GREEN BUILDING AND ENERGY OPTIMIZATION CHALLENGES IN HIGH-RISE BUILDINGS

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Abstract

Green building has been a key trend in the building profession for the past twenty years. The professional's environmental awareness has put the topic of energy optimization at the top of the architectural profession and has helped to introduce and apply green building designs at the level of urban landscapes. High-rise buildings use a large share of the global energy consumption, which is 40% of the world's total energy use. Thus, the present study emphasizes on the review of challenges in green building and energy optimization in high-rise buildings. Only a systematic literature search was conducted, and peer-reviewed journals, conference papers, technical reports and policy documents were reviewed for their relevance to the issues of green building and energy optimization in high-rise buildings. Results of this study show that budget limitations, managerial and organizational policies, legal issues, technical and scientific infrastructure, and cultural and geographical aspects are all affecting the widespread use from energy optimization in current high-rise hotels and need to be considered in future studies. The study suggests integrating the principles into updated local building codes, enhancing professional education in green building design, and raising developer and public awareness.

Keywords: Energy-Optimization, Green-Building, High-Rise Building, Urban-Landscapes.

1.0 Introduction

Nowadays, energy crisis is among the most widespread discussions and numberless studies are being conducted throughout the world (Doraj et al., 2021). Energy is an important consideration in the socio-economic development of various countries in the modern times. The optimization and management of energy consumption, as one of the ways to ensure the energy security, is therefore a topic of significant interest that is considered by energy policymakers (Moreira et al., 2022). The building industry has a significant contribution towards the environment, as it is responsible for one third of the global greenhouse gas emissions and 40% of the global energy use (Bartlett & Howard, 2000). Indeed, buildings can consume up to 60% of the carbon emissions, and up to 90% of overall electricity use (Rahmani et al., 2023) in a high-rise high-density city like Hong Kong. As the residential building sector consumes approximately 30% of the total energy used worldwide, buildings account for approximately 36% of carbon dioxide (CO_2) emissions the main causative pollutant for global warming (Saleki & Bahramani,2018; Ascione, et al., 2021).

In the future this percentage will rise, due to the exponential increase in population and urbanisation. As a result, cities grow upwards, as there is not enough space in the city to house the growing population (Lima, et al., 2019). Also, the urban expansion will bring about changes in the energy use pattern, with the additional high energy demand associated with building construction industry being one of the main concerns for the governments, particularly in developing countries, where the availability of more modern buildings in the urban area has played a major role in meeting the ever-increasing demand for housing from the tremendous influx of people to the fast-growing cities. Moreover, the urban expansion will result in changes in energy use pattern, which is further exacerbated by varying climate conditions (Riahi et al., 2014; Shen et al., 2021) thereby, evoking the need for green building.

2.0 Literature Review

During the past decades, several studies are directed towards developing measures to promote building energy management, conservation and sustainability (Hong et al., 2019; Kadaei et al., 2023). Overall, five measures are identified that have an impact on reducing the ecological footprint of buildings: building insulation (Qian et al., 2019), equipment system (Capellán-Pérez et al., 2018), renewable resources (Ascione et al., 2021), conserving behaviours (Hong et al., 2019), and control and management systems. Designing and implementing these measures based on climate data and characteristic features of the building will further augment the building performance (Qian et al., 2019). Cao et al. (2017) analysed the impact of the current climate trend on building heating and cooling load, and found that the effect of the current trend is more evident in winter than in summer. The heating loads were measured to drop 1%–4%, and cooling loads to rise 0%–3% according to different locations (Cao et al., 2017). This outcome can provide information for the design criteria of the energy conserving measures Energy Conserving Measures. The optimization approach proposed in this paper gives insights about the critical parameters for the ultimate energy performance of high-rise buildings, and will be used as decision support tool for minimizing the high-rise building energy consumption, with a view towards a green built environment (Chime & Ibimilua, 2023).

Gan et al. (2019) proposed an energy performance-based optimization method to optimize the energy efficiency for the floor plan design for high rise residential buildings. To comprehensively investigate the ideal layout for optimizing the building's energy efficiency, an evolutionary genetic algorithm (GA)-based simulation-based optimization method was devised in their study.
Their proposed optimization approach was used as an example to create the layout design for a 40-story public housing building in Hong Kong. The results indicated that GA makes attempt at using maximum natural energy sources (e.g., sun, natural ventilation through wind) to minimize total energy consumed by 30 to 40% for lighting and air conditioning. The optimization strategy can be applied in high rise residential buildings to save a considerable amount of energy, and is also a factor towards a green built environment.

High-rise office building architectural and engineering features were investigated to assess their performance-driven impact in various climatic scenarios by Hong et al. 2019. Using the evaluation findings acquired by utilizing the benefits of the climate features, the most sustainable construction model was then created. The results revealed that the performance of a building can be different in different climates according to different factors such as plan ratio, core position and the atrium effect. A square building plan (no atrium, split core position) gave the best performance in the hot-summer-mild-winter (HSMW) climate zone, whereas a rectangular building plan (1:1.44 plan ratio, split core position, central atrium) gave the best performance in the warm-summer-cold-winter (WSCW) climate zone. Furthermore, a combination of passive methods was developed to allow to reach the sustainability and comfort targets in the WSCW zone, benefitting from the advantage of the building and climate. Structures in the HSMW zone require active strategies, however. There are different green building certification systems like LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), GRIHA, etc. which have been developed to offer frameworks and green development standards for the evaluation and accreditation of green structures.

The drive towards green building has been growing steadily over the last few years, as governments, organisations and individuals alike have come to understand how vital sustainable building methods are to the world. The movement aims to reduce the environmental impact, save resources, and build a more sustainable built environment by encouraging environmentally responsible buildings. Green building" is a term that refers to strategies, methods and materials that are more environmentally responsible than traditional building practices. Potbhare et al. (2009), estimate that residential and commercial building operations consume approximately 20, 30 and 40 percent of the primary energy in Canada, Mexico and the United States, respectively. A further 20-25% of waste arising from these buildings is dumped in landfill, whilst 5-12% of water used in a building is used for daily activities.

In recent years, numerous countries have developed new rating systems to enhance understanding of the sustainability of the buildings sector. Some of the prominent international rating tools are BREEAM (The Building Research Establishment's Environmental Assessment Method) in United Kingdom, HK-BEAM (The Hong Kong Building Environmental Assessment Method) in Hong Kong, LEED (The Leadership in Energy and Environmental Design) based on BREEAM in USA, Green Star rating system in Australia, and the Green Mark rating system in Singapore. Green buildings are certified in India by IGBC (Indian Green Building Council), TERI (The Energy and Resources Institute) and Eco-Housing. The assessment tools are designed to help assess how well the green building concepts are adopted in the building sector and how far the building industry has come towards sustainable development. The rating tools aim to continually learn and improve how green buildings perform and how they affect the environment, offer a benchmark to evaluate how a building impacts the environment, and establish objective benchmarks against which buildings can be evaluated in a trustworthy manner (Cole & Valdebenito, 2013). Research is still required on issues related to green building, and energy optimization in high rise buildings.

3.0 Materials and Methods

The literature search method applied to this study was to identify a wide range of academic and professional resources which cover green building and energy optimization problems in high-rise buildings. The search process began by identifying key terms such as "Energy Optimization", "Green Building", "built environment", "High-Rise Building", for the broad but focused scope of materials needed to encompass relevant research (Cooper et al., 2018). These keywords were searched alone and along with other keywords and Boolean operators (AND, OR) to narrow and make their results more precise. Main search databases included were Google Scholar, Scopus, Web of Science, Science Direct and specialized databases such as Nigerian Journal Online (AJOL) and the sources that were used included peer-reviewed journal articles, conference proceedings, theses, government reports and policy documents (Ioannidis et al., 2023). The search period was limited to the past 15 years, as a way to reflect current research trends and recent progress, though seminal papers prior to this were included where relevant (Danese et al., 2018). Besides electronic databases, a manual search was conducted in relevant repositories of various universities, institutional websites, and technical reports by various environmental agencies and urban planning bodies in Nigeria to collect grey literature or locally based studies that are not always well represented in international databases (Beck & Mitkiewicz, 2025).

4.0. Findings

4.1. Energy consumption in high-rise buildings While most current tall buildings display fourth generation properties in only meeting regulatory energy performance requirements, more buildings are being built and designed to have a much lower primary energy usage. The demand for more sustainable high-rise buildings has grown and become even more significant with increasing climate change, especially because the IPCC has predicted a possible global temperature increase of between 1.8°C and 4°C by the end of this century.

The first building to symbolically embody environmentally responsible design was the Commerzbank in Frankfurt, designed by Foster and Partners in 1997. The precedents that come before this example are the work of Ken Yeang's bioclimatic skyscrapers, the National Commercial Bank in Jeddah (1984) designed by SOM, and Frank Lloyd Wright's Price Tower in Oklahoma (1956). The Commerzbank combines a range of energy efficient measures in its design, such as the full height central atrium which maximises natural light and ventilation, large sky gardens to allow more daylight to reach the offices, a water based chilled ceiling cooling system and a Klima facade system of operable windows to allow for natural ventilation for much of the year.

The characteristics are typical of fifth generation skyscrapers, which typically have higher surface area-to-volume ratios of 0.10 to 0.22 m2/m3, as opposed to 0.09 m2/m3 for fourth generation buildings. This is realised by using shallow floor plates like in the GSW Headquarters in Berlin (1999), or by introducing larger atria in deeper floor plans like the Swiss Re Tower, London (2004) and the Deutsche Post Tower, Bonn (2002). The design strategies will enhance the daylighting and natural ventilation to limit the use of artificial light.

There are drawbacks, however, as larger surface area to volume ratios can lead to higher heating requirements during the winter months, but this can be partly overcome by smart lighting solutions using photo and motion sensors to help manage lighting in the interiors. For example, reduce up to 25% of electricity consumption for lighting in the Bank of America Tower, New York (2008). These developments indicate the new trend in the design of energy efficient tall buildings and that primary energy demand in future skyscrapers might be further reduced by returning to some of the features of first- and second-generation energy-efficient buildings, such as increased façade opacity and thermal mass.

Figure 1: Green building envelope design showing open sky gardens (Oldfield et al., 2009).

4.2 Characteristics of Green Building

Green building can be described as an idea that came into existence, as a solution to, environmental and socio-economic challenges. Though sustainable construction has been used for years, the modern green building started gaining attention towards the latter part of the twentieth (20th) century. Since then, research work, technology and heightened global awareness about environmental sustainability, have contributed to further development of the idea. Green building is currently one of the solutions to combat climate change.

Green building, which may be defined as sustainable building, is a type of construction that aims at reducing negative effects on the environment while increasing occupants' wellbeing and comfort. Green building includes all environmentally friendly practices during planning, construction, operation and maintenance of buildings. Green buildings are able to reduce energy consumption, emissions and costs thanks to implementation of energy-saving technologies including LEDs, efficient windows and insulation, efficient HVAC.

The key features of green buildings are:

a) They are energy efficient, because, green buildings are designed in a way that allows them to use less energy, through efficient lighting, insulation, windows, and HVAC systems.
b) Green buildings use sustainable materials, that have a recycled content, and are rapidly renewable, as well as, low impact material extraction process.
c) The majority of green buildings make use of renewable energy sources, like, solar panels, wind turbines or geothermal system that will make them less dependent on non-renewable energy sources, and emit less greenhouse gases.
d) Healthy indoor environments, can be provided with the help of low emission materials, adequate ventilation, daylighting and outdoor views.
e) Green buildings encourage waste reduction and recycling through the use of recyclable and biodegradable materials.

4.3 Environmental Impacts of Green Buildings

The benefits of green buildings towards the environment include reduction in greenhouse gas emissions by operating the building efficiently and utilizing renewable energy systems. They also help conserve water, by decreasing consumption, promoting good water management, and limiting water pollution. In addition, sustainable building material and recycling, generates less environmental degradation and maintains ecosystems.

4.4 Social Impacts

Eco life improves IEQ and thus occupant health, comfort and well-being in green buildings. Incorporates sustainable public spaces that will enable social interaction and community engagement to encourage environmental responsibility. Besides, the green building projects, help create jobs in the local area and promote the development of related green construction businesses, which would help to build a sustainable future, and a more inclusive society.

4.5 Economic Benefits

Individuals, organizations, and communities can reap significant economic rewards from green buildings. While sustainable attributes, might have a higher upfront cost, energy efficient designs, renewable energy systems, and water-saving practices, lower operating and utility expenses over the longer haul. These buildings can benefit in terms of higher property values, and returns on rent, thereby adding to the competitiveness in the market. Better indoor environmental quality also leads to better health, comfort, and productivity for the occupants. In addition, green buildings promote community development through well-designed public spaces, create jobs and promote the growth of the green construction industry.

4.6 Barriers to Green Buildings

There are a number of barriers to the large-scale roll-out of green buildings, despite its environmental, social and economic benefits.

a) High initial investment: Sustainable technologies and building materials for eco-friendly construction can have a higher cost impact initially, which makes some developers and investors hesitant to invest.

b) Poor awareness and expertise: Low awareness of how green buildings benefit in the long term, low government incentives and lack of skilled professionals in sustainable construction, especially in developing regions, limit the use of green buildings.

c) The negative perceptions: Some stakeholders believe that green buildings are not aesthetically pleasing or functional, and therefore, the acceptance of the sustainable design is lowered.

d) Policy and regulatory barriers: Limited political will, poor building codes and the lack of a comprehensive green building code are significant barriers to the wider adoption of green buildings.

5.0. Discussion

The Living Building Challenge (LBC) is considered to be one of the strictest sustainable building performance-based certification programs. It sets a standard for buildings to operate as efficiently and symbiotically as natural ecosystems. The LBC is not only about the intentions and design of a building, but also about the measured performance of its operation, which makes it one of the highest standards in the built environment when it comes to sustainability. Certified projects must show net zero performance over a minimum of 12 consecutive months of use in energy, water and waste. The framework is structured around seven performance categories, each of which is broken down into 20 imperatives dealing with various elements of sustainable development.

Renovation of existing buildings is an important sustainability measure. Retrofitting is about making existing equipment more energy efficient by using, for example, high efficiency HVAC systems, variable speed drives, electronic ballasts and changing incandescent light bulbs to compact fluorescent or LED bulbs.

Low-income sustainable housing: Energy saving features are more commonly added to affordable housing projects, even when budgets are tight. These can be simple energy-efficient electrical installations, insulated ceilings, internal and external plastering, moisture barriers under floors, and the basic installation of energy-efficient buildings.
Water conservation: Buildings use a significant proportion of water and water fixtures that are designed to be ultra-low flow, rain water catchment, retrofitting, wastewater re-use, and the incorporation of other innovative water saving technologies are all important.

The emergence of zero carbon buildings has been driven by the increasing climate change awareness and the need for carbon neutral buildings. The aim of these buildings is to be energy neutral, with minimal consumption of energy and high output of energy generated through renewable sources of heating, cooling, ventilation, lighting and hot water systems.
Green roofs are roofs that are covered with soil and plant species and offer several environmental benefits. They enhance thermal insulation, decrease heating and cooling requirements, mitigate stormwater runoff, filter air pollutants, increase urban biodiversity, and mitigate urban heat islands.
Vegetated walls installed on the interior or exterior of the building can be created with a hydroponic system or soil-based system. They not only add beauty but also help improve air quality by biofiltration, keep buildings cooler in the summer and warmer in the winter, and create a healthier outdoor and indoor environment.

Biomimicry is the use of solutions found in nature, in building design. One such example is the Eastgate Centre in Harare, Zimbabwe, which has a passive ventilation system that is designed to be similar to the ventilation system of termite mounds to help maintain a constant temperature within the building, thus minimizing the need for mechanical air conditioning.
Closed loop material cycles, with the elimination of waste and the reusability of building materials as biological or technical nutrients, are the emphasis of the design philosophy of

'cradle to cradle'. These buildings are designed to rehabilitate ecosystems while reducing environmental footprint at the building's life cycle.

Glass Fiber Reinforced Gypsum (GFRG) panel system: GFRG panels are made with recycled gypsum waste for durable and lightweight structures. The system can provide the buildings a service life of more than several decades, saves material usage, and decreases construction time, and can even replace the conventional beams and columns.
Monolithic concrete construction with aluminium formwork: This method is for the casting of walls, slabs, columns, beams and stairs, all in one. Allows for quick construction, decreases the usage of steel, enhances structural quality, and creates minimal construction waste since the formwork is 100% recyclable.

Low emittance windows and smart glass – Low emittance windows employ a metallic oxide coating that helps to reduce unwanted solar heat gain but also provides building heat retention during colder weather, thus reducing HVAC energy use. Smart glass also enhances the energy performance by automatically turning transparent in the presence of sunlight to optimise the use of daylight and indoor thermal comfort.

6.0. Conclusion

As a tool for green architecture, green buildings are gaining in popularity, and are now encouraged by governments, developers and property owners around the globe. While their use has grown significantly in recent years, the knowledge of the principles and benefits of green buildings is still fairly low. As a result, there is a need to increase awareness to promote the use of these as an effective means of sustainable environmental management and development.

The green building movement, is an attempt to minimize environmental impacts of the built environment, by promoting sustainable building design, and practices from the planning, design, construction, operation and maintenance of buildings. It aims to conserve resources, enhance energy efficiency, lower greenhouse gas emissions, and create healthier indoor environments, for occupants.

There are certain principles that are associated with green building practices. Advanced building technologies and passive design strategies that minimize energy inputs for heating, cooling, lighting and electrical appliances contribute to energy efficiency. The concept of resource conservation emphasizes the reduction of materials consumed, reuse and recycling, and the reduction of construction and demolition waste. Water conservation is ensured by using water efficient fixtures, rainwater harvesting, wastewater re-use and other innovative water management systems. Good indoor environmental quality is provided through proper air exchange, maximising natural light and the use of low emission building materials to benefit the health and comfort of the occupants. Sustainable site selection is minimizing ecological disturbance – protecting biodiversity and reducing impacts to surrounding ecosystems. Meanwhile, life cycle assessment, measures the environmental impact of buildings from materials, to construction, use, maintenance, and deconstruction; and allows for more sustainable building decisions, throughout the entire building life cycle. For the promotion of sustainable construction, some internationally accepted certification systems, have been developed, such as, Leadership in Energy and Environmental Design (LEED), the Building Research Establishment Environmental Assessment Method (BREEAM) and Green Rating, for Integrated Habitat Assessment

(GRIHA). These frameworks, offer clear and quantifiable ways to measure the environmental performance, of buildings.

The world, as a whole, is becoming more and more green building friendly, and this is due to the well-known environmental, social and economic advantages, of green buildings. Green building is a feasible route to sustainable development, by balancing, the environmental benefits, with the economic and social considerations. Research shows that together, energy efficiency, resource conservation, water management, indoor environmental quality, sustainable site selection, and life cycle assessment, improve energy optimization, especially in high-rise buildings.

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