IJSRA

International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(Research Article)

Thermal performance of green balconies of residential buildings: A Case Study in Wari, Dhaka

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International Journal of Science and Research Archive, 2024, 13(02), 2981-2989

Publication history: Received on 08 November 2024; revised on 16 December 2024; accepted on 18 December 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.13.2.2509

Abstract

This study investigates the impact of green balconies on the thermal performance and indoor environmental quality of residential buildings in Dhaka, Bangladesh, which experiences a warm-humid climate year-round. Green balconies, incorporating vertical landscaping or potted plants are evaluated for their potential to reduce indoor temperatures, enhance thermal comfort, and contribute to energy savings. Field measurements were conducted in a high-rise residential building, with data collected on indoor temperatures, relative humidity, and solar radiation for both green and non-green balconies. Results show that green balconies can reduce indoor air temperatures by up to 6.5 °C, with an average reduction of 3.0°C in room temperature, compared to non-green balconies. The presence of greenery effectively mitigates heat gain, particularly through evapotranspiration and shading, improving thermal comfort and reducing reliance on mechanical cooling systems. Additionally, green balconies contribute to energy efficiency, with potential energy savings of up to 20%. The study further emphasizes the importance of optimal design, including the use of densely arranged potted plants, to maximize the cooling effect. This research highlights the effectiveness of green balconies as a passive cooling strategy for tropical climates, offering sustainable solutions for residential buildings by improving both environmental and occupant well-being.

Keywords: Green Balcony; Indoor; Temperature; Residential building; Thermal performance

1. Introduction

Balconies in residential buildings serve as a vital buffer space between indoor and outdoor environments, enhancing comfort, saving energy, and creating additional living space (Ribeiro et al., 2020). Studies also show that well-designed balcony spaces improve residents' satisfaction and contribute to sustainable living (Wing Chau et al., 2004; Kennedy et al., 2015).Integrating green balconies into residential designs enhances indoor comfort, supports sustainability, and improves residents' well-being, making them a valuable feature in residences. Green infrastructure, such as green balconies, plays a significant role in mitigating the urban heat island (UHI) effect and improving indoor comfort. By incorporating greenery on building facades, particularly on balconies, the surrounding temperature can be reduced, creating cooler and more comfortable urban environments (Santamouris et al, 2014). Vertical greenery systems, including green balconies, lower indoor temperatures and boost energy efficiency by cooling the air through evapotranspiration, which minimizes the reliance on air conditioning (Wong et al., 2010). In tropical climates, green facades and balconies are particularly beneficial for enhancing urban microclimates, reducing surrounding temperatures, and cutting down on the need for mechanical cooling, thereby improving indoor thermal comfort and saving energy (Hwang et al., 2015).

Moreover, green balconies help regulate humidity levels and mitigate the UHI effect, contributing to improved thermal comfort in tropical climates like Dhaka (Lee & Kwon, 2022; Li et al., 2023). Green walls and balconies are highly effective in densely built urban canyons, where they help lower temperatures and enhance indoor comfort (Ruddy et al., 2017).

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These vertical greening systems help regulate airflow and temperature, optimizing the building's envelope performance and improving energy efficiency (Wong et al., 2010). Additionally, green balconies improve both air quality and lighting conditions, offering a sustainable solution for enhancing occupant well-being in urban environments (Zhang et al., 2020).

The energy consumption of buildings can be significantly influenced by the presence of green balconies, which help improve indoor environmental quality and reduce the need for mechanical cooling. Recent studies (Santamouris et al, 2021) highlight that green balconies contribute to lower indoor temperatures by mitigating the UHI effect, reducing reliance on air conditioning, and leading to energy savings of up to 30%. Furthermore, vertical greenery systems like green balconies help reduce cooling loads by providing natural shade, which can reduce electricity consumption by approximately 20% (Wong et al., 2020). Studies have shown that integrating green elements on building facades can improve the energy efficiency of buildings by lowering peak energy demands by as much as 15%, particularly in tropical climates like Dhaka, where cooling needs are high (Hwang et al., 2015). These green infrastructures contribute to thermal comfort, reducing energy use in both cooling and heating systems, with potential savings of up to 25% in energy costs (Li et al., 2023). Thus, the presence of green balconies offers a sustainable approach to reducing energy consumption in buildings while improving the indoor environment.

Optimizing the design of the building envelope helps create a more comfortable and energy-efficient indoor environment for residents (Yu et al., 2008; Mitterer et al., 2012; Ascione et al., 2016). Well-designed balconies play a crucial role in improving energy efficiency and promoting sustainability. Determining the indoor temperature (Tsp) is crucial in residential buildings, especially when heating demand is high, as it directly affects energy consumption (Ghahramani et al., 2018). Lowering the heating setpoint (Tsp) is one of the main ways to save energy (Heidarinejad et al., 2014). Many studies have focused on reducing energy consumption for indoor air conditioning while ensuring building comfort (Mao et al., 2018; Mao et al., 2019; Yang et al., 2019; Kim et al., 2018; Jin et al., 2022). Optimal working conditions for air conditioning comfort and energy consumption focus on the impact of nighttime thermal loads on building envelopes (Mao et al., 2017). Huang et al. (2024) found that energy consumption could be reduced by controlling the temperature effectively.

Different buildings in various climates require different heating temperature setpoints (Tsp). For example, the ASHRAE 55-2013 standard recommends an indoor Tsp of 20-24°C in winter, while China’s GB50736 standard suggests 18-22°C for long-term stay areas. Studies have also shown that indoor Tsp significantly affects energy use, with Gianniou et al. (2024) finding an average Tsp of 19.1°C in Aarhus, Denmark, and Lin et al. (2024) showing the importance of indoor Tsp in tropical climates. Additionally, research by Gorazd et al. (2024) and Lin et al. (2024) in Hong Kong found common Tsp ranges of 20-22°C.

This study explores passive cooling strategies for residential buildings in Dhaka, focusing on the cooling effect of green roofs in high-rise apartments. Since cities in this region experience hot and humid weather year-round, developing passive cooling solutions is crucial to reduce energy demand from increasing air conditioning use. However, there is uncertainty about the effectiveness of green balconies in cooling and maintaining comfortable temperatures throughout the day and night in Dhaka's warm humid sub-tropical climate. The findings offer insights for optimizing residential thermal comfort and energy efficiency through tailored architectural designs.

1.1. Aims and Objectives and scope

The aim of this research is to enhance the thermal performance of the indoor environment, thereby improving the quality of living. It seeks to identify strategies, including the use of green balconies, to reduce energy consumption while promoting thermal comfort. Hence the objective of the study three fold:

- To investigate the existing conditions of balconies in the warm-humid climate of Bangladesh, focusing on their design and contribution to indoor thermal comfort.
- To compare and analyze thermal performance data of residential buildings with and without green balconies, assessing their effectiveness in improving indoor environmental quality.
- • To determine the optimum configuration and placement of green balconies to achieve maximum thermal performance and improve indoor air temperature.

"How does greenery affect the structural integrity and indoor environmental quality of residential buildings in Dhaka City?"

1.2. Scope

This study will focus on vertical landscaping or gardening integrated into the design of residential buildings. It aims to assess the thermal performance of these green features and promote their use as an effective strategy for enhancing thermal comfort in modern residential building designs.

1.3. Hypothesis

The purpose of this study is to test empirically the following question:

- The presence of a green balcony will lead to a measurable decrease in indoor room temperature.
- The green balcony will result in a significant reduction in heat gain in the indoor environment.
- The incorporation of a green balcony will positively impact the variation of indoor temperatures, contributing to enhanced thermal comfort.

2. Literature Review

2.1. Temperature Reduction through Green Balconies

Table 1 literature based

Source	**Temperature Reduction (°C)**	**Findings**	**References**
Wong, N. H., et al.(2010), "Green Roofs and Green Walls for Urban Sustainability	2-4 °C	Green balconies can reduce indoor temperature by 2-4°C through shading and evapotranspiration.	Wong et al. (2010)
Susorova, I., et al. (2013), "Urban Green Spaces and Building Energy Efficiency "Specific Emphasis on Apartments	1.5-3 °C	Significant indoor temperature reduction with dense vegetation and south-facing balconies vegetation and south-facing balconies.	Susorova, I., et al. (2013),
Cheng, V., et al. (2011), "Energy Efficiency in Urban Green Spaces"	1.8-4 °C	Green balconies reduce cooling energy demand by 20-30%.	Cheng et al. (2011)
Moon, S., et al. (2024), "Passive Cooling Strategies in Green Architecture"	3-5 °C	Green balconies showed an average reduction of 3°C to 5°C in peak indoor temperatures.	Moon et al. (2024)
Naganathan, H., et al. (2024), "Optimizing Comfort and Sustainability: Green Cooling"	2-3 °C	Green balconies reduce cooling energy demand by 20-30%.	Naganathan et al. (2024)

All these researchers support the cooling potential of the green balcony through experiment conducted with different parameters. However, there is uncertainty on the usefulness of green balconies in cooling and maintaining suitable temperature throughout day and night in the residential building.

Figure 1 Green Balcony in the building. (Source: Authors house, 2024)

3. Material and methods

This study was conducted on a high-rise residential building located in Dhaka, Bangladesh, specifically focusing on the thermal performance of balconies. The experimental balcony was unobstructed by shadows or reflected solar radiation due to the absence of nearby structures. A green setup consisting of eight densely arranged potted plants was installed on the balcony, as depicted in Figure 1. Potted plants were selected for their practicality, cost-effectiveness, efficient rainwater drainage, and minimal impact on the structural integrity of the balcony.

The research concentrated on a typical south-facing balcony and its adjacent indoor room. Data collection was carried out during the summer months and was divided into heating and non-heating periods. The collected data were used to create comparative models of balconies with and without greenery, along with their connected indoor spaces, to evaluate differences in thermal performance.

The study area was Wari, a residential zone in southern Dhaka, which experiences a tropical wet and dry climate. Average temperatures in Dhaka range from 18 °C in January to 29 °C in August, with an annual average rainfall of approximately 1,854 mm. These climatic conditions provided a relevant context for examining the thermal performance of green balconies.

3.1. Study Objects

This study focused on the indoor thermal environment of residential buildings in a warm climate, examining the influence of green and non-green balconies on indoor temperature and humidity during summer. Field measurements were conducted in two separate phases:

- Phase 1 (June 11–13, 2024): Measurements were taken from an empty balcony to establish baseline data. This phase aimed to gather initial temperature and humidity data from the balcony without any greenery to understand the natural thermal conditions of the space.
- Phase 2 (June 14–16, 2024): Measurements were taken on two balcony configurations: one with potted plants (green balcony) and the other without greenery. This phase focused on comparing the thermal performance of the green balcony setup with the non-green setup, following the addition of a rooftop garden. The measurements in this phase provided insights into the cooling effect and overall thermal performance of the green balconies compared to the non-green balconies.

Data collection was carried out using Rotronic temperature sensors and humidity loggers to monitor both internal and external conditions. These instruments provided real-time readings of indoor temperature and relative humidity (RH). Measurements were taken every 15 minutes and averaged on an hourly basis to ensure comprehensive analysis. The study was conducted in a fully occupied building, with no mechanical cooling systems in operation, ensuring that the results were not influenced by artificial climate control.

Fluctuations in the recorded temperature and RH were impacted by factors such as the opening and closing of windows, as well as adjustments to indoor environmental elements like fans, heating, and air conditioning. Table 1 presents the measurement variables and the placement of the instruments used in the study.

3.2. Comfort Zone for Dhaka

In regions with consistently high temperatures and humidity, such as Dhaka, achieving indoor thermal comfort is a significant challenge. For naturally ventilated buildings, the comfort temperature range typically falls between 24 °C and 30 °C, depending on outdoor conditions and the adaptability of occupants (de Dear & Brager, 1998). Relative humidity levels ideally remain below 70%, though Dhaka frequently exceeds this threshold during the monsoon season (Rahman et al., 2021). Enhanced air movement through ceiling fans or natural cross-ventilation has been shown to significantly improve comfort in warm, humid conditions (Nicol & Humphreys, 2002).

Adaptive thermal comfort models, including EN 15251 and ASHRAE Standard 55, suggest that residents can tolerate higher indoor temperatures when passive cooling strategies such as shading, ventilation, and greenery are effectively utilized. Specifically, green balconies and vertical gardens contribute to mitigating the urban heat island effect, fostering cooler microclimates, and improving indoor thermal comfort by lowering air temperatures and increasing humidity control (Santamouris et al., 2014).

4. Results and discussion

4.1. Comparison of Indoor Temperature: Green Balcony vs. Non-Green Balcony

The thermal performance of green and non-green balconies was analyzed to evaluate their effectiveness in reducing indoor air temperatures in high-rise buildings and influencing the surrounding microclimate. Key metrics, including indoor temperature, ambient air temperature, and relative humidity, were compared, with indoor temperature serving as a primary indicator of thermal performance.

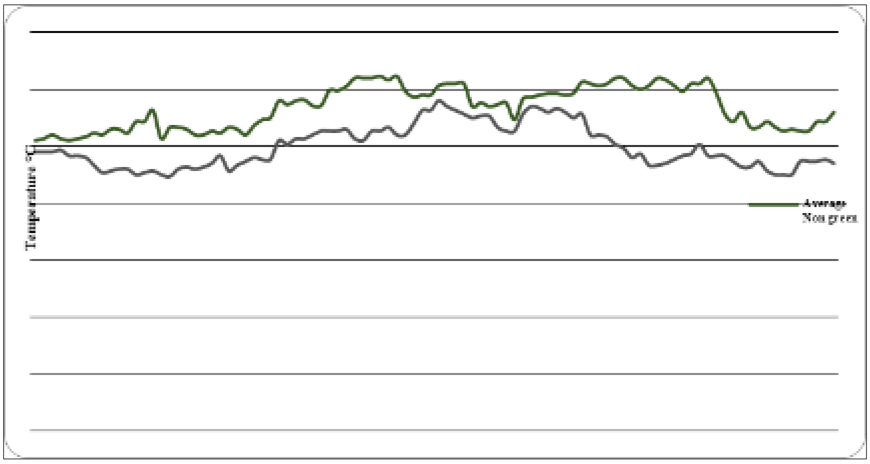

Figure 2 Profile of Green Balcony and Non Green Balcony Indoor temperature

Table 2 Recording of temperature and measurements in Non Green Balcony during the 11-13 June 2024**.**

Month (June)	Outdoor temperature	Indoor temperature
Day 1	34°C-28°C	32°C-27°C
Day 2	34°C-29°C	32°C-26°C
Day 3	33°C-24°C	30°C-23°C

Table 3 Recording of temperature and measurements in Green Balcony during the 14-16 June 2024

Month (June)	Outdoor temperature	Indoor temperature
Day 4	31 °C-26 °C	28 °C-22 °C
Day 5	32 °C-29 °C	29 °C-23 °C
Day 6	33 °C-28 °C	30 °C-22 °C

The analysis revealed significantly higher indoor temperatures on non-green balconies compared to green balconies. As shown in the graph profile (Figure 2). Field experiments demonstrated that the maximum indoor temperatures on green balconies were reduced by approximately 3 °C to 6.5 °C. The maximum surface temperature on non-green balconies reached 39°C, whereas green balconies recorded a notably lower surface temperature of 17.2 °C. Furthermore, potted soil surfaces shaded by plants were observed to maintain temperatures as low as 22.5 °C, underscoring the cooling benefits provided by greenery.

On sunny days, the temperature difference between potted soil surfaces on green balconies and non-green balcony surfaces reached up to12 °C. Non-green balconies absorbed and retained substantial solar radiation during the day, releasing it as long-wave radiation at night, resulting in considerable temperature fluctuations. In contrast, the greenery system on green balconies acted as thermal insulation, minimizing these fluctuations. Shaded soil surfaces consistently exhibited lower temperatures than shaded indoor surfaces.

The cooling performance of green balconies was further amplified during rainy days. Wet soil surfaces intensified the cooling effect through evaporation, significantly reducing temperatures. The temperature difference between non-green balcony surfaces and wet soil surfaces was as high as 39°C. The green balconies maintained consistently low surface temperatures during rainy periods due to the combined effects of evaporative cooling and the shading provided by densely arranged potted plants.

In the tropical climate of Dhaka, the study highlighted the effectiveness of green balconies in reducing indoor temperatures and enhancing thermal comfort. Densely covering balcony surfaces with potted plants maximized shading and evapotranspiration, optimizing thermal performance. The arrangement of greenery played a critical role in absorbing solar radiation and shielding indoor spaces from temperature fluctuations.

4.2. Comparison of Indoor Surface Temperature

Green balconies significantly improve thermal performance by reducing indoor surface temperatures, enhancing thermal comfort, and minimizing solar heat transfer into the indoor environment.

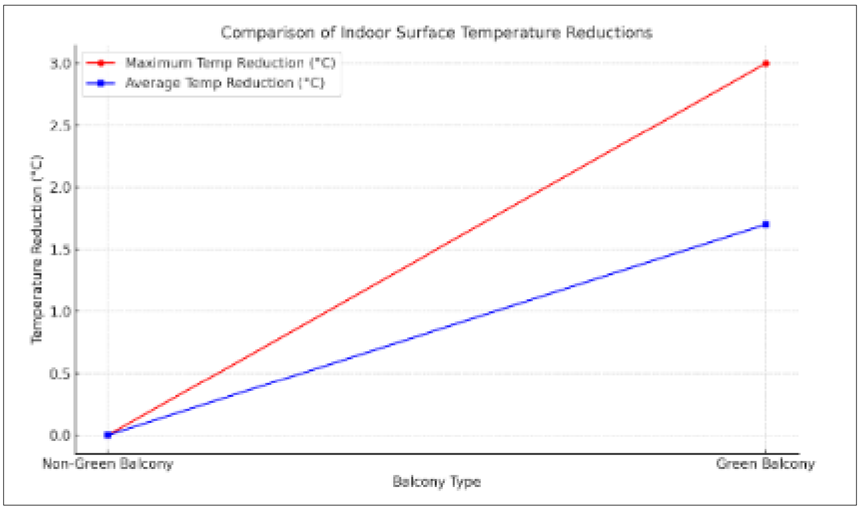

Figure 3 Comparison of Indoor Surface Temperature Reduction

As shown in the table 2, 3, indoor surfaces associated with green balconies experienced a maximum temperature reduction of 3.0 °C and an average reduction of 1.7 °C compared to surfaces in spaces with non-green balconies. These results emphasize the effectiveness of green balconies in moderating indoor surface temperatures, thereby contributing to improved thermal comfort and reduced heat transfer from external sources. Green balconies provide significant thermal benefits by reducing room temperatures, improving thermal performance, and minimizing solar heat transfer into the indoor environment.

As observed from the graph profile Figure (3), the presence of a green balcony results in a maximum room temperature reduction of 3.0°C and an average reduction of 1.7 °C compared to non-green balconies. This highlights the effectiveness of green balconies in enhancing indoor comfort and mitigating heat transfer from external sources.

4.3. Comparison of Internal and External Air Temperatures

The thermal performance of green balconies was assessed to evaluate their effectiveness in reducing indoor air temperatures and their potential for cooling energy savings. As shows an Figure 4. average indoor air temperature reduction of 2.4 °C during sunshine hours, with the greatest temperature drop occurring during peak heating periods (12:30 PM to 2:30 PM) and the smallest reduction observed during off-sunshine hours.

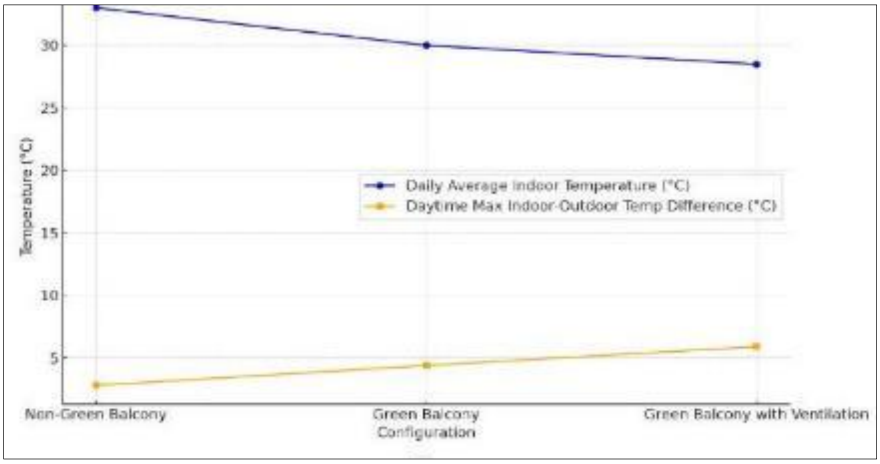

Figure 4 Comparison of Internal and External Air Temperatures

Green balconies significantly reduce solar heat energy transmission indoors, achieving a reduction more than three times greater than that of non-green balconies .Additionally, the temperature fluctuation between indoor and outdoor environments is minimized at night when a green balcony is present, compared to spaces with a non-green balcony. The daily average indoor air temperature for a non-green balcony is approximately 33.0 °C, whereas it drops to 30.0 °C with the presence of a green balcony.

Diurnal temperature variations further highlight the advantages of green balconies; the maximum temperature difference between indoor and outdoor environments during the daytime is 4.4 °C for green balconies, compared to only 2.8 °C for non-green balcony. When adequate ventilation is integrated, indoor air temperatures can drop an additional 1.5 °C relative to standard indoor temperatures associated with green balconies.

Overall, green balconies are crucial for thermal protection, significantly reducing the thermal load on residential buildings and enhancing indoor comfort.

5. Conclusion

The results confirm that green balconies provide thermal benefits to both the indoor environment and the surrounding outdoor microclimate of the building. They contribute to reducing energy consumption for cooling, mitigating indoor temperature fluctuations, and also help reduce the effects of global warming by controlling CO_2 levels. The heat transfer from the outdoor environment to the indoor space is lower in buildings with green balconies compared to those with non-green balconies, primarily due to the shade provided by the dense arrangement of potted plants. Green balconies also help lower the average indoor air temperature more effectively than non-green balconies.

During the day, green roofs can reduce indoor air temperature by 3 °C to 6.5 °C, and at night, they can lower the temperature by about 3 °C compared to non-green balconies. Proper night ventilation further enhances the cooling effect, bringing the indoor temperature closer to the outdoor temperature. The combination of green balconies and adequate night ventilation offers a significant cooling potential, contributing to thermal comfort in the indoor environment.

Green balconies serve as an effective passive cooling solution and provide essential thermal benefits, making them a crucial strategy for architectural design in Bangladesh's warm-humid climate. The use of balcony greenery systems, which are easy to construct, maintain, and replace with potted plants, offers a highly effective solution for contemporary buildings in tropical Bangladesh. This approach aligns with energy efficiency, environmental sustainability, and the well-being of the ecosystem. The design of green balconies incorporates not only environmental considerations but also economic and social aspects, contributing to overall sustainability.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclsoed.

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