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Original Article

Zinc Roof Color's Effect on Temperature and Global Warming Potential in Humid Tropical Buildings

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Abstract - *Zinc roofing is a common choice in humid tropical regions, yet its contribution to energy efficiency remains under-investigated. This study looked at how three different colors of zinc roofs, silver (unpainted), blue-painted, and maroon-painted, affected temperature and the environment when used on the same buildings in Manado, Indonesia, during three months of the dry season. Temperature data were collected from the roof surface, attic, and interior space. A Life Cycle Assessment (LCA) based on ISO 14040/44 was conducted, incorporating emissions and cooling energy associated with each roof's reflectance properties. Findings revealed that maroon-colored roofs consistently caused higher attic and indoor temperatures, exceeding those under silver and blue roofs by more than 1°C. The silver roof showed the lowest Global Warming Potential (GWP) at -27.16 kg CO_2-eq/m² over a 20-year lifecycle, followed by blue at -0.76 kg CO_2-eq/m², while the maroon roof resulted in the highest emissions (+7.444 kg CO_2-eq/m²). These results emphasize the role of roof color in optimizing thermal comfort and minimizing environmental impact, highlighting silver-coated zinc as the most sustainable roofing option in hot-humid settings.*

Keywords **–** *Global Warming Potential, Humid tropical climates, Life Cycle Assessment, Roof color, Thermal performance, Zinc roof.*

1. Introduction

Roofs play a vital role in moderating indoor thermal conditions and safeguarding structures from external climatic elements. In low-rise constructions, the roof typically constitutes a larger area than the walls, making it a principal medium for heat transfer. This influence extends to mean radiant temperatures and overall indoor comfort. In air-conditioned buildings, thermal gains through the roof and attic space directly contribute to increased energy consumption for cooling.

Hence, roofing design and attic ventilation are essential for achieving energy efficiency, reducing reliance on fossil fuels, and mitigating environmental impacts such as greenhouse gas emissions. In tropical regions characterized by high humidity and solar intensity, roofs absorb, store, and reflect solar radiation, which alters internal air temperature and relative humidity. Adaptations such as using shaded spaces and traditional materials demonstrate local responses to these climatic conditions. The thermal performance of roofs depends on several variables, including material type, ceiling structure, and roof surface color [1, 2]. Inadequate choices may result in higher attic and indoor temperatures, increasing the need for active cooling solutions [3, 4].

In Manado, North Sulawesi, Indonesia, over 95% of residential structures utilize zinc roofing due to its lightweight properties and structural benefits [5], particularly in earthquake-prone regions along the Pacific Ring of Fire [6, 7]. Zinc roofs are known to absorb and re-emit a substantial portion of solar energy, contributing up to 70% of total heat gains in tropical buildings. Strategies such as passive cooling, reflective coatings, and thermal insulation are implemented to mitigate this heat load [8, 9]. Although various studies have analyzed roof coatings and their thermal effects, few have examined the specific characteristics of zinc roofing in hot and humid climates. Cultural and aesthetic considerations also influence roof color selection. In Manado, colors such as maroon and blue are commonly used, reflecting local identity and preferences. Promoting sustainable alternatives that remain culturally acceptable is therefore important. This study explores the thermal and environmental implications of three prevalent zinc roof finishes, maroon, blue, and silver, commonly seen in Manado. It integrates field measurements with Life Cycle Assessment (LCA) analysis to determine which roof color best balances energy efficiency and ecological impact. The frequency of these roof colors in the study area is illustrated in Figure 1.

Fig. 1 Typical zinc roofs in Manado, Indonesia, predominantly appear in three color variants: blue, maroon, or unpainted silver, reflecting common local practices in roofing material finishes

Numerous prior studies have examined the role of reflective coatings in reducing roof surface temperatures and associated cooling loads. For comparison, Synnefa et al. [10] and Hernández-Pérez [11] examined reflective coatings on conventional materials and demonstrated their cooling benefits. However, their scope did not include zinc roofing in tropical environments nor integrate thermal outcomes into life cycle carbon assessments. Therefore, this study expands upon such findings by specifically analyzing commonly used zinc roofs in Indonesia with different coatings, providing localized and material-specific insights. Advanced coatings, including thermochromic, have been studied. Kitsopoulou et al. [12] found that coatings can reduce heat loss by 0.2 to 3.0 W/m²K, making them important for building exteriors and roofing. Kolokotsa et al. [13] tested mineral-based coatings for energy efficiency and thermal performance. Reflective roofing techniques reduce overheating and improve comfort in tropical heat waves [14].

Rahmani et al. [15] found that cold roofs minimize cooling loads and increase photovoltaic efficiency, resulting in 1.91% power production improvements. Nie et al. [16] tested cold coatings in 32 U.S. climate zones. They found that 30 30 30% to 50% comfort increases during high temperatures, energy savings, operational expenses, carbon emissions, and interior thermal discomfort. Suehrcke et al. [17] determined that the thermal mass of roofs is negligible for daily heat input. The primary factor was surface reflectivity. Smith et al. [18] discovered that dielectric-coated metal roofs exhibit superior reflection of solar infrared compared to paints, reducing cooling energy use and providing visual diversity.

Park et al. [19] observed that Seoul's surface reflectivity under cool roof systems affected indoor thermal conditions more than humidity and insulation in a congested metropolitan setting. They suggested regional climate and architecture affect cool roof requirements. In their study, Tzuc et al. [20] used artificial intelligence algorithms to predict roof coating-induced changes in indoor temperature with an accuracy of roughly 90 percent. This indicates that material progress is noteworthy. According to Hu et al. [21], thermochromic compounds and nano-TiO_2 additions can lower the temperature of plastic substrates by up to 10°C and asphalt concrete roofs by 3.5°C. Zhao et al. [22] found that yellow, red, blue, and green cold coatings increased reflectivity and reduced summer roof temperatures, saving simulation energy. Parker et al. [23] stressed the synergy of ceiling insulation, duct systems, HVAC sizing, and roof reflectivity in energy efficiency. Hernández-Pérez et al. [24], Piselli et al. [25], and Elnabawi et al. [26] found that reflective coatings reduce the urban heat island effect in arid locations. Many studies focus on concrete or composite roofs, but few on painted zinc roofing in humid tropical locations. The thermal conductivity of zinc roofs affects building heat transmission and occupant comfort.

A life cycle assessment (LCA) of painted zinc roofing addressed this gap by assessing its environmental impact. LCA evaluates environmental impacts from raw material extraction to end-of-life management. Zinc roofing manufacture, coating, performance, and recyclability are examined. The building industry has a large environmental impact; hence, such a study is needed to guide sustainable methods while retaining functional efficacy and lifespan. Le et al. [27] used LCA in Western Australia to find that sheet metal roofs had a 9.85 t CO_2-eq—the carbon footprint, with 96% of emissions from raw material acquisition. Recycling cuts footprints by 73%. The World Steel Association [28] confirmed that high-quality steel roofing, with its recyclability and low maintenance, can outperform alternative materials in environmental requirements when coated. Roy et al. [29] found that globally produced coated steel coils have less than 70% the environmental impact of New Zealand-made ones.

Although many studies have focused on the thermal performance of concrete or composite roofs, very few have explored the behavior of zinc roofing, especially when painted, in humid tropical regions. This study compares zinc roofing to other commonly used materials, such as clay tiles and concrete roofs, regarding thermal conductivity, heat retention, and emissivity to provide a broader context. Previous research on clay tile roofs in similar climates showed superior passive cooling but higher embodied energy, while concrete roofs offered thermal mass benefits but retained heat longer. The novelty of this work lies in its dual-layered evaluation: first, by experimentally quantifying the differences in thermal performance among variously colored zinc roofs using controlled field structures; and second, by integrating these differences into a comprehensive Life Cycle Assessment (LCA) to determine their broader environmental impact. Unlike previous studies focusing solely on thermal data or generalized LCA models, this research uniquely correlates real-world thermal measurements with long-term environmental costs.

2. Materials and Methods

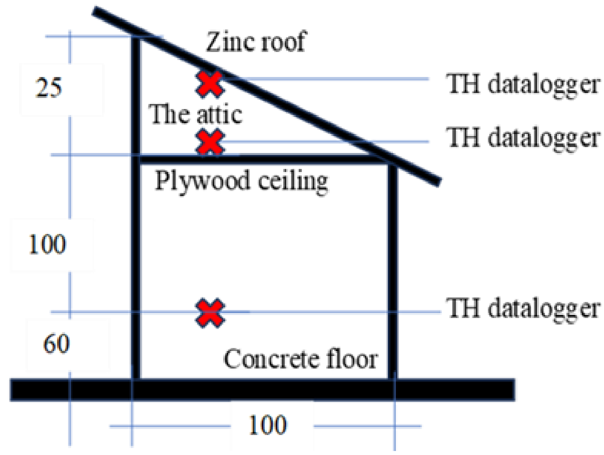
This study compared the thermal and environmental performance of zinc roofs finished in silver (unpainted), blue, and maroon colors. The goal was to determine which color contributed most effectively to reducing indoor and attic heat buildup in a humid tropical environment.

2.1. Experimental Setup

Three identical test structures were constructed, each with a 1.00 × 1.00 m floor plan and standing at heights ranging from 1.60 to 1.85 meters. All units featured zinc roofing and plywood ceilings. One structure remained unpainted (silver), while the others were coated with blue or maroon acrylic-polyester paint. To ensure consistency, the test models were placed in an open area with uniform orientation to minimize the effects of shading, wind, and solar angle differences, as shown in Figure 2a. Due to space and material limitations, the sample size was limited to three units, but measurements were taken repeatedly over an extended period to enhance reliability.

Table 1 presents the construction materials and specifications for the test cells. Since the buildings had plywood panels over wooden frames and no natural ventilation or openings, the temperature could not be controlled.

(a)



(b)

Fig. 2 Three test building models with zinc roofs painted silver, blue, and maroon (a); interior layout showing the placement of measuring instruments used to monitor thermal conditions in each test room (b)

Table 1. Materials used in test models

Component	Area (m²)	Thickness (mm)	Density (kg/m³)
Zinc roof	2.72	0.2	7,135
Plywood wall	3.75	3	680
Plywood ceiling	1.00	3	680

2.2. Instrumentation and Data Collection

Temperature readings were gathered using GSP-6 sensors mounted on roof surfaces and RC-4HC thermohygrometers placed in the attic and indoor space (approximately 60 cm above the floor), as shown in Figure 2b. Each device could record up to 16,000 data points with an accuracy of ±0.5 °C for temperature and ±3% for relative humidity, as shown in Table 2. Data were logged at 10-minute intervals over a three-month dry season (June-August). While the three-month monitoring provides a representative snapshot, longer durations, ideally covering both dry and wet seasons, would improve the robustness.

Table 2. Instrumentation used for thermal measurements

Instrument Type	Model	Capacity (points)	Temperature Accuracy (°C)	Humidity Accuracy (%)
Thermo-hygrometer	GSP-6	16,000	±0.5	±3
Thermo-hygrometer	RC-4HC	16,000	±0.5	±3

2.3. Site Description and Climatic Conditions

The experiment was conducted in Manado, Indonesia (1.4583° N, 124.8260° E), characterized by a humid tropical climate. Temperature ranges from 26.9 °C in January to 29.1 °C in October. Rainfall is heaviest from November to March, peaking in January at 465 mm. Humidity varies seasonally between 64% and 81%. Climate Consultant software [30] validated annual temperature and humidity patterns, confirming the need for passive cooling strategies. Data shows that daily temperatures surpass thermal comfort criteria from 08:00 to 20:00, supporting passive cooling solutions.

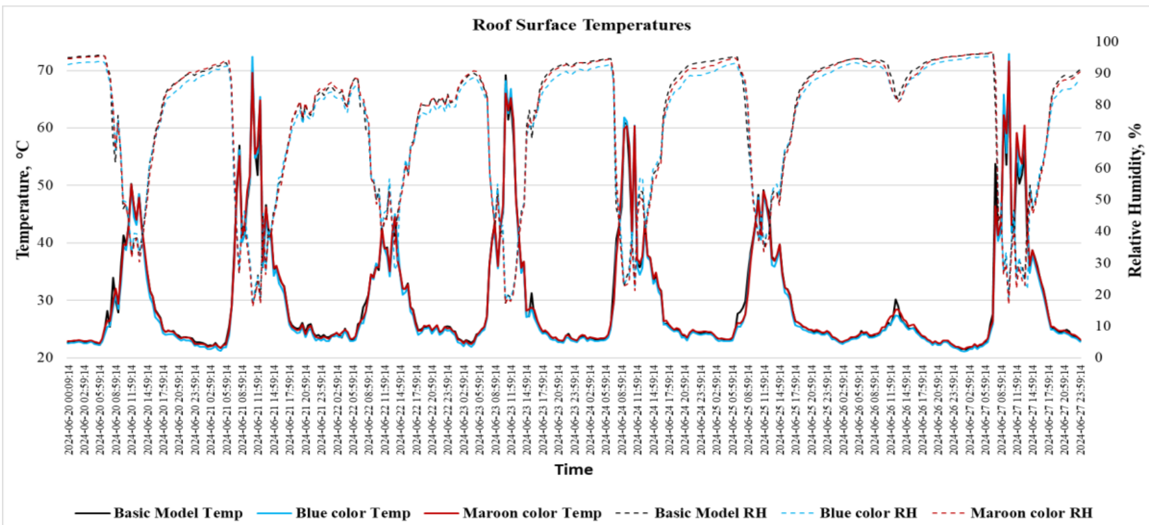
2.4. Life Cycle Assessment (LCA) Framework

A cradle-to-grave LCA was performed in accordance with ISO 14040 and 14044 [31, 32]. The scope included production, painting, transport, installation, maintenance, and end-of-life phases. The functional unit was one square meter of roofing over a 20-year lifespan. Data were derived from published databases and scientific literature. The emissions were calculated as follows: 6.7 kg CO_2-eq/m² for zinc sheet production [33], 1.2 kg CO_2-eq/m² for painting (for colored roofs only) [34, 35], 0.144 kg CO_2-eq/m² for freight (ship and truck) [36, 37], 0.10 kg CO_2-eq/m² for installation [38], and 0.6 kg CO_2-eq/m² per repaint cycle every 10 years [34, 35]. Recycling at the end of life reduced emissions by 1.3 kg CO_2-eq/m² [39]. This method enabled the comparison of emissions from each roofing type throughout its life cycle and their correlation with energy savings due to variations in thermal efficiency.

3. Results and Discussion

3.1. Roof Surface Temperatures

Measurements over eight days under varied weather conditions revealed that surface temperatures for all roof colors, silver, blue, and maroon, were relatively similar (Figure 3a). The maroon and blue roofs showed slightly higher maximum temperatures, but statistical analysis indicated no significant difference ($p > 0.8$) between roof types. The small variation is likely due to external influences such as cloud cover and airflow. Although the maroon roof had higher absorptivity (0.85) and emissivity (0.90), these properties did not produce dramatic differences in surface heat [40, 41].



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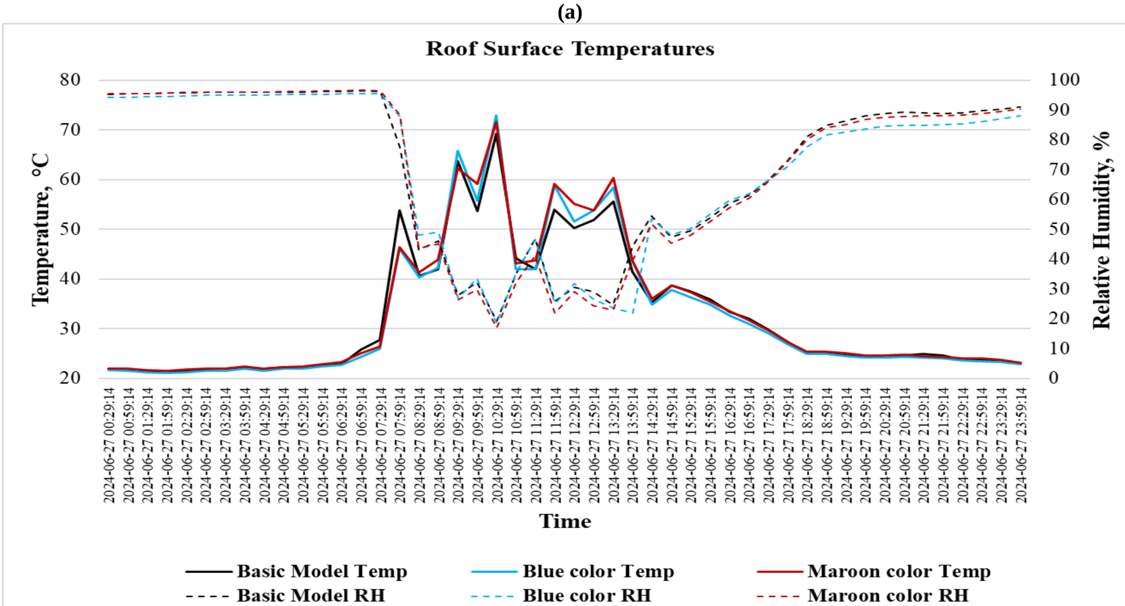

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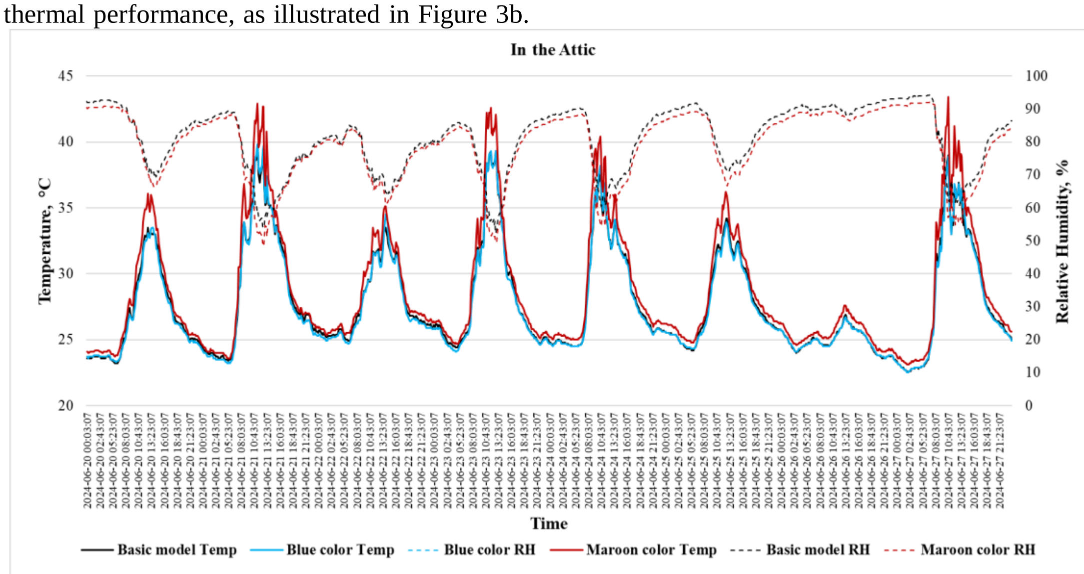
Fig. 3 Typical zinc roofs in Manado, Indonesia, predominantly appear in three color variants: blue, maroon, or unpainted silver, reflecting common local practices in roofing material finishes

Average temperatures ranged from 29.6°C to 30.1°C across all roof types. Silver roofs heated up earlier in the morning, followed by blue in mid-morning, and maroon in the afternoon. This sequence reflects microclimatic responses to solar exposure. Despite the similarity in surface data, deeper differences were noted in attic and interior temperatures. Interestingly, maroon roofs frequently corresponded with significantly higher internal air temperatures, suggesting that heat transfer into attics and building envelopes considerably impacts thermal comfort and energy efficiency, necessitating comprehensive inclusion in life cycle assessments. Surface temperature measurements for untreated (silver), maroon-painted, and blue-painted zinc roofs show minimal overall variation in thermal performance, as illustrated in Figure 3b. Peak surface temperatures were predominantly observed on the blue and maroon roofs. The blue and maroon roofs generally exhibited the highest surface temperatures.

3.2. Attic Air Temperature

Attic temperature results showed clear differences aligned with roof color. The maroon roof consistently resulted in the highest attic temperatures, with a mean of 28.6 °C and a peak of 43.4 °C. In contrast, the silver and blue roofs had lower average values (27.7 °C and 27.6 °C, respectively), as shown in Figure 4a. The maroon roof's high thermal absorption led to increased heat transfer through conduction and radiation.



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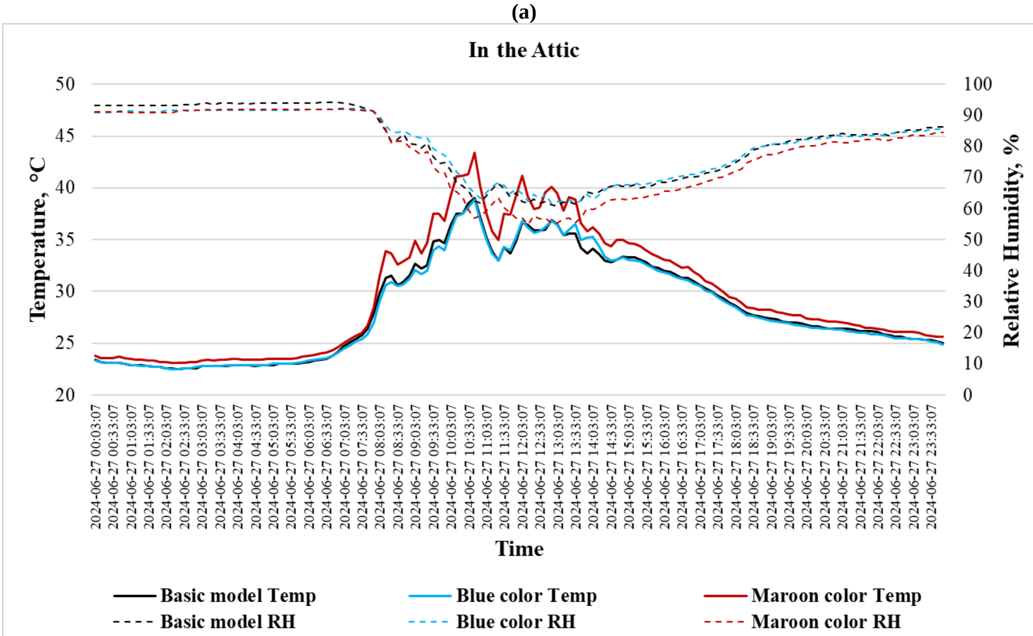


(b)

Fig. 4 (a) Attic temperature distribution for each of the three roof colors over a period of eight days, and (b) Daily trends for each of the three roof colors.

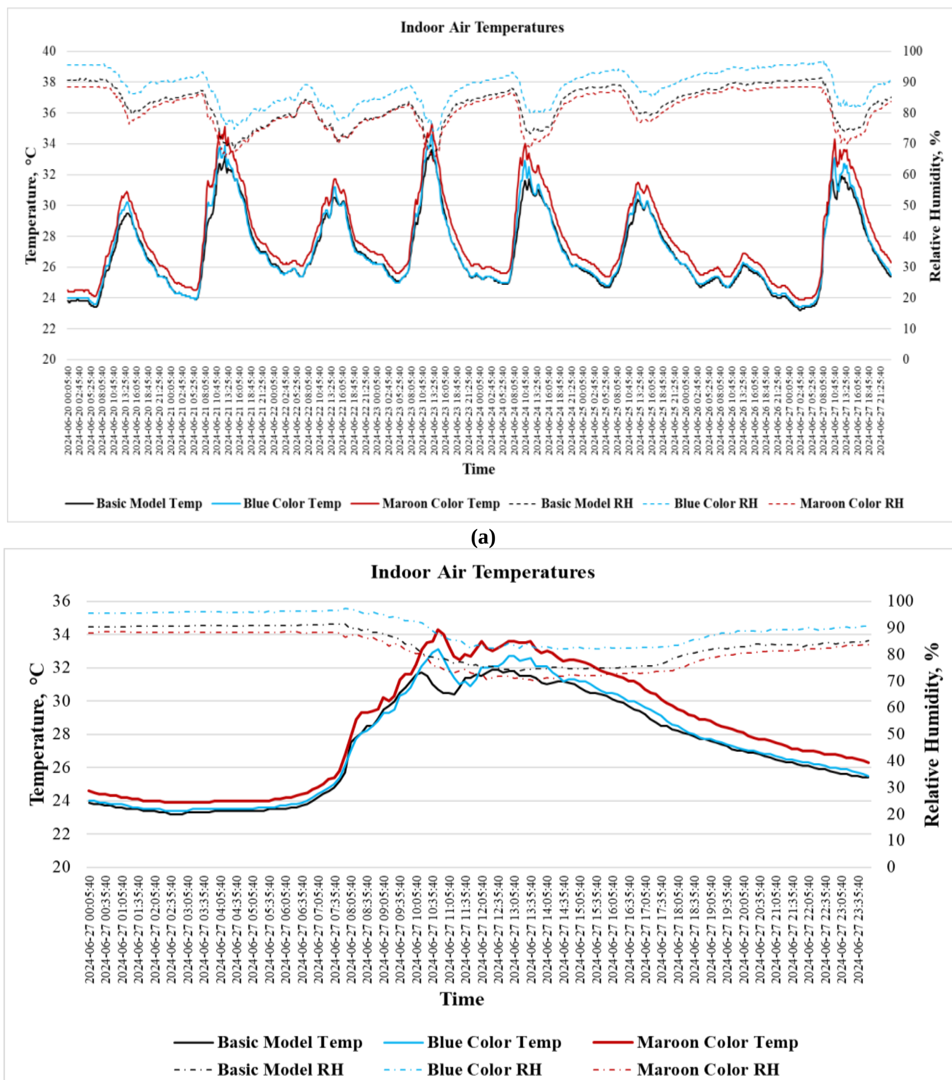
Daily averages reinforced these patterns, with maroon roofs consistently showing the highest attic temperatures (29.58 °C), followed by unpainted (28.37 °C) and blue (28.29 °C) roofs (Figure 4b).

Statistical comparisons confirmed that the differences between maroon and both silver and blue roofs were significant ($p < 0.05$), while silver and blue were not significantly different ($p = 0.89$). This confirms that higher surface absorptivity leads to more heat entering the attic, influencing cooling loads and occupant comfort. The elevated temperatures in maroon roofs are attributable to their higher absorptivity ($\alpha = 0.85$) and emissivity ($\varepsilon \approx 0.90$), which enhance both solar heat absorption and heat emission into the attic space. In contrast, blue and unpainted roofs, with lower absorptivity ($\alpha = 0.04$), limited heat gain and maintained lower attic temperatures despite minor differences in emissivity.

These findings underscore the thermal advantages of blue-painted zinc roofs in reducing attic heat accumulation and cooling energy demands. The significant thermal impact of maroon roofs highlights the need to integrate attic temperature dynamics into energy models and Life Cycle Assessments (LCAs) for a more accurate evaluation of roofing material performance throughout the building's operational phase.

3.3. Indoor Air Temperature

The impact of roof color extended to indoor air temperature. Rooms under maroon roofs recorded the highest internal temperatures, with an average of 28.3 °C and peaks reaching 35.3 °C (Figure 5a). Silver and blue roofs maintained lower average temperatures at 27.2 °C and 27.5 °C, respectively, as shown in Figure 5b. The higher absorptivity of maroon surfaces allowed for greater thermal gain through the roof assembly.



(b)

Fig. 5 (a) Indoor air temperature profiles for each of the three roof colors during eight days, and (b) Daily trends for each of the three roof colors.

Rooms beneath maroon roofs consistently recorded the highest indoor temperatures, attributed to higher absorptivity ($\alpha \approx 0.85$) and emissivity ($\varepsilon \approx 0.90$), facilitating greater solar heat gain and radiative transfer into interior spaces. The enhanced heat transfer from the roof to the attic and occupied areas led to significantly elevated internal temperatures. In contrast, the blue and unpainted zinc roofs, with low absorptivity ($\alpha = 0.04$), maintained lower indoor temperatures, with only a negligible and statistically insignificant difference between them.

The indoor temperature differences between maroon and the other two roof types were statistically significant ($p < 0.05$), with no significant difference between silver and blue. These findings demonstrate that while surface temperatures may appear comparable, the thermal performance inside the building varies significantly, reinforcing the importance of selecting roof finishes that limit heat transmission. Maroon-painted roofs may significantly increase cooling energy needs in hot, humid climates. Blue-painted roofs provide a balance between aesthetics and thermal performance. These insights are vital for integrating thermal data into LCAs to inform sustainable and climate-responsive building design. Normality tests were conducted to validate the assumptions prior to applying ANOVA.

In cases where normality was rejected, non-parametric tests were used. Pearson correlation analyses were also applied to explore the relationship between surface temperature, attic temperature, and indoor comfort. Results showed a strong positive correlation ($r > 0.75$) between roof absorptivity and indoor temperature rise.

Boxplots and heat maps could be added in future publications to visualize daily temperature fluctuations across roof colors better to enhance clarity.

3.4. Life Cycle Assessment of Carbon Emissions

A 20-year Life Cycle Assessment (LCA) was conducted to evaluate the Global Warming Potential (GWP) per square meter of zinc roofing systems with varying surface treatments. The LCA encompasses six key phases: material production, surface coating, transportation, installation, maintenance, and end-of-life recycling. Emissions data were drawn from standard databases and publications [31-39].

Table 3 summarizes emissions: Zinc sheet production contributed 6.7 kg CO_2-eq/m²; painting added 1.2 kg CO_2-eq/m² (for blue and maroon roofs only); transportation and installation accounted for 0.144 and 0.10 kg CO_2-eq/m², respectively; repainting maintenance added 0.6 kg CO_2-eq/m² (every 10 years); and recycling at end-of-life reduced emissions by 1.3 kg CO_2-eq/m². Total 20-year GWP values were 5.644 kg CO_2-eq/m² (silver), 7.444 kg CO_2-eq/m² (blue), and 7.444 kg CO_2-eq/m² (maroon), as shown in Table 4.

Table 3. The life cycle data for materials and production processes

Component	Material	Emission CO_2-eq (kg CO_2-eq/m²)
Zinc sheet production	Galvanized steel (zinc-coated steel)	6.7
Painting process	Acrylic/polyester-based paint (40–60 μm)	1.2
Transportation	Freight Ship: Surabaya-Manado (1,800 km) and diesel truck (50 km)	0.144
Installation	Energy and light equipment	0.10
Maintenance	Repainting (per 10 years) only for painted ones.	0.6
End of life	Metal recycling (85%)	-1.3

Table 4. GWP calculation, total kg CO_2-eq per m² per 20 years

Roof Color	Silver	Blue	Maroon
Production	6.7	6.7	6.7
Painting	0	1.2	1.2
Transportation	0.144	0.144	0.144
Instalation	0.10	0.10	0.10
Maintenance	0	0.6	0.6
End of life	-1.3	-1.3	-1.3
Total	5.644	7.444	7.444

Although blue and maroon roofs had the same embodied emissions, blue's moderate reflectivity (25%) allowed for reduced cooling energy, while maroon (20%) performed poorly. Silver, with 65% reflectivity, minimized the need for mechanical cooling, thus achieving the best environmental performance. The findings support previous literature advocating reflective roofs in hot-humid environments [40, 41, 42]. Assuming maroon roofs consumed 6 kWh/m²/year [43] in cooling, blue and silver roofs offered annual savings of 0.5 and 2.0 kWh/m², respectively. Over 20 years, this equated to 10 kWh (blue) and 40 kWh (silver) in cooling energy savings (Table 5).

The LCA compared the total Global Warming Potential (GWP) over 20 years for each roof color. Silver roofs showed the lowest net GWP at –27.16 kg CO_2-eq/m², followed by blue at –0.76 kg CO_2-eq/m². Maroon roofs had the highest net emissions at +7.444 kg CO_2-eq/m². These values include emissions from production, painting, maintenance, and cooling energy, with end-of-life recycling considered a negative offset (Table 6).

Table 5. The Life Cycle Assessment (LCA) of roof colors

Roof Color	Silver	Blue	Maroon
Reflectivity	65%	25%	20%
Air Conditioning Consumption	4.0 kWh/m²/tahun	5.5 kWh/m²/tahun	6 kWh/m²/tahun
Estimation Saving (vs. Maroon)	2.0 kWh × 20 = 40 kWh	0.5 kWh × 20 = 10 kWh	-
Total Savings (20 years)	40 kWh	10 kWh	0

Table 6. Net GWP (Post Energy Compensation)

Roof Color	GWP Before Compensation	Energy Compensation	Net GWP
Silver	5.644	-32.8	-27.16
Blue	7.444	-8.2	-0.76
Maroon	7.444	0	7.444

In contrast, maroon-painted roofs, reflecting only 20% of solar radiation, had the highest net GWP of +7.444 kg CO_2-eq/m². Although blue and maroon roofs share identical material and coating emissions, the moderate reflectivity of blue roofs (25%) results in improved thermal performance and a reduced net GWP of -0.76 kg CO_2-eq/m².

These findings reinforce previous studies that link higher roof reflectivity to decreased cooling demand [44, 45]. From a life cycle perspective, roof color selection is critical in designing low-carbon, energy-efficient buildings for tropical climates.

Design decisions should prioritize reflective roofing solutions to maximize environmental performance. Accordingly, building policies and standards should support the adoption of high-albedo materials in hot-humid regions to optimize long-term sustainability outcomes.

In broader terms, the selection of roof color affects thermal comfort and total energy expenditure. In tropical climates where air-conditioning costs can represent 30–50% of total household energy bills, even minor reductions in indoor temperature can yield significant economic benefits. For instance, a 1°C reduction in indoor temperature can cut cooling loads by up to 7%. This demonstrates how reflective roofing has potential economic advantages over time.

3.5. Limitations and Further Considerations

This study confirms that roof color, particularly maroon-painted zinc, significantly impacts surface, attic, and indoor air temperatures during the day, with maroon roofs consistently exhibiting the highest thermal loads. While silver and blue roofs showed no significant temperature difference, silver displayed a slight advantage in thermal regulation. Limitations in measuring reflectivity and absorptivity suggest more precise instruments and extended testing under controlled conditions.

Nighttime data revealed different thermal behavior, emphasizing the importance of time-segmented analysis and consideration of factors like solar intensity, shading, and microclimate. The study's narrow scope, limited sample size, short duration, and single building type suggest that broader research is necessary. Real-world energy use is also affected by occupant behavior, building use, HVAC performance, and regional climate variability.

While this study focused on Manado, its findings may not be universally applicable. Variations in solar radiation, building typologies, and user behaviors in other humid tropical regions could lead to different thermal and energy performance outcomes.

The LCA relies on standardized transport, maintenance, and recycling assumptions that may not reflect diverse global conditions. Factors such as fuel type, grid emissions, and infrastructure in Manado may limit generalizability. Energy savings from reduced AC use are likewise influenced by user behavior and weather extremes.

Future studies should incorporate additional construction elements (e.g., fasteners, drainage, insulation) and update emission inventories to reflect regional and technological developments. Despite limitations, the findings support using high-reflectivity silver roofing for improved thermal comfort and environmental performance in tropical climates.

4. Conclusion

This study assessed the thermal behavior and environmental impact of three zinc roofing types, silver (unpainted), blue-painted, and maroon-painted, in a humid tropical climate using identical test structures. While surface temperature differences were minimal, the influence of roof color on attic and indoor thermal performance was significant. Maroon-colored roofs consistently exhibited higher temperatures in both attic and interior spaces, due to their high absorptivity and emissivity properties. Blue-painted roofs showed moderate performance, offering better thermal outcomes than maroon but less effective than unpainted silver. Silver roofs emerged as the most thermally efficient, maintaining the lowest internal temperatures across all zones. These thermal patterns correlated strongly with the Life Cycle Assessment (LCA) results, where silver roofs demonstrated the lowest net Global Warming Potential (GWP), followed by blue, with maroon being the least sustainable. The findings reinforce the importance of roof color as a functional design decision, rather than merely an aesthetic preference. In hot and humid regions, roof finish significantly affects indoor comfort and long-term energy use. Unpainted silver zinc roofs are therefore strongly recommended for tropical applications due to their high reflectivity, low maintenance, and superior life cycle performance. Where aesthetic constraints exist, blue-painted zinc may serve as a compromise, while maroon roofs should be avoided.

This research underscores the critical role of material and color selection in enhancing energy efficiency and reducing carbon emissions. It offers evidence-based guidance for architects, planners, policymakers, and local communities to support climate-resilient, sustainable building practices in tropical environments. Engaging with local builders, suppliers, and homeowners could facilitate greater adoption of sustainable roofing options. Policy recommendations should be co-developed with stakeholders to ensure cultural fit and practical feasibility.

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Author contributions

JIK: conceptualization, methodology, formal analysis and investigation, original draft preparation, review and editing, funding acquisition, resources, and supervision; OBS: methodology, funding acquisition, resources, supervision; OHR: formal analysis and investigation, review and editing; JCM: review and editing, supervision. All authors have read and agreed to the published version of the manuscript.

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