SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I1P112

Volume 13 Issue 1, 140-148, January 2026

Original Article

Green Roofs as Thermal and Noise Insulation on Corrugated Zinc Roofs in Tropical Residential Buildings

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Received: 07 November 2025 Revised: 09 December 2025 Accepted: 08 January 2026 Published: 14 January 2026

Abstract *- Corrugated zinc roofs in residential buildings in humid tropical areas often create high temperatures in the dry season and noise in the rainy season. This research is a comparative experiment that analyzes the difference in thermal and acoustic performance between two spaces with different types of roofs, i.e., conventional corrugated zinc roofs, and corrugated zinc roofs with green roof systems. The results showed that the difference in temperature fluctuations on green roofs was recorded at 4.40°C lower than conventional roofs, which reached 9.00°C. Meanwhile, the difference in relative humidity fluctuations was recorded as 7.31% lower on green roofs. The lowest noise level during rain was also recorded on green roofs, which was 48.85 dBA, indicating that the noise level is still within the tolerable range for acoustic comfort in residential buildings in urban areas. In comparison, conventional roofs show the lowest noise levels of 55.15 dBA. Therefore, green roofs can be an alternative roofing material that supports the creation of comfortable spaces in humid tropical regions.*

Keywords *- Corrugated zinc roofs, Green roofs, Noise insulation, Thermal insulation, Tropical residential buildings.*

1. Introduction

The phenomenon of urbanization and environmental degradation has resulted in an increase in the world's energy and carbon crisis. China, the United States, the European Union, Russia, and Indonesia are among the top emitters worldwide, with Indonesia accounting for about 3.48% of the global population, which also contributed 2.49% of global emissions and had the largest increase in relative terms in 2024 [1, 2]. The building sector contributes about 40% of total global emissions from energy consumption, with cooling and space heating systems being the primary contributors [3, 4]. For this reason, it is important to reduce emissions in the building sector and also as a strategy to achieve the United Nations (UN) Sustainable Development Goals (SDGs).

The roof of a building has a significant role in the increase in such temperatures because it absorbs and conducts a large amount of heat into the room during the daylight period [5]. Most heat transfer occurs through the building envelope [6, 7]; therefore, the planning of the roof, such as the model and its materials, needs to be planned accurately. Such a condition shows the urgency of implementing a low-carbon architecture strategy oriented towards energy efficiency and environmental sustainability [8, 9]. One of the globally recognized passive approaches is the green roof system, due to its ability to improve the thermal performance of buildings while lowering energy consumption, and it plays a significant role in the development of sustainable design strategies for large and dense cities [10, 11].

Like major cities in Indonesia that have undergone urban development, the city of Surakarta, as the most populous city in Central Java, has also experienced the impact of urbanization. The increase in population has triggered an increase in energy demand in residential buildings, resulting in a significant impact on environmental emissions [12, 13]. Such a condition is exacerbated by the characteristics of a humid tropical climate characterized by high air temperatures and a large intensity of solar radiation throughout the year. Consequently, urban communities are increasingly relying on artificial cooling systems such as Air Conditioners (AC) to achieve thermal comfort indoors [14, 15]. For this reason, climate zone classification is necessary to develop a design strategy for energy-efficient buildings [16].

Until now, there are still many residential buildings in Surakarta that use lightweight structures for roofing systems like corrugated zinc roofs, particularly among low-income households, because their price is relatively lower compared to other materials. In addition, zinc roofs also produce high noise levels due to the intensity of rainfall during the rainy season and urban noise pollution [17] because of their light and thin materials. For this reason, innovative architectural solutions are needed to solve these problems.

Vegetation is a great source of thermal comfort due to its ability to absorb heat [18]. Research on green roofs in China [19] proved that the application of green roofs is effective in blocking outdoor heat from entering indoors during summer; likewise, in preserving the indoor heat during winter. In summer, the indoor temperature without a green roof was 0,6°C lower than the indoor temperature with a green roof. In winter, the indoor temperature with a green roof was 0,7°C higher than the indoor temperature without a green roof. Another research on green roofs in Sri Lanka [4]. Revealed that the application of green roofs released CO2 emissions nearly 90% lower than conventional roofs. This reinforces the findings of various previous research that show that the application of passive design strategies, such as green roofs, is effective in improving thermal comfort while supporting increased energy efficiency in buildings [20, 21].

Vegetation also has a major influence on reducing noise [22, 23]. Another research in China also showed that the application of green roofs can reduce noise levels by 2–4 dBA, with an additional reduction of about 1 dBA in the area around the roof [24]. It therefore reinforces the findings of various previous research that show that the vegetation in buildings, such as in green roof systems, is effective in reducing noise [25]. Horizontal vegetation strategies in the form of green roofs provide significant ecological, social, and economic benefits [26] with varying effectiveness depending on the surrounding climate [27].

The research on green roofs in China, Sri Lanka, and various other countries suggested the effectiveness of green roofs in thermal and noise insulation. However, its application in those studies is different from this research; while research in China and Sri Lanka had green roof application on flat concrete roofs, this research has green roof application on corrugated zinc roofs, hence, the applicability of these results to other types of roofing materials, especially corrugated zinc roofs, is questionable.

Research and application of green roofs on lightweight structures such as corrugated zinc roofs in humid tropical climates are still limited, both in terms of thermal and acoustic [28]. Most previous research has focused on concrete-roofed buildings in temperate climates, conducted on a simulation or laboratory basis [29, 30], and field measurements have not been carried out in humid tropical conditions. Therefore, direct field research examining the simultaneous thermal and acoustic performance in green roof systems on corrugated zinc roofs in humid tropical climates is needed to be applicable to low-cost housing in dense urban areas.

All in all, this research addresses these gaps through a one-year field experiment in a humid tropical environment, comparing identical rooms with and without green roofs to test the performance of green roofs on corrugated zinc based on the roof's ability to insulate thermal and noise. This research suggests that heat and noise insulations are significant in contributing to the development of passive design strategies, which may be implemented in low-cost housing in dense urban areas, as well as expand understanding of the potential of green roofs as a solution to improve the thermal and acoustic comfort of humid tropical residential buildings. Furthermore, this research fills the gap in previous research that focused on concrete-based green roof systems in temperate climates by presenting evidence regarding the application of light green roof systems in humid tropical climate conditions.

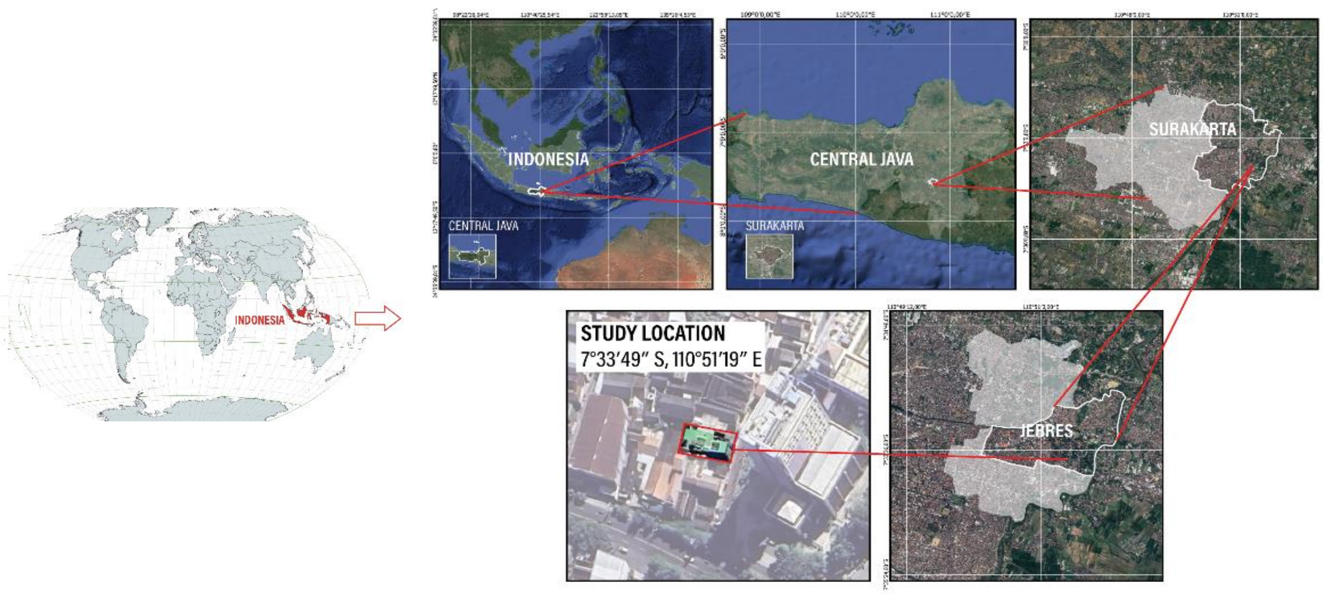

Fig. 1 Map of the research location with Geographic Information System (GIS)

2. Materials and Methods

This research relates to previous research that discussed how this roof strategy can work to minimize thermal and noise in humid tropical countries. A significant difference is explained in this research, which uses quantitative methods compared to the previous research that used field measurement methods with small-scale test modules. This research employs quantitative methods to provide more accurate results than similar research conducted in Malaysia through experiments on two different types of roofs [31], i.e., corrugated zinc roofs without plants and corrugated zinc roofs with plants, where there is a room with the same specifications. The free variables include the type of roof, i.e., conventional roofs and green roofs, while the bound variables are the temperature and humidity of the air in the room, as well as the noise level in the room.

Humid tropical climates are variables that affect the performance of roofs. To ensure accurate results, factors such as space dimensions, orientation, and materials are created in the same arrangement in both rooms. Data were compared to evaluate the effectiveness of green roof systems in thermal and noise insulation to create thermal and acoustic comfort in residential buildings in humid tropical climates.

2.1. Materials

The research location is in Surakarta, Central Java, Indonesia, an area experiencing rapid population growth and expansion of built-up land [32]. Climatologically, Surakarta, including Jebres District, has hot and humid conditions throughout the year [33]. Specific location determination is carried out using QGIS (Figure 1) to see geospatial data, in the form of coordinate points, microclimate conditions, and earth surface conditions. The location of the research is in a residential building on Jl. Mendung IV No.60, Jebres, with coordinates 7°33'49"S, 110°51'19"E, which is used as a representative case research for urban humid tropical areas.

This site selection was intended to reflect real environmental exposure commonly experienced by low-cost residential buildings in dense tropical urban areas. To reduce potential biases, measurements in both test rooms were conducted simultaneously under identical weather conditions. Thermal data were collected continuously for 24 hours over a one-year period, from January to December, capturing both dry and rainy seasons. Noise measurements were conducted during the rainy season, when roof impact noise is most pronounced, using repeated measurements to ensure consistency.

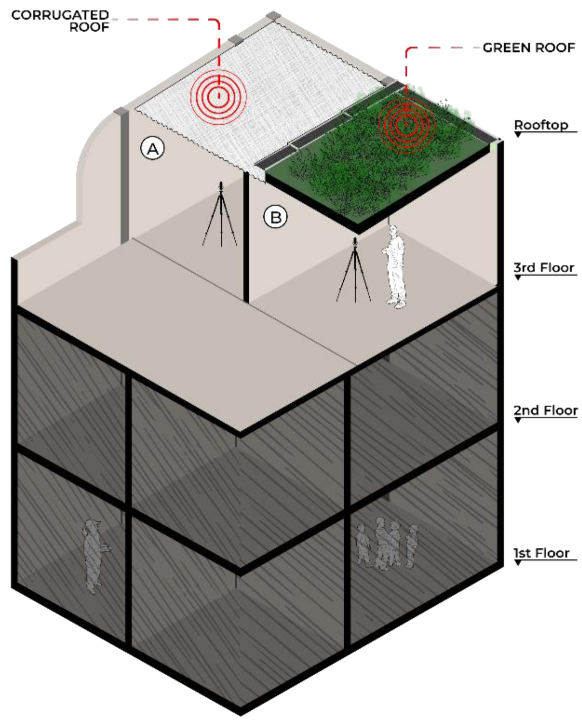

Fig. 2 Perspective cut diagram of existing test chamber and field measurement setup

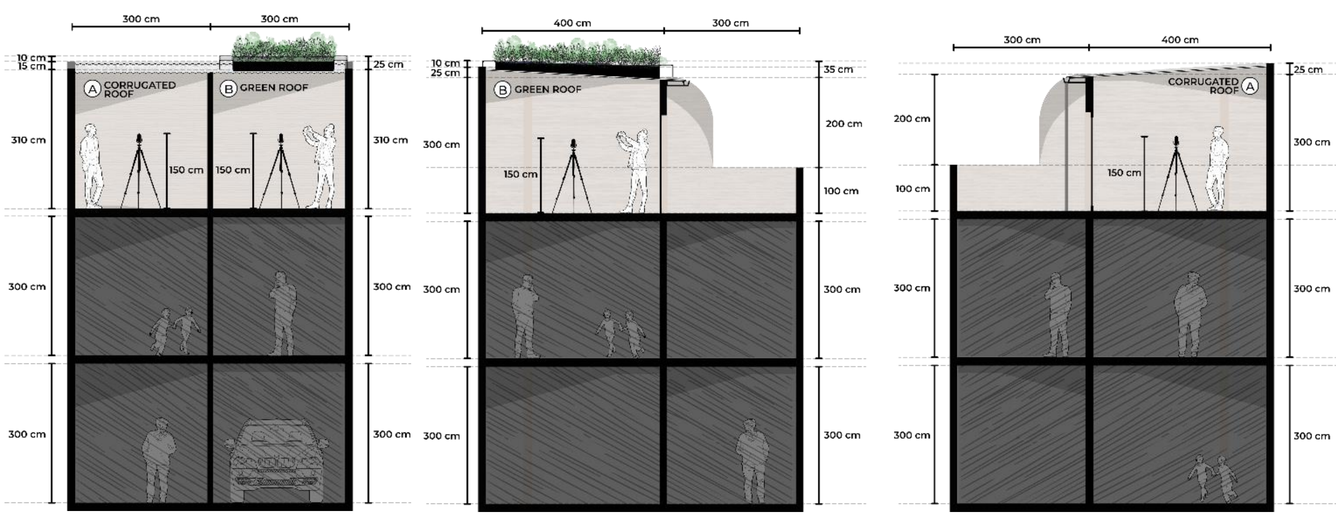

Fig. 3 Diagram of the existing test chamber section and field measurement arrangement, (a) Cross section, (b) and (c) Longitudinal section.

The research compared two rooms with an area of 4 x 3 meters and a height of 2.5 meters. The two test rooms have the same dimensions, construction materials, walls, and floor positions. The differences in the roof components of both rooms include:

- Test Room A (base case): Existing unit with a conventional corrugated zinc roof without plants. This space serves as a sample of multi-storey residential buildings in general in humid tropical areas.
- Test Room B (improve case): An existing unit with a corrugated zinc roof modified with plants, consisting of waterproof coating, waterproof tarpaulin, planting media, and vegetation.

The two test room models that have been illustrated using SketchUp free version website and refined using the figma free version website, in two dimensions and three dimensions as in Figures 2 and 3, are then used as a basis for evaluating thermal and noise performance through data comparison between test room A and test room B on multi-storey residential buildings in dense urban areas with humid tropical climates.

2.2. Methods

The research used quantitative methods with a comparative analysis, as illustrated in Figure 4. Data were collected from the research objects, encompassing temperature, humidity, and noise levels. The collected data were then summarized and visualized through graphical representations to facilitate easier analysis. The data were analyzed using a comparative study approach, where dominance between data object A and data object B was evaluated to assess normality. Data points that deviated significantly from the curve were considered abnormal and excluded from further use, while normal data were retained to derive the research findings.

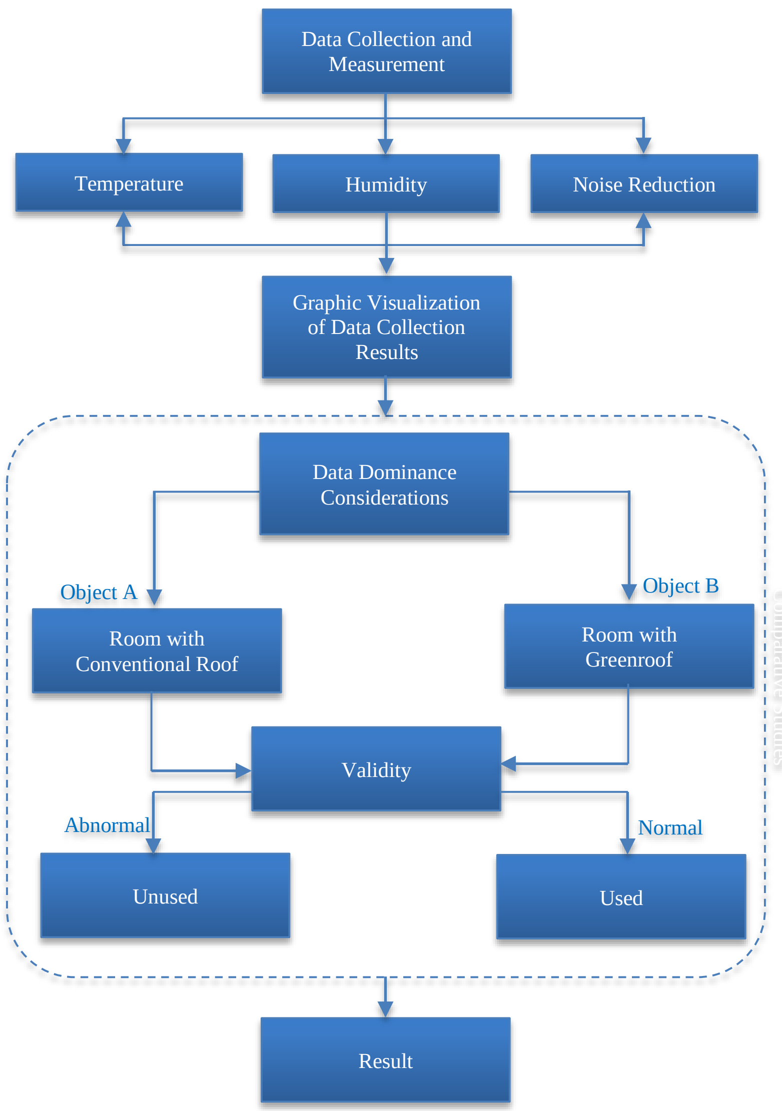

Fig. 4 Research method diagram

Thermal measurements were carried out using Wet Bulb-Globe Temperature (WBGT) meters in test rooms A and B. Meanwhile, to measure indoor noise levels using Sound Level (SL) meters. The two measuring instruments are installed at a height of 1.5 meters above the floor surface. WBGT was chosen because of its complete measurement variables; it responds to important components such as humidity, air temperature, solar radiation, and wind, thus providing comprehensive thermal data [18, 34] to measure the comfort level of a space.

Measurements were carried out over a period of one year, for 24 hours from January to December. The data was taken as a representation of indoor air temperature and humidity, both in the rainy and dry seasons in humid tropical climates. Temperature and humidity were observed and recorded (Figures 5 and 6). Meanwhile, the measurement of noise levels is conducted during the rainy season, which is recapped in 10 measurements with consideration of the high noise level in the room (Figure 8). Both will be presented in the form of graphs that can provide an overview of the comparison of heat and noise insulation capabilities between green roofs and conventional roofs at the research site, as the basis for thermal and acoustic comfort analysis.

The research shows the results of an analysis that can compare the measurement results of temperature conditions, air humidity, and noise levels between test rooms A and B. Measurement data is entered into OriginLab for processing and visualization purposes. Initial data is data from the measurement of air temperature and humidity every hour throughout the year, from 00:00 to 23:00 (UTC+07:00) for each month, as well as noise level data from ten tests during rainy conditions. Before being imported into OriginLab, the raw data is processed first to obtain an annual hourly average, so that a general pattern of temperature and humidity fluctuations throughout the day is obtained. Visualization of temperature and humidity is carried out using multi-panel multi-axis graphs (2Ys Y–Y) that allow the simultaneous presentation of two variables on a single coordinate field. Moreover, a comparison of noise levels is visualized using a Basic 2D graph (Line + Symbol) to show the variation in results between tests more clearly. The visualization results provide a quantitative picture of the extent to which the application of vegetation layers on corrugated zinc roofs can insulate heat and noise in residential buildings in humid tropical climates.

3. Results and Discussion

3.1. Thermal Insulation

Each data point resulting from measurements in test rooms A and B is a measurement that is carried out at the same time and in the same weather conditions. Based on measurements using WBGT meters, the level of thermal discomfort was felt in the time range of 11:00 to 14:00 (UTC+07:00). After analyzing the measurement data, it concluded that there was a significant increase in temperature in test room A around that time, the peak was at 12:00 (UTC+07:00). As shown in Figure 5, the air temperature continued to rise from 06:00 (UTC+07:00) and decreased from 13:00 to 23:00 (UTC+07:00), which verifies the movement and intensity. On the other hand, Relative Humidity (RH) shows the opposite pattern. The RH value tends to be high at night and has decreased since 07:00 (UTC+07:00).

In test room A, it shows that the lowest air temperature of the year occurs at 05:00 (UTC+07:00) with a value of 27.27°C, while the highest air temperature of the year occurs at 12:00 (UTC+07:00) with a value of 36.27°C, with a temperature fluctuation range of up to 9.00°C. Meanwhile, the highest RH value occurred at 05:00 (UTC+07:00) with a value of 69.89%, and the lowest value was recorded at 12:00 (UTC+07:00) of 44.86% with a humidity range of 25.03%. The data illustrate that a room with a zinc roof without a plant cover has considerable fluctuations in temperature and humidity in one day. The zinc surface that has high heat absorption causes a rapid increase in temperature during the day.

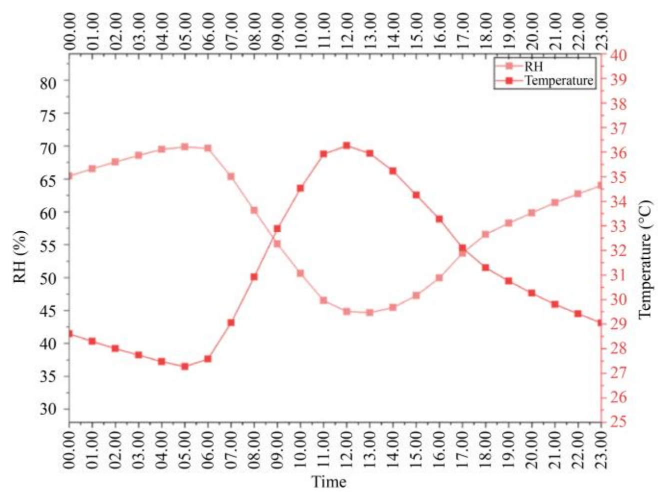

Fig. 5 Average temperature and humidity of test chamber A throughout the year

Meanwhile, a green roof applied in test room B has a significant difference in the measurement results of room temperature and RH values compared to test room A. As such, the average measurement of temperature and humidity throughout the year in test room B shows that the lowest air temperature (27.78°C) occurred at 06:00 (UTC+07:00), while the highest temperature (32.18°C) occurred at 14:00 (UTC+07:00), with a temperature fluctuation range of only about 4.40°C (Figure 7). On the other hand, the highest RH value (70.97%) occurred at 06:00 (UTC+07:00), and the lowest value (53.25%) was recorded at 14:00 (UTC+07:00), with a humidity range of 17.72%. In effect, zinc roofs with plant covers had smaller temperature and humidity fluctuations.

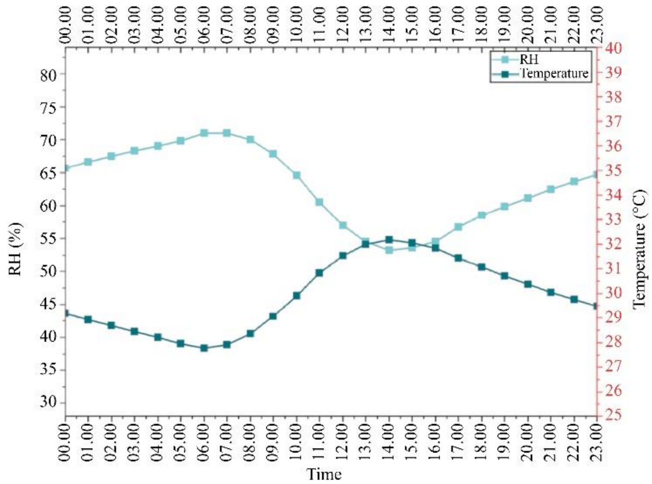

Fig. 6 Average temperature and humidity of test chamber B throughout the year

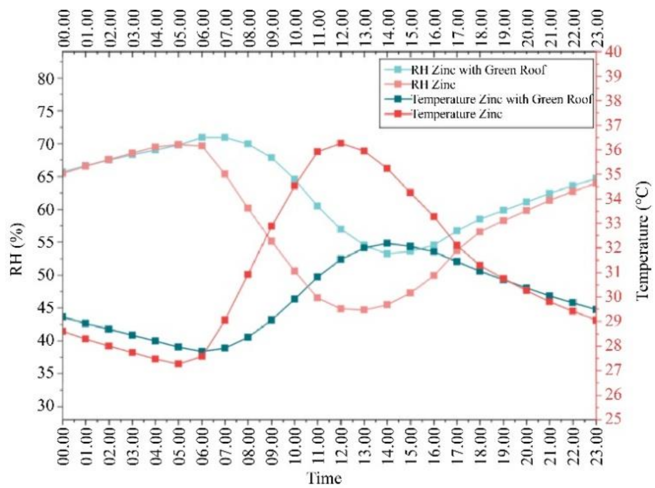

Fig. 7 Average temperature and humidity of test rooms A and B throughout the year

The significant difference shown in Figure 7 indicates that the application of green roofs on corrugated zinc roofs can serve as a mitigation strategy to improve thermal comfort because this type of roof is known to have heat-absorbing properties. Therefore, the green roof system can reduce the room temperature in comparison with conventional roofs, showing significant potential in reducing the burden of space cooling and contributing to carbon emission mitigation efforts in the building sector.

The research demonstrates superior thermal comfort through the application of green roofs on corrugated zinc structures, reducing daily temperature fluctuations from 9.00°C to 4.40°C and humidity variations from 25.03% to 17.72%, compared to conventional zinc roofs. This is achieved through vegetation acting as a natural insulator that curbs heat absorption and solar intensity more effectively than synthetic materials in existing research [18]. The advantage stems from the green roofs' shade and conductivity-reducing properties, offering a sustainable, cost-effective alternative that extends prior findings by aligning with real-time data peaks, thereby enhancing energy efficiency and carbon mitigation in humid tropical settings.

3.2. Noise Insulation

According to Yang & Jeon (2020), one of the main problems with corrugated zinc roofs is the low acoustic insulation ability against rain noise and urban noise [17]. With that in mind, this research observed the specific feature that affected low acoustic insulation. For instance, Data were captured in test rooms A and B as measurements carried out at the same noise time and conditions. Measurements during the rainy season, to illustrate, with the general conditions that it was rainy, included a presence of high and disturbing noise.

To sum up, the noise level measurement in test room A is between 55.15 dBA and 73.75 dBA, with an average of 63.44 dBA. Meanwhile, the noise level measurement in test room B is between 48.85 dBA and 69.7 dBA, with an average of 57.99 dBA (Figure 8).

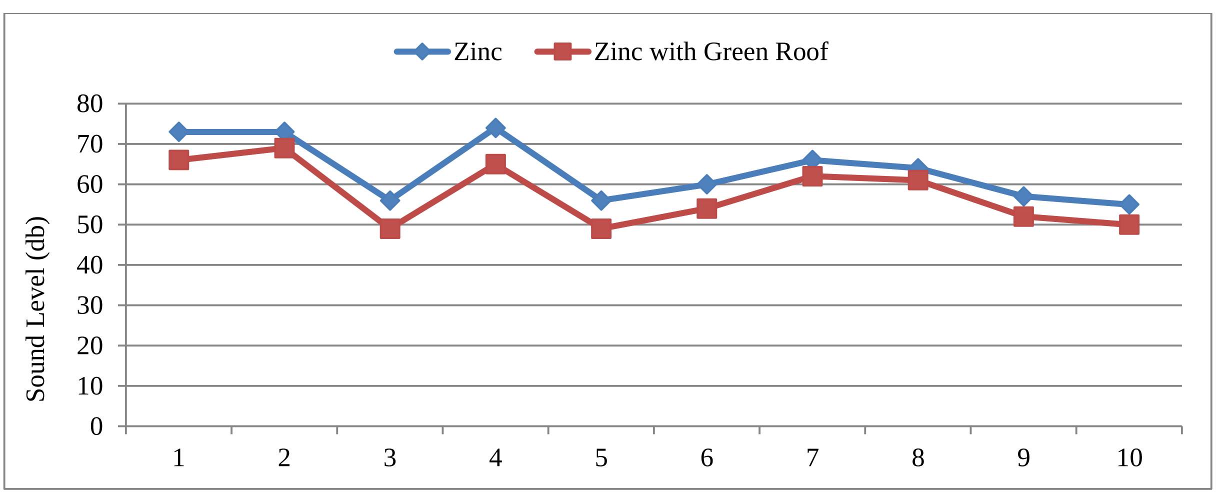

Fig. 8 Comparison of the noise level of test rooms A and B

Equally important, the highest difference value was recorded at 8.35 dBA in the fourth measurement, where the noise in test room B was lower than in test room A. In addition, the average difference in noise level between test rooms A and B was 5.45 dBA. Such results indicate that test room B using a green roof system can reduce noise levels compared to conventional roofs in test room A.

The noise value in test room B with a planted roof was consistently lower compared to test room A, which used a roof without plants. This indicates that the vegetation layer on the roof acts as a natural sound absorber that can reduce sound transmission [22, 23], especially when there is rainwater impact or noise exposure in urban areas.

These findings are in line with the results of research by Lu et al. (2025), which reported that the application of green roofs can reduce noise levels by 2-4 dBA, with an additional reduction of about 1 dBA in the surrounding area. The effectiveness of a green roof system is also influenced by the type of vegetation and its substrate layer [24].

The research recommends the implementation of mixed planting strategies by utilizing plant types that are resistant to dry conditions to reduce the distance between vegetation and increase soil porosity, so that noise reduction capabilities can be maximized.

The comparison of Test A and B rooms stipulates that green roof systems on corrugated zinc provided a significant improvement in thermal and acoustic performance compared to conventional zinc roofs without plants. As far as thermal insulation is concerned, test room B indicated lower daily temperature fluctuations, with a maximum temperature disparity of 4.40°C compared to 9.00°C in test room A.

More importantly, the vegetation retained the sun's heat and slowed down the rate of temperature increase during the day, while keeping the air humidity around the roof stable. As for the acoustic insulation, the average noise value in test room B using a corrugated zinc roof with plants was 5.45 dBA compared to test room B using a regular roof without plants.

As such, vegetation functions as a natural absorbent and dampening layer that reduces sound transmission, particularly from rainwater impacts and urban noise. Overall, the measurement and analysis of field measurement data suggest that the green roof system with corrugated zinc has the potential to improve the thermal and acoustic comfort of buildings in humid tropical climates.

4. Conclusion

This research pertained that the application of green roof systems on corrugated zinc roofs in humid tropical climates significantly improves the thermal and acoustic insulation of buildings. Two test room models measuring 4 x 3 meters for one year indicated that the temperature of the room under the green roof experienced minimal fluctuations and a lower peak compared to conventional zinc roofs. Such findings enhance the contention that vegetation has immense potential as natural heat insulation. In addition, the green roof system has also been proven to be able to reduce the average noise level by up to 5.45 dBA, indicating reduced noise levels caused by rain and urban noise. Noise insulation is affected by a green roof layer consisting of tarpaulin material, planting media, and vegetation.

Furthermore, green roofs on corrugated zinc structures have the potential to be an effective passive design strategy for thermal and noise insulation. Accordingly, thermal and acoustic comfort is achieved while supporting energy efficiency and carbon mitigation in buildings in humid tropical urban areas. The green roof model is an improved model on corrugated zinc applicable for implementation in high-rise residential buildings in dense urban areas in humid tropical climates. This finding has the potential to impact the formulation of building policies and architectural design practices, particularly in the context of buildings with lightweight roof systems commonly used in humid tropical regions. From a policy perspective, the results of this research have the potential to be incorporated into green building standards, energy efficiency guidelines, and sustainable housing regulations in humid tropical areas. In design practice, the corrugated zinc roof systems with vegetation have the potential to be applied in both new buildings and as a retrofit solution for existing structures. Overall, these outcomes underscore the viability of green roofs as a sustainable solution for enhancing building performance in humid tropical climates, warranting further integration into regulatory frameworks and design methodologies. Future research could focus on the long-term performance evaluation of corrugated zinc roofs with vegetations growth, maintenance requirements, and resistance to extreme climate conditions.

Acknowledgments

This research is funded by RKAT PTNBH Universitas Sebelas Maret for the 2024 Fiscal Year through the Research Group Research Grant (HGR-B UNS) scheme with Research Assignment Agreement Number: 194.2/UN27.22/PT.01.03/2024.

Author Contributions

Conceptualization, S.Y.; methodology, S.Y.; formal analysis, A.Y.A.; visualization, A.B.R. and A.M.B.; data curation, A.B.R. and A.M.B.; validation, S.Y.; writing—original draft preparation, A.M.B.; writing—review and editing, M.C.M. and G.C.A.; supervision, A.Y.A.; funding acquisition, S.Y. All authors have read and agreed to the published version of the manuscript.

References

[1] Monica Crippa et al., "*GHG Emissions of all World Countries*," Publications Office of the European Union, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[2] World Development Indicators: Table 2.1-World Development Indicators: Population Dynamics, The World Bank, 2025. [Online]. Available: https://wdi.worldbank.org/table/2.1#

[3] Giouli Mihalakakou et al., "Earth-Sheltered Buildings: A Review of Modeling, Energy Conservation, Daylighting, and Noise Aspects," *Journal of Cleaner Production*, vol. 472, pp. 1-23, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[4] Malka Nadeeshani et al., "Carbon Footprint of Green Roofing: A Case Study from Sri Lankan Construction Industry," *Sustainability*, vol. 13, no. 12, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] P. Boobalakrishnan et al., "Thermal Management of Metal Roof Building using Phase Change Material (PCM)," *Materialstoday: Proceedings*, vol. 47, pp. 5052-5058, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[6] Ancuța Maria Măgurean, "Three-Dimensional Numerical Model for Heat Transfer Dynamic Analysis for the Building-Soil Interaction by Applying the Similarity Theory," *Thermal Science and Engineering Progress*, vol. 43, pp. 1-10, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[7] O. May Tzuc et al., "Modeling the Effect of Roof Coatings Materials on the Building Thermal Temperature Variations based on an Artificial Intelligence," *Journal of Physics: Conference Series*, *Peruvian Workshop on Solar Energy (JOPES 2021)*, Lima, Peru, vol. 2180, no. 1, pp. 1-7, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[8] Edoardo De Cristo et al., "A Systematic Review of Green Roofs' Thermal and Energy Performance in the Mediterranean Region," *Energies*, vol. 18, no. 10, pp. 1-38, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[9] Thácia Danily de Oliveira Santos et al., "A Systematic Analysis on the Efficiency and Sustainability of Green Facades and Roofs," *Science of The Total Environment*, vol. 932, pp. 1-13, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[10] Alena Harbiankova, and Maria Manso, "Integrating Green Roofs and Green Walls to Enhance Buildings Thermal Performance: A Literature Review," *Building and Environment*, vol. 270, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[11] Abdessamad Idouanaou et al., "The Potential of Green Roof Strategies for Reducing CO_2 Emissions and Energy use in Moroccan Office Buildings," *Green Technologies and Sustainability*, vol. 3, no. 3, pp. 1-11, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[12] Saeed Rayegan et al., "Modeling Building Energy Self-Sufficiency of using Rooftop Photovoltaics on an Urban Scale," *Energy and Buildings*, vol. 324, pp. 1-19, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[13] Valentyna Riabchuk et al., "Utility-based Context-Aware Multi-Agent Recommendation System for Energy Efficiency in Residential Buildings," *Information Fusion*, vol. 112, pp. 1-15, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] Naja Aqilah et al., "Analysis on Electricity use and Indoor Thermal Environment for Typical Air-Conditioning Residential Buildings in Malaysia," *Urban Climate*, vol. 37, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Keigo Miyamoto et al., "Relationship Between Cooling Methods and Energy Consumption for the Development of Low-Carbon Collective Housing in Indonesia," *Sustainability*, vol. 16, no. 4, pp. 1-17, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[16] I Dewa Gede Arya Putra et al., "Development of Climate Zones for Passive Cooling Techniques in the Hot and Humid Climate of Indonesia," *Building and Environment*, vol. 226, pp. 1-17, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[17] Wonyoung Yang, and Jin Yong Jeon, "Design Strategies and Elements of Building Envelope for Urban Acoustic Environment," *Building and Environment*, vol. 182, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[18] Greta Frosini et al., "The Impact of Trees on the UHI Effect and Urban Environment Quality: A Case Study of a District in Pisa, Italy," *Atmosphere*, vol. 15, no. 1, pp. 1-17, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[19] Lu Cai et al., "Reduction in Carbon Dioxide Emission and Energy Savings Obtained by using a Green Roof," *Aerosol and Air Quality Research*, vol. 19, no. 11, pp. 2432-2445, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[20] Hassan A. Alnashri, Abdulrahman S. Fnais, and Abdulrahman A. Bin Mahmoud, "Barriers and Strategies for Implementing Passive House Design : The Case of the Construction Sector in Saudi Arabia," *Buildings*, vol. 15, no. 17, pp. 1-22, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[21] Jenan Abu Qadourah, "Energy Efficiency Evaluation of Green Roofs as a Passive Strategy in the Mediterranean Climate," *Results in Engineering*, vol. 23, pp. 1-8, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[22] Margherita Ferrante et al., "Urban Greenness for the Protection of Adverse Effects of Noise on Human Health : A PRISMA Systematic Review," *Science of The Total Environment*, vol. 978, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[23] Claudia Kawai et al., "Urban Noise Vs . Nature ' S Calm : A Swiss Study of Noise Annoyance and the Role of Residential Green," *City and Environment Interactions*, vol. 27, pp. 1-10, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[24] Jian Lu et al., "Extensive Green Roofs for Noise Abatement: Combined Acoustic Effects of Substrate and Vegetation in a 3D Environment," *Building and Environment*, vol. 270, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[25] Francesco Ferrario et al., “Evaluating Nature-based Solutions as Urban Resilience and Climate Adaptation Tools : A Meta-Analysis of their Benefits on Heatwaves and Floods,” *Science of The Total Environment*, vol. 950, pp. 1-12, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[26] Chang Xi, and Shi-Jie Cao, “Challenges and Future Development Paths of Low Carbon Building Design : A Review,” *Buildings*, vol. 12, no. 2, pp. 1-12, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[27] Meltem Sarul, Filiz Bal Kocyigit, and Cagri Yilmaz, “A Critical Review on Multifunctional Building Envelope Materials for Simultaneous Mitigation of Urban Heat and Noise Islands,” *International Journal of Environmental Research*, vol. 19, no. 5, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[28] António Tadeu et al., “Acoustic Absorption, Scattering, and Diffusion Provided by Green Roof Systems,” *Building and Environment*, vol. 262, pp. 1-17, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[29] Yiqun Pan et al., “Building Energy Simulation and its Application for Building Performance Optimization: A Review of Methods, Tools, and Case Studies,” *Advances in Applied Energy*, vol. 10, pp. 1-24, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[30] Vítor Freitas Mendes et al., “A Systematic Review of Methods for Evaluating the Thermal Performance of Buildings through Energy Simulations,” *Renewable and Sustainable Energy Reviews*, vol. 189, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[31] Siew Bee Aw et al., “Strategic Integration of a Vegetative Component on a Metal Roof base : An Evaluation of its Impacts on Thermal and Acoustic Performance in the Tropics,” *Buildings*, vol. 14, no. 4, pp. 1-20, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[32] Erma Fitria Rini et al., “Infrastructure Planning for Climate Change Adaptation based on Land Development and Surface Temperature Typology,” *BIO Web of Conferences*, vol. 155, pp. 1-7, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[33] Chico Hermanu Brillianto Apribowo et al., “Performance Enhancement of Photovoltaic Panels using Passive Heatsink Cooling and Single-axis Solar Tracking,” *Scientific Bulletin of Electrical Engineering Graduates*, vol. 7, no. 2, pp. 147-157, 2025. [Google Scholar] [Publisher Link]

[34] Hiroki Yamaguchi et al., “Using Wet-Bulb Globe Temperature Meters to Examine the Effect of Heat on Various Tennis Court Surfaces,” *Scientific Reports*, vol. 14, no. 1, pp. 1-9, 2024. [CrossRef] [Google Scholar] [Publisher Link]