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Atmospheric conditions, indoor air quality, and material deterioration: Implications for human safety in Edjeba, Warri-South LGA, Nigeria

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Abstract

This study evaluated the impact of building age on indoor air quality by assessing particulate matter (PM 0.3–PM 10), gaseous pollutants (CO_2, CO, H_2S, formaldehyde, TVOCs, combustible gases), and microclimatic parameters (temperature, relative humidity, and moisture content of building materials and furniture). Buildings were stratified into five age categories: <1 year, 1–5 years, 6–10 years, 11–15 years, and >15 years. Measurements were conducted using standard air quality monitoring equipment, and data were expressed as mean ± SEM. Statistical differences were determined at $p<0.05$. Results indicated that PM 0.3 concentrations peaked in >15-year-old buildings (e.g., 42.3 µg/m^3), whereas PM 0.5 and PM 1.0 levels were highest in 6–10-year-old structures (30.2 µg/m^3 and 27.8 µg/m^3, respectively). PM 10 was undetectable across all categories. Gaseous pollutant analysis revealed that carbon monoxide (CO) concentrations were significantly elevated in buildings aged 6–10 years (488.42 ± 1.40 ppm) and 11–15 years (486.77 ± 2.51 ppm), surpassing the <1-year category (476.38 ± 6.14 ppm). Combustible gases (EX) followed a similar trend, with peak levels in 6–10-year-old buildings (15.88 ± 0.69 ppm). Microclimatic data showed a progressive decline in indoor temperature with building age, from 29.08 ± 0.17°C in <1-year buildings to 24.44 ± 0.31°C in >15-year-old structures. Relative humidity was highest in >15-year-old buildings (72.53 ± 1.89%), while furniture moisture content peaked at 44.94 ± 0.61% in the 6–10-year category. Oxygen concentration was notably reduced in >15-year-old buildings (14.7 ± 0.43 ppm), highlighting ventilation inefficiencies. These findings emphasise that mid-aged buildings (6–15 years) are particularly prone to pollutant accumulation due to structural ageing and ventilation degradation. Regular air quality monitoring, refurbishment of ventilation systems, and moisture management strategies are recommended to safeguard indoor environmental quality across the building lifespan.

Keywords: Indoor air quality, building age, atmospheric conditions, material deterioration, human safety

Introduction

Indoor air quality (IAQ) and microclimatic conditions are increasingly recognised as critical determinants of human health, productivity, and comfort, particularly in urban and peri-urban environments of developing countries. The World Health Organization (WHO, 2020) [1] estimates that over 3.8 million premature deaths occur annually due to exposure to household air pollution, much of which arises from poor ventilation, material emissions, and inadequate environmental controls within buildings. In tropical regions such as the Niger Delta, where high humidity, temperature extremes, and diverse building practices intersect, indoor environmental conditions present additional risks to both structural integrity and human well-being.

Building age is a key factor influencing indoor environmental quality. Newly constructed or recently renovated buildings often exhibit elevated levels of volatile organic compounds (VOCs) and fine particulates due to emissions from paints, adhesives, and other materials, a phenomenon often described as ‘new building syndrome’ (Zhang *et al*., 2021) [2]. In contrast, older buildings may accumulate particulates and moisture due to material degradation, compromised ventilation systems, and poor maintenance, which exacerbate microbial growth and structural decay (Xing *et al*., 2020) [3]. Mid-aged structures, meanwhile, frequently experience peak pollutant accumulation as construction-related emissions subside but deterioration processes become increasingly significant (Chen *et al*., 2020) [4].

Microclimatic factors such as relative humidity, indoor temperature, and material moisture content also play vital roles in shaping occupant safety and comfort. High humidity has been strongly linked to microbial contamination and allergic respiratory diseases, while prolonged thermal stress undermines cognitive performance and increases vulnerability to heat-related illnesses (Cheong *et al*., 2022) [5]. The deterioration of building materials under these conditions not only compromises structural durability but also increases the release of airborne pollutants, thereby intensifying exposure risks.

Despite the well-documented global burden of indoor pollution, limited empirical studies have examined the combined effects of atmospheric conditions, indoor air quality, and material deterioration in Nigerian residential settings. In the Niger Delta, characterised by rapid urbanisation, ageing infrastructure, and high environmental humidity, evidence remains scarce on how these factors interact across buildings of different ages and how they impact human safety. Such knowledge is essential for developing context-specific interventions that safeguard health while enhancing the longevity of buildings and furnishings.

This study therefore assessed atmospheric conditions, indoor air quality, and furniture/building material deterioration across residential structures of varying ages in Edjeba, Warri-South Local Government Area, Delta State, Nigeria. By examining particulates, gaseous pollutants, microclimatic parameters, and moisture dynamics, the study aimed to (i) determine how building age influences indoor environmental quality; (ii) evaluate the implications for occupant safety; and (iii) identify priority areas for environmental management and building maintenance. The findings provide evidence for policymakers, building managers, and public health stakeholders to guide interventions that balance environmental safety, structural durability, and human well-being in tropical urban settlements.

Materials and Methods

Study Area

The study was conducted in Edjeba, Warri-South Local Government Area, Delta State, Nigeria (5°31′28″N, 5°45′16″E). The area is a densely populated settlement located within the humid tropical Niger Delta, characterised by high annual rainfall, elevated relative humidity, and significant anthropogenic activities that influence indoor and outdoor air quality. Buildings in Edjeba vary in age, design, and maintenance practices, making the site suitable for assessing the relationship between atmospheric conditions, building characteristics, and indoor environmental quality.

Study Design and Building Classification

A stratified sampling approach was employed to categorise residential buildings into five age groups: <1 year, 1–5 years, 6–10 years, 11–15 years, and >15 years. This classification was based on construction records and occupant reports. A minimum of five representative buildings were selected per category, yielding a balanced dataset across the different building age groups.

Indoor Air Quality Monitoring

Indoor air quality was assessed using a calibrated multi-gas and particulate analyser (Aeroqual Series 500, New Zealand) and a particle counter (Temtop M2000C, USA). Measurements included particulate matter fractions ($PM_{0.3}$, $PM_{0.5}$, $PM_{1.0}$, $PM_{3.0}$, $PM_{5.0}$, and PM_{10}), gaseous pollutants (carbon dioxide [CO_2], carbon monoxide [CO], hydrogen sulfide [H_2S], total volatile organic compounds [TVOCs], and formaldehyde [HCHO]), oxygen (O_2), and combustible gases (EX). All instruments were factory-calibrated, and field checks were conducted prior to deployment.

Sampling was carried out between 09:00–11:00 h and 14:00–16:00 h to capture both morning and afternoon indoor conditions. For each building, measurements were taken in the living room at a height of 1.5 m above the floor to approximate the human breathing zone. Three replicate readings were recorded and averaged.

Microclimatic Parameters

Indoor temperature (°C), relative humidity (%), and moisture content of building structures were determined simultaneously with air quality monitoring. Relative humidity and temperature were measured using a digital hygrometer (Extech 445715, USA). Building moisture content was assessed using a pin-type digital moisture meter (Protimeter Mini, UK), with readings taken from walls at three equidistant points per room.

Furniture Analysis

Wooden furniture samples (wardrobes, tables, and chairs) within the same buildings were evaluated for moisture content and surface temperature. Moisture was measured using the digital moisture meter, while temperature was determined using a non-contact infrared thermometer (Fluke 62 MAX+, USA). Each measurement was repeated in triplicate, and mean values were used for analysis.

Data Analysis

Data were expressed as mean ± standard error of mean (SEM). Statistical analysis was performed using SPSS version 25.0 (IBM, USA). One-way analysis of variance (ANOVA) was applied to test for differences among building age categories. Where significant effects were observed, Tukey's Honest Significant Difference (HSD) post hoc test was used to separate means. Statistical significance was set at $p < 0.05$.

Results and discussion

The distribution of particulate matter ($PM_{0.3}$–PM_{10}) across building age categories (Figure 1) revealed distinct size- and age-related patterns. Fine particulates ($PM_{0.3}$) were highest in buildings older than 15 years, reflecting progressive structural degradation, dust accumulation, and ventilation inefficiencies (Xing *et al*., 2020; Hussein & Kulmala, 2008) [3, 6]. Newly constructed or recently renovated buildings (1–5 years) also exhibited elevated $PM_{0.3}$ levels, consistent with 'new building syndrome' driven by off-gassing from paints, adhesives, and construction dust (Zhang *et al*., 2021) [2].

By contrast, mid-aged buildings (6–10 years) recorded the highest concentrations of $PM_{0.5}$, $PM_{1.0}$, and $PM_{5.0}$. This indicates a critical phase of material wear, dust resuspension, and insufficient maintenance, which amplify the release of mid-sized particulates (Morawska *et al*., 2017; Chen *et al*., 2020) [4, 8]. However, concentrations declined in 11–15-year-old buildings, likely due to renovations and improved cleaning or ventilation practices (Zhao *et al*., 2020).

Coarse particulates ($PM_{3.0}$) were most elevated in <1YR and 1–5YR buildings, reflecting residual construction emissions and early occupancy activities, but declined steadily with building age due to gravitational settling and routine cleaning (Salthammer *et al*., 2018; Mendes *et al*., 2015). PM_{10} concentrations were undetectable across all building categories, underscoring the limited persistence of coarse particles indoors, where they rapidly settle and are removed through surface cleaning (Chen & Zhao, 2011) [9].

Overall, the results highlight a size-selective behaviour of indoor particulates: ultrafine fractions persist and intensify in older buildings, mid-sized particles peak in mid-aged structures, while coarse fractions dominate only in newer buildings. These findings emphasise the dynamic relationship between building age, maintenance quality, and ventilation performance. Targeted interventions—including post-construction airing, periodic deep cleaning, and retrofitting ventilation in mid-aged structures—are therefore essential for sustaining indoor air quality and minimising human health risks.

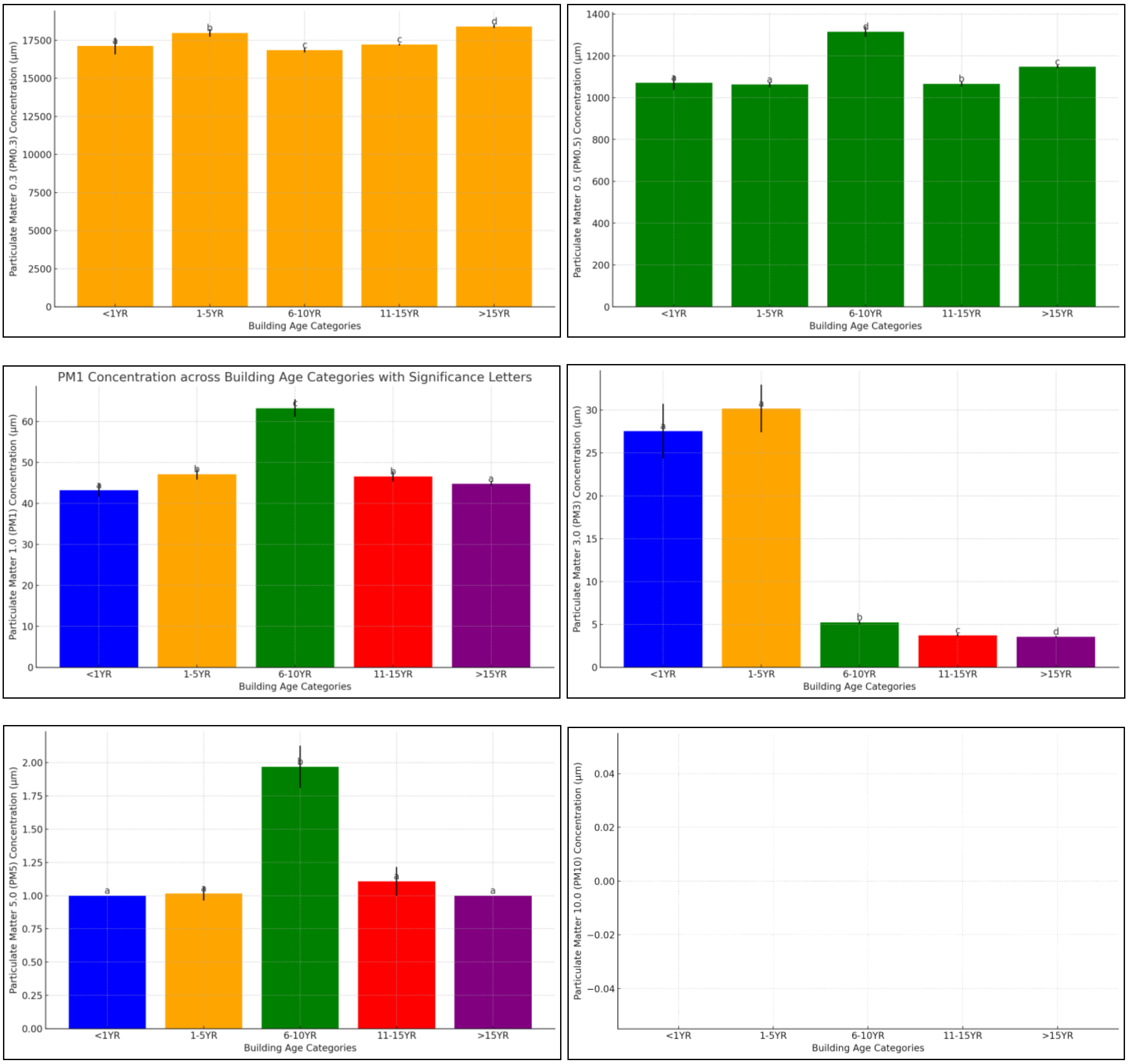

Fig: 1 Indoor particulate matter ($PM_{0.3}$–PM_{10}) concentrations in buildings of varying age categories (<1YR, 1–5YR, 6–10YR, 11–15YR, and >15YR). Values are expressed as mean ± SEM. Bars with different alphabets indicate significant differences ($p<0.05$)

The analysis of indoor gaseous pollutants shown in Figure 2 revealed mixed influences of building age on air quality parameters. Carbon dioxide (CO_2) concentrations (~400 ppm) remained uniform across all building categories, with no significant differences. This suggests that CO_2 levels are primarily governed by occupant density and ventilation rates rather than building age (Persily & de Jonge, 2017).

Similarly, total volatile organic compounds (TVOCs) showed no age-related differences, reflecting the predominance of ongoing indoor sources such as household products, furnishings, and cleaning agents over material ageing effects (Weschler, 2009). Formaldehyde (HCHO) concentrations exhibited slight variation, peaking in 11–15-year-old buildings but still remaining below WHO guideline limits (0.08 ppm) (WHO, 2010). This trend likely reflects cumulative secondary emissions from ageing materials that diminish in older structures following renovations or material depletion (Hodgson *et al*., 2002) [17].

Hydrogen sulfide (H_2S) levels were consistent across all age groups but unusually elevated (~43 ppm), suggesting site-specific contamination (e.g., plumbing leaks or sewage infiltration) rather than building age effects (ATSDR, 2006). Oxygen (O_2) levels showed significant age-related variation, with newer buildings (1–5 years) having the highest concentrations, while >15-year-old buildings exhibited the lowest. This decline highlights the role of ageing structures and compromised ventilation in reducing indoor oxygen availability (Azuma *et al*., 2018) [23].

Carbon monoxide (CO) concentrations peaked in mid-aged buildings (6–10 and 11–15 years), significantly exceeding those of newer (<1YR, 1–5YR) and older (>15YR) structures. This indicates that ventilation efficiency deteriorates during the mid-life phase of buildings, leading to pollutant entrapment, while renovations or natural ventilation pathways may mitigate levels in older buildings (Zhang *et al*., 2020) [24]. Similarly, combustible gases (EX) followed a comparable trend, with significantly higher concentrations in mid-aged buildings, underscoring the need for proactive maintenance of ventilation systems to prevent hazardous accumulation.

Overall, while CO_2, TVOCs, and HCHO largely reflect stable indoor conditions not tied to building age, oxygen depletion, CO, and combustible gases highlight vulnerabilities in mid- and late-aged buildings. These findings stress the importance of periodic air quality monitoring and targeted ventilation interventions to sustain safe indoor environments throughout a building's lifecycle.

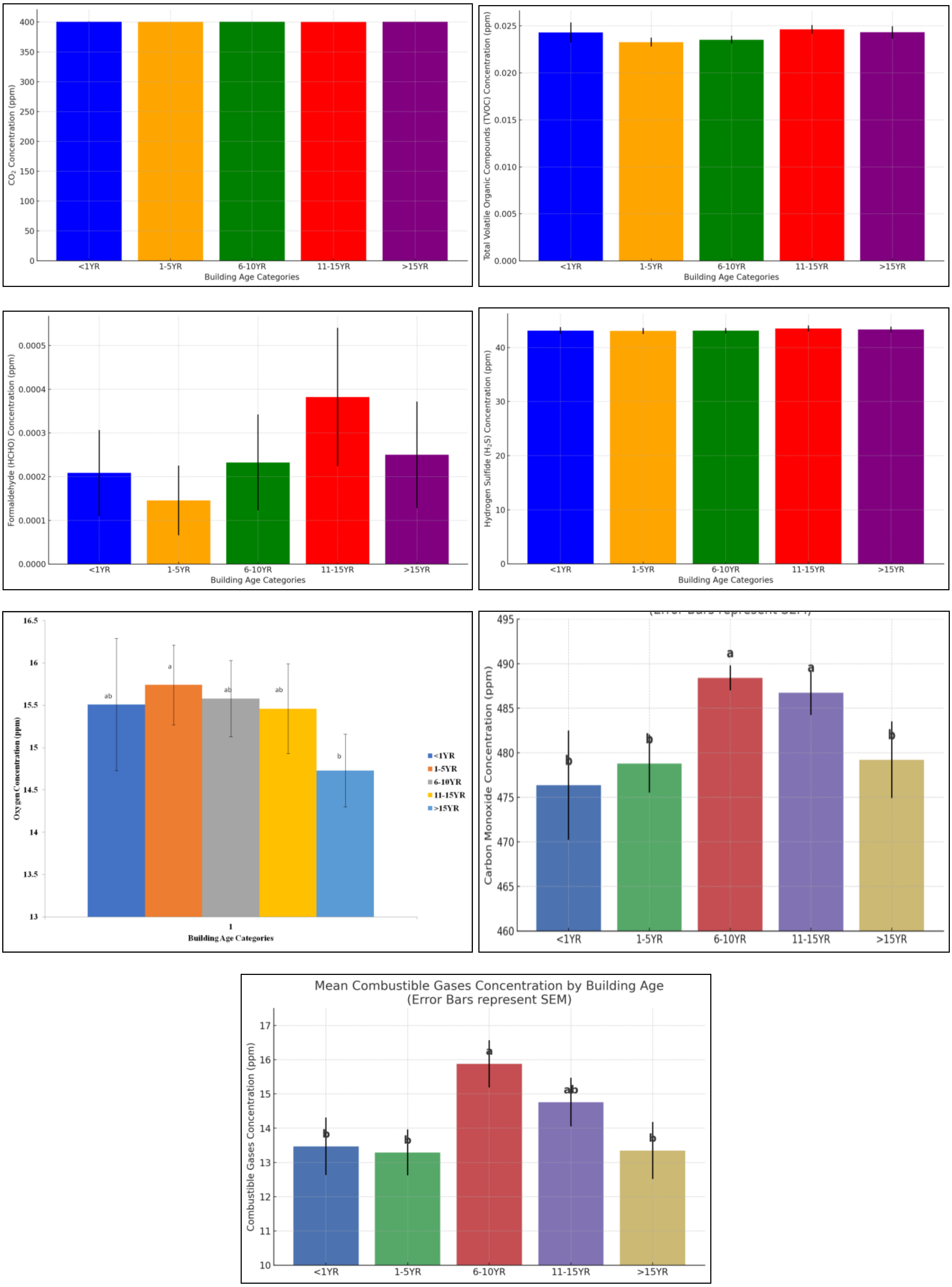

Fig 2: Indoor gaseous pollutants (CO_2, TVOCs, HCHO, H_2S, O_2, CO, and combustible gases) across building age categories (<1YR, 1–5YR, 6–10YR, 11–15YR, >15YR). Values are mean ± SEM. Bars with different letters indicate significant differences at $p < 0.05$; bars with the same letters are not significantly different

The assessment of microclimatic parameters shown in Figure 3 revealed distinct age-related patterns. Relative humidity increased progressively with building age, with the >15 years category recording the highest values, significantly exceeding those of <1YR and 6–10YR buildings. This trend reflects the deterioration of building envelopes and ventilation efficiency in older structures, which promote moisture infiltration and hinder humidity regulation (Zhang *et al*., 2020) [24]. Intermediate values observed in the 1–5YR and 11–15YR categories suggest fluctuating maintenance efficacy and partial degradation of air barrier systems. Elevated indoor humidity in older buildings is a recognised driver of mould proliferation and respiratory health risks (WHO, 2010).

Moisture content showed a contrasting pattern, peaking in 1–5YR buildings and declining sharply in 6–10YR structures, which exhibited the lowest values. The elevated moisture in newer buildings is consistent with residual construction moisture and incomplete curing of materials (Kalamees *et al*., 2019) [25]. By 6–10 years, dissipation of this residual moisture and intact building barriers likely minimise accumulation. In older buildings (>15YR), intermediate moisture content suggests a balance between natural ventilation pathways created by structural wear and occasional remedial works. Elevated moisture content, particularly in the early post-construction phase, underscores risks of long-term structural degradation and microbial growth if not effectively managed (Cheong *et al*., 2022) [5].

Indoor temperature displayed an inverse relationship with building age, with newer buildings (<1YR and 1–5YR) exhibiting the highest values and older buildings (>15YR) the lowest. This decline is attributable to enhanced insulation and airtightness in modern buildings that trap heat (Azuma *et al*., 2018) [23], while ageing structures develop air leakage pathways that facilitate passive cooling (Zhang *et al*., 2020) [24]. Elevated temperatures in newer buildings highlight potential challenges of thermal discomfort and heat stress, while the lower values in older buildings suggest energy inefficiency from uncontrolled air exchange.

Together, these findings demonstrate that relative humidity tends to rise with building age, residual moisture peaks in early life stages, and temperature declines as structures age. The interplay of these parameters underscores the necessity of age-specific interventions: moisture management in new buildings, proactive ventilation maintenance in mid-aged structures, and thermal comfort strategies in older buildings to safeguard occupant health and building integrity.

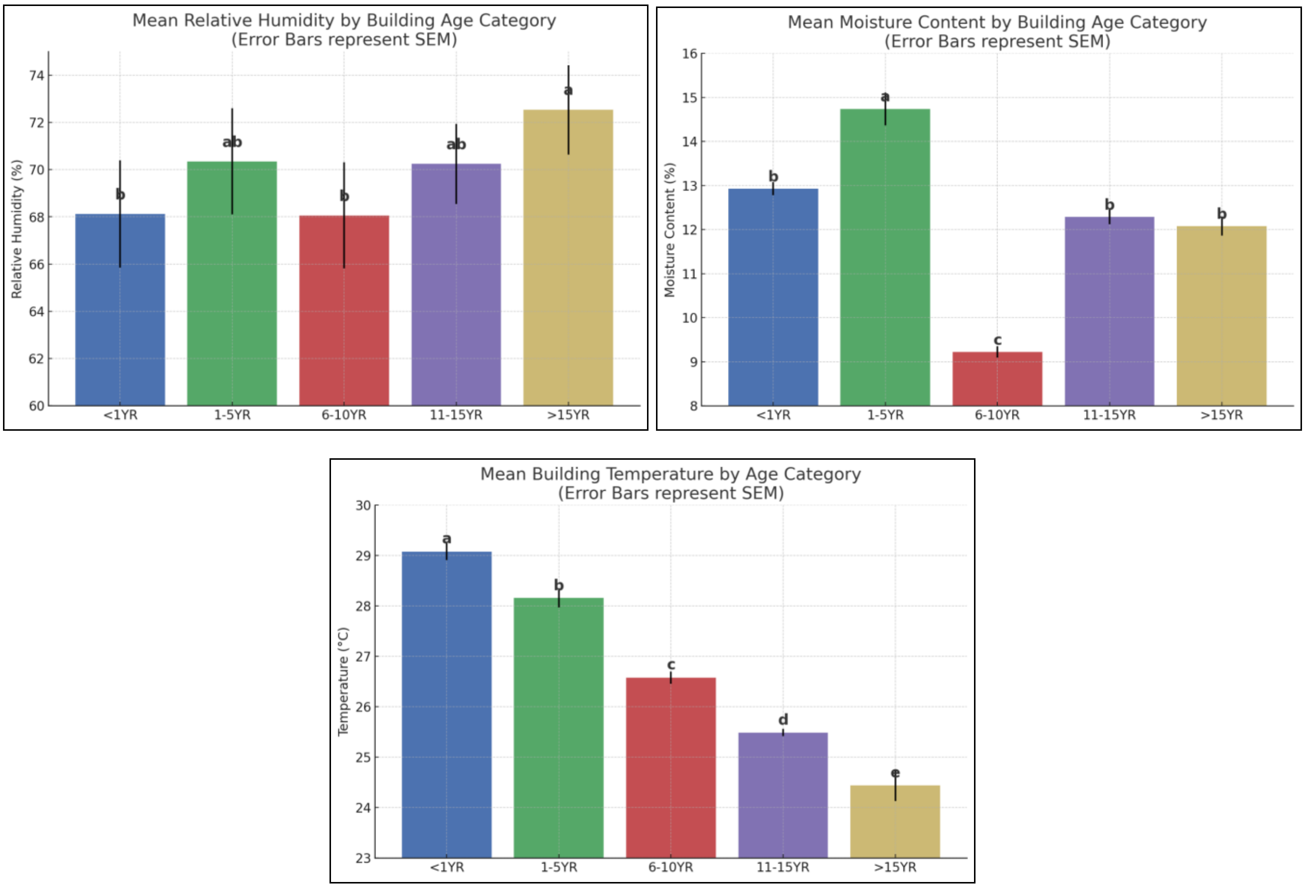

Fig 3: Indoor relative humidity (%), building moisture content (%), and temperature (°C) across building age categories (<1YR, 1–5YR, 6–10YR, 11–15YR, >15YR). Values are mean ± SEM. Bars with different letters indicate statistically significant differences at $p < 0.05$.

The analysis of wooden furniture revealed clear age-dependent trends in both moisture content and temperature. Moisture content peaked in 6–10YR buildings, significantly exceeding all other categories, while >15YR structures also exhibited elevated levels compared to <1YR buildings. This pattern suggests cumulative absorption of ambient humidity in mid-aged buildings where residual construction moisture, limited ventilation, and usage practices promote retention (Kalamees *et al*., 2019) [25]. In contrast, the lowest values were recorded in <1YR buildings, likely reflecting kiln-dried or treated materials and the tighter moisture control of modern construction. Intermediate levels observed in 1–5YR and 11–15YR categories highlight transitional phases where moisture stabilisation or partial environmental control occurs. Elevated moisture content in mid-aged and older furniture poses risks of structural weakening, fungal colonisation, and indoor air quality deterioration (Cheong *et al*., 2022) [5].

Furniture temperature followed an inverse relationship with building age. The highest temperatures were recorded in <1YR buildings, declining progressively across the age spectrum, with >15YR structures exhibiting the lowest values. Elevated temperatures in new buildings reflect residual construction heat, low-emissivity treated surfaces, and limited ventilation efficiency (Azuma *et al*., 2018) [23]. As buildings age, increased passive ventilation from structural wear facilitates heat dissipation, leading to thermal equilibration of furniture with ambient conditions (Cheong *et al*., 2022) [5]. The variability in older (>15YR) buildings suggests differential deterioration or remedial interventions that influence thermal retention inconsistently.

Collectively, these findings indicate that furniture in mid-aged buildings is most vulnerable to moisture-related degradation, while furniture in newer buildings is more prone to thermal stress. Both conditions have implications for occupant comfort, material preservation, and indoor air quality, underscoring the need for adaptive moisture and temperature control strategies across the building lifespan.

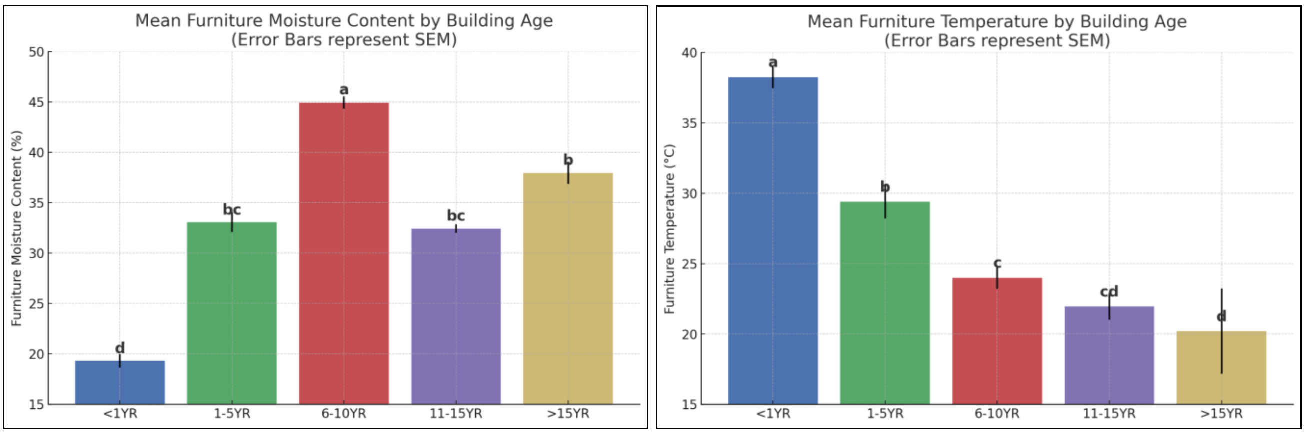

Fig 4: Moisture content (%) and temperature (°C) of wooden furniture across building age categories (<1YR, 1–5YR, 6–10YR, 11–15YR, >15YR). Values are mean ± SEM. Bars with different letters indicate statistically significant differences at $p < 0.05$.

Conclusion

This study shows that building age significantly affects indoor air quality and safety in Edjeba, Warri-South LGA. Older buildings were associated with higher ultrafine particulate and humidity levels, while mid-aged structures recorded elevated concentrations of carbon monoxide, combustible gases, and moisture retention in furniture. Newer buildings, though generally safer, demonstrated risks of heat entrapment and residual construction-related emissions.

The findings underscore the need for routine indoor air quality monitoring, targeted ventilation upgrades, and strict post-construction airing protocols. Policymakers, regulatory agencies, and building managers should prioritise age-specific interventions—such as moisture control in new buildings, preventive maintenance in mid-aged buildings, and refurbishment of ventilation systems in older structures.

Adopting these measures will not only safeguard occupant health but also extend the lifespan of buildings and furniture, reduce healthcare burdens from poor indoor environments, and align housing practices in the Niger Delta with international safety and sustainability standards.

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