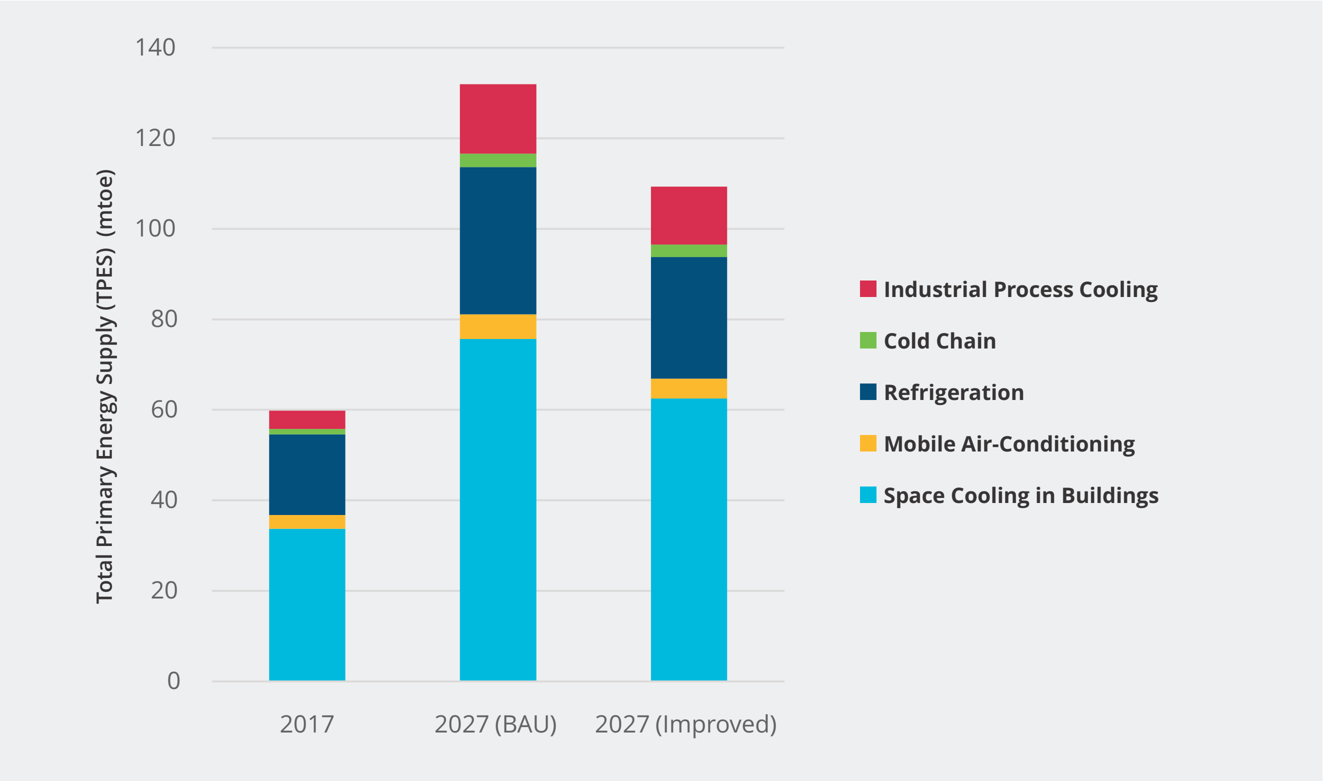


Figure 7.3 Annual Primary Energy Supply in 2017, 2027 (BAU) and 2027 (Improved) by Sector



Note: A constant primary energy conversion efficiency as per IESS Level 2 for 2017 has been assumed for all scenarios. However, the reduction in T&D losses and increased share of renewable mix shall impact the cooling related primary energy supply in future years.

Figure 7.4 Annual Carbon Emission in 2017, 2027 (BAU) and 2027 (Improved) by Sector

7.2 Sector-wise Key Interventions

Each of the sector-specific chapters discusses the key drivers for improvements that were considered in the development of the Improved Scenario at the sub-sector level. While a multitude of factors contribute towards the improvement potential, Table 7.3 highlights the key intervention areas that will result in highest savings in energy and emission – this is to say, that while all interventions are important, the ones identified are most effective for the respective sectors.

Table 7.3 A Map of Key Interventions to Achieve Highest Energy and Carbon Savings

● = High Impact ◐ = Medium Impact ○ = Low Impact

	Technology Interventions	Operational Interventions		Market Interventions	
	Equipment efficiency/ advanced technology	Better O&M practices	Better refrigerant-related servicing practices	Low GWP refrigerant variants	Energy Efficient Building Design
Space Cooling in Building					
RAC	●	◐	●	●	●
Chiller System	◐	●	◐	●	●
VRF System	○	◐	●	◐	●
Packaged DX	○	◐	●	◐	●
Fan	●	◐			○
Air Cooler	●	◐			○
Mobile Air-Conditioning					
Passenger LDV	●	◐	●	◐	
Passenger HDV	●	◐	●	◐	
Refrigeration					
Domestic-type Refrigerator	●	○	◐	◐	
Stand-alone Unit	●	○	◐	◐	
Vending Machine	●	○	◐	◐	
Remote Condensing Unit	●	●	●	◐	
Water cooler	●	○	◐	◐	
Supermarket & Hypermarket	●	●	●	◐	

	Technology Interventions	Operational Interventions		Market Interventions	
	Equipment efficiency/ advanced technology	Better O&M practices	Better refrigerant-related servicing practices	Low GWP refrigerant variants	Energy Efficient Building Design
Cold Chain					
Cold Storage	●	◐	●	◐	
Packhouse & Ripening Chamber	●	◐	◐	●	
Reefer Vehicle	●	○	●	◐	
Industrial Process Cooling					
Process Chiller (Ammonia)	◐	●	◐	○	
Milk Chiller (Ammonia)	◐	●	◐	○	
Industrial AC (Non-ammonia)	◐	●	◐	●	

7.3 Promising Alternatives

Given the ten-year outlook of this study, the improved scenarios predominantly factor in impacts from foreseeable technology improvements and interventions, and well-accepted strategies. That said, there are some imminent alternatives and technologies that promise a positive impact but given that industry experts are not yet able to quantify this impact between now and 2027, these alternatives are not factored into our Improved Scenarios. A short discourse on these promising alternatives is presented below:

7.3.1 District Cooling (DC)

A UNEP[53] study highlighting the various benefits of the DC system, indicates that a modern district energy system, combined with energy efficiency measures could contribute over 50% of the carbon reductions required in the energy sector by 2050 to keep the global temperature rise within 2-3°C. Its main benefits are:

- DC systems consume 40-50% less energy as compared to conventional cooling.
- DC systems typically require about 15% less capacity than conventional distributed cooling systems for the same cooling loads due to load diversity and flexibility in capacity design and installation.
- DC systems provide peak power savings by incorporating thermal storage capability that can smooth out power requirements over the course of a day, thereby reducing the strain on the power system during peak hours.

DC systems are most viable for comfort cooling applications in dense and mixed-use developments, i.e. a combination of commercial, residential, institutional, and industrial buildings. While the technical potential of DC is established, and proven globally through various projects, the Indian market doesn't yet have a viable business model to support main streaming and uptake on DC systems in the near-term, i.e., within the 10-year timeframe of this study. The key challenges are high initial investment, lack of technical expertise for design, little policy level support, and absence of favourable financial and business mechanisms.

7.3.2 Trigeneration

Trigeneration or combined cooling, heating and power (CCHP) offers an optimal solution for generating air conditioning and/or refrigeration. The trigeneration systems are suitable for industrial and commercial applications where there is a continuous demand for electricity, heating and cooling at the same time.

They have multiple advantages such as onsite generation of electricity, heat and power, maximum total fuel efficiency, reduced fuel and energy costs, lower electrical demand during peak time, elimination of HCFC/CFC refrigerants and emission reduction. However, its use is limited to specific applications where there is a simultaneous demand for heat and power and uninterrupted availability of fuel.

7.3.3 Low Carbon Refrigerants

Several alternative refrigerants such as HFOs are being currently explored. The Indian automobile industry is testing new refrigerants such as HFO1234yf for MACs to gear up for export to developed countries. However, there are some concerns regarding HFOs: their highly toxic decomposition products, and a very costly and energy-intensive production process. It is also less energy efficient than the currently prevailing HFC134A.

Carbon dioxide is being evaluated as another option in MAC systems but there are issues when it is used in high ambient temperatures. In Europe, carbon dioxide is successfully used in the MAC sector as well as in supermarkets. It is already in application in the cold chain sector in other parts of the world. Its full-scale implementation and penetration should be explored after addressing concerns about high pressure piping and use at high ambient temperatures.

Ammonia, due to its toxic nature, does not find application in comfort cooling; however, it is under consideration as an option for commercial application of chillers particularly in supermarkets.

7.3.4 Geothermal Cooling

Geothermal cooling systems can be suitable for stationary cooling applications such as buildings and cold storage. Where feasible, such systems can replace or augment existing refrigeration systems, leading to significant energy savings. A typical system uses 25% to 50% less electricity than conventional systems and require less space for hardware compared to conventional systems. These systems offer relatively

7.3.5 Radiant Cooling

Radiant cooling system is highly efficient compared to conventional air conditioners **due to high temperature cooling. The energy to drive water** through the ducts is significantly lower than that of air which translates in substantial energy savings. These systems pose inevitable risk of condensation in humid conditions and hence call for an ancillary dedicated outdoor air system to avoid condensation which increases the initial investment. These systems are available in various models including floor mounted, wall mounted and slab embedded systems. It is also a viable retrofit option for existing buildings.

7.3.6 E-Mobility

The Indian automotive sector is likely to witness a greater penetration of electric vehicles in the next decade or so – expectedly, this will have a bearing on the energy used for air-conditioning, however, the industry experts couldn't fully quantify this.

7.3.7 Thermal Energy Storage

Thermal energy storage can significantly reduce energy costs by allowing cooling equipment to be predominantly operated during off-peak hours. In addition, some system configurations result in lower first costs and lower operating costs compared to non-storage systems. However, not every

cooling system presents a cost-effective application, so careful consideration of site-specific conditions is warranted. The prospects of such systems are attractive if the average cooling load is significantly less than the peak cooling load; it is most applicable in new constructions or when old equipment require replacing. Such systems are inherently more complicated than non-storage systems and require special expertise and more attentive O&M.[48]

7.3.8 Dual Path Technology

Dual Path system work on a principle that divides the sensible and latent heat loads which enables the systems to use two different technologies in tandem where sensible cooling is provided by an air to air heat exchanger and latent heat is removed by refrigeration based dehumidification. Dual path systems can typically reduce the HVAC installed tons by ~20% over a conventional single path system, and the annual energy use by ~25%. Additionally, it provides excellent humidity control always and improves indoor air quality – but this comes at a first cost premium. It can find application in supermarkets, hospitals, large commercial buildings and in industrial process. However, where good control of outdoor air quantity, and humidity control of supply air is not required, the added cost of the dual path system will not be offset by the benefits.[49]

8. Future Recommendations

There is increasing recognition amongst industry and policy makers alike about the critical need to establish cooling as a government priority. The upcoming India Cooling Action Plan announced by the Government of India, which seeks to integrate all cooling efforts in the areas of technology, manufacturing, efficiency and environmental considerations, is a welcome step in this direction. We hope that the future recommendations suggested below will find their way into the strategies and policies that evolve in the near future to proactively address India's cooling energy demand.

The recommendations are based on interventions that broadly fall within three categories: technology interventions, market transformation through policy and other drivers, and operational interventions. We propose three overarching recommendations (A, B and C) that we feel are fundamental and cross-cutting in nature, followed by some specific actions grouped under each of the three intervention categories.

A. Address space cooling in the building sector as a priority area for intervention

Building sector space cooling has a dominant share of the entire cooling energy demand at around 57%. The building sector also shows potential improvement in year 2027, at roughly 17% reduction in energy consumption and total emissions. Given this dominance, both in consumption and the potential for improvement, this sector warrants increased attention and hence a significant portion of the policy, technology and market based interventions will have to be directed at space cooling as a priority.

In the light of significant increase (1.5-2X) in building area by 2027 (from 2017), it is important to reinforce the need to build in strategies and interventions to reduce the cooling demand itself. Role of building energy code is increasingly important in this regard. We recommend making the implementation of ECBC, and the upcoming ECBC-R, mandatory in all states and ensuring compliance through strict governance. Per our analysis, at least 1/3rd of the potential energy savings from refrigerant-based space cooling in buildings could come from proper implementation of envelope and HVAC related guidelines and minimum performance thresholds driven by code.

B. Leverage global best practices and existing knowledge for India's benefit

Policy makers should closely monitor what others regions/countries are practising in terms of policies, regulations and technology pathways, and what are the leading best practices along with market based instruments, and leverage this knowledge towards India's benefit. For instance:

- Closely monitoring their refrigerant pathways, regulations and technological innovations, India can discern important learnings and opportunities for leapfrogging, and shape the best possible course for the Indian market.
- While India had done well with its Standards and Labelling program for air conditioners, it would be beneficial to review successful practices in accelerating MEPS (Minimum Energy Performance Standard), such as Japan'sTop Runner Programme49, to adopt relevant market enablers and technology.
- For the MAC sector, India should keep a close eye on the developments in Europe, as they are on a faster track to refrigerant transition, to ensure that the best technology and policy pathways are adopted in India.

C. Ensure that best available technology (BAT) is brought to the Indian market

Keeping in view the criticality of what is at stake, India should push to bring the best available technology to the Indian market. We must explore where are the technology leaders and the manufacturing hubs, with significant R&D budgets and talent and closely monitor what can be learned/leveraged from these. Technological developments will typically be led by companies with a strong focus on R&D and technological innovation. For instance, for chiller systems, US is the leading innovation and manufacturing hub; for RACs, China leads the worldwide manufacturing (in 2012, over 70% of the worldwide RAC production was manufactured in China) and Japanese manufacturers are the leaders in producing the most efficient RACs. Indian policy makers and industry stakeholders should jointly keep an eye on the manufacturers, particularly the innovators, be it in the field of refrigerants or energy efficiency, and explore how can our policies and market encourage and attract these innovative manufacturers to develop or bring the best available technology to India.

D. Technology interventions

Equipment Efficiency and Labelling

- Encourage and enforce more stringent Minimum Energy Performance Standard for RACs. We recommend doubling the RAC ISEER from the historical rate of improvement to at least 6% per annum, which isalready supported by the current level of technology available in the Indian market. It is important to reiterate here that per our analysis, nearly 2/3rd of the potential energy savings from RACs in 2027 will come from equipment efficiency improvements.

  Government support and incentives will go a long way towards creating viable market conditions for high efficiency RACs, as has been demonstrated by examples the world over. Leveraging global market best practices and learning from manufacturing leaders (as suggested in B and C) will prove beneficial for India. Successful examples also show us that with a combination of the right policy actions and market forcers, equipment efficiency can be decoupled from price points. Japan with its Top Runner Programme has been able to double RACs' efficiency in 10 years. In a span of 10 years (1995-2005), operational efficiency of RACs in Japan improved by 7.2% per year and this increased the Coefficient of Performance from 2.55 to 5.10. It has also been shown that the inflation-adjusted RAC prices continued to drop even as the efficiency of RACs doubled. This is an important observation – and one that often gets overlooked in the cost related discussions in India. The future analysison cost-effectiveness of efficiency should take the inflation-adjustedprices into account. Closer at home, EESL recently requested manufacturers to supply 50,000 units with an ISEER of 5.2 (more than BEE 5* rated RAC). The lowest price quoted to them was on an average 25-30% lower than the average price of the 5-star RACs available to Indian consumers through the retail channel.
- Develop S&L programs for refrigerant-based cooling equipment including, but not limited to, VRFs, and commercial refrigeration equipment; encourage a greater proliferation of labelled cooling equipment, that are still in the voluntary phase, by innovative and effective market mechanisms.
- Make BEE Star Labelling of high market volume cooling equipment like ceiling fans mandatory. Promote greater penetration of energy efficient and super energy efficient fans in residential and commercial buildings. Following the recent success of EESL's LED drive, demand aggregation and bulk procurement is one way of driving this change. Given the current level of technology – with 50 W and 35 W fans already available in the market – we recommend a focused drive towards improving the wattage of typical ceiling fans sold and used in 2027 to ~35 W as compared to the 75 W fans used today.
- Review and ratchet up fuel efficiency norms for LDV in tandem with manufacturer capability and fast-track implementation of similar norms for HDV.

Enable a Robust R&D Ecosystem

- Facilitate R&D for low-energy cooling technologies such as radiant cooling, structure cooling, geothermal cooling and dual path technology. Leverage ongoing government initiatives such as Housing for All and Smart Cities to develop sustainably cooled 'Demonstration Projects' in a few sites, piloting low energy cooling solutions.
- Encourage R&D on low GWP and natural refrigerants, ensuring all safety and EE requirements are being met. The Government can come out with an evaluation framework for rating refrigerants keeping in mind all the key criteria, to send a clear and strong signal to manufacturers and safeguarding the interest of its citizens and the environment.
- Develop safety regulations for ammonia-based cooling and ensure its strict implementation in industrial process cooling and cold chain.
- Cultivate and leverage the expertise available in academic and research institutes of excellence in the country, and drive them towards research that will help address the cooling challenge facing the country.

E. Drive market transformation through robust policy and other drivers

- Enforce formulation and implementation of policies at the state level. Example are

- In line with Ministry of Finance's General Financial Rules (GFR) - Office Memorandum No. 26/6/12-PPD regarding procurement of energy efficient electrical appliances for Ministries/Departments, all other ministries and CPWD and state PWD departments should follow the lead. These guidelines should govern the procurement of energy efficient room air conditioners, ceiling fans and refrigerators for all State/UT Departments.
- All States and UTs should notify and incorporate ECBC-2017 in municipal building bye-laws for stringent enforcement and compliance in all new construction, wherever applicable

- Establish policy frameworks and incentives to enable DISCOMS to implement a Demand Responseand variable Time-of-Use programs targeted at cooling load reduction – this will find application in the building (residential and commercial) and industrial sectors.
- Establish policy to create state-level financial instruments for low-cost/preferential line of credit to real estate projects with a demonstrably high cooling efficiency.
- Drive adoption of energy efficient building envelop materials into mainstream through consistent testing and rating protocols, and market transformation strategies.
- Generate market momentum towards smart cooling through awareness campaigns, access to information and technical assistance.

F. Operational interventions

- Create more emphasis on capacity building, training and certification of servicing sector technicians, in alignment with the National Skill Development Mission. This will optimizing operational energy performance of cooling equipment, and ensure better refrigerant management during servicing and at end-of-life. Our analysis shows that a greater focus on O&M of large AC systems will contribute roughly 2/3rd of the total energy savings in commercial buildings in 2027 and will inform retro-commissioning and retrofitting the old and inefficient stock.
- In addition to capacity building and training, States and UTs candrive proliferation of trained and certified HVAC O&M service technicians. Leading by example, the State/UT governments should issue pubic procurement guidelines for trained and certified HVAC service technicians for public buildings.
- Leveraging the advancements in IoT, the market and industry should migrate towards controls-based cooling equipment for buildings and industries

About AEEE

AEEE is a policy advocacy and energy efficiency market enabler with a not-for-profit motive. It is the only organisation in India which works on creating awareness about energy efficiency as a resource. It advocates for data driven and evidence-based energy efficiency policies that will unleash innovation and entrepreneurship within the country to create an energy-efficient economy. AEEE works using a collaborative approach on multiple projects in the following thematic areas that encompass almost all aspects of Energy Efficiency: ESCO & EE Finance; Buildings, Systems and Technologies; EE Urban Infrastructure and Utilities. The organisation is headed by Dr Satish Kumar, an energy expert who brings decades of global and Indian experience and expertise to the table. He is supported by an extremely competent team of professionals. AEEE is governed by an Executive Council that comprises leaders from the development sector, industry stalwarts, and entrepreneurs. AEEE has also partnered with leading organisations to bring a vibrant synergy in the impact of its work.

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