A Review on Energy Solutions for decarbonizing the buildings

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Abstract

The world's population is increasing, and this growth often results in the expansion of urban areas. As more people move to urban areas in search of employment and better living conditions, There's the rising demand for infrastructure and services. The sector that produces the most greenhouse gas emissions in India, at about 35% of total emissions across all economic sectors, is the electricity and heat industry. The growing demand for space heating and cooling is primarily responsible for the residential sector's one-fifth share of the world's energy consumption and greenhouse gas emissions. Carbon dioxide, methane, and nitrous oxide are examples of greenhouse gases that trap heat and absorb infrared radiation, keeping the earth's surface warm. India's per capita carbon dioxide (CO_2) emissions have increased dramatically over the past few decades, reaching a peak of 1.91 metric tons in 2022 from 0.39 metric tons in 1970. This represented a 5.5 percent rise over 2021 levels. Total CO_2 emissions in India also reached a record high in 2022. Low-carbon and energy-efficient buildings are important components of sustainable urban development. Energy use, carbon emissions, and overall environmental impacts are all significantly influenced by the construction and operation of buildings. Operational carbon emissions are CO2 emissions produced during the use stage by materials, heating, cooling, lighting, and appliances using energy. By enhancing residential buildings' energy performance and lowering operating carbon emissions through energy, the research study will focus on energy efficiency techniques that increase the chance of constructing a zero-energy building.

Keywords : *Carbon Emissions, Energy, Residential Buildings, Composite Climate.*

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1 Introduction

As more people move to urban areas in search of employment and better living conditions, there is a rising demand for infrastructure and services. The need for housing and commercial spaces results in increased construction activities, contributing to a higher demand for energy and raw materials. The growing urban population requires more water and electricity for domestic and industrial purposes. As urban areas expand and experience temperature extremes, the demand for heating and cooling through HVAC systems rises. The cumulative effect of urbanization and infrastructure development is a higher energy demand, often met through the burning of fossil fuels. Today's power plants, industry, cars, and buildings account for two-thirds of India's total emissions between now and 2040. In general, the building sector consists of everything from construction to operation, and it is also subdivided into residential and non-residential buildings. These include the procedure for adding buildings to the regions of land adjacent to the building's service, operation, and maintenance. The top five emitters of carbon dioxide in 2023 remain the same as in 2022: China, the United States, India, Russia, and Brazil. These five nations collectively are responsible for almost half of the world's carbon emissions. With 32% of global emissions in 2023 coming from China, the country is the biggest emitter in the world. With 14% of worldwide emissions, the United States is the second-largest emitter.

India is the third-largest emitter, with 9% of global emissions (Greenfield, 2023). Territorial Emissions (3.3 GtCO2): India's territorial emissions are primarily driven by its electricity and heat production, industry, and agriculture sectors. Consumption-based Emissions (2.8 GtCO2): The lower consumption-based emissions suggest that India functions as a net exporter of emissions-intensive products (Greenfield, 2023).

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1.1 Carbon emissions in India:

Per-capita energy-related Carbon emissions result to be higher in more economically developed countries but can vary significantly depending on the structure of the economy and energy systems. For example, countries with a greater reliance on carbon-intensive transportation (such as driving and flying), a higher proportion of energy-intensive industries (like steel or chemicals), or significant dependence on fossil fuels for electricity generation typically exhibit higher per-capita emissions (World Energy Outlook 2023, 2023). The amount of CO2 emissions per person in India increased by 93% from 2000 to 2021, reaching 1.619 tons.

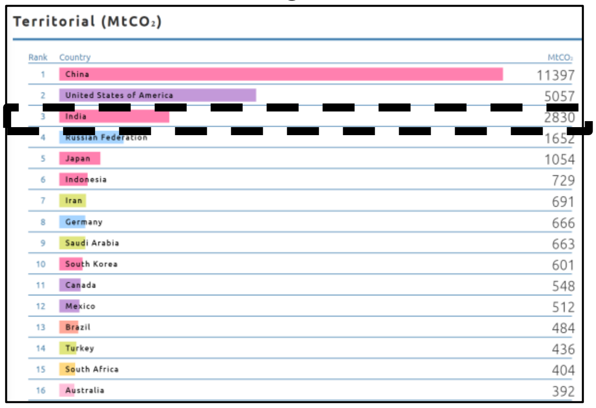

Figure 2 Global carbon Emissions for 2023. **Source:** Global Carbon Atlas

CO2 emissions by sector: The distribution of energy-related CO2 emissions across sectors is shaped by the economy's structure and its energy systems. Power plants contribute emissions through burning fuels for generating electricity and heat. In the transportation sector, the majority of emissions in most countries stem from cars, which, despite the rise of electric vehicles (EVs), still heavily rely on oil-based fuels. Residential emissions predominantly arise from fossil fuel heating in many countries. In industry, emissions primarily result from the combustion of fossil fuels to generate heat for processes such as paper or steel production. It's important to note that this overview excludes CO2 emissions directly generated by specific processes like cement production, which can be significant (World Energy Outlook 2023, 2023).

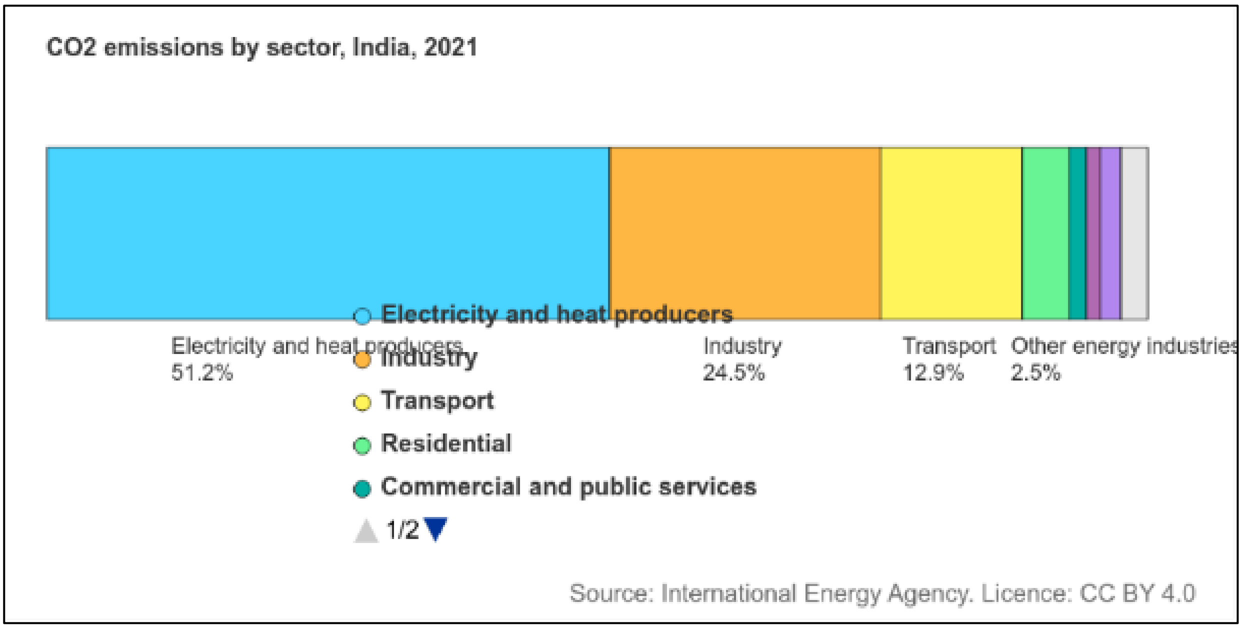

Figure 1 Distribution of carbon dioxide emissions worldwide in 2023, by sector. (Source :IEA 2019)

1.1 Issues and Challenges:

Significant problems in the areas of economics, the environment, technology, and society face the building industry. These challenges stem primarily from unprecedented changes in the global and regional climate, overcrowding, intense urbanization, wasteful resource consumption, and social inequality. The policies that are

STHALA/ ISSN 2582-9491

selected and the potential solutions to these issues will have a substantial impact on the future socioeconomic routes and the rate of global growth, as well as the quality of life for several billion people today and in the future.

A) Overpopulation and Rapid Urbanisation: As to the United Nations, the global population could reach 11 billion by 2050, with the majority of this additional population residing in cities, resulting in an additional 6.5 billion people living in urban areas. At midyear, India's population is projected to be 1,428,627,663 in 2023. India's population represents 17.76% of the global population. Most of the predicted growth in cities is in Asia and other developing nations, which could pose a significant challenge to the building industry's ability to supply the extra demand for new infrastructure, and commercial, and residential buildings.

b) Greenhouse Gas Emissions and Global Climate Change*:* In 2018, the building sector was responsibility for approximately 39% of the carbon dioxide emissions connected to processes. Depending on the extent to which building energy needs and the nearly 50% of power production system capacity currently devoted to buildings are decarbonized, the building industry may become carbon neutral by 2050 or later, or it may remain carbon intensive.

c) Local Climate Change and Urban Overheating: The result of heavy industrialization and urbanisation is a major increase in city ambient temperature. The Urban Heat Island (UHI) phenomenon has been seen in more than 450 cities across the globe. Urban overheating can reach temperatures of up to 10 °C, with an average of about 5 °C. Increased urban temperatures have an adverse effect on urban building energy consumption and the health, survival, and quality of the environment of cities.

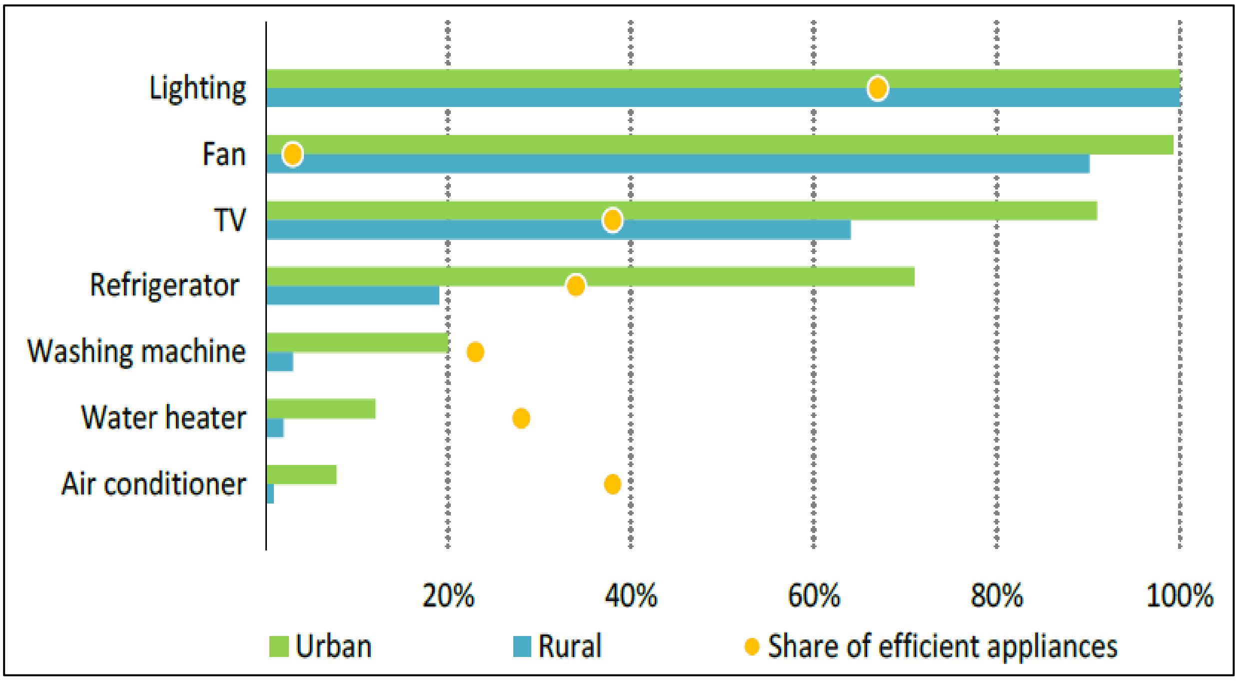

Figure 3 The proportion of households that utilize appliances2019.
(Source: IEA based on Agarwal et al (2020))

D) High Energy Consumption*:* The primary energy grows significantly, more than doubling between 2019 and 2050. The annual growth rate typically ranges from 2.4% to 2.6%. India's substantial growth has caused it to rise from approximately 7% in 2019 to roughly 14% in 2050 across all scenarios for

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primary energy consumption worldwide. Future analyses of building energy consumption indicate possibilities to reduce the sector's energy consumption by 2050 or beyond by utilizing renewable power extensively and enhancing energy-saving measures within buildings.

e) High Global Environmental Impact: The worldwide environment is significantly impacted by the building industry. The industry uses resources and raw materials, generates waste, and pollutes the environment. A considerable extra usage of raw materials is also linked to the building sector's future decarbonisation. Increasing industrial efficiency, recycling, and adhering to the circular economy's tenets appear like sensible policies, but the construction industry faces a clear and formidable hurdle in doing.

1.2 Aim: The aim is to review the various passive and active strategies for reducing carbon emissions in residential buildings. The Objectives is to identify and understand the various specific parameters that can be optimized to reduce carbon dioxide emissions.

1.3 Need of the Study:

a) The increase in CO_2 level that contribute to ocean acidification as well as atmosphere pollution which harms marine life and ecosystems.
b) The carbon emissions in various types of buildings, in which the carbon emissions of residential buildings are 514.66 kg CO2 e/m3; office buildings, 533.69 kg CO2 e/m3; and commercial buildings, 494.19 kg CO2 e/m3 (Ashok Kumar, 2021).
c) The topic is the need of the hour given India's Commitments of Net Zero Carbon by 2070 at CoP 26 Glasgow Summit. There is a need to develop low carbon Net Zero strategies in construction of Built environments.

2. **Literature Review:**

Worldwide, structures are built for commercial, residential, and office use. They contribute significantly to a nation's socioeconomic development in addition to consuming a large amount of energy and natural resources. Buildings are responsible for 40–50% of greenhouse gas emissions globally and consume 30–40% of all primary energy (al., 2007).Thus, achieving sustainable growth in society is crucial for the building construction sector. Development that has a high economic and social benefit but little negative influence on the environment is considered sustainable development. An interdisciplinary approach that tackles several aspects, such as energy conservation, better material use, including water conservation, material reuse and recycling, and emissions management, is needed to meet the objectives of sustainability.

A. **Emissions from the Residential Sector:**

India has low CO2 emissions per capita, but it is the third-largest emitter in the world. Its electricity industry in particular has a carbon intensity that is significantly higher than the global average. Air pollution has become one of India's most delicate social and environmental problems, and particulate matter emissions play a significant role in it. In 2019, ambient and home air pollution caused well over a million premature deaths (AGENCY, 2021). In 2019, India accomplished a historic milestone: nearly all households now have access to electricity. This means that more than 900 million people have had an electric connection to their homes since 2000. While per capita CO2 emissions in 2040 (2.4 t CO2 per capita) are still 40% lower than the global average at that

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time (4 t CO2 per capita), total emissions are almost 50% higher than 2019 levels. Although it is still difficult to provide all potential customers with sustainable, affordable, and dependable access, building power consumption has almost doubled over the last 10 years, surpassing that of the overall economy. Even though most Indian families only use electricity to power televisions, ceiling fans, and light-emitting diode (LED) bulbs, this has been fueled by rising appliance consumption. Building will continue to produce more emissions. In the upcoming decades, the total floor area is predicted to continue growing, serving as a major contributor to emissions. The floor area may more than double by 2060 compared to 2020 (UNEP 2017; IEA 2017a). Greater floor space necessitates greater heating and cooling. Space heating and cooling are significant contributors to building energy consumption and emissions. Buildings that increase in size and quantity will also emit more embodied emissions since they will require more materials during construction. Floor space and energy consumption per person vary greatly between and between nations, frequently based on the affluence and climate zone of the respective nation. As living standards rise, Asia and Africa are predicted to see the majority of the growth in floor space. It is currently possible to take action to guarantee that the construction of new buildings minimizes CO2 emissions from the process and simultaneously meets the growing demand for thermal comfort (UNEP 2022a). The Paris Agreement's target of keeping the rise in global temperature to 1.5°C will need significant improvements in all buildings. According to the data that is available to the public, none of the evaluated indicators are on track. The global diversity of buildings means that different building types and locations will require different approaches to decarbonization, as well as different technologies and methods based on the structures' intended uses. For example, different strategies are needed to suit the needs of heating and cooling in different climatic zones.

3.Emerging Energy Solution for Decarbonisation:

Buildings' thermal demands are predicted to be primarily met by electricity by 2050, up from 20% in 2020, and primarily by biofuels by the same year. In contrast to zero in 2020, the usage of low-carbon gases such as hydrogen, biomethane, and synthetic methane in building gas distribution networks will

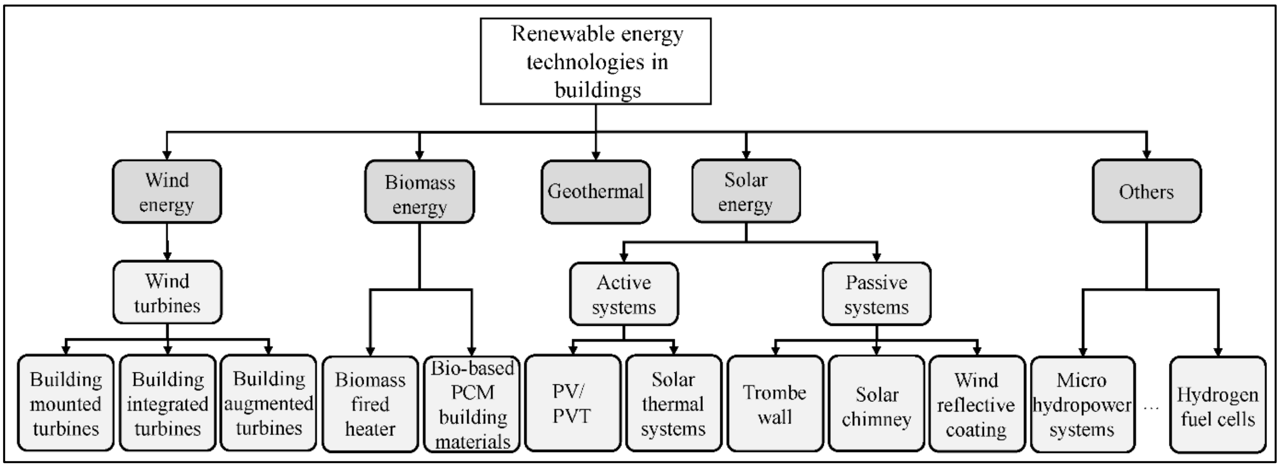

Figure 4 Integration of renewable energy in buildings. Source: (Wu & Zhong, 2023.)

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expand to 10% by 2030 and 75% by 2050 (IEA, 2021). While gas heaters should be able to run on hydrogen, the percentage of gas used for heating is predicted to fall to roughly 0.5% in 2050 from 30% in 2020. From the approximately 20% of homes that use electricity for heating now, that number should increase to 35% by 2030 and almost 55% by 2050. Typically, energy technologies that are developed and commercially available account for nearly 79% of the predicted reduction in CO2 emissions; the remaining 30% may come from energy innovations that are still in the prototype or demonstration stages. Until 2030, there should be a decrease of over 30% in direct emissions and a reduction of CO2 in total emissions.

3.1 Renewable Energy Integration in Buildings:

Renewable energy is essential for both addressing climate change and decarbonizing buildings. The International Renewable Energy Agency's (IRENA) strategy states that by 2050, renewable energy sources could supply at least 60% of the final energy consumed in many countries (Zhu, et al., 2020). One of the most significant technologies is solar energy since it is plentiful and adaptable. Among renewable energy markets worldwide, India ranks fourth in terms of attractiveness. As of 2020, India was fourth in installed capacity for wind, fifth in solar, and fourth in installed capacity for renewable power. Roughly 10% of the world's primary energy needs are met by biomass energy, which makes it an essential renewable energy source. When combined with heat pumps, biomass-fired heaters can offer a financially sensible option for the heating requirements of buildings. By meeting up to 65% of the demand for space heating, these heaters help reduce dependency on the grid and heat pumps. Additional forms of renewable energy have also been tested in buildings, including hydrogen fuel cells and micro-hydro. Householders in isolated locations frequently use micro-hydroelectric systems, which use the energy of flowing water to power turbines and generate electricity. Although not widely used in buildings yet, hydrogen energy is being researched as a possible way to decarbonize building heating and cooling systems. The most common method is fuel cells, which may provide buildings with heat and power. Projects to investigate its potential are still in their early stages. However, there are obstacles to the broad integration of hydrogen energy in buildings, including high production costs, inadequate infrastructure, and safety concerns related to handling hydrogen (Wu & Zhong, 2023.). Solar power has the potential to significantly reduce CO2 emissions and provide a sustainable source of energy. While there are challenges in its adoption, the benefits of solar power cannot be ignored. As we continue to strive toward a more sustainable future, solar power will play an increasingly important role in reducing our impact on the environment. solar energy in buildings through solar photovoltaic systems, solar thermal energy, and building-integrated solar cells presents a promising pathway to reduce CO2 emissions, promote sustainable development, and enhance energy efficiency. These findings underscore the importance of integrating solar energy technologies into building design and operations to achieve environmental sustainability goals.

3.2 Building Envelope-

Building geometry and the physical, optical, and thermal properties of its constituents determine the effectiveness of the building envelope (Sarihi S, 2021). Building energy use and indoor thermal comfort are significantly impacted by these characteristics (Ascione F, 2021). The high temperatures during the day make it challenging to optimize these qualities in tropical settings. Energy savings depend on how important they should be in the tropics. The analysis presented in the next part, as seen in Fig. 4, categorizes several façade and envelope

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design characteristics. Building shape and associated characteristics are taken into careful account. Thermal qualities, optical properties, physical properties, and geometry are the four categories that are derived.

3.2.1 Thermal properties: The temperature of the indoor air and the envelope surface, as well as the building energy loads, are depending on a number of factors, including solar radiation, the outdoor air temperature, and the optical and thermal properties of the envelope (Cicelsky A, 2014). Insulation and thermal mass are two characteristics of thermal qualities (Mousavi N, 2022). Thermal transmittance, or U-value (W/m2 K), thermal conductivity, or W/mK, and thermal resistance, or R-value (m2 K/W), are what define insulation (Kumar A, 2013). By reducing the rate at which heat enters a building mass by conduction, suitable insulating materials can reduce energy usage in comparison to typical building materials, they show low thermal conductivity. The overall mass of all structural components is known as thermal mass, and it has an impact on the material's ability to store energy. It is dependent upon the wall, roof, and floor's thickness, density, and specific heat (Wong I, 2016).

3.2.2 Physical properties: The window-to-wall ratio, often known as the opening ratio, determines how much incident solar radiation penetrates indoor rooms. WWR has an approximate 47.4% contribution to the operating carbon from the cooling loads (Hamida A, 2021). A low WWR is beneficial for façades with a low U-value in climates that are dominated by cooling **(Sarihi S M. S., 2021)**. Increased ratios may result in overheating and increased energy need for cooling. Thermal comfort can be improved and indoor air temperature can be lowered by lowering WWR from 1 to 0.4.

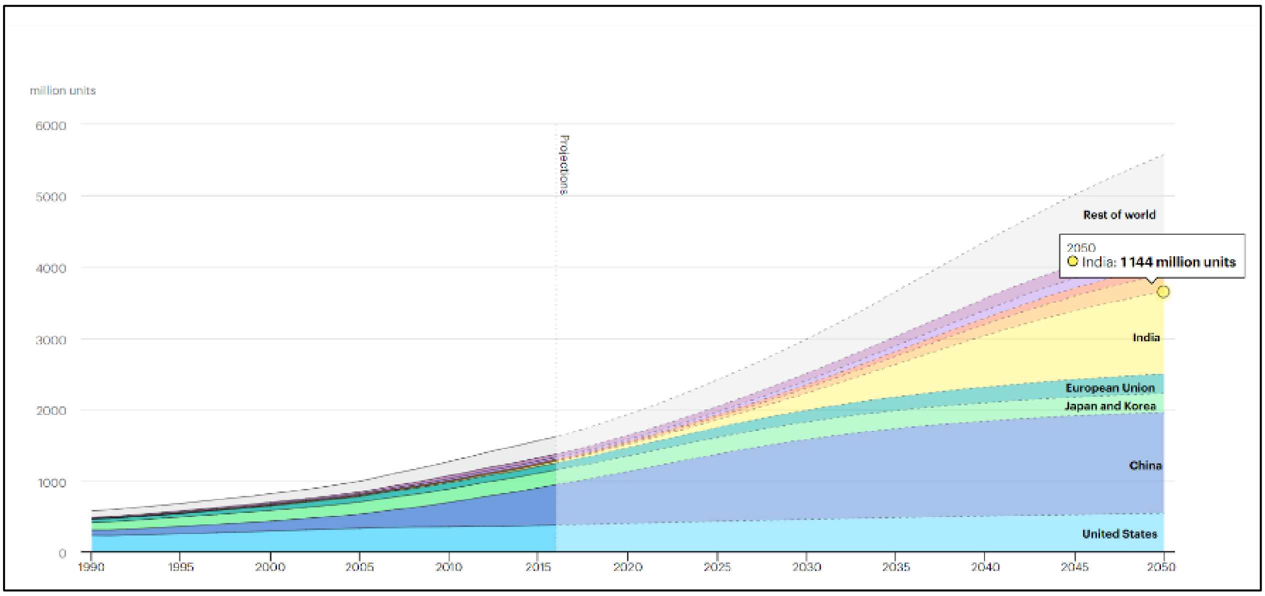

Figure 5 Global air conditioner stock, 1990-2050. (Source: iea) 2018

Shading systems: The best way to prevent solar radiation is to shade your exterior systems, especially. Various shade typologies can reduce cooling energy use by 25–50%. Another way to reduce heat transfer is to add vertical vegetation to outside walls. About

STHALA/ ISSN 2582-9491

40–80% less solar energy is absorbed by the layers of creeping plants.

3.2.3. Geometry: Climate, building shape, and building orientation are extra factors that influence a structure's energy performance in addition to the other envelope qualities already covered. During the building design process, these aspects must be carefully considered. There aren't many studies on building geometry in tropical countries, according to the literature. Thus, without limiting itself to the tropics, the next part examines the most recent research on building shapes across all climate zones.

3.3 Optimisation of the HVAC system-

The India Cooling Action Plan, or ICAP, was released by the Ministry of Environment, Forests, and Climate Change in response to the country's increasing need for cooling and the related environmental effects. The ICAP acknowledges that, in hot climates like India, cooling is important to people's productivity and well-being and that it is correlated with economic growth. Systems using refrigerants supply much of this cooling. Over the next 20 years, India's cooling demand is expected to increase tenfold, which will cause refrigerants to climb five to eight times. There will be a four and a half-fold rise in the amount of energy required for cooling. The biggest growth sector in buildings is space cooling. During the cooling system's lifespan, these refrigerant gases leak out and are released into the atmosphere upon system disposal. These refrigerants also have an independent effect on the greenhouse effect worldwide. Reducing the amount of refrigerants placed in our building stock can be achieved by designing buildings with lower cooling demands. ODP and GWP are the metrics that assess the direct impact of a refrigerant after being released into the environment. The indirect impact of a refrigerant is the annual amount of carbon emissions caused by the energy consumption of the HVAC system in which it is installed.

3.3.1 Energy Conservation Measures through HVAC system

The design strategies for reducing the energy use of HVAC systems. A more comprehensive list is available under the additional resources section, early-stage HVAC design (Settlements, 2024).

i. One, explore the possible use of natural ventilation and minimize the area targeted for mechanical cooling.
ii. Two, set indoor temperatures as high as possible and use fans to enhance comfort.
iii. Three, explore the possible use of evaporative cooling systems, and four, think about ways to improve system design itself.

Often, this approach is more cost effective in reducing energy consumption than just selecting efficient equipment. Window or split or packaged or VR units. Inverter driven compressors. Inverter driven compressors are variable speed compressors. They respond to the cooling demand by slowing down or speeding up the compressor motor, and therefore, deliver only as much capacity as required. This saves energy compared to a constant speed compressor. Brushless, electronically commutated DC motors and variable speed fans. Indoor units with variable speed fans and brushless electronically commutated DC motors save energy by varying the fan speed to meet the cooling required instead of running the fan at

STHALA/ ISSN 2582-9491

constant speed, irrespective of the cooling demand.

3.3.1 Air Cooled and Water-Cooled Chillers Chilled water systems choose a water cooled system if possible. Water cooled systems have cooling towers. In cooling towers, the heat is rejected to water which is cooler than the dry bulb temperature of the air. This reduces the work required to be done by the compressor.A water cooled chiller typically consumes about 0.6-0.8 kilowatts per ton. Compared to air cooled chillers that consume more than one kilowatt per ton. However, water needs to be available and should meet the quality standards specified by the manufacturer. Sometimes the water needs to be treated to meet those quality standards. Higher chiller leaving temperatures. Typically, chillers for commercial systems are designed such that the temperature of the chilled water loop leaving the chiller is at about 6-7 degrees Celcius. When ambient humidity levels are acceptable and dehumidification may not be required, it may be possible to raise the chiller leaving temperatures. Raising the chiller leaving temperature by one degree Celcius improves the chiller efficiency by approximately 3-4%. Variable speed drives for compressor pumps, cooling tower fans, condenser fans. Most components in a chilled water system will benefit from variable speed drives, VSD, or variable frequency drives, VFD. Whenever the building is not experiencing peak load conditions and the equipment is operating at part load, the efficiency of a VFD chiller is significantly higher than a constant speed chiller. VFDs can also be used on pumps, cooling tower fans, and condenser fans in order to reduce the speed proportional to the cooling demand. Reducing fan or pump speeds by half, reduces the power consumption by 1/8 of the power required at full speed. AHUs and air delivery. Effective air distribution should ensure that the cold air is supplied to all areas and does not short cycle back to the air handler without picking up heat. Supplying cooled air to a space that is returned back to the AHU without picking up heat from the space is a waste of energy. Such short cycling can be avoided by careful placement of supply diffusers and return openings.

3.**3.1 VRF System**: VAV and VFD units, variable air volume, or VAV units, vary with the amount of air supplied to a space by using feedback from a temperature sensor located in the condition space. They provide only the amount of air that is required for cooling. Reducing the amount of cold air delivered increases the comfort for the occupants, and also can signal the AHU to reduce other aspects of delivering cooling. With a VFD on the fan in the AHU, significant energy can be saved when compared with a constant air flow system that runs at full capacity always. Reducing fan speed by 1/2, reduces the energy consumption by 1/8 of the energy consumption at full speed. Low pressure drop design for ducts and pipes. Ducts and pipes with a smaller cross section area have higher resistance to air and water flow. This requires energy to push the air or water. Even a small increase in the duct and pipe sizes can reduce the energy consumption significantly. Increasing the duct or pipe diameter by a factor of two, reduces the power consumption by a factor of 32, while the cost approximately doubles. This means that a lot of energy can be saved by a relatively small increase in cost. Careful design integration can use this to

STHALA/ ISSN 2582-9491

an advantage to overcome problems with space limitation for increasing duct and pipe diameters (Settlements, 2024). To mitigate climate change, it is crucial to explore energy-efficient cooling solutions. In large buildings, implementing such solutions can be challenging because of the necessity for extensive copper piping, which can be costly and pose a risk of refrigerant leaks. For these larger structures, chilled water cooling systems are often preferred. These systems use chillers to cool water, which is then circulated through pipes around the building. Fans blow air over these pipes, cooling the air and removing heat from the spaces. Radiant cooling systems, which expose occupants to these chilled water pipes installed in ceilings or designed as chilled beams, are another option. However, in humid climates, radiant systems must be carefully designed to prevent condensation inside the building. Since radiant systems provide only sensible cooling, a secondary air-cooling system may be required to manage humidity or latent loads. Chillers extract heat from the building and use air-cooled condensers or cooling towers to release it into the atmosphere. Choosing the right HVAC system is essential for achieving both comfort and cost-effectiveness in installation and operation. Integrating low-energy cooling systems also involves designing an efficient building envelope and implementing appropriate passive measures (Settlements, 2024).

4. CONCLUSION

In conclusion, addressing carbon emissions in buildings requires a multifaceted approach that prioritizes energy-efficient solutions. Adopting cutting-edge HVAC technologies, such as radiant cooling and chilled water cooling, can drastically lower energy use without sacrificing comfort. These systems, when combined with a well-designed building envelope and passive design strategies, offer a viable path to minimizing the environmental impact of buildings. Integrating energy solutions centered on façade optimization and renewable energy sources can efficiently reduce carbon emissions in buildings. A well-designed façade plays a crucial role in minimizing energy consumption by enhancing natural light, improving insulation, and reducing the need for artificial heating and cooling. Incorporating features such as high-performance glazing, shading devices, and reflective materials can significantly lower a building's energy demand. Coupling these façade improvements with renewable energy sources, like solar panels or wind turbines, further amplifies the impact. Buildings may reduce their overall carbon footprint and dependency on fossil fuels by producing clean energy on-site. When combined, these tactics form a potent mix that promotes the shift to sustainable building practices while simultaneously increasing energy efficiency.

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