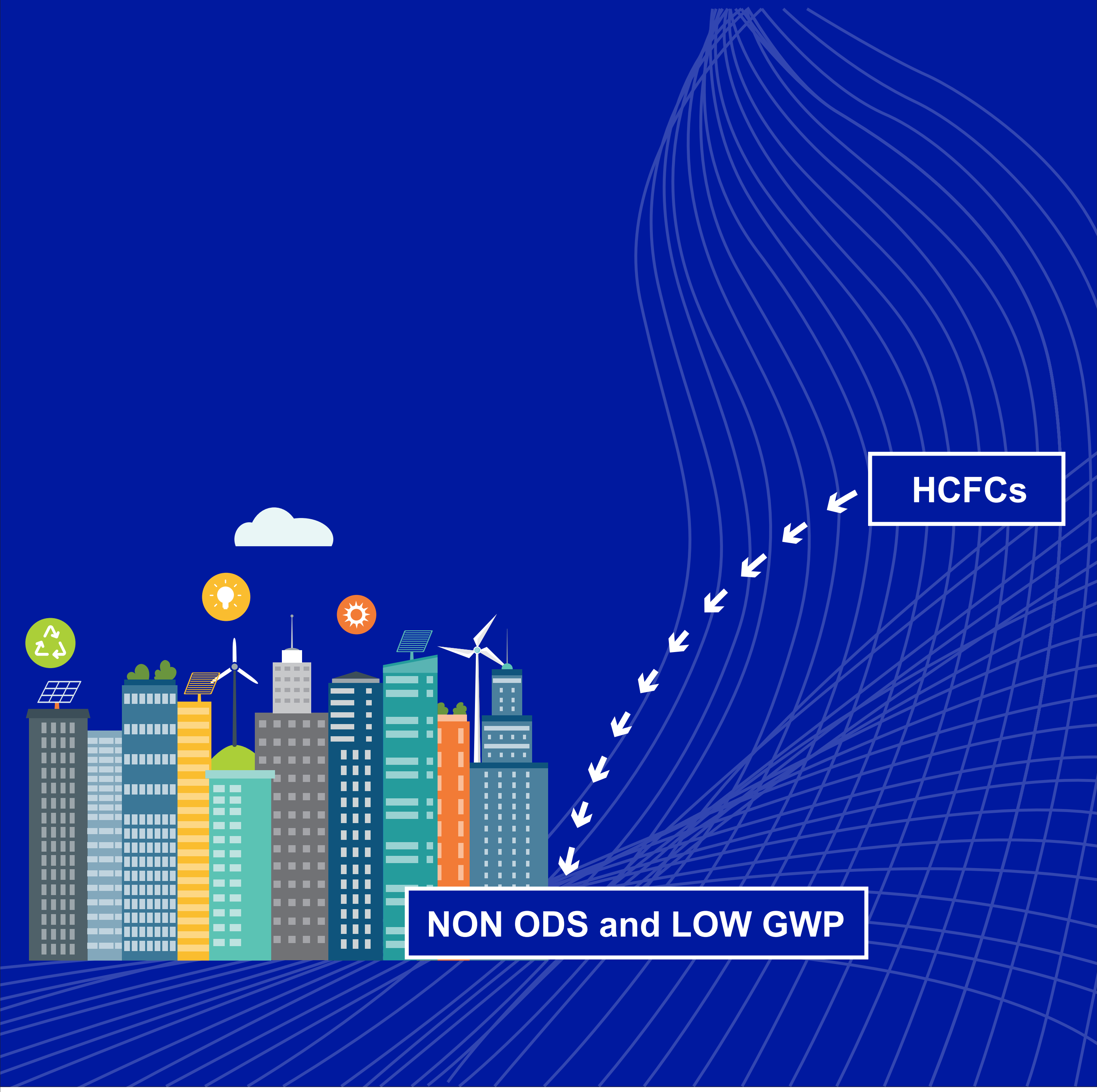
HCFC PHASE-OUT AND ENERGY EFFICIENCY IN BUILDINGS



UN environment
United Nations Environment Programme

Ozone Cell
Ministry of Environment, Forest and Climate Change
Government of India

EESL

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New Delhi, India, 2017

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This document was developed as a part of UN Environment's and Ozone Cell's, MoEF & CC work on integrating Ozone Depletion Substance issues in building sector with a view to raise awareness on zero Ozone Depletion Potential and low Global Warming Potential technologies under the Hydrochlorofluorocarbons (HCFC's) Phase Out Management Plan (HPMP). This handbook on 'HCFC Phase-out and energy efficiency in buildings' was authored with the active engagement and support of

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MINISTER OF ENVIRONMENT, FOREST & CLIMATE CHANGE

सत्यमेव जयते

MESSAGE

Substantial electrical energy is consumed by the 'Building Sector'. Space cooling of built environment contributes a major share to the electricity consumption. The refrigeration and air-conditioning systems in buildings account for significant amount of Hydrochlorofluorocarbon (HCFC) consumption and also energy use in buildings. In addition to refrigeration and air-conditioning systems, HCFCs are used as foam blowing agents for insulation of buildings and also in firefighting equipment.

Rapid growth is projected in the building sector due to urbanization including the Smart Cities programme of the Government. Building sector interventions not only offer substantial potential for bringing in energy efficiency but also to phase-out Ozone Depleting Substances. Direct and indirect carbon emissions relating to building sector as a result of energy consumed and equipment used have a significant impact keeping in view life span of buildings

Energy efficiency in buildings is not only linked with reduced energy consumption but also reduction in cooling requirements and thus use of ozone depleting substances. Thus, using the right alternatives will go long way towards achieving complete phase-out of ODSs. Energy efficiency in buildings and equipment is key to mitigating both ozone depletion and impacts on climate change. In this context, it is necessary that adequate awareness is created among various stakeholders of building sector regarding the importance of energy efficiency, use of energy efficient appliances and its contribution towards HCFC Phase-out plan of Govt of India.

A special component on building sector interventions was included under enabling component of the HCFC phase out management plan of the country. The enabling activities under HPMP are being implemented by UN Environment. To implement the building sector interventions under HPMP the Ministry has collaborated with the Energy Efficiency Service Limited, a JV of Public Sector Undertakings of Ministry of Power, Government of India. India as a signatory to the Montreal Protocol has ensured successful implementation of programmes to phase out production and consumption of several ODSs.

I am glad to note that coinciding with 30th anniversary day of Montreal Protocol, the UN Environment, EESL and the Ministry of Environment, Forests and Climate Change (MoEF&CC), Govt. of India have come out a handbook which deals with issue of HCFC Phase-out and energy efficiency in Buildings. I am sure, this handbook will serve as an effective reference document for end users, manufacturers, architects etc. on various aspects of energy efficiency and HCFC phase-out plan in buildings. I congratulate all those who have put their best effort to bring out this book.

Date: 12.09.2017

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MESSAGE

Built space is growing rapidly fuelled by improving economic conditions and a demand for housing and commercial spaces. Significant portion of the energy consumed by buildings relate to air conditioning. Apart from electricity consumption, refrigeration and air-conditioning (RAC) system use ozone depleting substances - hydrochlorofluorcarbons (HCFCs) - as refrigerants. Making buildings more energy efficient also simultaneously reduces the cooling requirement. Thus reducing the use of Ozone depleting substances.

Adhering to the commitment of the country under the Montreal Protocol, India is implementing the HCFC phase out management plan (HPMP) under which the HCFCs would be phased out by 2030 except for a small portion required for servicing of old equipments. The ultimate goal is to end the use of ozone depleting substances by switching over to non-ozone depleting and environment friendly technologies. The HCFC is currently used in various sectors including refrigeration, air-conditioning and foam manufacturing. And, building is a major sector in this context.

Under the enabling component of HPMP which is being implemented by UN Environment a series of interventions in building sector are being implemented with a view to bring down HCFC consumption through integration of with energy efficiency aspects. The Ministry has partnered with Energy Efficiency Services Ltd. to implement these activities. The integration of HCFC phase out with energy efficiency is the key.

This is a significant initiative taken by the Ozone Cell, Ministry of Environment, Forests and Climate Change (MoEF&CC), Govt. of India along with UN Environment and EESL to bring out a handbook on the cross cutting issue linking energy efficiency and ODS phase out in building sector This handbook which will launched on the occasion of World Ozone Day – 2017 and the 30th anniversary of Montreal Protocol will serve as a guiding document for all concerned stakeholders involved in this sector.

I wish all the success for implementation of the HPMP in building sector of India.

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MESSAGE

India has been successfully implementing phase out of ozone depleting substances since 1993 under the Montreal Protocol. Presently, the Hydrochlorofluorcarbons (HCFC) phase out Management Plan (HPMP) is being implemented in the country. India has voluntarily followed a low carbon development path, while phasing out HCFCs by adopting non-ODS, low Global Warming Potential (GWP) and energy-efficient technologies in its HPMP. The transition from HCFCs to environment-friendly, technically proven and economically viable alternatives is a challenging task.

HCFC is being used in various sectors like refrigeration and air conditioning (RAC), foam manufacturing etc. These sectors have direct linkage with other related sectors such as urban development, agriculture through cold chain sector, and industrial development. The construction activities have surged in both residential and commercial segments in the urban segments across the country. This is a result of rapid urbanization as also Government schemes such as Smart Cities and Housing for All. It is widely recognized that with rapid urbanization the need for air-conditioned built environments will also rise. HCFC is are also used in the insulation foam in buildings and the fire extinguishing equipment. Increase in the energy efficiency of buildings is directly related to reduction in the use of HCFCs through reduced cooling requirement. This offers an advantage to synergize the benefits of gains in energy efficiency with phase out of ODSs.

As part of enabling component under HPMP the Government along with UN Environment had included activities relating to building sector interventions which link issues of energy efficiency and phase out of ODSs in building sector. Though separately, the Government of India taken various steps to improve energy efficiency in the buildings through different programs/interventions the latest Energy Conservation Building Code (ECBC), 2017 is another policy intervention as far as new buildings are concerned. The Ministry has linked with the Energy Efficiency Services Ltd. (EESL) to implement activities under HPMP related to building sector interventions. It is felt that adequate awareness needs to be created among building owners, manufacturers of appliances, architects and even policy makers at state and central level on energy efficiency in buildings and its linkage to HPMP.

It is in this context that the publication of the handbook on issues related with energy efficiency HCFC Phase-out in Buildings Sector is timely and assumes significance. I congratulate the team associated with bringing out this handbook I am sure that this handbook will be quite beneficial to various stakeholders in building sector in achieving the very objective of energy efficiency and meeting timelines of HPMP.

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MESSAGE

OzonAction of UN Environment complements the Ministry of Environment, Forests and Climate Change and its National Ozone Unit (NOU) that has taken the lead by prioritizing the building sector in their HCFC phaseout management plan. This handbook will go a long way to assist India to phase out HCFCs from its building sectors. The handbook explains the inevitable synergy between ozone protection and climate change mitigation and how using the right alternatives and technologies can give dual benefits.

Developing countries have a big opportunity to leapfrog to alternative technologies from the current use of HCFCs and HFCs. Thus, countries can skip the step of transitioning to high-GWP options such as HFCs benefitting ozone layer and climate protection. The HCFC banks in existing buildings and equipment can be replaced with low-GWP alternatives where possible, while the remaining will eventually be recovered at the end of life. Although building sector is one of the largest contributors of greenhouse gas emissions, it also offers the biggest and most cost-effective opportunities for energy efficiency. Policies promoting energy efficiency in buildings are key to implement HCFC phaseout from buildings.

In the current times of increasing environmental awareness, National Ozone Units have opportunities to integrate energy efficiency strategies at a program and policy level for HCFC phaseout and HFC phase down from buildings and equipment. Each policy instrument has its advantages and disadvantages and the results depend strongly on how appropriate the instrument is to the local context and how it is implemented. Identifying the appropriate mix of policy measures that is best suited to the local context and market scenario is important to implement the phaseout process. This can be achieved by making priority targets for energy efficiency, program and policy amendments, identifying gaps between existing initiatives and best practices, and selecting the appropriate alternatives. Capacity building efforts, training programs and financial incentives along with transfer of knowledge will go a long way in implementing strategies for HCFC phaseout.

On the occasion of the World Ozone Day and the 30th Anniversary of the Montreal Protocol, on behalf of UN Environment, I wish all success to India in their efforts and assure all stakeholders of OzonAction's unflinching support to meeting the HCFC phaseout targets in India.

EXECUTIVE SUMMARY

Montreal Protocol has been the most successful international treaty for global environmental protection. India is a second largest producer and consumer of HCFCs in Article 5 countries after China. The building sector refrigeration and air-conditioning systems accounted in 2015 for 43% of HCFC consumption in India (Ozone Cell, 2017). HCFCs are also used as foam blowing agents for manufacturing building insulation. The foam sector HCFC consumption in India accounted for 21% of foams manufacturing in 2015.

HFCs are already a widely used popular alternative to HCFCs gaining 31% of the refrigerant market share in India in 2013 (BSRIA, 2014). The Kigali Amendment to the Montreal Protocol calls for the phase down of HFCs to protect the climate system. As per the Montreal Protocol, India has to achieve complete phase out of HCFCs by 2030 and simultaneously start phase down of HFCs by 2028. According to Environment Protection Agency, HFC emissions from Asia Pacific building sector are projected to increase by 7 times in the refrigeration sector and about 15 times in the residential air conditioning sector by 2030 as compared to the 2010 emissions (EPA, 2012). Thus, it is quite critical to adopt low-GWP refrigerants to curb phase-in of high GWP HFCs.

Building stock in India is predicted to grow five-fold to reach 10,400 million square meters in 2030 compared to the built area in 2005 (Environmental Design Solutions Pvt Ltd, 2010). The building sector in India is already consuming close to 40% of the electricity and this is expected to increase to 76% by 2040 (CSE, 2014). In air conditioned commercial buildings, as much as 40%-50% of the energy end use is attributed to space conditioning to provide comfort for occupants.

People are using their growing incomes to purchase air conditioners and other energy using equipment to improve their living standard. Moreover, the demand for air conditioners in India is expected to grow from 3.8 million a year to 6.2 million in 2020-21 (increase of 63% Cumulative Annual Growth Rate (CAGR) (Ozone Cell, 2017). Thus, the projected new building construction and growing GDP will increase the demand for air conditioning for better living and working environment.

A three pronged approach have been identified as key in phasing out the use of HCFCs in buildings.

1. Reduce demand for refrigerants through energy efficient equipment and buildings.

HCFCs are used as refrigerants in air-conditioning to provide space cooling in buildings. The building design (including location, orientation, structure and layout), the choice of building materials and equipment determine the 'cooling loads', or cooling requirements. Higher building loads require larger cooling capacity air-conditioning equipment and consequently, increased use of refrigerants. Energy-efficient building design takes into account the various parameters mentioned above, making it possible to use smaller air-conditioning equipment, consuming less energy and refrigerants. Thus, energy efficiency directly reduces the demand for refrigerants.

Buildings and air conditioning equipment are also responsible for GHG emissions which are either direct or indirect. Direct emissions occur due to release of refrigerants such as HFCs and alternatives from the air conditioning equipment into the atmosphere during manufacturing, operations and end of life recovery. Use of high-GWP HFCs as alternatives to HCFCs is thus a major concern.

Indirect emissions occur as a result of electricity used by air conditioning equipment as well as buildings over its operational life time. The amount of indirect emissions depends on the carbon intensity of the fuel used to generate the electricity at the power plants. Energy efficient buildings and equipment use less electricity over its operational lifetime, thus reducing the indirect GHG emissions. Therefore, it is utmost important to use low-GWP energy efficient equipment and design efficient buildings. Hence, promoting building energy efficiency will benefit both ozone and climate.

2. Replace HCFCs with zero Ozone Depleting Potential (ODP) and low Global Warming Potential (GWP) alternatives.

Hydrofluorocarbons (HFCs) are the third-generation refrigerants being used to replace HCFCs. They do not deplete the ozone layer but, being potent GHGs, are controlled under the Kigali Amendment to the Montreal Protocol. When looking for viable alternatives, low-GWP and zero ODP refrigerants should be prioritized, and Ozone Cell can serve as an essential information source. Awareness and information outreach will enhance the industry's understanding of the problem and promote efforts in exploring other options for phasing out HCFCs.

3. Use not-in-kind alternative technologies that do not rely on use of fluorocarbon Rrefrigerants.

Finally, the ultimate goal should be moving towards using technologies that do not use ODS and high-GWP HFC of any kind. There are technologies other than the vapour compression based chillers, that work with natural refrigerants such as ammonia, water and hydrocarbons. Several successful case studies have been presented in this handbook for reference. Policies promoting energy efficiency include building energy codes, energy-efficiency standards and appliance and equipment labels. Other examples cited in the handbook include utility programs and pilot projects that showcase the feasibility of these new technologies.

The building sector offers substantial potential to protect the ozone layer and the environment, but strategies need to be coordinated to achieve both simultaneously. India has a unique opportunity to leap frog the use of high GWP refrigerants and avoid the phase-in of such refrigerants in new equipment and reduce the refrigerant demand in new energy efficient buildings.

India also has policies and programs addressing the use of ozone depleting substances and building energy efficiency independently. One of them, such as the National Building Code has requirements on the use of zero-ODP and low-GWP refrigerants. Overall, India is prepared to transition to low-GWP alternatives.

CONTENTS

ACRONYMS & ABBREVIATIONS

AFFF	Aqueous Film Forming Foam
BEE	Bureau of Energy Efficiency
BERDE	Building for Ecologically Responsive Design Excellence
CAP	Compliance Assistance Program
CFC	Chlorofluorocarbon
CH_4	Methane
CO_2	Carbon Dioxide
CO_2-eq	Carbon Dioxide Equivalent
COP	Coefficient of Performance
CTC	Carbon Tetrachloride
ECBC	Energy Conservation Building Code
GBCS	Green Building Certification System
GBES	Green Building Evaluation System
GBI	Green Building Index
GHG	Greenhouse Gas
GRIHA	Green Rating for Integrated Habitat Assessment
GRSBE	Green Rating System for Built Environment
GWP	Global Warming Potential
H_2O	Water
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluoroolefins
HPMP	HCFC Phase-out Management Plan
HVAC	Heating, Ventilation and Air Conditioning
IGBC	Indian Green Building Council
IPCC	Intergovernmental Panel on Climate Change
ISLP	Integrated Standards and Labeling Programme
LEED	Leadership in Energy and Environment Design
LiBr	Lithium Bromide

MBr	Methyl Bromide
NBC	National Building Code
N_2O	Nitrous Oxide
NH_3	Ammonia
NOU	National Ozone Unit
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substance
PFC	Perfluorocarbon
PU	Polyurethane
RAC	Refrigeration and Air Conditioning
SF_6	Sulfur Hexafluoride
SHGC	Solar Heat Gain Coefficient
TEAP	Technology and Economic Assessment Panel
TERI	The Energy and Resources Institute
TOC	Technical Options Committee
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
US EPA	United States Environmental Protection Agency
VIP	Vacuum Insulated Panel
VLT	Visual Light Transmittance
VOC	Volatile Organic Compound
WWR	Window-to-Wall Ratio
XPS	Extruded Polystyrene

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1 Introduction

INTRODUCTION 1

The modern science suggests that earth's ozone layer was formed some 400 million years ago and remained practically undisturbed for virtually for all that time. Man-made substances such as hydrochlorofluorocarbon (HCFC) react with ozone molecule destroying its composition. This results in the thinning of the stratospheric ozone which is referred to as ozone depletion and HCFCs are one of the family of ozone depleting substances (ODS). The "Montreal Protocol on Substances that Deplete the Ozone Layer" is an international treaty designed to protect the ozone layer by phasing out the production and consumption of a number of substances that cause ozone depletion. The Montreal Protocol currently calls for a complete phase-out of HCFCs by 2020 for developed countries and by 2030 for developing countries with a very small servicing tail up to 2030 and 2040 respectively.

HCFCs are largely used as refrigerants in air conditioning and refrigeration equipment as well as for foam manufacturing. India is the second largest producer and consumer of HCFCs in the world. 93% of the HCFC-22 used as refrigerant in India in 2015 was in the building sector. 14% of all HCFC-141b were used for building insulation in 2015 (Ozone Cell, 2017). The tropical climate of India coupled with rising income and increasing population is driving the demand for air conditioning in buildings. Thus, it is important for the building sector in India to phase-out HCFCs using low-GWP alternatives by 2030 to meet the Montreal Protocol targets.

HFCs are currently being used as alternatives to HCFCs, many of which have a high Global Warming Potential (GWP). The most recent Kigali Amendment was signed in October 2016 to control HFC use under the Montreal Protocol. Under this landmark agreement, India has committed to start phasing down HFCs by freezing at the baseline (average of 2024 to 2026) in 2028 and reduce it to 15% of the baseline level in 2047.

The phase out of HCFCs could phase-in the use of HFCs, unless low-GWP alternatives are prioritized. However, since the HCFC phase out schedule has just started in 2015, Indian industry has been making all efforts to leapfrog to low-GWP options from the current use of HCFCs. Thus, technology and policy interventions that can promote and increase further the adoption of zero ODP and low-GWP alternatives in buildings would be critical for achieving the twin benefits of ozone and climate protection.

Ozone Depletion and Climate Change are linked

It is well known that ODSs are greenhouse gases that contribute to the radiative forcing of the climate (Figure 1). The reduction in ODS consumption due to the implementation of the Montreal Protocol has helped mitigate climate change.

HCFC was introduced as a low-ODP transitional substance to substitute some of the high-ODP CFCs. Article 5 Countries are now phasing out HCFCs from various sectors, in accordance with the Montreal Protocol schedule. HFCs are the second -generation alternatives to HCFCs, developed as zero-ODP substances. However, under the UNFCCC and its Kyoto Protocol, the emissions of HFCs are controlled along with other Kyoto basket of potent greenhouse gases. These are responsible for direct and/or indirect greenhouse gas emissions that contribute to the radiative forcing of the climate. Yet, the consumption of HFCs continues to increase because of increased cooling requirements across the globe and are still being used as a substitute for phasing-out HCFCs in Article 5 countries, in compliance with the Montreal Protocol.

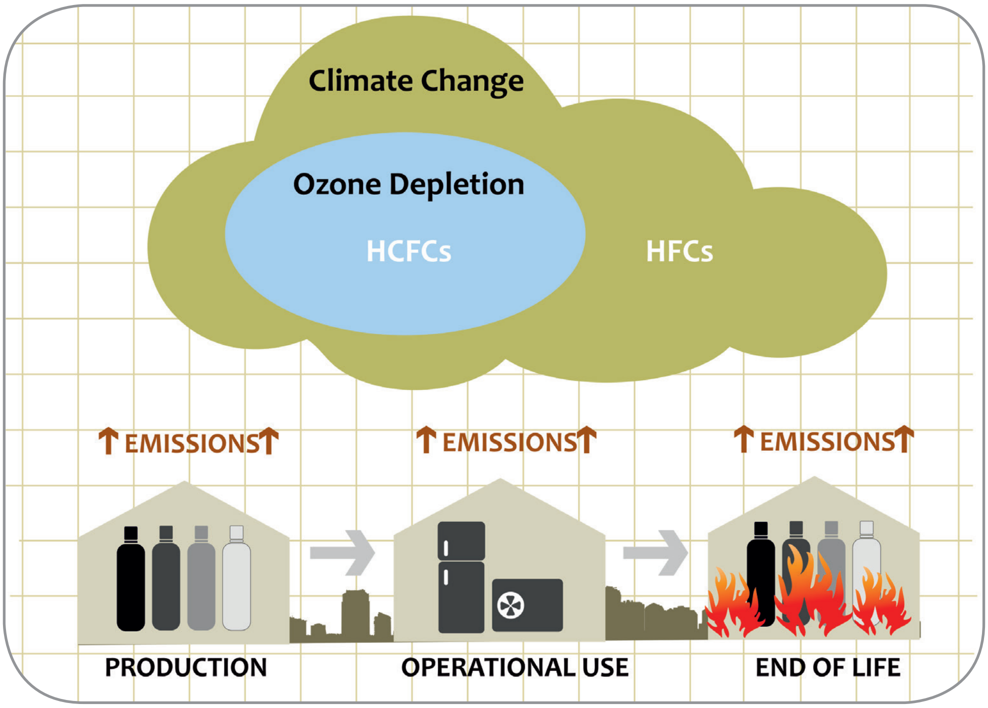


Figure 1. Climate change and ozone depletion

By managing the use of alternatives like HFCs and/or by using other low-GWP options, actions under the Montreal Protocol can result in climate benefits that align with the Kyoto Protocol reduction target.

HFC emissions are projected to rise to about 3.5 to 8.8 GtCO2-eq in 2050 which is comparable to the reduction of 8 GtCO2-eq achieved due to phasing out of ODS between 1988 and 2010 (UNEP 2011). This clearly means that without intervention, HFC emissions are projected to offset the climate benefits achieved by Montreal Protocol through phasing out ODS.

Objective and scope of the report

The objective of the report is to bring out the significance of the building sector in the country and introduce the reader how to convert challenges to opportunities in phase-out of HCFCs in the building sector.

The building sector is explained in detail in Chapter 3 in terms of future growth in building stock and cooling demand. This clearly establishes the challenges and opportunities unique to the sector in the current scenario. HCFC use in buildings is explained in detail in Chapter 4. A high level phaseout strategy is discussed in Chapter 5. Energy efficiency is the key to achieving HCFC phase out by reducing the demand for refrigerants.

The strategies to achieve energy efficiency are discussed in Chapter 6. Chapter 7 lists all the different alternatives available to the current use of HCFCs. Addressing the HCFCs locked in existing buildings is equally important as discussed in Chapter 8. Finally, in Chapter 9, a comprehensive assessment of policies and programs in India that address both ozone and climate change is done. It brings out the fact that some policies address both issues of ozone depletion and climate protection while others address both issues independently. Hence synergy between the policies is essential to achieve an integrated phaseout.

While the building sector includes several typologies, the scope of this report is limited only to the residential and commercial building type.

2 Montreal Protocol and the building sector

MONTREAL PROTOCOL AND THE BUILDING SECTOR 2

The ozone layer is a thin layer of ozone gas found in the atmosphere, about 10 to 50 kms above earth. The ozone layer protects the earth by absorbing most of the ultraviolet-B (UV-B) rays from the sun. If the ozone layer depletes, the excess of UV-B will reach the earth and cause skin cancer, eye cataracts, destroy life in the ocean among several other issues.

It was in the early stage of industrialization in 1974, when the world community received the hypotheses of two chemists - F. Sherwood Rowland and Mario Molina, from the University of California, USA that the ozone layer might be affected by continuing emissions of chlorofluorocarbons (CFCs), a widely used family of industrial chemicals. CFCs were invented in 1928 for commercial applications such as air conditioning, aerosols, refrigeration and solvents. CFC was considered as “wonder gas” since it was non-toxic, non-corrosive, non-flammable, versatile and had a long life.

Scientists discovered that CFCs did not mix with water and entered the atmosphere reacting with the ozone layer. The chlorine atoms in the CFCs reacted with the ozone molecules breaking the chemical bond and destroying the ozone layer. This non-stop continuous process has caused a decline in the amount of total ozone in the stratosphere over the years. The discovery of “ozone hole” or the severe thinning of the ozone layer over Antartica in 1985 shocked the world (UNEP, 2000). It has been considered as one the major environmental disaster of this century.

The world community came together to address this issue through the Vienna Convention for the Protection of Ozone Layer in 1985. This catalyzed further activities on the scientific and political levels to develop better understanding of the subject. This was later followed by the Montreal Protocol in 1987.

Montreal Protocol

The “Montreal Protocol on Substances that Deplete the Ozone Layer” is an international treaty designed to protect the ozone layer by phasing out the production and consumption of a number of substances that cause ozone depletion. The treaty was opened for signature on September 16, 1987, and entered into force on January 1, 1989. Since then, it has undergone four amendments: 1990 (London), 1992 (Copenhagen), 1997 (Montreal) and 1999 (Beijing). Due to its widespread adoption and implementation, it has been hailed as an example of exceptional international cooperation. Countries that are signatories to the Protocol are termed as “Party(ies)”.

This year, 2017, marks the 30th anniversary of the Montreal Protocol which is an important milestone for the protection of the ozone layer. Scientists predict that the ozone layer will be fully restored by the year 2050 or slightly later, if we complete the implementation of the Protocol (UNEP, 2000).

Impact of the Montreal Protocol

ODSs include over 90 chemicals such as CFCs, HCFCs, halons, methyl bromide, carbon tetrachloride (CTC) and methyl chloroform. As of 1st January, 2010 the production and consumption of key ODSs like CFCs, Carbon tetrachloride (CTC), halons, and Methyl Chloroform have been completely phased out globally. These substances not only have high Ozone Depleting Potential (ODP), but also have high Global Warming Potential (GWP). As an example, CFC-12 has a GWP of 10,800. The phaseout efforts under Montreal Protocol achieved reductions of about 11.6 GtCO2-eq emissions between 1988 and 2010 (UNEP, 2011b). Thus, the reduction in ODS has helped significantly towards mitigate climate change.

While the Montreal Protocol control initiated the phase-out process, it is the amendments to the Protocol adopted regularly based on scientific evidence which have actually resulted in meaningful results in terms of reduction in the release of ozone depleting substances. The London Amendment in 1990 and the Copenhagen Amendment in 1992 were the major milestones in the history of the Montreal Protocol. The controls set in these amendments played a pivotal role in ozone layer recovery.

Further, the 2nd Meeting of Parties held in London also decided to establish a financial mechanism to provide technical and financial support to the developing countries to meet their compliance obligations to the Montreal Protocol. The financial mechanism proved as the key to the success of the Montreal Protocol.

Accelerated Phase-out of HCFCs

HCFCs were developed as low-ODP transitional substances to substitute high-ODP CFCs in some applications. These are used in refrigeration & air-conditioning, foam blowing, aerosols and firefighting applications. Some of the commonly used substances are HCFC-22, HCFC-141b, HCHC-142b, HCFC-123, HCFC-124 and HCFC-225; all of which are controlled under Annex C Group 1 Substances.

Recognizing the success of the Montreal Protocol, the 19th Meeting of the Parties (MOP) held in September 2007 on the occasion of 20th Anniversary of the Montreal Protocol, agreed to accelerate the phase-out of hydrochlorofluorocarbons (HCFCs) by 10 years for early recovery of the ozone layer. The Montreal Protocol currently calls for a complete phaseout of production and consumption of HCFCs by 2020 for developed countries and by 2030 for developing countries with a very small servicing tail up to 2030 and 2040 respectively (Figure 2).

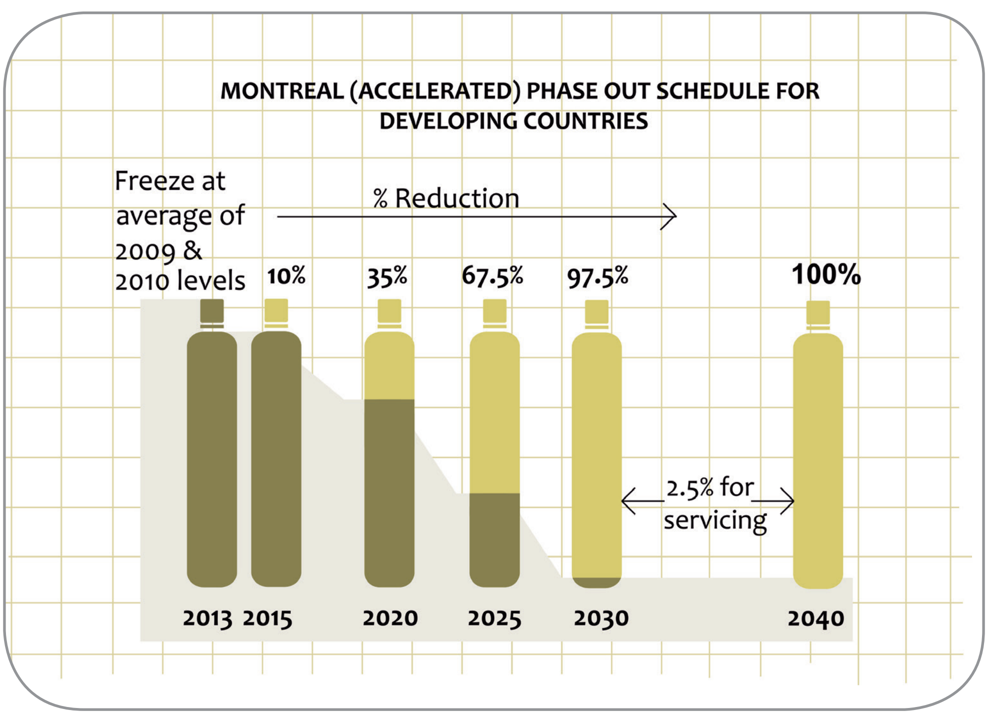


Figure 2 HCFC phaseout schedule in developing countries

India's commitment for HCFC phaseout

India became Party to the Montreal Protocol on 19th June, 1992. With continued efforts from different stakeholders, industry and the policies developed by the Ministry of Environment, Forest and Climate Change, (MOEF & CC) India has successfully phased-out the production and consumption of CFCs, CTC and halons, and Methyl Chloroform as on 1st January, 2010.

Considering the importance and challenges in the implementation of the accelerated phase-out of HCFCs, India initiated activities as early as 2009 by developing a road map for phaseout of HCFCs.

HCFC phase-out management plan (HPMP) stage-I

The HPMP Stage-I was developed to implement the phaseout process for a period of four years from 2012 to 2016 to achieve the freeze target by 2013 and 10% phase-out targets of HCFCs by 2015 as per the Montreal Protocol.

The plan prioritized the phase-out of HCFC-141b used in foam manufacturing. HPMP Stage-I has been implemented by conversion of 15 large enterprises in the foam manufacturing sector from HCFC-141b to non-ODS, cyclopentane technologies. The enterprises participating in the HPMP stage-I were large consumers of HCFC-141b and also capable of handling the alternative technology based on cyclopentane which is a flammable blowing agent. Safety measures for storage, handling and use during manufacturing of foam needed were easily put in place by the enterprises.

In addition, Technical Assistance (TA) has been provided to 15 Systems Houses for developing HCFC-free polyol formulations with low-GWP for use as blowing agents. These indigenously developed alternatives could be subsequently used by micro, small and medium enterprises (MSMEs) in phasing out HCFCs from their operations.

The refrigeration and air-conditioning (RAC) servicing sector accounts for a significant proportion of the HCFCs consumed in the country. Activities, such as development of training material, training of trainers and technicians etc. related to the servicing sector were initiated to support the HCFC phase-out targets. The HPMP Stage-I trained more than 11,000 technicians across the country.

Impacts of HPMP Stage-I

The HPMP Stage-I, has successfully phased-out a total of 341.77 ODP tonnes of HCFCS. Of this, 310.53 OPD tonnes of HCFC 141b has been phased out in the foam manufacturing sector and 31.24 ODP tonnes of HCFC-22 from the RAC servicing sector.

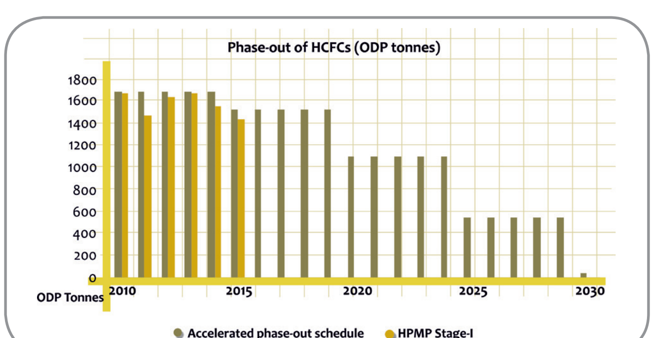


Figure 3 Phaseout under HPMP Stage-I

By doing so, India has achieved its Montreal Protocol targets for HCFC freeze in 2013 and 10% reduction in 2015. In fact, the reductions have been more than what was expected as per the schedule (Figure 3). This has also resulted in corresponding GHG emissions reduction that will go a long way in the protection of both ozone and climate.

HCFC phase-out management plan (HPMP) Stage-II

The HPMP Stage-II launched in February, 2017 by the MoEF&CC targets the complete phase-out of HCFC-141b in foam manufacturing sector by 2020. Further, the target is to phaseout HCFC-22 from six major room air-conditioner brands in the country by 2022 and to train about 17,000 refrigeration and air-conditioning (RAC) technicians on alternative technologies and good servicing practices.

The HPMP Stage-II would also address the capacity building and awareness about the harmful effects of HCFCs with regards to Ozone Depletion and global warming both from emissions of HCFCs and energy consumption in RAC Sector. The HPMP Stage-II also prioritizes phase-out of HCFCs and increasing energy efficiency in building sector.

Impact of HPMP Stage-II

Successful implementation of the HPMP-Stage-II will result in sustainable reductions of 8,190 MT or 769.49 ODP tons of HCFC consumption from the starting point of 1691.25 ODP tons in 2023, contributing to India's compliance well in advance with the control targets for Annex-C, Group-I substances (HCFCs) under the Montreal Protocol (Figure 4).

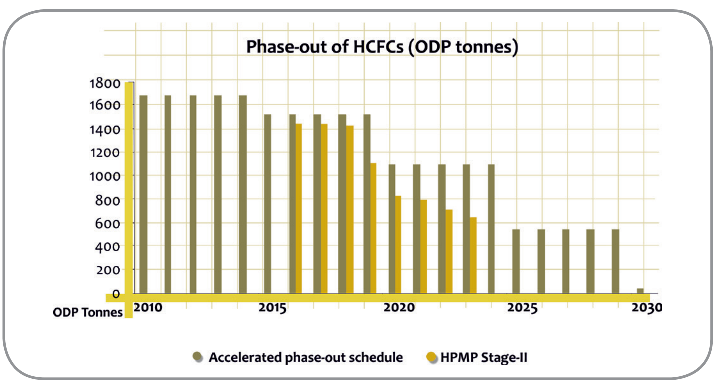


Figure 4 Phaseout under HPMP Stage-II

In addition, the project will result in net direct CO2-equivalent emission reductions of about 8,530, 900 Metric Tonnes CO2 eq. per year from 2023 onwards.

Kigali Amendment and phase-down of HFCs

HFCs have been introduced as zero-ODP alternatives to HCFCs in several applications. However, under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, HFCs are part of Kyoto basket of GHGs and these are potent greenhouse gases emissions of these gases contribute to the radiative forcing of the climate. While the objective of ozone layer protection is being addressed, climate change concerns are increasing on the other hand. Hence the growing use of HFCs as alternatives to HCFCs is a major concern.

HFC emissions are projected in a business as usual scenario to rise to about 3.5 to 8.8 GtCO2-eq in 2050 which is comparable to the reduction of 11.6 GtCO2-eq achieved due to phasing out of ODS between 1988 and 2010 (UNEP, 2011b). This clearly means that without intervention, HFC emissions are projected to offset the climate benefits achieved by the Montreal Protocol through phasing out ODS. Globally, there are many ongoing efforts and discussions to address this issue of HFC phase down as part of the Montreal Protocol.

197 countries reached to a historical agreement for phase-down of HFCs under the ambit of the Montreal Protocol at its 28th Meeting of Parties held in Kigali Rwanda on 15th October, 2016. This is the Kigali agreement which is the latest amendment to the Montreal Protocol.

As per the agreement, countries are expected to reduce the manufacture and use of Hydrofluorocarbons by roughly 80-85% from their respective baselines, till 2045. This phase down is expected to arrest the global average temperature rise upto 0.5o C by the year 2100.

Countries have been divided into four groups having a specific schedule for HFC phase-down. This phase-down schedule is especially beneficial for countries where the baseline production and consumption of HFCs is currently very low but there is a high demand in the future as the economy grows.

Non-Article 5 countries

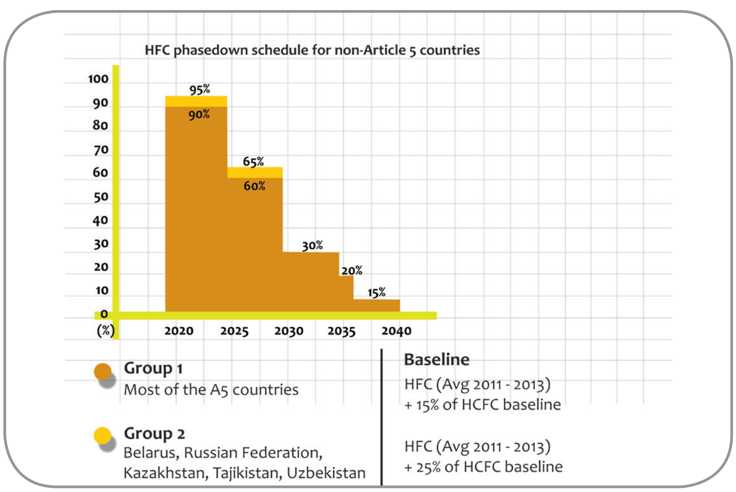


Figure 5 HFC phase-down schedule for non-Article 5 countries

- **Group 1** consists of developed economies like USA, UK and EU countries that will start to phase down HFCs by 2019 and reduce it to 15% levels by 2036. The baseline for reduction will be the average of 2011 to 2013 with an addition of 15% of HCFC baseline.

- **Group 2** consists of countries like Belarus, Russian Federation, Kazakhstan, Tajikistan and Uzbekistan that will start to phase down HFCs by 2019 and reduce it to 15% levels by 2036. The baseline for reduction will be the average of 2011 to 2013 with an addition of 25% of HCFC baseline.

Article 5 countries

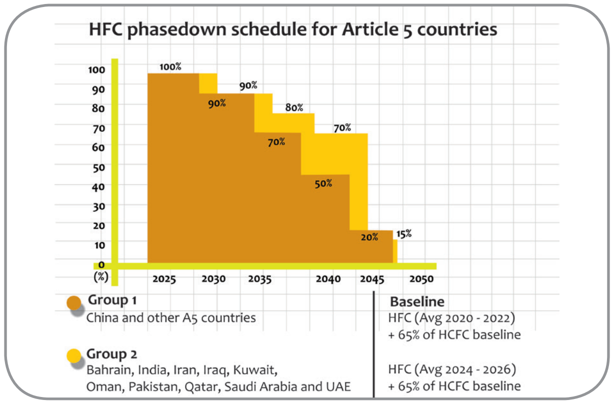


Figure 6 HFC phase-down schedule for Article 5 countries

- **Group 1** consists of emerging economies like China, Brazil as well as some African countries that will start phase down in 2024 and reduce it to 20% of the baseline levels by 2045.

- **Group 2** consists of developing economies and some of the hottest climatic countries like India, Pakistan, Iran, Saudi Arabia that will start phasing down HFCs with a freeze at the baseline in 2028 and reduce it to 15% of the baseline levels by 2047.

The Kigali amendment is unique, in which control measures of non-ODS substances have been included under the ambit of Montreal Protocol. Secondly, the agreement calls for "phase-down" instead of "phase-out" since the low-GWP alternatives are not yet widely available for all the applications where HFCs are currently used. The technical and financial assistance to meet the obligations of phase-down of HFCs in Article 5 countries will be met by the Multilateral Fund for the implementation of the Montreal Protocol. It is important to note that phase-down will be quantified in terms of CO2 equivalent emissions since HFCs have no ozone depleting potential.

Impact of Kigali Amendment

Energy Efficiency would be the main driver for successful implementation of Kigali Amendment. Policies and regulatory initiatives will drive the replacement of existing high energy consuming HCFC-22 and R-410A room air conditioning units with low-GWP energy efficient units. This would result in a triple benefit – improved energy efficiency, HFC phase-down and reduced GHG emissions.

This landmark amendment to the Montreal Protocol will play a vital role in helping countries leapfrog to low-GWP technologies while implementing HPMPs.

Impact on India's building sector

One of the objectives of India's HPMP Stage-II is to phase-out of HCFC-22 in room air conditioner manufacturing and servicing of refrigeration and air conditioning (RAC) sector. In a hot climate like India, the demand for air conditioners in India is expected to grow from 3.8 million a year to 6.2 million in 2020-21 (Ozone Cell, 2017). Moreover, space conditioning uses about 40%-50% of the total energy use in commercial buildings.

Thus, in a growing economy like India, the demand for refrigerant and energy use is only going to increase. Focusing the phaseout efforts in the building sector becomes obvious to achieve the HCFC phase-out targets as well as to reduce the HFC use in buildings. By promoting low-GWP technologies in the building sector during this early stage, India can leapfrog to low-GWP alternatives from HCFCs. The following chapters enumerate in detail about the HCFC use in the building sector and potential solutions for HCFC and HFC phaseout.

3 Significance of Building sector

SIGNIFICANCE OF BUILDING SECTOR 3

India is one of the fastest growing economies in the world. While the economic growth indicates several employment and wealth creation opportunities for the country, there is a growing concern about the impact on environmental resources. It is important to meet this rising energy demand in the most sustainable manner with the least environmental impact.

Construction activity contributed to about 7.8% of India's GDP in 2015 (Asian Development Bank, 2016). In addition to being a significant economic activity, construction also results in GHG emissions. While population and urbanization will continue to increase in a developing economy, it is worthwhile to note that the GDP growth per unit of energy has been higher in India at USD 8.4/ kg of oil equivalent compared to the world average at USD 7.4/ kg of oil equivalent (Figure 7). This indicates the use of energy efficient technologies and also the efficient fuel mix used for energy supply (Asian Development Bank, 2016).

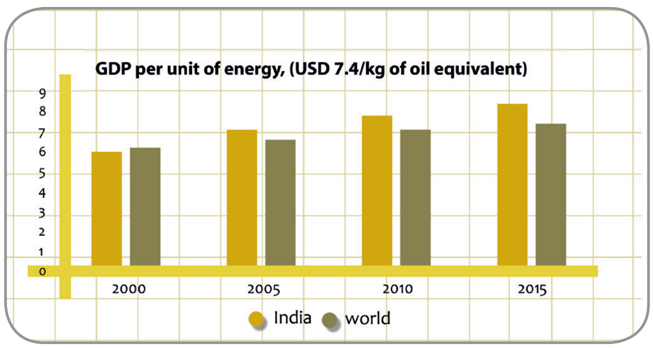


Figure 7 GDP per unit user of energy

Current building stock in India and growth

Total constructed area in India was around 2100 million square meters in 2005 and is predicted to grow five-fold to reach 10,400 million square meters in 2030 (Environmental Design Solutions Pvt Ltd, 2010). This growth will be steered by the residential and commercial sectors which will expand by 4 to 5 times from 2005 levels. Expanding population and greater economic activity will be the main triggers for this growth.

Commercial space is expected to increase from a total stock of 458 million square meters in 2005 to 3435 million square meters in 2030 (CAGR of 8.39%). Commercial space can be further divided into retail, offices, hospitality, hospitals, and educational/ institutional buildings.

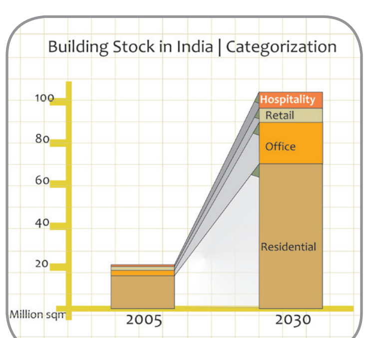


Figure 8 Building stock of India
Data source: (Environmental Design Solutions Pvt Ltd 2010)

An Energy Conservation and Commercialization (ECO-III) study estimated the total commercial floor space area to be approximately 516 million square meters in 2005 and expected this to expand by around 3 times to around 1,930 million square meters in 2030 (Kumar et al., 2010). It may be concluded, therefore, that about 70% of the 2030 commercial build stock is yet to be built in India. Therefore, given the substantial demand for new buildings, it is important to ensure using low-GWP alternatives for cooling and energy efficient building designs to keep the national GHG emissions in check.

Energy use and demand from building sector

According to IPCC Assessment Report 5, buildings accounted for a significant 32% of total global energy use in 2010 (Lucon et al., 2014a). Due to relatively larger building stock of residential sector, it accounted for 24% of the total energy use compared to commercial buildings that accounted for only 8% (Figure 9).

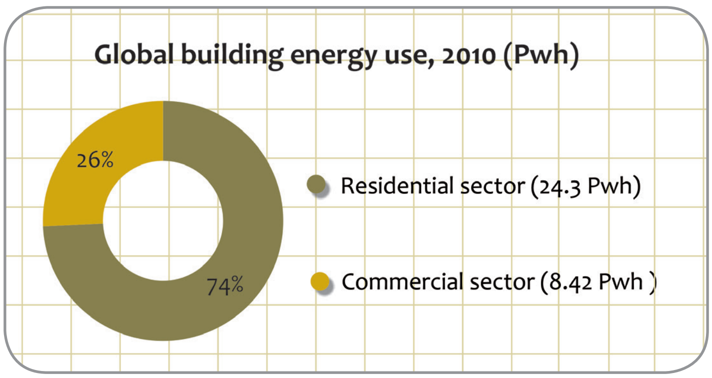


Figure 9 Global building energy use, 2010

Given that more than half of the world's new construction is taking place in China and India alone (BEE, 2008), building energy use will constitute a significant part of total energy consumption. In 2010, the annual per capita energy use of Asia Pacific was 26% of the global building sector (Lucon et al., 2014a). While global building energy use is projected to double or triple by 2050, Asia's share is projected to increase to 35% by 2030 (BEE, 2008).

The building sector in India is already consuming close to 40% of the electricity and this is expected to increase to 76% by 2040 (CSE, 2014). As per the Bureau of Energy Efficiency, residential building sector consumes 26% and commercial building consumes 11% of the total energy use (BEE). The International Energy Outlook 2016 report projects the growth in energy consumption in the residential sector by 3.2% per year and the commercial sector by 3.7% per year (EIA, 2016). Clearly construction activity is only to going to increase in India.

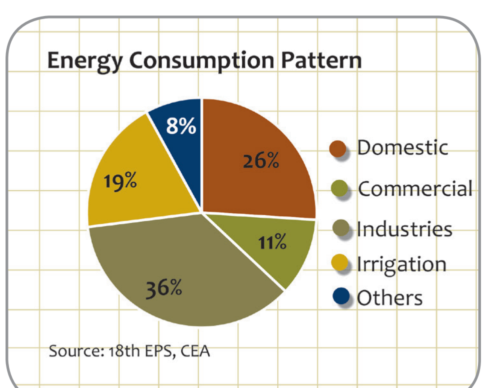


Figure 10 Building energy use in India

Construction and urbanization have a strong correlation with energy use and climate change. Globally, cities occupy only 2% of the earth's total land area but account for 75% of total resource use and nearly 80% of global GHG emissions (Lindfield and Steinberg, 2012). India has the second largest population in the world and 31% is living in urban areas (Asian Development Bank, 2016). This has a huge impact on energy and resource consumption as well as the demand for built infrastructure.

Demand for space cooling in India

Significant amount of energy is used towards heating and cooling spaces that is required to provide thermally comfortable environment to occupants. In air conditioned commercial buildings, as much as 40%-50% of the energy end use is attributed to space conditioning. This demand for cooling is closely related to climate typology as well.

India has a predominantly hot climate where comfort cooling is required in some form for most of the year. Rising incomes and a natural preference for comfortable indoor temperatures are resulting in rapid growth of energy use for space cooling. Moreover, in a changing climate, where extreme temperatures and heat waves have started occurring in summers, the need for air conditioning is growing.

Currently, ceiling fans are the most commonly used means to provide comfort cooling. The market penetration of air conditioners in the residential building sector in India is only about % which is very less compared to 87% in a developed country like USA (EIA, 2016). However, the demand for air conditioners in India is expected to grow from 3.8 million a year to 6.2 million in 2020-21 (increase of 63% Cumulative Annual Growth Rate (CAGR) (Ozone Cell, 2017). People are using their growing incomes to purchase air conditioners and other energy using equipment to improve their living standard.

In this context, promoting space cooling equipment that use low-GWP refrigerant and are energy efficient is critical. It is important to prevent locking-in measures in buildings that do not align with ozone and climate change mitigation goals. The challenge is great, but so are the opportunities.

Global Greenhouse Gas Emissions from Buildings

GHG emissions from global building sector have more than doubled since 1970 to reach 9.2 GtCO2-eq emissions in 2010 accounting for 18% of all energy related GHG emissions (Figure 10). The largest growth in the building sector has taken place in Asia during this period (Lucon et al., 2014b).

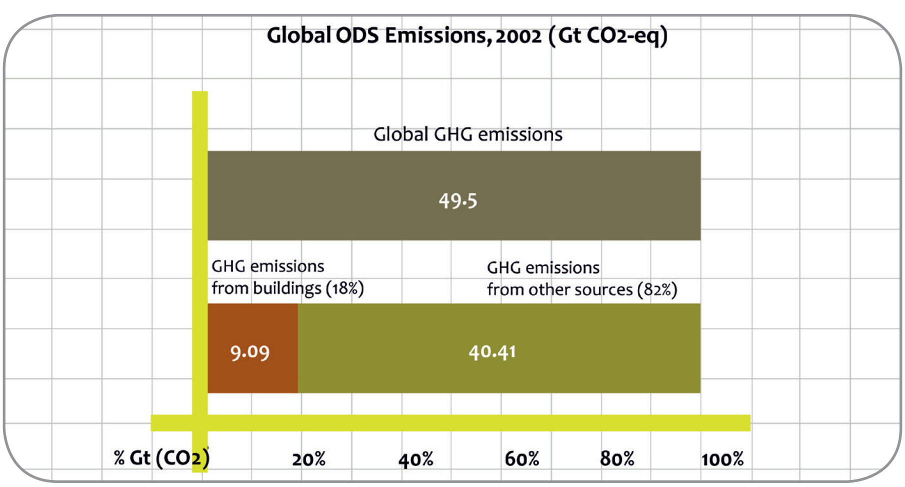


Figure 11. Global GHG (GtCO2-eq) emissions from buildings, 2010
Image source: (Lucon et al., 2014)

While the developed countries have a higher share of 47% of the building related GHG emissions, Asia's share is a significant 28% (2.6 GtCO2-eq) (does not include Japan, Korea, Australia and Pacific Island Countries) (Figure 11).

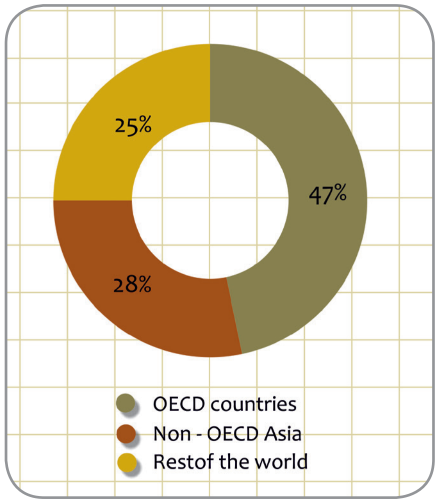


Figure 12 GHG emissions from building sector in Asia, 2010
Data source: (Lucon et al., 2014a)

Buildings consume energy throughout their life cycle, contributing to both direct and indirect greenhouse gas emissions. Indirect GHG emissions are due to the burning of fossil fuels at the power plants that supply electricity and other forms of energy to buildings. Direct GHG emissions are due to the leakage of refrigerants from air conditioning and refrigeration equipment during manufacturing, operations and disposal at end of life.

Indirect emissions due to energy consumption of buildings is at least double that of direct emissions (Figure 12) (Lucon et al., 2014a). Similar trend can be observed for building sector in the Asia Pacific as well. In commercial buildings, about 40% - 50% of the energy used is attributed to air conditioning for occupant comfort. Energy efficient buildings have a lower cooling demand allowing air conditioning equipment to be of a smaller size and hence use a lower refrigerant charge.

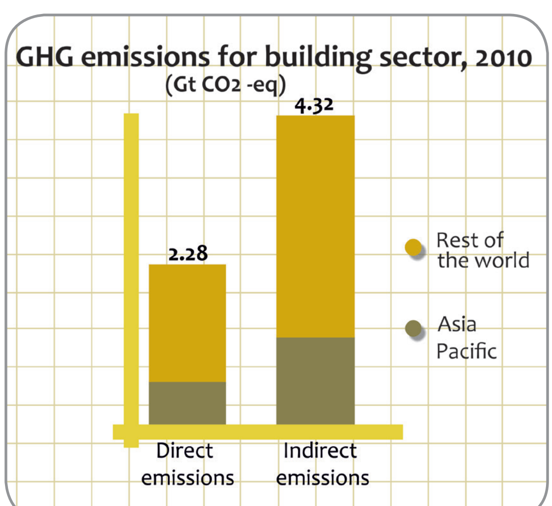


Figure 13 Direct and indirect emissions from building sector in Asia (GtCO2-eq), 2010
Data Source: (Lucon et al., 2014a)

Moreover, HCFC using equipment is also responsible for significant indirect emissions due to use of electricity during its operational lifetime. Thus, improving energy efficiency of buildings reduces the demand for refrigerants as well as reduces the GHG emissions.

F-gas emissions from buildings

F-gases or fluorinated gases include HydrofluoroCarbons (HFCs), PerFluorocarbons (PFCs) and Sulphurhexafluoride (SF6). Of these, HFCs are used as alternatives to HCFCs in the building sector. It is important to note that the emissions of F-gases being greenhouse gases emissions are controlled under the Kyoto Protocol. Although, HCFCs are also greenhouse gases, but their production and consumption are being phased out under the Montreal Protocol. Therefore, these have not been included in the Kyoto basket of gasses and UNFCCC.

In 2010, F-gas emissions accounted for 1 Gt CO2-eq globally. The IPCC Fifth Assessment report attributes 33% of the total global F-gas emissions in 2010 to the building sector (Figure 14). A substantial part of an additional 22.3% of F-gas emissions (21% from HFC and SF6 production and 1.3% from foam blowing), could also be attributed to buildings making it about 55% of the total F-gas emissions (Lucon et al., 2014).

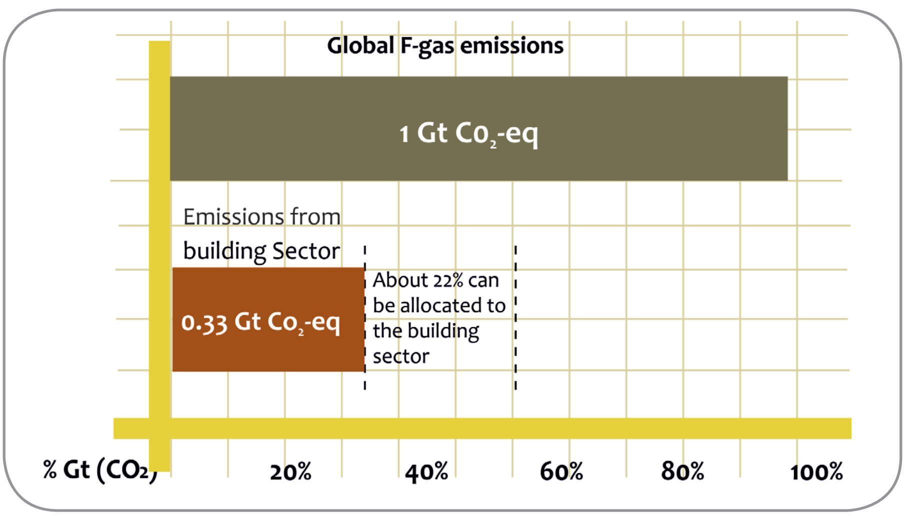


Figure 14 Global F-gas emissions (GtCO2-eq), 2010
Image source: (Lucon et al., 2014)

About 41% of the global F-gas emissions in Mt CO2-eq was from Asia Pacific in 2015. India was responsible for 13% of these emissions. With the HCFC phaseout in place, the demand for HFCs will continue to increase. Of these, the HFC Emissions from use of substitutes for ODS is projected to increase nine times by 2030 with respect to 2010 levels (EPA, 2012)

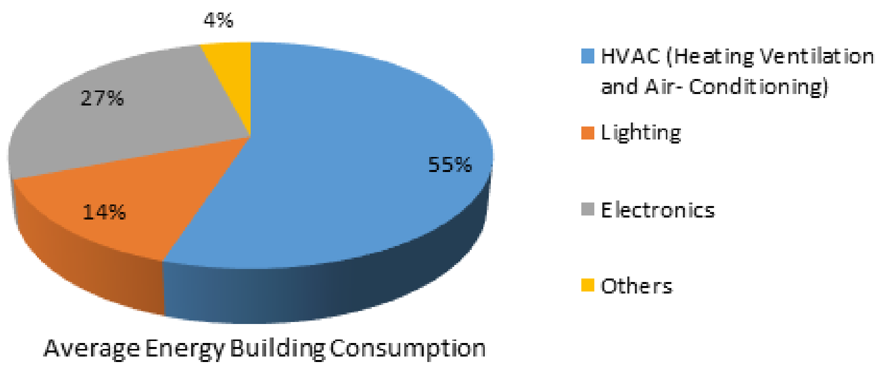


Figure 15: Average Energy Building Consumption
Data source: TERI, Roadmap to Energy Efficient Buildings

The major portion of energy consume by buildings its from air-conditioning (figure 15) It follows that the use of HCFCs in buildings significantly contributes to greenhouse gas emissions. Given that new buildings will continue to be built in India, addressing this sector for HCFC phase-out is imperative. In the knowledge of these forecast trends, the HPMP Stage-II has been designed to use low-GWP technologies and to avoid the phase-in of high GWP HFCs.

4 Use of HCFCs in Buildings

Used as refrigerants, HCFCs are present in refrigeration and air-conditioning systems in buildings. They are also used as blowing agents in manufacturing of foam used for insulation in buildings. HCFC based fire extinguishers have also been used some buildings especially the data storage and processing centers. HCFCs are largely used as refrigerants.

HCFCs have dominated the refrigerant market in Asia with a 68% share followed by HFCs (BSRIA, 2014). The low GWP refrigerants were merely 1% at 1,806 tonnes and hydrocarbons being highly flammable had a negligible share of only 423 tonnes (Figure 16). The Kigali Amendment will drive the uptake of low-GWP alternatives.

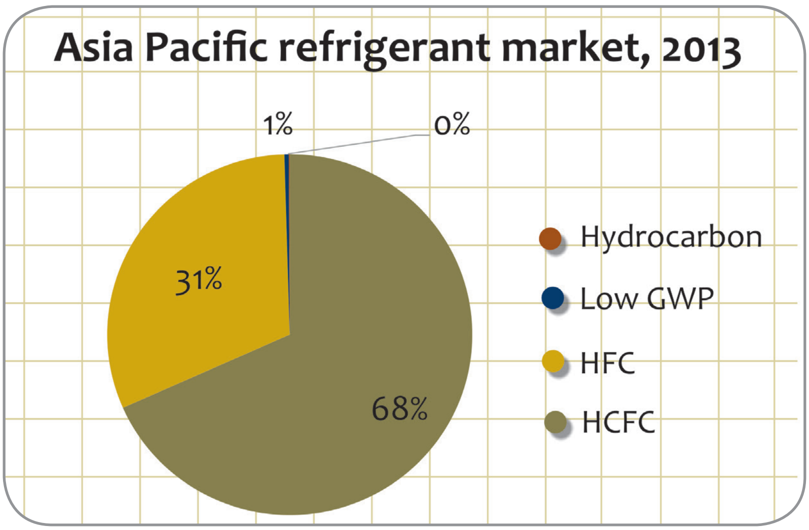


Figure 16 Refrigerant market in Asia, 2013

In 2013, the market share of HCFCs in the Asian air-conditioning and refrigeration segment was 58% and 78% respectively (BSRIA, 2014). HCFC-22 dominates this segment as refrigerant. While HCFCs have been most preferred refrigerants, their phaseout is bringing opportunities for alternative refrigerants and Figure 16 shows that HFCs are trending as the popular alternative in the Asian market.

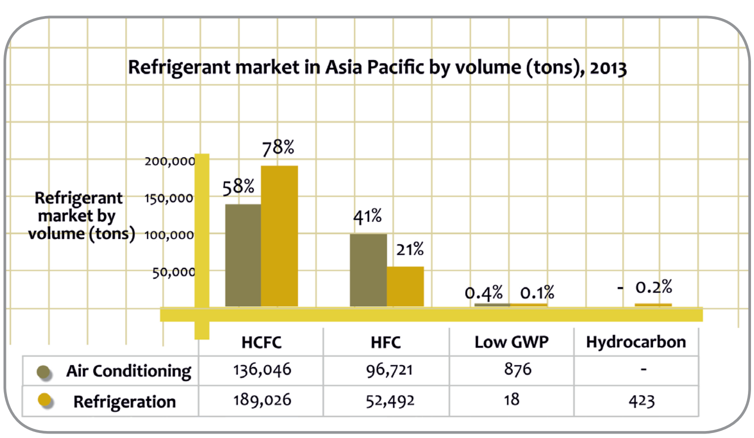


Figure 17 Refrigerant market by type in Asia

Production and consumption of HCFCs in India

India is a second largest producer and consumer of HCFCs after China among developing countries. It produces only HCFC-22. All other HCFCs, like HCFC-141b, HCFC-142b, HCFC-123, HCFC-124 etc. are being imported. HCFC-22 is used for both the feedstock and non-feedstock (controlled) uses.

43% of the HCFCs in India were used for refrigeration and air conditioning servicing in 2015 (Figure 18). The use of HCFCs was also significant for the foams sector with 21%. Of the remaining 36% of the HCFCs in India 35% is used as refrigerants in new equipment manufacturing.

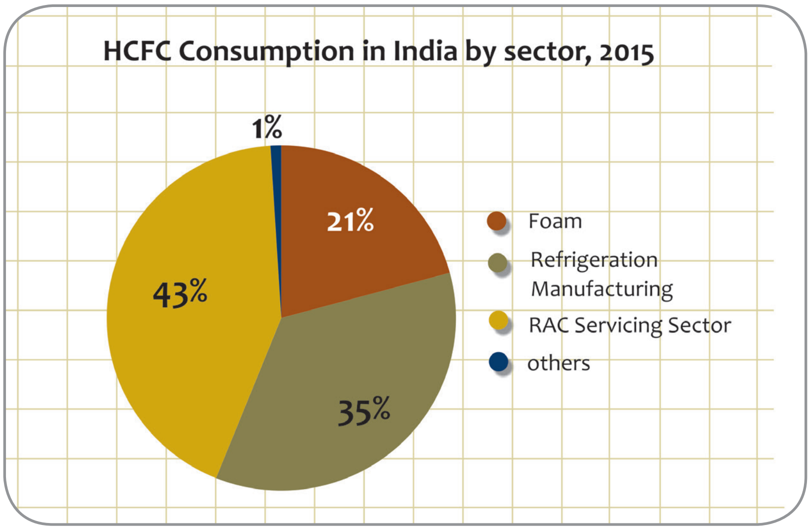


Figure 18 HCFC consumption by sector in India, 2015

At 78%, HCFC-22 is the most popular ODS being used in India compared to other ODSs such as R-141b, R-142b and R-123 (Ozone Cell, 2017). HCFC-22 is largely used as refrigerant (Figure 19).

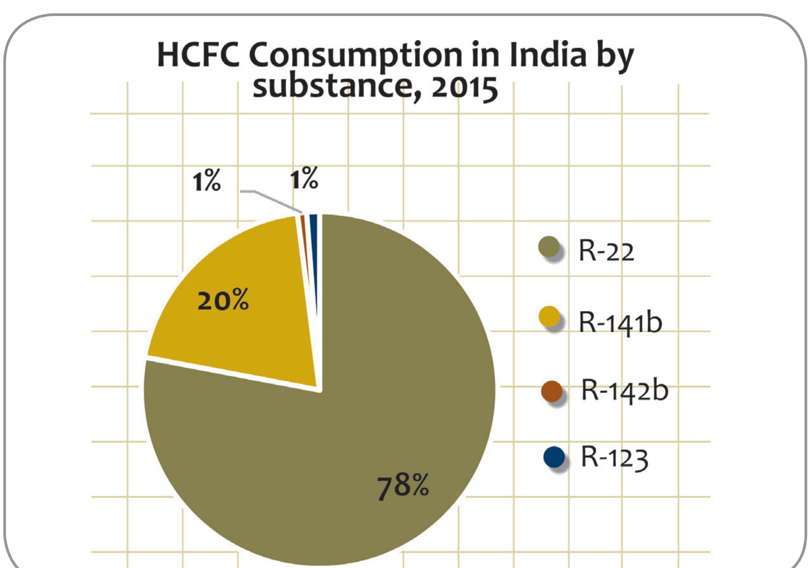


Figure 19 HCFC consumption by type in India, 2015

HCFC Production in India

Figure 19 shows total production of HCFC-22, feedstock uses and controlled uses from the baseline years (2009 and 2010) to 2015. It could be noticed that the production of HCFC-22 continues to be more or less constant as the installed production capacity was frozen since July 2000. There is a considerable decrease in production of HCFC-22 for controlled uses while there is an increase in the production of HCFC-22 for feedstock applications.

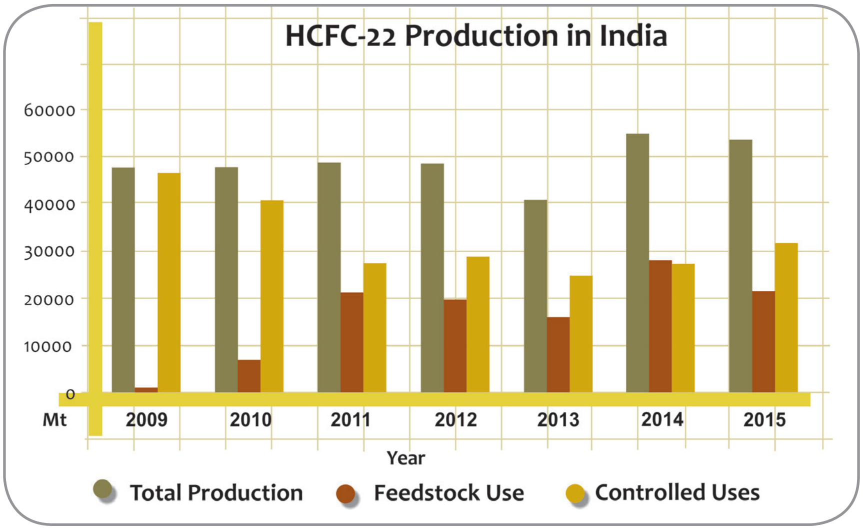


Figure 20 HCFC production in India, 2015

HCFC Consumption in India

India has been reporting the data on production, import and export of all the ozone depleting substances including HCFCs under Article 7 of the Montreal Protocol to the Ozone Secretariat since it became a Party to the Montreal Protocol. The calculated HCFC consumption based on the data reported during 2009 to 2015 is shown in Figure 21.

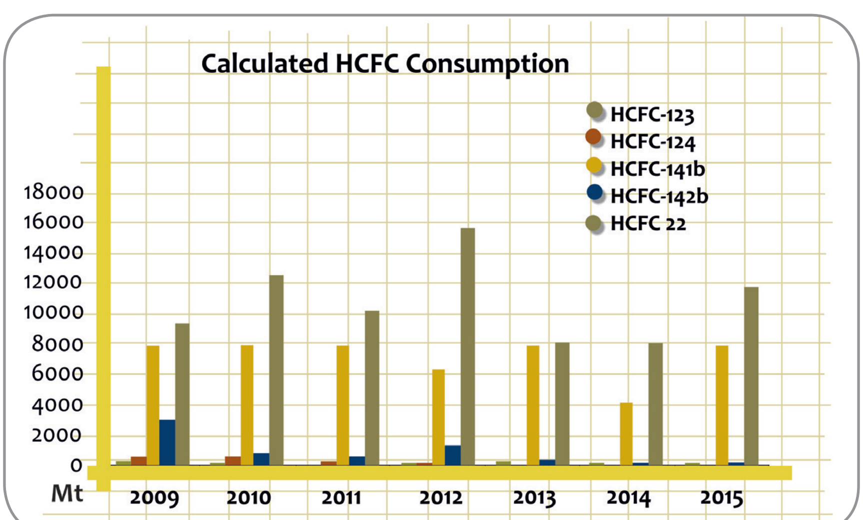


Figure 21 HCFC consumption in India, 2015

Building air conditioning and HCFCs

Building sector has been witnessing very high growth in the country both for the residential and commercial sub sectors to cater the need of growing population and GDP in the country. India being a tropical country, harsh weather conditions prevail in most regions in the country. Air-conditioning systems are used to provide comfort cooling or heating for building occupants. The role of HCFC as a refrigerant in air-conditioning systems is to remove heat from the occupied space and provide cooling, or vice versa.

Building heating systems typically use electricity or natural gas to generate heat, they do not use refrigerants except in heat pump systems. Therefore, these have not been addressed. Heat pumps using HCFCs as working fluid for heating are included here. In a limited way, heat pumps are energy efficient and also becoming popular in India.

HCFC-22, for over 60 years, has been the predominant refrigerant in small, medium-sized and large air-conditioning systems, with the exception of centrifugal chillers where HCFC-123 is used. 77% of HCFC-22 in India was used as refrigerants in room air conditioners followed by 14% in ducted split systems (Figure 22).

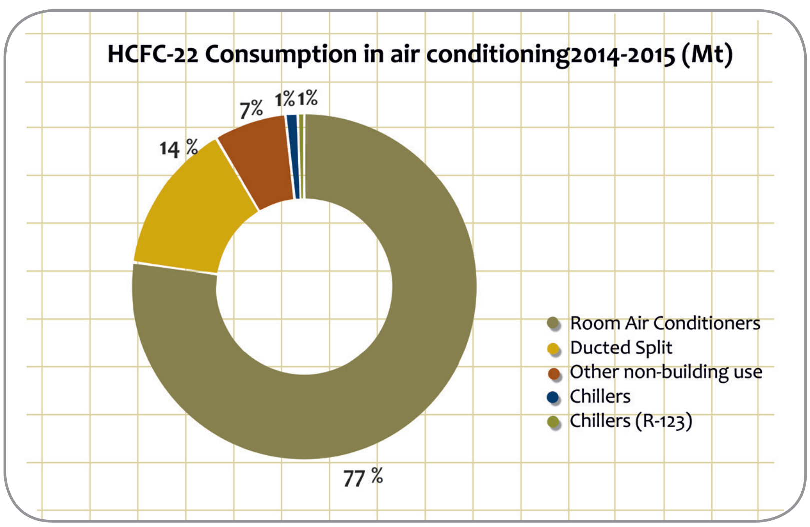


Figure 22 HCFC use in air conditioning, 2014-2015

Almost all the global manufacturing capacity for small residential air-conditioning systems is concentrated in Article 5 countries (UNEP-TEAP, 2014).

The size of an air-conditioning system for a building depends on the cooling capacity of the equipment and the type and size of the space. Cooling capacities of air-conditioning systems can range from less than 1 kW for unitary systems to several MW for large central systems (chillers). The average charge of HCFC-22 is approximately 0.25 to 0.30 kg per kW of cooling capacity. Broadly the systems used for air conditioning of building could be classified in the two categories, unitary systems and chillers.

Unitary Systems

Unitary air conditioning systems like window/ split units, multi-split units and variable refrigerant flow (VRF) are widely used for conditioning of spaces like residential buildings, offices and small commercial outlets. These could be further classified based on their capacity and design in the following:

Air Conditioners with < 3TR Cooling Capacity

These units are commonly used in residential houses. There is growing demand in the country. These are of various designs and are used as per the choice of building owners and requirement of the space. Most of such units, prior to 2015, have been using HCFC-22 and still there is use of HCFC-22 in such units which is being phased-out under the HPMP Stage-II. Some of these are shown in Figure 23.

Split Air Conditioner

Floor Mounted AC

Cassettes Type

Window AC

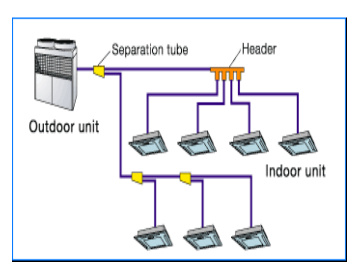
Figure 23 Unitary air conditioners less than 3 TR capacity

Unitary Air Conditioners with > 3 TR Cooling Capacity

These units are commonly used systems for small to medium commercial establishments. The demand of such units is also growing very fast. There are of various designs especially based on type of compressor used and cooling capacity. Such units have also been using HCFC-22 as refrigerant. Now the manufacturing is shifting to other refrigerants especially to HFCs. Some of such units are shown in Figure 24.

Ducted Packaged Units

Multi split units



Variable refrigerant flow (VRF)

Figure 24 Unitary air conditioners more than 3 TR capacity

Table 1 gives a summary of the typical characteristics of each type of unitary air conditioning Systems.

Table 1: Typical configurations of air conditioning systems

Source: Technical Options Committee Report on Refrigeration, Air Conditioning and Heat Pumps (May-2014)

Type		Primary configuration	System layout	Capacity range (kW)	HCFC-22 charge range (kg)
Small self-contained	Window	Small self-contained	Self-contained	1 – 10	0.3 – 3
	Portable	Small self-contained	Self-contained	1 – 10	0.3 – 3
	Through-the-wall	Small self-contained	Self-contained	1 – 10	0.3 – 3
	Packaged terminal	Small self-contained	Self-contained	1 – 10	0.3 – 3
Split (non-ducted)		Non-ducted split	Remote	2 – 15	0.5 – 5
Multi-split		Non-ducted and ducted split	Remote	4 – 300	2 – 240
Split (ducted)		Ducted split	Remote	4 – 17.5	1 – 7
Packaged rooftop		Ducted commercial	Self-contained	7 – 750	5 – 200
Ducted commercial split		Ducted commercial	Remote	10 – 750	5 – 250

Chillers

Chillers provide comfort air conditioning in large commercial buildings and building complexes. The chiller systems cool water that is pumped through heat exchangers in air handlers or fan-coil units for cooling and dehumidifying the air. Chillers also are used for process cooling in commercial and industrial facilities such as data processing and communication centers, electronics fabrication, precision machining, molding, and mining (particularly in deep mines with high thermal gradients). District cooling is another application that provides air conditioning to multiple buildings through a central large chilled water distribution system.

Types of chillers

a) Mechanical vapour compression chillers

Chillers commonly employ a vapour compression cycle using reciprocating, scroll, screw, or turbo (centrifugal or mixed axial/centrifugal flow) compressors. Heat typically is rejected through air-cooled or water-cooled heat exchangers. Evaporative condensers and dry coolers also can be used for heat rejection. Vapour compression chillers use either positive displacement or centrifugal compressors.

Positive Displacement Chillers

The positive displacement category includes reciprocating piston, rotary, screw, and scroll compressors. Not all refrigerants can be used in these systems because compressors generally are designed for specific refrigerants and applications. The positive displacement chillers mainly use HCFC-22 or alternatives like HFC-134a, R-407C, R-410A. There is still large number of chillers using HCFCs globally.

Figure 25 typical screw chiller

Centrifugal Chillers

Centrifugal chillers with one, two and three compression stages are commonly employed for large cooling capacity of 300TR or more for building air conditioning systems. Low pressure refrigerants like HCFC-123 are commonly used in these systems. There are numerous of such systems installed in the country for commercial building air conditioning.

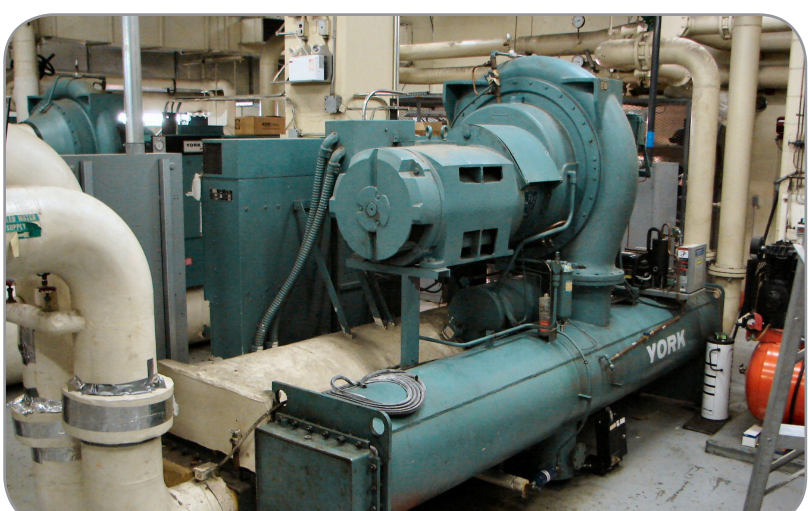


Figure 26 Typical Centrifugal Chiller

b) Typical absorption chiller

Absorption chillers work on the principle of vapor absorption and are used for large cooling capacities in central air-conditioning systems. The main energy source for such systems is steam, hot water or waste heat recovered from an industrial process. Electricity is only required for operating internal pumps and controls. These systems do not use HCFCs. Large absorption systems commonly use water and lithium bromide. Small absorption chillers may use an alternative fluid pair, R-717 and water where water is the absorbent. The efficiency of these systems tends to be relatively lower than the vapour compression chillers. Several efforts are being made to improve energy efficiency of these systems.

figure 26a

Chiller capacity ranges

Table 2 lists the various cooling capacities of chillers with type of HCFC used. (Most buildings, particularly in larger capacities, use multiple chillers)

Table 2: Typical configuration of chillers

Chiller Type	Approximate Capacity Range (kW)	Refrigerant used
Scroll, rotary, and reciprocating water-cooled	10 - 1,200	HCFC-22
Screw water-cooled	100 – 7,000	HCFC-22
Screw, scroll, rotary, and reciprocating air-cooled	10 – 1,800	HCFC-22,
Centrifugal water-cooled	200 - 21,000	HCFC-123
Centrifugal air-cooled	200 – 7,000	No use of HCFCs mainly use HFC-134a
Absorption (Ammonia-water, air or water cooled)	17 – 85	R-717 (Ammonia)
Absorption (Ammonia-water, water cooled)	700 – 3500	R-717 (Ammonia)
Absorption (water-lithium bromide – shell and tube)	140 -18,000	R-718 (Water)
Absorption (water-lithium bromide – shell and coil)	17 – 120	R-718 (Water)

Typical Installations of Air-Conditioning Systems in Buildings

Unitary Air Conditioners

Window air conditioners – All components required to cool or heat a space (condenser, evaporator, compressor and fan) are included in one or more factory made assemblies. Window air conditioners are also referred to as “unitary systems.” This system is commonly used for air conditioning of individual rooms rather than entire buildings. This through-the-wall portable system is commonly used in residential applications. Cooling capacities range from 1 kW to 10.5 kW, and the average charge size is about 0.7 kg (EPA, 2010).

Figure 27. Window air conditioner

Split air conditioners – Split systems have a separate indoor unit that houses the evaporator and fan; this unit is connected to a separate outdoor unit that houses the compressor and the condenser. Cooling capacities for this system range from 2 kW to 20 kW, and such systems are used in residential and small office buildings.

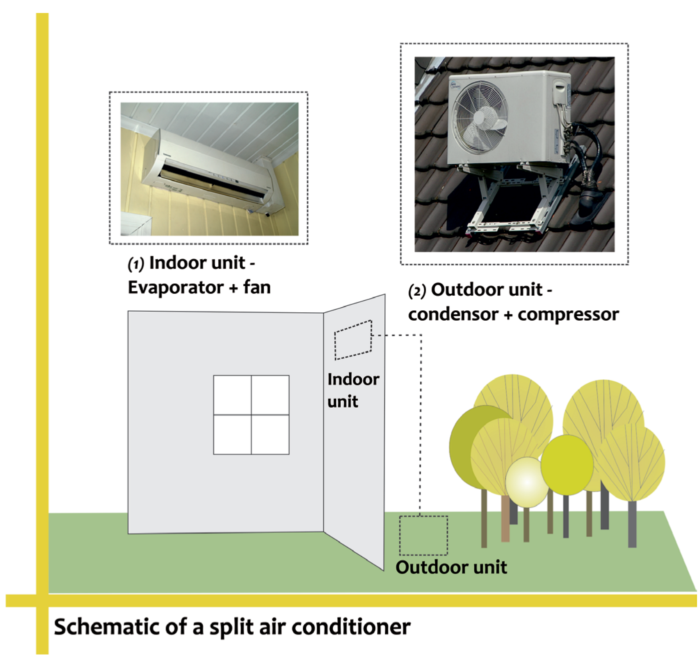


Figure 28. Schematic of a split system

Central air conditioning systems

These systems circulate cool air in the building though supply and return ducts. A central air conditioner can be a multi-split system unit, a packaged unit, or a chiller with air handling units.

Multi-split systems – These are used to cool several rooms or an entire building. The working principle is similar to that of the split system but involves multiple fan coil units and condensing units. The indoor fan coil units supply cool air to the occupied areas and the outdoor condensing units are typically placed on the roof or on the ground adjacent to the building. Multi-split systems can be ducted or non-ducted systems. Cooling capacities range from 4.5 kW to 135 kW for a non-ducted multi-split system, and the charge sizes range from 0.5 kg to 90 kg; cooling capacities for a ducted split system range from 5 kW to 17.5 kW with charge sizes of 1 kg to 6 kg.

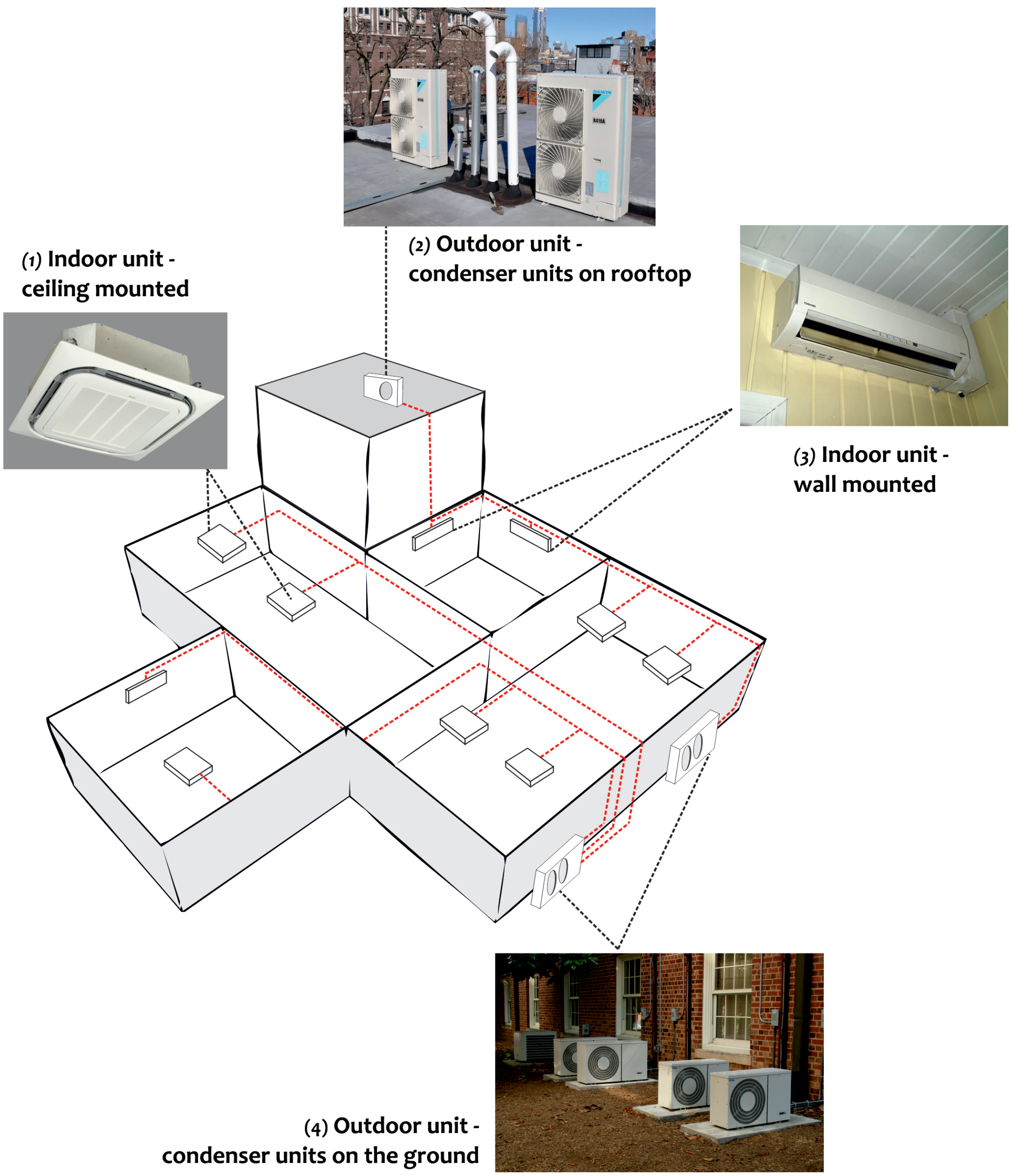


Figure 29. Schematic of a multi-split system

Packaged units – These are also unitary systems where all the air-conditioning components and air supply fans are included in a single assembly. The system is located outdoors, either on the roof or on the ground adjacent to the building. Packaged units cool the building through ducts. Cooling capacities of packaged units are usually larger than the multi-split systems and smaller than chillers. Packaged air conditioners often include electric heating coils or a natural gas furnace, which makes it a heat pump providing both heating and cooling.

10 ton packaged unit

Figure 30. A 10-ton packaged air-conditioning unit

Chillers – Chillers are used to cool very large commercial and industrial buildings. Working on the principle of a vapor compression refrigeration cycle, chillers are manufactured and factory-assembled as a packaged system. Chillers are usually located in a central plant inside or outside the building, limiting refrigerant containment to a central location. This centralized arrangement minimizes leaks and simplifies refrigerant handling. Chillers can be air-cooled or water-cooled based on the type of condenser.

Table 3 lists the HCFCs currently in use for various air-conditioning systems.

Air-Conditioning Systems	HCFCs Currently in Use
Heat pumps	HCFC-22
Unitary ACs	HCFC-22
Window units	HCFC-22
Packaged terminal ACs	HCFC-22
Chillers	HCFC-22, HCFC-123

Table 3. HCFC use in air-conditioning systems

Building insulation

Insulation can have a substantial impact on a building's energy-efficiency performance. Thermal insulation is used in walls, roofs, floors, and pipes to keep heat in or out of a building. Insulation is also used in refrigeration systems. As construction of new buildings increases in developing countries, so will the demand for building insulation.

In the process of manufacturing building insulation foam, HCFCs are used as blowing agents. During the foaming process, blowing agents create bubble-like cellular structures that are either open or closed. Closed cell foams are more rigid than open cell foams. The blowing agent is trapped in the bubbles, along with air and polyurethane (PU) solids, giving the foam its thermal properties.

Growth in thermal insulation foams continues to be driven by progressively stringent energy-efficiency requirements in appliances and buildings (UNEP, 2011a; Foams TOC). In India, only 14% of the total ODS used for insulation is used in buildings (Ozone Cell, 2017).

Several types of foams are used in building/construction applications:

1. **Extruded polystyrene (XPS) boards** are used as extruded sheets or boards. HCFC-22 and HCFC-142b are commonly used as blowing agents.

2. **Polyurethane (PU)** is used as rigid continuous panels, discontinuous panels, spray foams, board stocks, blocks and pipe-in-pipes. PU is used as insulation for housing and in commercial and industrial buildings (in walls, roofs, floors, tanks and pipes). HCFC-141b is commonly used as a foam-blowing agent.

Insulation typically remains intact for the lifetime of the building, which ranges from 25 to 70 years.1 Many countries in the US and Europe have increased the requirement for the amount of insulation to be used in homes/buildings over time as energy-efficiency standards have become more stringent.

Table 4 lists the HCFCs currently in use and the different foam insulations used in different areas of buildings.

Foam Type	Use	HCFC Currently in Use
XPS board	Walls, floors, roofs of residential and commercial buildings	A blend of HCFC-142b andHCFC22 (60:40) mixture)
Continuous panel	Walls, roofs, industrial buildings	HCFC-141b
Discontinuous panel	Cold storage; common in developed countries.	HCFC-141b
Spray	Primarily used for retrofitting applications	HCFC-141b
Board stock	Walls and roofs	HCFC-141b
Block	Roofs, cold storage	HCFC-141b
Pipe	Insulation of pipes used in heating and cooling systems	HCFC-141b
PU rigid insulation	Domestic refrigerators and freezers	HCFC-141b

Table 4. HCFC use in building construction foams

For a long time, non-ODS substances like hydrocarbons and liquid CO_2 have been used in the insulation sector. India has reported the use of non-ODS polyols in the manufacturing of 82% of building insulation in 2014 (Ozone Cell, 2017).

Not-in-kind alternatives like glass fiber insulation are commonly used in the residential buildings sector where cost is a major concern. As insulation requirements become more stringent, the thickness of these natural materials will have to increase to compensate for lower thermal conductivity. For this reason, it is necessary to use alternatives that are thinner and yet have better thermal resistance.

Firefighting

Fire protection is a highly regulated sector in most countries. ODSs are used as firefighting agents or fire suppressants. Requirements for firefighting agents include issues such as space, weight, safety, "cleanliness" (no residue), effectiveness against specific classes of fires and the ability to adapt to special circumstances (e.g., very cold conditions).

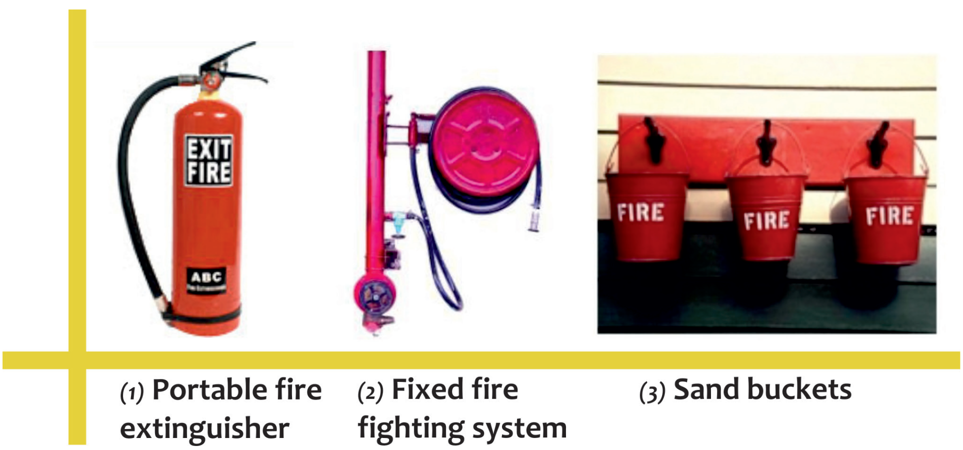


Figure 31. Firefighting systems

Halons were widely used in fixed and portable fire extinguishing systems in the 1960s. These high ODP substances were phased out in 2010 in developing countries. Due to the occasional use of these systems, there are many legacy fire extinguishing systems still operational in buildings. The selection of alternatives depends on the hazard being protected.

5 Steps to Phasing-Out HCFCs from Buildings

STEPS TO PHASING-OUT HCFCS FROM BUILDINGS 5

From the information presented in the previous chapters, it is evident that buildings are major users of HCFCs that contribute substantially to ozone depletion and climate change. Phasing-out HCFCs from buildings is a huge challenge, since new construction will continue to increase in rapidly developing country like India. However, the HPMP Stage-II has prioritized phaseout initiatives in the building sector; especially for foams and air conditioning. Further, as per the Ozone Depleting Substances (Regulation and Control) Amendment Rules, 2014 the use of HCFCs as refrigerants and in foam manufacturing will be prohibited from 1st January, 2025 and 1st January 2020 respectively.

The good news is that ozone and climate friendly interventions can be made in the 70% of the new building stock that is estimated to be built by 2030. Studies have shown that approximately 30% of the projected global CO2 emissions from residential and commercial sectors (2010 baseline) could be cost-effectively reduced by around 2020 (Barker et al, IPCC, 2007). The challenge is that the uptake of new technologies need to be in synchronization with this development.

Approach for HCFC phaseout in buildings

A three pronged approach is the key to phasing-out HCFCs from the building sector. The measures enumerated in this approach could be implemented simultaneously or in a progressive manner. Each measure may require the involvement of different stakeholders (Figure 32).

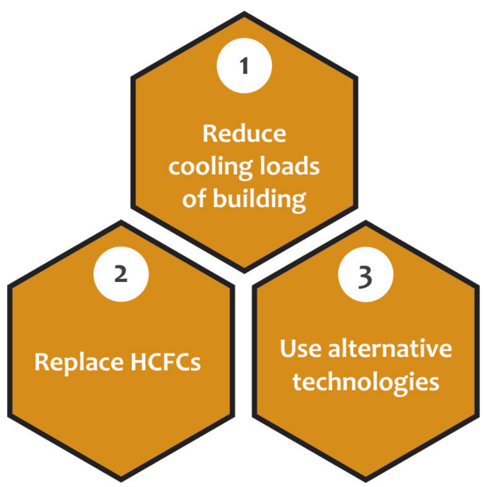


Figure 32. Steps to implementing HCFC phase-out

1. Reduce cooling loads in buildings

The most important step in achieving HCFC phase-out is reducing the demand for refrigerants through energy efficient building design and equipment.

HCFCs are used as refrigerants in air-conditioning equipment to heat and cool spaces. Refrigerant charge (the quantity of HCFCs filled in the system) depends on the size of the equipment, which in turn, is determined by a building's heating and cooling loads. Good building design with adequate insulation will minimize heat transfer between the internal space and the external environment, thereby reducing heating and cooling requirements. Energy-efficient buildings with lower heating and cooling needs can install equipment with smaller capacity, using less refrigerant. Thus, energy-efficient buildings can directly reduce the demand for refrigerants.

Further, energy-efficient buildings consume less electricity and thus produce lower indirect greenhouse gas emissions. While producing the same amount of cooling as conventional models, energy-efficient air-conditioning and refrigeration equipment use less refrigerant and electricity. This energy savings is beneficial to both ozone protection and climate change efforts, underscoring the necessity of addressing building energy efficiency when phasing-out HCFCs.

The approach to improve energy efficiency and design strategies is explained in detail in Chapter 6. Key concepts are summarized below (Figure 33).

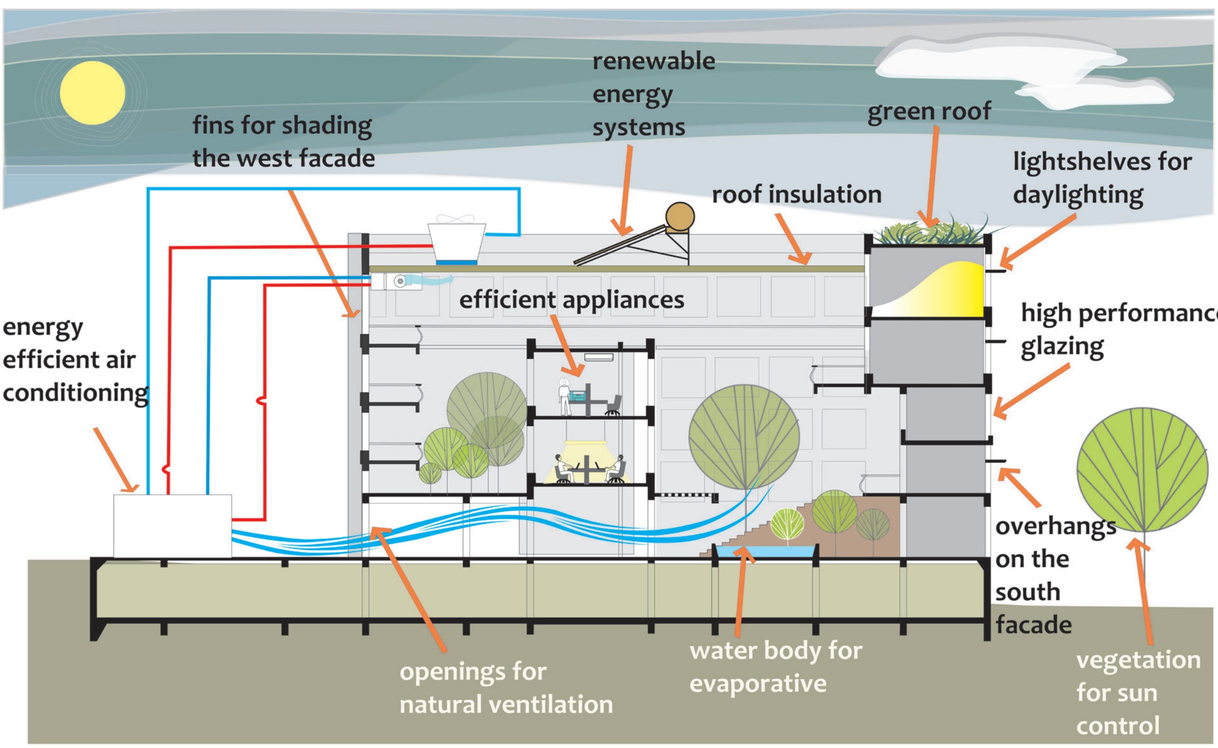


Figure 33 Steps to reduce refrigerant demand through energy efficient building design and equipment

- **Reduce envelope loads**

  To start with, a good building envelope should be ECBC compliant. This includes, but not limited to having the right orientation, reduced window-wall ratio, appropriate shading devices, envelope materials with code compliant U-values, and other passive cooling strategies. This approach will result in substantial reduction in cooling requirement without any compromise to occupant comfort.

- **Reduce internal loads**

  Using energy efficient light fixtures and a reduced connected load will reduce the heat rejection inside the space. Further, using daylight will reduce the need to use the light fixtures. These strategies will directly impact the cooling requirements of a building.

- **Optimum indoor temperature**

  Air conditioning systems are sized to provide cooling for a certain temperature and humidity range. The cooling system sizes can be reduced by about 2%-4% for every 1°C rise in the design set point. This would reduce the cooling loads and quantity of refrigerant charge required for the system.

- **Energy Efficient Heating, Ventilating and Air Conditioning (HVAC)**

  Once the cooling requirements are reduced, the size of the air conditioning required will be small. Using an energy efficient equipment will further reduce the size required for cooling. Smaller equipment will have a smaller refrigerant charge. Using star rated equipment for smaller air conditioning systems and Energy Code compliant efficiencies for larger systems such as chillers will help in reducing the refrigerant demand in buildings.

  Further, policies and program promoting energy efficiency in building and equipment is essential to achieve phaseout in the entire building sector. This is explained in detail in Chapter 10. Guidelines for increasing energy efficiency is given below. Policy makers can consider this flowchart as an approach to identify the gaps in existing policies and areas where new initiatives can be introduced.

Guidelines for increasing building energy efficiency

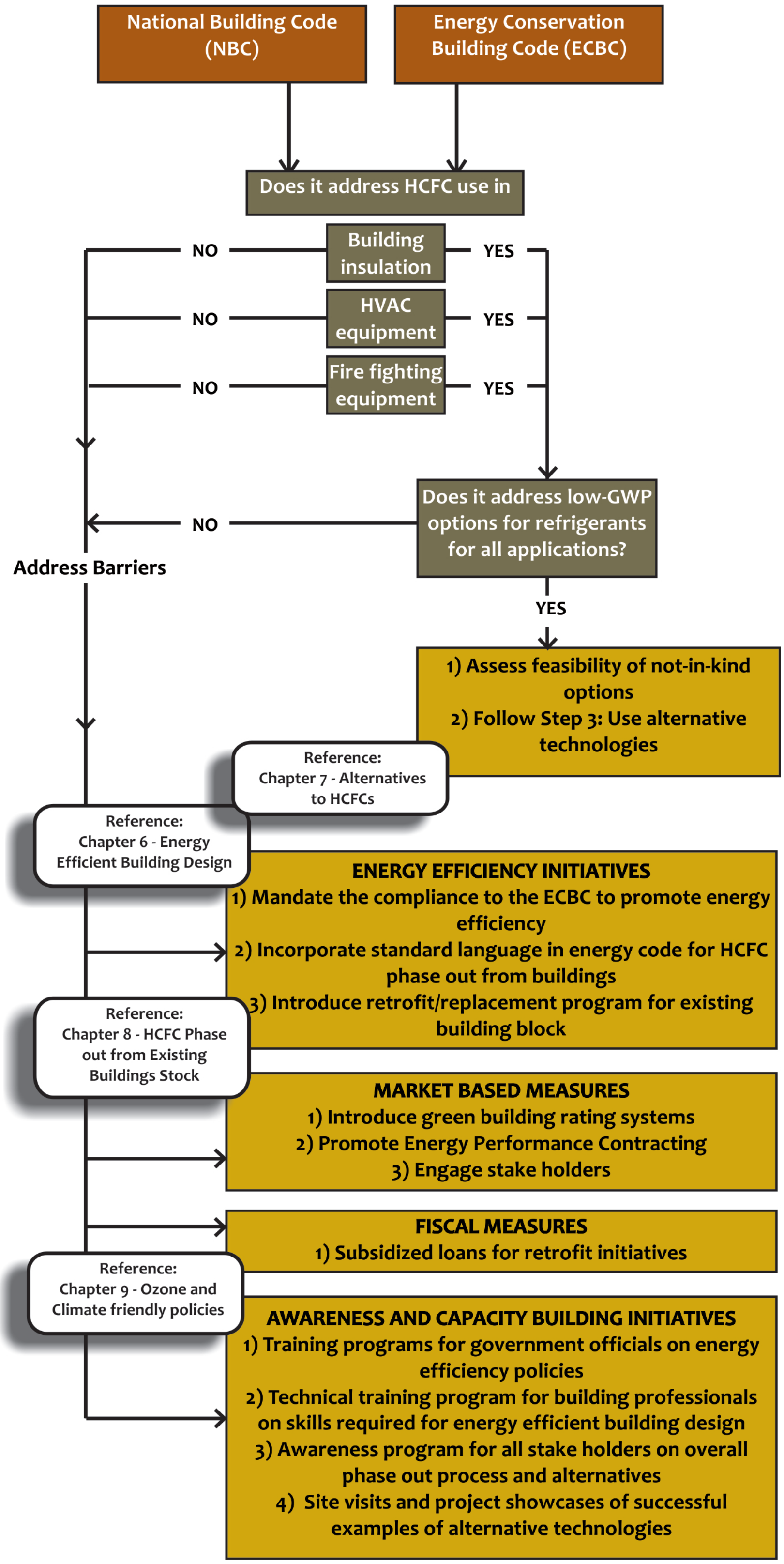


Figure 34. Guidelines for building energy efficiency

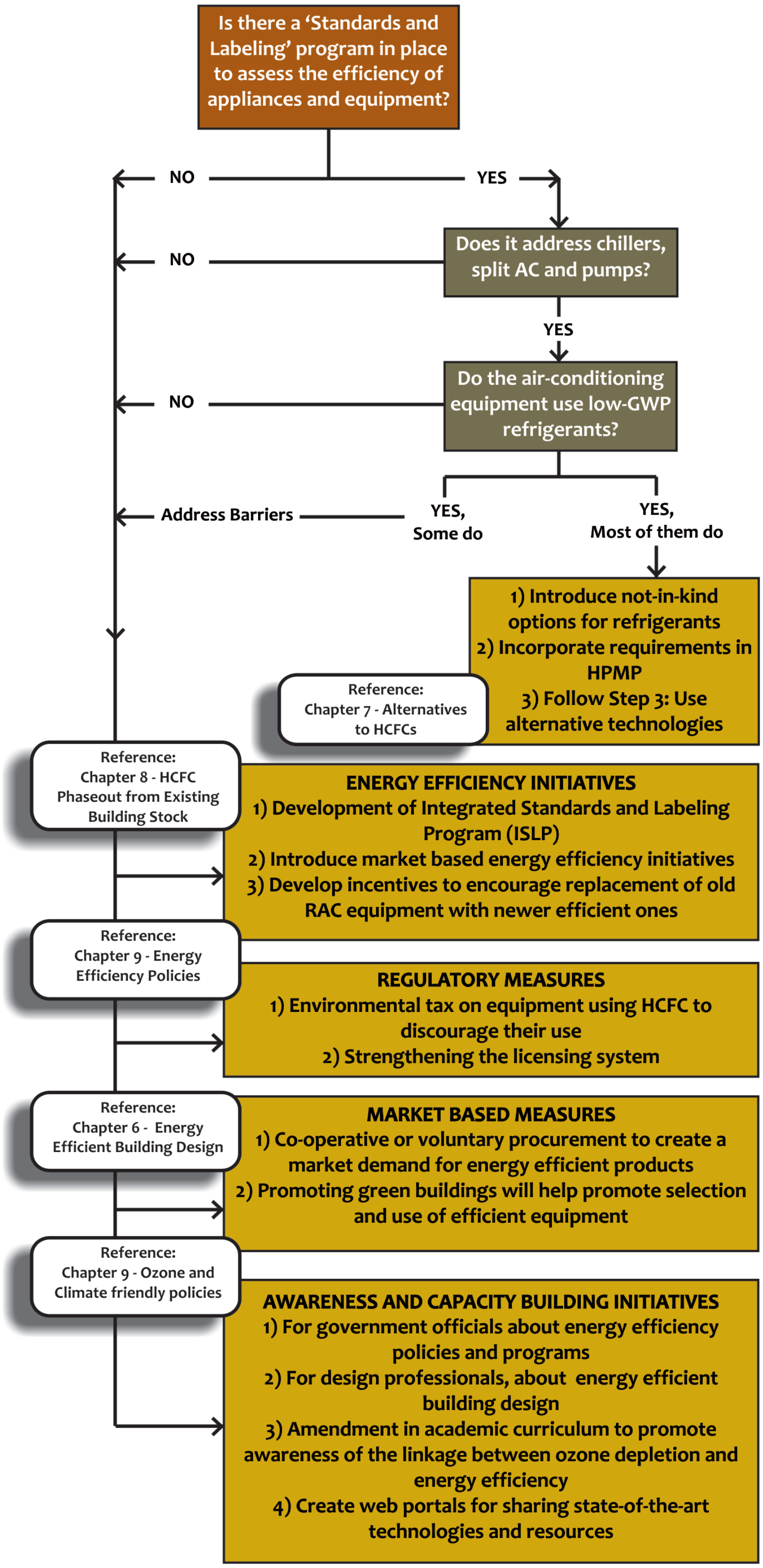


Figure 35. Guidelines for equipment energy efficiency

2. Replace HCFCs

Using low-GWP refrigerants and foam blowing agents is key to achieving successful phaseout of HCFCs in the building sector.

HCFCs were widely use since fluorocarbon refrigerants were invented. However, use of HCFCs further increased when CFCs were phased out. HCFCs became the most widely used alternative for some applications. The most extensively used HCFC is HCFC-22, which has an ODP of 0.055 and an atmospheric lifetime of 11.9 years. In order to achieve phase-out, HCFCs must be replaced with zero-ODP and low-GWP alternatives in the refrigeration, air-conditioning equipment, building insulation and firefighting sectors.

The HCFC alternatives have been explained in detail in Chapter 7. Key concepts are summarized below.

- ### Use zero-ODP refrigerants

  HFCs are being widely used to replace HCFCs in any applications. They do not deplete the ozone layer but, being potent greenhouse gases, are now controlled under the Montreal Protocol as per the Kigali Amendment to the Protocol. Thus, zero-ODP alternatives that also have low-GWP should be prioritized to potentially leapfrog the use of HFCs.

- ### Use low-GWP foam blowing agents

  HCFCs are used as blowing agents in the process of manufacturing foam insulation. Well-insulated buildings can prevent heat transfer from the interior space to the external environment, and good insulation is essential to energy efficiency. Blowing agents can affect the thermal (and other) properties of the insulation material. The main criteria for selecting foam-blowing alternatives are thermal efficiency, thickness of the material, and cost. Many low-GWP technologies are already available in this sector such as cyclopentane, CO2, Hydrofluoroolefins, methyl formate and water. Other alternatives such as glass fiber, mineral fibre, and glass wool are also available for insulation.

- ### Use alternative fire retardants

  Many non-ODS alternatives, such as ABC powder, water and CO2, have been used in firefighting for a long time. These alternatives are also widely acceptable in other applications. However, some specialized cases require “clean agents” where fluorinated substances might have been used; in these cases, zero-ODP and low-GWP alternatives should be considered.

3. Use alternative technologies

Alternative technologies for refrigeration, air conditioning, insulation and firefighting include low-GWP options such as natural refrigerants, as well as not-in-kind options, which do not use any kind of fluorinated gas. Since the largest use of HCFCs is in the air-conditioning and refrigeration sectors, most alternative technologies are targeted at these sectors. Alternative technologies are explained in detail in Chapter 7.

Some technically proven non-ODS and low GWP alternative technologies have already been used for air conditioning systems. Hydrocarbons, like propane, are already being used in both new equipment and to retrofit older systems that use HCFC-22. While some technological challenges, like system efficiency, have been resolved, issues such as flammability still need to be addressed.

Developing countries can use the HCFC phase-out as an opportunity to skip the step of transitioning to zero-ODP and high-GWP options such as HFCs, and go directly to cleaner alternative technologies. Stakeholders can be involved in the process of adopting alternative technologies. As shown in Figure 36 training programs, capacity building efforts, knowledge transfer and financial incentives will be required.

Guidelines for using alternative technologies

TRAINING AND CAPACITY BUILDING	1) National servicing training on good practices 2) Enhancing skills to use low-GWP alternatives 3) Capacity building of technical institutions
INSTITUTIONAL MEASURE	1) Initiate pilot projects demonstrating feasibility of new technology 2) Establish energy agencies to implement energy efficiency programs
ECONOMIC AND MARKET BASED INSTRUMENTS	1) Energy Performance Contracting 2) Financial incentives to use new technologies 3) Green building rating systems
INFORMATION AND OUTREACH PROGRAM	1) Public advocacy and training 2) Public awareness and campaign

Figure 36. Guidelines for identifying alternative technologies

6 Energy-Efficient Building Design

ENERGY-EFFICIENT BUILDING DESIGN 6

Increase in the total energy demand is inevitable given the projected demand for new building stock. Adding to that is the rising aspirations for a comfortable lifestyle and increasing time spent indoors. It is important to meet this demand in a sustainable manner by ensuring energy efficiency is integral to all buildings through policies and technologies. Although the building sector is the largest contributor of human-related greenhouse gas emissions, it also holds the greatest potential for reducing these emissions (Barker et al, IPCC, 2007).

Buildings are designed to last for 30 to 50 years. Energy-efficient building design reduces the requirements for cooling as compared to conventional buildings. The size of air-conditioning equipment in energy-efficient buildings is much smaller, leading to a reduced demand for ODSs and alternatives. Such buildings also minimize the use of electricity and other energy resources, reducing indirect greenhouse gas emissions associated with energy production.

Roadmap to energy efficient building design

Energy efficient buildings must harness all potential advantages from the site, surroundings, and should be designed for the climate. The decisions about building form, orientation, shading, and ventilation, taken during the early design stage have the most significant impact on the energy use of the building. Passive design strategies aim at achieving thermal comfort using as little active cooling and heating as possible. This means reducing cooling requirement during the summer and heating in the winter through appropriate orientation, external shading, appropriate amount of glazing, and natural ventilation.

Energy-efficient, climate responsive design requires a whole building perspective that integrates architectural and engineering concerns as early as in the schematic design process. An energy-efficient building envelope, coupled with efficient lighting system and air conditioning equipment will cost less to build and operate than a building where systems are designed in isolation from each other. Energy efficient buildings can typically reduce heating and cooling energy consumption by 30% to 50% (UNEP; Green Economy, 2011). India has some landmark buildings that have taken energy efficiency to the next level by achieving the goal of a Net Zero Energy building. Some examples have been discussed later in this chapter.

Energy efficient building design process

The first step to designing an energy efficient building is to integrate passive design principles. This is done by analyzing the climate, sun, wind, rain, geology and surrounding context and designing the building in response to these parameters. Appropriate building form, orientation, fenestrations, shading devices and materials will ensure that the building is designed to be climate responsive minimizing heat gains reducing cooling requirements. This first step gives the maximum cost and energy benefits to a building.

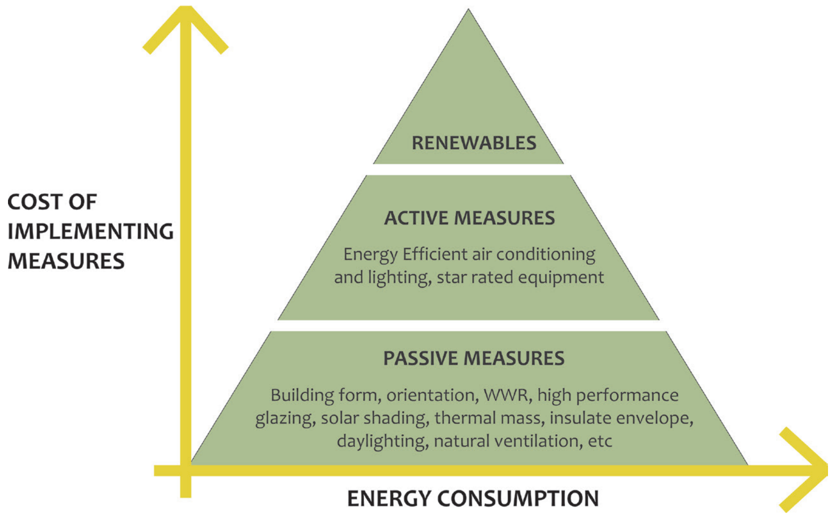


Figure 37 Energy efficient building design process

The second step is to install energy efficient lighting and air conditioning equipment to ensure building will use less energy during operations. Depending on the climate, low energy cooling options such as evaporative cooling, geothermal system, to name a few should be preferred over conventional air conditioning systems which can help reduce the overall energy use of the building. If conventional cooling systems are to be selected, then the most energy efficient system should be selected. Some projects might employ aggressive measures like dynamic shades, phase change materials, smart controls and other strategies to further reduce the overall energy use.

Once the energy use is optimized, the final step in the design process is to utilize renewable systems to generate energy required by the building. This clean source of energy will reduce the dependency on fossil fuels and further reducing the greenhouse gas emissions.

Further to the concepts discussed so far, It is important to remember that energy-efficient buildings do not guarantee lower energy consumption. Energy savings can be limited by a 'rebound effect' wherein efficiency gains from a new technology are undermined by an increase in consumption of the resource involved. For example, building occupants may feel they can use the air conditioner for longer hours because they know it is energy-saving (UNEP; Green Economy, 2011). While the increase in energy consumption is an ongoing issue that must be addressed, energy-efficient technologies remain an essential tool for reducing energy consumption, protecting the ozone layer, and mitigating climate change.

Integrated design process

Conventional building design follows a linear process where the planning, detailed design, construction, and operations takes place sequentially. Such a process often fails to recognize that buildings are part of larger, complex systems. As a result, solving for one problem may create other problems elsewhere in the system.

In contrast, an integrated process is highly collaborative. This approach requires the whole project team to think of the entire building and all of its systems together at the very initial design stage. This method emphasizes connections between different systems and communication among professionals and stakeholders throughout the life of the project. It breaks down disciplinary boundaries and rejects linear planning and design processes that can lead to inefficient solutions. This process enables the team to optimize systems, reduce operating and maintenance costs and minimize the need for incremental capital.

An integrated-design approach requires investing more time and efforts early in the design phase when there is flexibility to assess options to ensure that all project proponents are on board to achieve collective goals of sustainability. This approach has been shown to produce better results than investing in capital equipment upgrade at later stages. To achieve a successful Net Zero Energy project, it is essential to follow an integrated design process.

Using simulation tools in the design process

Building designs can be very complex today. The traditional linear design process is very limiting in terms of achieving an integrated energy efficient building. However, advances in computational tools for design applications, coupled with techniques from the field of artificial intelligence, have led to new possibilities in the way the computers can inform and actively interact with the design process.

Using simulation tools to optimize building design has now become an essential part of the design process. It gives an opportunity to assess several design iterations in response to real conditions and hence allow to optimize the building performance. Many simulations tools are available today including eQuest, EnergyPlus and others. Using these tools, the team can predict the building performance in terms of energy use, daylighting, carbon emissions and other criteria.

The figure below is an example of an output of iterative process analyzing various building systems using simulation software to select the best cost-effective technologies for a project.

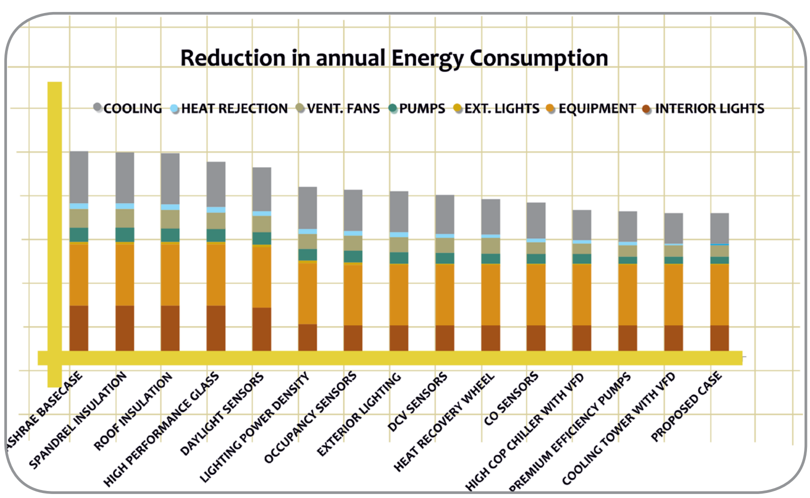


Figure 38 simulation output

Goals of an energy efficient building

A building is designed to keep occupants comfortable and this needs to be done using the least energy as possible. All buildings are subject to thermal loads. Thermal loads or heat loads denote the amount of cooling or heating required to provide occupant comfort. It is called heat loads because primarily, heat is either removed from the space for cooling or added to the space for heating. Thus, heat loads are specifically referred to as **cooling loads** and **heating loads**. It takes energy to either add heat to remove heat. Hence larger thermal loads will mean more energy used by the building to provide comfort.

A building's heating and cooling load determines the size of its air-conditioning system. Loads are impacted by climate, building design, function, as well as the materials and equipment used (Figure 39). Two primary components that determine these loads are described below:

1. **External heat loads:** The exterior façade of the building including exterior walls and roof, windows and skylights is called the building envelope. The property of these materials will determine the heat gain from outside to inside. This is called envelope load. The architecture of the building greatly impacts the envelope load. Warm air from outside entering the building through the window cracks is called infiltration. This adds unwanted heat to the building interiors.

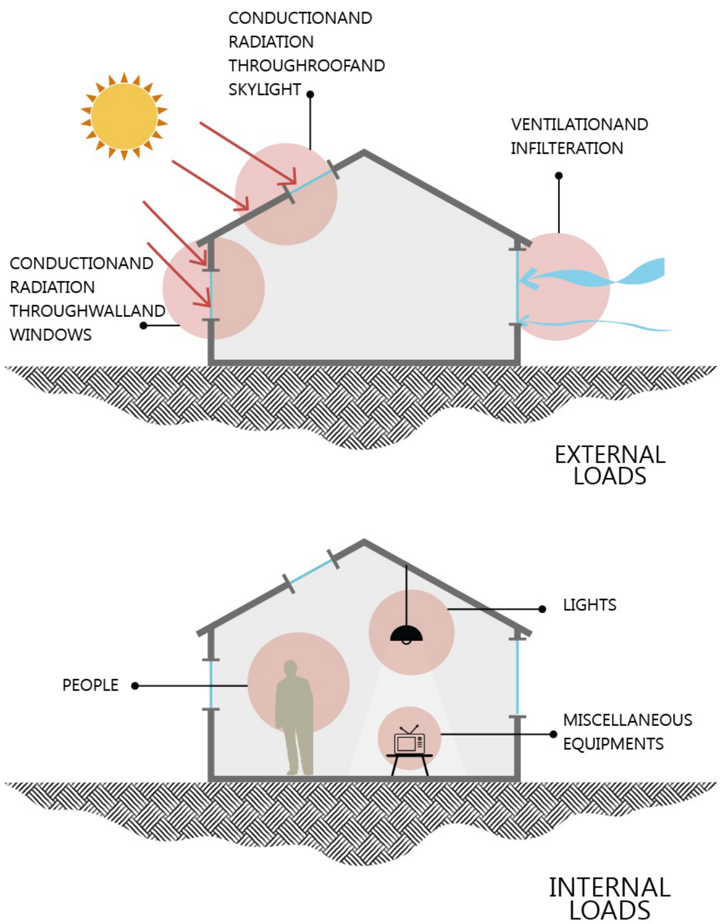


Figure 39 Thermal loads of a building

2. **Internal heat loads:** This includes electrical lighting, building occupants and services like elevators, appliances and equipment. All these components throw heat into the space and determine the 'internal load,' which is made up of the following:

a. **Plug load** – Heat expelled by electrical appliances and equipment such as computers, elevators, servers, printers, refrigerator, kitchen equipment and so on. These contribute significantly to the heat loads of buildings.

b. **Lighting load** – Heat expelled by light fixtures. For example, a typical fluorescent light fixture gives out 22% light and 78% heat (Lechner, Norbert 2000). Lighting load is substantially larger in commercial buildings compared to residential buildings.

c. **Occupancy load** – Heat produced by metabolic activity in the human body. A person doing light work generates about 100 watts of heat, and therefore contributes to a building's interior load. The occupancy load is usually higher in commercial office buildings than in residential buildings.

Figure 40 shows the typical cooling load breakup for a 40,000 sq. ft. commercial and 1,500 sq. ft. residential building.

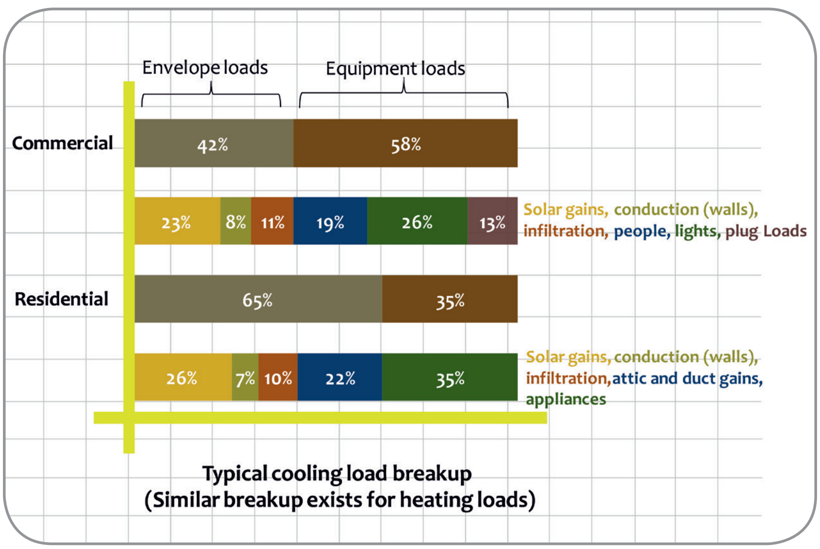


Figure 40. Breakup of typical cooling loads in a building

Load distribution is different for commercial and residential buildings due to differences in building use and occupancy. An effective building envelope can provide significant reduction in cooling loads for a residential building, while efficient equipment can have a major impact on commercial buildings.

Reducing thermal loads is the goal of an energy efficient building.

Once loads decrease, the refrigerant charge used in air-conditioning equipment can be reduced for smaller cooling capacities. Using alternative refrigerants for the remaining load requirements will complete the phase-out of HCFCs from HVAC systems.

Strategies for energy efficient building design

It is in the early stages of building design that there is greatest opportunity for achieving high environmental performance. Passive design principles take into account building form, orientation, materials, services and other aspects as explained below to reduce heat gain.

Building Form and Orientation Optimization

The most basic passive design principle for reducing external loads is to create a building form that is appropriate to the climate. The shape of vernacular buildings is often determined by the specific characteristics of climate typology.

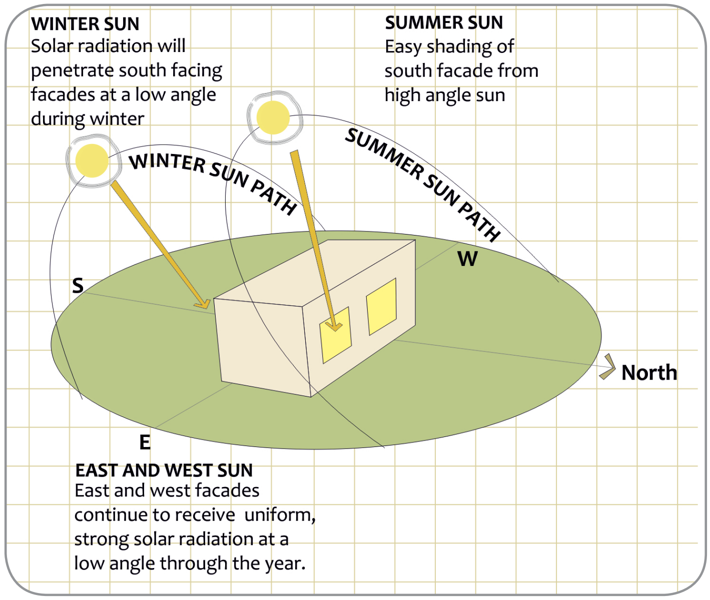


Figure 41 Building form and orientation for passive design

Heating and cooling loads vary depending on how buildings are oriented with respect to the sun. Buildings in cold climates, for example, are compact so as to minimize heat loss, while buildings in tropical climates are spread out to allow for air movement. In hot, dry climates, adequate shading is required to minimize the impact of solar radiation. Appropriate building orientation can result in reducing cooling demand and energy use compared to a wrongly oriented building.

Shading Strategies

Shading devices are critical in a hot climate in order to block direct solar radiation thereby reducing heat gain. Shading has the biggest impact on the energy saving potential in hot and dry climate followed by warm and humid, temperate, and composite climate. Efficient shading devices prevent noontime glare and summer overheating, while allowing sufficient sunlight to enter during the winter. Flexible systems such as blinds or moveable exterior shades allow users to control their solar access as needed.

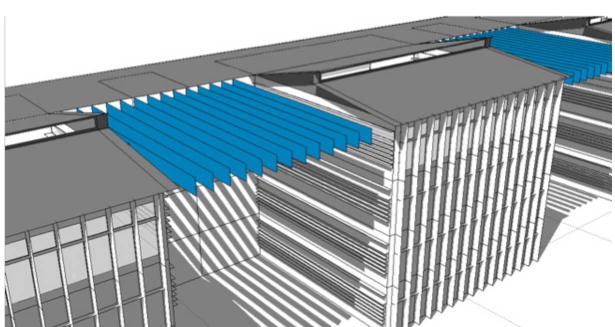


Figure 42 Shading design strategies

Shading devices along with fenestrations should be designed such that the direct solar radiation is blocked while allowing useful daylight in the building. This will ensure that fewer artificial lights are used during daytime resulting in less heat rejection from fixtures, and consequently lower cooling loads. Shading reduces the effective solar heat gain coefficient (SHGC) of the glazing. This means that a cheaper glass with high SHGC can be used instead of high cost, low SHGC glass.

Envelope Material Selection for Reduction of Heat Gain

A building envelope creates a barrier between the interior living spaces and exterior natural forces. Just like a building is designed to meet the structural loads, it should also be designed to meet the thermal loads. Thermal properties of the wall, roof and fenestrations play an important role in determining the cooling loads of a building.

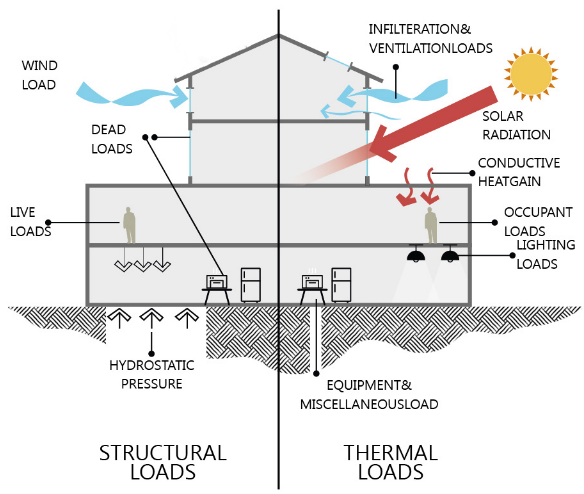


Figure 43 Analogy between structural loads and thermal loads

The thermal conductivity of walls, windows, floors, roofs and other exterior elements affects heat transfer. A good building envelope has high thermal resistance (indicated by the term 'resistance value' or 'R-value') and low thermal conductance (or 'U-value'). The Energy Conservation Building Code (ECBC) of India has a prescribed minimum R-value for walls, windows and roofs according to different climate zones.

Another passive design strategy is to use materials that have high thermal mass. Mass and density of a building material affects this heat storing capacity in buildings. High density materials such as concrete, bricks and stone have high thermal mass, while materials such as wood or plastics have low thermal mass. This heat storing capacity of building material helps in achieving thermal comfort for occupants by providing time delay which moderates fluctuations in the indoor temperature. This strategy works the best in a hot dry climate where the temperature changes between day and night can be about 10 to 15 degrees Celsius.

Adequate Window-to-Wall Ratios

The 'window-to-wall ratio' (WWR) indicates how much window space there is in relation to wall space on a given façade. This ratio has a major impact on building loads. In general, glass does not insulate as well as a solid wall. The amount of glass used on a building façade affects the solar heat gain in the buildings. In warm climate, a building with a WWR of 95% will have large cooling loads as compared to a similar building with a WWR of 40%. Calculating an appropriate WWR is key to reducing building loads and increasing energy efficiency.

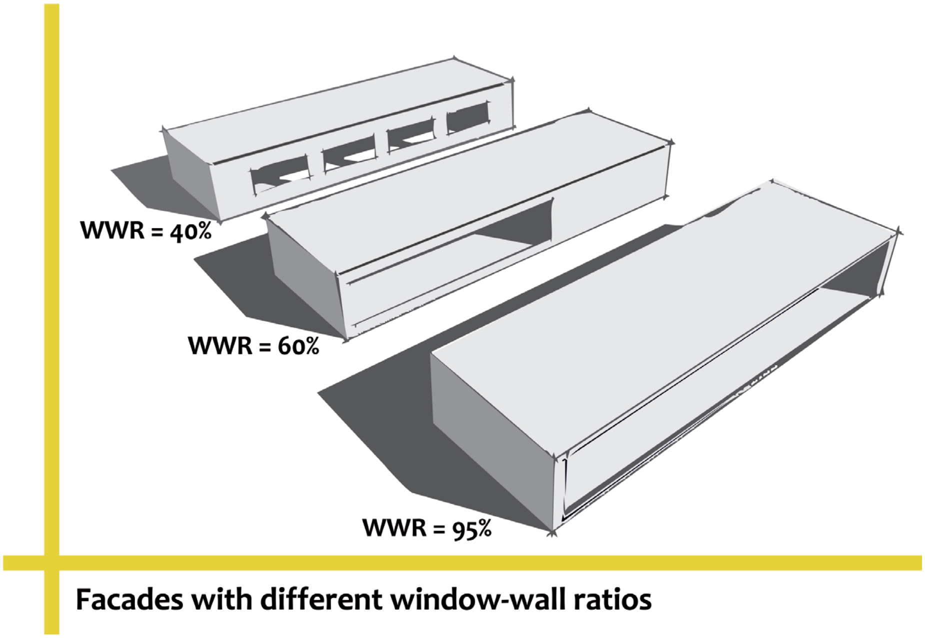


Figure 44. Window-to-wall ratios

Selection of Glazing to Optimize Heat Load and Daylight

Today glass is used extensively in buildings. Often commercial buildings have close to 90% glazing with very little opaque walls. This trend is also observed in premium residential buildings. While it lets in ample daylight, glass also contributes substantially to heat gain, and eventually, to increased air-conditioning requirements.

The type of glass and its properties affect both the amount of daylight and heat that passes into a space. The amount of light that passes into a given space is measured as Visual Light Transmittance (VLT)[2]. Heat gain is

[2] Visible Light Transmittance (VLT) is an optical property that indicates the amount of visible light transmitted. Expressed as a number between 0 and 1, higher VLT indicates more daylight.

measured using the solar heat gain coefficient (SHGC)1 for radiation and U-value for conduction. A good building design with a reduced building load will use glass with high VLT and low SHGC. When choosing glass, it is important to find a good balance between daylight and heat gain.

The Double Glazed Unit (DGU) is now a common feature in most commercial buildings and can also be found in some residential buildings. A typical DGU is comprised of two panes of glass separated by a gap which can be vacuum-sealed, or filled with air or an inert gas such as krypton and argon. DGUs equipped with this system have U-values2 ranging from 3W/sqm oK to about 1W/sqm oK, as compared to regular glass, which has a U-value of 6W/sqm oK. Thus, a DGU's thermal conductivity is at least half of that of regular glass which means it can reduce atleast 50% heat gain due to fenestration. This is significant for buildings that have extensive glazing. The 'low-emissive coating' on glass helps reflect heat and gives the glass a desirably low SHGC.

Another very important consideration when installing windows is how well they are sealed. Properly sealing a window is as important as using quality glass. Avoiding thermal bridging and leakages will ensure the optimal thermal performance of the entire system.

A fenestration system with low U-value and low effective SHGC can result in reduction of heating and cooling demand by 6-11% in moderate climate and between 8-16% in hot humid, hot dry, and composite climates. These savings increase to 8-17% for moderate, and 12-26% for hot humid, hot dry, and composite climates, if high performance fenestration system, with low-e glass, frames with thermal breaks, and well-designed shading are factored in.

It is important to remember that an opaque wall will always have better thermal performance than glass. Thus, buildings with large window-to-wall ratio are bound to have higher cooling loads. Even if such buildings have the most energy efficient equipment and air conditioning system, they still have not met the fundamental goal of reducing cooling load through building envelope.

Maximize daylighting

Daylighting is a building design strategy to use light from sun. Presence of natural light in an occupied space brings a sense of wellbeing, increases

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[3] SHGC is the fraction of incident solar radiation admitted through a window, both directly transmitted and absorbed, and subsequently released inward. SHGC is expressed as a number between 0 and 1. The lower the SHGC, the less solar radiation transmitted.

[4] The rate of heat loss is indicated in terms of U-value. The lower the U-value, the greater a window's resistance to heat flow and the better the insulation.

awareness of one's surrounding and also increases energy saving potential with reduced dependence on artificial light. Appropriate use of windows, skylights, clerestories, and other apertures in the building provide means to harvest daylight.

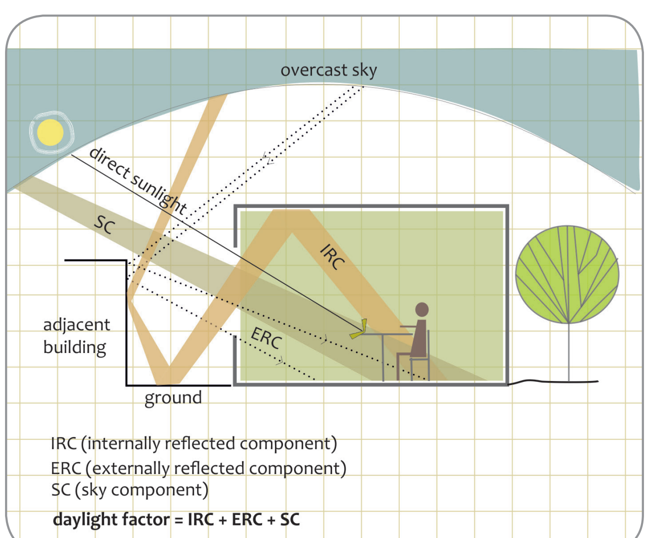


Figure 45 Daylighting as a passive design strategy

Remember that, more the sunlight that enters the building, more the heat that needs to be dealt with. Thus, by placing apertures correctly, nature can work with you. Integrating daylighting with artificial lighting can considerably reduce energy consumption, building by reducing the lighting energy demand by up to 20-30%. Thus design consultants and decision makers need to appropriately balance daylight harvesting features and minimize solar heat gains. Hence, daylighting becomes an integral part of a building design strategy from early design phase to lower the energy consumption of a building.

Use cool roof

Just as light-coloured clothing can help keep a person cool on a sunny day, cool roofs use solar-reflective surfaces to maintain lower roof temperatures. Highly reflective and light coloured roofs have now become an inclusive part of energy efficiency measure in a building.

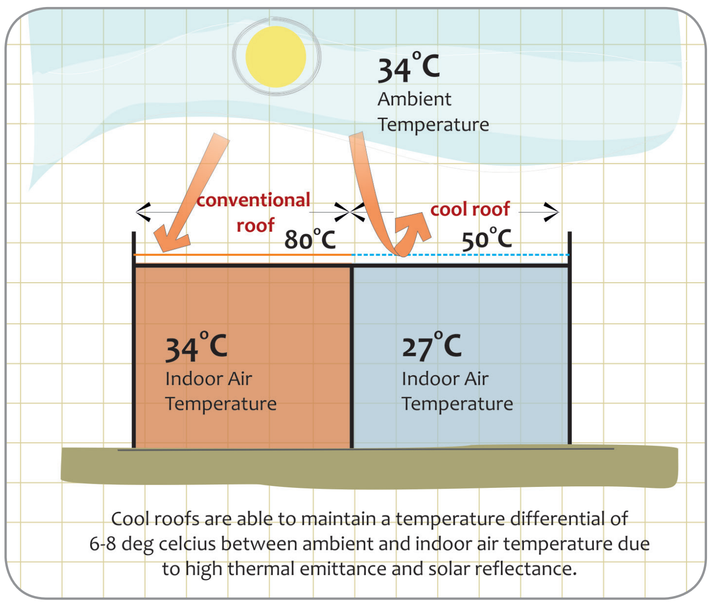


Figure 46 Cool roof

Cool roofs can be used to reduce energy bills by decreasing air conditioning needs, improve indoor thermal comfort and decrease roof operating temperature. Traditional dark roofs reach temperatures of 66ºC (150ºF) or more in the summer sun, in contrast a cool roof under the same conditions could stay more than 28ºC (50°F) cooler. Cool Roofs reduce annual air conditioning energy use of a single storey building by up to 15%.

Heat Island Effect is a phenomenon where the solid surfaces of buildings and surroundings radiate heat to the atmosphere which in turn increases ambient air temperatures compared to surrounding vegetated areas. The consequence of urban heat islands is the increased energy required for air conditioning and refrigeration in cities in hot climates. Cool roof is a well-known strategy to mitigate urban heat island effect.

Use of vegetation in and around buildings

Trees and shrubs create different air flow patterns, provide shading and keep the surroundings cooler in warm weather. Vegetation can be used for energy conservation in buildings in the following ways:

- Shading of buildings and open spaces through landscaping
- Roof gardens (or green roofs)
- Shading of vertical and horizontal surfaces (green walls)
- Buffer against cold and hot winds
- Changing direction of wind

Vegetation is a flexible controller of solar and wind penetration in buildings. It reduces direct sun from striking and heating up building surfaces and lowers the outside air temperature which in turn effects the heat transfer from outside to building envelope and interior.

Vegetation also alters the micro-climate of a site and has been used as micro-climate manager for as long as buildings have been built. This is possible through evapotranspiration. Plantation also shades building surfaces and open ground, thus inducing lower surface temperatures. Since this shading is almost permanent, the low temperatures do not vary much even when exposed to harsh radiation occasionally during hot seasons.

Green roofs or roof gardens can also be used as they help to reduce heat loads in a building. The additional thickness of the growing medium provides extra thermal insulation. Proper landscape design and vegetation can be used effectively by architects from an early design phase to lower the ambient temperature and thus reducing the resulting demand for air conditioning loads in a building.

Utilize natural ventilation

Fresh air in a building brings health benefits and increased comfort level to its occupants. Fresh air provision is considered as an efficient and a healthy solution as it reduces the need for mechanical means to ventilate a building.

Passive design measures can be judiciously used to influence movement of outside air into a built space by bringing in fresh air. Natural Ventilation is particularly effective in moderate and cold climates. In such climates it can partially offset or even totally eliminate the requirement of a cooling system. In composite climate, winter, spring, and autumn months provide an opportunity to run the building on natural ventilation rather than mechanical cooling. These interventions affect air-conditioning loads.

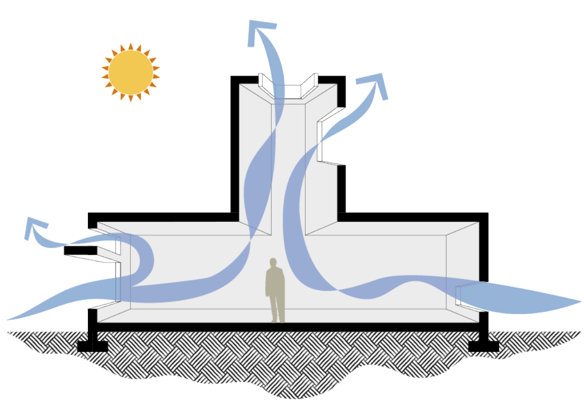


Figure 47 Convection through ventilation

Various forms such as appropriate orientation and form, openings in building envelope (windows, doors and ventilators), operable windows, internal space planning, etc. are various natural ventilation strategies that can be adopted. Other advanced ventilation techniques are courtyard effect, stack effect, wind tower, or air earth tunnels.

In air-conditioned buildings, strategies like energy recovery wheel can be used. It reduces the fresh air heat load significantly by exchanging heat and humidity between ambient fresh air and the exhaust air of the building. The Demand Control Ventilation which uses CO2 sensor to optimize the intake of the fresh air as per the occupant density, also reduces the fresh air load. These strategies are part of the efficiently designed HVAC system.

Reduction in Lighting Load

Lighting energy accounts for more than a quarter of total energy consumption in buildings. Light fixtures produce large amounts of heat in addition to light. This heat gain attributed to lighting is called lighting load.

Good lighting design will first reduce the connected loads using efficient lighting design and high efficacy fixtures such as LED and CFLs. Energy efficient lighting fixtures are now readily available in the market that make is possible to achieve a Lighting Power Density (LPD) of 7 watts per square meter with no added effort and cost.

The ECBC - 2017 specifies lighting efficiency requirement in terms of lighting power density (LPD) in order to provide flexibility to the designer to meet the design as well as the efficiency requirements.

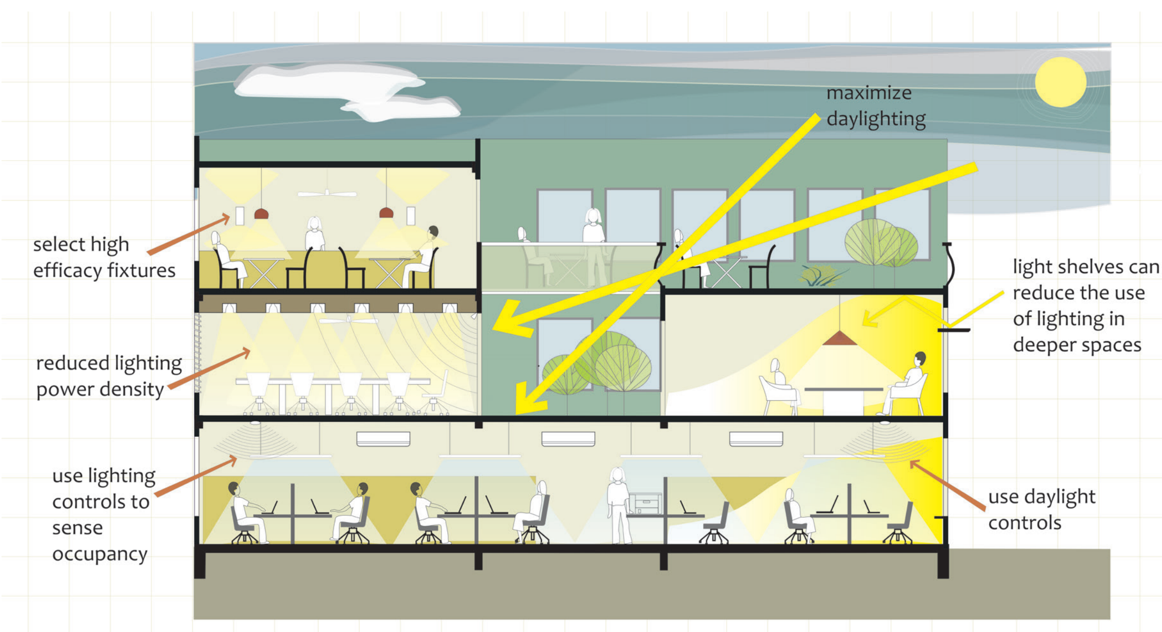


Figure 48 energy efficient lighting in commercial buildings

Lighting energy use can be reduced by integrating daylighting during daytime operational hours. Using lighting controls based on time, occupancy, lighting-level strategies, or a combination of them can further reduce the lighting energy over the lifetime of the building. Switching off the lights in an unoccupied space or during the availability of glare free day light could save up to 50 % of the lighting energy.

Reduce plug loads

Plug loads account for about 20%-40% of the building electricity consumption. Efficiency in appliances can go a long way in using energy judiciously in buildings. It depends on both – appliances the users buy, and the way they are used.

Energy Efficiency Standards & Labelling (S&L) programs have seen success in bringing about an increase in the supply and quality of energy efficient products. In India, the Bureau of Energy Efficiency (BEE) initiated the appliance S&L program in 2006. The BEE Label rates appliances on a scale of 1 to 5 stars based on their efficiency; with the most efficient appliance getting a 5 star label and the least efficient labelled as 1 star. This star rating scheme is applicable to room air conditioners and refrigerators among many other appliances.

Occupant awareness and education as well as plug-load controls such as load sensing and scheduled timer controls go a long way in reducing the plug loads over the operational life of the building.

High performance HVAC systems

All the strategies explained so far help reducing heat gain which is the fundamental step in achieving energy efficiency. The cooling capacities of air conditioning equipment for such building will be substantially small that will ultimately result in using a lower refrigerant charge in the equipment. Thus, the push for energy efficiency is also helping ozone protection.

The use of high performance HVAC equipment can result a 30%-40% reduction in annual energy consumption over a conventional building. This can be achieved with a simple payback period of about three to five years.

Appropriate System Sizing

Most of the air conditioning systems/units in the country are overdesigned and have significantly higher installed cooling capacity. This is a result of the design practices followed in the industry, to design the system for worst climatic conditions based on meteorological data prevailed over a period in city(s)/region with some considerations and maximum load on the building. Probability to occur simultaneously the maximum load and worst outdoor temperature is extremely low. Appropriately sized system reduces initial cost as well as operational energy consumption, oversized system operates less efficiently.

Interior thermostat temperature

A well-designed building provides its occupants with a thermally comfortable environment. Certain combinations of air temperature, relative humidity, air motion and mean radiant temperature will result in conditions that most people consider thermally comfortable. The lower and upper limits of these parameters constitute the 'thermal comfort zone.'

Air conditioning systems provide cooling as per the thermostat controls. Typically, commercial buildings have a static thermal comfort zone, meaning that internal air temperatures and humidity do not change throughout the year, no matter what the weather is like outside. Since most commercial buildings are centrally air conditioned, keeping a static thermal comfort zone makes operations easier. However, this also means constant heating or cooling, which can become excessive during certain seasons. Air-conditioning demand is high in peak summer period in such buildings, and the air conditioning systems tend to be oversized.

Adopting the appropriate thermal comfort settings can yield significant energy and cost savings in buildings. The cooling system sizes can be reduced by about 2%-4% for every 1°C rise in the design setpoint. This would reduce the quantity of refrigerant charge required for the system. The reduction in HCFC use will decrease for such units by at least 15% (assuming minimum pre-set indoor temperature is 24˚C). This would also result in reduction in greenhouse gas emissions and global warming.

The operating energy is also directly proportional to the thermostat settings and comfort conditions. Using a ceiling fan and reducing surface temperatures of wall and roof can ensure thermal comfort even at higher air temperatures. By increasing indoor design temperature from 22°C to 24°C, there is saving in cooling energy which can reduce annual energy consumption upto 8%-10%, and further increasing the temperature to 26°C, the energy consumption can be reduced 15%-20% as shown in Figure 48

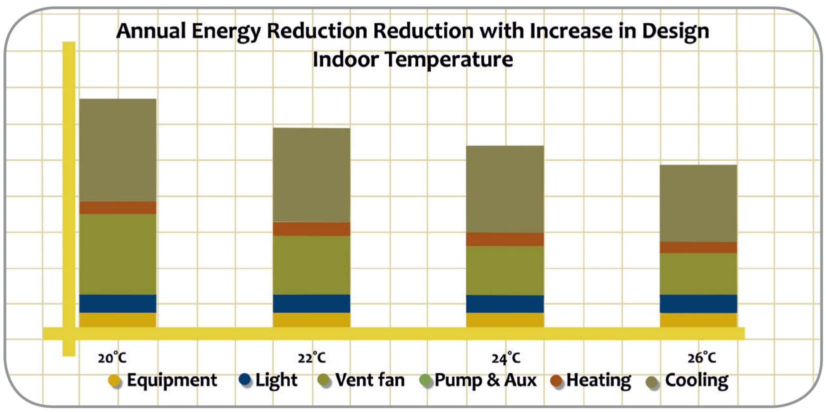


Figure 49 Energy reduction with increase in design indoor temperature

An expanded thermal comfort zone allows for seasonal variations in the indoor temperature, and reduces the need for constant heating and cooling. When occupants are allowed to control indoor thermal conditions, by opening windows, changing the thermostat, or other measures, they tend to use mechanical systems only when necessary. Buildings designed with an expanded comfort zone reduce the need for air conditioning and use of refrigerants.

Part-load Performance of HVAC Equipment

HVAC systems are sized to meet design heating and cooling conditions that historically occur only 1% to 2.5% of the time. Thus, HVAC systems are oversized for at least 97.5% to 99% of the time. Therefore, systems with good part load performance should be a basis of the selection along with COP/Efficiency rated at ARI conditions.

Smart Control Strategies

Smart control strategies allow the Building Management System (BMS) to optimize operating parameters for the entire HVAC system to achieve the lowest energy consumption. It allows to identify issues and check success of solutions. To achieve this, it is important to install submeters for different parts of the HVAC system and sensors for many areas in the building to be able to get data and finetune the building operations.

Commissioning of systems

Commercial HVAC systems do not always work as expected. Problems can be caused by the design of the HVAC system or because equipment and controls are improperly connected or installed. After a HVAC system has been installed, commissioning and on-going tuning of the system will allow the system to function as per the original design intent, optimize its operation and obtain maximum energy savings.

Operations and Maintenance (O&M) Program

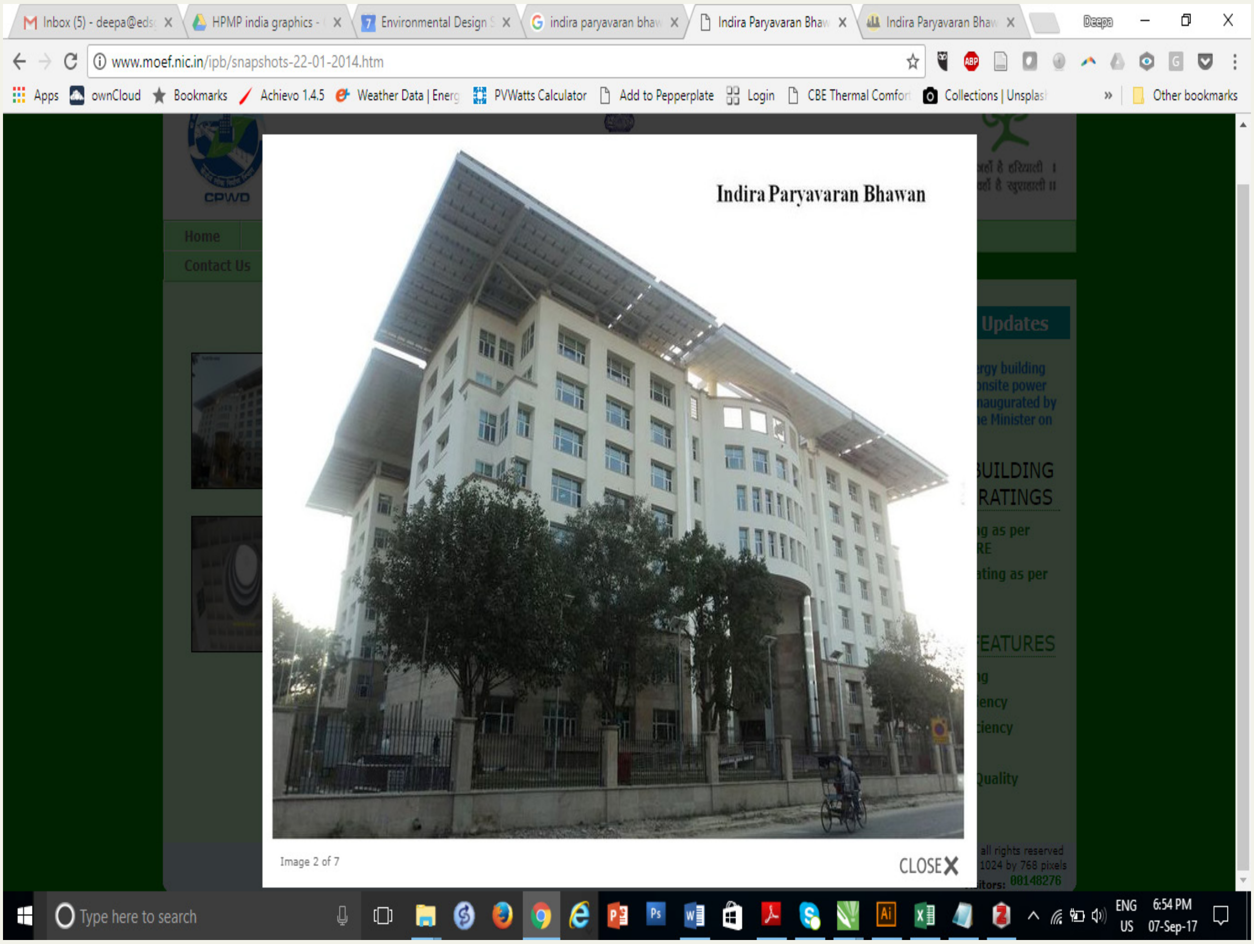
Proper performance and energy-efficient operation of HVAC systems can only be ensured through a successful O&M program. The building design team should provide systems that will perform effectively at the level of maintenance that the owner is able to provide.

The more designers become aware of passive design principles and learn about existing energy-efficient buildings, the more they will be likely to use these principles in their future projects. Three buildings that have demonstrated exemplary building design and energy performance achieving the challenging goal of Net Zero Energy are discussed in detail below.

CASE STUDY 1

Indira Paryavaran Bhawan, Headquarter Building of MoEF (Ministry of Environment & Forests), New Delhi, India

Indira Paryavaran Bhawan, the new office building for Ministry of Environment and Forest (MoEF) sets a radical change from a conventional building design.



The project team put special emphasis on strategies for reducing energy demand by providing adequate natural light, shading, landscape to reduce ambient temperature, and energy efficient active building systems. Several energy conservation measures were adopted to reduce the energy loads of the building and the remaining demand was met by producing energy from on-site installed high efficiency solar panels to achieve net zero criteria.

Project details

This 300,000 ft2 office has RCC framed structure with 3 basements and comprises of two blocks, one of which is Ground + 6 Floors and other one is Ground + 7 Floors.

The building has incorporated following energy efficient measures:

- High performance double-glazed windows
- Efficient building envelope
- Optimized window to wall ratio
- Use of daylight in 75% of total occupied areas
- Use of energy efficient lighting fixtures
- Use of daylight sensor to optimize operation of artificial lighting
- Innovative energy saving regenerative elevators
- The air-conditioning system for the building has the following characteristics:
- Pre-cooling of fresh air from toilet exhaust using heat recovery wheel
- Variable Speed Water cooled Screw chillers
- Double skin air handling units with variable frequency drives
- Highly energy efficient VFD Driven Screw Chillers with IkW of 0.56 kW/TR
- Geo thermal heat exchange technology installed for heat rejection from air conditioning system
- 77% of the building is air-conditioned with the use of vertical coil chilled Beam (Induction Units) with drain pans.
- Water conservation measures like low discharge water fixtures, dual flushing cistern, low demand plants in landscaping, Drip irrigation system for green areas, rain water harvesting system, make-up water tank for chiller plant and irrigation have been implemented in the project.

Project Highlight

- Indira Paryavaran Bhawan uses 70% less energy compared a conventional building.
- Very low Energy Performance Index (EPI) of 43.75 kWh/m2/yr
- India's Largest Net Positive Energy Office building with 923 kW of rooftop solar photovoltaic panels
- Awarded by GRIHA (Green Building rating system in India) as "Exemplary Demonstration of Integration of Renewable Energy Technologies".
- Achieved Highest Green Building Ratings i.e. LEED PLATINUM and GRIHA 5 Star

CASE STUDY 2

Eco Commercial Building, Noida, Uttar Pradesh, India

The “Eco Commercial Building or ECB” is located at Noida in Northern India. Under Bayer Initiative for Climate Protection, this project was launched in 2007 by Bayer Material Sciences Pvt. Ltd. as a prototype for all its future buildings.

Project details

This office building has a total built-up area of 9,600 sq ft, spread over ground & first floor.
The building has incorporated following energy efficient measures:
Insulated AAC block walls (U-value - 0.04 Btu/hr.ft2.deg.F)

- Highly insulated roof (U-value - 0.03 Btu/hr.ft2.deg.F)
- Optimum glazed areas (33.8% of overall façade)
- Double glazed units in windows
- Use of daylight in 87% of the occupied spaces minimizing need of artificial lighting.
- Use of daylight sensors
- Use of occupancy sensors in un-occupied areas like stores, toilets etc.
- 40% reduced Lighting Power Density (LPD) over ASHRAE 90.1 2004
- Highly energy efficient VFD Driven Screw Chiller
- Use of Active Chilled Beams

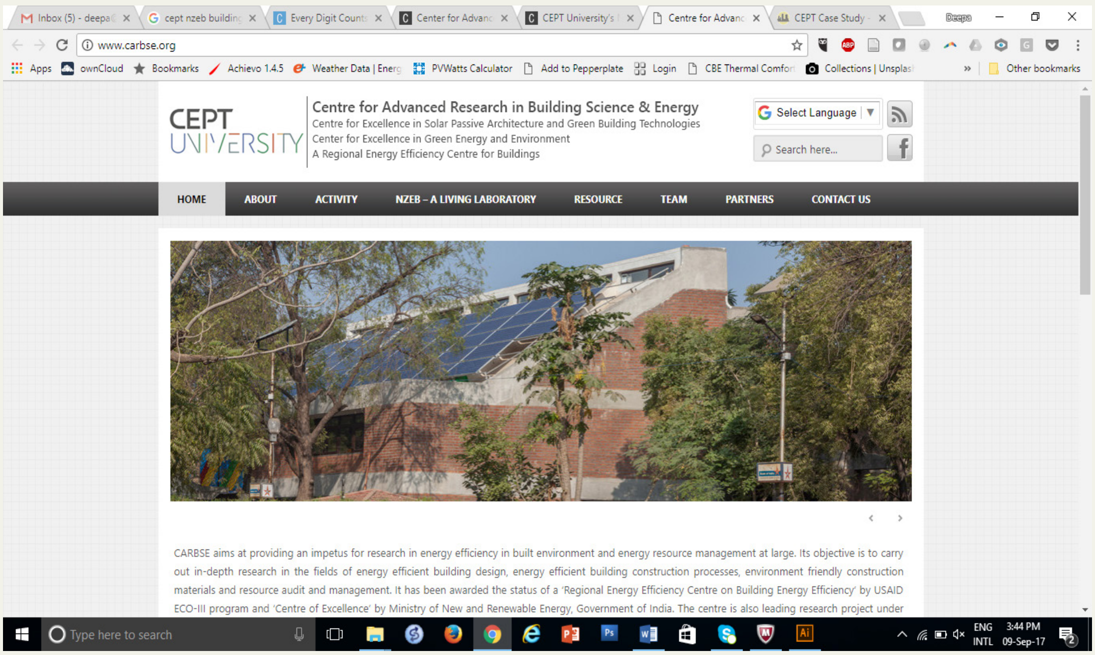
Project highlight

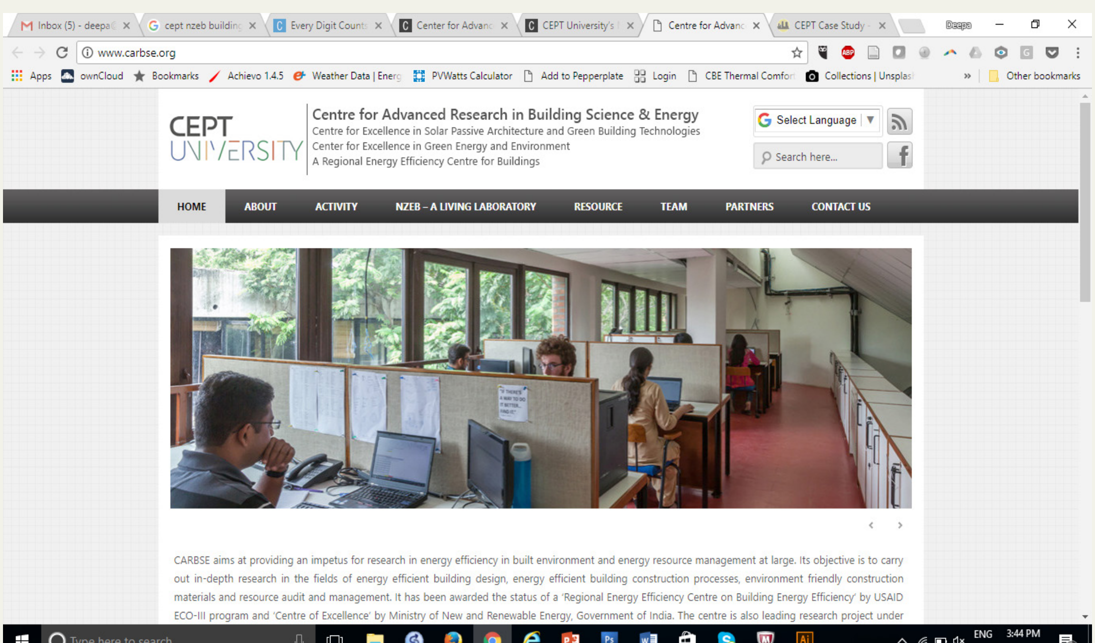
- First Net Positive Energy building in India that was achieved by having 100% on-site energy generation through the use of 57 kW photovoltaic system spread over a total roof surface area of approximately 444 sqm.
- 60% energy savings over conventional building
- Awarded with ASHRAE Technology Award
- Achieved Highest Green Building Ratings i.e. LEED PLATINUM and GRIHA 5 Star

CASE STUDY 3

A living lab at CEPT, Ahmedabad, Gujarat, India

The living laboratory on CEPT university Campus is home to the Center for Advanced Research in Building Science and Energy (CARBSE). This Net Zero Energy Building is a fitting example of how a lab for continuous and in-depth energy-efficiency research can be a demonstration building in itself. This hi-tech lab houses the state-of-the-art equipment which tests and measures thermal and luminous effect in buildings and building components.

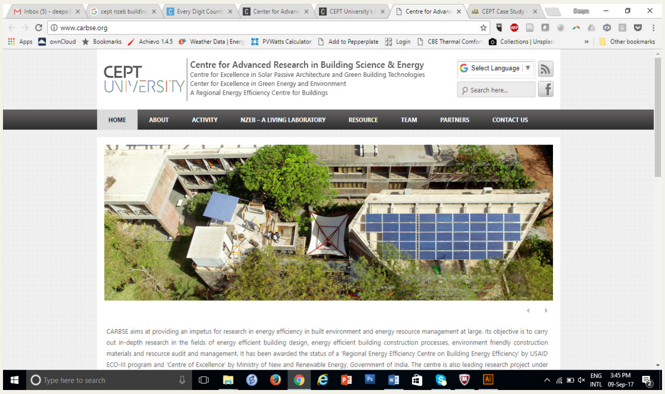




Project details

The 498 sqm lab building has incorporated following energy efficient measures:

- Insulated walls and roof
- High performance double glazing
- Clearstories, vision glazing and light shelf on the south façade bring in diffused daylight.
- Lighting load is limited to 4.7 watts per square meter using energy efficient light fixtures. Task lighting has been provided.
- Hybrid ventilation and cooling system combining natural ventilation and radiant cooling to maximize the use of fresh air for passive cooling, and still offset peak temperature discomfort.
- In the natural ventilation mode, the thermal chimney is opened to allow natural draft through the building.
- In mechanical system mode, the building will run primary (active radiant system with direct outdoor air units) and secondary cooling system (VRV / digital scroll) to maintain space comfort.
- Demand control ventilation, economizer based on enthalpy, chilled water reset, heat recovery wheel optimization algorithm, and chiller performance optimization.



Project highlight

A unique exemplary feature of this building is the integration sensors and controls in this building continuously monitor building performance and occupant comfort.

- At any point, approximately 900 high accuracy research grade sensors are operational in the building.
- Envelope, energy, and environment systems have been specified with built-in controllers for integration with the building control system.
- Building controls are designed to configure various indoor comfort condition algorithms based on schedule, based on custom adaptive comfort equation, and based on equation of outdoor/indoor conditions, or based on PMV algorithm
- The lab has fed 15% surplus energy into the electricity grid in 2015-16.
- Very low Energy Performance Index (EPI) of 58 kWh/m2/yr

7 Alternatives to HCFCs

As evident in the report so far, HFCs are trending as an alternative to HCFCs, especially in the use of refrigerants. To meet the Montreal Protocol targets, HCFCs need to be phased out and HFCs need to be phased down. While the phasedown of HFCs will technically begin much later by 2028, it is in best interest of in the industry to start using non-HFC and low-GWP alternatives as refrigerants and for various other applications in the building industry. Alternatives for air conditioning, insulation, and fire fighting is discussed in detail in the following sections.

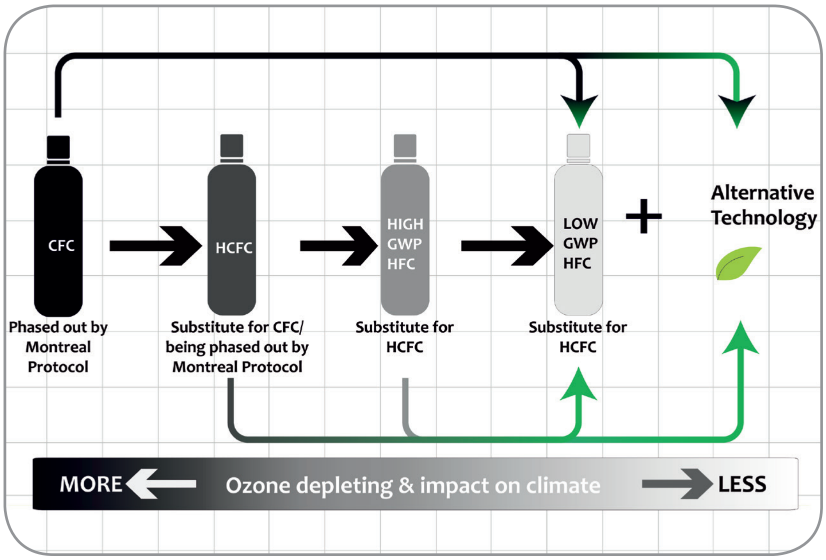


Figure 50. ODS phase-out process

Alternatives for refrigerants used in building air conditioning

It has been a challenging task for the air conditioning industry to develop a safe and environment friendly alternative to HCFC. Whatever refrigerant is chosen will always have to be a balance between several factors, the availability and cost of the refrigerant (and the associated equipment), the system energy efficiency, the safety and convenience of applicability, environmental issues and many more. Not all the alternatives can be used direct replacement of HCFC in the application. Some cases may require the redesign of the system or change of technology. One of the known challenges of the low-GWP alternatives is that of flammability to some extent.

Alternatives to HCFC-22 for air-conditioning

Fluorocarbon refrigerants

There are only two single-component refrigerants; R-290 and R-32 which could be considered as replacement of HCFC-22 for the air conditioning sector.

R-290 (Propane) is highly flammable (A3 category) with a GWP of 3. It's use is limited to very small cooling capacity air conditioners with safety measures. HFC-32 is a mildly flammable (A2L category) refrigerant with GWP of 675. It is now being used in several markets for window, split air conditioners and light commercial units of cooling capacity ranging from 1 kW to 16kW.

In view of limited single component refrigerants, several blends like R-407C, R-410A have been developed by mixing two or three HFCs. More than 60 such blends have been synthesized; the recent one being Hydrofiuoro Olefins (HFOs). Most of these blends having lower GWP are flammable. A comprehensive list of alternative refrigerants is given in Appendix 2.

Natural refrigerants

Natural substances, that exist in our biosphere, e.g. water, ammonia, carbon dioxide and hydrocarbons, are also considered as promising alternative refrigerants for some niche areas and applications. However, technologies to use natural refrigerants, in some cases need more time to develop or may be restrictive owing to safety issues but may bring forward robust and long-term solutions.

Hydrocarbons

Hydrocarbons such as R-290 (propane), R-600a (isobutane) and R-1270 (propylene) have zero-ODP and very low-GWP. For example, propane has a GWP of 3. Compared to HCFCs and HFCs, systems using hydrocarbons offer high efficiency, reduced charge sizes and a host of other benefits such as compatibility with mineral oil. Owing to its excellent thermodynamic efficiency, HC-290 is being used, in room ACs, up to 5 kW cooling capacity.

Ammonia (R-717)

Ammonia (R-717) is a thermodynamically attractive fluid which is in use for decades in industrial refrigeration and cold storages, but is toxic and flammable (B2L). Therefore, proper training for service and maintenance is required. Ammonia has proved itself to be a viable substitute to HCFC-22 for very limited location-specific buildings for air conditioning. It is widely used in cold storage, super markets etc.

Water (R-718)

Water is a thermodynamically attractive, non-toxic and non-flammable refrigerant and above all is not detrimental to the environment. However, systems using water suffer from economics due to relatively large compressor size and other system design issues.

Carbon Dioxide (R-744)

CO2 is one of the most promising natural refrigerants i.e. zero ODP and GWP of 1. It does not have the issues of toxicity or flammability. However, its vapor pressure is exceptionally higher and critical temperature 31.1oC is very low. CO2 has successfully been used in low temperature and water heating applications.

A list of alternative refrigerants to HCFC-22 along with GWP and safety class as per ASHRAE Standard 34 is given in Table 5.

Table 5 Alternatives to HCFC-22

Current and Potential Future Refrigerants for air conditioning sector Class of Flammability is denoted in red color			
Equipment	HCFC Refrigerant	HFC Refrigerant(GWP) (Currently Used)	Potential Low -GWP Refrigerant
Room ACs	HCFC-22 (1810)	R-410 A (2100) R-407 C (1700)	-HFC-32 (675), A2L -R-290 (3), A3 -HFC/HFO blends e.g, R - 452B (680);A2L R - 444B (310)A2L
Ducted & Packaged AC	HCFC-22 (810)	R-410A (2100) R-407A (1700)	-HFC-32 (675), A2L -HFC/HFO blends e.g, R - 452B (680); A2L R - 444B (310); A2L
Scroll Chiller	HCFC -22 (1810)	R-410A (2100) R-407A (1700)	-HFC-32 (675), A2L -HFC/HFO blends e.g, R - 452B (680); A2L R - 444B (310); A2L

Alternatives to HCFC-123 for building air-conditioning

HCFC-123 is a low-GWP HCFC refrigerant which will be phased out in the country by 2025 as per the Ozone Depleting Substances (Regulation and Control) Amendment Rules, 2014. It is more commonly used in chillers of larger cooling capacities rather than room air conditioners. HCFC-123 is an energy efficient refrigerant due to its thermodynamic and thermophysical properties.

HFC-134a and HFC-245fa based centrifugal chillers have been used for similar applications. HFC-134a chillers are also available with similar cooling capacity and efficiency. These are commonly used for building air conditioning in the country. HFC-245fa has found limited use in centrifugal chillers, heat pumps, and organic Rankine cycle (ORC) power generation cycles but not in building air conditioning.

Although having high GWP, HFC-134a and HFC-245fa are the popular options for replacing HCFC-123. However, centrifugal and screw chillers using HFC blends as well as HFOs have also been developed. Table 6 lists the alternatives to HCFC-123 in chiller application.

Table 6 Alternatives to HFC-123 in chillers

Current and Future Potential Refrigerants for Chillers (Low and Medium Pressure) Class of Flammability is denoted in red color			
Equipment	HCFC Refrigerant	HCFC Refrigerant (GWP) (Current)	Potential Low –GWP Refrigerant
Screw Chiller	------	HFC -134a (1430) Medium Pressure	**Medium Pressure:** -HFO-1234yf (<1);A2L -HFO-1234ze (<1) A2L -R-513A (600); A1
Centrifugal Chiller (Low Pressure Chillers)	HCFC -123 (79) Low Pressure	HFC -134a (1430) Medium Pressure	**Low Pressure:** -HFO-1233 zd (1);A1 -HFO-1336mzz (2); A1 **Medium Pressure:** -HFO-1234yf (<1);A2L -HFO-1234ze (<1) A2L - R-514A (1.7) B1

Not-in Kind Technologies

Absorption Chillers

Absorption chillers use a heat source and a combination of a refrigerant and absorbent to provide cooling. The heat source can be natural gas, steam, hot water, waste heat, or solar energy. Typically, these systems use a combination of water (refrigerant) and lithium bromide (absorbent), or ammonia (refrigerant) and water (absorbent).

There are several advantages to this system. Not only does it use less energy than conventional electric chillers, but it also does not require halocarbon refrigerants. Absorption cooling systems are quiet, vibration-free, and require little maintenance, as there are no moving parts except for the pump.

Since they do not require electricity to operate, absorption cooling systems are appropriate for use in areas where there is no reliable supply of electricity or where there is a high electricity demand. The systems are suited to buildings with simultaneous need for air conditioning and heating, as well as large commercial buildings. Absorption chillers are manufactured and used in the country.

District Cooling

District Cooling (DC) is a system in which water is chilled (cooled) at the central water chilling plant and distributed to residential, commercial and/or industrial consumers for use in air-conditioning, process cooling and other industrial applications. The chilled water is distributed through a network of insulated water pipe lines. The DC system eliminates the installation of water chilling plant at each building or facility. Only heat exchangers/air-handling system(s) with air-distribution systems are installed at each building site.

In principle DC system is similar to central air conditioning system designed for a building or a building complex but scale and modalities of operations are entirely different as the water chilling plant is remotely located at the appropriate place owned by a Public Utility or by a Private Energy Distribution Utility. The Utility owner is responsible for its operation, distribution, metering of chilled water maintenance DC system, and collection of revenue etc. Figure....Shows a schematics of typical District Cooling System.

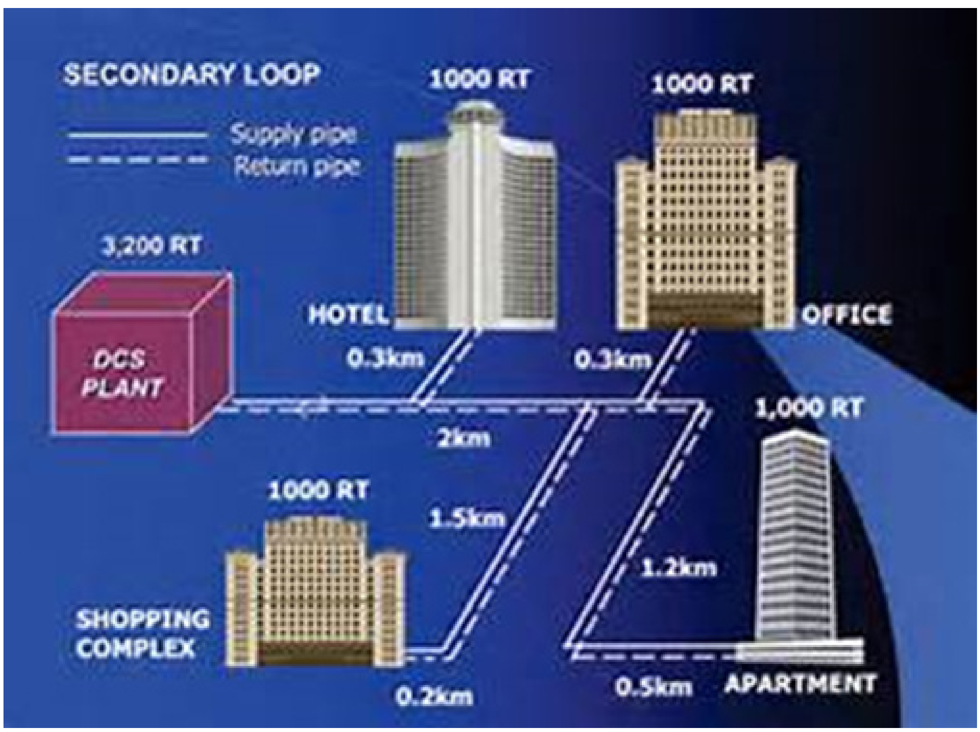


Figure 50a: Schematic Diagram of District Cooling System

Water chilling plant for a District Cooling

The water chilling plant could be comprised of vapour compression or electric- driven centrifugal/screw chillers, absorption refrigeration machines, gas/steam turbine- or engine- driven compression equipment OR a combination of mechanically driven systems and thermal energy driven absorption systems. Figure.... shows a cooling system used for district cooling installation.

Figure 50b: Water Chilling Plant for a District Cooling System

Salient features of District Cooling system

- **Diversity in cooling requirement:** DC System is designed by aggregating the cooling requirements of different buildings, industrial processes, equipment, etc, which use energy under different operating conditions and set peak demands at different times of day. Serving this variety of cooling requirements (loads) allows the DC cooling plant to operate at optimal output over a longer time period.

- **Energy Efficient Cooling:** The central water chilling plants of large cooling capacity are highly energy efficient system that provides air-conditioning in various zones in a city or building complexes. DC System provided chilled water to multiple users through underground piping network. The system will usually consume 65 per cent to 80 per cent of energy as compared to conventional air conditioning.

- **Use of Low-Global Warming Potential Refrigerants:** The DC system location allows using environment friendly low-GWP refrigerants including flammable refrigerants like ammonia, hydrocarbons, HFOs etc. This also allows a combination of cooling systems, vapour compression/absorption systems with a wide flexibility of choice of refrigerants including flammable/toxic refrigerants. This would reduce use of high-GWP hydrofluorocarbon (HFCs) and CO_2 emissions.

- **Economies of scale and cost saving:** The DC system will have capital savings from avoided investment in individual building cooling equipment; reduced labour and maintenance expenses due to simplified operating systems; lower costs for water, chemicals, refrigerants, insurance etc.

- **Space Saving in Building:** The DC system does not require installation of water chilling plants in individual building or building complexes. It has an extra floor space and enhances aesthetic sense of buildings by directly providing chilled water to the building for air conditioning

District cooling systems may prove to be very energy efficient and economical for meeting cooling requirements for large building complexes especially for new townships and smart cities.

Evaporative cooling

An evaporative cooler cools air by the evaporation of water. The cooler adds humidity to indoor air and is particularly well suited to hot, dry climates. Hot and dry air from outside passes through water-saturated pads, absorbing water vapor. The moisture cools down the hot air which is directed into the room by a fan. Meanwhile, warm air pushed out through the windows or other openings.

Unlike air conditioning, evaporative cooling is an open system that does not re-circulate indoor air. It requires a continuous supply of water and outside air to maintain the cooling effect.

In residential applications, evaporative coolers can be installed as portable units or as ducted systems. They can also be used on an industrial scale. This system is effective in hot and dry climate, however it requires water and may not be feasible in areas with limited water supply. These systems are commonly used in areas like Nagpur, Jaipur and others where the climate it hot and dry.

CASE STUDY 1

Solar powered absorption system at Audubon Center, Debs Park, California, USA

This nature center is entirely powered by on-site solar systems, and functions completely off the grid.

A 10-ton solar absorption cooling system provides air-conditioning and space heating for the entire 467-square-meter building.

System Overview:

A 74-square-meter array of vacuum tube solar collectors generates hot water that evaporates the lithium-bromide solution in the absorption chiller. This process generates water vapor at low pressure, which is condensed back for re-circulation. This low-pressure evaporation produces chilled water in the single-effect chiller. A 25-KW solar photovoltaic system provides the electricity required to run the pumps and fans to supply cool air in the building. The hot water provides space heating during the winter.

Cost of the System: USD 90,000

Advantages:

- Uses water vapor as the refrigerant.
- The system displaces 15 kW of peak cooling demand for a 10-ton system, reducing GHG emissions that would have been produced if the electricity was supplied from the grid.
- Significant energy savings: The system uses only 0.4 kW/ton of electricity to operate as compared to a 1.6 kW/ton for a similar size compressor-type HVAC system.
- Solar arrays provide added insulation to the roof, thereby reducing cooling loads by 20%, which impacts the size of the HVAC system.

Source: http://www.californiasolarcenter.org/solareclips/2004.02/20040210-10.html

CASE STUDY 2

Evaporative cooling for Orient Craft Ltd., a garment factory in Rajasthan, India

Orient Craft Ltd. is one of the leading garment manufacturing and export houses in India. Their 18,353-square-meter facility in the hot, dry region of Bhiwadi, Rajasthan, is an energy efficient building.

System Overview:

The factory design uses good thermal mass in walls, low lighting loads, a very low window-to-wall ratio of 13%, and adequate shading, reducing the cooling load by 60% in comparison with conventional buildings.

Seventy-seven percent of the building area is entirely conditioned by the evaporative cooling system. In the office areas, a split system is used due to space constraints. A variable refrigerant flow system is used in the embroidery rooms, as the equipment has to be maintained at low temperatures.

Highlights:

- 35% energy savings compared to similar conventional buildings.
- Through the successful use of zero-ODP and low-GWP options, the project provides an effective example for energy efficiency.

Source: Environmental Design Solutions Pvt. Ltd.

Trigeneration System

Trigeneration is the simultaneous production of three forms of energy—cooling, heating and power—from only one fuel input. In a typical trigeneration system, gas fired generators are used to produce electricity. This process generates waste heat, which is then directed to the chillers and boilers. In this system, absorption chillers are used to produce chilled water for space cooling. Boilers generate hot water for space heating and other purposes.

In a trigeneration plant, up to 80% of primary energy reaches end use, as opposed to only 33% in conventional power plants. Thus, this system can be extremely efficient.

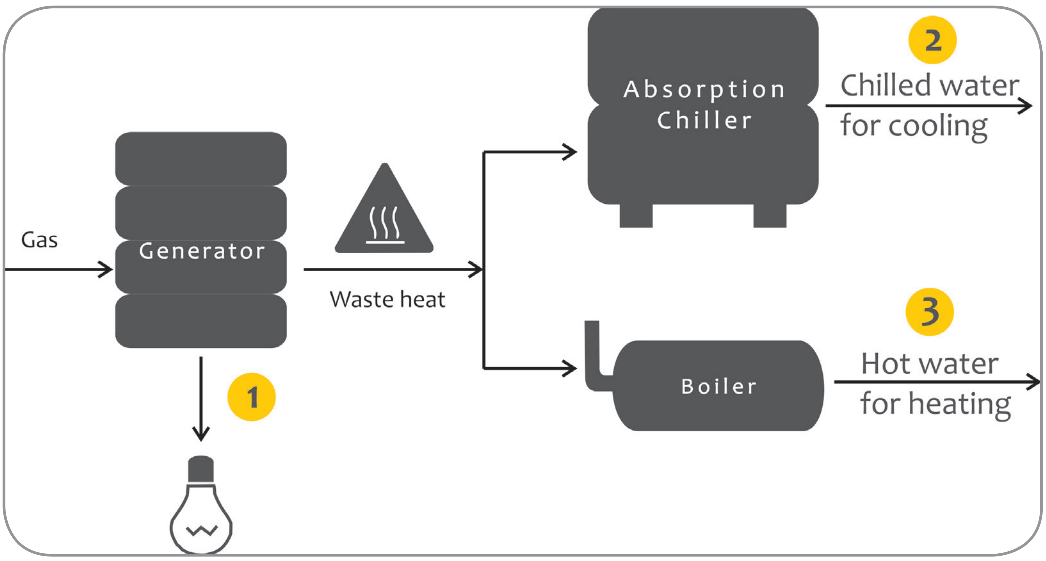


Figure 51: Typical trigeneration system

Trigeneration has its greatest benefits where electricity, heating and cooling are needed continually. Such installations include universities, hospitals, colleges and other large commercial buildings.

Since electricity is produced on-site, it minimizes the greenhouse gas emissions and transmission losses that occur when using electricity from the grid. Not only trigeneration is efficient, but it is also relatively independent energy source. In critical applications, such as hospitals, this system can provide a reliable level of back-up power.

By using recovered waste heat to operate absorption chillers instead of grid-produced electricity, trigeneration systems offer substantial cost savings and reduce greenhouse gas emissions. Absorption chillers commonly use water or ammonia as a refrigerant, which makes this a zero ODP and GWP system.

CASE STUDY 3

Trigeneration system at Jai Prakash Narayan Apex Trauma Centre, Delhi, India

This pilot project was implemented in 2011 by the Bureau of Energy Efficiency (BEE) and German International Cooperation (GIZ), under the Indo-German Energy Program (IGEN) programme.

System Overview:

The pilot plant is saves 20% to 30% of primary energy from coal power plants in comparison with conventional systems. An estimated 40,000 tons of carbon dioxide emissions will be avoided over 20 years.

Highlights:

Plant size	347kWe
Baseline cost	265 lk/yr
Electricity consumption	347 kW. (Excess electricity is goes to the grid)
Cooling load	355 TR (VAM – Vapour Absorption Machine)
Heating load	~20 kW (kitchen/laundry)
Est. payback period	3.2 yrs
Est. annual savings	1.3 Cr

Source: http://www.energymanagertraining.com/Trigen/main.htm

Jai Prakash Narayan Apex Trauma Center at AIIMS, Delhi

Phase change materials

Phase change materials absorb heat during melting and reject heat upon solidification, similar to the phase change of water to ice and vice versa. When used in walls, these materials absorb and reject heat, thereby reducing a building's need for energy-consuming air-conditioning and electrical heating.

In principle, phase change materials work like a thermal mass wall. While such walls can be quite thick, certain phase change materials, such as encapsulated paraffin plaster, can offer large thermal mass in a thinner material. Paraffin, which can be derived from vegetable oils, usually has an energy storage capacity that is only 60% to 70% that of water or ice, but it has a phase change temperature close to room temperature, i.e., 20°C. This means that the temperature of the space is adjusted before the room becomes uncomfortably hot.

Phase change materials are gaining attention in the building sector for space conditioning purposes. Higher cost can be a barrier to implementing this system.

Alternatives for building insulation

Insulation plays an important role in reducing the heat transfer across the building envelope. This lowers the cooling loads and hence the cooling capacity of air conditioning system. HCFCs are used as blowing agent in the manufacturing of insulation foams to create the cellular structure that is integral to insulation material. The sandwich panels as well as spray foams are used in building.

HCFC-141b is widely used as blowing agent for insulation foams. Currently, this is being phased out under HPMP Stage-II as per the Ozone Depleting Substances (Regulation and Control) Amendment Rules, 2014. A number of alternatives have been developed for the foams sector which is listed in Table 7.

Further, non-foam alternatives such as cellulose, glass wool and rock wool are also used in the market for building insulation. These materials also have better fire resistance compared to foams. Such products tend to have larger thickness compared to the foams for similar thermal performance. More awareness of such products can help its market uptake.

Table 7 Alternatives to HCFC-141b for foams

Alternatives to HCFC – 141b For Foam Sector (Flammable)					
	Cyclo -Pentane	**n-Pentane**	**Iso-Pentane**	**Methyl Formate**	**Methylal**
Molecular Weight	70.1	72.1	72.1	60	76.1
Boiling Point	49.3	36.0	28.0	31.5	42.0
Foam Properties	Good	Good	Good	Acceptable	Acceptable
Flammable Limits in Air (Vol %)	1.4 - 8.0	1.4 – 8.0	1.4 – 7.6	5.0 – 2.0	2.2 – 19.9
GWP (100 years)	<25⁰	<25⁰	<25⁰	Negligible	Negligible

Alternatives to HCFC – 141b For Foam Sector (Non – Flammable)				
	CO_2 (Water)	Formacel 1100	Solstice™ Liquid BA	Forane ™1233zd
Common Name		1336mzz (Z)	1233zd (E)	1233zd (E)
Molecular Weight	44	164	130.5	130.5
Boiling Point (^{0}C)	In Situ Reaction	33	19	19
Foam Properties	Acceptable	Very Good	Very Good	Very Good
GWP (100 Years)	1	2		<7

Alternatives for firefighting equipment

When using a fire suppressant, a primary concern is the residue that the agent leaves on surfaces after use. ‘Clean agents’ vaporize easily and do not leave any residue. Clean agents are required for specialized applications such as protecting priceless artefacts in museums and sterile areas in hospitals and labs. Such applications might use halocarbons and blends.

For most other common applications such as residential and commercial buildings, non-ODS alternatives such as CO2, water and dry chemicals can be easily used.

8 HCFC Phase-out from existing building stock

HCFC PHASE-OUT FROM EXISTING BUILDING STOCK 8

There is large installed air conditioning equipment with HCFCs in the existing building stock in the country. As per the expert estimates there is inventory of residential air conditioners (room air conditioners) and commercial air conditioning equipment about 11 million residential units and 32 million Ton of RefrigerationTR) of commercial air conditioning in 2016. The average working life of existing equipment would range from 5 to 10 years of residential air conditioners and 15 to 30 years for medium and large capacity chillers as such equipment are still sold in the country. The manufacturing of air conditioning equipment with HCFCs will cease from 1st January, 2025, five years prior to the complete phase-out of HCFCs as per the Montreal Protocol schedule. The manufacturing has been still continuing mainly due to non-availability of safe environment friendly technologies for all the refrigeration and air conditioning applications.

HCFC phase-out from existing building air conditioning equipment

- There are several ways to phase-out or reduce use of HCFCs in the existing Building stock.
- Retrofit (refrigerant change and system components)
- Replacement of existing Equipment by non-HCFC low-GWP energy efficient equipment
- Reduce use of HCFCs by recovery, recycling and reclamation refrigerants
- Retrofitting of Existing Equipment

Retrofitting of existing air conditioning equipment is one of the options to phase-out of HCFCs from existing building stock. In general, the air conditioning equipment is designed to operate with a pre-decided refrigerant to get optimal performance. The thermophysical properties vary from refrigerant to refrigerant; this necessitates change in design of the equipment. Whenever, a system is retrofitted with another refrigerant, the change in performance like cooling capacity and energy efficiency is expected. Usually the performance deteriorates due to several reasons, thermosphysical properties of refrigerant, incompatibility with lubricating oil and inadequate matching of system components etc. This may not only lead to increased energy consumption but also reduce the equipment working life. The retrofitting of existing systems should only be under taken under the guidance of Original Equipment Manufacturer (OEM). Never retrofit a normal working unit for the sake phase-out HCFCs.

Retrofit Refrigerants for HCFC-22 Based Systems

A number of blends of two or more HFCs with some small percentage of hydrocarbon blends HFCs and HFOs and pure hydrocarbons have been proposed as alternatives to HCFC-22 for retrofitting of existing equipment. Table 8 lists some these alternatives along with their characteristics.

Table 8 Refrigerant Options to HCFC-22 for Retrofitting of Existing Room Air Conditioners

Refrigerant	Refrigerant Specification	Safety Class	GWP (100 years)	Observation
R-290*	Propane	A3	5	Highly Flammable
R-407C	R-32/125/134a	A1	1700	High-GWP**
R-417A	R-125/134a/600	A1	2300	High-GWP, performance issues
R-422D	R-125/134a/600a	A1	2700	High-GWP
R-424A	R-125/134a/600/ 600a	A1	2400	High-GWP
R-425A	R-32/134a/227ea	A1	1500	High GWP
R-428A	R-125/143a/290/ 600a	A1	3700	High GWP
R-433A*	R-1270/R-290	A3	4.2	Highly Flammable
R-434A	R-125/143a/134a/ 600a	A1	3300	High GWP
R-438A	R-32/125/134a/600/ 600a	A1	2000	High GWP
R-442A	R-32/125/134a/152a/ 227ea	A1	1900	High GWP
R-444B*	R-32/152a/1234ze (E)	A2L	93	Mildly Flammable
N-20B	-----	A1	988	Medium GWP**
DR-3*	-------	A2L	148	Low GWP**
ARM-20B*	-------	A2L	251	Medium GWP**

*As per Executive Committee Decision Retrofitting with flammable refrigerants is to be carried out as per National Regulation and responsibility

** The classification of Low- Medium- High GWP is based on relative values: Montreal Protocol does not specify any such categorization

It could be seen from Table 8 that there is almost no safe and environment friendly alternatives for retrofitting of HCFC-22 air conditioning units. There is no Montreal Protocol decision about the use of refrigerants for retrofitting of existing units. Some HFCs and HFO blends with low-GWP may be the potential refrigerants for retrofitting if required.

Retrofit Refrigerants forHCFC-123 chillers

Centrifugal compressors by nature must be designed specifically for a refrigerant and a particular set of operating conditions for the refrigerant cycle in which they are used. Direct refrigerant substitution in centrifugal chillers can be made only in cases where the properties of the substitute refrigerant are nearly the same as those of the refrigerant for which the equipment was designed, or when the impeller speed and/or impeller geometry can be changed easily. In the past, this has been accomplished by gear changes in open drive chillers and with variable speed drives in both open and hermetic compressor chillers. The compressor surge margin must be checked using the properties of the substitute refrigerant.

HFO-1233zd(E) with a GWP of 1, HFO-1336mzz (Z) with GWP of 2 and R-514 a blend of R-1336mzz (Z) and R-1130 with a GWP of 1.7 could be the retrofit options for HCFC-123 chillers. However, it may be noted that the cos of retrofitting some time as high as 80% of the new chillers to reach the same cooling capacity and efficiency. This needs a thorough evaluation of various options.

Replacement of existing HCFC Equipment by low-GWP energy efficient Equipment

Energy efficiency will be the main driver in phasing-out of HCFCs especially in view of Kigali Amendment to the Montreal Protocol for phase-down of HFCs and also encourages energy efficiency to reduce GHG emissions. This would play an important role in phasing-out of HCFC from the existing building stock.

This may prove to be more economical for the users to replace the existing HCFC based inefficient air conditioning equipment by energy efficient low-GWP rather than retrofitting, if the equipment has already been in service for certain period and consumes significantly higher electricity than the newly available air conditioners with environment friendly refrigerant. This would be a Win-Win-Win situation, the saving of electricity bill, protection of the ozone layer by phasing out HCFCs and the protection of environment by reducing CO2 and HCFC emissions.

Reduce use of HCFCs by recovery, recycling and reclamation refrigerants

The conservation of refrigerants is an effective measure to reduce consumption and emissions of refrigerants. The need to conserve refrigerant has led the industry to develop a specific terminology for the following processes (ISO-1990).

- **Recover**: to remove refrigerant in any condition from a system and store it in an external container.
- **Recycle**: to clean the extracted refrigerant using oil separation and single or multiple passes through filter-driers which reduce moisture, acidity, and particulate matter. Recycling normally takes place at the field job site.
- **Reclaim**: to reprocess used refrigerant to virgin product specifications. Reclamation removes contaminants such as water, HCl and HF reaction products, other acids, high boiling residue, particulates/solids, non-condensable gases, and impurities including other refrigerants. Chemical analysis of the refrigerant is required to determine that appropriate specifications are met. The identification of contaminants and required chemical analysis are specified by

reference to national or international standards for new product specifications. Reclamation typically occurs at a reprocessing or manufacturing facility.

Refrigerant recovery

Recovery of refrigerant, especially the fluorocarbon refrigerants like HCFCs and HFCs has become an integral part of servicing of refrigeration and air conditioning equipment. Pump-down process similar to recovery of refrigerant was already in practice in servicing of large cooling capacity refrigeration and air conditioning systems prior to the Montreal Protocol came in existence. The incentive for refrigerant recovery is the cost of refrigerant and environment protection. The regulatory framework is also a driving force for recovery of refrigerant especially in some non-Article 5 countries.

Refrigerant recovery equipment mainly comprises of recovery machine, storage cylinder, and hoses. The affordability of technicians except large servicing stations to procure such equipment is still weak. Moreover, the recycling and reclamation network is also non-existing in India and several other developing countries. In developing countries including India, although there is a good awareness among the service technicians but due to lack of infrastructure, the necessary recovery and recycling equipment and reclamation centres coupled with transportation costs the recovery, recycling and reclamation are not yet effectively used by servicing technicians. However, recovery of refrigerant especially from medium and large systems is an effective process to reduce HCFC consumption.

Refrigerant recycling

Refrigerant recycling conserves refrigerant during the service, maintenance, repair of refrigeration and air-conditioning equipment. Recycling reduces oil, acid, particulate, moisture, and non-condensable (air) contaminants from used refrigerants.

In the interest of conservation of refrigerant and protection of environment, Refrigerant recovery and recycling system should be established in the countries. Recover and recycling equipment should be made available to service technicians in every sector. The logistic process should be easy to understand and cover all players from point of sale to the customer, and back to point of return. It may be noted that due to incompatibility issues and the array of refrigerants used recovery/recycling equipment intended for use with one refrigerant and/or type of air-conditioning system may not be adequate to service other refrigerants or sectors. Recently recovery and recycling equipment with oil less compressors have been developed and available in the market which would enable the service technicians to handle variety of refrigerants.

Currently, the automotive air-conditioning industry typically reuses recycled refrigerant without reclamation in a different owner's system. Acceptance in other sectors is still in the initial stage.

Refrigerant reclamation

Reclamation is a very effective for refrigerant conservation and to reduce the refrigerant demand in the country. In this process recovery and reclamation of used refrigerants can, to a certain extent in some countries, meet the servicing requirements. Reclamation extends the lifespan of the refrigerant as well as the equipment and decreases the dependency on virgin refrigerant by placing it back into service. Reclaimed refrigerants are tested and verified to meet specifications that are like newly produced refrigerants product specifications, such as those provided in (AHRI, 2012). The reclaimed refrigerants can be repacked and sold to new users.

There are some reclamation centres established in the country during CFC phase-out regime. These are small capacity portable refrigerant reclamation equipment capable of reclaiming about 80 kg of refrigerant per hour. These facilities have not yet been utilising due to lack of network and system in place. Moreover, reclamation is essentially a market-driven industry. If there is no demand for a particular refrigerant, the costs to send recovered refrigerant to reclamation facilities will be a disincentive to reclaim.

Many service centres will not be able to afford storage for recovered refrigerants as well as the cost of sending small quantities of recovered refrigerant to reclamation facilities is also a disincentive to reclamation efforts. Recognizing, the effectiveness of reclamation centres in conservation of refrigerants efforts should be to make to function in the country.

HCFC Phase out Retrofitting of Existing Building Envelop- Insulation

Insulation used in buildings has very long life and HCFCs used as blowing agent remain more or less intact in the foam. There is no need to replace insulation for phase-out HCFCs from existing buildings until it is necessary. However, there are several existing buildings may not be insulated and hence use more energy for space heating and cooling. In such cases, spray foam with non-HCFC low-GWP blowing agent may be applied. The foam layer can be formed on walls or wall cavities as well as roofs. It is relatively easy to insulate roofs instead of the walls of existing buildings. This could be taken up when building is being renovated.

Retrofitting firefighting equipment

Fire extinguishing using halons is very rare as the production and consumption of halons was phased out since 2002 in the country. Some HCFC-123 based systems are still used in some applications especially in data centers and electronic equipment manufacturing and storage facilities. The need for phase-out in existing building stock in this sector is limited.

It may be noted that there is a huge bank of HCFCs in air conditioning systems of existing Building stocks. There is a potential to phase-out HCFCs in this sector. All efforts are to be made to address this sector.

9 Ozone and climate friendly policies

OZONE AND CLIMATE FRIENDLY POLICIES 9

Globally, policies have played a significant role in helping a country achieve their long-term goals. This chapter will enumerate the policies, programs and technologies currently in place in India that address energy efficiency, HCFC and HFC use as well as alternatives in the building sector. An assessment of these mechanisms will help to understand the potential and preparedness of the country to achieve the integrated transition to low-GWP alternatives by 2030.

There is a distinct opportunity for India to influence the direction of new development towards using low GWP alternatives and lowering GHG emissions through strategic policy planning and implementation. Policies are required to ensure country-wide uptake of non-ODS alternatives and reducing building emissions to help the country to achieve its long-term goals. To achieve an integrated transition to low-GWP alternatives, it is important for policies and program focused on energy efficiency and ozone depletion to have synergy.

Policies and programs in India

A study of various policies and programs that address the use of refrigerants, foams and fire suppressants in buildings has been done in this chapter. Further, policies that focus on improving energy efficiency of buildings are also studied. This is important since such requirements will impact the cooling demand and hence the quantity of refrigerants used in air conditioning equipment in buildings. Moreover, it also gives an overview of the level of stringency required for energy use in buildings to reduce GHG emissions.

Although not a regulation, programs such as green building rating systems have also been included in this study to provide an insight on the market driven trends on environment friendly buildings. Additionally, India's commitment to the latest HFC amendment has also been included in this chapter since this is a significant step towards low-GWP transition for the country. This overview is also insightful to understand the gaps, strengths and prioritize strategies in developing an integrated approach to achieve the twin benefits of ozone protection and climate change. Each of these policies and program are explained in detail in the following sections.

HCFC Phaseout Management Plan (HPMP)

The HPMP is a national strategy developed for phasing out HCFCs by 2030 with a 2.5% service tail until 2040 in compliance with the Montreal Protocol. The focus of the HPMP is to reduce the production and consumption of HCFCs as well as facilitate the uptake of alternatives. The HPMP is a high-level outline including reduction targets for all the different HCFCs being used in the country. Countries are also encouraged to take into account the global warming implications of the alternative substances and technologies. But HPMPs commonly do not specifically have a sector specific phasing out strategy.

Status in India

The HPMP Stage-II of India was launched in February 2017 with a strong focus on the building sector. The plan will prioritize the complete phaseout of HCFC-141b among all other HCFCs since it has a relatively high ODP. Thus, building insulation will be HCFC-free by 2020. Further, the Plan targets to phaseout HCFC-22 from six major room air-conditioner manufacturers in the country by 2022 and to train about 17,000 refrigeration and air-conditioning (RAC) technicians on alternative technologies and good servicing practices. Thus, the HPMP is clearly focused on the building sector.

It is important to note that alternatives to HCFCs can continue to be used even if the refrigerant demand is not reduced. But that only solves half the issue being ozone depletion. In order to avoid adverse impact on climate, low-GWP alternatives have to be prioritized. Most HPMPs do not emphasize on reducing the demand of alternatives at the end user which is a fundamental step in achieving phaseout. This could potentially be done by referencing existing policies that focus on reducing refrigerant demand within the HPMP.

National Building Code

Building Code is one of the most basic regulations specifying minimum standards mandatory for building construction and occupancy. The Code mainly contains administrative regulations, development control rules and general building requirements; fire safety requirements; stipulations regarding materials, structural design and construction (including safety); and building and plumbing services. All new building construction including commercial or residential are required to comply with these standards. Many Codes also include mandatory standards for renovation of existing buildings.

There are largely two methods of compliance with building codes - a prescriptive or a performance approach. The prescriptive method includes a set of defined minimum standards for functional requirements. The performance method of compliance is offered by the more mature and advanced Codes where there is flexibility in demonstrating compliance wherein individual building components may or may not meet the prescriptive standards, but the whole building design should meet the intent, targets and objectives of the Code.

Even the more advanced building codes in the Asia Pacific region have stringent requirements for energy efficiency of air conditioning systems and overall building energy use with the intent of reducing GHG emissions, but there is no explicit requirement for use of refrigerants, insulation material and chemicals used in firefighting systems.

Status in India

The National Building Code (NBC) of India covers all types of new building construction. It does not address existing buildings. The Code was first published in 1970 and the most recent amendments were issued in 2016. The NBC offers a prescriptive compliance approach only.

NBC includes a section on sustainability called “Part 11 – Approach to Sustainability”. The Code now includes requirements for the using zero ozone depletion potential (ODP) and ultra-low global warming potential (GWP). It also includes requirements on energy efficient air conditioning. Further, building energy efficiency is also addressed by requirements on the envelope and passive design parameters.

Building Energy codes

Building energy codes are set of standards specifically focusing on minimum and best practice energy efficiency standards for all components of a building. The fundamental difference between a building code and a building energy code is that the former is focused on the functional and safety requirements of building design and construction such as fire safety, sanitation, space requirements; while the latter is focused on thermal specifications of materials, climate responsive design requirements and energy using equipment in buildings.

Some of the advanced building codes integrate these requirements within the Building Code itself while many countries have a separate standalone Energy Code that requires to be complied with in addition to the Building Code. Studies have shown that mandatory regulatory measures such as building codes are the most cost-effective means of reducing energy consumption in the building sector when successfully enforced (UNDP-GEF, 2009).

Countries such as Australia, China and Japan have integrated codes where their Building Codes have mandatory energy efficiency requirements and hence there is no separate Energy Code in these countries.

Status of India

The Energy Conservation Building Code (ECBC) was developed by the Government of India for new commercial buildings in 2007 which has been updated and published as ECBC-2017. The ECBC sets minimum energy standards for commercial buildings having a connected load or contract demand of 100 kW. The Code is currently in voluntary phase of implementation. About 22 states of India are at various stages of mandating the Code.

The focus of the Code is on improving the energy efficiency of buildings including the envelope, air conditioning and lighting systems. The Code prescribes three levels of energy efficiency performance levels. The Code compliant building will incorporate the mandatory and prescriptive requirement as per the Code. The ECBC Plus Building (ECBC+Building) and Super ECBC buildings are voluntary levels which intend to be more energy efficient beyond the Code compliant building.

Although there is no direct correlation with the NBC, there is harmony between the requirements of both the Code. However, the ECBC is technology neutral does not address the use of any category of refrigerants in buildings.

Kigali Amendment to Montreal Protocol

Montreal Protocol has been successful in getting countries to completely phaseout the production and consumption of CFCs and now commit to phaseout the production and consumption of HCFCs with an accelerated phase-out schedule. The production and consumption of HCFCs are reported under the Montreal Protocol. One of the popular alternatives being HFCs as a zero ODP substance is currently being controlled under the Kyoto Protocol, many of which have a high GWP. On 15th October 2016, the historical agreement of phase down of HFCs under the ambit of Montreal Protocol took place in Kigali, Rwanda. As per the agreement, countries are expected to reduce the manufacture and use of Hydrofluorocarbons (HFCs) by roughly 80-85% from their respective baselines, till 2045.

Status of India

India has also committed to the Kigali amendment and will start phasing down HFCs by 2028 and reduce it to 15% of 2024-2026 levels till 2047.

Standards and Labeling for equipment and appliances

Standards and Labeling (S&L) programs offer policymakers a direct method to regulate the sale of products in the market. S&L is one of the most common and cost-effective policy tools to reduce the demand for electricity through energy efficient appliance and equipment. It is also a great opportunity to educate consumers about energy efficiency and create awareness about long term views on energy use.

S&L typically covers consumer appliances such as refrigerator, water heaters and equipment such as air conditioning, lighting, as well as large systems such as central air conditioning and boilers. There are two components in the S&L program as given below.

1. **Standards**: Most S&L programs have Minimum Energy Performance Standards (MEPS) that the product must meet or exceed before they can be sold to customers. It ensures the phasing out of inefficient products from the market so that consumers have access to more efficient range of products, creating significant energy and greenhouse gas savings at a household and at the national level. MEPS is most effective if it is mandatory.

2. **Labels**: An informative label listing the energy consumption of the appliance or the equipment is affixed to a product in order to encourage consumer to make informed choices while purchasing. The labels are of two types:

   a. **Comparative Label:** This label compares the energy performance of the product with respect to the highest performance for the same category. Usually this is indicated by stars, tick marks or similar symbols to show the comparative performance.

   b. **Endorsement Label**: This label is used to highlight the best performers in a product category. This helps the product build a competitive edge and also improves the overall competition for energy efficiency in the market.

Many countries have the S&L program in place. In the Asia Pacific region, China has the maximum number of products covered (about 138) under the S&L program followed by Korea (Republic of) with 103 products endorsed.

Korea (Republic of) has set up a good example by taking the S&L program to higher MEPS in order to achieve their aggressive national target for energy savings. Korea's High-efficiency Appliance Certification Program endorses and promotes about 40 products that perform better than the established minimum criteria for the national efficiency standards. Korea (Republic of)'s energy efficiency label on the products carries additional information on CO2 emissions. Korea (Republic of)'s 'e-Standby program' was one of the first in the world to limit standby power of equipment under 1W which is the electricity used by the appliance when not in use but still plugged into the electrical socket. Failing to comply with the requirements carries a monetary penalty for the manufacturer.

Unlike other regulation, the uniqueness of the S&L program is the ability to reach out to the end consumers whose choices will go a long way in ensuring environmental benefits. Energy efficient equipment reduce the overall building electricity requirement thereby reducing the indirect GHG emissions from buildings.

Although, S&L requirements typically do not address use of ODS in equipment and appliances, they have a great potential to do so. Often, manufacturers have to make changes to their production line and manufacturing technology in order to meet the MEPS where there is potential to use different refrigerants that may have an impact on energy efficiency.

Status of India

The S&L program was launched in India in 2006 by the Ministry of Power covering 28 different kind of appliances such as air conditioning, refrigerator, lighting, inverter, ceiling fans, and many others. Under this program, the Bureau of Energy Efficiency (BEE) has introduced star labeling system for these appliances. India has the MEPS and LC labels for room air conditioning. Central heating system, central air conditioning and chillers have the LE rating. The program does not address the ozone depleting susbtances.

Regulations for foams and fire fighting industry

Most countries introduced regulations for building insulation in the 1970s during the oil crisis as an energy conservation measure.

The HPMP outlines the use of HCFCs in foams and firefighting. But industry regulations should also reflect these to achieve the objective of phaseout. Status analysis shows that not all countries have a formal regulation for these two industries as well as there is limited information available for several countries. Only 13 countries have general regulations for foams and 9 countries have regulations for firefighting systems. Of these, only 8 countries have regulations that specifically control the use of HCFCs in building insulation foams, specifically HCFC-141b. Regulations in the firefighting industry largely focus on safety standards and prohibit the use of Halons while only 6 countries have specific requirements for the HFCFs as fire suppressants (Figure 22).

Some countries have moved a step further such as the foam regulation in Japan has not only banned the use of HCFC-141b, but also requires that building insulation should be HFC free.

Status of India

In India, manufacturers of firefighting equipment have an option to get their product 'Ecomark' certified. In addition to many environmental factors, the Ecomark certification requires that gas suppressant should not have atmospheric lifetime of more than a year and a specific list of HCFCs with high GWP are prohibited to be used. Such programs clearly encourage the selection of low-GWP alternatives.

Green building rating system

Green buildings are increasingly gaining attention globally. Green buildings are designed to have lower environmental impact than conventional buildings, using less energy, materials, water and other resources. Rating systems provide guidelines for designing energy efficient new buildings and assessing their environmental performance.

The program typically covers design aspects such as site development, building energy use, water use, material use, refrigerant use, equipment efficiency, waste management, indoor air quality, landscape and passive building design. Projects are awarded points based on the number of criteria and the extent to which they are implemented.

Unlike building energy codes, green building rating systems are essentially market-driven tools that influence building practices, these rating systems are guided by Green Building Councils, member-based organizations that partner with industry and national governments to support local market needs. Green building rating systems are designed to help developers to incorporate green features in the buildings.

The Leadership in Energy and Environmental Design (LEED) system developed by the United States is being used globally as a green building standard as well as being adapted by countries to incorporate their local requirements. Several countries in the Asia Pacific region, particularly, have developed their indigenous green building assessment systems that address regional issues relevant to the local climate, construction industry and resources.

While rating systems place heavy emphasis on building energy performance, they also stipulate standards for ODS use, in keeping with the Montreal Protocol. Some requirements are mandatory, while others are optional. A strong, market-driven and market-driving tool influencing the entire construction industry, green building rating systems can not only help mitigate climate change, but also play an important role in phasing out HCFCs.

Table 9 Error! Reference source not found. lists green building rating tools used in the Asia Pacific region, as well as a summary of ODS requirement for different building components.

Table 9 Green building assessment tools and ODS use in buildings

Green Building Assessment Tool	Applicable Region	Requirements of ODS use in buildings			
		Insulation	HVAC	Refrigeration	Fire Suppression
GRIHA	India	✓	✓	✓	✓
IGBC	India	-	✓	✓	✓
LEED	Developed by USA; Used World wide	-	✓	✓	✓
BERDE	Philippines	✓	✓	✓	✓
LOTUS	Vietnam	-	✓	✓	-
GBI	Malaysia	-	✓	✓	✓
Green Mark	Singapore	-	✓	✓	-
Greenship	Indonesia	-	✓	✓	✓
GRSBE	Sri Lanka	-	✓	✓	✓

While the use of CFCs in HVAC systems is prohibited across all rating systems, the use of HCFCs is an optional criterion in the GreenMark, Greenship, BERDE and LOTUS rating systems. LOTUS has a mandatory requirement for using refrigerants having GWP less than 2000 and ODP <0.02 for refrigerants used in air conditioning, thereby encouraging the move toward low-GWP alternatives. On the other hand, GreenMark has an optional credit point for using refrigerants with GWP less than 100.

Only GRIHA and BERDE rating systems address the use of ODS in building insulation. LEED has an optional criterion for the use of non-HCFC fire suppressants. As a step further, BERDE has an optional criterion for no-ODS products as refrigerants and fire suppressants.

Green building rating systems have stringent energy consumption requirements, which impact both the size of air-conditioning systems and the refrigerant demand. Rigorous rating systems can contribute to phasing out ODSs and simultaneously prevent direct and indirect greenhouse gas emissions.

Green building rating systems promote the use of HCFC alternatives, thereby aiding HCFC phase-out. As green buildings gain momentum in developing economies, rating systems will play a significant role in HCFC phase-out.

Status of India

Following green building rating systems are in place in India

1. Green Rating for Integrated Habitat Assessment (GRIHA)
2. Leadership in Energy and Environmental Design (LEED)
3. The Indian Green Building Council (IGBC)

Green Rating for Integrated Habitat Assessment (GRIHA)

The Ministry of New and Renewable Energy has adopted a national rating system, GRIHA, which was developed by The Energy and Resources Institute (TERI). It is an indigenously developed rating system completely tuned to the climatic variations, architectural practices and existing practices of construction in India, and attempts to revive vernacular passive architecture. The GRIHA rating system takes into account provisions of the National Building Code 2016, the Energy Conservation Building Code 2017 launched by the BEE, and other IS codes. GRIHA has been developed to rate newly constructed commercial, institutional and residential buildings, while a separate GRIHA rating system for existing commercial buildings has also been developed to tap the massive energy and emissions saving potential locked in the existing building stock. GRIHA emphasizes on national environmental concerns, regional climatic conditions and indigenous solutions.

Leadership in Energy and Environmental Design (LEED)

The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™, developed and managed by the United State Green Building Council (USGBC), is the most widely used rating system in North America. Buildings are given ratings of platinum, gold, silver, or "certified", based on green building attributes. LEED is evolving rapidly; in the United States, at least nine types of specific programs exist, including those for new commercial construction and major renovation projects, existing building operation and maintenance, commercial interiors, homes, schools, neighborhoods and retail. LEED is one of the most prominent rating systems currently being adopted in many countries around the world.

The Indian Green Building Council (IGBC)

IGBC, founded by the collaboration between the Confederation of Indian Industry (CII) and Godrej, has taken steps to promote the green building concept in India. It rates buildings on environmental performance and energy efficiency during design, construction and operation stages.

While all the three rating systems are voluntary for adoption, it is mandatory for public buildings developed by the Central Public Works Department (CPWD) are to be atleast GRIHA three star rated. Several incentives have been introduced in terms of property tax rebates, extra FAR (Floor Area Ratio) to projects opting for green building rating.

As per GRIHA, it is mandatory to use CFC and HCFC free insulation, CFC free refrigerant in air conditioning, refrigeration and fire fighting systems. LEED and IGBC ratings require CFC free refrigerant in the building air conditioning but does not address building insulation. Further, all the three rating system does not explicitly require the selection of low-GWP alternatives.

Summary

The first step in achieving phase out is to have policies and programs addressing ODS use and energy efficiency; which India already has. The second step is to have synergy between these programs so that an integrated phaseout can take place. In that context, the National Building Code (NBC) and the green building rating systems are the only two instruments that address both ozone depletion and climate change. The HPMP has also clearly prioritized the air conditioning and foams with respect to the building sector in its plan.

Table 10 Summary of policies in India

Policy/Program	Address ODS in air conditioning	Address ODS in building insulation	Address ODS in fire fighting	Address building energy efficiency
HCFC Phaseout Management Plan	✓	✓		
National Building Code	✓			✓
Energy Conservation Building Code				✓
Kigali Amendment	✓	✓	✓	
Standards and Labeling program for appliances and equipment				✓
Regulations for foams and firefighting industry			✓	
Green building rating systems	✓	✓	✓	✓

While NBC is a regulation, the green building rating systems are voluntary for adoption. However, green building rating systems address all the areas in buildings where ODS is used. Further they address other environmental issues such as water, waste and indoor air quality in building in addition to energy efficiency. Green building rating systems are also consistently updated pushing the uptake of new energy conservation measures. Hence other regulations can benefit by having a synergy with green building rating systems.

For example, the Building Control Regulations of Singapore mandates that all new buildings need to meet the lowest GreenMark score of 50 points to meet the minimum environmental performance. GreenMark is Singapore's indigenous green building rating system. It also requires that the air conditioners used in residential buildings should have the energy label of atleast 'two ticks'. This is a good example of establishing a synergy between Building Code and a more dynamic market driven green building rating system.

Overall, India is in a good place with its policies to move ahead in the direction on low-GWP alternatives. The synergy between different instruments as suggested above will really ensure a successful phaseout without locking in high-GWP substances in the new building stock.

Glossary

GLOSSARY

Article 5 countries

Any Party that is developing country and whose annual consumption of the controlled substances in Annex A is less than 0.3 kg per capita on the date of entry into force of the Montreal Protocol or any time thereafter until 1 January 1999. Article 5 countries are eligible for assistance in meeting compliance requirements. Currently, 147 of the 191 parties to the Montreal Protocol meet these criteria.

Carbon dioxide equivalent (CO2-eq)

CO2-eq is a quantity that describes the amount of CO2 in a given amount of greenhouse gases that would have the same global warming ability when measured over a specified time scale. This is a simple way to place emissions of various climate change agents on a common footing in order to account for their effect on the climate.

Not-in-kind alternatives

Not-in-kind alternative technologies achieve the same product objective without the use of halocarbons, typically by using an alternative approach or unconventional technique.

Hydrochlorofluorocarbons (HCFCs)

These are chemicals that contain hydrogen, fluorine, chlorine, and carbon. They do deplete the ozone layer, but have less potency compared to CFCs. Many HCFCs are potent greenhouse gases. HCFCs are used as feedstock, refrigeration, foams, solvents, fire extinguishing equipment and sterilants.

Hydrofluorocarbons (HFCs)

These are chemicals that contain hydrogen, fluorine, and carbon. They do not deplete the ozone layer and have been used as substitutes for CFCs and HCFCs. Many HFCs are potent greenhouse gases.

Global warming potential (GWP)

GWP is a relative index that enables the comparison of the effects of the emissions of various greenhouse gases (and other climate changing agents) on the climate. CO2, the greenhouse gas that causes the greatest radiative forcing because of its overwhelming abundance, is chosen as the reference gas. The GWP represents the combined effect of the differing atmospheric lifetimes (i.e., how long these gases remain in the atmosphere) and their relative effectiveness in absorbing outgoing thermal infrared radiation. The Kyoto Protocol is based on GWP from pulse emissions over a 100-year time frame.

Ozone depletion potential (ODP)

This is a measure of the extent of depletion of the ozone layer by a given ODS, relative to that depleted by CFC-11 (CFC-11 has an ODP of 1.0). The Montreal Protocol uses the steady-state ODP that is defined by the time integrated change of global ozone due to a unit mass emission of the ODS at the earth's surface, relative to that from a similar emission of a unit mass of CFC-11.

Radiative forcing

A measure of how a climate-forcing agent influences the energy balance of the earth. A positive value indicates a net heat gain to the lower atmosphere, which leads to a globally average surface temperature increase; a negative value indicates a net heat loss.

kW (kilo watt)

Watt is a measurement of power in the metric system. Power is a measure of the rate at which energy flows. For example, a 60-Watt bulb will consume electricity at the rate of 60 Watts. Equipment such as computers, boilers and air conditioners come with power ratings to describe the rate at which they use energy.

1 kilowatt = 1000 Watts

Btu (British thermal unit)

Btu is a measurement of power in the inch-pound system.

1 watt = 3.416 Btu

1000 Btu = 1 kBtu

Coefficient of performance (COP)

COP is a measure of efficiency of a mechanical refrigeration system. A COP of 4 indicates that for every unit of electrical energy consumed, the heating or cooling provided by the equipment will be 4 times that. Therefore, a higher COP indicates better efficiency. A 370-ton water-cooled screw chiller using HCFC-123 or HFC-134a refrigerants can have a COP of 6.4.

Appendix 1, 2 and 3

APPENDIX 1:

SUMMARY OF GREEN BUILDING RATING SYSTEMS

COMPARISON OF REQUIREMENTS IN GREEN BUILDING RATING SYSTEMS FOR USE OF OZONE DEPLETING SUBSTANCES IN BUILDING							
Green Building Assessment Tool	Applicable Region	Applicable Category	Requirements for using Ozone Depleting Substances in buildings				
			Level of Rigor	Building Envelope	Refrigerants for HVAC	Refrigeration	Fire Suppression
LEED (Leadership in Energy and Environmental Design)	created by USA; used worldwide	LEED NC v3 - New construction	Mandatory	-	No CFC	-	
			Optional	-	No HCFC or Refrigerant to comply with the formula	-	No HCFC and Halons
BERDE (Building for Ecologically Responsive Design Excellence)		New and existing buildings	Optional	(Whole Building) Life Cycle Inventory of GHG emissions from buildings, including HCFC, PFC, SF6 in additon to CO2, CH4 and N2O	No ODS		No ODS
GBES (Green Building Evaluation System)	China	Residential and public Bldgs	-	-	-	-	-
LOTUS Rating Tool	Vietnam	Residential and non-residential bldgs	Mandatory	-	All refrigerants should have GWP <2000 and ODP <0.05	-	-
			Optional	-	All refrigerants used are HFCs	-	-
GreenMark	Singapore	New buildings	Optional	-	Zero ODP and GWP <100; leak detection system required at critical areas.	-	-

COMPARISON OF REQUIREMENTS IN GREEN BUILDING RATING SYSTEMS FOR USE OF OZONE DEPLETING SUBSTANCES IN BUILDING

Green Building Assessment Tool	Applicable Region	Applicable Category	Requirements for using Ozone Depleting Substances in buildings				
			Level of Rigor	Building Envelope	Refrigerants for HVAC	Refrigeration	Fire Suppression
GBI (Green Building Index)	Malaysia	Non-residential new and existing buildings	Optional	-	No CFC or use natural refrigerants	-	zero ODP and negligible GWP or clean agents
		Existing industrial buildings	Optional	-	No CFC or use natural refrigerants	-	zero ODP and negligible GWP or clean agents
Greenship	Indonesia	New buildings	Mandatory	-	No CFC	-	No Halons
			Optional	-	No ODS in the whole building system	-	-
		Existing buildings	Mandatory		ODP <1 for new refrigerants; CFC to be		
			Optional		Zero ODP in the entire system		
GBCS (Green Building Certification System)	Korea				inadequate information		
GRSBE [GREEN Rating System for Build Environment]	Sri Lanka		Mandatory	-	CFC reduction	-	-
			Optional	-	Ozone depletion measures	-	-
GRIHA (Green Rating for Integrated Habitat Assessment)	India	New construction (institutional and commercial)	Mandatory	CFC and HCFC free insulation	CFC free refrigerant	CFC free refrigerant	No halons
IGBC Green Homes	India	Residential bldgs	Prerequisite	-	No CFC	-	-

APPENDIX 2: LIST OF ALTERNATIVES

List of alternatives for HCFC-22 use in the air-conditioning sector

Refrigerant Designation	Refrigerant Specification	Safety Class	ODP	GWP (100 Yr)	Characteristics
HFC-32	Single Component	A2L	0	675	Used in several markets, Mildly flammable
HFC-161	Single Component	A3	0	12	Highly flammable
R-290	Single Component	A3	0	5	Introduced for small units Highly flammable
R-407C	RHC-32/125/134a	A1	0	1700	Widely used, high GWP
R-410A	R-32/125	A1	0	4	Widely used. High GWP
R-417A	R-125/134a/600	A1	0	2300	High GWP
R-419A	R-125/134a/F-170	A1	0	2900	High GWP
R-422D	R-125/134a/600a	A1	0	2700	High GWP
R-444B	HFC-32/1234ze (E)/152a	A2L	0	310	Low-GWP
R-446A	HFC-32/1234ze(E)/R-600	A2L	0	480	Low GWP
R-447A	HFC-32/125/1234ze (E)	A2L	0	600	Medium GWP
R-447B	HFC-32/125/1234ze (E)	A2L	0	583	Medium GWP
R-448A	HFC-32/125/1234yf/134a	A1	0	1400	High GWP
R-449A	HFC-134a/125/1234yf/32	A1	0	1400	High GWP
R-452A	HFO-1234yf/HFC-32/125	A1	0	2100	High GWP
R-452B	HFO-1234yf/HFC-32/125	A2L	0	680	Mildly Flammable, Medium GWP
N-20 B	Blend of HFCs & HFO	A1	0	988	Medium GWP
DR-3	Blend of HFCs & HFO	A2L	0	148	Low-GWP
ARM-20B	Blend of HFCs & HFO	A2L	0	251	Low GWP
ARM-71A	Blend of HFCs & HFO	A2L	0	460	Mildly Flammable
HPR-2A	Blend of HFCs & HFO	A2L	0	600	Mildly flammable

R-717	Single Component	A2B	0		Mildly toxic & flammable Use location specific
R-744	Single Component	A1	0	1	Very high pressure
R-1270	Single Component	A3	0	1.8	Highly Flammable

Table 11. Alternatives for air conditioning

List of alternatives for HCFC-123 use in the air-conditioning sector

Refrigerant Designation	Safety Class	ODP	GWP (100 Yr)	Characteristics
Single component	A1	0	1	Ultra-low-GWP
Single component	A2L	0	<1	Ultra-low-GWP
Single component	A2L	0	<1	Ultra- low-GWP
Single Component	A2L	0	2	Ultra- low-GWP
R-513A (HFO-1234yf/134a)	A1	0	560	Medium Pressure
R-514A [HFO-1336mzz(Z)/1130(E)]	B1	0	1.7	Low Pressure

Table 12. Alternatives for air conditioning

List of alternatives for HCFC use in the building insulation sector

Alternatives	ODP	GWP	Characteristics
HFC-152a	0	124	used in some applications
HFO-1234ze	0	7(UNEP, 2011b)	Low/no flammability
Cyclopentane	0	3	High flammability; widely applied for PU foams; thermal performance very close to HCFC foams; suitable for large facilities due to high equipment conversion cost; retrofit candidate

Water	0	0	Used as water vapor
CO_2 (R-744)	0	1	Poor insulating property; high density
Methylal	0	-	Under evaluation
Di-methyl ether	0	-	Established markets in China and EU; moderate flammability
Methyl formate	0	-	Good blowing efficiency; require less blowing agent compared to HCFC-22

Table 13. Alternatives for building insulation

List of alternatives for HCFC use in the firefighting sector

Alternatives	ODP	GWP	Characteristics
HFC-134a	0	1430	Relatively higher cost compared to HCFCs
HFC-236fa	0	9810	Clean agents; high GWP
HFC-227ea	0	3220	Clean agents; high GWP
Lodofluorocarbon (FIC-1311, FIC-21711)	0	-	Contains inert gases
Perfluoroketone (FK-4-1-12)	0	9160	Clean agent; high GWP
CO_2 (R-744)	0	1	Used at clean agents in fixed systems
Water	0	0	Most commonly used alternative
AFFF	0	0	Water-based synthetic foam; low viscosity; ability to quickly cover large areas
Dry chemicals	0	0	Powder form such as ABC powder; effective for combination of fires
Aerosol powders	0	0	Used in hand-held portable devices; combination of gas and fine powder

Table 14. Alternatives for fire suppressants

APPENDIX 3: GRIHA CHECKLIST

Sample checklist of the GRIHA green building rating system with all the assessment criteria and the respective point allocation

GRIHA (GREEN RATING FOR INTEGRATED HABITAT ASSESSMENT)

Green Building Rating System, India

Criteria Checklist

SITE SELECTION AND SITE PLANNING		
Points	**Criterion 1**	**Site Selection**
0	Mandatory	**Site plan** to be in conformity with development plan/master plan/UDPFI guidelines
1		**Site located within km** radius of existing bus stop, commuter rail, light rail, or metro station, **and/or** the proposed site must be a **brownfield site**
Points	**Criterion 2**	**Preserve and protect landscape during construction/compensatory depository forestation**
YES/ NO	Applicability check 1	There are several existing mature trees on site that can be preserved
1	Mandatory (If AP1 = Yes)	Preserve existing vegetation by means of non-disturbance or damage to trees and other forms of vegetation; OR Replant trees/plants within site premises in the ratio of 1:3
1		Ensure proper timing of construction with respect to rain; **AND** Confine construction activity to pre-designated areas, as per GRIHA
1		Proper implementation of staging and spill prevention plan; **AND** Effective erosion and sedimentation control to prevent erosion
1		Trees/plants replanted within site premises >25% than minimum requirement, as per GRIHA
Points	**Criterion 3**	**Soil conservation (post construction)**
YES/ NO	Applicability check 2	Top soil quality meets the quality standard of top preservation criteria, as per criterion 3

1		Proper topsoil laying for vegetative growth (If YES for AP2)
1		Stabilization of soil (If YES for AP2)
Points	**Criterion 4**	**Design to include existing site features**
3		Zoning of areas on-site is appropriate for the existing site features (such as slopes, vegetation, water bodies, and other natural formations); **AND** Carry out detailed site analysis and ensure sustainable site planning
Points	**Criterion 5**	**Reduce hard paving on site**
1		Total paved area under parking lots, roads, paths, and other uses not to exceed 25% of site area; **OR** Net imperviousness of site should not exceed the imperviousness factor, as prescribed by NBC 2005 (BIS 2005b), whichever is more stringent
0	Mandatory	Total surface parking not to exceed limit permitted by local by-law
1		More than 50% of the total paved area to have pervious paving or open grid pavements or grass pavers or shading through the use of vegetated pergolas or covered with coating of SRI >0.5 OR More than 50% of the total paved area to have a combination of the above
	Criterion 6	**Enhance outdoor lighting system efficiency**
1		Luminous efficacy of 100% of lamps used in outdoor lighting to meet the corresponding lamp luminous efficacy, as mentioned in Table 6.1
0	Mandatory	Automatic controls for 100% of the outdoor lights
Points	**Criterion 7**	**Plan utilities efficiently and optimize on site circulation efficiency**
1		Various transportation and service corridors shall be minimized and consolidated, and the pedestrian walkways are to be shaded
1		Use of aggregate utility corridors

1		Consolidation of utility corridors along the previously disturbed areas or along new roads in order to minimize unnecessary cutting and trenching and ensure easy maintenance
HEALTH AND WELL-BEING		
Points	**Criterion 8**	**Provide, at least, minimum level of sanitation/safety facilities for construction workers**
1	Mandatory	Compliance with NBC 2005 norms for construction safety
1	Mandatory	Health and sanitation facilities as per NBC 2005
Points	**Criterion 9**	**Reduce air pollution during construction**
2	Mandatory	Demonstrated air pollution preventive measures
BUILDING PLANNING AND CONSTRUCTION		
Points	**Criterion 10**	**Reduce landscape water requirement**
1		If landscape water demand is reduced by up to 30%
1		If landscape water demand is reduced by up to 40%
1		If landscape water demand is reduced by up to 50%
Points	**Criterion 11**	**Reduce building water use**
YES/ NO	Applicability clause	All faucets that are installed in spaces with water head heights less than 15 feet (4.6 m) in a gravity fed systems can be exempt for calculations in criterion 11
1		If building water demand is reduced by up to 25%
1		If building water demand is reduced by up to 50%
Points	**Criterion 12**	**Efficient water use during construction**
1		Minimize potable water use for construction

Points	Criterion 13	Optimize building design to reduce conventional energy demand
2	Mandatory	The Window-Wall Ratio (WWR) and/or Skylight-Roof Ratio (SRR) shall be limited to the prescribed levels, as per Table 13.1 (GRIHA Manual Introduction Volume-I), and all fenestration shall meet the SHGC requirements of ECBC 2007 OR shading requirements as suggested in 13.1.4 OR 13.1.5, as per clause 13.2.3 to 13.2.5
2	Mandatory	Minimum 25% of the living area shall be daylighted, meeting the daylight requisites prescribed in NBC 2005
2	Mandatory	Over-design of lighting system is avoided, and lighting levels shall meet NBC 2005
1		Daylighted area >50% of the total living area and meets the prescribed level of daylight
		Daylighted area >75% of the total living area and meets the prescribed level of daylight
Points	**Criterion 14**	**Optimize energy performance of building within specified comfort limits**
6	Mandatory	Compliance with Energy Conservation Building Code 2007
2	Mandatory	Compliance with thermal comfort condition as per the National Building Code 2005, and 10% reduction from minimum EPI as per GRIHA
4		Every 10% reduction in EPI (2 points); 20%–50% (8 points)
Points	**Criterion 15**	**Utilization of fly ash in building structure**
1		15%–25% replacement of Portland cement with fly ash (by weight of cement used) in structural concrete
1		Fly ash more than 25% (1 additional point)
2		Minimum 40% usage of fly ash (by volume of materials used) for 100% load-bearing and non-load-bearing walls
1		Minimum 15%–25% replacement by fly ash (by weight of cement used) in plaster/masonry mortar
1		Replace more than 25% of cement by fly ash (by weight of cement used) in plaster/masonry mortar

Points	Criterion 16	Reduce embodied energy of construction by adopting material efficient technology (e.g. pre-cast systems, ready-mix concrete, etc.)
1		Structural application: demonstrating a minimum 2.5% reduction in the embodied energy when compared with equivalent products for the same application
1		Structural application: demonstrating a minimum 5% reduction in the embodied energy when compared with equivalent products for the same application
1		Non-structural application: demonstrating a minimum 5% reduction in the embodied energy when compared with equivalent products for the same application
1		Non-structural application: demonstrating a minimum 10% reduction in the embodied energy when compared with equivalent products for the same application
Points	**Criterion 17**	**Use low-energy material in interiors**
2		A minimum of 70% of the total quantity (gross area) of all interior finishes and products used should be low-energy finishes for sub-assembly/internal partitions/paneling/false ceiling/in-built furniture
1		70% of flooring
1		70% of doors/windows and frames
Points	**Criterion 18**	**Renewable energy utilization**
2	Mandatory	Rated capacity of renewable energy system is equal to or more than 1% of total connected loads for lighting (interior and exterior) and space conditioning
1		Renewable energy system meets annual energy requirements of equal to or more than 5% of the internal lighting consumption or its equivalent in the building
1		>10%
1		>20%
1		>30%
2		If the total energy generated by the on-site or off-site renewable energy system is equivalent to 100% or more of the total annual energy consumption for only interior artificial lighting

Points	Criterion 19	Renewable energy based hot-water system
YES/ NO	Applicability clause 3	The total hot water requirement is more than 500 L/d
1		Annual energy saved by proposed renewable energy system is 20%–50% of the annual energy required for water heating to meet the hot water requirements of the occupants in the building (If YES to AC3)
1		Energy saved = 50%–70% (If YES to AC3)
1		Energy saved >70% (If YES to AC3)
Points	**Criterion 20**	**Waste water treatment**
YES/ NO	Applicability clause 4	The total waste water generation on-site is more than 10 kL/d
2		Treated water should meet the BIS recommended disposal standards (If YES to AC4)
	Criterion 21	**Water recycle and reuse (including rainwater)**
YES/ NO	Applicability clause 5	Groundwater table is high and groundwater recharge is not advisable as per the Central Ground Water Board norms
0	Mandatory	Details of filtration system to show that adequate preventative measures are being taken to avoid contamination of aquifer by the recharged rainwater
1		Annual water reuse of 25% (If YES to AC 4)
1		Annual water reuse of 50% (If YES to AC 4)
1		Annual water reuse of 75% (If YES to AC 4)
2		Recharge of surplus rainwater into aquifer (If YES to AC 5)
Points	**Criterion 22**	**Reduction in waste during construction**
1		Segregation of inert and hazardous waste **AND** Recycling and safe disposal of segregated waste

Points	Criterion 23	Efficient waste segregation
1		Provision of multi-colored bins for waste segregation at source
Points	**Criterion 24**	**Storage and disposal of waste**
1		Provision of separate space for hygienic storage of segregated waste before transfer for recycling
Points	**Criterion 25**	**Resource recovery from waste**
YES/ NO	Applicability check 6	Organic solid waste generation on-site is more than 100 kg/d
2		Zero waste generation from site: resource recovery measures (If YES for AC 6)
Points	**Criterion 26**	**Use of low - VOC paints/ adhesives/ sealants.**
1		100% of all paint used in the interior is low VOC
1		100% of all the sealants and adhesives used are water based rather than solvent based/low in oil solvent content
1		100% of composite wood products with no urea-formaldehyde resin
Points	**Criterion 27**	**Minimize ozone depleting substances**
1	Mandatory	Insulation to be free of CFCs and HCFCs; **AND** HVAC and refrigeration equipment to be CFC free; **AND** fire suppression systems and fire extinguishers to be halon free
Points	**Criterion 28**	**Ensure water quality**
2	Mandatory	Water quality conforming to BIS standard
Points	**Criterion 29**	**Acceptable outdoor and indoor noise levels**
1		Outdoor noise levels per CPCB—Environmental Standards
1		Indoor noise levels—NBC 2005
Points	**Criterion 30**	**Tobacco and smoke control**

1	Mandatory	The company policy for ban/prohibition of smoking within the building premises, a signed template by HVAC/architect consultant certifying that all compliances are met
Points	**Criterion 31**	**Universal Accessibility**
1		Compliance with NBC 2005 on requirements for Planning of Public Buildings Meant for Use of Physically Challenged

6	**BUILDING OPERATION AND MAINTENANCE**	
Points	**Criterion 32**	**Energy audit and validation**
0	Mandatory	Energy audit shall be conducted by a BEE-certified energy auditor
Points	**Criterion 33**	**Operation and maintenance**
2	Mandatory	Metering and sub-metering of energy and water; documentation of the O&M best practices for the building's electrical and mechanical systems
Points	**Criterion 34**	**Innovation Points (Beyond 100)**
4		

	Project Totals
One Star: 50–60 points; Two Stars: 61–70 points; Three Stars: 71–80 points	
Four Stars 81–90 points; Five Stars: 91–100 points	

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"The species that survived were not the most intelligent, but the ones that were most adaptable to change."

– Charles Darwin

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