

FIELD EVALUATION OF ATTIC-INDOOR TEMPERATURE DYNAMICS BENEATH A LIGHTWEIGHT METAL ROOF IN A HOT-HUMID TROPICAL CLIMATE, OWERRI, NIGERIA

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Abstract

Lightweight metal roofs are widely used in hot-humid residential environments, yet long-term field evidence on the relationship between attic and occupied-space air temperatures beneath such roof configurations remains limited. This study evaluated the diurnal and seasonal attic-indoor temperature dynamics of a residential building in Owerri, Nigeria, comprising a black stone-coated metal roof, an attic with no purpose-provided ventilation, and a plaster-of-Paris ceiling. Attic and occupied-space air temperatures were synchronously monitored from 2 October 2024 to 22 June 2025 at six-hour intervals, yielding 1,052 paired observations. Descriptive statistics, temperature-amplitude analysis, Pearson correlation and ordinary least-squares regression were used to characterise the relationship between the two monitored environments, with Newey–West heteroskedasticity- and autocorrelation-consistent standard errors applied to regression inference. Mean attic air temperature was 31.15 °C compared with 30.57 °C in the occupied space, while temperature amplitudes were 7.40 °C and 5.85 °C, respectively, corresponding to an attic-to-indoor temperature-amplitude ratio of 0.79. Mean attic-indoor temperature difference decreased from 0.66 °C during the dry-season period to 0.40 °C during the wet-season onset. Attic and occupied-space temperatures were strongly positively correlated ($r = 0.956$, $p < 0.001$), and the regression model showed a high degree of shared linear variation ($R^2 = 0.913$). These findings provide field-based observational evidence of strong but temporally variable thermal coupling between the attic and occupied space for the investigated roof-attic-ceiling configuration. They further indicate the relevance of considering roof solar heat gain, attic ventilation and ceiling thermal resistance within an integrated building-environment approach to passive thermal design. The findings are configuration-specific and do not establish attic temperature as an independent cause of occupied-space thermal conditions.

Keywords: Attic-indoor dynamics; Field monitoring; Hot-humid climate; Lightweight roof; Thermal attenuation

INTRODUCTION

Residential buildings in hot-humid tropical climates are subjected to substantial thermal loads arising from high ambient temperatures, intense solar radiation and elevated atmospheric

humidity. The resulting indoor thermal conditions are influenced by interactions between climatic forcing, site characteristics and building-envelope properties, including orientation, surrounding shading, ventilation, fenestration, construction materials and internal heat gains. Consequently, the thermal behaviour of a building cannot be considered independently of its site and external environment; rather, indoor temperature represents the combined response of the building and its occupied spaces to multiple external and internal thermal influences.

Within the building envelope, the roof is particularly important because of its substantial exposure to incident solar radiation. During daytime periods, part of the incident solar energy is reflected by the roof surface, while the remainder is absorbed and converted to heat. The magnitude of this heat gain and its subsequent transmission depend on roof material and colour, solar absorptance and reflectance, surface emissivity, insulation, geometry, ventilation and exposure to shading. Recent field evidence from tropical Africa demonstrates the importance of roof construction in modifying indoor thermal conditions. Amankwaa et al. (2025), in a 389-day field study involving 16 classrooms in Accra, Ghana, found that metal-roofed classrooms experienced substantially higher temperatures than comparable concrete-roofed classrooms, demonstrating the importance of roof type in determining thermal exposure under tropical climatic conditions.

The thermal influence of a lightweight metal roof, however, should not be interpreted as a direct or isolated relationship between the external roof covering and indoor air temperature. The roof assembly, attic space, ceiling and occupied indoor environment are physically distinct but thermally interacting components. Solar energy absorbed by the external roof covering may be conducted through the roofing material and subsequently exchanged with the attic environment through convection and long-wave radiation. Attic air temperature therefore represents the thermal condition of the enclosed roof cavity rather than the temperature of the roof material itself. Its thermal behaviour is further influenced by roof geometry, attic volume, ventilation, insulation, ceiling characteristics and prevailing outdoor climatic conditions.

The attic and ceiling consequently form important intermediate components in the thermal pathway between the external roof and the occupied space. Evidence from Nigeria demonstrates the potential importance of thermal resistance within this pathway. Bashir and Leite (2022) evaluated aerogel insulation for residential buildings under Nigerian tropical climatic conditions and found that its application, particularly within the attic and floor-slab configurations investigated, reduced indoor mean air and operative temperatures and lowered simulated building-energy consumption. Although based principally on building-energy simulation, the study demonstrates the potential importance of insulation in limiting heat transmission through tropical building envelopes.

Attic ventilation represents another important mechanism for controlling accumulated roof-space heat. Moharrami et al. (2025), using field measurements and building-energy simulation in tropical residential buildings, demonstrated that hybrid attic ventilation reduced indoor temperature and relative humidity and produced measurable reductions in cooling-energy demand. These findings are particularly relevant to lightweight roof configurations because they indicate that the thermal conditions occurring beneath the roof covering are

influenced not only by roofing material but also by the capacity of the attic to remove accumulated heat.

Strategies that reduce solar heat absorption at the external roof surface can further moderate thermal loading within the roof–attic system. Aw et al. (2024), through field measurements of insulated and uninsulated metal roofs in tropical Malaysia, demonstrated that modification of the external metal-roof configuration through the introduction of a vegetative layer improved its thermal performance. More broadly, recent investigations of tropical building envelopes have demonstrated that material configuration and passive thermal-control interventions can modify heat transmission through the envelope and reduce thermal loads under hot climatic conditions (Elenga et al., 2025). These findings support an integrated approach in which roof-surface characteristics, insulation, attic configuration and heat-removal mechanisms are considered collectively rather than treating the roof covering as an isolated thermal component.

Indoor air temperature, however, is not determined solely by heat transferred through the roof–attic–ceiling configuration. Heat exchange through walls, windows and floors, together with orientation, outdoor air temperature, ventilation, infiltration, occupancy, equipment and other internal heat sources, may simultaneously affect the thermal state of an occupied space. Accordingly, a statistical relationship between attic and indoor air temperatures should be interpreted as evidence of thermal association or coupling rather than proof that attic temperature is the sole cause of indoor temperature variation. This distinction is particularly important in observational field studies in which individual heat-transfer pathways are not experimentally isolated.

Field monitoring provides an important means of investigating these thermal interactions under actual climatic and building conditions. Unlike idealised boundary conditions, long-term measurements capture the combined influence of real weather exposure, construction characteristics and temporal variations in the building environment. The long-term field investigation by Amankwaa et al. (2025), for example, demonstrates the value of extended monitoring for identifying persistent temperature differences associated with roof construction under tropical African conditions. Similarly, synchronised monitoring of attic and occupied-space air temperatures can reveal the strength and temporal pattern of their thermal relationship across repeated diurnal cycles and seasonal transitions.

Despite increasing research on roof materials, insulation and passive attic heat-control strategies, long-term field evidence characterising synchronised attic–indoor air-temperature dynamics beneath lightweight metal roofs remains comparatively limited in hot-humid Nigerian residential environments. Existing studies provide evidence of the potential effectiveness of envelope insulation and other passive interventions, but there remains a need for field-based investigation of how attic and occupied-space air temperatures vary together over extended periods within actual residential roof–attic–ceiling configurations.

Against this background, the present study investigates attic–indoor air-temperature dynamics in a residential building in Owerri, southeastern Nigeria, comprising a stone-coated lightweight metal roof, an unventilated attic and a plaster-of-Paris ceiling. Using long-term

synchronised field measurements, the study characterises diurnal and seasonal temperature behaviour, evaluates the attenuation of temperature fluctuations between the attic and occupied space, and statistically examines the association between the two monitored environments. Rather than assuming that attic temperature is the sole determinant of indoor thermal conditions, the study evaluates attic–indoor thermal coupling within the investigated configuration while recognising the potential influence of other building, site and environmental factors.

Statement of the Problem

Residential buildings in hot-humid tropical environments are exposed to substantial and recurrent thermal loads resulting from high ambient temperatures and solar radiation. Lightweight metal roofs, which are widely used in Nigerian residential construction, are particularly responsive to solar heating because of their low thermal mass. However, the thermal conditions occurring beneath such roofs are influenced not only by the roof covering but also by the configuration of the attic, its ventilation characteristics, the thermal resistance of the ceiling, external climatic conditions and other building and site factors.

The attic constitutes an important intermediate thermal zone between the external roof assembly and the occupied indoor environment. Solar-induced heating of the roof can contribute to elevated attic temperatures, while subsequent heat exchange across the ceiling may influence the occupied space. Recent studies have demonstrated that roof construction, insulation and attic ventilation can modify thermal conditions in tropical buildings (Bashir & Leite, 2022; Aw et al., 2024; Amankwaa et al., 2025; Moharrami et al., 2025). Nevertheless, indoor air temperature is simultaneously influenced by other heat-transfer pathways and environmental factors, including walls, fenestration, floors, outdoor air temperature, ventilation, orientation, shading, occupancy and internal heat gains. The contribution of attic thermal conditions must therefore be investigated as part of this wider building–environment interaction rather than treated as the sole determinant of indoor temperature.

Despite increasing research on tropical building-envelope performance and passive heat-control strategies, long-term field evidence characterising synchronised attic and occupied-space air temperatures beneath lightweight metal roofs remains limited in hot-humid Nigerian residential environments. Much of the available literature has focused on overall thermal comfort, envelope interventions, simulations or comparisons of roofing materials, with comparatively less attention given to the long-term temporal coupling between attic and occupied-space air temperatures under actual residential conditions. Consequently, the extent to which temperature fluctuations within an unventilated attic are attenuated between the attic and occupied space, how this relationship varies across diurnal and seasonal periods, and the strength of the statistical association between the two thermal environments remain insufficiently documented for common Nigerian residential roof configurations.

This empirical gap limits the evidence available for evaluating the thermal behaviour associated with lightweight roof–attic–ceiling configurations and for identifying roof-specific passive design measures appropriate to hot-humid residential environments. Long-term

synchronised field monitoring is therefore required to characterise attic–indoor air-temperature dynamics under actual climatic exposure while recognising the influence of other building, site and environmental factors. The present study addresses this gap through field monitoring of a residential building in Owerri, Nigeria, comprising a stone-coated metal roof, an unventilated attic and a plaster-of-Paris ceiling.

Aim and Objectives of the Study

The aim of this study is to evaluate the diurnal and seasonal relationship between attic and occupied-space air temperatures beneath a lightweight stone-coated metal roof with a plaster-of-Paris ceiling in a hot-humid tropical residential building using long-term synchronised field measurements.

The study has two principal objectives:

- i. To characterise the diurnal and seasonal variation of attic and occupied-space air temperatures and evaluate the attenuation of temperature fluctuations between the two monitored environments.
- ii. To determine the statistical relationship between attic and occupied-space air temperatures and examine its implications for passive roof design in hot-humid tropical residential environments.

Study Area and Site Context

The study was conducted in Owerri, the capital of Imo State in southeastern Nigeria. Owerri lies within a hot-humid tropical climatic region characterised by generally high air temperatures, substantial annual rainfall, elevated relative humidity and considerable solar exposure. These climatic conditions impose recurrent thermal loads on building envelopes, particularly roof surfaces exposed to solar radiation, and provide an appropriate environmental context for investigating attic–indoor temperature dynamics in residential buildings.

The monitored residential building is located within the Federal Housing Authority (FHE) Estate, Lower Irete, Owerri. The estate is a densely built-up residential neighbourhood comprising the study building and other surrounding residential buildings. Consequently, the monitored building was not thermally isolated from its immediate surroundings but existed within an established urban residential setting in which neighbouring buildings formed part of the local environmental context. No substantial vegetation was identified as a dominant shading element around the monitored building; however, the potential influence of surrounding buildings on local solar exposure and airflow is recognised.

The immediate site context is relevant to the interpretation of the measurements because surrounding development can influence solar access, shading and local airflow, while prevailing climatic conditions provide the external thermal forcing to which the building envelope responds. Accordingly, the measured attic and occupied-space air temperatures are

interpreted as thermal responses occurring within the actual building–site–climate environment rather than as effects attributable exclusively to the roof covering. The exact cardinal orientation of the monitored building was not documented during the field-monitoring campaign and is therefore not used as an explanatory variable in the analysis. Detailed characteristics of the building, roof–attic–ceiling configuration and temperature-monitoring locations are presented in the Methodology section. The location of the study area is shown in Figure 1. Location of the study area: (a) Imo State within Nigeria; (b) Owerri within Imo State; and (c) Federal Housing Authority Estate, Lower Irete, within the Owerri urban area.



Figure 1(a) :Map of Imo State within Nigeria Nigeria
Source : Emeribole (2015)

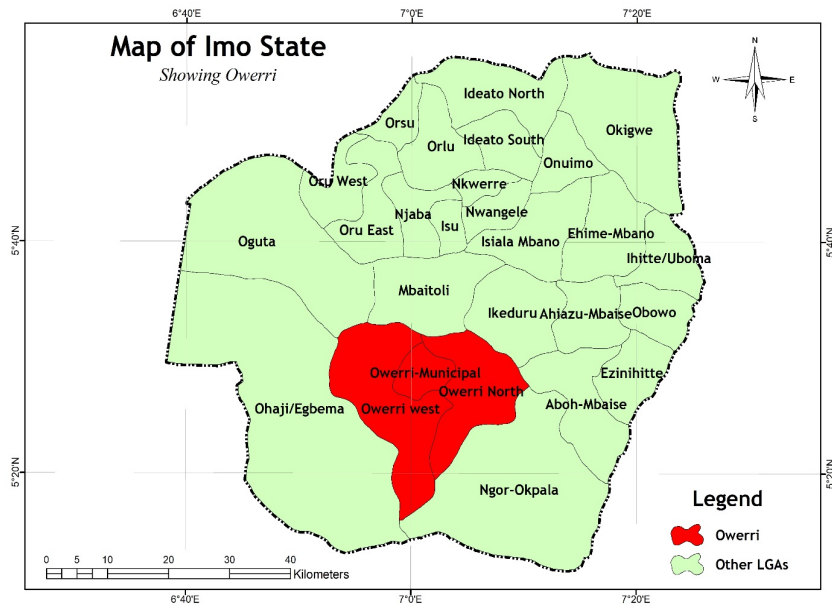


Figure 1(b): Map of Imo State showing Owerri
Source : Emeribole (2015)

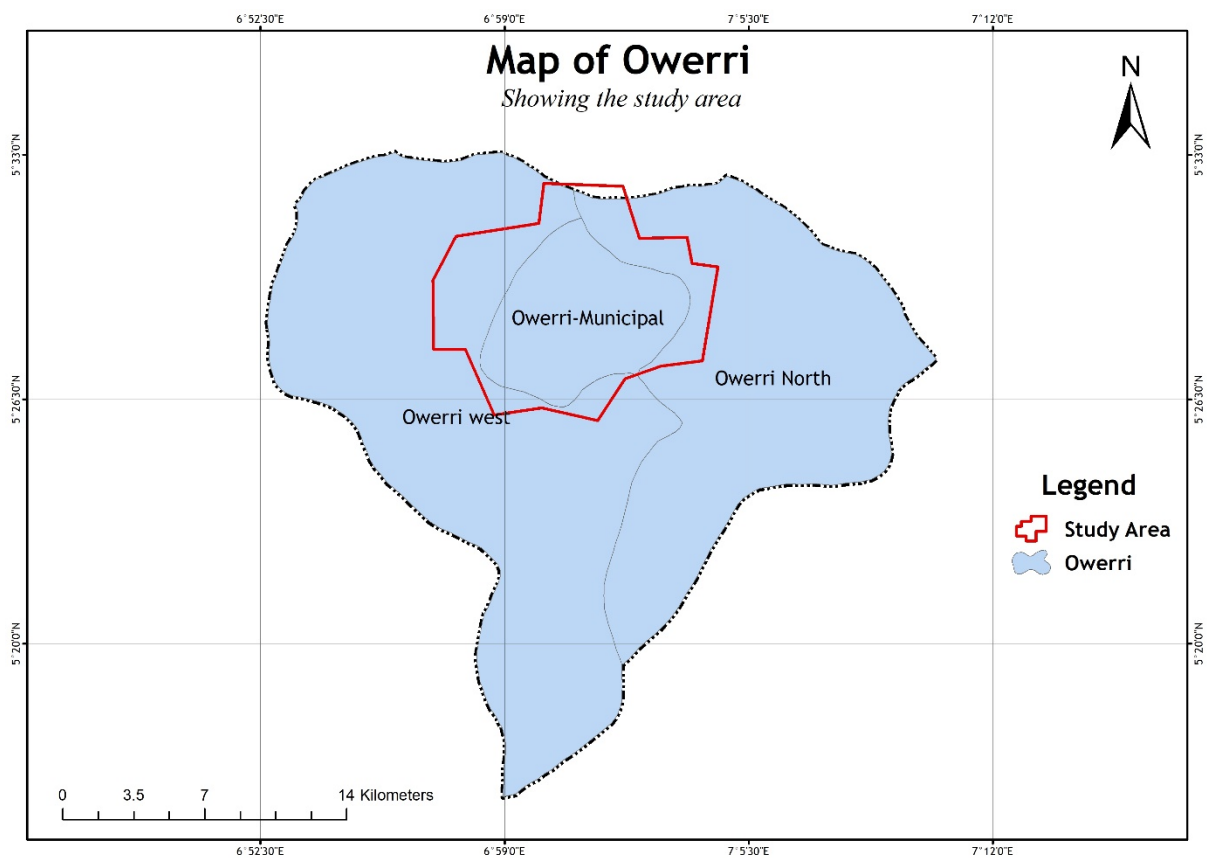


Figure 1(c): The study area within Owerri
Source : Emeribole (2015)

LITERATURE REVIEW

Theoretical Framework

This study is primarily anchored in General Systems Theory and is complemented by Ecological Modernisation Theory (EMT). The two perspectives perform different but related functions. Systems Theory provides the conceptual basis for interpreting the thermal interactions among the external environment, roof assembly, attic space, ceiling and occupied indoor space, while EMT provides a broader framework for relating empirical thermal-performance evidence to environmentally responsive technological and design improvement.

General Systems Theory: General Systems Theory conceptualises a system as an organised set of interrelated components whose behaviour is shaped by interactions among the components and by exchanges across the system boundary. A central principle of the theory is that complex phenomena should not be understood solely by examining individual components in isolation; rather, attention should be given to the relationships, flows and feedback processes that connect them within the larger system (von Bertalanffy, 1972; Caws, 2015).

Applied to building thermal behaviour, this perspective permits the investigated building to be conceptualised as an open thermal system that continuously exchanges energy with its external environment. Solar radiation, outdoor air temperature, atmospheric conditions, surrounding development and airflow constitute external influences acting on the building envelope. Within the building, the roof covering, attic air space, ceiling and occupied indoor environment constitute physically distinct but thermally interacting subsystems. The ceiling forms an important thermal interface between the attic and occupied space, separating the two air environments while permitting heat transfer through conduction and surface heat exchange. Accordingly, variations in attic air temperature may contribute to the thermal conditions of the occupied space through heat transfer across the ceiling, although indoor air temperature is also influenced by other components of the building–environment system.

The relevance of Systems Theory to the present study lies particularly in its emphasis on interaction rather than isolated causation. The attic is not treated as synonymous with the roof assembly or occupied space, nor is indoor air temperature assumed to result exclusively from attic thermal conditions. Instead, attic and indoor temperatures are interpreted as system-response variables occurring within a wider building–site–climate interaction. Other components, including walls, windows, floors, ventilation pathways, occupancy and internal heat gains, may also influence the indoor thermal state. This systems perspective therefore supports interpretation of the measured attic–indoor relationship as thermal coupling within an interconnected building system rather than as evidence of a single causal heat-transfer pathway.

The dynamic nature of the framework is also relevant to the diurnal and seasonal focus of the investigation. External climatic forcing varies over time, producing corresponding temporal responses within the attic and occupied space. Differences in temperature amplitude,

attic–indoor temperature gradients and the statistical association between synchronised attic and indoor air temperatures can therefore be interpreted as indicators of how the monitored subsystems respond to changing environmental forcing. Systems Theory consequently provides the principal conceptual basis for examining the temporal interaction between the two monitored environments while recognising the influence of the wider building and site context.

Ecological Modernisation Theory: Ecological Modernisation Theory emerged as an approach to understanding how environmental pressures associated with modern development may be addressed through technological innovation, institutional change and the incorporation of environmental considerations into production and design processes. Rather than treating economic or technological development as inherently incompatible with environmental protection, EMT emphasises the possibility of restructuring technologies and practices so that environmental performance becomes integrated into development processes (Mol & Spaargaren, 2000).

Within the built environment, this perspective is relevant to efforts to improve the environmental performance of buildings through evidence-based technological and design interventions. Residential buildings in hot-humid climates frequently depend on mechanical cooling when envelope configurations are unable to moderate external thermal loads effectively. From an ecological-modernisation perspective, empirical evaluation of building-envelope behaviour can inform modifications such as improved roof reflectance, insulation, attic ventilation, radiant barriers and other passive heat-control measures that seek to reduce unnecessary thermal loading while maintaining the functional requirements of the building.

EMT is therefore not used in this study to explain the physical mechanisms of heat transfer between the attic and occupied space. That function is provided primarily by Systems Theory and established building-physics principles. Rather, EMT provides the broader sustainability-oriented rationale for translating empirical findings into environmentally responsive roof-design strategies. In this way, the theory connects measurement and performance evaluation with the potential improvement of residential building technologies and passive environmental control.

Together, the two theoretical perspectives establish a complementary framework for the study. Systems Theory explains the investigated roof–attic–ceiling–indoor configuration as part of an interconnected thermal system responding dynamically to climatic and site conditions, while Ecological Modernisation Theory situates the resulting empirical evidence within the broader pursuit of technologically informed and environmentally responsive residential design.

Review of Empirical Literature

Roof Solar Heat Gain and Material Characteristics: The roof constitutes an important component of the thermal envelope in tropical buildings because of its prolonged exposure to solar radiation. The thermal response of a roof is influenced by the properties and

configuration of its constituent materials, including solar absorptance and reflectance, thermal conductivity, emissivity, thermal mass, surface treatment and insulation. Lightweight metal roofing is particularly responsive to variations in solar exposure because of its relatively low thermal mass, although the amount of heat subsequently transferred towards the building interior depends on the complete roof–attic–ceiling configuration rather than on the roof covering alone.

Recent field evidence from tropical Africa demonstrates the significance of roof construction under actual climatic exposure. Amankwaa et al. (2025) monitored 16 classrooms in Accra, Ghana, for 389 days and found substantial differences in indoor thermal conditions between metal- and concrete-roofed classrooms. Temperatures in the metal-roofed classrooms reached 39.8 °C and exceeded outdoor temperature by as much as 5.9 °C, whereas the concrete-roofed classrooms generally exhibited lower temperatures. Although schools differ from residential buildings in occupancy and use, the study provides important long-term African field evidence that roof construction can contribute to differences in indoor thermal exposure under tropical conditions.

Roof-surface modification can similarly alter the amount of solar heat transmitted into the underlying construction. Through field measurements on insulated and uninsulated metal-roof configurations in tropical Malaysia, Aw et al. (2024) demonstrated that introducing a vegetative component above a metal roof improved its thermal performance. Their findings reinforce the broader principle that the thermal behaviour associated with metal roofing is not an immutable property of the sheet material itself but can be modified through changes to the roof assembly and its exposure to solar radiation. Consequently, assessment of lightweight roofs should consider the roof covering as one component within a larger thermal pathway.

Attic Thermal Behaviour and Ventilation: Between the roof covering and the ceiling, the attic functions as an intermediate thermal environment whose temperature responds to heat transmitted through the roof as well as to heat exchange with its enclosing surfaces and any ventilation occurring within the space. In an unventilated or inadequately ventilated attic, heat accumulated during periods of intense solar exposure may increase attic air and surface temperatures. The magnitude and persistence of this response can vary with roof geometry, attic volume, ventilation openings, insulation, ceiling characteristics and prevailing outdoor conditions.

Moharrami et al. (2025) provide recent empirical evidence of the importance of attic ventilation in tropical residential buildings. Using simultaneous field measurements in two one-storey terrace houses together with building-energy simulation, the authors evaluated a hybrid attic-ventilation strategy under tropical conditions. The ventilated configuration produced an average reduction of approximately 1 °C in indoor temperature and 7% in relative humidity, while simulation indicated an approximately 10% reduction in building energy consumption. These results demonstrate that attic ventilation can modify the thermal conditions occurring between the roof and occupied space and support the treatment of attic ventilation status as an important characteristic when interpreting roof-related thermal behaviour.

The relevance of this evidence to lightweight roof systems is particularly important because the attic should not be regarded merely as an empty space beneath the roof. Rather, it constitutes a thermally active zone in which heat received from the roof can be exchanged with the ceiling and other enclosing surfaces. Whether this heat is retained or removed partly depends on the ventilation characteristics of the cavity. Thus, distinguishing between ventilated and unventilated attics is necessary when comparing empirical findings across buildings.

Ceiling and Insulation as Thermal Attenuation Layers: The ceiling provides a physical separation and thermal interface between the attic and occupied indoor environment. Heat exchange between these environments is therefore mediated by the thermal characteristics of the ceiling assembly. Ceiling material, thickness, insulation and associated air layers can influence the extent to which thermal fluctuations occurring within the attic are transmitted towards the occupied space. This distinction is particularly relevant when attic and indoor air temperatures are monitored simultaneously because differences in their temperature amplitudes may indicate attenuation between the two environments, although such attenuation cannot be attributed to the ceiling alone without direct heat-flux and surface-temperature measurements.

In the Nigerian context, Bashir and Leite (2022) investigated aerogel insulation in a residential building model representative of tropical conditions and found that insulation applied to the attic and floor slabs produced the greatest effects among the configurations examined. The simulations indicated reductions exceeding 6% in mean indoor air and operative temperatures and more than 15% in energy consumption. Although the study was simulation-based rather than a long-term field investigation, its findings demonstrate the importance of insulation at the attic–ceiling interface and provide Nigeria-specific evidence that modifications within this part of the envelope can influence indoor thermal conditions.

The potential of thermal-storage materials to modify heat transmission through building envelopes has also received recent attention. Elenga et al. (2025) evaluated building-envelope configurations incorporating phase-change materials across tropical climatic conditions and demonstrated that material thickness, position and phase-change temperature influenced envelope and energy performance. Such findings further indicate that thermal transmission through the envelope depends on the composition and arrangement of its layers. For the present study, this evidence reinforces the need to interpret the plaster-of-Paris ceiling as an integral component of the roof–attic–ceiling thermal pathway rather than treating attic and occupied-space temperatures as directly connected without an intervening physical layer.

Field Evidence from Tropical and African Buildings: Despite substantial research on building-envelope improvement, the empirical basis for understanding roof-related thermal behaviour in tropical Africa remains comparatively limited, particularly where long-term field measurements are required. Simulation studies permit controlled comparison of material and design alternatives, but their results depend on assumptions concerning weather data, occupancy, ventilation, material properties and boundary conditions. Field monitoring complements such studies by documenting the thermal behaviour of actual buildings under changing climatic and site conditions.

The long-term measurements reported by Amankwaa et al. (2025) are particularly relevant in this regard because they demonstrate that prolonged monitoring can reveal temperature patterns and exposure conditions that short experimental campaigns may not capture. Their 389-day dataset showed persistent differences associated with roof construction under real tropical African conditions. In Nigeria, however, much of the available evidence continues to emphasise simulation and whole-building performance; for example, Bashir and Leite (2022) examined insulation interventions through building-energy modelling rather than synchronised long-term measurements of attic and occupied-space air temperatures.

Evidence from tropical Malaysia provides useful complementary information. Field measurements by Aw et al. (2024) examined thermal modification of metal roofs, while Moharrami et al. (2025) combined residential field monitoring with simulation to demonstrate the thermal benefits of attic ventilation. Collectively, these studies establish the importance of roof configuration, insulation and attic ventilation, but differences in climate, construction practice, building use and monitoring design limit direct transfer of their quantitative findings to Nigerian residential buildings. Locally observed field data therefore remain necessary.

Attic–Indoor Temperature Coupling: The relationship between attic and occupied-space air temperatures represents a more specific issue than general roof or envelope performance. Solar heating of the roof can raise temperatures within the attic, while heat exchange across the ceiling provides one pathway through which attic thermal conditions may contribute to the indoor environment. However, the occupied-space temperature also responds to outdoor air temperature, walls, windows, floors, ventilation and infiltration, orientation, shading, occupancy and internal heat gains. A strong statistical relationship between attic and indoor temperatures should therefore be interpreted as evidence of thermal coupling or co-response within the building system rather than as proof that attic temperature independently determines indoor temperature.

Existing empirical research provides indirect support for this relationship but leaves important questions unresolved. The improvement associated with attic ventilation reported by Moharrami et al. (2025), for example, indicates that altering attic conditions can be accompanied by measurable changes indoors. Similarly, the influence of attic insulation identified for Nigerian residential construction by Bashir and Leite (2022) demonstrates the significance of the intermediate roof–attic–ceiling pathway. Nevertheless, these studies were primarily designed to evaluate specific interventions rather than to characterise the long-term temporal relationship between synchronously measured attic and occupied-space air temperatures.

Long-term paired measurements are particularly useful because the degree of thermal coupling may not remain constant throughout the day or across seasons. Daytime solar loading may produce greater attic–indoor temperature divergence, whereas reduced solar forcing and delayed heat release may alter the relationship during evening and night-time periods. Seasonal changes in solar exposure, ambient temperature, rainfall and atmospheric moisture can further modify the thermal responses of both environments. Characterising these

temporal patterns requires measurements extending beyond short-term experimental periods and analysis that distinguishes association from causation.

Research Gap: The reviewed literature demonstrates that roof material and configuration, insulation, attic ventilation and other envelope interventions can substantially modify thermal conditions in tropical buildings. Recent field studies have strengthened the empirical evidence concerning metal roofs and attic-ventilation strategies (Aw et al., 2024; Amankwaa et al., 2025; Moharrami et al., 2025), while Nigerian research has demonstrated the potential significance of attic insulation through building-energy simulation (Bashir & Leite, 2022). However, comparatively little field evidence is available on the long-term, synchronised thermal behaviour of the attic and occupied space beneath common lightweight metal-roof configurations in hot-humid Nigerian residential buildings.

More specifically, the literature does not adequately establish how attic and occupied-space air temperatures vary together over extended diurnal and seasonal periods, the extent to which attic temperature fluctuations are attenuated in the occupied environment, or the strength of the statistical association between the two monitored thermal environments under actual residential conditions. This gap is particularly evident for unventilated attic configurations incorporating lightweight stone-coated metal roofing and plaster-of-Paris ceilings, as represented by the configuration investigated in the present study. The present study addresses this empirical gap through long-term synchronised field monitoring of attic and occupied-space air temperatures in a residential building in Owerri, thereby providing configuration-specific evidence while recognising that indoor thermal conditions also reflect wider building, site and climatic influences.

METHODOLOGY

Research design

The study adopted a longitudinal field-monitoring design to investigate the temporal relationship between attic and occupied-space air temperatures under actual residential and climatic conditions. Synchronous temperature measurements were obtained from the attic and an occupied indoor space of the case-study building from 2 October 2024 to 22 June 2025. The extended monitoring period enabled the investigation of both diurnal and seasonal variations in the two thermal environments.

The study was observational rather than experimental. No deliberate modifications were made to the roof, attic, ceiling or normal environmental exposure of the building during the monitoring period. Consequently, the analysis was designed to characterise temperature patterns, attenuation and statistical association between the monitored attic and occupied space rather than to isolate the causal contribution of the roof or attic to indoor air temperature.

Case-study building and roof–attic–ceiling configuration

The monitored building is a two-storey residential building (one suspended floor) located within the Federal Housing Authority (FHE) Estate, Lower Irete, Owerri, Nigeria. The building was purposively selected to provide a residential case with substantial roof exposure to solar radiation while minimising major height-related shading from surrounding development. Buildings within the immediate neighbourhood are predominantly of comparable height, with one suspended floor; consequently, the study building's roof is not substantially overshadowed by taller adjoining structures. Buildings exceeding this height were deliberately excluded from the case-selection criteria because the study focused on roof-related thermal behaviour in low-rise residential construction, where the roof constitutes a major solar-exposed component of the building envelope. Nevertheless, because solar access and surrounding-building shading were not quantitatively measured during the monitoring campaign, their effects are treated as contextual influences rather than controlled experimental variables.

The building is covered by a multiple-hip roof finished with black stone-coated corrugated metal sheets supported on timber roof framing. The roof encloses an attic above a plaster-of-Paris (POP) ceiling that separates the attic from the occupied spaces below. The corrugated roof sheets terminate over a concrete fascia, leaving only small incidental openings between the crests of the corrugated profile and the top of the fascia. The soffit beneath the eaves is completely sealed, and no purpose-provided ridge, soffit, eave or gable ventilation openings are incorporated into the attic. The attic is therefore characterised as having no purpose-provided ventilation, while acknowledging the limited incidental openings associated with the corrugated roof profile.

The POP ceiling constitutes the physical and thermal interface between the attic and occupied indoor environment. The roof covering, attic air space, ceiling and occupied space were therefore treated as physically distinct but thermally interacting components of the investigated configuration. Heat transmitted through the roof can contribute to thermal conditions within the attic, while heat exchange across the ceiling provides one pathway through which attic thermal conditions may influence the occupied space. Indoor air temperature, however, may also be affected by walls, fenestration, floors, natural ventilation and infiltration, occupancy, internal heat gains, outdoor climatic conditions and surrounding-site exposure. Accordingly, the monitored configuration was treated as a case study of attic–indoor thermal interaction rather than as an experimental isolation of roof-induced indoor heat gain.

The roof pitch, attic height and attic volume were not measured during the field-monitoring campaign and were therefore not included as quantitative variables in the analysis. Their potential influence on attic thermal behaviour is acknowledged as a limitation of the study.

Instrumentation and sensor placement

Attic and occupied-space air temperatures were monitored using Elitech RC-4 electronic temperature data loggers. Two loggers were synchronised before deployment so that attic and indoor temperatures were recorded at corresponding times throughout the monitoring period.

The attic logger was positioned approximately at the mid-height of the attic air space, away from direct contact with the roof covering, timber framing and other enclosing surfaces. It was shielded from direct radiative and conductive influences as far as practicable so that the recorded values represented attic air temperature rather than the surface temperature of the roof covering or structural components.

The indoor logger was installed in the lobby of the occupied building at approximately 1.1 m above floor level. The lobby had neither an air-conditioning unit nor a mechanical fan; consequently, the monitored indoor air was not directly modified by these forms of mechanical cooling or air movement. The logger was positioned away from direct solar radiation and immediate contact with heat-producing equipment or enclosing surfaces. The 1.1 m measurement height placed the sensor within the occupied zone and is consistent with recognised practice for assessing thermal conditions at occupant level.

The two measurement locations represented distinct thermal environments. The attic logger measured air temperature within the enclosed roof cavity, whereas the lobby logger measured air temperature within the occupied indoor environment. Neither measurement represented roof-surface, ceiling-surface or wall-surface temperature. Accordingly, the resulting attic–indoor temperature relationship was interpreted as an association between the two monitored air environments rather than as a direct measurement of conductive heat flow through the roof–ceiling assembly. The photographs below shows the type of data logger and the positioning of the logger in the roof attic space.



Figure 2a: Elitech RC -4 temperature data logger used for attic and indoor temperature measurements
Source: Fieldwork (2025)

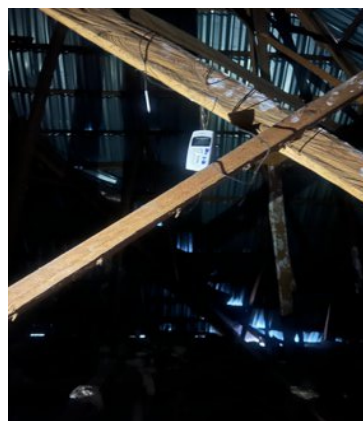


Figure 2b: Elitech RC -4 installed in the attic during field monitoring
Source: Fieldwork (2025)

Monitoring protocol and data preparation

The two data loggers were programmed to record temperature automatically at six-hour intervals throughout the monitoring period from 2 October 2024 to 22 June 2025. Measurements were therefore obtained at approximately four corresponding periods each day, representing night-time, morning, afternoon and evening conditions. Synchronisation of the instruments enabled direct pairing of attic and occupied-space observations recorded at the same time.

Following completion of the monitoring campaign, recorded data were downloaded and screened for completeness and temporal correspondence. Only observations for which valid attic and occupied-space measurements occurred at corresponding timestamps were retained for paired analysis, producing 1,052 paired observations.

The six-hour sampling interval was suitable for characterising broad diurnal and seasonal temperature patterns but did not provide sufficient temporal resolution to quantify short-duration or sub-six-hour phase shifts reliably. Consequently, an exact short time lag between attic and occupied-space temperature peaks was not treated as a directly measured performance indicator.

Data analysis

Descriptive and inferential statistical analyses were conducted to characterise the thermal behaviour and statistical relationship of the two monitored environments. Descriptive statistics included the mean, minimum, maximum, range and temperature amplitude of attic and occupied-space air temperatures. Paired temporal observations were also analysed to characterise diurnal and seasonal variations.

The attic–indoor air-temperature difference was calculated as:

$$\Delta T = T_{\text{attic}} - T_{\text{indoor}} \dots\dots\dots \text{equation (1)}$$

where ΔT is the attic–indoor air-temperature difference ($^{\circ}\text{C}$), T_{attic} is the attic air temperature ($^{\circ}\text{C}$), and T_{indoor} is the occupied-space air temperature ($^{\circ}\text{C}$). Positive ΔT values indicate higher attic than indoor air temperature, whereas negative values indicate the reverse.

Temperature attenuation between the two monitored environments was quantified using the attic-to-indoor temperature-amplitude ratio:

$$\text{AR} = A_{\text{indoor}} / A_{\text{attic}} \dots\dots\dots \text{equation (2)}$$

where AR is the attenuation ratio, A_{indoor} is the occupied-space temperature amplitude ($^{\circ}\text{C}$), and A_{attic} is the attic temperature amplitude ($^{\circ}\text{C}$). Values below 1.0 indicate a lower temperature amplitude in the occupied space than in the attic. ‘A’ represents the temperature amplitude of each monitored environment. It is calculated as half of the observed temperature range:

$$A = \frac{T_{\text{max}} - T_{\text{min}}}{2}; \dots\dots\dots \text{equation (3); where } T_{\text{max}} \text{ and } T_{\text{min}} \text{ are recorded maximum and minimum temperatures of the indoor and attic spaces, respectively.}$$

The term attenuation ratio is used to describe the measured relationship between the two air-temperature amplitudes without attributing the attenuation exclusively to the intrinsic thermal properties of the roof or ceiling assembly.

Pearson's correlation coefficient (r) was used to quantify the strength and direction of the linear association between synchronously measured attic and occupied-space air temperatures. Ordinary least-squares (OLS) regression was subsequently applied, with occupied-space air temperature specified as the response variable and attic air temperature as the predictor:

$$T_{\text{indoor}} = \beta_0 + \beta_1 T_{\text{attic}} + \varepsilon \dots\dots\dots \text{equation (4)}$$

where β_0 is the intercept, β_1 is the regression coefficient, and ε is the residual error term. The regression was treated as an associational rather than causal model because other building, site and environmental variables potentially affecting indoor air temperature were not simultaneously controlled.

Statistical significance was evaluated at $p < 0.05$. The statistical analyses were interpreted together with the descriptive, diurnal and seasonal temperature patterns to characterise thermal coupling between the attic and occupied space within the investigated building configuration.

RESULTS

Overall attic and occupied-space temperature characteristics

A total of 1,052 synchronised attic and occupied-space air-temperature observations were obtained during the monitoring period from 2 October 2024 to 22 June 2025. The descriptive and comparative thermal characteristics of the two monitored environments are presented in Table 1.

Table 1: Descriptive and comparative thermal characteristics of the attic and occupied space

Thermal characteristic	Attic space	Occupied space
Mean air temperature (°C)	31.15	30.57
Maximum air temperature (°C)	39.0	36.2
Minimum air temperature (°C)	24.2	24.5
Temperature range (°C)	14.8	11.7
Temperature amplitude (°C)	7.40	5.85
Attic-to-indoor amplitude ratio (AR)	-	0.79

Source: Fieldwork (2025)

The attic recorded a higher mean air temperature (31.15 °C) than the occupied space (30.57 °C), representing an overall mean difference of 0.58 °C. The maximum attic temperature of 39.0 °C also exceeded the occupied-space maximum of 36.2 °C, whereas the minimum temperatures were comparatively similar at 24.2 °C and 24.5 °C, respectively.

The attic exhibited a wider temperature range (14.8 °C) and greater temperature amplitude (7.40 °C) than the occupied space (11.7 °C and 5.85 °C, respectively). The resulting attic-to-indoor temperature-amplitude ratio of 0.79 indicates that the magnitude of temperature fluctuation in the occupied space was lower than that observed in the attic.

Diurnal attic–indoor temperature variation

The synchronised observations showed a recurring diurnal relationship between attic and occupied-space air temperatures. Temperature differences between the two monitored environments were generally more pronounced during the daytime heating period and narrower during the night-time and early-morning periods. The attic exhibited the greater diurnal response, while temperature variation within the occupied space was comparatively attenuated.

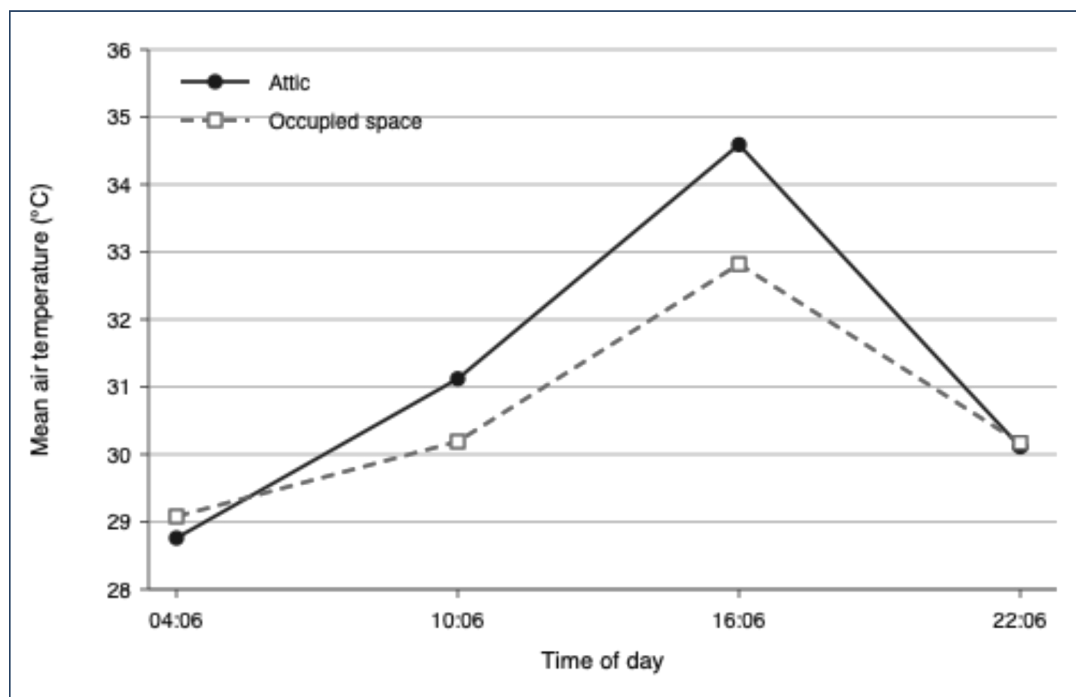


Figure 3: Mean diurnal profiles of attic and occupied-space air temperatures over the monitoring period

Source: Fieldwork (2025)

The diurnal profiles further show that changes in occupied-space temperature generally followed the direction of attic temperature variation but with a smaller magnitude of fluctuation. This pattern is consistent with the overall temperature amplitudes reported in

Table 1. These results describe the temporal relationship between the two monitored air environments and do not, by themselves, isolate the contribution of individual heat-transfer pathways through the roof–attic–ceiling configuration.

Seasonal variation in attic–indoor temperature difference

Seasonal analysis revealed variation in the magnitude of the temperature difference between the attic and occupied space over the monitoring period. The mean attic–indoor temperature difference (ΔT) was approximately 0.66 °C during the dry-season period (October–March) and decreased to approximately 0.40 °C during the wet-season onset (April–June). The attic therefore remained warmer on average than the occupied space during both periods, although the magnitude of the difference was smaller during the wet-season onset.

Monthly mean ΔT values also varied over the monitoring period. The difference increased from 0.27 °C in October to 0.63 °C in November and reached its highest monthly mean of approximately 1.03 °C in December. Mean ΔT subsequently decreased to 0.81 °C in January, 0.64 °C in February and 0.59 °C in March. During the wet-season onset, the corresponding values were 0.45 °C in April, 0.39 °C in May and 0.35 °C in June.

Table 2: Monthly and seasonal attic–indoor temperature differences

Period	Mean attic–indoor temperature difference, ΔT (°C)
October	0.27
November	0.63
December	1.03
January	0.81
February	0.64
March	0.59
April	0.45
May	0.39
June	0.35
Dry season (October–March)	0.66
Wet season onset (April–June)	0.40

Source: Fieldwork (2025)

The monthly and seasonal results demonstrate that the attic–indoor temperature difference was not constant throughout the monitoring period. However, because concurrent outdoor meteorological variables were not monitored, the observed seasonal differences are reported as temporal patterns rather than being attributed to individual climatic variables.

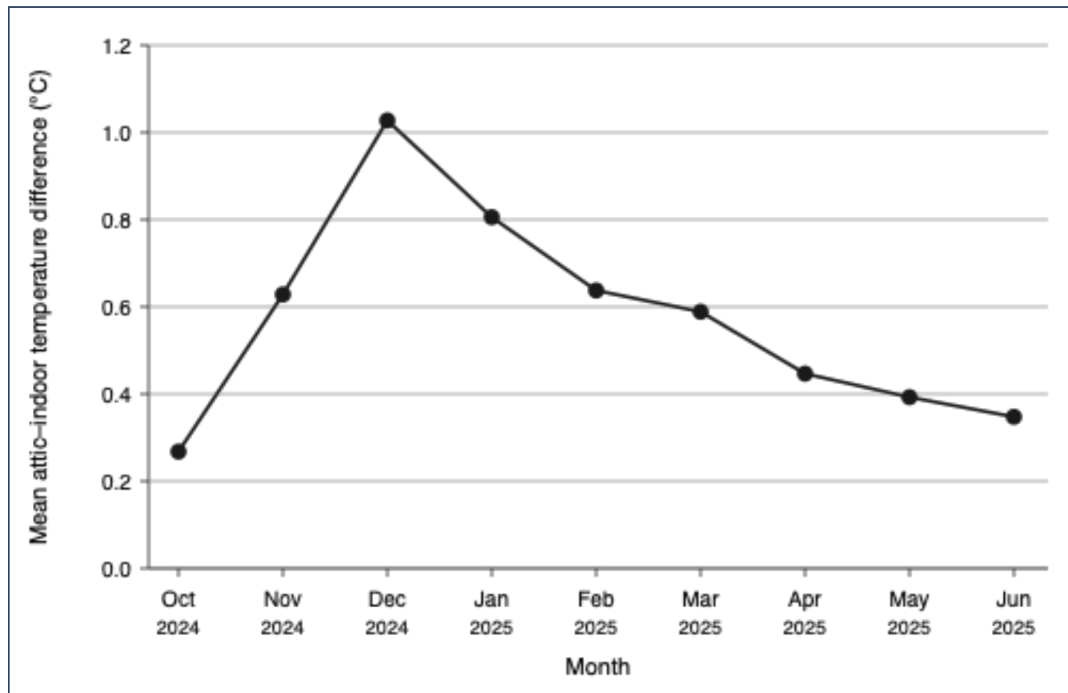


Figure 4: Monthly variation in mean attic-indoor air-temperature difference during the monitoring period.

Source: Fieldwork (2025)

Correlation and regression analysis

Pearson product-moment correlation analysis of the 1,052 synchronised attic and occupied-space temperature observations showed a strong positive linear association between the two monitored environments ($r = 0.956$, $p < 0.001$). Thus, increases and decreases in attic air temperature were closely associated with corresponding changes in occupied-space air temperature over the monitoring period.

To further characterise this relationship, an ordinary least-squares (OLS) regression analysis was performed with occupied-space air temperature specified as the response variable and attic air temperature as the predictor. Because the observations constituted a temporally ordered series, Newey–West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors were applied using a four-lag specification, corresponding to one 24-hour measurement cycle. The results are presented in Table 3.

Table 3: OLS regression of occupied-space air temperature on attic air temperature with Newey–West HAC standard errors (n = 1,052)

Regression Parameter	Estimate	Newey - west HAC SE	t-statistic	p-value
Intercept (β_0)	9.215	0.215	42.82	<0.001
Attic air temperature (β_1)	0.685	0.0067	102.88	<0.001

Source: Fieldwork (2025)

Model statistics: Pearson $r = 0.956$; $R^2 = 0.913$; Durbin–Watson = 0.925.

The relationship between attic and occupied-space air temperatures, together with the fitted linear regression line, is shown in Figure 5.

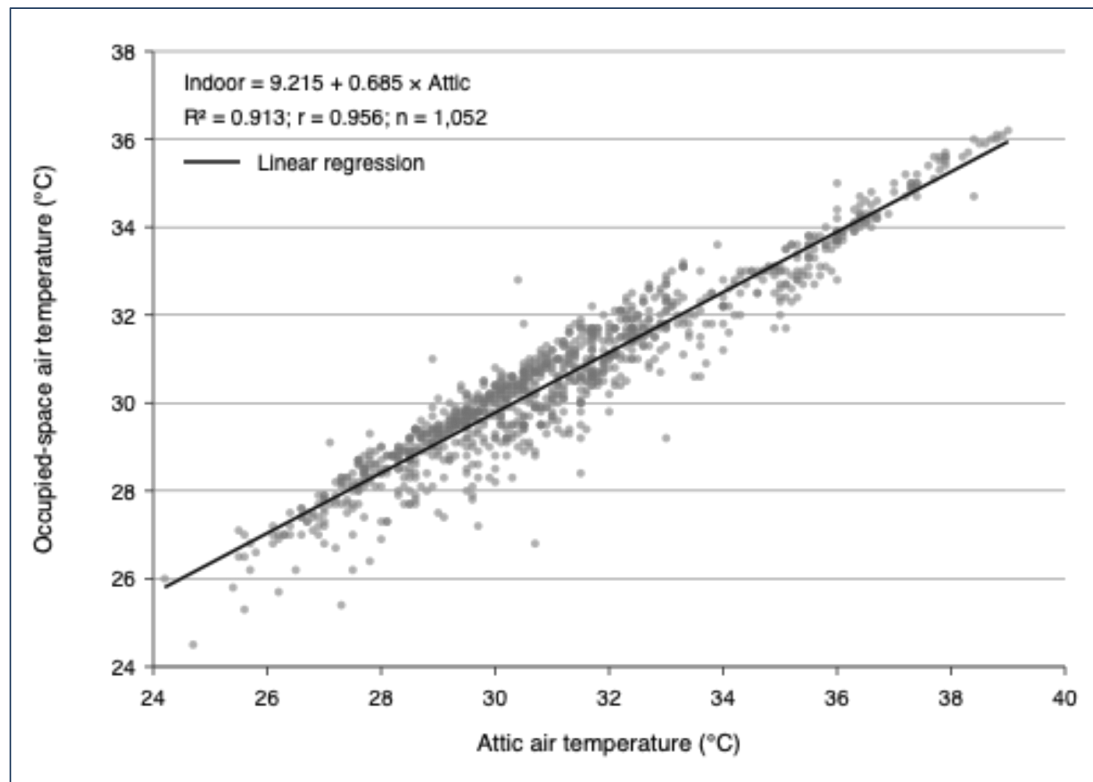


Figure 5: Relationship between attic and occupied-space air temperatures during the monitoring period.

Source: Fieldwork (2025)

The estimated regression equation was:

$$T_{\text{indoor}} = 9.215 + 0.685T_{\text{attic}} \dots\dots\dots\text{equation (5);}$$

where T_{indoor} represents occupied-space air temperature and T_{attic} represents attic air temperature. The slope coefficient indicates that, within the observed dataset, a 1 °C increase in attic air temperature was associated with an average increase of approximately 0.69 °C in occupied-space air temperature.

The model yielded $R^2 = 0.913$, indicating a high degree of shared linear variation between attic and occupied-space temperatures. The Durbin–Watson statistic of 0.925 indicated positive residual autocorrelation; consequently, Newey–West HAC standard errors were used for statistical inference. The strong association should nevertheless not be interpreted as evidence that attic temperature independently caused the observed variation in occupied-

space temperature, because both environments may also have responded to common external and building-related influences.

DISCUSSION

Thermal differentiation between the attic and occupied space

The monitoring results demonstrate clear thermal differentiation between the attic and occupied space. Although their mean air temperatures were relatively close, the attic recorded a higher mean temperature (31.15 °C) than the occupied space (30.57 °C), together with a higher maximum temperature and greater overall temperature variability. The attic maximum of 39.0 °C exceeded the occupied-space maximum of 36.2 °C, while the respective temperature ranges were 14.8 °C and 11.7 °C. In contrast, the minimum temperatures were comparatively similar at 24.2 °C in the attic and 24.5 °C in the occupied space. These differences indicate that the attic exhibited a greater magnitude of temperature variation over the monitoring period.

The greater temperature variability observed in the attic is consistent with its position immediately beneath the lightweight metal roof and with the absence of purpose-provided attic ventilation. Previous field studies in tropical environments have similarly demonstrated pronounced temperature responses associated with metal roofing. Amankwaa et al. (2025), for example, reported elevated temperatures in metal-roofed classrooms in tropical Africa, while Aw et al. (2024) demonstrated that the thermal response of metal roofing in a tropical environment was sensitive to modifications of the roof assembly. The present findings extend this evidence by providing synchronised long-term measurements of attic and occupied-space air temperatures within an actual residential building.

The observed attic–indoor temperature difference should nevertheless be interpreted within the wider building–environment system. The measurements do not isolate the roof as the sole determinant of occupied-space temperature. Walls, fenestration, floors, ventilation and infiltration, occupancy, internal heat gains, surrounding development and other environmental influences may also have contributed to the measured indoor conditions. The findings therefore characterise the thermal relationship between the monitored attic and occupied space for the investigated building configuration rather than establishing the independent thermal effect of the roof covering.

Temperature attenuation between the attic and occupied space

An important feature of the monitored thermal response was the reduction in temperature fluctuation between the attic and occupied space. As reported in Table 1, the attic temperature amplitude was 7.40 °C compared with 5.85 °C in the occupied space, giving an attic-to-indoor temperature-amplitude ratio of 0.79. Thus, the magnitude of the temperature fluctuation measured within the occupied space was approximately 79% of that observed in the attic.

The lower occupied-space amplitude demonstrates attenuation between the two monitored air environments. This attenuation should not, however, be interpreted as a directly measured thermal property of the POP ceiling. The study measured air temperatures rather than ceiling-surface temperatures or heat flux through the ceiling, and the occupied-space temperature was potentially influenced by several other building and environmental factors. The amplitude ratio therefore describes the observed relationship between the two air-temperature series rather than a material-specific decrement factor.

The thermal significance of the attic–ceiling pathway is supported by previous research. In a study of residential buildings under tropical Nigerian conditions, Bashir and Leite (2022) found that the application of aerogel insulation within the attic configuration produced substantial thermal and energy benefits among the investigated envelope applications. Complementary evidence from tropical residential buildings was provided by Moharrami et al. (2025), who found that modifying attic conditions through hybrid ventilation reduced indoor air temperature by approximately 1 °C. These studies indicate that interventions within the attic and at its interface with the occupied environment can modify indoor thermal conditions. The present field measurements complement such intervention-based research by demonstrating measurable attenuation between synchronously monitored attic and occupied-space air temperatures under actual residential conditions.

Diurnal behaviour and the role of attic ventilation

The diurnal profiles reveal a distinct time-dependent relationship between attic and occupied-space temperatures. At approximately 04:06, mean attic and occupied-space temperatures were 28.76 °C and 29.08 °C, respectively. By approximately 10:06, the attic mean had increased to 31.12 °C compared with 30.19 °C in the occupied space. The largest mean separation occurred at approximately 16:06, when the attic reached 34.59 °C compared with 32.82 °C in the occupied space, producing a mean difference of approximately 1.77 °C. At approximately 22:06, the two temperatures had converged to 30.11 °C and 30.17 °C, respectively. The diurnal profile therefore demonstrates stronger daytime temperature elevation within the attic and substantial convergence between the two monitored environments during the night-time periods.

The roof–attic configuration provides relevant physical context for interpreting this pattern. The attic had no purpose-provided ridge, soffit, eave or gable ventilation openings. Although small incidental openings occurred where the corrugated roof profile terminated over the concrete fascia, these openings were not designed as a ventilation system and their airflow performance was not measured. The attic is therefore more appropriately characterised as having no purpose-provided ventilation rather than being assumed to be completely airtight.

Attic ventilation represents one potential strategy for modifying such thermal conditions. Moharrami et al. (2025) reported reductions in indoor air temperature and relative humidity following the application of a hybrid attic-ventilation strategy in tropical residential buildings. This supports consideration of purpose-designed attic ventilation as a passive design measure in hot-humid residential construction. However, the present investigation did

not experimentally compare ventilated and non-ventilated attics, and the airflow rate through the incidental roof openings was not measured. Consequently, the magnitude of any temperature reduction that could be achieved through attic ventilation in the investigated building cannot be determined from the present results.

Seasonal variation in attic– temperature difference indoor

The seasonal analysis demonstrated that the magnitude of the attic–indoor temperature difference varied over the monitoring period. Mean ΔT decreased from approximately 0.66 °C during the dry-season period to approximately 0.40 °C during the wet-season onset. Importantly, this represents a reduction in the magnitude of the thermal gradient rather than a reversal: the attic remained warmer on average than the occupied space during both periods.

The monthly results reinforce this interpretation. Mean ΔT increased from approximately 0.27 °C in October to 1.03 °C in December before decreasing through the subsequent months. During the wet-season onset, mean differences of approximately 0.45 °C, 0.39 °C and 0.35 °C were recorded in April, May and June, respectively. The attic–indoor relationship was therefore not temporally constant despite the physical roof–attic–ceiling configuration remaining unchanged.

The observed seasonal moderation should not be interpreted as an intrinsic improvement in the thermal performance of the roof during the wet-season onset. Rather, it demonstrates that the relationship between attic and occupied-space temperatures varied across the monitoring period under naturally changing environmental conditions. Because concurrent outdoor meteorological variables were not measured as part of the present study, the specific climatic factors responsible for the observed seasonal variation cannot be isolated. The seasonal findings are therefore interpreted descriptively as temporal changes in attic–indoor thermal behaviour rather than being attributed to any individual meteorological variable.

Statistical coupling between attic and occupied-space temperatures

The calculated statistical analysis confirms a strong positive linear association between attic and occupied-space air temperatures. Pearson's correlation coefficient was $r = 0.956$ ($p < 0.001$), while the OLS model yielded $R^2 = 0.913$. The estimated regression coefficient ($\beta_1 = 0.685$) indicates that, within the observed dataset, a 1 °C increase in attic air temperature was associated with an average increase of approximately 0.69 °C in occupied-space air temperature. Together, these results demonstrate a high degree of statistical coupling between the two monitored environments.

The strength of this relationship should not be interpreted as evidence that attic temperature independently determined approximately 91% of occupied-space temperature variation. The coefficient of determination quantifies the goodness of fit of the specified linear model and does not establish causation. Both attic and occupied-space temperatures may respond simultaneously to common environmental forcing and other characteristics of the building.

The regression therefore quantifies association within the monitored configuration rather than isolating the causal contribution of attic temperature to occupied-space temperature.

The temporal structure of the measurements also required consideration in statistical inference. The Durbin–Watson statistic of 0.925 indicated positive residual autocorrelation, showing that the assumption of independent OLS residuals was not adequately satisfied. Newey–West heteroskedasticity- and autocorrelation-consistent standard errors were therefore applied using a four-lag specification corresponding to one 24-hour measurement cycle. The attic-temperature coefficient remained statistically significant ($\beta_1 = 0.685$, HAC SE = 0.0067, $t = 102.88$, $p < 0.001$). The persistence of the association after autocorrelation-robust inference strengthens confidence in the statistical relationship while leaving its interpretation explicitly associational rather than causal.

Implications for passive roof design in hot-humid residential buildings

The findings have several implications for passive roof design, although these should be understood as configuration-specific rather than universal prescriptions for lightweight metal roofs. First, the higher temperature level and greater fluctuation observed within the attic, particularly the pronounced daytime separation between attic and occupied-space temperatures, indicate the importance of limiting heat gains at the roof level. Roof-surface strategies that reduce solar absorption may therefore be considered where appropriate to the architectural, climatic and material context.

Second, the absence of purpose-provided attic ventilation in the investigated building highlights ventilation as a relevant design consideration. Appropriately designed eave, soffit or ridge ventilation may facilitate attic air exchange, although its effectiveness depends on vent geometry, airflow pathways, external wind conditions and other design factors. Because ventilation performance was not experimentally evaluated in this study, its potential benefit for the investigated configuration should be verified through comparative field investigation.

Third, the attenuation observed between the attic and occupied space indicates the importance of considering the attic–ceiling interface. Ceiling-level insulation, radiant-control measures and other strategies intended to increase resistance to downward heat transfer may complement roof-surface and attic-ventilation measures. Such interventions should be evaluated as components of an integrated roof–attic–ceiling system rather than as isolated solutions.

More broadly, the strong statistical coupling between attic and occupied-space temperatures indicates that attic thermal conditions warrant consideration in the passive design of low-rise residential buildings in hot-humid environments. This does not diminish the importance of other envelope and site variables. Effective thermal design requires coordinated consideration of roof properties, attic configuration, ceiling characteristics, fenestration, wall construction, natural ventilation, orientation, shading and surrounding-site conditions. The present findings therefore support an integrated building–environment approach to reducing heat exposure rather than attributing indoor thermal conditions to the roof alone.

Limitations of the Study

Several limitations should be considered when interpreting the findings of this study. First, the investigation was based on a single residential building with a specific roof–attic–ceiling configuration comprising black stone-coated corrugated metal roofing, a multiple-hip roof form, an attic with no purpose-provided ventilation, and a plaster-of-Paris ceiling. The findings therefore characterise the thermal behaviour of the investigated configuration and should not be generalised to all lightweight metal roofs or residential buildings in hot-humid climates. Comparative studies involving multiple buildings, roof materials, geometries, ceiling systems and ventilation configurations would be required to establish the extent to which the observed relationships apply to other building types.

Second, several physical characteristics that may influence attic thermal behaviour were not quantitatively documented during the monitoring campaign. These include roof pitch, attic height, attic volume and the rate of air exchange through the small incidental openings between the corrugated roof profile and concrete fascia. Although no purpose-provided ridge, soffit, eave or gable vents were present, the attic cannot be assumed to have been completely airtight. Consequently, the contribution of incidental air exchange to the measured attic temperatures could not be quantified.

Third, the study monitored air temperatures rather than the complete heat-transfer process through the roof–attic–ceiling assembly. Roof-surface temperature, ceiling-surface temperature and heat flux through the roof and POP ceiling were not measured. The observed attenuation between attic and occupied-space air temperatures therefore cannot be attributed exclusively to the thermal properties of the ceiling or interpreted as a direct measurement of downward heat transfer through the assembly.

Fourth, occupied-space air temperature was measured in a lobby without mechanical air conditioning or fan operation. Although this reduced the potential influence of active space-conditioning systems, the monitored indoor temperature may still have been affected by walls, fenestration, floors, natural ventilation and infiltration, adjoining spaces, occupancy and internal heat gains. These influences were not independently monitored or experimentally controlled. Accordingly, the strong statistical association between attic and occupied-space temperatures should not be interpreted as demonstrating that attic temperature was the sole or independent cause of indoor temperature variation.

Fifth, concurrent outdoor meteorological variables, including ambient air temperature, solar radiation, relative humidity and rainfall, were not monitored as part of the present dataset. Their individual contributions to the observed diurnal and seasonal attic–indoor temperature patterns could therefore not be quantified. Similarly, the building's exact cardinal orientation and the effects of surrounding-building shading and solar access were not quantitatively measured. These site and climatic factors are consequently treated as contextual influences rather than controlled explanatory variables.

Sixth, temperatures were recorded at approximately six-hour intervals. Although the long monitoring duration provided 1,052 paired observations and enabled assessment of broad diurnal and seasonal patterns, the sampling interval limits resolution of short-duration temperature peaks and precise timing of thermal responses between the attic and occupied space. Consequently, fine-scale phase shifts or short time lags cannot be reliably determined from the present measurements.

Finally, the observational design did not include a comparison building or experimental modification of the investigated roof–attic configuration. The study therefore cannot quantify the thermal effects that would result from introducing attic ventilation, reflective roof surfaces, ceiling insulation, radiant barriers or other passive interventions. The design implications arising from the findings should consequently be regarded as evidence-informed directions for further investigation rather than experimentally demonstrated performance improvements.

CONCLUSION

This study evaluated the diurnal and seasonal relationship between attic and occupied-space air temperatures beneath a lightweight stone-coated metal roof with a plaster-of-Paris ceiling in a hot-humid tropical residential building in Owerri, Nigeria. Long-term synchronised field monitoring provided field-based observational evidence of the thermal relationship between the attic and occupied space under actual residential conditions.

The attic recorded a higher mean air temperature than the occupied space (31.15 °C versus 30.57 °C) and exhibited greater temperature variability. An attic-to-indoor temperature-amplitude ratio of 0.79 demonstrated attenuation of temperature fluctuations between the two monitored environments. The relationship also varied seasonally, with the mean attic–indoor temperature difference decreasing from approximately 0.66 °C during the dry-season period to 0.40 °C during the wet-season onset. Pearson correlation analysis further demonstrated strong positive coupling between attic and occupied-space temperatures ($r = 0.956$). These findings indicate a close but temporally variable thermal relationship between the attic and occupied space; they do not establish that attic temperature independently determines indoor thermal conditions.

The findings highlight the importance of considering the roof, attic and ceiling as interacting components within the wider building–environment system. For the investigated configuration, the greater temperature variability within the attic and the observed attenuation towards the occupied space suggest that strategies addressing roof solar heat gain, purpose-designed attic ventilation and ceiling-level thermal resistance warrant consideration as complementary passive-design measures. Their effectiveness was not experimentally evaluated in this study and should therefore be established through comparative field investigation rather than inferred directly from the observed temperature relationships.

Overall, the study provides configuration-specific field evidence of diurnal and seasonal attic–indoor temperature coupling beneath a lightweight metal roof in a hot-humid residential

environment. Future research should extend monitoring across multiple buildings and roof configurations, incorporate concurrent outdoor meteorological measurements, quantify roof and ceiling surface temperatures and heat flux, document attic geometry and ventilation rates, and employ higher-frequency monitoring. Such investigations would strengthen understanding of roof–attic–indoor thermal interactions and provide a more robust empirical basis for passive roof design in hot-humid residential buildings.

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