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RESEARCH ARTICLE

Application of Sustainable Design Strategies for Enhancing Energy Efficiency and Indoor Environmental Quality in Automobile Training Centres, Nigeria

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Abstract

The building sector remains a major contributor to global energy consumption and greenhouse gas emissions, while poor indoor environmental quality (IEQ) continues to affect occupant health, comfort, and productivity. These challenges are particularly critical in specialized facilities like automobile training centres, where engine testing, welding, spray painting, and mechanical repairs generate heat, noise, and air pollutants. This study evaluated sustainable design strategies for improving energy efficiency and IEQ in an automobile training centre under warm-humid climatic conditions in Nigeria. A systematic review of 47 peer-reviewed articles, technical reports, and case studies published between 2000 and 2024 was conducted. Data were analyzed thematically across four categories: passive design techniques, high-performance building envelopes, renewable energy integration, and smart building systems, alongside IEQ parameters including thermal comfort, indoor air quality, daylighting, and acoustic performance. Findings revealed that passive strategies such as optimal orientation, cross-ventilation, high roof volumes, and solar shading reduced cooling energy demand by up to 40%. High-performance envelopes improved thermal performance by approximately 30%, while solar photovoltaic systems reduced grid dependence by up to 60%. IEQ improvements were achieved through integrated ventilation, low-emission materials, enhanced daylighting, and acoustic control measures. The study concludes that early incorporation of sustainable design strategies is critical for achieving energy-efficient, safe, and healthy learning environments, and recommends performance-based regulations, professional training, and contextual adaptation of technologies to local climatic and functional requirements.

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1. INTRODUCTION

The building sector accounts for nearly 30–37% of global energy use and carbon emissions (IEA, 2023), with challenges intensified in developing countries like Nigeria by rapid urbanisation, unreliable energy supply, and weak regulatory enforcement (UNEP, 2022). Sustainable building design integrates environmental responsibility, resource efficiency, and occupant well-being across a building's life cycle, with two interdependent objectives at its core: energy efficiency (reducing demand for heating, cooling, lighting, and ventilation) and indoor environmental quality (IEQ), encompassing thermal comfort, air quality, daylighting, and acoustics (World Green Building Council, 2021). These objectives are often in tension: airtight envelopes improve thermal performance but restrict airflow, while enhanced ventilation benefits IEQ but can raise energy use if unmanaged (Allen *et al*., 2020; Awada *et al*., 2022). Internationally, frameworks such as LEED and BREEAM provide benchmarks for integrated sustainable performance (Doan *et al*., 2021), but their application in Nigeria remains constrained by limited awareness, high implementation costs, and weak enforcement of building regulations (Akinwolemiwa *et al*., 2020; Oyedepo, 2021).

1.1. Problem Statement

Despite the growing availability of sustainable design principles, their integration into Nigerian building practice remains limited, resulting in excessive energy consumption and deteriorating IEQ in poorly designed facilities. A critical gap exists in the simultaneous application of strategies that address both energy efficiency and IEQ as integrated design objectives, particularly in specialized building typologies such as automobile training centres. Such facilities present unique environmental challenges, including heat generation from engine testing, air pollutants from welding and spray painting, and acoustic disturbances from machinery. Yet, they remain largely underrepresented in sustainable building design literature within the Nigerian context. This study, therefore, addresses the inadequate integration of sustainable design strategies that concurrently enhance energy efficiency and indoor environmental quality in automobile training facilities under warm-humid climatic conditions.

1.2 Aim and Objectives

Aim: This study aimed to evaluate the application of sustainable design strategies for enhancing energy efficiency and improving indoor environmental quality in an automobile training centre under warm-humid climatic conditions in Nigeria.

Objectives:

1. To examine the principles and frameworks of sustainable design as applied to the built environment.
2. To identify passive and active design strategies effective in reducing energy consumption in warm-humid climates.
3. To assess the key indoor environmental quality parameters relevant to workshop and training facilities.
4. To evaluate the relationship between energy efficiency measures and indoor environmental quality outcomes in sustainable building design.
5. To recommend contextually appropriate sustainable design strategies for automobile training centres in Nigeria.

2.0 LITERATURE REVIEW

2.1 Theoretical Framework

This study is anchored on the Integrated Sustainable Design Framework (Figure 1), which posits that energy efficiency and IEQ are interdependent performance outcomes. Drawing on climate-responsive architecture, building performance optimisation, and occupant-centred design, the framework provides the conceptual basis for evaluating sustainable strategies in automobile training centres, where passive strategies, high-performance envelopes, renewable energy systems, and IEQ parameters must be optimised simultaneously under warm-humid conditions.

2.2 Sustainable Design in Buildings

Sustainable building design minimises environmental impact while enhancing human health, comfort, and resource efficiency across a building's life cycle. Doan *et al*. (2021) describe it as integrating environmental, economic, and social dimensions through energy-efficient systems, climate-responsive strategies, and sustainable materials, with the "healthy buildings" concept placing occupant well-being alongside energy performance as a core objective (Allen *et al*., 2020). LEED and BREEAM provide structured benchmarks for these principles globally. Critically, however, most sustainable design literature addresses generic typologies—offices, schools, residential buildings, leaving specialised facilities such as automobile training centres, with their unique operational challenges, significantly underrepresented and requiring contextual adaptation of existing frameworks.

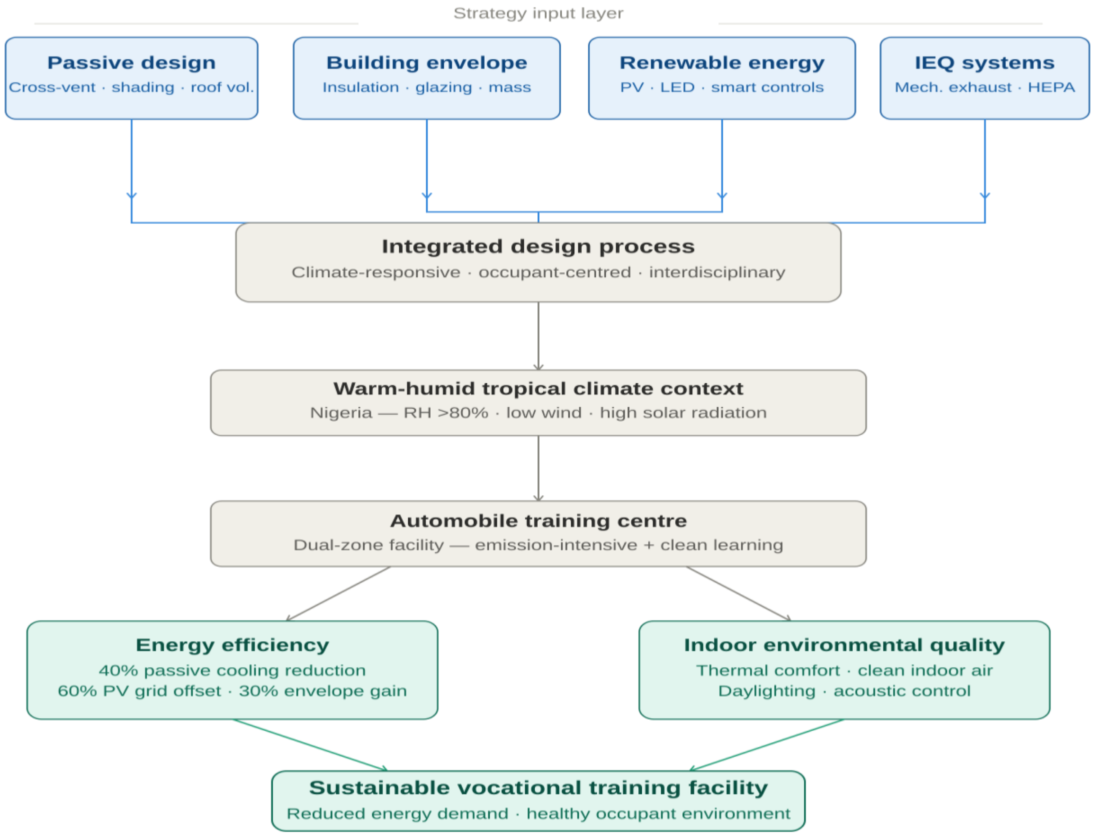

Figure 1. Integrated sustainable design framework mapping strategy inputs (passive design, building envelope, renewable energy, IEQ systems) to joint performance outcomes in automobile training centres under warm- humid tropical conditions.
Source: Author's Construction (2026)

2.3 Energy Efficiency in Sustainable Buildings

Energy efficiency is a fundamental component of sustainable building design, focusing on reducing operational energy demand while maintaining acceptable levels of comfort and functionality. The IEA (2023) reports that the building sector accounts for nearly one-third of global energy use and carbon emissions, underscoring the urgency of energy reduction strategies.

Passive design strategies are among the most cost-effective approaches to reducing energy consumption, particularly in hot climates. Building orientation, shading devices, natural ventilation, thermal mass, and daylighting have been shown to significantly reduce cooling loads. Oyedepo (2021) demonstrated that climate-responsive orientation in Nigerian buildings could reduce mechanical cooling demand by up to 30%. High-performance building envelopes, including insulated walls, low-emissivity glazing, and airtight construction, further minimise heat transfer between interior and exterior environments. UNEP (2022) reported that envelope improvements could reduce building energy consumption by 30–50%, depending on climate and building type.

Active systems, including energy-efficient HVAC systems, LED lighting, and smart building controls, complement passive strategies by dynamically adjusting performance based on occupancy and environmental conditions. Advanced building performance simulation tools are now widely used to predict energy outcomes during the design phase, enabling informed decision-making early in the project lifecycle (IEA, 2023). In the context of automobile training facilities, energy demands are substantially elevated due to the operation of heavy machinery, mechanical equipment, spray booths, and welding stations. These activities generate significant thermal loads that conventional passive strategies alone may be insufficient to address. Akinwolemiwa *et al.* (2020) noted that workshop environments in tropical climates require integrated energy strategies that combine passive cooling, mechanical ventilation, and renewable energy systems to manage both operational loads and occupant comfort effectively.

2.4 Indoor Environmental Quality (IEQ)

IEQ refers to the overall condition of the indoor environment as it relates to occupant health, comfort, and well-being. It is assessed through four primary parameters: thermal comfort, indoor air quality, lighting quality, and acoustic comfort. Research indicates that occupants spend approximately 80–90% of their time indoors, making IEQ a critical determinant of health outcomes and productivity (World Health Organization [WHO], 2021).

Thermal Comfort: Thermal comfort is influenced by air temperature, humidity, air movement, clothing, and metabolic activity. Standards such as ASHRAE 55 (2020) and ISO 7730 (2005) provide analytical frameworks for assessing thermal comfort using indices such as Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD). In warm-humid climates, achieving thermal comfort without over-reliance on mechanical cooling requires climate-responsive strategies including natural ventilation, shading, and thermal mass (IEA, 2023). In automobile workshops, metabolic heat generated by physical labour further intensifies thermal stress, necessitating enhanced ventilation and cooling interventions beyond standard comfort thresholds.

Indoor Air Quality: Indoor air quality is a major occupational health concern in workshop environments. Activities such as engine testing, spray painting, welding, and mechanical repairs release carbon monoxide, volatile organic compounds (VOCs), particulate matter, and heavy metal fumes into the indoor atmosphere (WHO, 2021). Prolonged exposure to these pollutants is associated with respiratory diseases, neurological damage, and increased cancer risk among workshop occupants (UNEP, 2022). Improving ventilation rates, using low-emission materials, and installing localised exhaust systems at pollutant sources are critical strategies for maintaining acceptable air quality in such facilities. Awada *et al*. (2022) established that source-control ventilation strategies in workshop environments reduced airborne pollutant concentrations by up to 55% compared to general dilution ventilation alone.

Daylighting and Visual Comfort: Natural daylight reduces energy consumption and enhances occupant mood, concentration, and circadian rhythm regulation (World Green Building Council [WGBC], 2021). In workshop environments, adequate daylighting improves task visibility, reduces eye strain, and supports safe equipment operation. Strategies such as roof monitors, clerestory windows, translucent roofing panels, and light shelves are particularly effective in large-span workshop spaces where conventional window placement may be insufficient.

Acoustic Comfort: Noise pollution is a significant occupational hazard in automobile training facilities, where machinery, compressed air tools, engine testing, and metal fabrication generate sustained high-decibel noise levels. Chronic exposure to excessive noise is associated with hearing loss, cognitive impairment, and elevated stress (Allen *et al*., 2020). Sustainable design addresses acoustic performance through sound-absorbing ceiling and wall materials, strategic spatial zoning of noisy and quiet activities, vibration isolation of heavy equipment, and compliance with occupational noise exposure standards. In training facilities, acoustic control is particularly critical to ensure effective communication between instructors and learners.

2.5 Integration of Energy Efficiency and IEQ

Integrating energy efficiency and IEQ is a central challenge in sustainable design. Airtight, well-insulated envelopes improve thermal performance but restrict airflow; conversely, enhanced ventilation improves air quality but can raise cooling loads if solar gain is uncontrolled (IEA, 2023). The WGBC (2021) advocates integrated design processes that optimise all systems simultaneously from the earliest design stages. In automobile training facilities, this integration is especially complex, given the concurrent presence of high thermal loads, chemical pollutants, acoustic disturbances, and occupational safety requirements.

2.6 Passive and Vernacular Design Approaches

Passive design utilises sunlight, wind, and thermal mass to regulate indoor conditions without mechanical systems and is widely recognised as the most cost-effective foundation for sustainable design in hot climates (IEA, 2023). Nigerian vernacular architecture, featuring thick earthen walls, courtyard configurations, and elevated floors, embodies these principles (Akinwolemiwa *et al*., 2020). Contemporary applications include west-facing facade minimisation, deep roof overhangs, cross-ventilation layouts, and thermally stable materials. In automobile training centres, these strategies must accommodate large floor plates and high equipment loads; high-roof volumes with ridge ventilation and insulated metal deck roofing are particularly effective passive cooling solutions for workshop-scale buildings in tropical climates (Oyedepo, 2021).

3.0 RESEARCH METHODOLOGY

3.1 Research Design and Framework

This study adopted a qualitative research design within a descriptive research framework to evaluate the application of sustainable design strategies for enhancing energy efficiency and indoor environmental quality (IEQ) in automobile training centres in Nigeria. The descriptive approach was selected because it enables systematic identification, examination, and evaluation of phenomena as they exist in their natural context, making it appropriate for architectural and environmental performance studies (Saunders *et al*., 2019). The qualitative orientation allowed for an in-depth exploration of design strategies, environmental conditions, and relationships between building performance variables across the selected facilities.
The study was structured around three sequential phases:

- Phase 1: Systematic literature review to establish the theoretical and conceptual framework
- Phase 2: Field observation and physical assessment of selected automobile training centres
- Phase 3: Thematic analysis of collected data to identify patterns, strategies, and performance outcomes

This phased framework ensured methodological coherence between the study's aim, objectives, data collection procedures, and analytical approach.

3.2 Data Sources

Both primary and secondary data sources were employed to address the study's objectives comprehensively.

Primary Data: Primary data were collected through structured observational surveys conducted across the ten selected automobile training centres. The observational instrument comprised a standardised assessment schedule developed to evaluate each facility against defined environmental and design performance criteria. Photographic documentation was used to supplement observational records, providing visual evidence of existing conditions and design features across all sampled facilities.

Secondary Data: Secondary data were obtained through a systematic review of 47 peer-reviewed journal articles, technical reports, and documented case studies published between 2000 and 2024. The literature search was conducted using three primary academic databases: Scopus, Google Scholar, and Web of Science. Search strings were constructed around the following key terms and Boolean combinations: (“sustainable building design” OR “green building”) AND (“energy efficiency” OR “passive design”) AND (“warm-humid climate” OR “tropical climate”); (“indoor environmental quality” OR “IEQ”) AND (“workshop” OR “vocational training facility”); and (“automobile workshop” OR “automotive training centre”) AND (“ventilation” OR “thermal comfort” OR “air quality”). Sources were included if they: (i) were published in peer-reviewed journals or official technical reports between 2000 and 2024; (ii) addressed at least one of the four thematic categories (passive design, building envelopes, renewable energy, or IEQ); (iii) were conducted in tropical, sub-Saharan African, or warm-humid climatic contexts; and (iv) were available in full text in English. Sources were excluded if they focused exclusively on cold-climate or temperate building design without transferable findings, were grey literature without institutional authorship, or were published before 2000. Of the 47 sources retained, 34 were peer-reviewed journal articles, nine were institutional technical reports (IEA, UNEP, WHO, WGBC), and four were documented case studies of sustainable workshop or training facility design. Secondary data provided the theoretical foundation, comparative benchmarks, and performance standards against which primary observations were evaluated.

3.3 Population and Sampling

Population: The study population comprised automobile training centres and related workshop facilities located across Nigeria, representing the broader building typology under investigation.

Sampling Method: A purposive sampling technique was employed to select ten automobile training centres, prioritising contextual relevance and information richness over statistical representativeness (Creswell & Creswell, 2018).

Selection Criteria: Facilities were selected based on the following criteria:
- Active operation as an automobile training or workshop facility at the time of the study
- Located within Nigeria's warm-humid climatic zones
- Accessibility for physical observation and assessment

Sample Size Justification: Ten facilities provided adequate depth for qualitative assessment (Patton, 2015), representing private academies, government technical institutions, and commercial workshop centres across Lagos, Abuja, Osogbo, Esa Oke, and Port Harcourt.

Table 1. Sample Size and Location.

S/N	Sample size	Location
1.	Autoclinic Technical Training Centre	Lagos
2.	Lufteriber Automobile	Lagos
3.	Afeme Mechatronics workshop	Abuja
4.	Froshtech Academy	Lagos
5.	Bola Ige Mechatronics Institute	Esa Oke
6.	Automedics Auto Care	Lagos
7.	Autospark Mechanic workshop	Lagos
8.	Govt. Technical College	Osogbo
9.	West Africa Automotive Institute	Lagos
10.	Autofixer	Porthacourt

- Variation in facility size, ownership type, and geographic location to ensure diversity of findings

Sample Size Justification: Ten facilities provided adequate depth for qualitative assessment (Patton, 2015), representing private academies, government technical institutions, and commercial workshop centres across Lagos, Abuja, Osogbo, Esa Oke, and Port Harcourt.

3.4 Data Collection Instrument

A structured observational assessment schedule was developed as the primary data collection instrument. The schedule was organised into five thematic sections aligned with the study's objectives:
1. Site and building orientation — facade direction, solar exposure, shading provisions
2. Building envelope assessment — wall materials, roof construction, insulation type, glazing
3. Passive design features — ventilation openings, roof height, natural lighting provisions
4. IEQ conditions — thermal environment, air quality indicators, daylighting levels, noise sources
5. Energy systems — presence of renewable energy installations, mechanical ventilation, and artificial lighting types

Each section contained clearly defined observable indicators, enabling consistent and replicable assessment across all ten facilities. Photographic records were taken at each facility to document physical conditions and design features.

3.5 Data Analysis

Collected data were analysed using thematic analysis, following the six-phase procedure outlined by Braun and Clarke (2006):
1. Data familiarisation — review of all observational notes and photographic records
2. Initial coding — systematic labelling of observed design features and environmental conditions
3. Theme generation — grouping of codes into recurring patterns across facilities
4. Theme review — cross-checking themes against the raw data for consistency
5. Theme definition — clearly naming and describing each identified theme
6. Reporting — synthesizing findings into coherent analytical narratives supported by literature

Four primary themes were identified through this process: passive design strategies, building envelope performance, renewable energy integration, and IEQ conditions. Findings from field observations were triangulated with secondary literature to enhance analytical depth and contextual interpretation.

3.6 Validity, Reliability, and Bias Control

To ensure the credibility and trustworthiness of the study's findings, the following measures were adopted:

- **Validity:** Assessment indicators were grounded in ASHRAE 55, ISO 7730, and LEED criteria
- **Reliability:** The same standardized schedule was applied across all ten facilities
- **Triangulation**: Primary observational data were cross-referenced with secondary literature findings to strengthen interpretive accuracy
- **Bias control:** Observations were conducted blind to expected outcomes; photographic evidence was retained for verification.

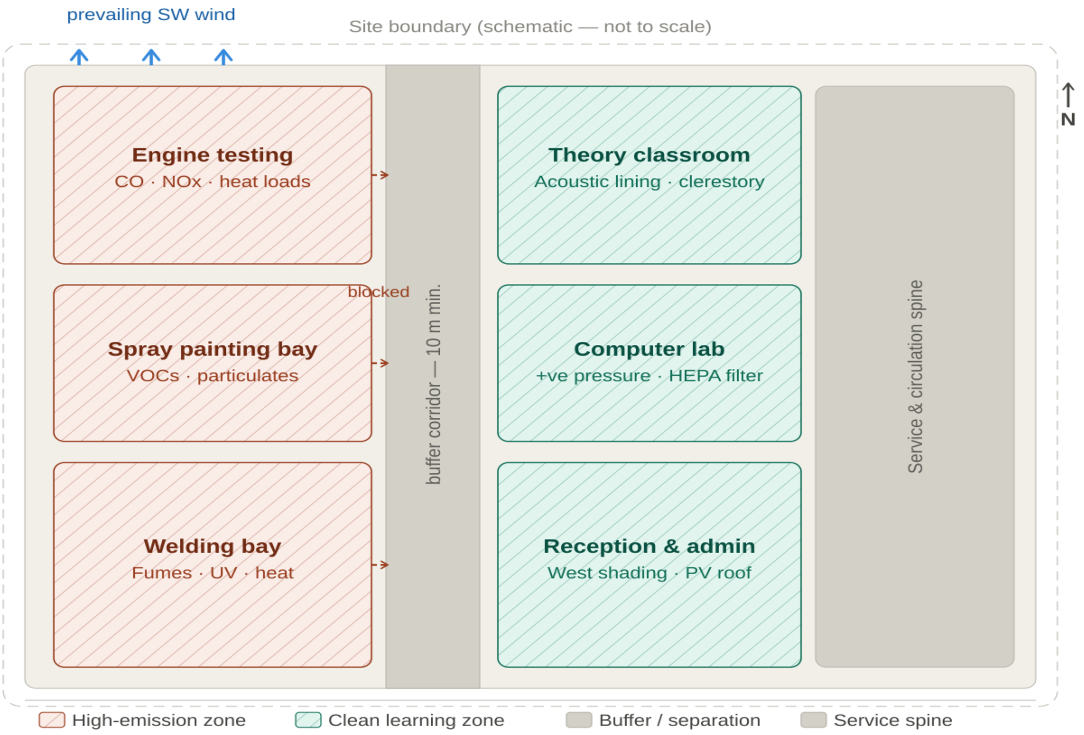

Figure 2. Schematic plan showing functional zone separation in a model automobile training centre (not to scale).

Source: Author’s Construction (2026)

Figure 3. Site plan showing orientation and zone separation of spaces in an automobile training centre (not to scale).
Source: Google Maps (2026)

4.0 FINDINGS

The findings presented in this section are based on structured observational assessments conducted across ten automobile training centres in Nigeria, analysed thematically across six performance indicators.

4.1 Passive Ventilation System

Cross-ventilation was observed in 80% of assessed spaces through openable windows, large sliding doors, and strategically placed opposing wall openings across workshops, classrooms, and administrative areas. The remaining 20% demonstrated inadequate passive provision, relying on mechanical systems for air circulation. While openings were generally present, their alignment with prevailing wind directions was inconsistent, limiting ventilation effectiveness. Oyedepo (2021) established that effective cross-ventilation reduces indoor temperatures by 3–5°C in warm-humid climates, indicating that opening placement requires greater design deliberation across these facilities.

Figure 4. Theory Classroom Featuring Large Openings for Natural Passive Ventilation
Source: Author's Compilation (2026) based on field observations.

Figure 5. Workshop Facade with Sliding Doors and Roof Skylight for Combined Daylighting and Ventilation
Source: Author's Compilation (2026) based on field observations.

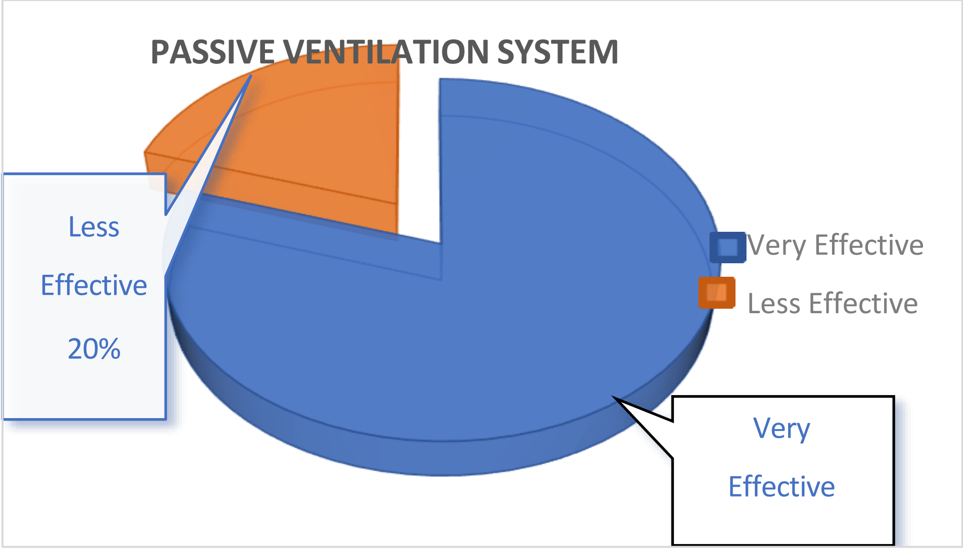

Figure 6. Passive Ventilation System
Source: Author's Compilation (2026) based on field observations.

4.2 Natural Daylighting Sufficiency

Assessment indicated that 80% of spaces demonstrated reduced artificial lighting dependence through skylights, clerestory windows, translucent roofing panels, and large facade openings. The remaining 20% exhibited high artificial lighting dependence due to deep-plan configurations and inadequate apertures. Complete elimination of artificial lighting is impractical in automobile facilities, given precision task requirements and occupational safety standards. IEA (2023) recommends roof-level daylighting apertures for large-span industrial spaces, suggesting that targeted retrofitting of skylight and monitor roof elements would significantly improve energy performance in the underperforming facilities.

Figure 7. Wide Openings Serving as Primary Passive Ventilation Strategy in an Office Space
Source: Author's Compilation (2026) based on field observations.

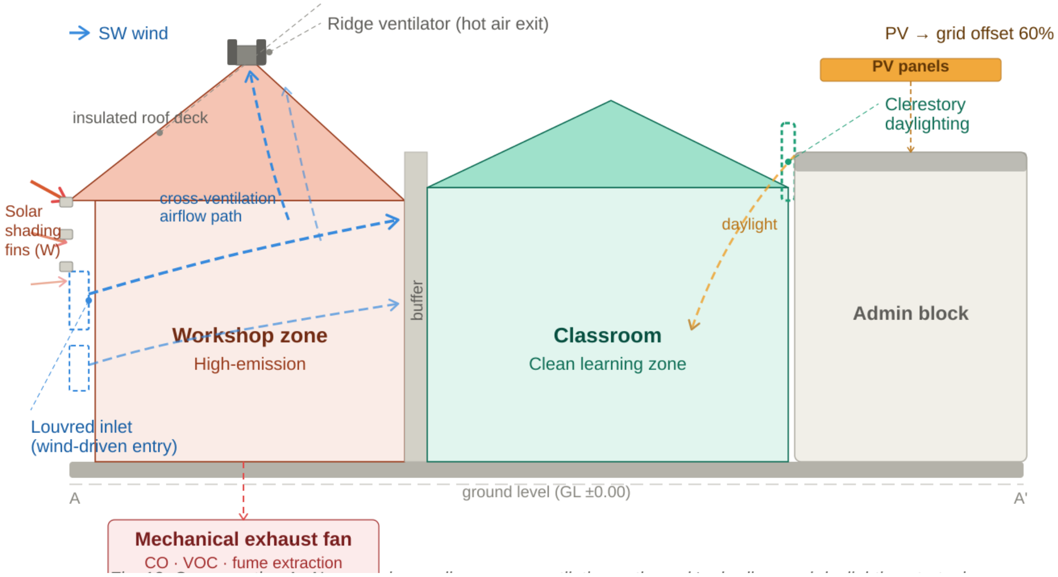

Figure 8. Cross-sections illustrate passive cooling strategies: cross-ventilation paths, ridge ventilator, insulated roof deck, solar shading fins, clerestory daylighting, and source-control mechanical exhaust.
Source: Author's Construction (2026)

Figure 9. Automobile Workshop Interior Demonstrating Integrated Artificial and Natural Daylighting
Source: Author's Compilation (2026) based on field observations.

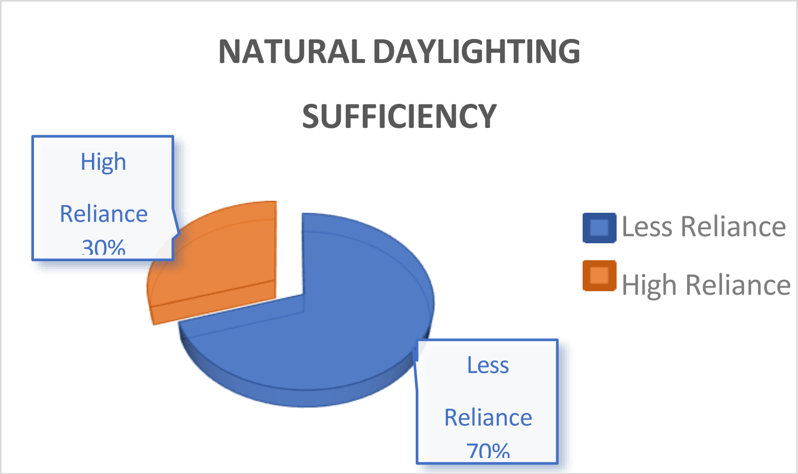

Figure 10. Natural Daylighting Sufficiency
Source: Author's Compilation (2026) based on field observations.

4.2. Shading Device

Shading devices, including roof overhangs, extended eaves, covered corridors, and high-level windows, were observed in 80% of sampled facilities, while 20% lacked adequate shading provision. Unshaded facilities exhibited visibly elevated thermal discomfort, particularly in west-facing spaces during afternoon hours. Akinwolemiwa *et al*. (2020) demonstrated that properly designed external shading reduces solar heat gain through openings by 40–60% in tropical climates. The absence of shading in 20% of facilities represents a significant passive design deficiency with direct implications for thermal comfort and cooling energy demand in warm-humid Nigerian conditions.

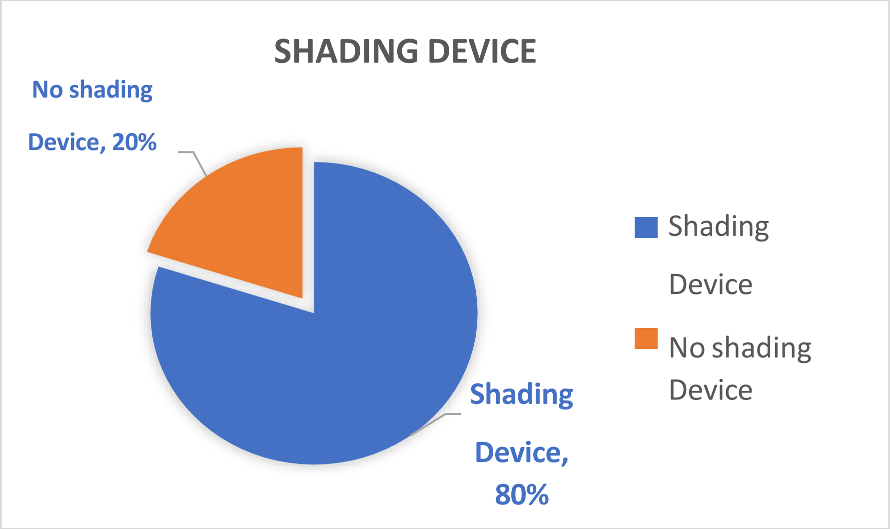

Figure 11. Shading Device
Source: Author's Compilation (2026) based on field observations,

4.4 Building Envelope Insulated

Sixty percent of assessed facilities incorporated insulated envelopes, including insulated metal deck roofing, cavity walls, and heat-reflective finishes, demonstrating comparatively better internal thermal conditions. The remaining 40% featured uninsulated single-skin metal roofing and solid masonry walls, exhibiting significant radiant heat transfer into occupied spaces during peak hours. UNEP (2022) reported that envelope improvements reduce building energy consumption by 30–50%, depending on climate and construction type. In workshop environments where machinery generates substantial internal heat loads, uninsulated envelopes compound thermal stress and increase dependence on mechanical cooling systems.

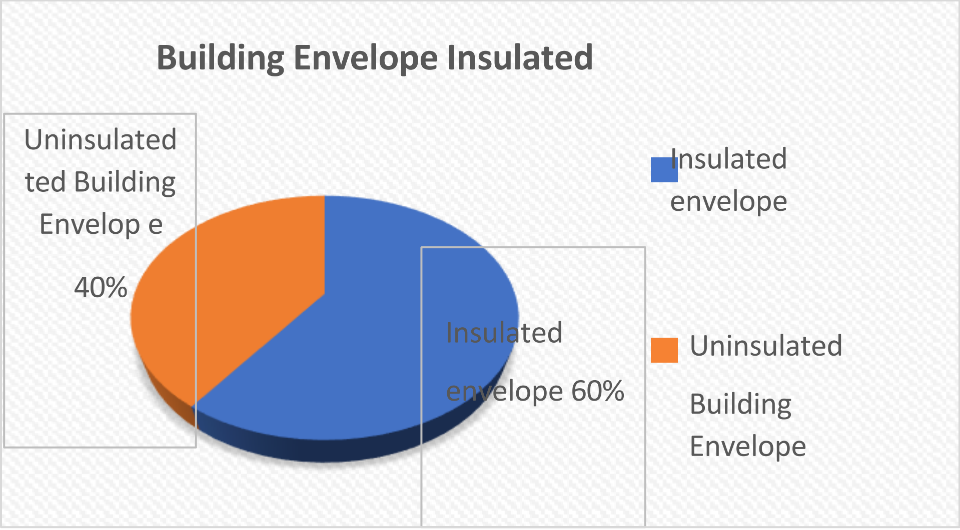

Figure 12. Building Envelope Insulated
Source: Author's Compilation (2026) based on field observations,

4.5 LED Lighting Installed

All ten sampled facilities had universally adopted LED lighting as their primary artificial light source, representing a complete transition from less efficient fluorescent and incandescent technologies. LED systems offer up to 75% reduction in lighting energy consumption with significantly longer operational lifespans (IEA, 2023). However, universal LED adoption does not guarantee optimised energy performance. Variations in fixture density, lumen output calibration, and the absence of occupancy-responsive lighting controls were observed across facilities, suggesting that further system-level optimisation could yield additional energy savings beyond the baseline efficiency benefit of LED installation alone.

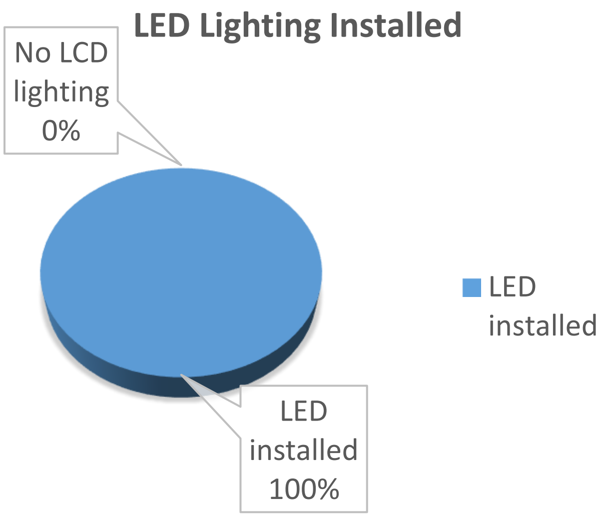

Figure 13. LED Lighting Installed
Source: Author's Compilation (2026) based on field observations,

4.5 Mechanical Ventilation with Filter

Only 40% of assessed facilities incorporated mechanical ventilation systems, including exhaust fans and localised extraction units near pollutant sources such as welding bays and spray booths. The remaining 60% relied entirely on natural ventilation, with visible fume accumulation observed in enclosed workshop areas during peak activity. WHO (2021) recommends mechanical source-control ventilation as a minimum requirement where combustion and chemical pollutants are generated. Awada *et al*. (2022) demonstrated that source-control mechanical ventilation reduces airborne pollutant concentrations by up to 55%, confirming that many sampled facilities fall below internationally recommended indoor air quality thresholds. This deficit carries particular significance under the climatic conditions prevalent in Nigeria's warm-humid zones. Cross-ventilation strategies that perform adequately during dry season periods become critically limited during high-humidity months (April–October) when outdoor wind velocities can fall below 1.0 m/s and ambient relative humidity regularly exceeds 80%. Under such conditions, buoyancy-driven passive ventilation reliant on temperature differentials between indoor and outdoor air loses effectiveness, as the reduced thermal gradient between hot workshop interiors and a warm, humid exterior diminishes the stack-effect driving force. Simultaneously, high ambient humidity impairs the natural dilution of airborne pollutants, allowing carbon monoxide, welding fumes, and spray paint aerosols to accumulate to hazardous concentrations even in nominally "open" workshop bays with large sliding doors. Akinwolemiwa *et al*. (2020) noted that in workshop environments in tropical West Africa, passive ventilation alone cannot achieve the air change rates required by occupational safety standards (ASHRAE 62.1 specifies a minimum of 0.5 L/s per m^2 for workshop spaces with chemical pollutant sources) during peak humidity periods. The implication for automobile training centres is that source-control mechanical ventilation, particularly localised exhaust systems positioned within 0.5 metres of welding stations, spray booths, and engine testing bays is a non-negotiable design requirement rather than an optional supplement to passive strategies.

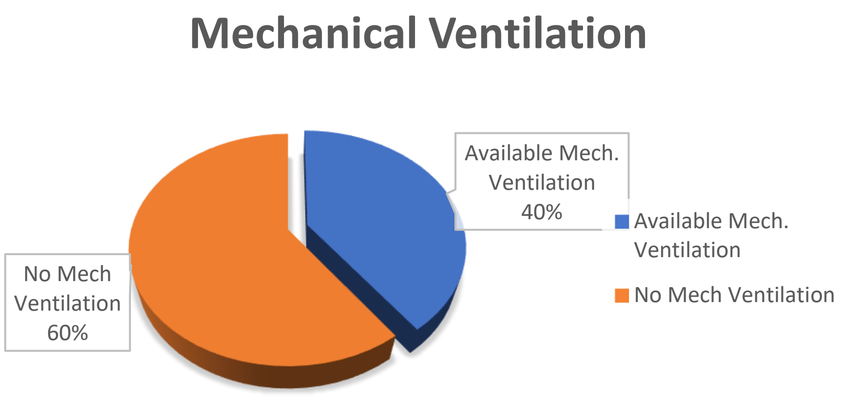

Figure 14. Mechanical Ventilation with Filter
Source: Author's Compilation (2026) based on field observations,

Table 2: Summary of Findings

Performance Indicator	Compliant (%)	Non-Compliant (%)	Implication
Passive ventilation	80	20	Opening placement requires aerodynamic optimisation
Natural daylighting	80	20	Roof-level apertures needed in deep-plan spaces
Shading devices	80	20	20% exposed to excessive solar heat gain
Building envelope insulation	60	40	Thermal performance gap in 40% of facilities
LED lighting	70	30	Controls optimisation recommended
Mechanical ventilation	40	60	Critical pollutant-control deficit in majority

Table 3: Thematic Coding Structure — Observed Design Features Mapped to Analytical Themes

Observed Design Feature / Code	Analytical Theme	Facilities Coded (n=10)	IEQ / Energy Implication
Cross-ventilation openings (opposing walls, sliding doors)	Passive Design Strategies	8 of 10 (80%)	Thermal comfort; reduced cooling energy demand
Skylights, clerestory windows, translucent roof panels	Passive Design Strategies	8 of 10 (80%)	Daylighting quality; reduced artificial lighting load
Roof overhangs, extended eaves, covered corridors	Passive Design Strategies	8 of 10 (80%)	Reduced solar heat gain; thermal comfort
Insulated metal deck roofing, cavity walls, heat-reflective finishes	High-Performance Building Envelopes	6 of 10 (60%)	Reduced radiant heat transfer; lower cooling energy demand
LED lighting installations	Renewable Energy / Smart Systems	10 of 10 (100%)	75% lighting energy reduction; visual comfort
Exhaust fans and localised extraction units at pollutant	IEQ Conditions — Indoor Air Quality	4 of 10 (40%)	Pollutant concentration reduction of up to 55%; occupational health

Observed Design Feature / Code	Analytical Theme	Facilities Coded (n=10)	IEQ / Energy Implication
sources			compliance

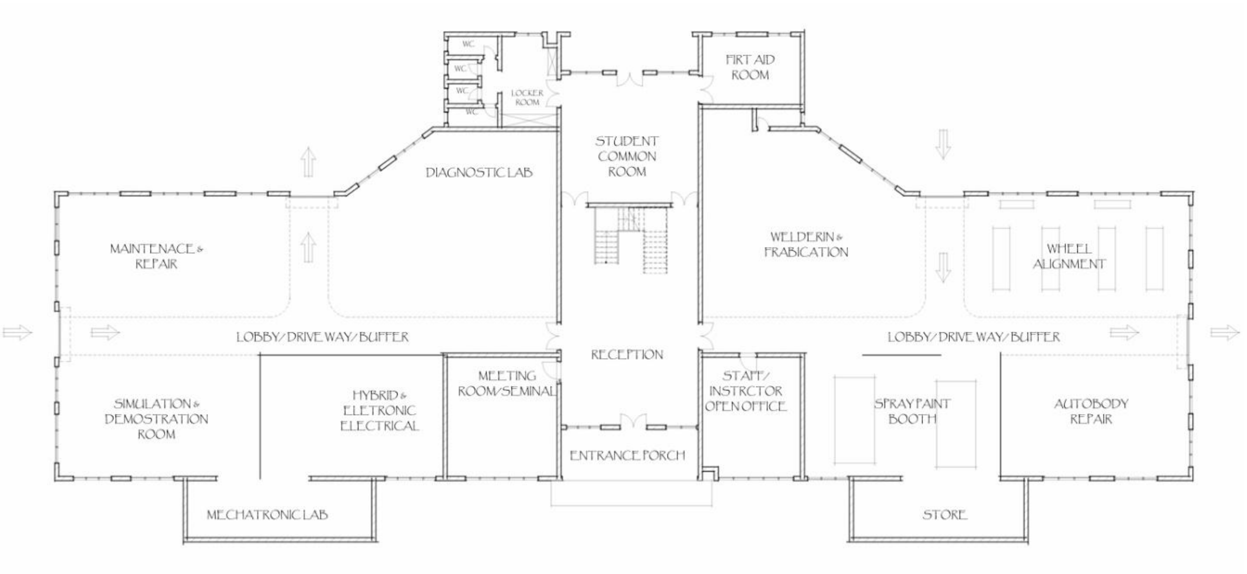

Figure 15. Architectural design plan showing functional zone separation in a model automobile training centre (not to scale).
Source: Author's Compilation (2026) CAD Design

Table 4: Sustainable Workshop Zone Design Matrix — Functional Zones, Environmental Challenges, and Targeted Design Responses

Functional Zone	Primary Environmental Challenge	Targeted Sustainable Design Response	Performance Benchmark
Spray Painting Bay	High VOC emissions (isocyanates, solvents); fire risk; particulate matter	Enclosed negative-pressure spray booth with filtered mechanical exhaust; spatial separation from classrooms (minimum 10m buffer); low-emission paint systems	ASHRAE 62.1: minimum 0.5 L/s per m²; VOC below WHO threshold (≤0.3 mg/m³ total VOC)
Engine Testing and Mechanical Repair Area	Carbon monoxide (CO), NOx emissions; high localised heat loads from running engines	High-volume cross-ventilation with large opposing openings; solar chimney or ridge ventilator for stack-effect extraction; CO sensor-activated mechanical exhaust; high roof volume (minimum 5m clear height)	CO concentration ≤9 ppm (8-hour average, WHO 2021); indoor temperature ≤28°C (ASHRAE 55)
Welding Bay	Metal fume particulates, UV radiation, intense localised heat; risk of respiratory disease with chronic exposure	On-tool extraction arms positioned within 300mm of the weld point; acoustic partitions separating welding bays from clean zones; insulated roof deck to reduce radiant heat gain; opaque shielding panels	PM2.5 ≤15 µg/m³ (WHO 2021 annual guideline); respirable metal fume ≤1 mg/m³ (occupational limit)
Theory Classroom / Lecture Room	Thermal discomfort from proximity to workshop heat zones; acoustic intrusion from machinery; insufficient	Buffer zone separation from high-emission workshops; clerestory windows and light shelves for daylighting; acoustic wall lining (NRC ≥0.75); cross-ventilation	Daylight factor ≥2% (IEA 2023); background noise ≤40 dB(A); PMV within ±0.5 (ASHRAE 55)

Functional Zone	**Primary Environmental Challenge**	**Targeted Sustainable Design Response**	**Performance Benchmark**
	daylighting in deep-plan layouts	layout aligned with prevailing wind; occupancy-controlled LED lighting	
Computer Laboratory / Diagnostic Suite	Equipment heat gain from servers and computers; glare on screens; sensitivity of equipment to dust and humidity	Mechanical air-conditioning with HEPA filtration; north-facing fenestration to minimise direct solar gain; controlled relative humidity (45–60%); positive-pressure supply air to prevent pollutant ingress from adjacent workshop zones	RH 45–60%; temperature 22–24°C; illuminance 300–500 lux (CIBSE Guide A)
Reception / Administration Block	Solar heat gain on west-facing facades; general thermal discomfort; high artificial lighting dependence	West facade shading devices (external horizontal fins or brise-soleil); natural cross-ventilation; daylighting via clerestory or atrium; solar PV rooftop to offset electrical loads; reflective roof finish	Solar shading reduces heat gain by 40–60% (Akinwolemiwa *et al*., 2020); PV reduces grid dependence by up to 60% (IEA 2023)

4.6 Study Limitations

Some limitations are acknowledged to properly contextualise the scope and generalisability of this study. First, the research adopted an observational methodology based on structured visual assessment rather than direct quantitative environmental measurements; as a result, key parameters such as indoor temperature, relative humidity, air pollutant concentrations, illuminance levels, and noise decibels were not instrumentally measured, which limits the precision of the performance evaluation. Second, the sample comprised only ten automobile training centres, predominantly located in Lagos, with minimal representation from other Nigerian geopolitical zones; consequently, the findings may not fully capture variations in climatic conditions, construction practices, and facility standards across the country. Third, the absence of quantitative performance data means that the reported percentage outcomes are based on observational estimates rather than statistically validated measurements, and therefore caution is required when generalising specific performance claims beyond the sampled facilities. Finally, several performance benchmarks referenced in the analysis were derived from international literature conducted under different climatic, socio-economic, and regulatory contexts, which may affect the direct applicability and transferability of the reported performance improvements to the Nigerian context.

5.0 CONCLUSION

This study evaluated the application of sustainable design strategies for enhancing energy efficiency and indoor environmental quality (IEQ) in automobile training centres under warm-humid climatic conditions in Nigeria. Through a systematic literature review and structured observational assessment of ten facilities, the study established that passive design strategies, high-performance building envelopes, renewable energy integration, and mechanical ventilation systems collectively contribute to improved energy performance and occupant comfort in this building typology. Observational findings revealed that 80% of sampled facilities incorporated passive ventilation, natural daylighting, and shading devices to varying degrees of effectiveness, while only 60% demonstrated adequate building envelope insulation. Notably, 60% of facilities lacked mechanical ventilation with filtration, representing a critical indoor air quality deficit in environments where engine fumes, welding emissions, and spray paint aerosols pose significant occupational health risks. Universal LED adoption across all sampled facilities indicated progress toward energy-efficient artificial lighting, though system-level optimisation through occupancy-responsive controls remains largely unrealised.

The study confirmed that energy efficiency and IEQ are interdependent objectives. Passive strategies, such as cross-ventilation, solar shading, and roof-level daylighting, simultaneously reduce energy demand and improve comfort, but are insufficient alone in workshop environments with high pollutant loads; source-control mechanical ventilation is therefore essential. A critical gap remains between the availability of sustainable design principles and their contextual application in Nigeria, constrained by limited technical expertise, high implementation costs, and weak regulatory enforcement barriers requiring coordinated intervention across policy, professional practice, and building regulation frameworks.

5.1 Recommendation

Based on the observational findings of this study, the following recommendations are proposed for automobile training facilities in Nigeria's warm-humid climatic zones. Design professionals should prioritise passive ventilation openings deliberately aligned with prevailing wind directions, incorporate roof-level daylighting elements such as skylights and monitor roofs as standard features, and treat building envelope insulation as a baseline design requirement rather than an optional provision. Source-control mechanical ventilation with filtration must be integrated into all workshop spaces generating chemical and combustion pollutants, as passive ventilation alone is insufficient to meet occupational air quality standards. Regulatory bodies should revise building codes applicable to workshop facilities to include mandatory minimum standards for envelope insulation, mechanical ventilation, and indoor air quality, benchmarked against ASHRAE 55 and ISO 7730 standards. Performance-based regulations contextually adapted to Nigerian conditions should be developed and consistently enforced. Facility operators should prioritise roof insulation retrofitting in uninsulated buildings and install occupancy-responsive LED lighting controls to optimise existing energy-efficient fixtures. Government agencies should expand incentive programmes to reduce the financial barriers associated with renewable energy adoption in vocational training institutions, ensuring that sustainable design becomes economically accessible across all facility categories.

5.2 Future Research Directions

Future work should prioritise: instrumental quantitative measurement of temperature, humidity, CO, VOC, illuminance, and acoustic levels across Nigerian automobile training facilities; post-occupancy evaluations of sustainably designed facilities; cost-benefit analyses of passive and active strategies in Nigerian workshop typologies; comparative studies across Nigeria’s climatic zones; and development of Nigeria-specific sustainable design guidelines for vocational training facilities.

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