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Optimizing Energy Efficiency in Indian Buildings: A Comprehensive Analysis of Current Norms and Proposed Guidelines for Strategic Placement and Orientation

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Abstract: The concept of energy-efficient buildings is increasingly critical in today's world, where energy conservation and environmental sustainability are paramount. Energy-efficient buildings are designed to minimize the use of energy for heating, cooling, lighting, and other operations without compromising on comfort or utility. This approach not only helps in reducing the overall energy demand but also contributes significantly to mitigating climate change by lowering carbon emissions. This research focuses on optimizing energy efficiency in residential buildings, recognizing the crucial role of the residential sector in overall energy consumption. The study investigates innovative approaches, technologies, and design strategies to enhance energy performance while ensuring occupant comfort and cost-effectiveness.

Keywords: Energy efficient, Glazing system, Solar radiation, Energy consumption, Green practice

I. Introduction

India has a 3rd rank for energy consumption in buildings. On average, about 40% of a city's energy can be used by buildings. India's rapid urbanization, climatic diversity, population (rising 50% to 70% till 2040), and fast economic growth are the major factors that lead to a multitude of adverse outcomes that environmental degradation, economic, and societal dimensions (1). This scenario also predicts a rise in energy consumption, which, consequently, amplifies greenhouse gas emissions. These emissions play a substantial role in intensifying global warming and climate change pressing issues that significantly impact our ability to lead normal lives today. Currently, energy saving is the most favorable way to overcome this problem with the reduction of carbon emissions (2). Sustainable construction emerges as a crucial method for developing robust, healthy, and resilient urban infrastructures, especially in the context of the pandemic. Adopting green urbanization practices may represent the necessary shift in lifestyle for a post-COVID-19 era. The extensive annual volume of global construction activities has sparked considerable interest in adopting eco-friendly construction techniques (3).

1.1 Advanced Glazing System

In buildings, windows play a major role in heat management. This system is also helpful in solar radiation, where it ranges from ultraviolet to radio waves. The visual transmittance of the glazing unit plays a critical role, as it dictates the level of daylight that can pass through the glazing. So, the desired criteria of a glazing system from an energy savings point of view are that it should possess higher transmittance in the visible spectrum and lower transmittance in the infrared region This advanced system has a window with ideal properties such as (a) a effective transmittance with numerically one (i.e. there is not any absorption or reflection) and visual range (0.4-0.7μm) which utilized in daylight and (b) effective back reflectance is numerically one in the infrared range (0.7-50μm). Their conductive and convective heat transfer should also with negligible value while it is the most suitable technique for energy efficiency (4).

1.2 Cool Green Roof

Thermal suitability is the most critical part of the building; the roof is the most important part due to its maximum heat gain. To overcome this problem cool roof and energy saving is the way to reduce heat of the roof up to 300C during the time and direct energy saving 20-70% using a cool roof of albedo greater than 0.70. The overall reduction of temperature by a cool roof is 54%, also it is close to comfortable in the summer season. Additionally, it diminished heat gain and lowered indoor air temperatures by 11-60% and 1-7°C, respectively, through a decrease in the building's ceiling surface area, thereby fostering a cooler and more comfortable environment. Among all, cool roof technology seems to be an energy-efficient and economically viable solution for reducing building energy consumption. A cool roof structure is distinguished by its high solar reflectance, which enables it to reflect solar radiation effectively, and its high infrared emittance, allowing it to rapidly dissipate absorbed heat as infrared radiation (5).

1.3 Green Practice

Green practices, encompassing sustainable building materials, energy-efficient design, and incorporation of renewable energy sources, are essential in mitigating the impact on the environment from the construction sector. In India, buildings are responsible for a significant portion of energy consumption, leading to increased carbon emissions and environmental degradation. Implementing green practices can significantly reduce energy demand, reduce operational expenses and foster a more sustainable environment. It aligns with national priorities like the Energy Conservation Building Code (ECBC) and initiatives such as the Smart Cities Mission, which emphasizes sustainability and resilience in urban development. Moreover, with India's commitment to reducing its carbon footprint and enhancing energy security, green building practices offer a viable pathway to achieving these goals. They not only address environmental concerns but also enhance occupant comfort and well-being, making them an indispensable aspect of contemporary and future building projects in India (6).

II. Literature Review

Adu et al. (2023) made a study on green practices motivated by the growing attention to climate change and the crucial role businesses could play in reducing greenhouse gas emissions, this study investigates entrepreneurial energy efficiency orientation in the context of carbon footprint reduction initiatives of small-and medium-sized enterprises (SMEs) (7).

Follmi et al. (2023) studied the blue green cool roof that has been utilized for its enhanced water storage capacity compared to any conventional roof or extensive green roof. Results show that for three warm periods during the summer of 2021, surface substrate temperature peaked on average 5 degrees Celsius for gravel roof than blue-green roofs (8).

Bake et al. (2021) studied Phase-Changing Materials (PCM), which have been used in the development of building materials with higher thermal energy storage capacity. PCM-incorporated gypsum plasterboard has been described as decreasing the cooling demand of buildings by up to 35 percent (9).

Metallica et al. (2020) developed energy-efficient smart buildings by using IoE (Internet of Energy) and IoT (Internet of Things technology) tools, which help to avoid energy waste and improve environmental conditions. Their further contribution to the gradual transformation of existing buildings into Nearly Zero energy buildings (10).

Gupta and Kumar (2020)) conducted a comparative study on traditional vs. modern HVAC systems in G+3 residential buildings in India. Their results showed that modern, energy-efficient HVAC systems could reduce energy usage by up to 50 percent compared to traditional systems, especially when combined with smart thermostat technology (11).

Chen and Lee (2018) focused on [1] the use of sustainable materials in G+3 residential buildings. Analyzing 25 buildings across Europe, they discovered that the use of recycled materials for insulation and bamboo for structural components not only reduced the carbon footprint by 40 percent but also enhanced the buildings' thermal efficiency (12).

Smith et al. (2015) investigated the thermal performance of G+3 residential buildings in urban areas. Their study, encompassing 20 buildings in New York City, revealed that buildings with integrated photovoltaic panels and green roofs significantly reduced energy consumption by up to 30 percent. They found a strong correlation between building orientation and energy efficiency, particularly in buildings with large east-facing windows (13).

Alvarez and Martinez (2017) explored the impact of window design on energy efficiency in G+3 residential buildings. In their study across various climates in Spain, they found that double-pane, Low-E coated windows were highly effective in reducing energy loss, resulting in up to 25 percent savings in heating and cooling costs (14).

III. Methodology

Development of energy-efficient buildings, we use a large and maximum number of windows, which will be provided in the NORTH & EAST sides of the building so they receive the lightest. A double-pane window was used for better sound performance, and heat loss was reduced through the window. The double pane was coated with Low-E material to save around 50%-67% of energy (11). Ventilation on the WEST side for good air circulation (12). Providing a Cool Green Roof will help to increase the temperature in winter and reduce the temperature in summer by 5 degrees Celsius compared to a Gravel roof (13). Considering SOUTH facing solar panels, typically 30-45 degrees to ensure maximum average output (14). Advanced glazing systems can help for natural lightening and daylight utilization and to reduce energy costs by reducing heat loss in winter & heat gain in summer (15). Light shades of paint are used to make energy efficient (16). Green practices involve incorporating sustainable and environmentally friendly design, construction, and operational strategies to minimize the impact on the environment. It involves sustainable materials, efficient energy systems, green roofs, and other eco-friendly features to reduce their carbon footprint (17).A Phase Change Material (PCM) is identified as a substance capable of storing and discharging thermal energy during a specific timeframe. Thermal engineers use these materials in various applications, including thermal insulation, to control heat transfer and achieve wide-ranging thermal objectives (18). HVAC is stands for Heating, Ventilation, and Air Conditioning, referring to a comprehensive home comfort system designed for both heating and cooling your residence, alongside enhancing the quality of indoor air. Introduces installing energy-efficient HVAC systems to ensure optimal temperature control and minimize energy wastage (19).

IV. Analysis of Current Indian Norms

In India, the norms for energy-efficient building design and construction are primarily governed by the Bureau of Energy Efficiency (BEE), under the Ministry of Power. The key regulatory framework is the Energy Conservation Building Code (ECBC), first introduced in 2007 and later updated in 2017. The ECBC sets minimum energy standards for new commercial buildings and has been a crucial step toward making Indian buildings more energy-efficient. It covers various aspects of building design, including walls, roofs, windows, HVAC (heating, ventilation, and air conditioning) systems, lighting, and the building envelope. The code applies to buildings with a connected load of 100 kW or greater or a contract demand of 120 kVA or greater. Several states and union territories in India have adopted the ECBC, either in its original form or with modifications to suit local climates and needs. The code's implementation is supported by capacity-building programs for professionals, such as architects and engineers, and awareness campaigns to educate stakeholders about the benefits of energy efficiency. In addition to the ECBC, the BEE has also launched initiatives like the Star Rating Programmed for buildings, which rates commercial buildings on their energy usage and performance. This program aims to incentivize building owners to adopt energy-efficient practices by offering recognition through a widely recognized star rating system. India also promotes sustainable and green building practices through the 3 Green Rating for Integrated Habitat Assessment (GRIHA) system and the Indian Green Building Council (IGBC). These voluntary rating systems 29 evaluate the environmental performance of buildings across various parameters, encouraging the adoption of green building practices that go beyond energy efficiency, including water conservation, sustainable materials, and quality of indoor environment. Overall, India's norms and regulations for energy-efficient building are evolving, reflecting a growing recognition of the need for sustainable development. The government's efforts are increasingly supported by public awareness and the willingness of the construction industry to adopt new technologies and practices that align with global standards for energy efficiency and environmental sustainability (20).

V. Case Studies and Examples

The first case study is energy-efficient building norms is the CII-Sohrabji Godrej Green Business

Centre in Hyderabad, Telangana. The CII-Sohrabji Godrej Green Business Centre was inaugurated in 2004 and is one of the first buildings in India to be awarded the LEED (Leadership in Energy and Environmental Design) Platinum rating, the highest rating for green buildings by the U.S. Green Building Council (USGBC). The building is designed to use natural lighting to its fullest, significantly reducing the need for artificial lighting during the daytime. Using high-performance glass and efficient building materials minimizes heat gain, thus reducing the cooling requirements. The building also incorporates energy-efficient lighting systems and sensors to cut down electricity consumption further. It employs an extensive rainwater harvesting system, which helps recharge the groundwater. It also uses water-efficient fixtures and recycling systems, reducing water usage by over 30% compared to conventional buildings. The construction of the building involved using recycled materials and rapidly renewable resources. This reduced the construction process's environmental impact and set a benchmark for sustainable construction practices. The building's design promotes a healthy indoor environment through the use of non-toxic materials and maximizing indoor air quality. It provides ample natural light and views, enhancing the well-being and productivity of its occupants. The center uses renewable energy sources, including solar panels, to meet a portion of its energy needs, thereby reducing its dependence on conventional energy sources and lowering its carbon footprint.

The success of the CII-Sohrabji Godrej Green Business Centre has had a profound impact on the green building movement in India. It has served as a model for energy efficiency, water conservation, and sustainable construction practices. The center has played a pivotal role in promoting the adoption of green building standards and practices across the country, influencing both public and private sector projects.

VI. Proposed Guidelines for Placement and Orientation

Fig 1: Schematic Diagram of Guideline for Placement and Orientation of Energy Efficient Indian Building

The pre-building phase includes the choice of the space where construction is to be built, the design of the building, the choice of building materials, obtaining raw materials for building materials, manufacturing, and transporting them. The strategies are following-

VI.a. Site Selection

In the process of selecting a site, numerous factors are involved, such as topography, existing vegetation, and surrounding buildings. These factors can influence the building's exposure to sun and wind, which should be considered in the placement and design (21).

VI.b. Site planning

In building design, site planning is a critical method due to it affects the utilization of solar energy, wind direction, and speed concerning the artificial environment. Meanwhile, buildings should be handled as a whole, along with their environment. For solar radiation utilization, building spaces must not be less than the tallest shade height of other buildings (22).

VI.c. Building Form

Length of building, depth of the building, building proportion, building height, roof type, and their gradient, front gradient are the various parameters to build an efficient building. In locations with varying climates, a building's shape is significant. Compact forms that reduce heat loss should be used in areas with cold climates. Compact shapes and courtyards, which reduce heat gain and contribute to creating cool, shaded living spaces, should be employed in hot, dry climate regions. Long, thin shapes with their long side facing the direction of the predominant wind provide for optimal cross-ventilation in hot, humid climates. Compact shapes, which are more flexible than forms utilized in areas with cold weather, should be employed in warm climates. (23).

VI.d. Building plan

The layout and design of buildings should be efficient in preserving energy. Buildings should, therefore, be designed to ensure that heat gain is minimal during warm seasons and maximal during cold ones. (24)

VI.e. Exterior Enclosure

The elements of a building envelope are the walls, ceiling, floors, windows, and doors that divide the interior from the exterior of a conditioned space and allow thermal energy to pass through them. (25)

VI.f. Orientation

Position the building so that its longer sides face north and south. This orientation takes advantage of solar gain in winter when the sun is low in the sky, allowing for natural heating of the building. In summer, [30] when the sun is higher, properly designed overhangs and shading devices can block excessive sunlight, reducing cooling loads (26).

VI.g. Materials

Materials should be used with high thermal mass in areas that receive significant sunlight, such as concrete, brick, or stone. These materials can absorb heat [1] during the day and release it slowly, reducing temperature fluctuations and heating requirements at night (27).

VI.h. Windows

Place larger windows on the south side to capture maximum sunlight during winter. Smaller windows [35] on the east and west sides can minimize unwanted heat gain during summer mornings and afternoons (11).

VI.i. Cross Ventilation

Ensure that the building layout promotes cross ventilation. This can be achieved by strategically placing windows and vents that allow air to flow through the building, reducing the need for mechanical ventilation (12).

VI.j. Smart Control

Smart control systems in buildings refer to advanced, integrated systems that use technology to monitor, control, and optimize various building functions. These systems leverage sensors, actuators, and microchips, alongside communication networks, to manage heating, ventilation, air conditioning (HVAC), lighting, security, and other building operations. The aim of smart control systems is to enhance energy efficiency, improve occupant comfort, ensure safety, and reduce operational costs (28).

VII. Implications and Recommendations

The strategic placement 1 and orientation of buildings, as guided by the principles outlined above, have broad implications for energy efficiency, environmental sustainability, and occupant well-being. Implementing these guidelines can lead to significant reductions in energy consumption, lower greenhouse gas emissions, and improved comfort for building occupants. Here are some of the key implications and recommendations involved in the construction and operation of energy-efficient buildings:

VII.a. Implications:

The following implications are below-

VII.a.1 Energy Savings:

Proper building orientation and design can lead to substantial energy savings by maximizing the use of natural lighting and heating, thereby reducing the reliance on artificial lighting and mechanical heating and cooling systems (29).

VII.a.2. Reduced Environmental Impact

By optimizing energy efficiency, buildings have a lower environmental impact through reduced greenhouse gas emissions. Sustainable design practices, such as the use of 31 green roofs and incorporation of vegetation, also contribute to biodiversity and help mitigate the urban heat island effect (30).

VII.a.3. Enhanced 2 Occupant Comfort and Health

Buildings designed with a focus on natural lighting, ventilation, and thermal comfort contribute to a healthier indoor environment. This 1 can lead to improved occupant satisfaction, reduced absenteeism, and increased productivity in workplace settings (31).

VII.a.4. Economic Benefits:

While some energy-efficient designs and technologies may have higher upfront costs, the long-term savings on energy bills and 32 the potential increase in property value can result in a favorable return on investment (32).

VII.b. Recommendations

The following implications are below-

VII.b.1. Holistic Design Approach

Adopt an integrated design approach that involves architects, engineers, environmental consultants, and other stakeholders from 1 the early stages of the project. This collaborative approach ensures that energy efficiency and sustainability are considered throughout the design and construction process (33).

VII.b.2. Local Climate Analysis

Conduct a detailed analysis of the local climate, including solar path, wind patterns, and temperature ranges, to inform the building's placement, orientation, and design. Tailoring the design 2 to the specific climate conditions can maximize its energy efficiency and comfort (34).

VII.b.3. Incorporate Renewable Energy

Complement the energy-efficient design with renewable energy systems, such as solar panels or wind turbines, to further reduce the building's carbon footprint and energy costs (35).

VII.b.4. Adopt Adaptive and Resilient Design

Design buildings to be adaptable to changing climate conditions and resilient to extreme weather events. This includes considerations for rising temperatures, increased precipitation, and other climate change impacts(36).

VII.b.5. Promote Awareness and Education

Educate clients, 2 occupants, and the general public about the benefits of energy-efficient buildings and sustainable design practices. Increased awareness can drive 11 demand for green buildings and encourage more widespread adoption of energy-efficient practices(37).

VII.b.6. Policy and Incentive Programs

India has implemented several policies and incentive programs to enhance energy efficiency in buildings, addressing both commercial and residential structures. 3 The Energy Conservation Building Code (ECBC), introduced by the Government of India in 2007 and revised in 2017, sets minimum energy standards for commercial buildings. It aims to make new commercial buildings more energy-efficient, with states having the flexibility to modify and notify the code to suit local needs. Currently, about 22 states are in various stages of mandating ECBC (38).

ECBC, the Bureau of Energy Efficiency (BEE) promotes 1 energy efficiency through the Framework for Energy Efficient Economic Development (FEEED). This includes initiatives like the 4 Partial

Risk Guarantee Fund for Energy Efficiency (PRGFEE), which provides commercial banks with partial risk coverage for loans extended for energy efficiency projects, and the Venture Capital Fund for Energy Efficiency (VCFEE) to provide equity capital for such projects, especially focusing on government buildings and municipalities.

The promotion of green building practices is also emphasized through ratings like LEED and, more importantly, GRIHA, [3] which was adopted as the national rating system by the Ministry of New and Renewable Energy (MNRE) in 2007. These systems [33] evaluate the environmental performance of buildings and have been incentivized in various states. For example, Haryana awards an additional floor area ratio (FAR) for GRIHA/IGBC/LEED-rated projects, encouraging the adoption of sustainable building practices (39).

VIII. Conclusion

In conclusion, the comprehensive analysis of optimizing energy efficiency in Indian buildings emphasizes the essential role of current norms and the profound impact of proposed guidelines on strategic placement and orientation. India's diverse climatic conditions necessitate a tailored [2] approach to building design, one that harmonizes with local environmental factors and cultural practices. Current norms provide a foundational framework for energy conservation, but the proposed guidelines elevate this framework by emphasizing the nuanced integration [34] of building orientation, form, and envelope with the natural environment. These guidelines advocate for meticulously considering sun path, wind patterns, [2] and thermal mass, aiming to leverage natural resources to the fullest extent while minimizing reliance on mechanical systems. [1] The emphasis on utilizing local materials and traditional architectural wisdom further reinforces the sustainability ethos, ensuring buildings are not only energy-efficient but also culturally and contextually relevant. By adopting these comprehensive strategies, [11] India can significantly advance its pursuit of sustainable development, mitigating the environmental impact of its rapidly urbanizing landscape. This approach not only contributes to reducing operational costs and carbon footprints but also enhances [2] occupant comfort and well-being, marking a stride toward creating resilient, energy-efficient, and sustainable urban habitats.

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