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Study on Low-Energy Building Design in Tropical Climates

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ABSTRACT:

This study investigates design strategies for low-energy buildings in tropical climates, focusing on wall insulation, roofing, floor slabs, windows, and energy-efficient building systems. By comparing traditional construction materials with modern alternatives, the research identifies methods to reduce cooling energy consumption, particularly in tropical regions such as Dhaka, Bangladesh. Leveraging simulation tools and established construction standards, the study evaluates the effectiveness of various architectural interventions, emphasizing cost-effective and locally available solutions.

Keywords: Low-energy building, tropical climate, external wall, internal wall, insulation, floor slabs, roof design, window design, energy simulation.

Introduction

The global demand for energy-efficient buildings has surged, driven by the depletion of natural resources and the adverse effects of climate change (International Energy Agency, 2021). In tropical climates, where temperatures and humidity levels are high, building design significantly influences indoor thermal comfort and energy consumption. Conventional construction methods, particularly the use of solid masonry walls, often lead to increased energy use due to poor thermal insulation properties (Prianto & Depecker, 2002). As a result, buildings in these regions rely heavily on mechanical cooling systems, which contribute to higher energy consumption and carbon emissions.

To address this issue, researchers and practitioners are exploring alternative construction materials and designs to improve energy efficiency while maintaining indoor comfort. Composite walls with air cavities, energy-efficient windows, and green roofing are emerging as viable strategies to reduce heat gain and cooling loads in tropical buildings (Wong & Li, 2007) (Cheung, Fuller, & Luther, 2005). Composite walls, in particular, have shown potential in decreasing the U-value, which measures heat transfer through building elements, resulting in improved insulation and reduced cooling requirements.

This study aims to investigate the impact of using composite wall structures, energy-efficient windows, and green roofing on creating low-energy buildings suitable for tropical climates. The findings are intended to guide architects, engineers, and policymakers in developing sustainable building practices in regions characterized by high temperatures and humidity.

Methodology

This study adopts a comparative analysis to evaluate traditional construction techniques against proposed low-energy building solutions. Building Information Modeling (BIM) software, such as ArchiCAD and Tekla, is utilized to develop two virtual models: one reflecting conventional building design and the other incorporating low-energy principles. The use of BIM allows for an accurate representation of building geometry, material properties, and energy performance, providing a robust framework for simulation (Volk, Stengel, & Schultmann, 2014).

Energy simulation tools, including Energy Plus and Design Builder, are employed to assess the thermal performance of key building components such as walls, windows, roofs, and slabs. These tools enable the integration of real-world data, including local climate conditions, occupancy patterns, and target energy consumption levels, to predict the building's energy performance accurately (Crawley, Hand, Kummert, & Griffith, 2008). Input data for the simulations encompass climate variables (temperature, humidity, solar radiation), material thermal properties (conductivity, density, specific heat), and design features like shading devices and natural ventilation strategies.

The effectiveness of different design strategies is evaluated based on several criteria, including U-values (thermal transmittance), energy consumption (kWh/m²), CO_2 emissions, and cost-effectiveness. The analysis involves a detailed comparison of the modeled scenarios, highlighting potential energy savings and environmental benefits. By focusing on quantifiable performance metrics, this methodology provides a comprehensive understanding of how alternative construction materials and designs can improve energy efficiency in tropical climates.

Results

External Walls

Conventional external walls in tropical buildings are usually constructed using solid masonry, which has a high U-value, leading to significant heat transfer and increased energy consumption for cooling (Meir, Pearlmutter, & Etzion, 1995). This study explores composite wall designs incorporating an air gap as an alternative. The proposed composite wall consists of layers of plaster, brick, an air cavity, and additional plaster. The findings indicate that a 250mm solid brick wall has a U-value of 1.76 W/m²K, whereas a 10-inch composite wall with air gaps significantly reduces this value to 0.22 W/m²K. Studies show that incorporating a 50mm air cavity can reduce solar heat gain by up to 7-10%, which enhances indoor thermal comfort and energy efficiency (Al-Sanea, Zedan, & Al-Ajlan, 2012).

Internal Walls

Internal walls mainly serve structural, privacy, and acoustic functions. In this study, a 125mm solid brick wall is considered sufficient for internal partitions, as internal walls do not directly contribute to solar heat gain. While reducing wall thickness could save space, it may compromise sound insulation and privacy, which aligns with findings that adequate wall mass is crucial for soundproofing (Yang & Hodgson, 2007). Therefore, the study suggests retaining traditional solid brick wall construction for interior partitions.

Insulation

Insulation is not commonly used in residential buildings in tropical regions like Dhaka due to cost and availability issues. This study suggests that air cavities in composite walls offer sufficient thermal insulation to reduce solar heat gain, mitigating the need for traditional insulation materials. Furthermore, the use of double-glazed windows and green roofing can further reduce heat transfer, aligning with previous research indicating their effectiveness in improving thermal performance in tropical buildings (Hosseini, Noorizadeh, & Zahmatkesh, 2018).

Floor Slabs

Typical floor slabs in the region are 9 inches thick, with a plastered ceiling and tiled flooring, providing both sound insulation and thermal mass, which helps stabilize indoor temperatures. The study finds that the existing slab design meets the requirements for low-energy buildings, as thicker slabs contribute to thermal mass that moderates temperature fluctuations (Kosny & Christian, 2001). Therefore, no modifications to slab design are necessary for improving energy efficiency in tropical climates.

Roof Design

Incorporating a green roof is a key strategy for reducing the solar radiation impact on buildings in tropical climates (Jaffal, Ouldboukhitine, & Belarbi, 2012). The study proposes adding layers for pavement, vegetation, and recreational areas to the existing 10-inch roof slab. Additionally, installing solar panels on selected roof sections provides an opportunity to generate renewable energy, reducing reliance on conventional power sources and contributing to sustainable building practices.

Windows

Traditional sliding aluminum windows allow for only about 50% ventilation, limiting natural airflow and increasing reliance on mechanical cooling. This study recommends modern aluminum sections with double-glazed swing windows, which can fully open to maximize natural ventilation, reducing heat transmission. Research indicates that floor-to-lintel height windows can significantly enhance natural lighting and air circulation, thus contributing to reduced energy consumption for cooling (Givoni, 1994).

Discussion

The findings of this study underscore the importance of adopting low-energy building solutions specifically tailored to tropical climates. Composite walls with air cavities significantly reduce heat transfer when compared to traditional solid masonry walls, aligning with previous research that highlights the effectiveness of air gaps in enhancing thermal performance (Al-Sanea, Zedan, & Al-Ajlan, 2012). Furthermore, modern window designs, such as double-glazed swing windows, greatly improve natural ventilation and light penetration, thereby reducing the reliance on mechanical cooling and artificial lighting (Givoni, 1994).

Incorporating green roofing systems and renewable energy solutions, such as solar panels, further optimizes building energy performance. Green roofs not only mitigate solar heat gain but also enhance the building’s insulation capacity and improve urban microclimates (Jaffal et al., 2012). Solar panels contribute to reducing the building's carbon footprint and energy consumption, which is crucial for sustainable construction practices in tropical regions.

Cost considerations remain a significant factor in adopting these low-energy solutions. While advanced glazing and composite walls might have higher initial costs, their long-term benefits, including reduced energy consumption and lower greenhouse gas emissions, provide a compelling case for their implementation (Hosseini, Noorizadeh, & Zahmatkesh, 2018). Utilizing locally sourced materials and construction techniques can further reduce costs, making these energy-efficient strategies more accessible for residential developments in tropical areas (Meir, Pearlmutter, & Etzion, 1995). Thus, the combination of initial investment and long-term savings supports the feasibility and sustainability of these design strategies.

Conclusion

This study illustrates that integrating composite walls, green roofing, energy-efficient windows, and suitable material selection can significantly decrease energy consumption in tropical buildings. While traditional construction methods meet structural requirements, modifications such as incorporating air cavities in walls and employing advanced window designs can enhance thermal performance and occupant comfort. These findings are in line with the growing body of literature advocating for energy-efficient building practices in warm climates (Al-Sanea, Zedan, & Al-Ajlan, 2012) (Givoni, 1994).

Future research could delve deeper into the integration of renewable energy systems and adaptive architectural elements, such as dynamic facades and shading devices, to further improve building sustainability and resilience in tropical regions. Emphasizing locally available materials and culturally sensitive design strategies can promote widespread adoption of these practices, ultimately contributing to more sustainable urban environments.

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