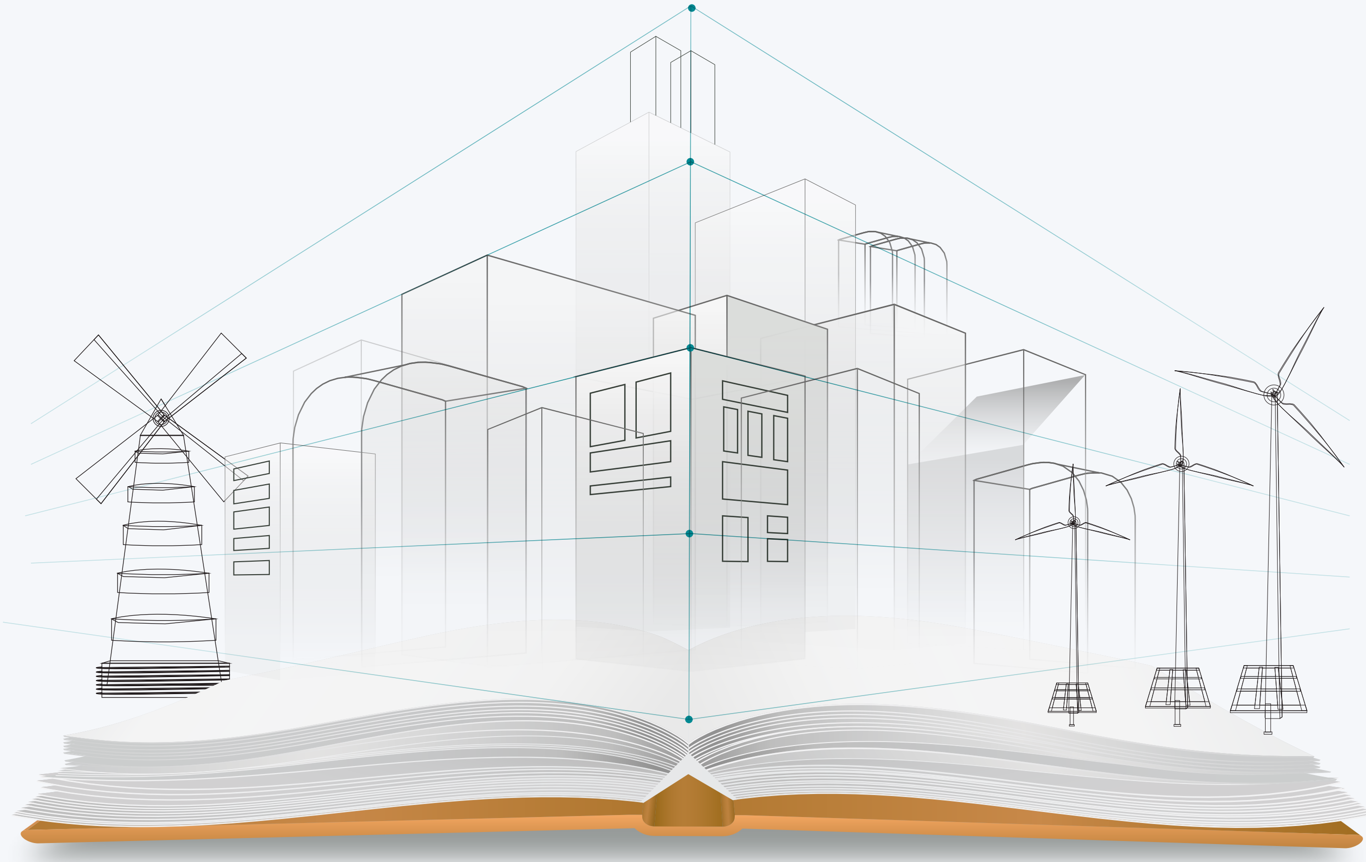
A GUIDE FOR INTEGRATION OF TOPICS RELATED TO HCFC PHASE OUT AND ENERGY EFFICIENCY IN ARCHITECTURAL CURRICULUM



UN environment
United Nations Environment Programme

प्रकृतिः रक्षति रक्षिता
Nature Protects if She is Protected
Ozone Cell
Ministry of Environment, Forest and Climate Change
Government of India

EESL

A GUIDE FOR INTEGRATION OF TOPICS RELATED TO HCFC PHASE OUT AND ENERGY EFFICIENCY IN ARCHITECTURAL CURRICULUM

सत्यमेव जयते

Ozone Cell
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This document was developed as a part of Ozone Cell's work on integrating architectural curriculum with Ozone Depleting Substances (ODS) issues with a view to raise awareness on zero Ozone Depletion Potential (ODP) and low Global Warming Potential (GWP) technologies. This handbook on "A Guide for Integration of Topics Related to HCFC Phase Out and Energy Efficiency in Architectural Curriculum" was authored with the active engagement and support of:

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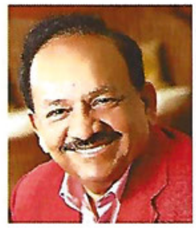

FOREWORD

India is the sixth largest economy in the world. The built environment is increasingly rapidly due to urbanization. Buildings sector is an important both in terms of material and energy use. Hydrochlorofluorocarbons(HCFC) are ozone depleting chemicals being phased out under the Montreal Protocol. These chemicals are being widely used as refrigerants in air conditioning equipment, as blowing agents in insulation foam and also in fire extinguishing systems. Making them pervasive in buildings. With the anticipated growth in demand for air-conditioning in the near future it has become critical to address the HCFC consumption in the building sector.

An important intervention to reduce use of HCFCs in the building sector is the move towards energy efficient buildings with use of passive interventions for cooling. This not only reduces the energy footprint of the building but also leads to reduction in cooling load thereby reducing the consumption of HCFCs. As part of building sector interventions being implemented under the HCFC Phase out Management Plan (HPMP), along with UN Environment, The Ministry has partnered with the Energy Efficiency Services Ltd. (EESL) for implementing these activities. As a first step a handbook was brought out last year on "***HCFC phase out and Energy efficiency in Buildings***"

In order to implement and design buildings which are energy efficient and have passive design interventions for cooling and thus reduced usage of HCFCs, it is important that the architecture curriculum includes topics related to Montreal Protocol in general and HCFC phase out and Energy efficiency in Buildings in particular.

The present Guide provides a template which could be used by all concerned to integrate topics related to Montreal Protocol, HCFC phase out, energy efficiency in buildings and passive interventions for cooling in the architectural curriculum. This shall be an important step in protection of Ozone Layer and the climate system.

Date: 14.09.2018

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Building sector consumes substantial amount of energy of which space cooling contributes major share. The refrigeration and air-conditioning systems in buildings also accounts for significant amount of Hydro chlorofluorocarbons (HCFC) consumption. As most of the buildings would be newly constructed in the near future, interventions at the design stage allow for maximum environmental gains.

Architecture plays an important role not only in the form of aesthetical angle but also optimum usage of resources like energy, water and materials. Thus Building design becomes an important tool for phasing out use HCFCs in new buildings and bringing in energy efficiency. The Ministry has partnered with the Energy Efficiency Services Limited (EESL), a joint venture of PSUs under Ministry of Power, Government of India to implement the activities related to building sector interventions under HCFC phase out management plan (HPMP). The UN Environment is the Implementing Agency for the enabling component of HPMP. The integration of topics on HCFC phase out and energy efficiency in architectural curriculum will help the future architects to introduce energy efficiency and use ozone friendly materials in new construction.

I am sure, this Guide will serve as an effective reference for any future changes to be brought in by Architecture training institutions in architecture curriculum. I congratulate all those who have put their best effort to bring out this book.

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

(Dr. Mahesh Sharma)

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A GUIDE FOR INTEGRATION OF TOPICS
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BACKGROUND

The objective of this document is to phase-out HCFC in building sector by introducing changes in the architectural curriculum for the architects. Compared to built-up area in 2005, building stock in India is predicted to grow five-fold, reaching 10,400 million square meters in 2030 (EDS, 2010). The building sector is already consuming close to 40% of the nation's electricity, and consumption is expected to increase to 76% by 2040 (CSE, 2014). In air-conditioned commercial buildings, as much as 40% - 50% of 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 standards. Thus, projected new building construction and rising incomes will only increase demand for air conditioning. Overall, architects are pivotal in identifying building materials and selection of energy efficient technologies in air conditioning and therefore it is propose to include concept of low GWP and low ODS in the architectural curriculum. Overall, they must be well versed with the alternative technologies for Phasing out HCFCs from the building sector.

INTRODUCTION

Humankind's battle with climate change is intensifying every passing day. With carbon dioxide levels crossing 400 parts per million in 2017[1], earth has already crossed a climate change tipping point. Which means that climate change is irreversible at this point. This is a state of emergency for the entire world and we need to put our act together to be able to accomplish the target set at the Paris Agreement to keep the global temperature increase of this century below 2 degrees. The entire worlds' eyes are set on the developing economies at this time for reducing the greenhouse gas emissions.

As per the latest World Bank report, India is likely to remain the fastest growing economy for the whole next decade with growth rates projected to be 7.3% to 7.5%[2]. Urban areas are key contributors in economic growth and it is not surprising that India has also seen rapid urbanisation in the recent past. At present, only 30% of the Indian population is urban but it is projected to increase to 40% by 2030[3]. This increase in population would create an immense demand of infrastructure across the cities in India. The single biggest challenge of the country now is to strike a balance between rapid development and environmental preservation.

i. Ozone Depletion

In addition to climate change, anthropogenic activities have also led to the depletion of the ozone layer. In the 1970s, scientists discovered that earth's primary protection from UV radiation, the stratospheric ozone layer, was thinning as a result of the use of chemicals that contained chlorine and bromine, which when broken down could destroy ozone molecules. Overexposure to ultraviolet (UV) radiation is a threat to human health. It can cause skin damage, eye damage, and even suppress the immune system. UV overexposure also interferes with environmental cycles, affecting organisms—such as plants and phytoplankton—that move nutrients and energy through the biosphere[4].

[1] The Keeling Curve, SCRIPPS Institute of Oceanography, https://scripps.ucsd.edu/programs/keelingcurve/

[2] Global Economic Prospects, World Bank, January 2018

[3] Trends of Urbanization in India: Issues and challenges in the 21st Century, Dr. Sadashivam, T. and Dr. Shahla Tabassu, International Journal of Information Research and Review, May, 2016

[4] Stratospheric Ozone Protection – 30 Years of Progress and Achievements, Environmental Protection Agency (EPA), USA

Scientific observations of the rapid thinning of the ozone layer over Antarctica, often referred to as the "ozone hole", catalysed international action and led to the Montreal Protocol. The Montreal Protocol on Substances that Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion.

ii. Ozone Depleting Substances (ODS) and the Building Sector

HCFCs have dominated the refrigerant market in Asia with a 68% share followed by HFCs. 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 centres.

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.

43% of the HCFCs in India were used for refrigeration and air conditioning servicing in 2015.

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.

Following are some ozone depleting substances whose production and consumption is controlled under the Montreal Protocol.

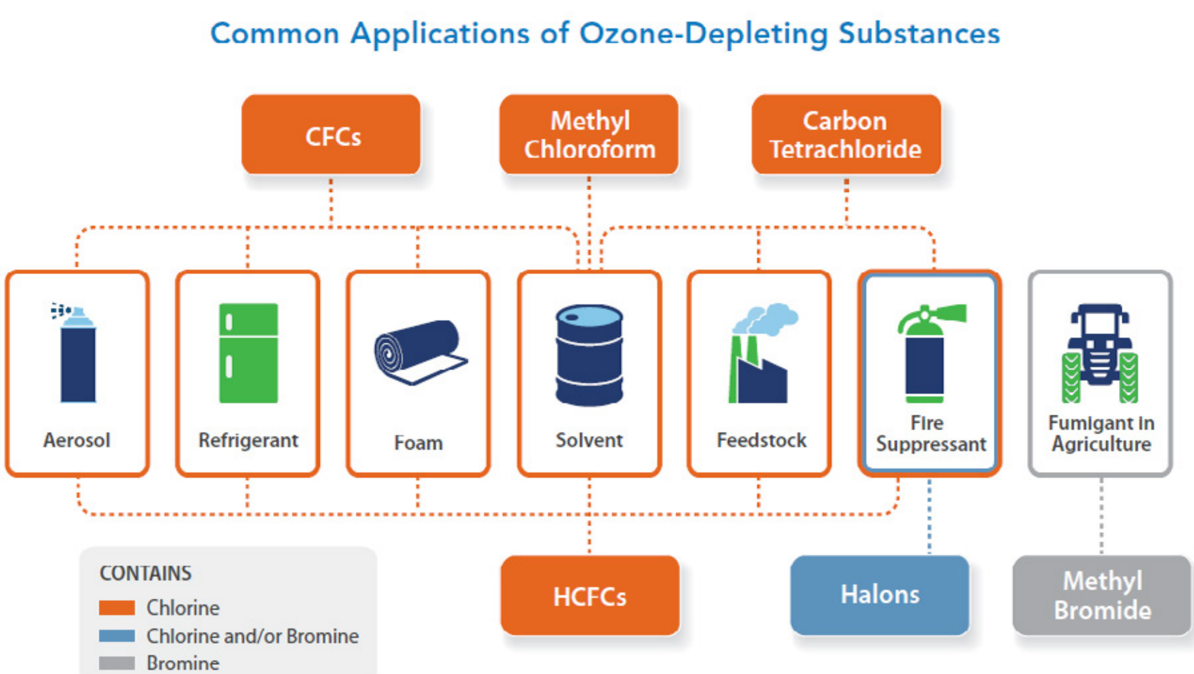

Figure 1- Common Application of Ozone Depleting Substances

iii. Phasing out HCFCs from the building sector

HCFCs were introduced in the 1990s as alternative chemicals for CFCs and added to the list of substances controlled by the Montreal Protocol. It was acknowledged at the time that these chemicals, with considerably lower ozone depleting potentials (ODP), were transitional and their production and consumption was also to be phased out under the Montreal Protocol. Although having considerably lower ozone depleting potentials than CFCs, many HCFCs have high global warming potentials, of up to 2000 times that of carbon dioxide.

The Stage-I of HCFC Phase-out management plan (HPMP) has been already implemented in the country and has successfully met all the ODS phase-out targets. It focused on phasing out HCFCs in the foam manufacturing sector, systems house and refrigeration and air-conditioning servicing sector. The HPMP Stage-II has prioritized phase-out initiatives in the building sector; especially for foams and air conditioning.

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.

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.
2. Replace HCFCs - Using low-GWP refrigerants and foam blowing agents is key to achieving successful phase-out of HCFCs in the building sector.
3. Use alternative technologies for refrigeration, air conditioning, insulation and firefighting.

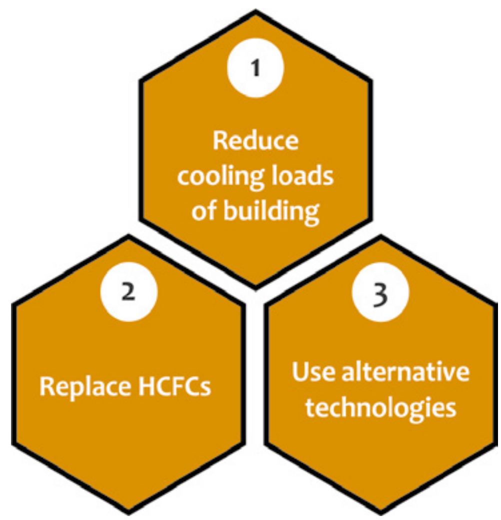

Figure 2- Three pronged approach for HCFC Phase-out

iv. Role of Architects in Phasing out HCFCs from the building sector

Sensitizing all the key stakeholders in the building industry is crucial for successful implementation of HPMP stage II. India is a tropical country that witnesses extreme heat for a significant duration of the year which has led to insulation and air-conditioning technologies being an integral part of modern construction. Considering that architects are pivotal in the selection of technologies and building materials, they must be well versed with the alternative technologies along with national priorities and policies for Phasing out HCFCs from the building sector.

The knowledge transfer can be accelerated by imparting the necessary knowledge to the upcoming future generation of architecture professionals during their learning years itself in addition to conducting awareness and capacity building programmes for the practicing architects.

v. Architecture education in India

The Council of Architecture (COA), a statutory body constituted by the Government of India under the provisions of the Architects Act, 1972, enacted by the Parliament of India, which came into force on 1st September, 1972, regulates the registration of Architects, standards of education, recognized qualifications and standards of practice in the profession of Architecture in India.

Under the provisions of the Architects Act, 1972 the Council of Architecture is required to prescribe the Minimum Standards of Architectural Education for imparting 5-year undergraduate degree course in Architecture (i.e. Bachelor of Architecture degree course) and also monitor the compliance of the same by the approved Architectural Institutions all over the country for award of recognized qualifications under the Act.

There are about 538 institutions in India, which are imparting undergraduate degree course in Architecture leading to recognized qualifications. The standards of Education being imparted in these institutions (constituent colleges/departments of universities, deemed universities, affiliated colleges/ schools, IITs, NITs and autonomous institutions) is governed by Council of Architecture (Minimum Standards of Architectural Education) Regulations, 1983, which set forth the requirement of eligibility for admission, course duration, standards of staff & accommodation, course content, examination etc. These standards as provided in the said Regulations are required to be maintained by the institutions[5]. The latest amendment to the regulations, COA Minimum Standards of Architectural Education, 2017 has already been drafted and submitted to the Ministry of Human Resource Development (MHRD) and will be implemented very soon.

In addition to the regulatory standard, the All India Council for Technical Education (AICTE) has also developed a model syllabus for the bachelor's degree course in Architecture with the intent to bring uniformity across various universities. The methods of education and training for architects are extremely varied in the India owing to the large size of the country and cultural diversity. Moreover, in today's globalized scenario, Architects are not limited to practicing in their own country but worldwide. The model curriculum has been designed with the intent of not only bringing uniformity in the pedagogical methods while maintaining the cultural richness but also to ensure worldwide recognition of the degrees conferred by Indian Institutes.

vi. Analysis of the Architecture Curriculum in India

AICTE states that, since architecture is created as synthesis of reason, emotion, and intuition, architectural education should be regarded as the manifestation of the ability to conceptualize, coordinate, and execute the idea of building rooted in human tradition. **The basic goal of the architecture education is to develop the architect as a generalist able to resolve potential contradictions between different requirements, giving form to the society's and the individual's environmental needs.**

It further states that, the vision of the future world cultivated in architectural schools should include the following goals:

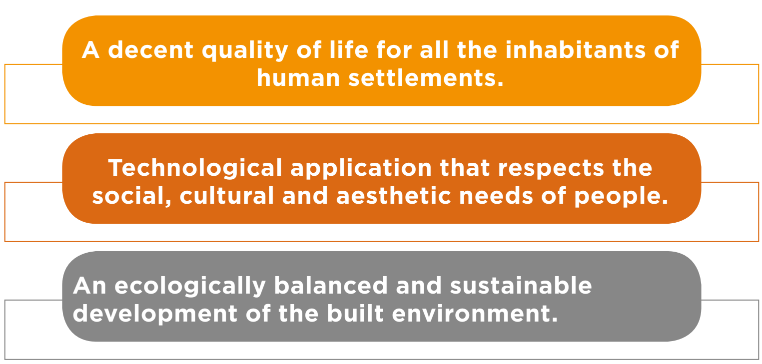

Figure 3- Goal of Architecture Education

[5] Architectural Education (as on 25th April 2018), Council of Architecture, www.coa.gov.in

Architecture education requires an understanding of both art and scientific principles. The intent of architecture education is to equip the student with tools that will help him make decisions even in a future scenario. Unlike other technical professional degrees, large part of education is imparted in non-conventional design studios that focus on developing understanding and reasoning of our built-environment. Design studios are based more on hands-on exercises than on literature or lecture driven education. The assessment too is therefore an in the form of an external jury instead of a written exam. Hence, the design studios take centre stage in the curriculum than the theory subjects that are an add-on for enhancing the basic knowledge.

Given the nature of the Architectural Profession, the COA Minimum Standards of Architectural Education, 2017 provides a robust framework with enough flexibility to each university to adapt their curriculum to make it most relevant in the given social context.

Following is the curriculum outlined by the COA for "Bachelor of Architecture":

The Architecture program shall be of minimum duration of 5 academic years or 10 semesters, inclusive of six months/one semester of practical training during 8th or 9th Semester.

The 10 semesters have been split into two stages:

Stage 1	Under the Choice based credit system, which is a student/ learner centric system, the courses of study in the Architecture Degree program shall be as under:	
1.1	**Professional Core (PC) Course:** A course, which should compulsorily be studied by a candidate as a core requirement is termed as a Core course.	Compulsory
1.2	**Basic Sciences and Applied Engineering (BS & AE) Course:** A course which informs the Professional core and should compulsorily be studied.	Compulsory
1.3	**Elective Course:** Generally a course which can be chosen from a pool of courses and are of two types: (i) Professional Elective (PE) which may be very specific or specialized or advanced or supportive to the discipline/ subject of study or which provides an extended scope (ii) Open Elective (OE) which enables an exposure to some other discipline/subject/domain or nurtures the candidate's proficiency/skill	Choice based
1.4	Employability Enhancement Courses (EEC) which may be of two kinds: (i) Employability Enhancement Compulsory Courses (EECC) (i) Skill Enhancement Courses (SEC)	Choice based

Following is the list of suggested courses by COA in each of the subject:

1. PROFESSIONAL CORE (PC)

1. Basic Design and Visual Arts
2. Architectural Design
3. Architectural Design Thesis
4. Architectural Graphics and Drawing
5. History of Architecture and Culture
6. Principles/ Theory of Architecture
7. Urban Design
8. Human Settlements Planning

9. Housing
10. Landscape Design
11. Site Planning
12. Carpentry and Model Making Workshop
13. Specifications, Cost Estimation and Budgeting

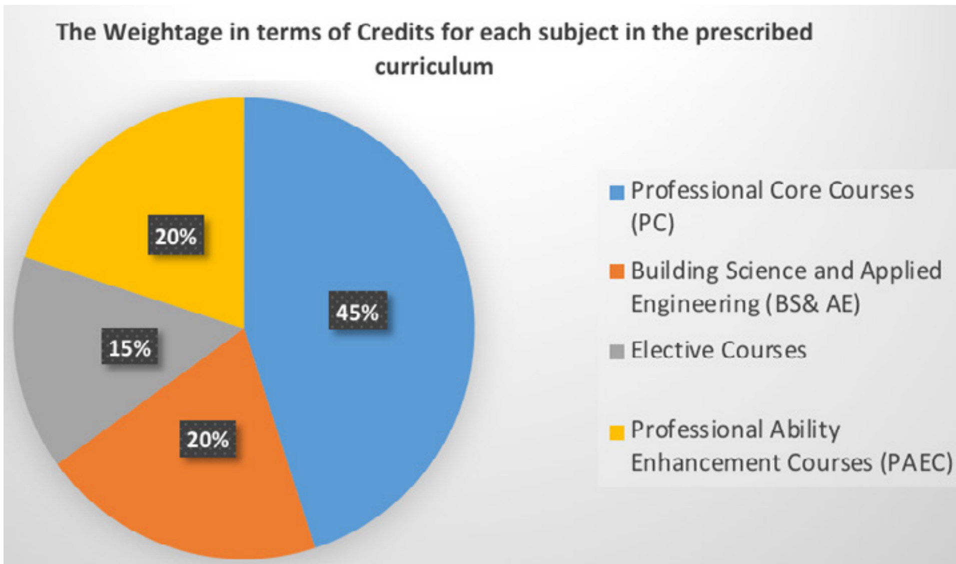

Figure 4- Current Weightage of subject prescribed in terms of credits.

2. BUILDING SCIENCES AND APPLIED ENGINEERING (BS& AE)

1. Building Materials
2. Building Construction
3. Applied Mechanics
4. Structural Design and Systems
5. Climatology
6. Building Services
7. Surveying and Levelling
8. Acoustics
9. Environmental lab
10. Environmental Science for Architecture

3. ELECTIVE COURSE (EC)

The list of electives given below is suggestive and the Institution/University may adopt the electives as found feasible.

3a. PROFESSIONAL ELECTIVE (PE)

1. Theory of Design
2. Vernacular Architecture
3. Interior Design
4. Art Appreciation
5. Art in Architecture
6. Graphic and Product Design
7. Contemporary Processes in Architecture
8. Architectural Journalism
9. Disaster Mitigation and Management
10. Green Buildings and Rating Systems
11. Sustainable Cities and Communities
12. Building Performance and Compliance
13. Architecture of South East Asia
14. Architectural Design with Steel
15. Architectural Design with Glass
16. Furniture Design
17. Appropriate Building Technologies
18. Earthquake Resistant Architecture
19. Architectural Conservation
20. Building Systems Integration and Management

3b. OPEN ELECTIVE (OE)

Courses approved by the Institution/University from subjects of study other than Architecture which will add value to the program and enable the overall development of the student.

4. PROFESSIONAL ABILITY ENHANCEMENT COURSES

4a. PROFESSIONAL ABILITY ENHANCEMENT COMPULSORY COURSES

1. Professional Practice
2. Internship/ Practical Training
3. Project Management
4. Dissertation /Seminar/ Research Methodology

4b. SKILL ENHANCEMENT COURSES

1. Communication Skills
2. Computer Studio
3. Building Information Modeling
4. Digital Graphics and Art
5. Entrepreneurship Skills for Architects
6. Foreign Language

vii. Inference

Development of any kind does have an impact on the environment. It is well understood by the architectural fraternity that giving due consideration to the environmental issues must be in-built in the DNA of a responsible architect. That is why it is evident from the curriculum that environmental topics are incorporated in not just elective but also mandatory courses.

Following topics have been covered under the **BUILDING SCIENCES AND APPLIED ENGINEERING (BS & AE)** course, which is mandatory and has 20% weightage in the overall assessment:

1. Building Materials
2. Environmental Science .
3. Climatology
4. Applied Climatology or Environmental Science for Architecture
5. Building Services

Additionally, following topics have been indicated in the list of professional electives:

1. Green Buildings and Rating Systems
2. Sustainable Cities and Communities
3. Building Performance and Compliance

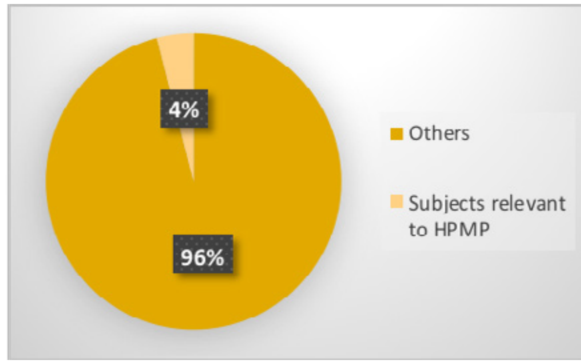

Figure 5- Present Curriculum Weightage for HPMP

It has been assessed that in the present curriculum for students of Bachelor of Architecture, topics related to HPMP comprise approximately 4% overall weightage.

Please refer Appendix I for Detailed subject matter under each head mentioned above.

The total marks of all subjects and courses in the Model Syllabus add to 2,300, out of these following are existing marks of topics relevant to HPMP Curriculum as per the "Model Syllabus for the Bachelor's Degree Course in Architecture" by AICTE

S.No.	Topic	Semester*	Overall Marks of topic	Approximate Marks of topics related to HPMP Syllabus
1	Building Materials	8 Semesters out of 10	1200	20
2	Environmental Science*	2nd	100	25
3	Climatology	3rd	150	150
4	Applied Climatology	4th	50	50
5	Building Services	2nd, 4th, 5th & 6th	600	125

** NOTE: Inclusion of "Basic Environmental Science" subject was mandated by MHRD in 2015, whereas the "Model Syllabus for the Bachelor's Degree Course in Architecture" was prepared in 2013. The approximate weightage is awarded to the subject based on some sample curricula.*

viii. Mapping of the proposed content with existing Architecture Curriculum

Proposed content	Mapping
Module 1 - Policies framework for Ozone & climate friendly technologies 1. Montreal Protocol 2. Accelerated Phase-out of HCFCs 3. India's commitment for HCFC phase-out a. HCFC phase-out management plan (HPMP) stage-I b. HCFC phase-out management plan (HPMP) Stage-II 4. Kigali agreement and HFC phase down 5. Impact on India's building sector	To be included in the **"Environmental Science"** course being taken up in 2nd Semester. **Proposed Marks in the said subject = 25**
Module 2 - Zero ODP building insulation 1. Alternative foam blowing agents 2. Vacuum Insulated Panel	To be plugged in with the topic of "Insulation" under **"Building Materials & Construction"** **Proposed Marks in the said subject = 20**
Module 3 - Climate passive strategies for energy efficient building design 1. Building envelope/façade 2. Interior zoning 3. Reducing thermal loads 4. Shading design	Already being covered under **"Climatology"** and **"Applied Climatology"** courses in 3rd and 4th Semesters.
Module 4 - Strategies for Energy Efficiency in Buildings 1. Energy consumption in buildings 2. Need for reducing building energy demand 3. Energy conservation measures (ECMs) 4. Introduction to Energy Conservation Building Code (ECBC) 5. Guidelines for selection of Energy Efficiency cooling equipment.	To be plugged in with the topic of "Electricity" under **"Building Services"** in 4th Semester **Proposed Marks in the said subject = 25**
Module 5 - Fundamentals of Air-conditioning systems 1. Unitary Systems 2. Chillers 3. Typical Installations of Air-Conditioning Systems in Buildings	Already being covered under **"Climatology"** and **"Applied Climatology"** courses in 3rd and 4th Semesters.
Module 6 – HCFC and high GWP refrigerants in buildings and phase-out plan 1. Building air conditioning and refrigerants 2. F-gas emissions from buildings 3. Steps for Phasing-Out HCFCs from Buildings 4. Alternatives to refrigerants and technologies	To be plugged in with the topic of "Air-conditioning" under **"Building Services"** in 5th Semester **Proposed Marks in the said subject = 125**

APPENDIX I

Subject matter relevant to HPMP Phase-out already included in the Architecture curriculum, as per the "Model Syllabus for the Bachelor's Degree Course in Architecture" by AICTE.

CLIMATOLOGY (Unit 3.7 - Part of 3rd Semester)

THEORY MARKS: 100

PROGRESSIVE MARKS : 50

Objective: To develop the knowledge required for understanding the influence of climate on architecture.

Outline:

Introduction – Elements of climate, measurement and representations of climatic data. Classifications of tropical climates, Major climatic zones of India.

Thermal comfort: Effect of climatic elements on thermal comfort environment. Body's heat exchange with surrounding environment. Thermal comfort indices viz., Effective temperature, bio-climatic chart etc., Kata-thermometer and globe thermometer.

Thermal performance of building elements: effect of thermo-physical properties of building materials and elements on indoor thermal environment. Thermal properties. Conductivity, resistivity, diffusivity, thermal capacity and time lag and 'U' value. Construction techniques for improving thermal performance of walls and roofs. Natural ventilation: Functions of natural ventilation, Design considerations, and effects of openings and external features on internal air flow.

Site Climate: Effect of landscape elements on site/micro climate.

Day Lighting: Advantages and limitations, Day light factor, components of Day light factor, design considerations.

Shading devices – Sun-path diagram, use of solar charts in climatic design. Types of shading devices. Procedure of designing shading devices. Design considerations for buildings in tropical climates with special reference to hot-dry, warm-humid and composite climates

Reference Books:

1) "Manual of Tropical Housing & Buildings (Part-II)" by Koenigsberger

2) "Housing, Climate and Comfort" by Martin Evans

3) "Buildings in the tropics" by Maxwell Fry

4) Climate Responsive Architecture "by Arvind Kishan, Baker & Szokolay".

CLIMATE RESPONSIVE ARCHITECTURE/APPLIED CLIMATOLOGY (Unit 4.7– Part of 4th Semester)

PROGRESSIVE MARKS: 50

Objective: To apply the principles of Solar Passive Architecture to design of buildings.

Outline: Introduction to passive techniques of cooling such as evaporative cooling, earth-tubing, wind scoops, roof ponds, shaded courtyards etc.,

Two design exercises (in hot dry and warm humid climate) with an objective to integrate passive cooling systems in the design.

Reference Books:

1) 'Housing, Climate and Comfort' by Martin Evans

2) 'Climate Responsive Architecture' by Arvind Kishan, Baker and Szokolay.

BUILDING CONSTRUCTION & MATERIALS – V (Unit 5.2 – Part of 5th Semester)

VIVA MARKS : 100

PROGRESSIVE MARKS : 50

Objective: To study constructional systems and detailing of special doors, windows, structural glazing and cladding.

Outline: Construction – PVC & FRP, frameless glass doors and windows and partitions. Wooden/ Steel/Aluminium sliding and folding doors and partitions. Steel doors for garages and workshops. Collapsible gate and rolling shutters, remote control systems of doors and gates. Structural glazing, aluminium composite panel cladding.

Materials – Insulation materials – Thermal and sound insulation materials. Glass – its manufacture in its various types like plate, tinted, decorative, reinforced, laminated glass block, fibre glass, glass murals, partially coloured glass, etching of glass and its applications in building industry for both exteriors and interiors. Glass fabrication techniques, fibre reinforced composite materials and products.

References:

1) "Construction Technology" by Chudley

2) "Construction of Buildings" by Barry

BUILDING SERVICES – III (Unit 5.3 – Part of 5th Semester)

EXAM MARKS: 100

PROGRESSIVE MARKS: 50

Objective:

To develop the knowledge and skills required for understanding the mechanical services in buildings and their integration with architectural design.

Outline:

Part – A Mechanical/Artificial Ventilation – Need for mechanical ventilation in buildings. Rate of ventilation for different occupancies. Methods and equipment employed for mechanical ventilation in buildings.

Air Conditioning – Definition, advantages and disadvantages, brief introduction to psychometric process, air cycle and refrigeration cycle. Summer and winter air-conditioning, calculation of air-conditioning loads, Zoning: purpose and advantages. Air-distribution systems: Ducts and duct systems. Air-outlets

Air-conditioning methods and equipment: window units, split units and central Air-conditioning systems. Location of air-conditioning equipment in buildings. Architectural requirement of various equipment.

Residential and commercial air-conditioning, energy conservation techniques. Introduction to the concept of 'Clean Room' and its architectural requirements.

Part – B Elevators (Lifts) and escalators – Brief history-types of Elevators like traction, Hydraulic etc., Double-decker, sky lobby, lift lobby, lift interiors etc., Definition and components. Elevators in a building: environmental considerations i.e., location in building, serving floors, grouping, size, shape of passenger car, door arrangement etc., Service requirements: Quality of service, quantity of service, time, passenger handling capacity, space and physical requirements, machine room spaces and their typical layout

Escalators – Definition, Application. Location and arrangement in buildings. Space requirement, Escalators V/S Elevators, Conveyor belts-movement of passengers and goods

Part – C Fire Safety - Causes of fire, reasons for loss of life due to fire, development of fire, fire load, fire hazards, grading of structural elements due to fire as per NBC. Classification of building types as per NBC Brief description of characteristics of combustible and non-combustible materials in case of fire.

Concepts in passive fire protection and control – including design of escape routes, pressurization and compartmentalization, etc., Active fire control using portable extinguishers. Basic concepts in fixed fire fighting installations. Automatic fire detection and alarm systems

Rules for fire protection and fire fighting requirements for High-rise buildings in India.

References:

1) 'Principles of Refrigeration' by Roy J Dosat

2) 'Air Conditioning and Refrigeration Data Hand book' by Manohar Prasad

3) 'Refrigeration and Air Conditioning' by Don Kundwar

MODULE 1

Montreal Protocol & ODS Phase Out

This module covers the international treaties and policy framework to combat ozone depletion.

Course: Environmental Science

2nd Semester, B Arch

1.1 INTRODUCTION

Overexposure to ultraviolet (UV) radiation is a threat to human health. It can cause skin damage, eye damage, and even suppress the immune system. UV overexposure also interferes with environmental cycles, affecting organisms—such as plants and phytoplankton—that move nutrients and energy through the biosphere.

In the 1970s, scientists discovered that Earth's primary protection from UV radiation, the stratospheric ozone layer, was thinning as a result of the use of chemicals that contained chlorine and bromine, which when broken down could destroy ozone molecules. The most common of these ozone-depleting substances (ODS) was a class of chemicals called chlorofluorocarbons (CFCs), which were widely used in a variety of industrial and household applications, such as aerosol sprays, plastic foams, and the refrigerant in refrigerators, air conditioning units in cars and buildings, and elsewhere.[2]

Scientific observations of the rapid thinning of the ozone layer over Antarctica from the late 1970s onward—often referred to as the "ozone hole"—catalysed international action to discontinue the use of CFCs.

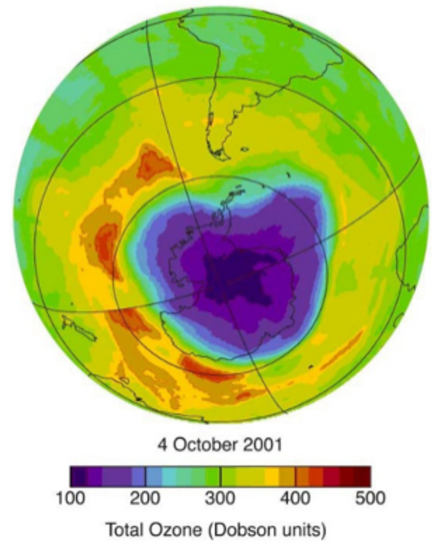

Figure 6- The Antarctic Ozone Hole

Source: National Oceanic & Atmospheric Administration (NOAA)

1.2 VIENNA CONVENTION

The Vienna Convention for the Protection of the Ozone Layer is a Multilateral Environmental Agreement. It was agreed upon at the Vienna Conference of 1985 and entered into force in 1988. It acts as a framework for the international efforts to protect the ozone layer. However, it does not include legally binding reduction goals for the use of CFCs, the main chemical agents causing ozone depletion. These are laid out in the accompanying Montreal Protocol.

The convention is based on the understanding that

a) Modification of the ozone layer which would result in a change in the amount of solar ultra-violet radiation having biological effects (UV-B) that reaches the Earth's surface and the potential consequences for human health, for organisms, ecosystems and materials useful to mankind;

b) Modification of the vertical distribution of ozone, which could change the temperature structure of the atmosphere and the potential consequences for weather and climate.

The Parties to the Convention, in accordance with article 3, shall co-operate in conducting research and systematic observations and in formulating recommendations for future research and observation in such areas as:

i. Physics and chemistry of the atmosphere

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[2] Stratospheric Ozone Protection – 30 Years of Progress and Achievement, United States Environmental Protection Agency (EPA), Washington DC, 2017

ii. Health, biological and photo degradation effects

iii. Effects on climate

Also, they cooperate for systematic observation on:

i. The status of the ozone layer

ii. The tropospheric and stratospheric concentrations of source gases for the HOx, NOx, ClOx and carbon families

iii. The temperature from the ground to the mesosphere, utilizing both ground-based and satellite systems

1.3 MONTREAL PROTOCOL

The Montreal Protocol on Substances that Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances that are responsible for ozone depletion. It was agreed on 16 September 1987, and entered into force on 1 January 1989, followed by a first meeting in Helsinki, May 1989. Since then, it has undergone eight revisions, in 1990 (London), 1991 (Nairobi), 1992 (Copenhagen), 1993 (Bangkok), 1995 (Vienna), 1997 (Montreal), 1998 (Australia), 1999 (Beijing) and 2016 (Kigali, adopted, but not in force).

It has been ratified by 197 parties, which includes 196 states and the European Union, making it and its parent treaty, the Vienna Convention for the Protection of the Ozone Layer, the first universally ratified treaties in United Nations history.

Due to its widespread adoption and implementation it has been hailed as an example of exceptional international co-operation, with Kofi Annan quoted as saying that *"perhaps the single most successful international agreement to date has been the Montreal Protocol".*

1.3.1 Key Components

The treaty is structured around several groups of halogenated hydrocarbons that have been shown to play a role in ozone depletion. For each group, the treaty provides a timetable on which the production of those substances must be phased out and eventually eliminated. The protocol has, Chlorofluorocarbons (CFCs) Phase-out Management Plan and Hydrochlorofluorocarbons (HCFCs) Phase-out Management Plan (HPMP).The provisions of the Protocol include the requirement that the Parties to the Protocol base their future decisions on the current scientific, environmental, technical, and economic information that is assessed through panels drawn from the worldwide expert communities.

Key components of the treaty include:

- Phase-out of ODS according to prescribed timetables for developing (Article 5) and developed (Non-Article 5) countries.
- A ban on ODS trade with non-signatory Parties and controls on ODS trade among Parties.
- Creation of the Multilateral Fund—the financial mechanism of the Montreal Protocol that aids Article 5 countries with Protocol compliance.
- A requirement for Parties who produce and consume ODS to provide a baseline and subsequent annual reports, and to conduct research, development, and information-sharing efforts on ODS substitutes.

To provide that input to the decision-making process, advances in understanding on these topics were assessed in 1989, 1991, 1994, 1998 and 2002 in a series of reports entitled 'Scientific assessment of ozone depletion'.

1.3.2 Amendments & Milestones

The Protocol originally required developed countries to begin phasing out CFCs in 1993 and to reduce total ODS consumption to half of 1986 levels by 1998.

Four Protocol Amendments and one Adjustment have since been put in place to strengthen the original requirements by stipulating accelerated timetables and accounting for new ODS.

Figure 7-Montreal Protocol Amendments & Milestones

Source: Stratospheric Ozone Protection – 30 Years of Progress and Achievement, United States Environmental Protection Agency (EPA)

1. **The London Amendment (1990)** required developed countries to eliminate CFCs, halons, and carbon tetrachloride by the year 2000 and required developing countries to eliminate these ODS by 2010. Methyl-chloroform has since been added to the list of ODS for elimination in developed and developing countries by 2005 and 2015, respectively.
2. **The Copenhagen Amendment (1992)** required CFCs, halons, carbon tetrachloride, and methyl chloroform be completely phased out in developed countries by 1996. HCFCs were also scheduled to begin phase-out in developed countries in 2004.
3. **The Montreal Amendment (1997)** produced a phase-out schedule for HCFCs in developing countries, and targeted the complete phase-out of methyl bromide for developed countries by 2005 and developing countries by 2015.
4. **The Beijing Amendment (1999)** increased restrictions on HCFC production and trade, and scheduled complete phase-out of methyl bromide for developed countries by 2004.
5. **The Montreal Adjustment on Production and Consumption of HCFCs (2007)** included commitments to accelerate the freeze year and the phase-out of HCFCs in developed and developing countries. For example, non-Article 5 parties agreed to increase the cap on HCFCs from a 65 percent reduction in 2010 to a 75 percent reduction by 2010 and Article 5 parties agreed to freeze HCFCs by 2013, rather than by 2016, among other adjustments.
6. **The Kigali Amendment (2016)** includes phase-down of non-ozone depleting substances, HFCs under the Montreal Protocol. Requires phase-down of HFCs of HFC to 15% of baseline level in developed countries by 2036 and in Article 5 countries to 15%-20% of the baseline levels by 2047.

1.3.3 Multilateral Fund (MLF)

With a view to assists the developing countries in their phase out efforts, a Multilateral Fund has been created. This is known as the Multilateral Fund (MLF) for the Implementation of the Montreal .The MLF assists the Executive Committee in implementation of production and consumption of Ozone Depleting Substances in Article 5 countries. The incremental cost includes, cost of transfer of technology, purchase of capital equipment and operational costs for switching over to non ODS technologies enabling the developing countries to phase out controlled substances. Enterprises using HCFCs technology established before 21st September 2007 are eligible for funding for conversion to non ODS technology from MLF .

India being an Article 5 country is entitled to access the technical and financial assistance for meeting the phase-out obligations under the Montreal Protocol.

1.3.4 Implementing Agencies

The work the Multilateral Fund finances on the ground in developing countries is carried out by four implementing agencies and some bilateral agencies. The World Bank, UN Environment, UNDP and UNIDO are designated as implementing agencies. The non-Article 5 countries can implement phase-out activities up to 20% of their contribution to the MLF. These are known as bilateral agencies.

1.4 IMPACT OF THE MONTREAL PROTOCOL

Since 1987, the Montreal Protocol has been strengthened to reflect the latest scientific information and technological advances. In the beginning, the Protocol addressed the production and consumption of primarily CFCs. Over the past thirty years, the global community has worked together to add amendments to the Protocol that address the phase-out of additional chemicals based on scientific and technical advises of Assessment Panels, the Environment Effect Panel (EEP), Science Asessment Panel (SAP) and Technology and Economic Assessment Panel (TEAP) and adjust the timeframes for phasing out certain chemicals for the early recovery of the ozone layer. Today, the Protocol provides a clear pathway for global reductions in the consumption and production of 96 substances, including CFCs, HCFCs, halons, methyl bromide and other ODS. The most recent amendment to the Protocol was adopted in October 2016 is for phase-down of HFCs which are non-ODS but have high Global warming Potential (GWP). HFCs being non ODS are not counted in the above numbers

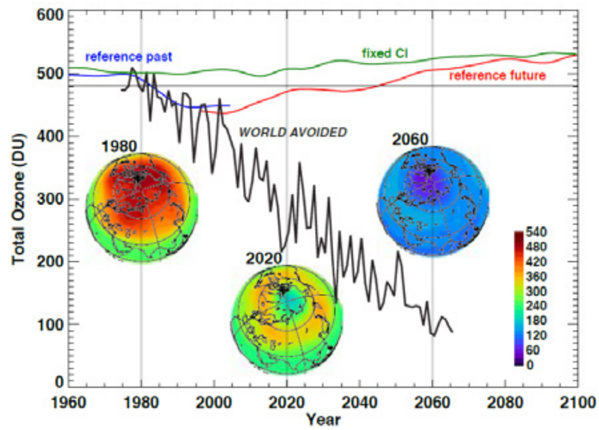

Figure 8- The Ozone depletion over the course of the 21st century in the 'World Avoided' scenario. The data are simulations for April in the northern hemisphere in the 'World Avoided', i.e. without the successful implementation of the Montreal Protocol (shown in black), and for a future in which the Montreal Protocol is successfully implemented (show in red). The two additional lines simulate ozone between 1960 and 2005 (blue) and a world in which ozone depleting substances never rose above 1960 levels (green). The false colour images show the geographical distribution of ozone in 1980, 2020 and 2060 (the scale is in Dobson units). Note the global collapse of stratospheric ozone by 2060.

The Figure 4 shows the changes in Antartic ozone hole starting from 1987 to 2016. The recent measurements clearly indicate that the ozone layer is on the path of recovery of the ozone layer and it is estimated that by 2060 the ozone layer will reach to 1980 level due to actions taken by the world community through the Montreal Protocol.

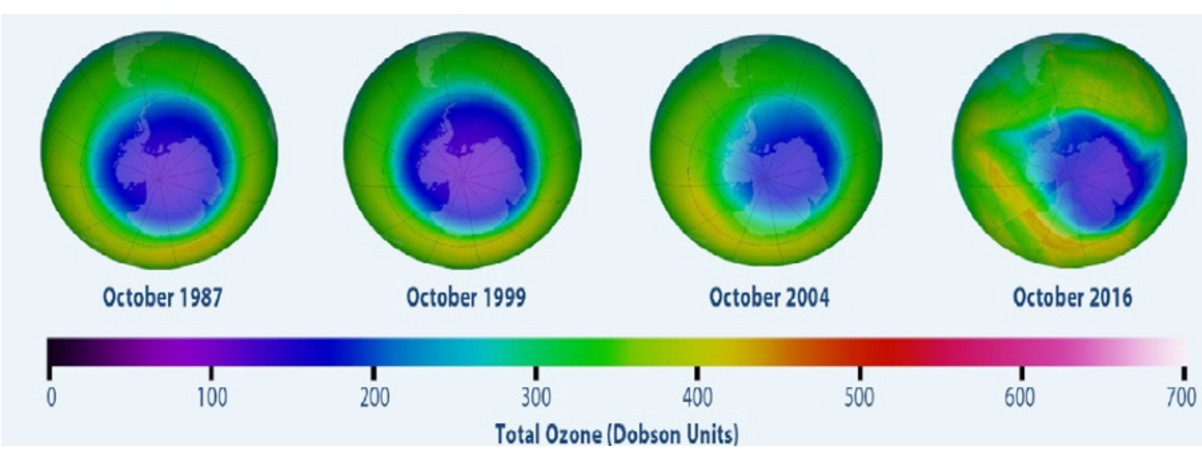

Figure 9- Changes in the Antarctic Ozone Hole between 1987 and 2016

As ODS have been controlled for gradual phase out by the Montreal Protocol and the international community has demanded new, safer alternatives to replace ODS, industries that have used ODS have responded with significant technological innovations. Many non-ozone-depleting alternatives have come onto the market, and equipment manufacturers have used the transition away from ODS as an opportunity to make other technological improvements, including improvements to energy efficiency and product design.

The production and consumption of entire groups of harmful ozone-depleting chemicals have been successfully phased out in developed countries. Overall, almost ninety-five per cent of all ozone-depleting substances have been phased out. This is a remarkable effort by the Parties to the Montreal Protocol.

1.5 SOME OZONE DEPLETING SUBSTANCES IN DIFFERENT INDUSTRY SECTORS

Following are some ozone depleting substances whose production and consumption is controlled under the Montreal Protocol.

1.5.1 Aerosols, Sterilant and Carbon Tetrachloride

Historically CFCs were used in aerosol products, as sterilant of medical equipment, and in a range of miscellaneous applications including food freezing, tobacco expansion, fumigation and cancer therapy. Carbon tetrachloride was used as solvent, process agent , as feedstock in the production of other chemicals including CFC-11 and CFC-12, pharmaceuticals and agricultural chemicals, and as a catalyst promoter.

1.5.2 Foams

Historically CFCs have also been used extensively in the manufacture of polyurethane, phenolic, polystyrene and polyolefin foam polymers, used in many different products. Common blowing agents have included CFC-11, CFC-12..

1.5.3 Halons

Similarly Halon 1211 has been widely used in portable fire extinguishers. Halon 1301 has seen widespread use in fixed systems throughout the industrial, commercial, marine, defence, and aviation industries. Halon 2402 has primarily been used in the defence, industrial, marine and aviation sector in some countries.

The strategy for the halon sector essentially consists of two approaches: replacing halons with alternatives, and halon banking. Alternatives to halons include halocarbon alternatives, inert gases, water mist, fine particulate aerosols and streaming agents. In some cases, fire protection strategies may be re-considered and the need for halons eliminated. Halon banking, which includes recovery, recycling and establishing inventories, is used by companies and countries for managing existing halon supplies to cover remaining critical uses.

1.5.4 HCFCs (hydrochlorofluorocarbons)

HCFCs (hydrochlorofluorocarbons) are widely used in the refrigeration, foam, solvent, aerosol and fire fighting sectors as a transitional substance to substitute CFCs. HCFCs are also used as feedstock (raw material) in the production for other chemical products.

1.5.5 Methyl bromide

Methyl bromide was widely used as a fumigant in agriculture, for pest control in structures and stored commodities, and for quarantine treatments. Fumigation is a technique that allows the gas to reach pests which are in soil, in durables, in perishables, and in structures and vehicles. This chemical controls a wide range of pests, including pathogens (fungi, bacteria and soil borne viruses), insects, mites, nematodes and rodents.

Use of methyl bromide has been eliminated by adopting alternatives, which have been identified for most of the applications However, production and consumption of methyl bromide has not yet controlled for use in Quarantine and pre-shipment (QPS) applications.

1.5.6 Solvents, Coatings & Adhesives

In the past, use of CTC and CFC-113 was essential in several industrial applications: in electronic assembly production processes, precision cleaning and general metal degreasing during manufacture, as well as in dry cleaning and other industrial applications. CFC-113 began to be used in the 1970s in metal degreasing and other areas owing to concern over the toxicity of the chlorinated solvents used previously.

For many years 1,1,1-trichloroethane was the solvent of choice to replace other more toxic chlorinated solvents for general metal cleaning. Carbon tetrachloride is no longer used as a solvent in most countries because of its toxicity, but it is still used in some parts of the world.

Table 1: Time table set for Phase-out of ODS as per the Montreal Protocol

Ozone depleting substances	Developed countries	Developing countries
Chlorofluorocarbons (CFCs)	Phased out end of 1995[a]	Total phase out by 2010
Halons	Phased out end of 1993	Total phase out by 2010
CCl_4(Carbon tetrachloride)	Phased out end of 1995[a]	Total phase out by 2010
CH_3CCl_3 (Methyl chloroform)	Phased out end of 1995[a]	Total phase out by 2015
Hydrochlorofluorocarbons (HCFCs)	Freeze from beginning of 1996[b] 35% reduction by 2004 75% reduction by 2010 90% reduction by 2015 Total phase out by 2020[c]	Freeze in 2013 at a base level calculated as the average of 2009 and 2010 consumption levels 10% reduction by 2015 35% reduction by 2020 67.5% reduction by 2025 Total phase out by 2030[d]

Ozone depleting substances	Developed countries	Developing countries
Hydrobromofluorocarbons (HBFCs)	Phased out end of 1995	Phased out end of 1995
Methyl bromide (CH_3Br) (horticultural uses)	Freeze in 1995 at 1991 base level[e] 25% reduction by 1999 50% reduction by 2001 70% reduction by 2003 Total phase out by 2005	Freeze in 2002 at average 1995-1998 base level[e] 20% reduction by 2005 Total phase out by 2015
Bromochloromethane (CH_2BrCl)	Phase out by 2002	Phase out by 2002
Hydrofluorocarbons (HFCs)	10% reduction by 2019[f] 30% reduction by 2024 70% reduction by 2029 80% reduction by 2034 85% reduction by 2036	Freeze in 2024[g] 10% reduction by 2029 30% reduction by 2035 50% reduction by 2040 80% reduction by 2045

[a] With the exception of a very small number of internationally agreed essential uses that are considered critical to human health and/or laboratory and analytical procedures.

[b] Based on 1989 HCFC consumption with an extra allowance (ODP weighted) equal to 2.8% of 1989 CFC consumption.

[c] Up to 0.5% of base level consumption can be used from 2020 until 2030 for servicing existing refrigeration and air conditioning equipment.

[d] Up to 2.5% of base level consumption can be used until 2040 for servicing existing equipment, subject to review in 2025.

[e] All reductions include an exemption for pre-shipment and quarantine uses.

[f] Some countries with economies in transition have a slightly delayed start to the HFC phase-down, but catch up to other developed party commitments by 2029.

[g] Some developing countries have a delayed start to the HFC phase-down, starting their freeze in 2028 instead of 2024 and finishing at 85% reduction by 2047

1.6 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 fire fighting 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 phase-out 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.

1.7 INDIA'S COMMITMENT TO MONTREAL PROTOCOL

India became Party to the Vienna Convention for the Protection of the Ozone Layer on 18th March, 1991 and the Montreal Protocol on Substances that Deplete the Ozone Layer on 19th June, 1992. The Government of India has entrusted the work relating to the ozone layer protection and implementation of the Montreal Protocol on Substances the Ozone Layer to the Ministry of Environment, Forest and Climate Change (MoEF&CC). The Ministry has established an Empowered Steering Committee (ESC) Chaired by Secretary (EF&CC), which is supported by two standing committees viz. Technology and Finance Standing Committee (TFSC) and the Standing Committee on Monitoring. The ESC is overall responsible for implementation of the Montreal Protocol provisions, review of various policies including implementation options, project approvals and monitoring. The Ministry has set up an Ozone Cell as a National Ozone Unit (NOU) to render necessary services for effective and timely implementation of the Montreal Protocol and its ODS phase-out program in India.

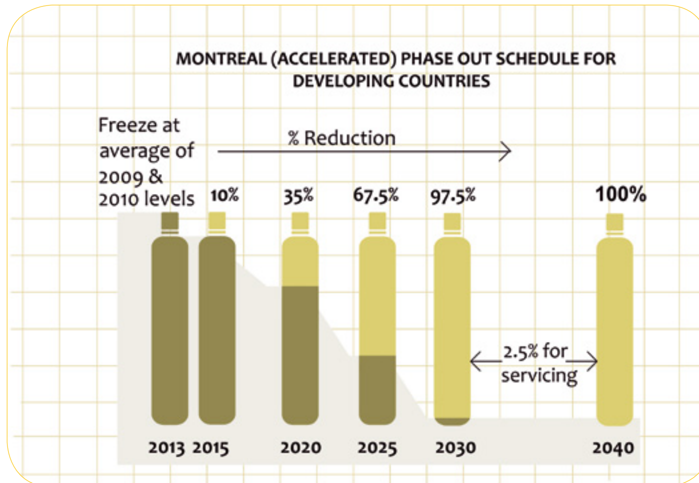

Figure 10- HCFC Phase-out in developing countries

India had prepared a detailed Country Program (CP) in 1993 for the phase-out of ODSs in accordance with its National Industrial Development Strategy by accessing funds from financial mechanism of the Montreal Protocol. The CP was updated in 2006. India has proactively phased out the production and consumption of CFCs except use in Metered Dose Inhalers (MDIs) used for treatment of Asthma and Chronic Obstructive Pulmonary Disease (COPD) ailments from 1st August, 2008. Subsequently, the use of CFCs in MDIs has been phased out from December, 2012. India has also completely phased out production and consumption of CTC and halons as of 1stJanuary, 2010.

In response to Decision of accelerated phase-out of HCFCs in September, 2007, India developed a Roadmap for the implementation of accelerated phase-out of HCFCs. The Figure 6 shows the Roadmap adopted for phase-out of HCFCs

Currently, the Ozone Cell is engaged in phase-out of production and consumption of next category of chemicals, Hydrochlorofluorocarbons (HCFCs) with an accelerated phase-out schedule as per the Montreal Protocol. HCFC Phase-out Management Plan (HPMP) – Stage-I

- o Foam Manufacturing Sector
- o Systems House
- o Refrigeration and Air-Conditioning Servicing Sector

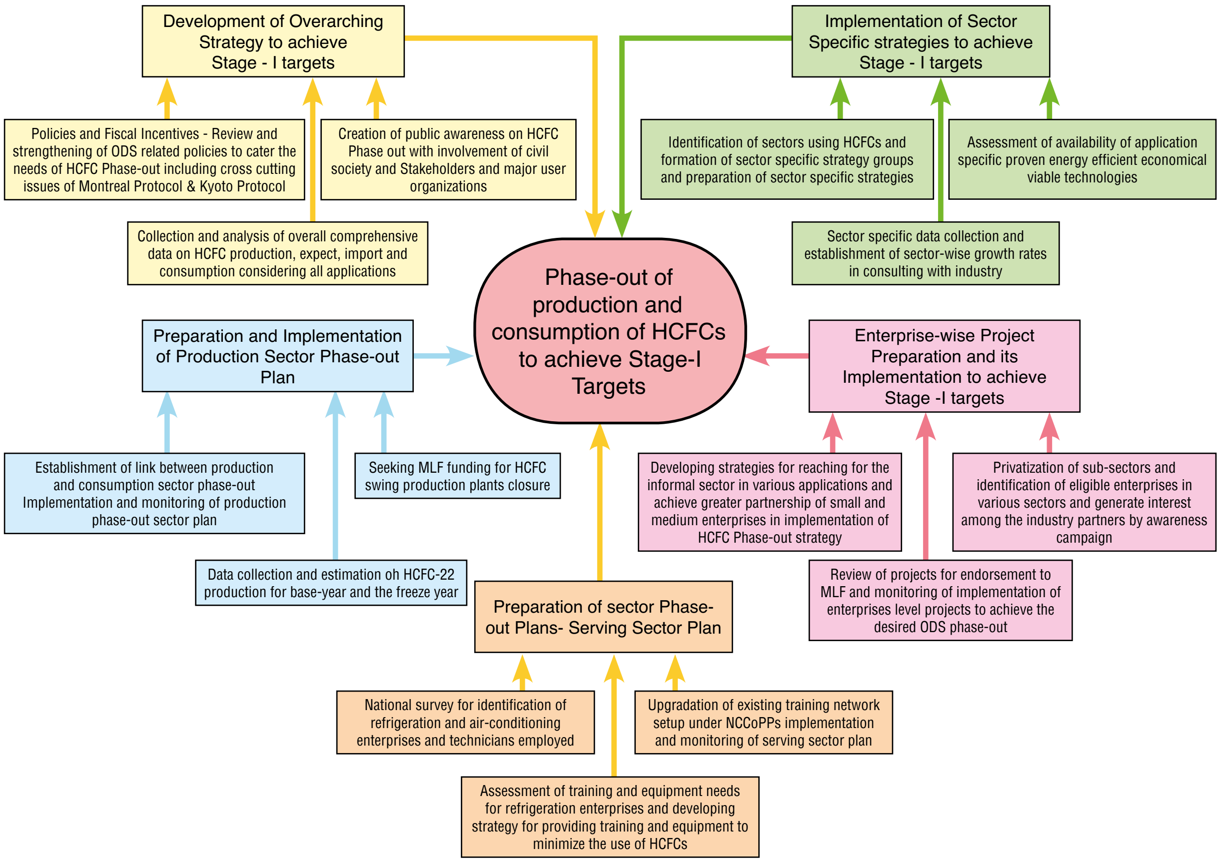

Figure 11- Roadmap for HCFC Phase-out in India at a glance

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

The 56th meeting of the Ex-Com of the MLF held in November, 2008 approved the preparation of HPMP Stage-I for India with UNDP as the lead implementing agency in association with UNEP and GIZ, Government of Germany.

The Stage-I of HPMP was approved by the Ex-Com in its meeting …held in April, 2012 to meet the phase-out targets of HCFCs, the 2013 freeze and 10% percent reduction in 2015. HPMP Stage-I has been already implemented in the country and has successfully met all the ODS phase-out targets. Stage-I of HPMP focused on phasing out HCFCs in the foam manufacturing sector, systems house and refrigeration and air-conditioning servicing sector. By 2015 total of 341.77 ODP tons of HCFCs were phased out through implementation of HCFC Phase-out Management Plan stage I.

Sectoral phase-out consist of OPD tons of 310.53 HCFC 141b in foam manufacturing and 31.24 ODP tons of HCFC-22 in RAC servicing sector respectively. The reduction in HCFC consumption is higher than the required amount to meet the target of freeze in 2013 and reduction of 10% in 2015. Over the past two decades, India has successfully implemented ODS phase-out projects that has enabled industry to smoothly and systematically transition to ozone friendly alternatives. India put in place comprehensive Ozone Depleting Substances (Regulation and Control) Rules, 2000 . These rules have been amended from time to time. The last amend was in 2014 to align the Rules to accelerated phase-out schedule of HCFCs . The Ozone Depleting Substance (Regulation and Control) Amendment Rules 2014 was published in the Gazette of India in April 2014

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

The HPMP-II was launched on 6th March, 2017 at New Delhi by late Shri Anil Madhav Dave, the then Hon'ble Minister of Environment, Forest and Climate Change.The HPMP Stage-II is aimed to phase-out HCFC-141b in manufacturing of foam by 2020 and has also taken up conversion of 6 large Room air conditioner manufacturers from HCFC-22 to HFC-32. The HPMP Stage-II specifically focusses on the MSME sector in foam manufacturing. Adequate attention has also been given to synergize the RAC servicing sector training under HPMP Stage-II with the Skill India Mission of the Government of India, in order to multiply the impact of skilling and training. It is estimated that nearly, 16000 to 17,000 service technicians will be trained under HPMP-II.

The HPMP-II also provides for promotion of energy efficiency, development building codes integrating HCFC phase out issues, cold chain development with non-HCFC alternatives and development of standards for new non- ODS and low GWP alternatives, while transitioning away from HCFCs. It is expected that there would be a net direct CO2-equivalent emission reductions of about 8.5 million metric tonne annually from 2023 onwards

1.7.3 Kigali agreement and HFC phaseout

On October 15, 2016 nearly 197 countries came together in Kigali to adopt a deal to phase-down global climate warming hydrofluorocarbon (HFC) emissions under the Montreal Protocol, drawing a set of differentiated baselines and freeze years within both Article 5 and non-Article 5 countries.

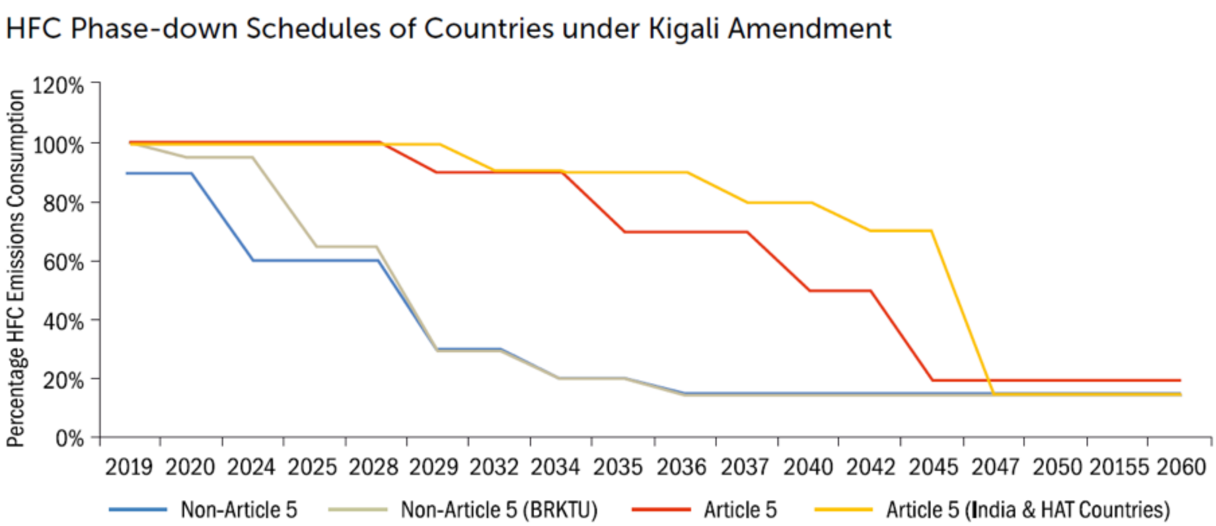

Figure 12- Phase-out schedule under Kigali.

1.8 IMPACT ON INDIA'S BUILDING SECTOR

The building sector in India is already consuming close to 40% of the electricity and this is expected to increase further.. 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. The refrigeration and air-conditioning systems in buildings account for significant amount of Hydrochlorofluorocarbons (HCFCs) consumption and also energy use in buildings. HCFCs are used as foam blowing agents for insulation of buildings and also in firefighting equipment. Increase in real estate and infrastructure development activities across all major sectors in India leads to necessary push to the high demand of HCFC based solutions.

The building sector offers substantial potential to protect the ozone layer and impact on the environment particularly on climate , but strategies need to be coordinated to achieve both simultaneously.

MODULE 2

Zero ODP Building Insulation

This module covers phasing out Ozone Depleting Substances in Building insulation

Course: Building Materials & Construction

As per the study schedule, B Arch

2.1 BACKGROUND

The primary purpose of a building is to provide thermal comfort and protection from natural elements. The buildings envelope is the physical separator between the interior and exterior of a building. The building envelope performs many different functions, offering security, fire protection, privacy, comfort and shelter from weather, as well as benefits such as aesthetics, ventilation and views to the outdoors. The key challenge is to optimise the design of the overall building and the building envelope to meet the needs of the occupants while reducing energy consumption.

In many parts of the world, buildings have long been constructed using local materials to maximise comfort given the local climate. Some examples include:

- Highly reflective roofs and walls in hot climates
- Thick thatched roofs offered insulating properties in cold climates
- Natural ventilation
- Heavy masonry structures with high thermal mass

However, modernisation has resulted in higher densities in urban areas, the need for faster construction techniques, and more affordable approaches that in many cases result in less efficient structures than old techniques.

2.2 HEAT TRANSFER IN BUILDINGS

Heat transfer takes place through walls, windows and roofs in buildings from higher temperature to lower temperature in three ways.

1. Conduction: It is the transfer of heat by direct contact of particles of matter within a material or materials in physical contact.
2. Convection: It is the transfer of heat by the movement of a fluid, air gas or liquid.
3. Radiation: It is the movement of energy/heat through electromagnetic waves in space without physical contact between materials.

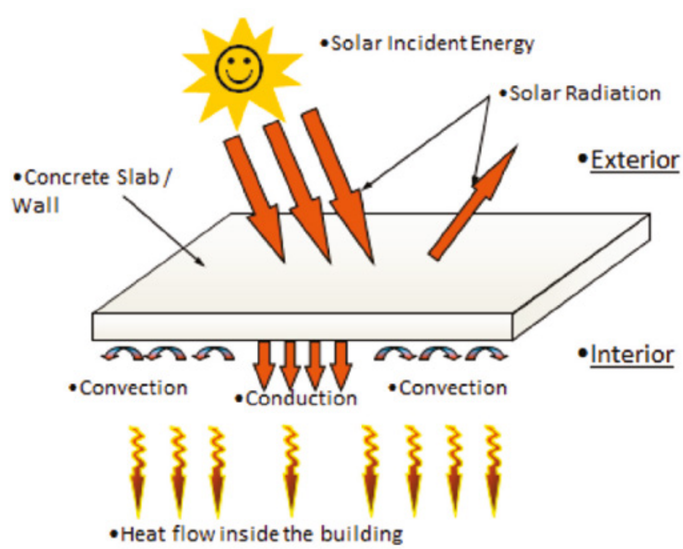

Figure 13: Schematic illustration of heat flow in building

Source: Training manual on application of building insulation, India Insulation Forum (IIF)

2.3 OPTIMIZING BUILDING ENVELOPE

Most of the heat transfer in a building takes place through the building envelope.

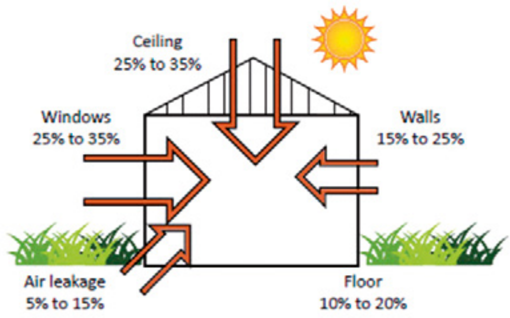

Figure 14: Heat Gain in summers

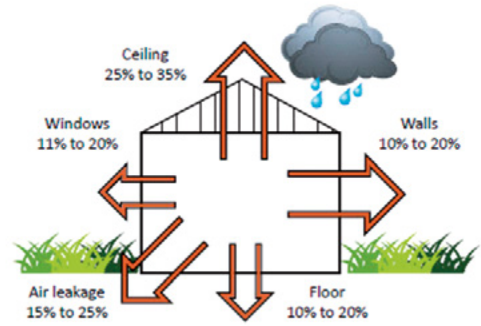

Figure 15: Heat loss in winters

Source: https://hub.globalccsinstitute.com/publications/zero-carbon-australia-buildings-plan/2-improving-thermal-performance-building-envelope

Basic methods for designing high-performance building facades include:

- Orienting and developing geometry and massing of the building to respond to solar position
- Providing solar shading to control cooling loads and improve thermal comfort
- Using natural ventilation to enhance air quality and reduce cooling loads
- Minimizing energy used for artificial lighting and mechanical cooling and heating by optimizing exterior wall insulation and the use of day lighting.

Table 2: Envelope design strategies for different climate types

Climate Type	Design strategies for sustainable facades
Hot Climate	• Solar control: protection of the facade from direct solar radiation through self-shading methods (building form) or shading devices. • Reduction of external heat gains: protection from solar heat gain by infiltration (by using well-insulated opaque facade elements) or conduction (by using shading devices) • Cooling: use of natural ventilation where environmental characteristics and building function permit. • Daylight: use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves
Cold Climate	• Solar collection and passive heating: collection of solar heat through the building envelope • Heat storage: storage of heat in the mass of the walls • Heat conservation: preservation of heat within the building through improved insulation • Daylight: use of natural light sources and increased glazed areas of the facade, use of high-performance glass, and use of light shelves to redirect light into interior spaces

Climate Type	Design strategies for sustainable facades
	• Solar control: protection of facade from direct solar radiation (shading) during warm seasons • Solar collection and passive heating: solar collection during cold seasons • Daylight: use of natural light sources and increased glazed areas of the facade with shading devices

Source: High-performance building envelopes: Design Methods for Energy Efficient Facades, Ajla Aksamija, University of Massachusetts, Amherst, USA

2.4 THERMAL PERFORMANCE OF BUILDING MATERIALS

The building envelope, i.e. roof, wall and fenestration, is a composition of layers with varying thermal properties. The envelope may be composed of blocks, sheets, membranes or pre-assembled components. The choice of the envelope depends on the climate, culture and available materials at a given location.

2.4.1 Thermal Resistance

The heat flow through a building material depends on the temperature difference across it, the conductivity of the materials used and the thickness of the materials. The temperature difference is an external factor while the thickness and the conductivity are properties of the material. A greater thickness means less heat flow and so does a lower conductivity. Together these parameters form the thermal resistance of the construction. The thermal resistance is proportional to the thickness of a layer of the construction and inversely proportional to its conductivity. A construction layer with a high thermal resistance (e.g. rock wool), is a good insulator; one with a low thermal resistance (e.g. concrete) is a bad insulator.

2.4.2 Thermal Conductivity (k)

It is a measure of the thermal conductivity of a material, that is, how easily heat passes across it. It is a fundamental property, independent of the quantity of material. It represents the steady-state heat flow through a unit area of a material resulting from a temperature gradient perpendicular to that unit area.

It is not dependent on material thickness.
k-values can be used to compare the thermal conductivities of different materials.
Unit: W/mK

2.4.3 Thermal Transmittance (U)

It denotes the material's ability to conduct heat and is the thermal conductivity of the complete building material composition, including its internal and external surfaces.

It is dependent on material thickness.
Unit: W/m2K

2.4.4 Thermal Resistance (R)

It is the ability of a material to prevent heat transfer. The overall R-value of a multi-layered element can be calculated by adding the R-values of its component materials.

It is dependent on material thickness.
Unit: m2K/W.

2.4.5 Relationship between k, R- value & U-value

R-value= thickness of material (d)/ K
U-value= 1/R- value.

2.4.6 Calculating U-values of multiple layers of materials

In any practical building element there will be extra thermal resistances, particularly those of the thin layers of air adhering to the outermost and innermost layers of the material, and the air in any substantial gap between the layers. Table 3 gives standard thermal values used for these. Note that the outside surface resistance is much lower than the value used for the inside surface. This is because the air is less likely to be still on the outside and will thus provide a relatively poorer insulation performance.

Table 3: Thermal resistances for surfaces and air gaps

Layer	Resistance m2K/W
Inside surface (Rsi)	0.13
Air gap	0.18
Outside surface (Rso)	0.04

The thermal resistances of the components of a building element can be added in series as in Figure 16, to give a total thermal resistance. The total thermal resistance of a practical building element will thus consist of the sum of those of all its layers plus the inside and outside surface resistances.

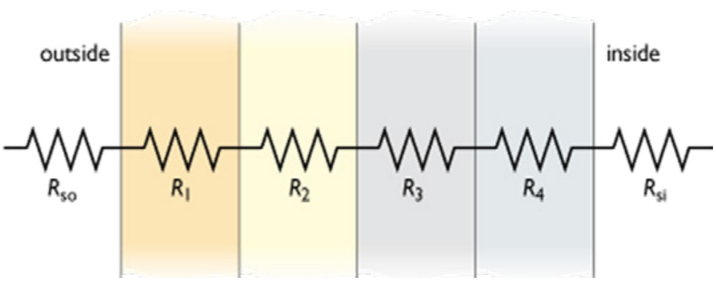

Figure 16: Summing Thermal Resistances

Source: http://www.open.edu/openlearn/nature-environment/the-environment/energy-buildings/content-section-2.3

Taking, for example, a wall construction with four layers (Figure 4), the total thermal resistance,

RT will be:

RT = Rso + R1 + R2 + R3 + R4 + Rsi m2K/W

The U-value of this wall is its inverse = 1/RT W/m2K

2.5 INSULATION MATERIALS

Thermal insulation is a material that blocks or slows the flow of heat through the building envelope. Proper insulation keeps out excess heat in hot weather and reduces heat loss in cold weather, and helps maintain a comfortable indoor environment without incurring maintenance costs.

While choosing an insulation product, two things must be kept in mind, the material and the application type. There are many insulation materials available in the market, some of these are listed below.[2]

2.5.1 Fiberglass

Fiberglass (or fiber glass)-which consists of extremely fine glass fibers is one of the most common insulation materials. It's available in different forms such as blanket (batts and rolls) and loose-fill and is also available as rigid boards and duct insulation.

Fiberglass loose-fill insulation is made from molten glass that is spun or blown into fibers. Most manufacturers use 40% to 60% recycled glass content. Loose-fill insulation is applied using an insulation-blowing machine.

Figure 17: Glass Fiber

Source: http://www.directindustry.com/prod/johns-manville/product-50780-1469493.html

2.5.2 Mineral wool

The term "mineral wool" typically refers to two types of insulation material:

1. Rock wool, a man-made material consisting of natural minerals like basalt or diabase.
2. Slag wool, a man-made material from blast furnace slag (the waste matter that forms on the surface of molten metal).

Mineral wool contains an average of 75% post-industrial recycled content. It doesn't require additional chemicals to make it fire resistant, and it is commonly available as blanket (batts and rolls) and loose-fill insulation.

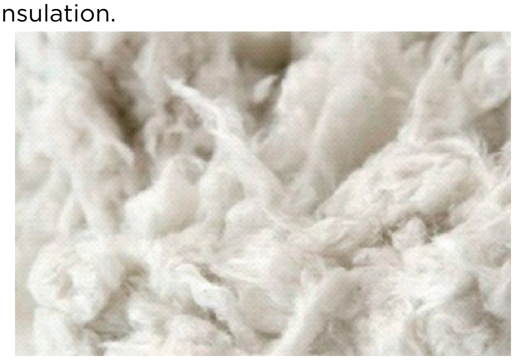

Figure 18: Slagwool

Source: http://columnistnews.com/global-slag-wool-market-2017-industry-trends-growth-rate-with-cagr-analysis-2022/

Figure 19: Rockwool

Source: http://www.ipefi.com/blown-rockwool-insulation/wonderful-blown-rockwool-insulation-7-weathershield-insulation/

[2] https://www.energy.gov/energysaver/weatherize/insulation/insulation-materials

2.5.3 Cellulose

Cellulose insulation is made from recycled paper products, primarily newsprint, and has a very high recycled material content, generally 82% to 85%. The paper is first reduced to small pieces and then fiberized, creating a product that packs tightly into building cavities and inhibits airflow.

Manufacturers add the mineral borate, sometimes blended with the less costly ammonium sulfate, to ensure fire and insect resistance. Cellulose insulation typically requires no moisture barrier and, when installed at proper densities, cannot settle in a building cavity.

Figure 20: Cellulose Insulation

Source: https://www.homelogic.co.uk/pros-cons-cellulose-insulation/

2.5.4 Natural fibers

Some natural fibers such as cotton, sheep's wool, straw, and hemp are used as insulation materials.

Cotton

Cotton insulation consists of 85% recycled cotton and 15% plastic fibers that have been treated with borate the same flame retardant and insect/rodent repellent used in cellulose insulation.

Some products use recycled blue denim manufacturing trim waste. As a result of its recycled content, this product uses minimal energy to manufacture. Cotton insulation is available in batts and costs about 15% to 20% more than fiberglass batt insulation.

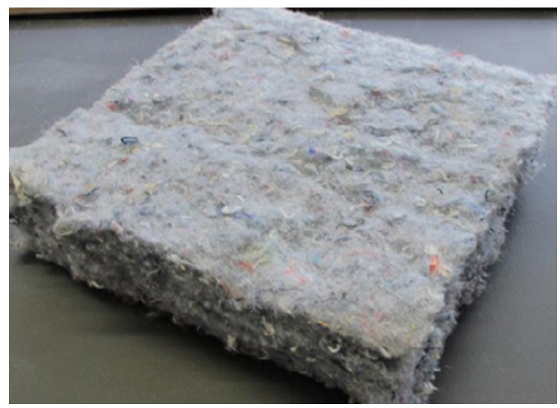

Figure 21: Recycled cotton insulation

Source: www. materials.ads.org.uk

Sheep's Wool

Wool insulation is made from sheep wool fibres that are either mechanically held together or bonded using between 5% and 20% recycled polyester adhesive to form insulating batts, rolls and ropes. Wool is a highly effective insulating material which performs better than its rated R value because it can absorb and release moisture.

Figure 22: Sheep wool

Source:https://materia.nl/article/products-cool-sheeps-wool-insulation/

Figure 23: Traditional Mongolian Yurt

Source: http://dcat.kg/yurt.html

Mongolian nomads used felted and woven sheep wool pads as an insulating layer on the walls and floors of their dwellings, called Ger or Yurts. A traditional yurt is a portable, round tent covered dwelling with skins or felt and used by nomads in the steppes of Central Asia. The felt is made from the wool of the flocks of sheep that accompany the pastoralists.

Wood fiber / straw insulation

Wood fibre insulation is made from forestry thinnings and saw mill residue. Binding is provided by polyolefin fibres and the fire retardant is usually ammonium phospate.

Figure 24: Wood fiber

Source: http://www.greenspec.co.uk/building-design/insulation-plant-fibre/

Hemp

Hemp is a variety of the Cannabis plant that is grown specifically for the industrial uses of its derived products. It is one of the fastest growing plants and was one of the first plants to be spun into usable fiber 10,000 years ago. Hemp insulation slabs are made from hemp or hemp mixed with either recycled cotton fibres or wood fibres, bound with a polyester binder and treated for fire resistance.

Figure 25: Hemp insulation slab

Source: http://www.greenspec.co.uk/building-design/insulation-plant-fibre/

Flax fiber insulation

Flax insulation slabs are made from flax fibers with a polyester binder and treated for fire resistance. Flax fibre was traditionally used for specialty pulp and paper, linen garments and other textile applications. Flax shives are the byproduct of fibre extraction. Shive content depends upon the fibre content of the straw and is normally in the 65-85% range. Flax shive markets include filler for plastic composites, loose fill insulation, absorbency products, pet and livestock bedding and others.

Figure 26: Flax fiber

Source: http://www.greenspec.co.uk/building-design/insulation-plant-fibre/

2.5.5 Hempcrete

Hempcrete or Hemplime is bio-composite material, a mixture of hemp shives and lime (natural hydraulic lime, sand, pozzolans) used as a material for construction and insulation. It is marketed under names like Hempcrete, Canobiote, Canosmose, and Isochanvre. Hempcrete is easier to work with than traditional lime mixes and acts as an insulator and moisture regulator. It lacks the brittleness of concrete and consequently does not need expansion joints. The result is a lightweight insulating material ideal for most climates as it combines insulation and thermal mass.

Hempcrete has been used in France since the early 1990's to construct non-weight bearing insulating infill walls.

Figure 27: Hempcrete

Source: www. www.apartmenttherapy.com

2.5.6 Cork Insulation

Cork insulation is made from cork bark that is harvested from the tree every 25 years. Cork granules are expanded and then formed into blocks, using the natural resin, through high temperature and pressure. The most common applications for cork insulation are in flat roofs and insulated render systems, both of which take advantage of cork's dimensional stability and resistance to compression.

Figure 28: Cork Insulation

Source: www.lime.org.uk

2.5.7 Perlite

Perlite is an amorphous volcanic glass that has a relatively high water content, typically formed by the hydration of obsidian. It occurs naturally and has the unusual property of greatly expanding when heated sufficiently.

When perlite ore is expanded by exposure to rapid, controlled heating, it grows up to 20 times its original volume and takes on a foam-like cellular internal structure, essentially clusters of microscopic glass bubbles. This physical transformation makes expanded perlite an extremely efficient, low density insulator.[3]

Perlite is available in a variety of forms for being utilized as insulation material in building construction such as, loose fill perlite, insulating boards, pipe insulation and perlite concrete.

Figure 29: Physical transformation of Perlite

Source: https://www.indiamart.com/proddetail/perlite-insulation-services-8814151130.html

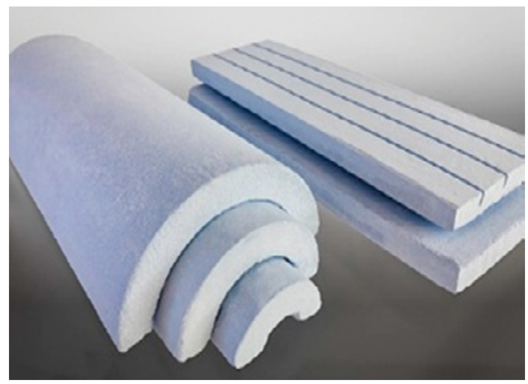

Figure 30: Perlite insulation products

Source: https://www.jm.com/en/industrial-insulation/perlite/sproule-wr-1200/

2.5.8 Vermiculite

Vermiculite is a hydrated magnesium aluminum silicate mineral which resembles mica in appearance. It is found in various parts of the world including Australia, Brazil, Bulgaria, Kenya, Russia, South Africa, Uganda, USA and Zimbabwe. Vermiculite, when subjected to heat, exfoliates to form elongated concertina like particles which are lightweight, incombustible, compressible, highly absorbent, and non-reactive.[4]

Binding systems such as sodium silicate, potassium silicates or calcium silicate are used to produce boards containing exfoliated vermiculite. Other materials used to bind vermiculite for manufacturing building boards include resins, portland cement and other inorganic binders.

Is Vermiculite Safe?

Although not all vermiculite contains asbestos, some products were made with vermiculite that contained asbestos until the early 1990s. Vermiculite mines throughout the world are now regularly tested for it and are supposed to sell products that contain no asbestos.

Pure vermiculite does not contain asbestos and is safe.

[3] https://www.perlite.org/industry/insulation-perlite.html
[4] https://www.vermiculite.org/resources/vermiculite

Perlite is available in a variety of forms for being utilized as insulation material in building construction such as, loose fill perlite, insulating boards, pipe insulation and perlite concrete.

Figure 31: Vermiculite Ore

Source:http://www.vermiculite.org/resources/vermiculite

Figure 32: Expanded Vermiculite

Source: https://olivali.en.ec21.com/

Figure 33: Vermiculite board

Source:https://www.sydneyfirebricks.net.au/

2.5.9 Polystyrene

Polystyrene (PS) is a synthetic aromatic hydrocarbon polymer made from the monomer styrene. Polystyrene can be solid or foamed. It is commonly used to make foam board or bead-board insulation, concrete block insulation, and a type of loose-fill insulation consisting of small beads of polystyrene. Polystyrene is commonly available in two forms, Expanded Polystyrene (EPS) and Extruded Polystyrene (XPS).
Expanded polystyrene insulation or EPS insulation is manufactured using a mould to contain small foam beads. Heat or steam is then applied to the mould, which causes the small beads to expand and fuse together. This manufacturing process does not form a closed cell insulation as there can often be voids between each of the beads where they are not touching one another.

Extruded polystyrene insulation or XPS Insulation is manufactured through an extrusion process. This manufacturing process involves melting together the plastic resin and other ingredients. The liquid formed is then continuously extruded through a die and expands during the cooling process. This produces a closed cell rigid insulation.

Figure 34: Close view of EPS

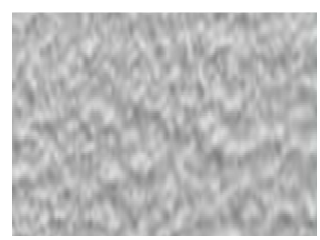

Figure 35: Close view of XPS

2.5.10 Polyisocyanurate

Polyisocyanurate or polyiso is a thermosetting type of plastic, closed-cell foam that contains a low-conductivity, hydrochlorofluorocarbon-free gas in its cells.

Polyisocyanurate insulation is available as a liquid, sprayed foam, and rigid foam board. It can also be made into laminated insulation panels with a variety of facings. Foamed-in-place applications of polyisocyanurate insulation are usually cheaper than installing foam boards, and perform better because the liquid foam molds itself to all of the surfaces.

Over time, the R-value of polyisocyanurate insulation can drop as some of the low-conductivity gas escapes and air replaces it -- a phenomenon is known as thermal drift or ageing. Experimental data indicates that most thermal drift occurs within the first two years after the insulation material is manufactured. Foil and plastic facings on rigid polyisocyanurate foam panels can help stabilize the R-value. Testing suggests that the stabilized R-value of rigid foam with metal foil facings remains unchanged after 10 years.

Figure 36: Polyisocynurate insulation with foil facing

Source: https://www.indiamart.com/proddetail/pir-panel-polyisocyanurate-13194474855.html

2.5.11 Polyurethane

Polyurethane is a foam insulation material that contains a low-conductivity gas in its cells. Polyurethane foam insulation is available in closed-cell and open-cell formulas. With closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Open-cell foam cells are not as dense and are filled with air, which gives the insulation a spongy texture and a lower R-value.

Like polyiso foam, the R-value of closed-cell polyurethane insulation can drop over time as some of the low-conductivity gas escapes and air replaces it in a phenomenon known as thermal drift or ageing. Most thermal drift occurs within the first two years after the insulation material is manufactured, after which the R-value remains unchanged unless the foam is damaged.

Foil and plastic facings on rigid polyurethane foam panels can help stabilize the R-value, slowing down thermal drift. Reflective foil, if installed correctly and facing an open air space, can also act as a radiant barrier. Depending upon the size and orientation of the air space, this can add another R-2 to the overall thermal resistance.

Polyurethane insulation is available as a liquid sprayed foam and rigid foam board. It can also be made into laminated insulation panels with a variety of facings.

Sprayed or foamed-in-place applications of polyurethane insulation are usually cheaper than installing foam boards, and these applications usually perform better because the liquid foam moulds itself to all of the surfaces.

Figure 37: Closed Cell Polyurethane

Source:https://glassfibre.ie/product/brown-polyurethane-foam-part-a-b-3/

Figure 38: Open cell Polyurethane

Source:https://www.alibaba.com/product-detail/high-density-polyurethane-foam-for-sofa_60527581354.html

Low-density foams are sprayed into open wall cavities and rapidly expand to seal and fill the cavity. Slow expanding foam is also available, which is intended for cavities in existing homes. The liquid foam expands very slowly, reducing the chance of damaging the wall from overexpansion. The foam is water vapour permeable, remains flexible, and is resistant to wicking of moisture. It provides good air sealing and is fire resistant and won't sustain a flame.

2.5.12 Urea-formaldehyde foam

Urea-formaldehyde (UF) foam was used in homes during the 1970s and early 1980s. However, after many health-related court cases due to improper installations, UF foam is no longer available for residential use and has been discredited for its formaldehyde emissions and shrinkage. It is now used primarily for masonry walls in commercial and industrial buildings.

UF foam insulation uses compressed air as the foaming agent. Nitrogen-based UF foam may take several weeks to cure completely. Unlike polyurethane insulation, UF foam doesn't expand as it cures. Water vapor can easily pass through it, and it breaks down at prolonged temperatures above 190°F (88°C). UF foam contains no fire retardant.

Figure 39: Sprayed-on Polyurethane

Source:https://www.constructionspecifier.com/making-sense-of-sprayed-polyurethane-foam/

2.5.13 Foam Concrete or Cementitious foam

Foamed concrete is a highly air entrained sand cement or cement only slurry with greater than 20% air by volume. Foamed concrete typically consists of a slurry of cement and fly ash or sand and water. This slurry is further mixed with a synthetic aerated foam in a concrete mixing plant. The foam is created using a foaming agent, mixed with water and air from a generator. Since no coarse aggregate is used in the production of the foam concrete or cellular concrete, the correct term would be to call it mortar instead of concrete.

The material is a lightweight, free-flowing, self-compacting, and highly insulating material. It exhibits good load bearing capacity and resistance to freeze thaw exposure. It is an extremely versatile product, which will flow through small enclosed voidsFoamed concrete is a highly air entrained sand cement or cement only slurry with greater than 20% air by volume. Foamed concrete typically consists of a slurry of cement and fly ash or sand and water. This slurry is further mixed with a synthetic aerated foam in a concrete mixing plant. The foam is created using a foaming agent, mixed with water and air from a generator. Since no coarse aggregate is used in the production of the

Figure 40: Foam concrete being applied as roof insulation

Source: https://www.leadcrete.com/application/foam-concrete-for-roof-insulation.html foam concrete or cellular concrete, the correct term would be to call it mortar instead of concrete.

The material is a lightweight, free-flowing, self-compacting, and highly insulating material. It exhibits good load bearing capacity and resistance to freeze thaw exposure. It is an extremely versatile product, which will flow through small enclosed voids

2.5.14 Phenolic foam

Phenolic (phenol-formaldehyde) foam was somewhat popular years ago as rigid foam board insulation. It is currently available only as a foamed-in-place insulation.

Phenolic foamed-in-place insulation uses air as the foaming agent. One major disadvantage of phenolic foam is that it can shrink up to 2% after curing, which makes it less popular today.

2.5.15 Aerogels

Aerogels have been in existence for more than 80 years. It is a lightweight solid derived from gel in which the liquid component of the gel has been replaced with gas. When the liquid is removed, what remains is "puffed-up sand," with up to 99% porosity. The result is a solid with extremely low density and low thermal conductivity. Nicknames include frozen smoke, solid smoke, solid air, solid cloud, blue smoke owing to its translucent nature and the way light scatters in the material. It feels like fragile expanded polystyrene to the touch. Aerogels can be made from a variety of chemical compounds.

Aerogel insulation is available in the form of blankets.

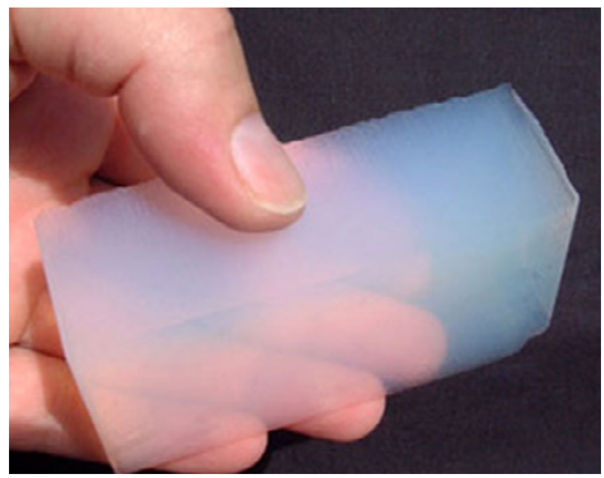

Figure 41 : Ultralight Aerogel

Source: https://gizmodo.com/5042227/homemade-experiments-with-aerogel-the-worlds-lightest-solid

2.6 INSULATION MATERIALS AT A GLANCE

Table 4: Insulation materials at a glance

Type	Thermal Conductivity W/mK	Density Kg/m3	Vapour Permeability	Recycled Content	Embodied Energy	Blowing agent
Fiberglass	0.035	15-20	Yes	Yes	Medium	No
Mineral wool	0.032–0.044	45-75	Yes	Yes	High	No
Cellulose	0.035-0.040	27-65	Yes	Yes	Low	No
Natural fibres cotton, hemp etc.	0.038-0.080	25-160	Yes	Yes	Low	No
Hempcrete	0.060	275	Yes	Yes	Low	No
Cork	0.35-0.43	20-90	Yes	Yes	Low	No

Type	Thermal Conductivity W/mK	Density Kg/m3	Vapour Permeability	Recycled Content	Embodied Energy	Blowing agent
Perlite	0.045-0.076	50-120	Yes	No	Medium	Yes
Vermiculite	0.63	70-170	Yes	No	Medium	Yes
Polystyrene EPS	0.034–0.038	15-30	No	No	High	Yes
Polystyrene XPS	0.033–0.035	20-40	No	No	High	Yes
Polyisocynurate & Polyurethane	0.023–0.026	30-40	No	No	High	Yes
Urea-formaldehyde foam	0.350	10-30	No	No	High	Yes
Foam Concrete or Cementitious foam	0.230-0.390	400-1200	No	Yes	High	No
Phenolic foam	0.020	35	No	No	High	Yes
Aerogels	0.014	150	No	No	High	Yes

2.7 INSULATION APPLICATION METHODS

2.7.1 Inverted earthen pots insulation

Maximum ingress of solar heat in tropical climates is from the roof. Covering flat roofs with inverted earthen pots is an easy and cost effective method to reduce solar gain. In this method, roof is covered by inverted earthen pots, placed abutting each other and the intervening space can be filled with cement/ lime mortar and finished with the terracing material. The pots provide increase the insulating value of the roof by virtue of the air gap created by them. Pots made with earth are recyclable and regionally available.

Figure 42: Inverted earthen pots insulation

Source: Earthen pots Insulation System: Thermal Comfort Design Competition for TARU

2.7.2 Mud Phuska

This is a traditional insulating technique for flat roofs where high thermal mass of mud is used to insulate the roof. Suitable earth for this treatment should not contain excessive clay or sand and should be free from stones and organic matter. In this system, the roof is first prepared by cleaning, painting the surface with residual type petroleum bitumen of penetration 80/100 and immediately spreading coarse sand and levelling it while the bitumen is still hot. Subsequently, a layer of puddled mud is applied to slope, maintaining an average thickness of around 100mm, followed by a 25mm thick coat of mud plaster which should be ideally allowed to mature for 7 days before application. This is finished with a coat of cow dung to fill any cracks that may have developed in the mud plaster.

2.7.3 Cavity Wall

A cavity wall consists of two layers of masonry, separated by a cavity of varying dimensions ranging from 50 mm to 100 mm. The masonry layers may consist of solid brick, structural clay tile or concrete masonry units. They are bonded together with stainless steel or PVC masonry ties, normally positioned at 900 mm x 450 mm in a staggered fashion (2.5 ties per m2). The isolation of the exterior and interior layers by the air space allows heat to be significantly absorbed and dissipated in the outer layer and cavity before reaching the inner layer and building interior. The cavity, ranging from 50 mm to 75 mm in width, may or may not contain insulation. It requires larger floor space – a 260 mm cavity wall which replaces a 230 mm thick wall reduces the carpet area of a typical bedroom (3.5 x 4.5 m) by 2%, considering only the 2 outer walls are replaced. However, this quantum of reduction can result in significant improvement in the building envelope, particularly, if applied on the unfavourable west orientation, which will cut into the major part of radiation that falls on building.

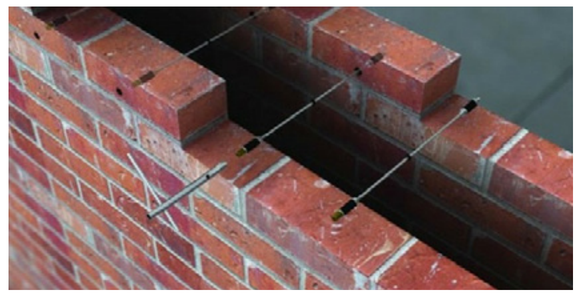

Figure 43: Cavity wall

Source: https://civilsnapshot.com/cavity-wall-advantages-and-disadvantages/

2.7.4 Rat-trap bond

The Rat-trap bond is a masonry technique in which the bricks are laid in such a manner that a discontinuous cavity is formed between two faces of the wall. Typically, a 75 mm cavity is formed in a 230 mm thick wall. This is done by placing the bricks on edge in a modular fashion (as shown). For the purpose of housing, this system can be used for in-fill walls (in an RCC frame) in multi-storied housing or for single storied row housing.

Reduces the number of bricks used, by at least 20%. Together with at least 30% saving in mortar, this technique can reduce the overall cost of wall by at least 25%.

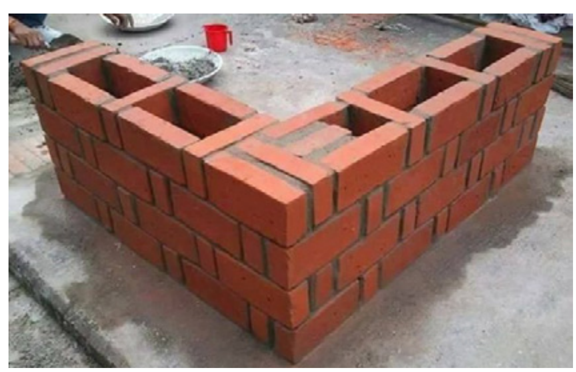

Figure 44: Rat trap masonry

http://architectureadmirers.com/rat-trap-bond-method-construction/rat-trap-bond/

2.7.5 Hollow masonry blocks

Bricks and blocks are the most common masonry units used for building construction across the world. Such blocks are also available with air cavities in them which significantly improves the thermal performance of the building and at the same time reduces the dead load of the structure. A vast number of options are available, such as hollow concrete blocks and hollow clay bricks.

Figure 45: Variety of hollow concrete blocks

Source: https://paddyengineering.blogspot.com

Figure 46: Variety of hollow clay bricks

Source: https://www.openpr.com/news

2.7.6 Lightweight masonry blocks

Light weight concrete masonry blocks are readily available in the market and widely used for construction all over the world. These blocks are high performance and are a preferred material for multi-storeyed buildings due to the significant reduction in dead load. Autoclaved Aerated Concrete (AAC) and Cellular Lightweight Concrete (CLC) are the two most common type of lightweight concrete blocks.

Table 5: Lightweight masonry blocks

Type	Picture	Description
Autoclaved Aerated Concrete (AAC)	 *Image Source: https://www.zureli.com/product/ecocim-autoclaved-aerated-concrete*	• Made of cement, sand, lime, gypsum • Also known as aircrete • It contains nearly about 50-60% of air voids. • It is a porous material and contains uniform air pockets. • Expansion agent like Al powder is used • The density of AAC ranges between 451-1000 kg/m3
Lightweight Concrete (CLC)	 *Image Source: http://www.building-supplies-online.co.uk/tarmac-toplite-standard-aerated-concrete-block-100mm-3-6n.html*	• Made of cement, fly ash, sand • It contains about 30-35% of air voids • Protein based or synthetic foaming agent is used for making it. • The density of CLC ranges between 400kg/m3 to 600kg/m3

2.7.7 Blanket: Batts and rolls

Blanket insulation is the most common and widely available type of insulation and comes in the form of batts or rolls. It consists of flexible fibers, most commonly fiberglass. Batts and rolls are also made from mineral (rock and slag) wool, plastic fibers, and natural fibers, such as cotton and sheep's wool. Batts and rolls are available in standard dimensions and are easy to install.

Figure 47: Fiberglass insulation batt

Source: www. kvtechconstruction.com

Figure 48: Hemp insulation batt

Source: http://eci.com.tr/hemp-insulation-batt/

Figure 49: Sheep Wool Insulation

Source:www.ecomerchant.co.uk/offers/thermafleece

2.7.8 Loose-fill and Blown-in

Loose-fill insulation consists of small particles of fibre, foam, or other materials. These small particles form an insulation material that can conform to any space without disturbing structures or finishes. This ability to conform makes loose-fill insulation well suited for retrofits and locations where it would be difficult to install other types of insulation.

The most common types of materials used for loose-fill insulation include cellulose, fiberglass, and mineral (rock or slag) wool. Some less common loose-fill insulation materials include polystyrene beads and vermiculite and perlite. Cellulose, fiberglass, and rock wool are typically blown-in using an electric blower.

Figure 50: Insulation being blown-in

Source:http://www.howtohomeinsulation.com/insulation_basics_insulating_home_blow_attic.html

2.7.9 Sprayed Foam and Foamed in place

Liquid foam insulation materials can be sprayed, foamed-in-place, injected, or poured. Foam-in-place insulation can be blown into walls, on attic surfaces, or under floors to insulate and reduce air leakage. Some installations can yield a higher R-value than traditional batt insulation for the same thickness, and can fill even the smallest cavities, creating an effective air barrier. Small pressurized cans of foam-in-place insulation can be used to reduce air leakage in holes and cracks, such as window and door frames, and electrical and plumbing penetrations.

Figure 51: Foam insulation being blown-in

Source:http://www.qualifiedremodeler.com/203713/sealing-knowledge-of-spray-foam-insulation/

There are two types of foam-in-place insulation: closed-cell and open-cell. Both are typically made with polyurethane. With closed-cell foam, the high-density cells are closed and filled with a gas that helps the foam expand to fill the spaces around it. Open-cell foam cells are not as dense and are filled with air, which gives the insulation a spongy texture.

2.7.10 Foam Board or Rigid foam

Foam boards or rigid panels of insulation can be used to insulate almost any part of the building, from the roof down to the foundation. They are very effective in exterior wall sheathing, interior sheathing for basement walls, and special applications such as attic hatches. They provide good thermal resistance (up to 2 times greater than most other insulating materials of the same thickness), and reduce heat conduction through structural elements, like wood and steel studs. The most common types of materials used in making foam board include polystyrene, polyisocyanurate (polyiso), and polyurethane.

Figure 52: XPS installation on wall

Source:http://dinosauriens.info/?u=Types+of+Insulation++Compare+Rigid+Foam+Insulation+EPS

2.7.11 Reflective sheet

Unlike most common insulation systems, which resist conductive and sometimes convective heat flow, radiant barriers and reflective insulation work by reflecting radiant heat. Reflective insulation incorporates radiant barriers typically highly reflective aluminium foils into insulation systems that can include a variety of backings, such as Kraft paper, plastic film, polyethylene bubbles, or cardboard, as well as thermal insulation materials.

Radiant barriers are more effective in hot climates, especially when cooling air ducts are located in the false ceiling. The various applications of reflective sheet insulation include ducting insulation, chilled water pipes, floor insulation, underdeck insulation, overdeck and wall insulation.

Figure 53: Reflective insulation on AC duct

Source: http://www.low-e.com/lowe_hvac.html

2.7.12 Structural insulated panels (SIPs)

Structural insulated panels (SIPs) are prefabricated insulated structural elements for use in building walls, ceilings, floors, and roofs. They provide superior and uniform insulation compared to more traditional construction methods.

SIPs not only have high R-values but also high strength-to-weight ratios. An SIP typically consists of 4- to 8-inch-thick foam board insulation sandwiched between two sheets of oriented strand board (OSB) or other structural facing materials. Manufacturers can usually customize the exterior and interior sheathing materials to meet customer requirements. The facing is glued to the foam core, and the panel is then either pressed or placed in a vacuum to bond the sheathing and core together.

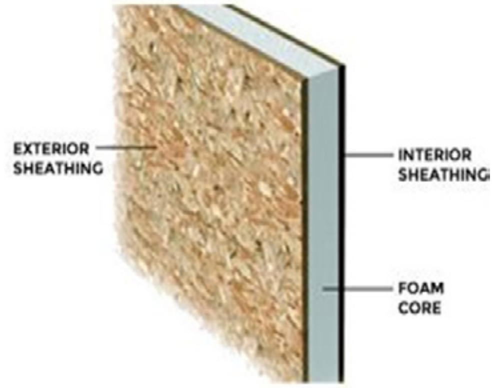

Figure 54: Typical SIP composition

Source:http://www.aboutsavingheat.com/news/2018/02/07/structural-insulated-panels-13

SIPs are available with different insulating materials, usually polystyrene or polyisocyanurate foam.

2.8 INSULATION INSTALLATION TECHNIQUES AT A GLANCE

Table 6: Insulation installation techniques

S.No.	Type	Material	Application	Category
1	Inverted earthen pots	Clay pots	Applied on Roof (Installed during construction)	Creating air cavities in conventional construction
2	Mud Phuska	Mud	Applied on Roof (Installed during construction)	
3	Cavity Wall	Burnt clay bricks Concrete blocks Fly ash bricks	Walls (Installed during construction)	
4	Rat-trap bond	Burnt clay bricks Fly ash bricks	Walls (Installed during construction)	
5	Hollow blocks	Burnt clay bricks Concrete blocks	Walls (Installed during construction)	
6	Lightweight blocks	AAC Blocks CLC Blocks	Walls (Installed during construction)	Cementitious foam

S.No.	Type	Material	Application	Category
7	Blanket: Batts and rolls	Fiberglass Mineral (rock or slag) wool Plastic fibers Natural fibers	Walls, ceilings, and floors (Installed during or after construction)	Low density material mmm moo poorly conducting fibre and foam with small air pockets
8	Blown-in and Loose-fill	Cellulose Fiberglass Mineral (rock or slag) wool Natural fibers	Walls, ceilings, and floors (Installed during or after construction)	
9	Sprayed Foam and Foamed in place	Cementitious Phenolic Polyisocyanurate Polyurethane	Walls, roof, and floors (Installed during construction)	
10	Foam Board or Rigid foam	Polystyrene Polyisocyanurate Polyurethane	Walls, roof, and floors (Installed during construction)	Low density material mmm moo poorly conducting fibre and foam with small air pockets
11	Reflective sheet	Foil-faced Kraft paper Plastic film Polyethylene bubbles Cardboard	Walls, ceilings, and floors (Installed during construction)	Thin reflective foils
12	Structural insulated panels (SIPs) and other composite panels	Foam board or liquid foam insulation core Straw core insulation	Walls, ceilings, floors, and roofs for new construction (Installed during construction)	Prefabricated composite panels

2.9 OZONE DEPLETING HCFCS IN BUILDING INSULATION MANUFACTURING

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. In India, only 14% of the total ODS used for insulation is used in buildings.

Insulation typically remains intact for the lifetime of the building, which ranges from 25 to 70 years. 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.

For a long time, non-ODS substances like hydrocarbons and liquid CO2 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.

Table 7: Ozone depleting HCFCs in building insulation manufacturing

Foam Type	Use	HCFC Currently in use
XPS board	Walls, floors, roofs of residential and commercial buildings	A blend of HCFC-142b and HCFC22 (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

2.10 PHASING OUT HCFCS IN BUILDING INSULATION

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.

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.

A variety of climate-friendly blowing agents have been or are being developed for use in building construction foam applications to replace CFCs, HCFCs, and HFCs. For example, for production of XPS boards, low-GWP hydrocarbon (HC) alternatives already comprise more than half of the global market, while CO2 is also being used. Similarly, for PU rigid foams, HCs are being used to produce panels, boards, blocks, and pipe-in-pipe foam. For spray foam, low-GWP alternatives, such as CO2, are being explored. Other low-GWP options, such as methyl formate and HFOs, have also been proposed across various building construction foam applications. These alternatives are described further below.

Table 8: Alternatives to HCFC – 141b For Foam Sector (Flammable)

Alternatives to HCFC – 141b For Foam Sector (Flammable)					
	Molecular Weight	Boiling Point	Foam Properties	Flammable Limits in Air (Vol %)	GWP (100 years)
Cyclo- Pentane	70.1	49.3	Good	1.4 - 8.0	<25o
n-Pentane	72..1	36.0	Good	1.4 - 8.0	<25o
Iso-Pentane	72.1	28.0	Good	1.4 – 7.6	<25o
Methyl Formate	60	31.5	Acceptable	5.0 – 2.0	Negligible
Methylal	76.1	42.0	Acceptable	2.2 – 19.9	Negligible

Table 9: Alternatives to HCFC – 141b For Foam Sector (Non-Flammable)

Alternatives to HCFC – 141b For Foam Sector (Non-Flammable)					
	Common name	Molecular Weight	Boiling Point	Foam Properties	GWP (100 years)
CO2 (Water)	-	44	In Situ Reaction	Acceptable	1
Formacel 1100	1336mzz (Z)	164	33	Very Good	2
Solstice™ Liquid BA	1233zd (E)	130.5	19	Very Good	<7
Forane™ 1233zd	1233zd (E)	130.5	19	Very Good	<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.

MODULE 3

Climate passive strategies for energy efficient building design

Already being covered under **“Climatology”** and **“Applied Climatology”** courses in 3rd and 4th Semesters.

MODULE 4

Strategies For Energy Efficiency In Buildings

This module covers active strategies for
energy efficiency in buildings.

Course: Building Services

4th Semester, B Arch

4.1 INTRODUCTION

Buildings account for 35% of total final energy consumption in India and building energy use is growing at a rate of 8% annually. Residential buildings make up for 75% of the entire construction market in India and were responsible for 20.4% of India's total electricity consumption in 2012. Rising population and increasing urbanisation, together with scarcity of land in urban areas, has resulted in an increasing demand for newly-constructed multi-story buildings in India. Consequently, projections show that by 2032 the total electricity consumption of the residential building sector will increase to 36.4%. Thus energy efficiency (EE) in the residential building sector has become an increasingly important issue and an imperative one in India.

4.2 NEED FOR REDUCING BUILDING ENERGY DEMAND

India has an ambitious development target of power for all to ensure secure supply of energy for economic growth. In many developing countries there is normally very little margin between existing power supply and electricity demand. With increasing electricity use from existing consumers and new connections, new generation needs to be brought on line to meet increasing demand.

Investments in energy efficiency in a building can be compared with the cost of capital investments necessary on the supply side of the energy system to produce a similar amount of peak capacity or annual energy production. Usually, the capital costs of efficiency are lower than comparable investments in increased supply and there are no additional operating costs of efficiency compared to substantial operating costs for supply-side options. In addition, energy efficiency investments generally have much shorter lead times than energy supply investments, a particularly important consideration in countries where the demand for energy services is growing rapidly. By setting energy efficiency targets for buildings, governments share the burden and cost of ensuring the security of energy supply with end-users.

The main benefit from measures to improve energy efficiency buildings is lower energy costs but there are usually other benefits to be considered too. Energy efficiency measures are meant to reduce the amount of energy consumed while maintaining or improving the quality of services provided in the building. Among the benefits likely to arise from energy efficiency investments in buildings are:

- Reducing energy use for space heating and/or cooling and water heating
- Reduced electricity use for lighting, office machinery and domestic appliances
- Lower maintenance requirements
- Improved comfort
- Enhanced property value

In developing countries where electricity is intermittent and power rationing is frequent, there is a large demand for diesel or renewable energy-based backup/stand-by power generation from end-users. Reducing power and energy requirements in buildings reduces the capital outlay required and the running costs of these stand-by systems.

In industrialized countries, policy, incentives, climate change targets and corporate image drive more efficient approaches to energy use in buildings. Codes and practice on energy regulations for buildings in developed countries include obligations for energy audits, requirements for building certification with ratings based on energy efficiency, carbon reduction targets for buildings, levies on energy consumption—charged per unit consumed to discourage high consumption, incentives such as exemption from building tax for good energy efficiency ratings, access to interest free/low-interest loans and grants for undertaking energy efficiency measures in buildings and, as part of their corporate social responsibility, some companies would like to be seen as a green company that promotes energy efficiency.

4.3 ENERGY EFFICIENT STRATEGIES

4.3.1 Typical energy flow in buildings

The building gross energy needs represent the anticipated buildings requirements for heating, lighting, cooling, ventilation, air conditioning and humidification. The indoor climate requirements, outdoor climatic conditions and the building properties (surface/transmission heat transfer and heat transfer due to air leakage) are the parameters used for determining what the gross energy needs of the building will be.

As illustrated in the diagram below, delivered energy, natural energy gains and internal heat gains all contribute to providing the energy needs of a building.

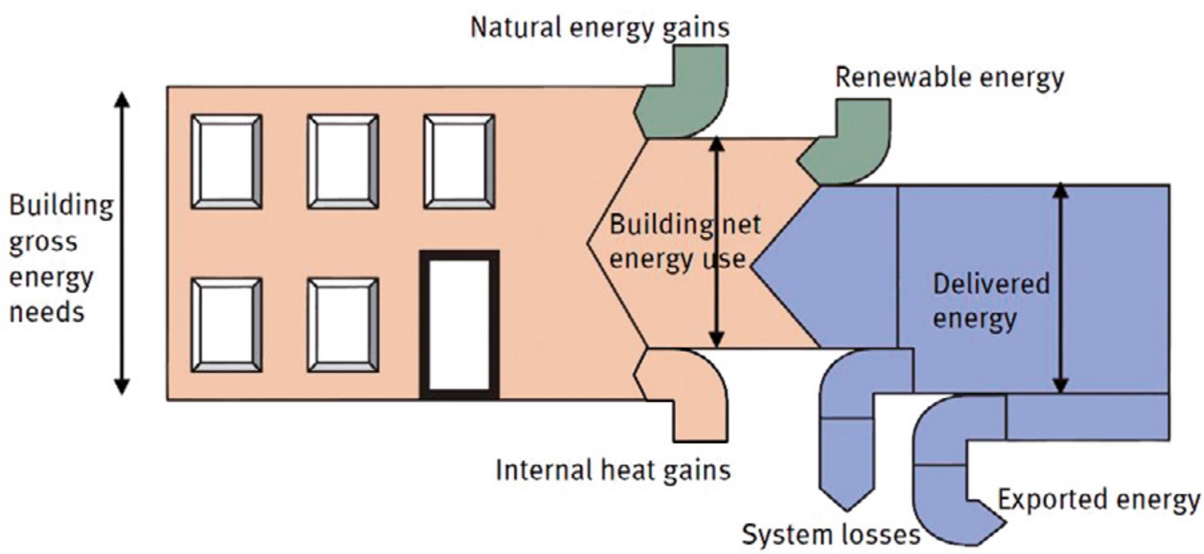

Figure 55: Energy flows in building

Source: Energy Efficiency in Buildings, UNIDO 2013

4.3.2 Natural energy gains

These include passive solar heating, passive cooling, natural ventilation flow, and daylight. Intelligent maximization of natural energy gains can result in significant reduction of delivered energy required to meet a building's energy needs. Environmentally smart buildings make intelligent use of energy resources, while minimizing waste.

Natural energy gains can be maximized by exploiting the potential contribution to a building's performance offered by the site and its surroundings through:

- A building plan which places functions in locations that minimize the need for applied energy;

- A shape which encourages the use of daylight and natural ventilation, and reduces heat losses;
- An orientation that takes account of the potential benefits from solar gains while reducing the risk of glare and overheating;
- Effective use of natural daylight combined with the avoidance of glare and unwanted solar gains;
- Natural ventilation wherever practical and appropriate, with mechanical ventilation and/or air conditioning used only to the extent they are actually required;
- Good levels of thermal insulation and prevention of unwanted air infiltration through the building envelope;
- Intrinsically efficient and well-controlled building services, well-matched to the building fabric and to the expected use.

This is best achieved at the building's design stage but can also be done during refurbishment or retrofitting.

4.3.3 Internal heat gain

Internal heat is the thermal energy from people, lighting and appliances that give off heat to the indoor environment. Whereas this is desirable in cold weather as it reduces the energy requirements for heating, in hot weather it increases the energy required for cooling. In office buildings, commercial stores, shopping centres, entertainment halls etc., much of the overheating problem during the summer can be caused by heat produced by equipment or by a high level of artificial lighting. When there are a large number of occupants or clients their metabolic heat can also add to the problem.

4.3.4 Delivered energy

This is the amount of energy supplied to meet a building's net energy demand i.e. to provide energy for heating, cooling, ventilation, hot water and lighting. It is usually expressed in kilowatt hours (kWh) and the main energy carriers are electricity and fuel, i.e. gas, oil or biomass for boilers. The delivered energy could be supplemented by on-site renewable energy, this could be in the form of solar PV, solar water heaters or wind.

4.3.5 Exported energy

This is the fraction of delivered energy that, where applicable, is sold to external users.

4.3.6 System losses

System losses result from the inefficiencies in transporting and converting the delivered energy, i.e. of the 100 per cent delivered energy, only 90 per cent may be used to provide the actual services, e.g. lighting, cooling or ventilation, due to the inefficiency of the equipment used.

When addressing the energy efficiency issue in buildings the main focus is on the energy used to attain the required indoor climate standards. The amount of energy a building will be required to purchase to attain this is dependent on:

- The properties of the building:
  - o The level of heat transfer: the lower the heat transfer the lower the heat loss during cold weather and heat gain during warm weather. This will reduce the energy requirements for heating or cooling;

o Whether the building is designed to minimize the need for applied energy depending on the outdoor climatic conditions.

- How efficiently the delivered energy is used to meet the building's net energy demand i.e. the efficiency of the equipment and appliances used;
- How efficiently energy is used by people in the building;
- The percentage of the building's energy requirement that is supplied by renewable energy.

4.4 DETERMINING A BUILDING'S ENERGY PERFORMANCE

Energy use indicators

The calculation of energy use in buildings is based on the characteristics of the building and its installed equipment. It is structured in three levels as illustrated below and the calculation is performed from the bottom up.

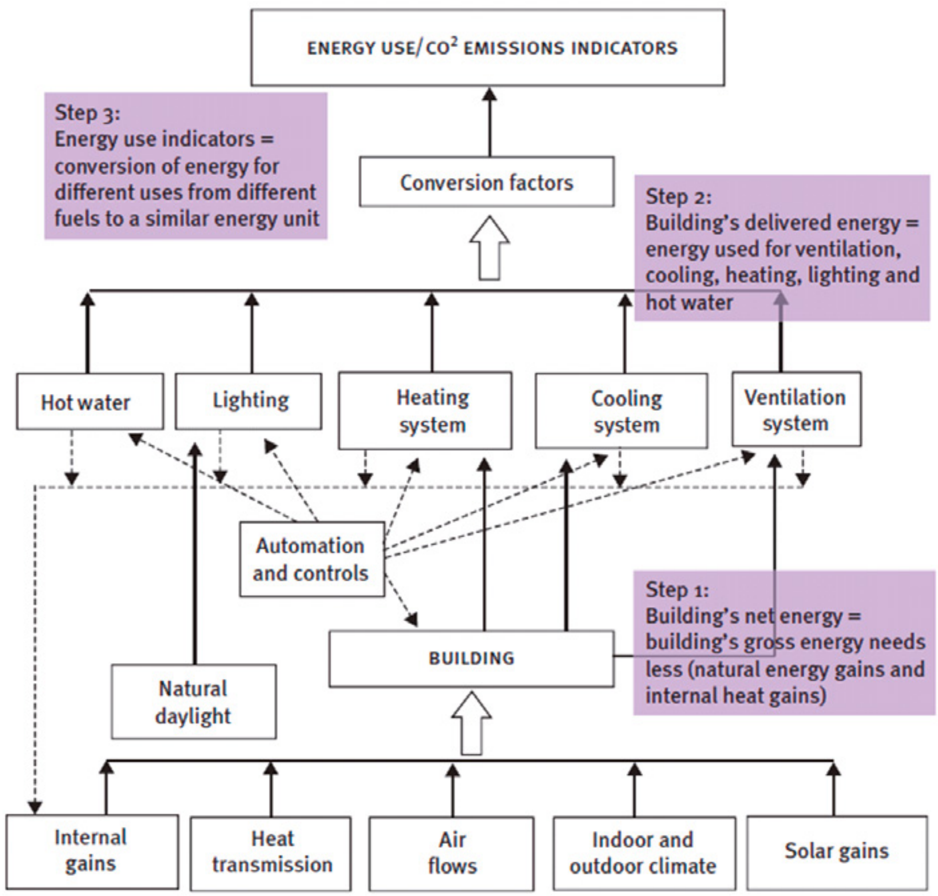

Figure 56: Overview of the calculation process of energy use indicators

1 Step one is the calculation of the building's net energy requirements, i.e. the amount of energy required to provide the indoor climate requirements as specified by the building code. The calculation is used to determine the net energy required based on the outdoor climate and indoor climate requirements while considering the contributions from internal gains, solar gains

and natural lighting and losses due to building properties, i.e. heat transmission and airflows (air infiltration and exfiltration). This calculation is used to determine the intrinsic energy performance of the building.

2 Step Two is the determination of the building's delivered energy, i.e. the energy performance of the building in actual use. This is the amount of energy used for heating, cooling, hot water, lighting, ventilation systems, inclusive of controls and building automation, and includes the auxiliary energy needed for fans, pumps, etc. Energy used for different purposes and by different fuels is recorded.

3 Step Three is the determination of the overall energy performance indicators. It combines the results from Step 2 above for different purposes and from different fuels to obtain the overall energy use and associated performance indicators. Since a building can use more than one fuel (e.g. gas and electricity), the different energy sources have to be converted and combined in terms of primary energy to provide the optional end result of the calculation of energy performance. Commonly used energy indicators for buildings are kWh/m2 (energy consumption in kilowatt hours per metre square of floor area) or CO2 emissions.

For purposes of this calculation, buildings are classified into categories depending on whether they are residential or non-residential, the type of building design and the building size and use. In addition to calculating the performance of existing buildings, energy performance calculations are also undertaken at the design stage for new buildings and refurbished buildings to simulate their energy performance.

4.5 ENERGY EFFICIENCY MEASURES FOR BUILDINGS

Energy efficiency measures for buildings are approaches through which the energy consumption of a building can be reduced while maintaining or improving the level of comfort in the building. They can typically be categorized into:

1. Reducing cooling demand;
2. Reducing the energy requirements for ventilation;
3. Reducing energy use for lighting;
4. Reducing energy used for heating water;
5. Reducing electricity consumption of office equipment and appliances;

4.5.1 Reducing cooling demand

Energy use in typical air-conditioned office buildings is approximately double that of naturally ventilated office buildings. The need for air-conditioning or the size of the systems installed can be reduced by:

- Controlling solar gains through glazing;
- Reducing internal heat gains;
- Making use of thermal mass and night ventilation to reduce peak temperatures;
- Providing effective natural ventilation;
- Reducing lighting loads and installing effective lighting controls.

a) Avoiding excessive glazing

Windows should be sized to provide effective day light while avoiding excessive solar gains. Large areas of glazing will increase solar heat gains in summer and heat losses in winter making it more difficult to provide a comfortable internal environment.

b) Use of shading

Solar gains can be reduced by the use of external shading, mid pane blinds (where blinds are integrated between the panes of the double or triple glazing unit) or by internal blinds. Internal blinds are the least effective method of controlling solar gains as the heat will already have entered the space. External blinds are the most effective but may be difficult to maintain and are less easily adjusted for controlling glare. Mid pane blinds often provide an effective compromise. They can be raised when solar gains and glare is not an issue or lowered when required. High angle summer sun can be controlled on south facing elevations by the use of overhangs and fixed shading devices. Solar gains to east and west glazing are more difficult to control and will require adjustable shading devices.

c) Solar control glass

Glazing is available with a range of selective coatings that alter the properties of the glass; ideally glazing should be selected with the highest light transmittance and the lowest solar heat gain factor. This will help provide daylight while reducing solar gains. All major glass manufacturers provide data on the properties of their products.

d) Selecting equipment with reduced heat output

Selecting office equipment with a reduced heat output can reduce cooling demands and by ensuring equipment has effective controls that automatically switch it off when not in use. The use of flat screen monitors can significantly reduce heat gains, while at the same time reducing energy use for the equipment and using office space more effectively. These benefits usually compensate for the higher cost of flat screen monitors.

e) Separating high heat load processes from general accommodation

Where a building includes energy intensive equipment such as mainframe computers, these are best located in a separate air-conditioned space, avoiding the need to provide cooling to the whole building.

f) Making use of thermal mass and night ventilation to reduce peak temperatures

Thermal mass is the ability of a material to absorb heat energy. A lot of heat energy is required to change the temperature of high-density materials such as concrete, bricks and tiles. They are therefore said to have high thermal mass. Lightweight materials such as timber have low thermal mass.

Thermal mass is particularly beneficial where there is a big difference between day and night outdoor temperatures. Correct use of thermal mass can delay heat flow through the building envelope by as much as 10 to 12 hours, producing a warmer house at night in winter and a cooler house during the day in summer. A high mass building needs to gain or lose a large amount of energy to change its internal temperature, whereas a lightweight building requires only a small energy gain or loss. Allowing cool night breezes and/or convection currents to pass over the thermal mass, draws out all the stored energy.

g) Reducing heat gains from lighting

Heat gains from lighting can be reduced by making best use of day lighting and by providing energy-efficient lighting installations with good controls.

h) Predicting the impact of passive cooling strategies

Computer simulation tools can be used to predict the likely comfort conditions in buildings and optimize glazing and shading arrangements.

4.5.2 Reducing the energy requirements for ventilation

When the cooling demand is sufficiently reduced by implementing the above measures, it may be possible to reduce heat gains so that air-conditioning is unnecessary and comfort conditions can be maintained through the use of natural ventilation. The energy required for ventilation can be minimized by:

- A building design that maximizes natural ventilation;
- Effective window design;
- Use of mixed mode ventilation;
- Using efficient mechanical ventilation systems.

a) Building design

The most effective form of natural ventilation is cross ventilation, where air is able to pass from one side of a building to the other. For this to work effectively it typically dictates that buildings are no more than 12-15 m in depth. However, in deeper plan spaces, natural ventilation can be achieved by introducing central atria and making use of the “stack effect” to draw air from the outer perimeter and up through the centre of the building.

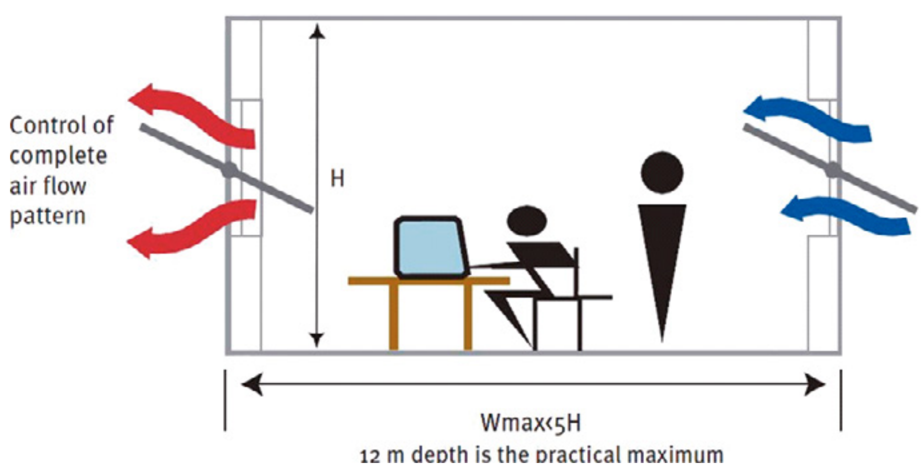

Figure 57: Cross Ventilation

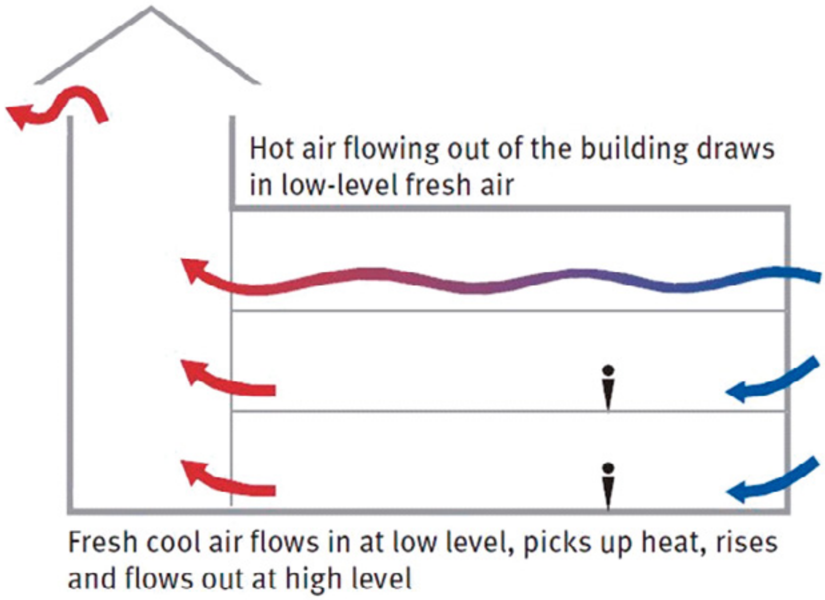

Figure 58: Stack effect

b) Effective window design

Windows should allow ease of control by building occupants and controlled ventilation that will not blow papers off desks, or cause draughts.

Night ventilation can be an effective method of maintaining comfort conditions in summer. Where night ventilation is used, it is important that building occupants understand how the building is intended to be operated, or that effective control measures are introduced, as it is counter intuitive to open windows before leaving a building at night. Other factors to consider include maintaining security, and controlling wind and rain. In some cases, high ambient noise levels or air pollution may prohibit the use of natural ventilation.

c) Mixed mode ventilation

Mixed mode ventilation strategies allow natural ventilation to be used for most of the year or to serve parts of a building. Mechanical cooling is used to deal only with peak design conditions in summer or to serve areas of the building that experience a higher build-up of heat.

d) Reducing energy use for mechanical ventilation

The main use of energy for both mechanical cooling and for air conditioning is the fans needed to circulate the air. Fan energy use for mechanical ventilation can be reduced by:

- Designing the system to reduce pressure drops;
- Selecting efficient fans;
- Utilizing variable speed fans to respond to varying load requirements;
- Avoiding excessive air supply volumes.

4.5.3 Reducing energy use for lighting

This can be accomplished through:

- Making maximum use of daylight while avoiding excessive solar heat gain;
- Using task lighting to avoid excessive background luminance levels;
- Installing energy-efficient luminaires with a high light output to energy ratio;
- Selecting lamps with a high luminous efficacy;
- Providing effective controls that prevent lights being left on unnecessarily.

a) Maximizing the use of daylight

Introducing natural light into buildings both saves energy but also creates an attractive environment that improves the well-being of building occupants. The provision of effective daylight in buildings can be assessed using average daylight factors and by ensuring that occupants have a view of the sky.

The average daylight factor will be influenced by the size and area of windows in relation to the room, the light transmittance of the glass, how bright internal surfaces and finishes are, the depth of reveals, and presence of overhangs and other external obstructions which may restrict the amount of day lighting entering the room.

Window design has a key impact on day lighting. As a rough rule of thumb, a window will introduce effective daylight into a room to a distance twice the head height of the opening. The use of high ceilings and clerestory windows can be effective in providing good daylight. Sun pipes and skylights can be used to introduce daylight to windowless areas.

b) Energy-efficient lighting system

An efficient lighting installation should be able to provide the required illuminance level for a particular use with minimum energy consumption. Efficient lights should be able to provide illuminance levels of 500 lux12 on a working plane for less than 12W/m2 of installed power.

c) Lighting controls

Lighting controls should be designed so that small groups of lights can be controlled individually with the controls provided adjacent to the work area. Perimeter lighting should be controlled separately to core lighting so that perimeter lights can be switched off when there is adequate daylight. Absence detection should be provided to rooms that are used intermittently. This should switch lights off automatically after a room or space has been unoccupied for a set period of time. Daylight sensors and timed switches should be used to prevent external lighting being left on unnecessarily. Daylight sensors can also be used to switch off internal lighting when daylight levels are sufficient.

4.5.4 Reducing energy used for heating water

This can be achieved by:

- Installing time controls, and setting them to correctly reflect the hours of hot water requirement;
- Setting sanitary hot water thermostats to the appropriate temperature—no more than 60oC for normal requirements (but ensure the water does not drop below 56oC);
- Switching off electric heating elements (immersion) when hot water from the boiler is available;
- Switching off any associated pumps when hot water is not required;

- Replacing any damaged or missing insulation from all hot water pipe work and cylinders, except where the pipes are providing useful heat into the space;
- Identifying a suitable hot water system.

Hot water provision is either provided via a central generation plant, with a distribution network to provide hot water to the required areas within a building, or by localized provision at the point it is required. Combined heating and hot water systems and separate heating and hot water systems are the two types of centralized hot water systems. In the case of localized hot water systems, water is heated and stored locally or is provided on demand. The most significant reduction in energy use for hot water can be achieved by providing solar water heating.

4.5.5 Reducing consumption of office equipment and appliances

Most businesses rely on a range of office equipment in order to function. From the basic essentials such as computers, monitors, printers, fax machines and photocopiers to projectors, scanners and teleconference facilities, it is widely recognized that these items have become integral to daily activity.

Office equipment is the fastest growing energy user in the business world, consuming 15 per cent of the total electricity used in offices. This is expected to rise to 30 per cent by 2020. There are also associated costs that are often overlooked, specifically those of increasing cooling requirements to overcome the additional heat this equipment produces. As ventilation and air conditioning are major energy consumers themselves, it makes good business sense to ensure they are only used when absolutely necessary.

Typical measures to reduce consumption which also apply to household appliances are:

- Switching off – switching off or enabling power down mode reduces the energy consumption and heat produced by equipment, which in turn lowers cooling costs;
- Upgrading existing equipment – some energy-efficient appliances may cost more to buy but will recoup savings over the lifetime of the equipment;
- Matching the equipment to the task – bearing in mind current and predicted requirements and purchase equipment that meet these;
- Taking advantage of energy labelling schemes – some well know energy labelling schemes are Energy Star, European Ecolabel Scheme, Energy Saving Recommended and The Market Transformation Program. BEE star labelled equipment & appliances.

4.6 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.

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.

4.6.1 Energy Conservation Building Code (ECBC)

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 set 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.

4.7 GREEN BUILDING RATING SYSTEMS

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.

Following green building rating systems are in place in India

4.7.1. 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.

4.7.2. 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, neighbourhoods and retail. LEED is one of the most prominent rating systems currently being adopted in many countries around the world.

4.7.3. 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 at least 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.

4.7.4 Excellence in Design for Greater Efficiencies (EDGE)

EDGE is developed by International Finance Corporation (IFC), a World Bank group. It is an online platform, a green building standard and a certification system for over 140 countries. The EDGE application helps to determine the most cost-effective options for designing green within a local climate context. EDGE can be used for buildings of all vintages, including new construction, existing buildings and major retrofits.

A project that reaches the EDGE standard of 20 percent less energy use, 20 percent less water use, and 20 percent less embodied energy in materials compared to a base case building can be independently certified. EDGE is part of a holistic strategy to steer construction in rapidly urbanizing economies onto a more low-carbon path.

4.8 GUIDELINES FOR SELECTION OF ENERGY EFFICIENCY COOLING EQUIPMENT

Standards and Labeling for equipment and appliances

Standards and Labelling (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.

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 labelling system for these appliances.

India has the MEPS (Minimum Energy Performance Standards) and LC (Label Codes) 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 substances.

4.9 ENERGY EFFICIENT BUILDINGS IN INDIA

Case study 1 - Indira Paryavaran Bhawan

Location : Jor Bagh Road, New Delhi

Site area : 9,565 m2

Built-up area : 31,400 m2 (18,726 m2 superstructure & 12,675 m2 Basement)

AC area : 1,1967 m2

Non AC area : 1,9433 m2

EPI : 24.13 KWh/ m2/year

Renewable Energy : Rated capacity of solar PV installed on site is 930 KW

Year of completion : 2013

Architect : Central Public Works Department (CPWD)

Certifications : GRIHA 5 Star & LEED Platinum

Indira Paryavaran Bhawan houses the Ministry of Environment & Forests and Climate Change (MoEFCC). Constructed in 2013, the building was envisaged as an exemplary energy efficient building.

Passive Energy Efficiency Measures:

The building is designed to reduce its operational energy requirements.

- The building orientation is primarily North–South. It is divided it into two long blocks that helps in reducing the heat ingress into the building and develops a shaded central landscaped court. This central courtyard, along with the large lower level punctures into the building envelope, aid in cross ventilation;
- The reduction in the window-to-wall ratio helps to lessen the heat gain as well the need for a high efficiency glass. Further, punctured windows provide climate appropriate shading. Most of the fenestration and habitable areas are located on the outer periphery, which permits good day lighting and view of the scenic surroundings from most of the locations of the offices.
- A large number of spaces including passages and lobbies are developed as non-air-conditioned spaces with provision for natural cooling and shading through stone jaalis.

Figure 59: The central courtyard facilitates cross ventilation in Indira Paryavaran Bhawan

Active Measures of Promoting Energy Efficiency

The HVAC system has used the Adaptive Comfort Model that accounts for our physiological capacities to adapt to a wider range of temperature and humidity conditions in real life. Using this model, the performance parameters for different electrical uses was made more efficient in comparison to the conventional standards for instance,

- air-conditioning load is designed for 450 sq. ft per TR instead of 150 sq. ft per TR
- lighting power density at 0.5 W per sq. ft instead of 1.1 W per sq. ft and
- other electrical loads at 4.5 W per sq. ft instead of 10 W per sq. ft.

An important decision by the ministry was to regulate the set point temperature to 26 °C 3 1 with an emphasis on lowering the thermal shock when moving between outdoors and indoors. This is more appropriate than the usual 20–22 °C and also promotes a climatically appropriate lifestyle.

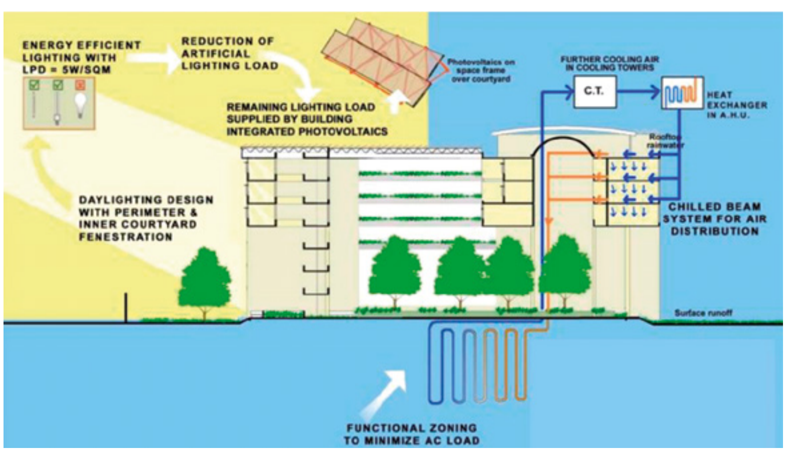

Figure 60: Energy conservation measures in Indira Paryavaran Bhawan

The other measures proposed for making the space conditioning in the building energy-efficient are:

- Part condenser water heat rejection by geothermal mechanism with a closed loop piping which minimizes the need for make-up water. This also helps in water conservation in cooling towers for the HVAC system.

- Chilled beam technology which reduces energy consumption by utilizing radiative cooling panels that depend on localized induction cooling by chilled water. This also reduces the AHU/FCU fan power consumption as it avoids the need for large quantities if air travel from the user space to the heat exchange point.
- Chilled water pumping system through DPS (Differential Pressure Sensor) and VFD (Variable Frequency Drive) which allows for separate control for the various spaces.
- VFD on cooling towers fans and air handling units
- Pre-cooling of fresh air from the toilet exhaust air through sensible and latent heat energy recovery wheel.

A solar photovoltaic system of 930 kWp is installed on the rooftop and on cantilevers protruding out from the building. Highly efficient solar panels above the terrace and the southern façade would produce more energy than required by the building over the period of a functional year making it a "Net Zero Energy" building.

Case study 2 – VVIP Circuit House

Location	: Pune
Site Area	: Approx 9584.24 m2
Built up Area	: 4886.90 m2
Air-conditioned Area	: 2629.93 m2
Non AC Area	: 2256.97 m2
EPI	: 89.16 KWh/m2/year
Renewable Energy	: Rated capacity of solar PV installed on site is 22 KW
Year of completion	: 2014
Certifications	: GRIHA 5 Star
Architect	: Sunil Patil

Circuit house is a government public building which not only accommodates the VIP authorities but also acts as a node for political meetings, government authorities' discussions and conferences. Usually, circuit houses have large number of visitors and occupancy can vary extremely.

The project is mainly divided into two parts-

- Accommodation – Guest suites
- Public areas –Conference and meeting hall facilities, Dining, Reception, VIP and visitor's waiting areas etc.

Energy Efficiency Measures

The focus was to design a climate responsive building with passive strategies for thermal and visual comfort along with innovative active strategies to achieve energy efficient green building.

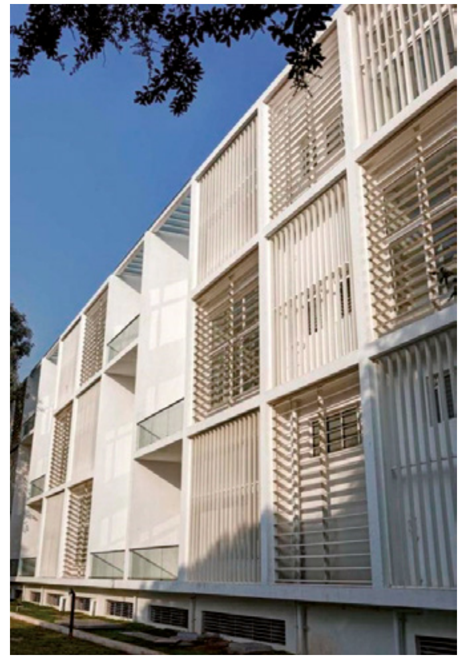

Figure 61: Louvers to shade the west facade

- The planning is derived from traditional Indian architecture – The shaded courtyard, transition spaces like passages and terraces, jalis in form of louvers carry vernacular ethos in highly contemporary architectural style in this building.
- Public building like VVIP circuit house has fluctuating occupancy and designing public area for the peak occupancy is not viable.

  Hence the buffer spaces like courtyards can serve the purpose of accommodating excessive occupancy in peak time.
- Orientation has been a key criterion while designing the main building. The building faces west and hence intermittent spaces are designed on this side to avoid harsh radiation. The residential zone lies on the north and the south. The solar radiations are blocked using shading devices still allowing good ventilation.
- In hot dry climate of Pune, water bodies have been introduced for evaporative cooling. They act as micro-climate modifier and also help in coiling of naturally ventilated public areas.
- The use of insulation in roofs ensures controlled heat gain

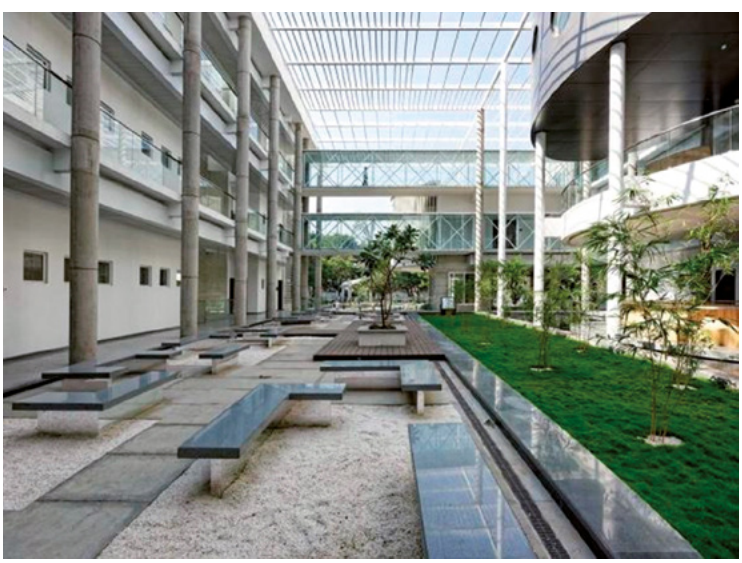

Figure 62: Central Courtyard

- Louvers are used to allow light and achieve thermal environmental comfort.
- All areas in the building have been designed for appropriate natural light and ventilation. LEDs are used for artificial lighting.
- An energy efficient HVAC system has been designed. Highly efficient HVAC system (VRV) brings down the energy performance index (EPI) of the building by 52.81%.
- 22 kW solar photo-voltaic renewable energy plant is designed to cater more than 30% of artificial lighting.
- Heat pump based hot water system for 90% of hot water demand is installed in this project.

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MODULE 5

Fundamentals of Air-conditioning systems

Already being covered under "Climatology" and
"Applied Climatology" courses in
3rd and 4th Semesters.

MODULE 6

HCFC in Buildings & Phase-Out Plan

This module covers the alternatives available for phasing out HCFC in buildings.

Course: Building Services

5th Semester, B Arch

6.1 INTRODUCTION

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 centres. HCFCs are largely used as refrigerants.

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

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

6.2 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.

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.

6.2.1 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.

Split Air Conditioner

Floor Mounted AC

Cassettes Type

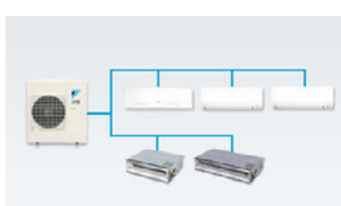
Window AC

Figure 63: Unitary air conditioners less than 3 TR capacity

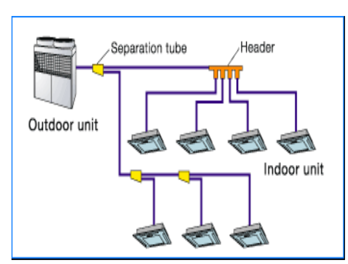
Unitary Air Conditioners with > 3 TR Cooling Capacity

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.

Ducted Packaged Units



Multi split units



Variable refrigerant flow (VRF)

Figure 64 Unitary air conditioners more than 3 TR capacity

Table 10: Typical configurations of air conditioning systems

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 commerical	Self-contained	7-750	5-200
Ducted commerical split		Ducted commerical	Remote	10-750	5-250

Source: Technical Options Committee Report on Refrigeration, Air Conditioning and Heat Pumps (May2014)

6.3 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 centres, electronics fabrication, precision machining, moulding, 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

6.3.1 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.

a) 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.

b) 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.

6.3.2 Absorption chiller

Absorption chillers work on the principle of vapour 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. The following table lists the various cooling capacities of chillers with type of HCFC used. Most buildings, particularly in larger capacities, use multiple chillers.

Table 11: Absorption Chiller

Chiller Type	Approximate Capacity Range (kW)	Refrigerant Used
Scroll, rotary, and reciprocating water-cooled	10-1200	HCFC-22
Screw water-cooled	100-7000	HCFC-22
Screw, scroll, rotary, and reciprocating air-cooled	10-1800	HCFC-22
Centrifugal water-cooled	200-2100	HCFC-123
Centrifugal air-cooled	200-7000	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)	1400-18000	R-718 (Water)
Absorption (water-lithium bromide - shell and coil)	17-120	R-718 (Water)

6.4 TYPICAL INSTALLATIONS OF AIR-CONDITIONING SYSTEMS IN BUILDINGS

6.4.1 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.

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 65 : Interior and Exterior view of Unitary AC

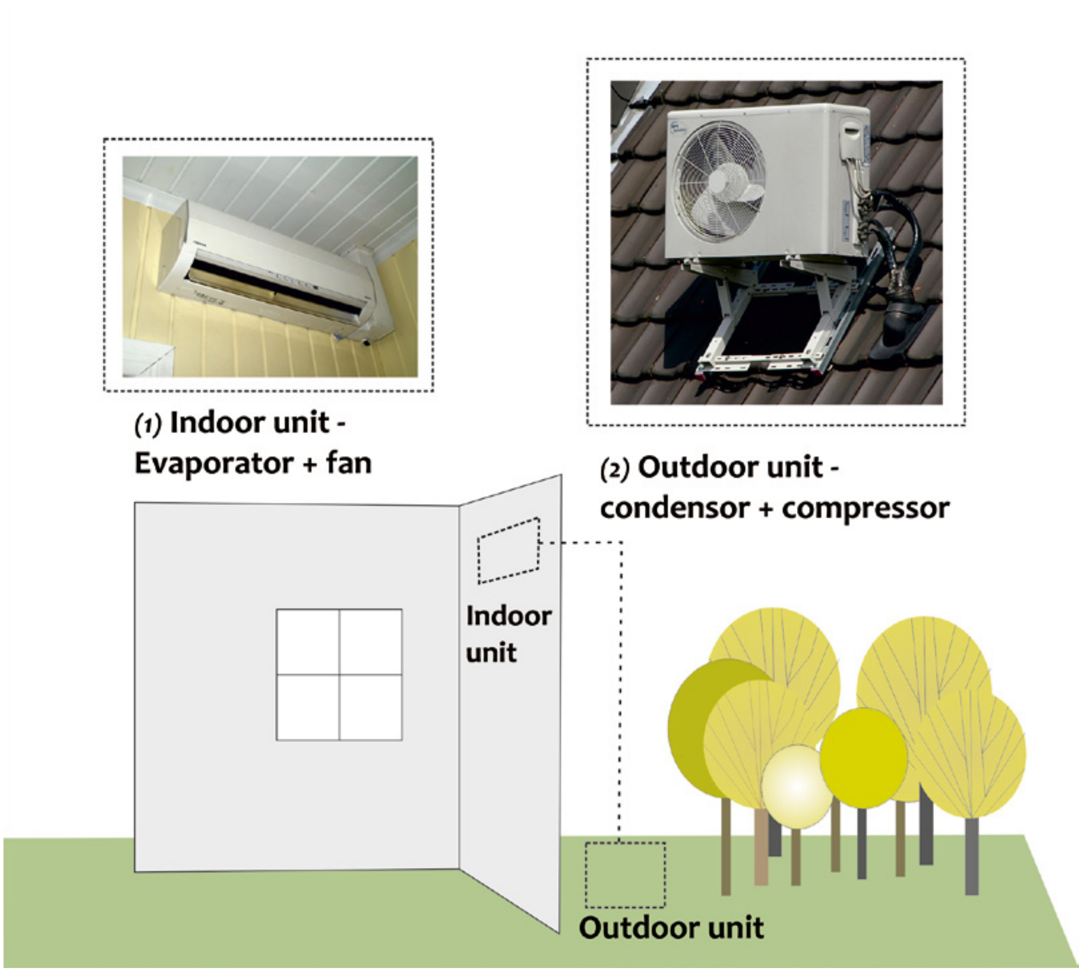


Figure 66 : Indoor and Outdoor unit of AC

6.4.2 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.

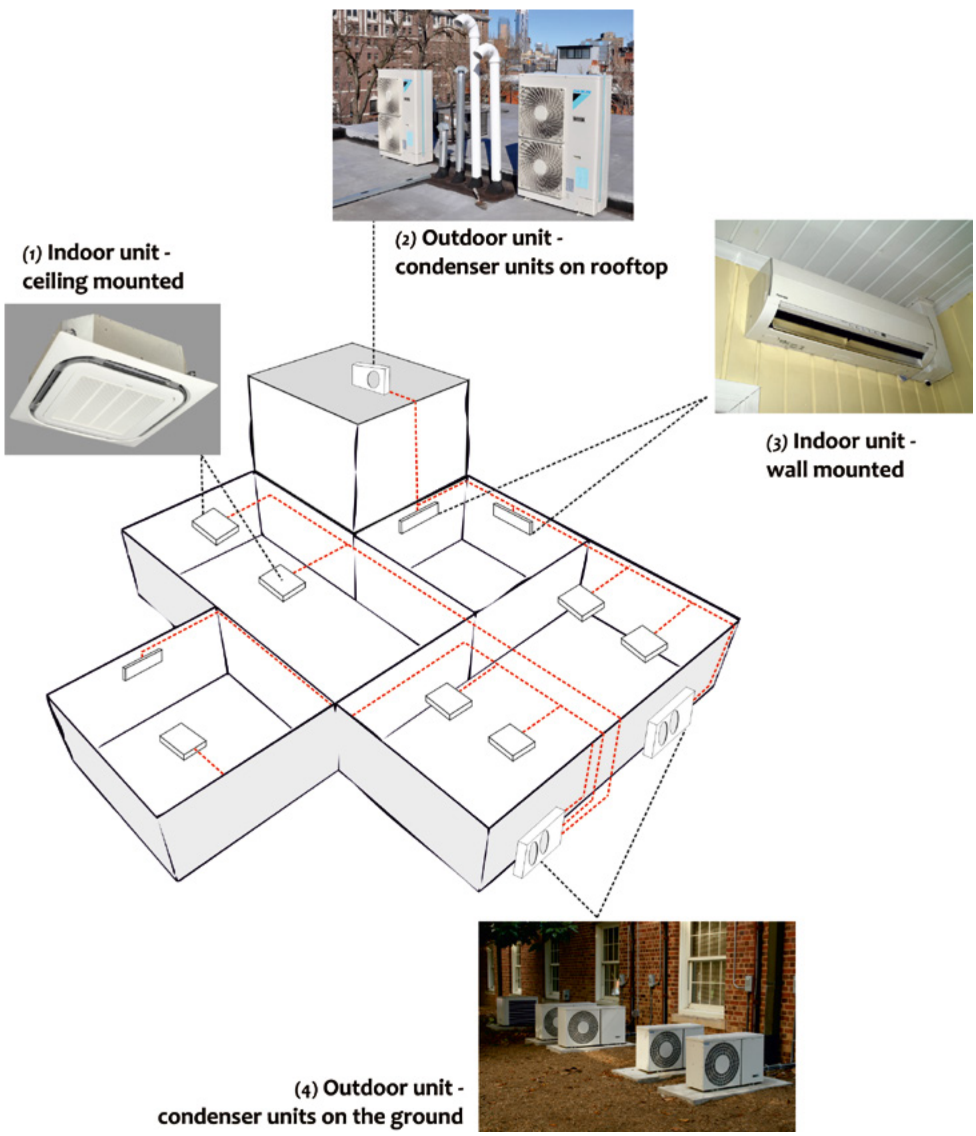


Figure 67 : Indoor and Outdoor unit of multi-split system.

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.

Figure 68 : Packaged air conditioner.

Chillers

Chillers are used to cool very large commercial and industrial buildings. Working on the principle of a vapour 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 12: HCFC use in air-conditioning systems

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

6.5 F-GAS EMISSIONS FROM BUILDINGS

Fluorinated gases (F-gases) are man-made gases that can stay in the atmosphere for centuries and contribute to a global greenhouse effect. There are four types: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6) and nitrogen trifluoride (NF3).

HFCs were developed in the 1990s to substitute substances such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). As these substances were found to deplete the ozone layer, the Montreal Protocol lays down provisions for them to be phased-out globally.

F-gases are ozone-friendly, very energy efficient, and safe for users and the public due to their low levels of toxicity and flammability. However, most F-gases have a relatively high global warming potential (GWP). If released, HFCs stay in the atmosphere for decades.

6.6 STEPS FOR PHASING-OUT HCFCS FROM 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.

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.

- 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.
- 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.

2. Replace HCFCs

Using low-GWP refrigerants and foam blowing agents is key to achieving successful phase-out 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 fire fighting sectors.

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.

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.

6.7 ALTERNATIVES TO REFRIGERANTS AND TECHNOLOGIES

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.

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. Its 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.

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 vapour 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 the following table.

Table 13: List of alternative refrigerants

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 e.g, R-452B (680); A2L R-444B (310); A2L
Ducted & Packaged AC	HCFC-22 (810)	R-410 A (2100) R-407 C (1700)	-HFC-32 (675), A2L -HFC/HFO blends e.g, R-452B (680); A2L R-444B (310); A2L
Scroll Chiller	HCFC-22 (1810)	R-410 A (2100) R-407 C (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 14: Alternatives to HCFC-123 for building air-conditioning

Current and Future Potential Refrigerants for Chillers (Low and Medium Pressure) Class of Flammability is denoted in red color			
Equipment	HCFC Refrigerant	HFC 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-1233zd (1); A1 -HFO-1336mzz (2) A1 **Low Pressure:** -HFO-1234yf (<1); A2L -HFO-1234ze (<1); A2L -R-514A (1.7); B1

Not-in Kind Technologies

a) 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.

b) 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.

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.

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 CO2 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.

c) 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 vapour. 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.

In addition, low energy cooling technologies like geothermal cooling, Earth air tunnel etc. can be added under this section.

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 vapour 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.

Advantages:

- Uses water vapour 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.

Figure 69 : Solar Power 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.

Figure 70 : Evaporative cooling for orient craft ltd.

Source: Environmental Design Solutions Pvt. Ltd

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

d) 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.

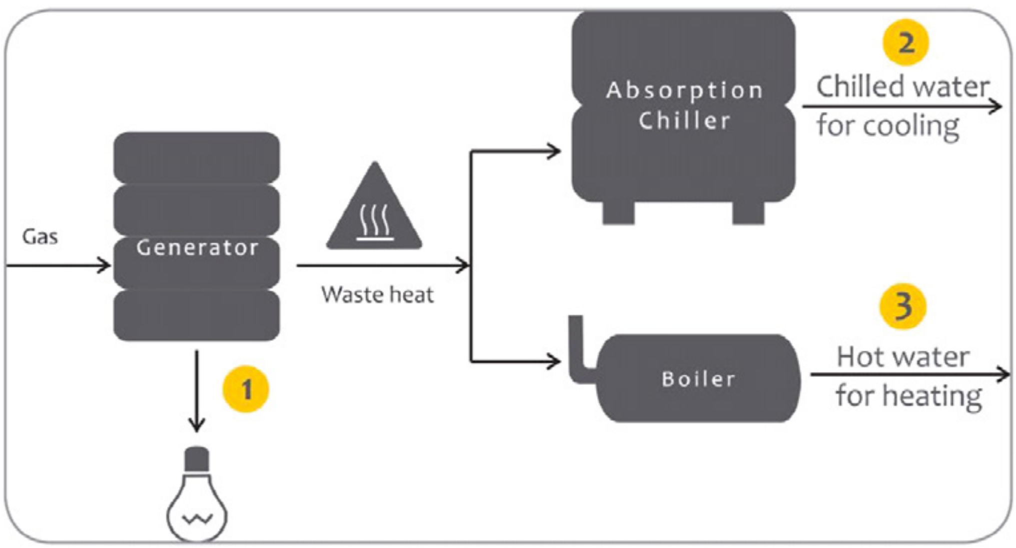


Figure 71 : Typical Trigeneration System

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

Figure 72 : Trigeneration System of AIIMS, Delhi

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

e) 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.

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