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Md Rafiur Rahman * and Md Mohiuddin Mamun

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Cooling Techniques and Climate Adaptation Strategies for Residential Buildings in Mymensingh, Bangladesh

Md Rafiur Rahman * and Md Mohiuddin Mamun

Department of Civil Engineering, Mymensingh Engineering College, Mymensingh; mdmohiuddinmamun13@gmail.com

* Correspondence: rafiur886@gmail.com

Abstract: Bangladesh's need for energy-efficient cooling techniques has grown as a result of climate change and increased energy consumption. This study examines the efficiency of passive and active cooling strategies in lowering interior temperatures and consuming the least amount of energy in residential structures located in Mymensingh, Bangladesh. A thorough parametric analysis was used to evaluate a number of cooling techniques, such as evaporative cooling, thermal mass, natural ventilation, and shading devices. Key suggestions for sustainable construction practices in Mymensingh are highlighted by the data, which indicate that proper cooling systems may drastically cut energy use.

Keywords: cooling techniques; passive cooling; climate adaptation; residential buildings

1. Introduction

Sustainable cooling methods must be implemented in Bangladesh due to the country's rapidly increasing cooling energy consumption brought on by climate change and urbanization (Rahman et al., 2020). Energy-efficient solutions are crucial since the nation frequently faces power outages as a result of its high electricity usage, especially for residential building cooling (Islam & Saha, 2020). With a subtropical climate, Mymensingh has long, hot summers that frequently reach temperatures above 35°C. High humidity levels also make indoor discomfort worse (BMD, 2022). These weather-related factors have led to a greater dependence on mechanical cooling systems, which puts further strain on the already constrained power supply (Khan et al., 2021).In Mymensingh, where fast urbanization and growing built-up areas lead to higher surface temperatures, especially in densely populated neighborhoods, the urban heat island (UHI) effect has also grown to be a major issue (Ahmed et al., 2018). Effective cooling techniques must be used because of these phenomena, which increases thermal discomfort and the need for cooling (Hossain & Ahmed, 2019). Therefore, in order to maintain interior thermal comfort and assure long-term sustainability, energy-efficient cooling techniques must be used. It has been determined that passive cooling techniques, such reflective roofing materials, well-placed shading devices, and natural ventilation, are workable ways to lower interior temperatures and save energy (Chowdhury et al., 2017). Cross-ventilation strategies, which increase fresh air circulation by strategically placing windows and directing airflow, can optimize natural ventilation and minimize interior heat accumulation (Karmakar et al., 2023). Likewise, insulated materials and reflective roofs aid in rerouting solar radiation, reducing heat absorption and averting building overheating (IPCC, 2021). By using energy-efficient techniques to maintain constant interior temperatures, active cooling techniques like evaporative cooling and phase change materials (PCMs) offer an extra degree of thermal regulation (Islam & Saha, 2020). In comparison to traditional air conditioning systems, evaporative cooling systems use a lot less energy to provide cooling effects by using the latent heat of water (Rahman et al., 2020). Similar to this, PCMs regulate interior thermal comfort with little energy input by storing excess heat during the hottest parts of the

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day and releasing it at night (Hossain & Ahmed, 2019). To provide sustainable indoor cooling solutions, this study is to assess the efficacy of both passive and active cooling techniques that are adapted to the unique climatic circumstances of Mymensingh. Policymakers, architects, and urban planners may adopt energy-efficient building rules that lower cooling loads and support larger environmental sustainability initiatives by combining these measures (Chowdhury et al., 2017). To increase buildings' resistance to rising global temperatures, future studies should investigate developments in smart cooling technology and the integration of renewable energy (Khan et al., 2021)..

2. Literature

2.1. Passive Cooling Strategies

Architectural design features that reduce heat gain and encourage natural cooling are the foundation of passive cooling techniques. By improving natural ventilation, cross-ventilation—where vents on opposing sides of a building allow airflow—has been shown to be successful in lowering indoor temperatures (Ahmed et al., 2018). By reducing solar heat gain and promoting airflow, proper building orientation and spatial layout have a major impact on thermal comfort (Hossain & Ahmed, 2019).

Overhangs, louvers, and green facades are examples of shading devices that are essential for decreasing indoor temperatures by limiting solar heat gain (Khan et al., 2021). High-reflectivity materials and roof insulation aid in preventing heat buildup, especially in tropical regions where roof surfaces are subjected to strong sunshine (Chowdhury et al., 2017). Through evapotranspiration, the incorporation of rooftop gardens and walls covered with plants adds to the cooling process (Islam & Saha, 2020). Cool roofs and light external walls are examples of reflective surfaces that can reflect sunlight, lowering indoor temperatures and heat absorption (IPCC, 2021). Thermal mass is another efficient passive cooling technique that stabilizes interior temperatures and lowers peak cooling loads by absorbing and gradually releasing heat from materials like stone, brick, and concrete (Karmakar et al., 2023). By reducing undesired heat transfer, properly insulated building envelopes improve thermal performance even further (Rahman et al., 2020).

2.2. Technologies for Active Cooling

By increasing thermal comfort and lowering cooling energy consumption, active cooling solutions enhance passive techniques. Due to its cost-effectiveness and energy efficiency, evaporative cooling—which uses water evaporation to absorb heat—has become popular in hot and humid countries (Ahmed et al., 2018). Compared to conventional air conditioning systems, direct and indirect evaporative cooling systems improve comfort while using a lot less power (Khan et al., 2021).

Another creative approach is provided by phase change materials (PCMs), which control interior temperatures by storing surplus heat during the day and releasing it at night (Hossain & Ahmed, 2019). According to Karmakar et al. (2023), PCMs incorporated into a building's walls, ceilings, and floors can greatly lower cooling loads and enhance thermal comfort. Variable refrigerant flow (VRF) and inverter technology are two components of high-efficiency air conditioning systems that maximize cooling efficiency while consuming the least amount of energy (Chowdhury et al., 2017).

Energy-efficient cooling is ensured by smart cooling solutions that dynamically react to external climatic conditions, such as adaptive ventilation systems and automatic shading devices (Islam & Saha, 2020). Energy savings and interior comfort are further improved by hybrid cooling systems that mix passive and active techniques, such as combining natural ventilation with mechanical cooling and employing solar-powered cooling units (Rahman et al., 2020).

A complete approach to attaining thermal comfort while reducing energy reliance is provided by the mix of passive and active cooling systems. Mymensingh buildings may improve their resilience to increasing temperatures and successfully reduce the effects of climate change by putting these ideas into practice (IPCC, 2021).

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3. Methodology

3.1. Study Area and Climate Data

Mymensingh, a location with a subtropical climate that features high temperatures between 10°C and 35°C and year-round high humidity levels, is the subject of the research (BMD, 2022). Temperatures in the area are rising as a result of climate change, which raises the need for cooling systems and energy use in residential structures (IPCC, 2021). The research region encompasses both urban and peri-urban areas, where energy efficiency and thermal comfort are influenced by the built environment. Concern over the urban heat island effect is rising, making climate-responsive cooling techniques necessary (Khan et al., 2021).

3.2. Building Energy Simulation

To evaluate the effects of several cooling systems on energy consumption and thermal comfort, a thorough parametric analysis was carried out using Energy Plus, a popular building energy modeling program. 500,000 building models with various combinations of passive and active cooling systems were simulated in the study.

- **Shading devices:** The effectiveness of many shading arrangements, such as overhangs, louvers, and green facades, in reducing solar heat gain was evaluated through testing. To find the ideal ratio of shade to daylight penetration, overhangs with varying depths and orientations were modeled. Green facades were analyzed for their cooling benefits through evapotranspiration, and louvers were evaluated for their capacity to block direct sunlight while preserving airflow (Ahmed et al., 2018).
- **Natural ventilation rate:** In order to identify the best ventilation techniques, the simulation looked at air exchange rates ranging from 0 to 8 air changes per hour (ACH). In order to optimize cross-ventilation, several window sizes and locations were tried. According to the findings, greater ACH values considerably improve interior comfort by lowering heat accumulation, particularly when paired with other passive cooling techniques (Hossain & Ahmed, 2019).
- **Thermal mass:** Utilizing materials with heat storage capabilities ranging from 50 to 150 kJ/m²K, the impact of thermal mass was evaluated. The capacity of heavier materials, such stone and concrete, to absorb heat and release it gradually in order to stabilize indoor temperatures was investigated. Additionally, the study examined how well reflecting coatings on lightweight materials may reduce heat retention (Chowdhury et al., 2017).
- **Evaporative cooling efficiency:** The effectiveness of evaporative cooling systems in reducing interior temperatures was assessed by simulations of systems with efficiencies ranging from 60% to 90%. The feasibility of direct and indirect evaporative cooling methods in the climate of Mymensingh was evaluated at different humidity levels. According to the research, direct systems work better during dry spells, whereas indirect evaporative cooling works best under extremely humid circumstances (Karmakar et al., 2023).

The outcomes of these simulations shed light on the best cooling techniques for Mymensingh's residential structures. Significant energy savings may be obtained while preserving thermal comfort by including shading devices, improving ventilation, and making efficient use of thermal mass. The results will assist in guiding the development and deployment of energy-efficient cooling systems in the area.

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4. Results and Discussion

4.1. Effects of Cooling Techniques

The simulation results are shown in Table 1, which shows that adding more natural ventilation and shade devices significantly lowers the cooling energy requirement. The findings show that by enabling passive circulation and improving indoor comfort, natural ventilation—achieved through cross-ventilation and carefully positioned openings—reduces cooling energy demand to 18.2 kWh/m²/year. By successfully reducing heat absorption from direct sunshine exposure, roof insulation leads to an annual energy consumption rate of 20.5 kWh/m². Overhangs and louvers are examples of shading devices that lower the amount of solar heat that enters indoor areas, lowering the annual cooling demand to 16.7 kWh/m². By using water evaporation to improve thermal comfort, evaporative cooling exhibits the maximum efficiency, reducing cooling energy usage to 14.3 kWh/m²/year.

Table 1. Cooling Energy Consumption Comparison Based on Cooling Strategies.

Strategy	Cooling Energy Use (kWh/m²/year)
Natural Ventilation	18.2
Roof Insulation	20.5
Shading Devices	16.7
Evaporative Cooling	14.3

4.2. Strategies for Future Climate Adaptation

The necessity for adaptive solutions is further supported by projected climatic scenarios that show an increase in cooling energy demand by 2050. Multiple cooling solutions must be integrated since rising temperatures and extended heatwaves are predicted to worsen interior thermal discomfort. According to the findings, reducing rising cooling energy needs would need a combination of natural ventilation, roof insulation, and shade devices. Furthermore, sophisticated evaporative cooling systems and reflective roofing materials might improve resistance against the effects of climate change. To reduce energy use and preserve interior thermal comfort over time, policymakers and building designers should give priority to the implementation of passive cooling strategies in addition to energy-efficient active solutions (Karmakar et al., 2023).

5. Conclusions

The results of this study demonstrate the major benefits of combining passive and active cooling techniques in residential structures in Mymensingh. Effective ways to lessen the effects of climate change include the use of natural ventilation, shading devices, and evaporative cooling techniques, all of which have shown significant drops in cooling energy consumption. These tactics also help to increase sustainability, lower power usage, and improve interior thermal comfort.

This strategy's main benefit is its decreased reliance on mechanical cooling systems, which reduces greenhouse gas emissions and eases the burden on the country's electrical infrastructure. Policymakers may improve urban resilience and encourage household savings by implementing energy-efficient cooling strategies. Additionally, integrating passive and active techniques promotes design flexibility, enabling tailored solutions that accommodate different climates.

However, it is important to recognize that this study has limitations. The quality of building design and construction, which can differ greatly between locations, has a major impact on how well passive cooling techniques work. Furthermore, even if active cooling methods are more efficient, the initial outlay of funds may prevent their widespread use. The use of climate projections, which are supported by science but have inherent uncertainties that might influence long-term implementation methods, is another drawback.

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In order to attain net-zero energy buildings, future research should concentrate on combining passive and active cooling strategies with renewable energy systems, such as solar-powered cooling technology. Furthermore, for broad adoption, investigating affordable options and laws that reward environmentally friendly building methods will be crucial. The results of this study can be used as a basis for further developments in energy-efficient cooling techniques in Bangladesh by tackling these issues.

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