

# Passive Cooling Strategies in Contemporary African Architecture: A Systematic Review of Thermal Comfort Outcomes

Eyiah-Botwe, E.

Department of Construction Technology and Quantity Surveying, Kumasi Technical University, Ghana.

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## ABSTRACT

Africa faces increasing thermal stress from rising temperatures, rapid urbanisation, and energy poverty, making it hard to provide indoor environments that are both comfortable and sustainable. Among the range of cooling solutions, passive cooling strategies using natural ventilation, shading devices, and materials with high thermal inertia are considered urban-scale interventions, all low-energy approaches that align with bioclimatic design

principles and allow for the incorporation of local knowledge. In this systematic review, the researcher seeks to bring together previous work on the thermal comfort outcomes of passive cooling strategies in contemporary architecture and to identify performance patterns that depend on context. Following the PRISMA 2020 guidelines, we selected ten post-2018 studies from databases including Scopus, Web of Science, ScienceDirect, and African Journals Online, along with grey literature and regional climate reports. The data was extracted according to strategy type, building typology, climate zone, thermal metrics (PMV, PPD, adaptive hours), and energy impact. The findings show that the application of multiple strategies together always produced better results than that of the single-strategy approaches, with a reduction in the indoor temperatures of 3-5°C and the cooling energy demand of 20-60%. The effectiveness highly depended on the climate, with cross-ventilation and shading being the best in hot-humid areas and high thermal mass being the most important in arid regions. The application of historical and vernacular designs increased the adaptability, especially when combined with modern innovations such as reflective coatings and PV shading. The analysis reveals a persistent gap between the designer's expectations and the users' comfort, thus highlighting an urgent requirement for standard evaluation and climate-based guidelines. Generally, the application of climate-responsive PCS can cause thermal comfort to be better, energy consumption to be less, and African urban resilience to be more durable.

**Keywords:** Adaptive comfort; passive cooling strategies; thermal comfort; vernacular architecture

## INTRODUCTION

Africa is among the continents most susceptible to the effects of climate change, and it is predicted that the average temperatures in the continent will be rising at a rate even higher than the global average and will go through more drastic weather conditions (Lucatell & Sánchez, 2022). The combination of these climate variables and the urban population increase of over 3.5% annually has led to a growing demand for cooling in West, East, and Southern African metropolises (UN-Habitat, 2024). At the same time, lack of electricity still exists as a barrier for poor families, who cannot afford the cost of mechanical cooling that is both reliable and inexpensive. All of this has led to a situation where the comfort levels required by people are clashing with the economic and infrastructural conditions of modern-day African cities.

Active cooling systems that are often conventional have the power to interrupt the natural cooling processes in the environment, while they are effective in temperate and high-income contexts. The electricity consumption in air-conditioning, for one, is the major source of peak loads and emissions of greenhouse gases. Moreover, it leaves the users affected by blackouts (Fajilla *et al.*, 2020). In light of the above, passive cooling strategies (PCS) have made a comeback as critical design solutions. The techniques of PCS include natural and stack ventilation, optimised building orientation, thermal mass, solar shading, evaporative cooling, and reflective or vegetated envelopes. These methods are based on bioclimatic design principles that harmonise the shape and the materials

used in the building with the local climate (Kaihoul *et al.*, 2021; Raven *et al.*, 2018). It is worth noting that Africa is endowed with a twofold opportunity: the rediscovery of cooling practices of the past that are still present in the form of vernacular architecture, as well as the use of modern materials and simulation-based design (Santos *et al.*, 2023).

Although more and more researchers are getting interested in the issue, the situation in Africa's contemporary architecture regarding passive cooling is still marked by a lack of evidence. Various empirical case studies are documenting individual strategies in residential, educational, and office buildings, but only in very few cases have the thermal comfort outcomes been quantified and then synthesised. Therefore, the architects and the decision-makers are deprived of a united proof base for evaluating the performance of different strategies in terms of effectiveness, conditions, and even their total extent.

There are still three major areas of ignorance. One of the areas is that the inconsistency in the thermal comfort metrics has led to a situation where studies can hardly be compared. The outcomes reported differ very much from one another, and the measures used in the studies are PMV and PPD to adaptive comfort hours and indoor operative temperatures, creating methodological discontinuities (Bueno *et al.*, 2021). Second, the studies conducted are quite often very limited to the specific region, thus the thermal comfort metrics are not properly defined. Africa has very different climate zones, building types, and occupancy patterns that are highly influenced by the cultural aspects, etc, but these are often left out when studying the application of passive cooling systems. Lastly, maintenance issues, trade-offs in design, and the behaviour of the occupants are not usually compiled, though they are very important to the actual performance of the system (Roetzel, 2019). Thus, there is no systematic review mapping process that classifies passive cooling as effective or ineffective based on standard thermal comfort benchmarks across Africa's diverse climatic regions.

This study aims to compile the results from different studies performed on the impact of passive cooling systems on thermal comfort in today's African buildings and to pinpoint the performance trends that depend on the context. The review's main research question is: What is the impact of passive cooling systems in modern African architecture on the thermal comfort outcomes that can be measured and are different according to the climate and the socio-economic situations?

From a theoretical standpoint, the review represents a leap forward in the bioclimatic design education by putting together the scattered performance data of the passive cooling strategies into a coherent taxonomy along with their thermal comfort outcomes and also dealing with the definitional and methodological problems (Hernández *et al.*, 2023). On the ground, the results give a hand to architects and developers in picking the strategies that have been tested for solid performance and that are capable of reducing the cooling energy demand that takes up more than 40% of the global electricity used by buildings (Marzouk, 2025; IEA, 2023). The synthesis also brings forth data that can be utilised to shape climate-responsive building codes, including the newly developed African ones like Ghana's GS 1807:2022, all the while contributing to SDG 7, which is about Access to Energy for All.

From the point of view of climate justice, the enhancement of passive thermal comfort has an impact on health, which can be considered a co-benefit; these include lower heat stress and heat-related morbidity in the populations that are poor and climate-vulnerable and where access to mechanical cooling is not possible (Hernández, 2022).

## **METHODS AND MATERIAL**

In this study, the researcher employed a systematic review for their approach, which enabled them to discover, choose, assess, and finally integrate the pieces of empirical evidence concerning the use of soft project management practices in the African infrastructure sector. The review was performed through meticulous steps and was in full conformity with the guidelines set out by the PRISMA statement for systematic reviews and meta-analysis (2020), which recommends a systematic approach that not only increases the transparency, reproducibility, and methodological rigor of the whole process but also diminishes the chances of biases related to selection and reporting (Page *et al.*, 2021). The patterns of the systematic review handbooks served as a basis for the consistent application of the search methods, assessment of eligibility, and synthesis of evidence

throughout the varied study designs related to project management research (Aromataris et al., 2022; Chandler et al., 2019). Thus, this part deals with the systematic review design (Section 2.1), eligibility criteria (Section 2.2), sources of information and search strategy (Section 2.3), process of study selection (Section 2.4), quality appraisal and evaluation of risk of bias (Section 2.5), data extraction methods (Section 2.6), data synthesis technique (Section 2.7), and reporting standards adhered to in the review (Section 2.8).

### **Systematic review design**

A systematic review design was used to combine pieces of evidence that were fragmented and conceptually diffuse about soft project management practices in African infrastructure projects. The soft practices of leadership, communication, trust-building, and stakeholder engagement are usually ambiguously defined, which, along with their varied application in different studies, makes it hard to merge the narratives. In such cases, systematic reviews emerge as the most suitable option since they permit total evidence coverage, structured synthesis, and bias reduction through protocol-driven procedures (Denyer & Tranfield, 2009; Snyder, 2019). This approach not only maintains the confidentiality of the chosen methodology but also boosts the reliability of the results obtained from different project management research. The review was done according to the PRISMA 2020 guidance, which means Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Page et al., 2021). A protocol for the review was made and registered in PROSPERO before the actual review, and the registration ID can be obtained upon request to make sure that there is no selection bias and no methodological changes done post hoc, following the best-practice guidance for systematic reviews (Aromataris et al., 2022). The review was executed using a five-step workflow which included: firstly, identifying records by means of structured database searches; secondly, screening titles and abstracts according to predetermined PICOS (population, intervention, context, outcomes, and study design) criteria; thirdly, full-text review against formal standards for eligibility assessment; fourthly, literature that complied with the full set of criteria was included; and fifthly, discussion of soft practice definitions, implementation approaches, and reported outcomes through thematic analysis was the method of synthesis. For the independent screening Rayyan software was used, while for the qualitative synthesis, NVivo was the one used. In order to cope with the conceptual ambiguity that is always associated with soft practices, an iterative refinement strategy was used. Initial broad search terms were supplemented with backward and forward citation chaining to include studies where soft practices were talked about indirectly rather than labelled directly, thus increasing conceptual coverage and analytical rigour (Denyer & Tranfield, 2009).

### **Eligibility criteria**

The review's exclusion and inclusion criteria were established according to the PICOS framework, which included Population, Intervention, Comparison, Outcomes, and Study design, thereby allowing systematic, transparent, and replicable study selection (Nawijn et al., 2019).

Table 1: Eligibility Criteria Based on PICOS

Element	Inclusion Criteria	Exclusion Criteria
Population (P)	Contemporary African buildings (post-2018); All building typologies (residential, institutional, commercial); All African climate zones (Köppen-Geiger classified)	Non-African case studies; Pre-2018 constructions; Buildings without occupancy/thermal measurements.
Intervention (I)	Explicit or implicit passive cooling strategies: Natural ventilation; Thermal mass utilisation; Evaporative cooling; Solar shading; Hybrid vernacular-contemporary systems	Active cooling systems (HVAC, mechanical ventilation); Purely theoretical/simulation studies without empirical data

Comparison (C)	Before-and-after retrofit comparisons; Passive vs. conventional building performance; Cross-strategy efficacy comparisons within the same climate zone.	No comparative element
Outcomes (O)	Quantifiable thermal comfort metrics: PMV/PPD indices; Adaptive comfort hours; Temperature/humidity differentials; Occupant satisfaction surveys (validated tools).	Qualitative assessments only; No thermal performance data
Study Design (S)	Empirical field studies; Controlled monitoring ( $\geq 72$ hrs continuous data); Peer-reviewed publications (2018-2025); English-language reports with full methodology	Editorials, opinion pieces, non-peer-reviewed reports, dissertations, and non-English publications.

To add the specific richness related to Africa's context, certain grey literature from the World Bank, African Development Bank, and Asian Development Bank, being the main multilateral development institutions, was included, where there was both methodological transparency and empirical grounding. The choice signifies the prevalence of donor-funded infrastructure delivery in Africa and the practical insights that are contained in such reports. The review was restricted to English-language sources due to limitations of resources, and was aware of the possible bias caused by language. The period of 2018–2025 was chosen to reflect the growing recognition of passive cooling systems on thermal comfort in today's African buildings and to pinpoint the performance trends that depend on the context, as per project studies literature (Ika, 2012). Due to the conceptual ambiguity surrounding soft practices, the eligibility decisions went for operational clarity instead of terminology. The ambiguities were sorted out through dual-reviewer validation during the full-text screening, thematic extraction of explicitly described behaviours (e.g., facilitated community dialogues, participatory decision-making), and the exclusion of studies where soft practices were only mentioned without clear implementation or linkage to project processes (Mashali et al., 2023).

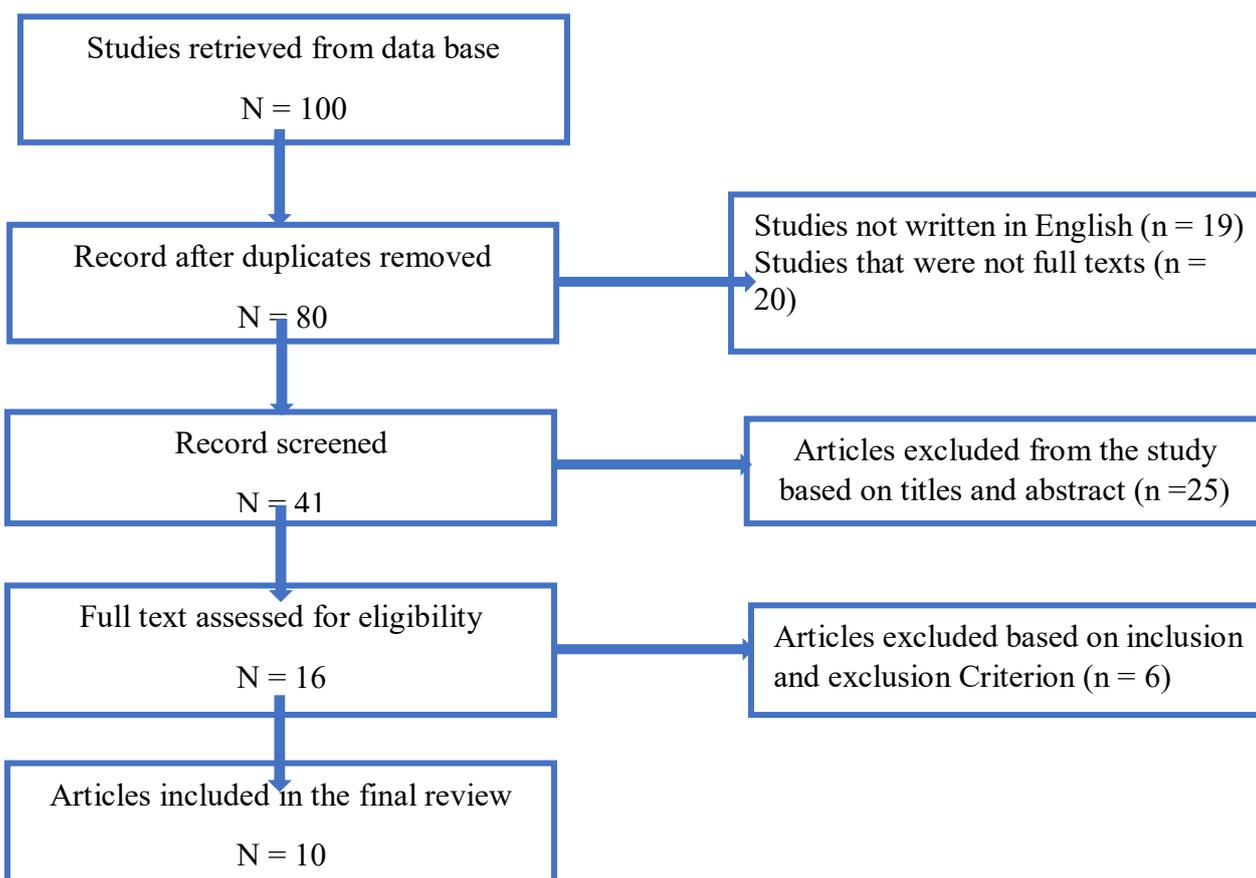


Figure 1: PRISMA reporting framework

## Information Sources and Search Strategy

A wide-ranging search was executed involving both multidisciplinary and architecture-exclusive databases to get rid of any possibility of bias and to get the coverage of the whole domain. The main bibliographic databases that were used were Scopus, Web of Science, ScienceDirect, Avery Index to Architectural Periodicals, African Journals Online (AJOL), and CumInCAD. These databases were selected due to their extensive indexing of research on architectural design, building science, and climate-responsive construction. In order to obtain technical guidance and applied research on thermal comfort, publications from ASHRAE, proceedings of Passive and Low Energy Architecture (PLEA) conferences, and the African Architecture Archive were reviewed. Grey literature was used to compensate for the lack of representation in the indexed journals of the region and consisted of UN-Habitat reports, African Union climate and housing policy documents, and selected university repositories that host peer-reviewed theses. The source selection process was guided by PRISMA-S to improve search transparency, sensitivity, and reproducibility, along with being contextually relevant to African architectural practice and climate research (Rethlefsen & Page, 2021).

The search methodology was conducted in accordance with the three principal concepts: population, intervention, and outcomes. The population of interest was expressed in terms such as (*"African architecture" OR "building design Africa" OR "vernacular architecture"*) along with (*"Africa" OR certain country names like "Ghana," "Nigeria," "Kenya," and "Morocco"*). Intervention terminology encompassed the whole range of passive cooling methods, namely, (*"passive cooling" OR "natural ventilation" OR "thermal mass" OR "evaporative cooling" OR "shading devices" OR "bioclimatic design"*). Outcome phrases were concentrated on results that could be measured, and they included (*"thermal comfort" OR "adaptive comfort" OR "PMV" OR "PPD" OR "temperature reduction"*). The search strategy utilised Boolean operators and truncation as well as additional climate descriptors, namely, (*"hot-dry" OR "hot-humid" OR "tropical"*) to refine the context more accurately.

The creation of a sample query in Scopus included the following elements: TITLE-ABS-KEY (*"passive cooling" OR "natural ventilation"*) AND (*"thermal comfort" OR PMV*) AND (*"African architecture" OR "building design Africa"*). Iterative refinement was carried out through pilot searches, introducing alternative terms like *"indigenous cooling techniques"* and *"climate-responsive design,"* and the review of keywords in fundamental studies to improve retrieval sensitivity.

The wide range of passive cooling terms used was not an obstacle at all; on the contrary, such local or colloquial names were accepted wherever they matched the cooling principles that were already recognised. Techniques such as windcatchers, courtyard cooling, thick earthen walls, and shading screens were clearly included. When the data were being extracted, the thermal comfort metrics were converted to a common measure in order to draw comparisons between the studies, in accordance with adaptive comfort theory and the recommendations from building science (Nicol & Humphreys, 2013).

## Study selection process

The whole process of study selection adhered to the rules laid down by the PRISMA 2020 guidelines, which, in consequence, ensured transparency, consistency, and reproduction of results (Page et al., 2021). All the records that were retrieved were first managed by EndNote in terms of references and removal of duplicates, and then the remaining dataset of unique records was uploaded to Rayyan for the purpose of assisting with the blinded and independent screening conducted by multiple reviewers.

### Phase 1: Title and Abstract Screening.

The first screening of the titles and abstracts was done independently by two reviewers. At this stage, a broad inclusion approach was adopted, by which any study reporting passive cooling strategies in the African architectural or building contexts was kept. Differences in opinion were settled through discussions, and the difficult cases were then sent to a third reviewer for ruling.

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**Phase 2: Full-Text Assessment.**

The articles in full text were evaluated on the basis of the already set PICOS criteria, paying special attention to the availability of empirical thermal comfort data like indoor temperature measurements, adaptive comfort indices, or PMV-based evaluations. At this point, the reasons for exclusion were clearly stated, including the most common ones, such as lack of empirical thermal performance data or non-African case locations.

**Phase 3: Final Inclusion.** The studies that met all the criteria were additionally verified in order to take their relevance to current architectural practice, which was defined as building projects after 2018, and to check that empirical evidence was collected from the case studies in Africa, into account.

Hybrid cooling systems that had both passive and active elements were only included if the passive strategies were the main cooling method. Studies that were predominantly of mechanical systems were excluded, while mixed systems were coded individually. A decision tree was used to determine the climate zones consistently across the cases. The inter-reviewer reliability was measured at the level of the abstract screening with the use of Cohen's kappa coefficient, where the target threshold was set at above 0.80, implying strong agreement. A meticulous audit trail of screening decisions was kept at all times during the process.

**Quality appraisal and risk of bias assessment**

A quality evaluation that was structured was performed to determine the strength of the included studies regarding the methods and risks of bias, focusing mainly on the thermal comfort measurement methods' validity. The appraisal pointed out the need to follow the established adaptive comfort principles and measurement standards (De Dear & Brager, 2002) because of the sensitivity of comfort outcomes to contextual and behavioural factors. All studies that met the eligibility criteria were included in the review to keep the evidence breadth; however, their contributions to synthesis and interpretation were weighted according to the quality that was assessed to prevent over-dependence on the findings of weakly methodological studies.

An appraisal framework was specifically created to suit the needs of passive cooling and thermal comfort research in the African architectural contexts. The four domains that were assessed were: (i) measurement rigor, which comprised instrument calibration, monitoring duration, and sample size adequacy; (ii) contextual documentation, covering climate zone classification, building typology, and occupancy patterns; (iii) design transparency, defined as clarity in describing passive strategy implementation and physical configurations; and (iv) bias control measures, such as accounting for seasonal variability or the use of control or reference buildings.

A uniform scale of 0–3 was applied to judge each domain, indicating a high, medium, or low risk of bias. This allowed for the comparative weighting of the studies without changing the methodology. The quality assessment was done separately by two reviewers who used a standardised evaluation form. The differences in their judgments were settled through discussions, and those that could not be settled were passed on to a third reviewer. The result of the appraisal was presented through traffic-light plots that made it more understandable. There were plans for sensitivity analyses to check the reliability of synthesised findings by dividing the results according to quality grades, climate zones, and types of buildings, which was in line with the already laid Cochrane guidance on bias and sensitivity testing (Chandler et al., 2019).

**Data Extraction**

The whole process of data extraction aimed to systematically capture and harmonise the evidence regarding the thermal performance of passive cooling strategies applied in contemporary African architecture. They were aligning the whole internal consistency, reducing the transcription errors, and facilitating a transparent synthesis with the recommended standards for systematic reviews in building and environmental research (Christine Sotsek et al., 2019) by a structured and piloted extraction process. A standardised data extraction form was created in Microsoft Excel and, in the cases of qualitative coding, was supported by NVivo. The extraction form was built on the PICOS framework, which ensured a close link between extracted variables and review objectives. Pilot testing of dual independent extraction was done on 10% of the included studies. The discrepancies noticed during the piloting stage were used for iterative refinement of variable definitions, coding

rules, and category boundaries before the main extraction started. The data was extracted under three main categories. The details of the strategy covered the cooling type (like evaporative cooling, shading, natural ventilation), materials, and the design integration level, and the vernacular terminology was recorded word by word if it was used. The thermal metrics were PMV, PPD, adaptive comfort hours, and indoor–outdoor temperature differentials, and the units were standardised across studies to allow comparison. The contextual factors included climate zone classification according to the Köppen–Geiger system, building type, and occupancy patterns, and hybrid strategies were coded separately to maintain clear analysis. Data from all studies were subjected to dual independent extraction. Weekly meetings were held to reconcile inconsistencies, and the unresolved issues were referred to a third reviewer for arbitration.

Table 2: Data Extraction

Authors	Year	Purpose of Study	Location	Study Type	Sector Focus	Passive Cooling Strategy	Implementation Mechanisms	Thermal/Comfort Outcomes	Contextual Factors	Study Limitations
Liu, C., Xie, H., Ali, H. M., Liu, J.	2022	Assess the effect of passive cooling on historical residential buildings	Zanzibar, Tanzania	Field study + questionnaire	Residential	Oriental (N-S), natural ventilation, window shading, light-colored walls	Questionnaire surveys, field measurement of indoor temperatures	PMV: 1.23 & 0.85; PPD: 37.35% & 20.56%; below ASHRAE 55	Hot-humid climate; historic building typology	Limited to two buildings; may not generalise to other climates
Abdul Kareem, M., Al-Maiyah, S.	2025	Evaluate passive design impact on low- and middle-income housing	Abuja, Nigeria	Simulation study	Residential	Cross-ventilation, shading devices, passive layouts	Building performance simulations of six housing prototypes	Up to 20% reduction in thermal discomfort; improved indoor comfort hours	Hot climate; urban low-cost housing; government blueprints	Model-based; field validation limited
Kabanshi, A., Choonya, G., Ameen, A., Liu, W.,	2023	Optimise window design for cooling energy	Niameny (Nigeria), Nairobi (Kenya), Harar	Simulation study	Residential/Institutional	Window sizing, orientation, PV-integrated shading	IDA-ICE simulations; PV panel modelling	WWR >70% increases discomfort without shading; internal blinds	Hot-dry and hot-humid climates; different hemispheres	Focus on windows; other passive strategies not

Mulenga, E.		reduction	e (Zimbabwe)					improve PMV	heres; varying building orientations	assessed
Santos, M. M., Ferreira, A. V., Lanzinha, J. C. G.	2022	Review passive solar systems for thermal comfort	Multiple African countries	Systematic literature review	Residential/Commercial	Passive solar heating/cooling, ventilation, shading	Review of existing studies; climate zone comparisons	Summarised thermal comfort improvements per strategy: adaptive comfort models	Multiple climate zones; cross-country comparisons	Limited to reported literature; heterogeneous metrics
Benziada, R., Kacemi, M., Mokhtari, A. M., et al.	2025	Assess urban morphology and building materials for comfort	Béchar, Algeria	Simulation + field measurement	Urban/Residential	Shading, high thermal inertia materials, compact urban forms	ENVI-met & TRNSYS simulations; thermal mapping	Thermal comfort rate: 22–60%; hot discomfort <1700h/year	Arid climate; urban morphology; material types	Model assumptions: limited building typologies
Kousis, I., Santamouris, M.	2025	Evaluate the long-term effectiveness of passive cooling under climate change	Multiple urban sites, Africa	Literature review + meta-analysis	Urban/Residential	Cool roofs, green roofs, urban greenery	Review and synthesis of 18 studies	Cooling energy savings: cool roofs 60%, green roofs 25%; thermal comfort improved but declines under RCP8.5	Multiple climate zones; urban areas	Future scenario uncertainties; heterogeneity in studies
Tellache, A., Lazri, Y., Laafer, A.,	2025	Compare thermal comfort	Algeria, Algeria	Field + simulation	Residential	Mixed-mode ventilation, passive shading,	Field measurements; DesignBuilder simulation	Current indoor discomfort >33% of annual hours;	Hot-summer Mediterranean climate	Limited to a specific climate scenario

Attia, S.		models for Mediterranean climates				natural ventilation	ons; occupant interviews	bedrooms are most vulnerable; model mismatch observed	; socio-economic conditions	o; may not generalise to other African climates
Olawale-Johnson, O. P., Ajwang, P., Ondimu, S. N.	2021	Evaluate passive measures to reduce cooling demand	Kiambu, Kenya	Field experiment + simulation	Residential	Solar shading, green roofs, cool paints	20-day field measurements; EnergyPlus & DesignBuilder simulations	Correlation $r=0.85$ between observed and predicted; reduced indoor temperatures	Hot-humid climate; microclimate variations; low-ventilation scenario	Short duration (20 days); limited temporal coverage
Prozuments, A., Ménéz, C., Orumwense, E., et al.	2025	Assess thermal comfort criteria and challenges	Pan-African	Literature review + survey	Multiple sectors	Passive cooling strategies (various)	Survey and review of existing standards	Highlighted the lack of unified metrics; buildings often exceed comfort thresholds.	Diverse climate zones; informal settlements; building codes	Broad review; limited quantitative thermal data
Dodoo, A., Ayarkwa, J.	2019	Examine climate change impacts on thermal comfort & energy	Accra & Ashanti, Ghana	Simulation	Residential	Orientation, shading, ventilation, and high thermal mass	IDA-ICE dynamic simulations; Meteorological climate data	Cooling energy: 113.9–104.4 kWh/m <sup>2</sup> ; increased by 6–50% under future climates; indoor comfort deteriorates	Hot-humid and semi-humid climates; future climate scenarios	Simulation-based; projections may differ from actual performance

Source: Authors' compilation (2026)

## **Data Synthesis Approach**

A mixed-methods synthesis, combining narrative and thematic approaches, was employed to integrate both quantitative and qualitative evidence on passive cooling strategies (PCS) in African buildings (Gough et al., 2025). This way, it was possible to spot similarities, differences, and connections between the use of PCS and thermal comfort in various environmental and economic settings.

**Phase I: Mapping Descriptively.** The characteristics of the studies, types of PCS, thermal metrics (PMV, PPD, adaptive hours), and contextual factors (climate zone, building typology, occupancy) were compiled in tables that indicated the application of the strategies in different African climatic zones.

**Phase 2: Thematic Synthesis.** A qualitative data coding process was applied that was based on the work of Gough et al. (2025) to create analytical themes which connected the implementation of PCS with thermal comfort outcomes. The studies were compared particularly on the context-specific factors that supported (e.g., integration of local design, availability of materials) and those that were the obstacles (e.g., not enough shading, not much adaptation by the occupant), to find out the impact of climate, type of building, and social-cultural aspects on the efficacy.

**Phase 3: Context-Outcome Pathway Analysis.** Qualitative Comparative Analysis (QCA) was applied to identify and represent the specific context-mechanism-outcome (CMO) configurations, which depicted how the climatic and building contexts bring about the mediating of PCS efficiency (Piquet et al., 2024).

The combination of the results from the different studies enhanced the validity of the interpretations, and the influence of the studies that contained limited thermal data clarity was assessed by conducting sensitivity analyses. The coding and the configurational analysis were made possible by the use of NVivo 14 and Microsoft Excel.

## **Reporting**

The review was performed strictly following the PRISMA 2020 guidelines (Page et al., 2021), which guaranteed that the review process was totally transparent, methodologically rigorous, and reproducible. This reporting framework gives an elaborate account of the search strategy, eligibility criteria, study selection process, data extraction procedures, and the quality assessment of the included studies. The different stages of identification, screening, and inclusion are documented clearly using a PRISMA flow diagram. Through a systematic mix of narrative and thematic synthesis, the final report brings together quantitative thermal performance data and qualitative contextual insights. The report explicitly indicates the categorisation of passive cooling strategies, the ways of measuring or simulating the results of thermal comfort, and the influence of contextual factors such as prevailing climatic conditions, building type, and use patterns in the performance results. By thoroughly documenting all methodological steps, the review not only increases the reliability and reproducibility of its results but also facilitates other researchers to check and repeat the process. The transparency of reporting the results provides a guarantee that the evidence produced about the effectiveness of passive cooling in African buildings is not only available but also usable for the purpose of researchers, architects, planners, and policymakers who are looking for climate-responsive design solutions that are suitable for the conditions of the region.

## **RESULTS AND DISCUSSION**

### **Results**

#### **Study Characteristics**

The systematic review was a wide-ranging one, indicating the use of passive cooling strategies in residential and urban buildings throughout Africa. It consisted of ten publications in peer-reviewed journals, which were based in different African countries like Zanzibar, Nigeria, Kenya, Algeria, Ghana, and some that were multi-country analyses (Ref. Table 3 below). The different kinds of study designs used included field measurements (Liu et al.,

2022; Olawale-Johnson et al., 2021), simulation-based modelling (Abdulkareem & Al-Maiyah, 2025; Kabanshi et al., 2023; Dodoo & Ayarkwa, 2019; Tellache et al., 2025), and literature syntheses (Santos et al., 2022; Kousis & Santamouris, 2025; Prozuments et al., 2025). It was decided that both the real and the simulated thermal performance results would be assessed comprehensively.

The climatic conditions were classified into different categories based on the Köppen–Geiger zones, which was a way of standardising environmental variations and making comparisons between studies easier. The studies included:

- Hot-humid (Aw): Zanzibar, Abuja, Nairobi, Kiambu, and Ghana; these places are characterised by high temperature, high humidity and rain that changes a lot from one season to another, thus having an impact on the effectiveness of natural ventilation and thermal comfort of the residents.
- Arid (BWh): Béchar and Niamey; these regions get sunlight of very high intensity, have very low humidity, and very big differences between day and night. Solids with high thermal inertia and shading are the only solutions to cope with such a situation.
- Mediterranean hot-summer (Csa): Algiers; moderate humidity during the long dry and hot summer, where adaptive ventilation and mixed-mode strategies were tested.
- Subtropical highland (Cwb): Harare; mild temperate climate with not extreme seasons, informing design changes for window orientation and envelope insulation.
- Pan-African reviews: Provided a cross-climatic synthesis and included various thermal zones and assessments of the strategies from vernacular-to-contemporary ones.

The variety of locations and climates in the chosen studies points to the necessity for solutions of passive cooling that are specific to the context. Research in hot-humid regions revealed the significance of cross-ventilation and shading, while dry areas showcased the application of thermal mass and reflective surfaces. The combination of Köppen–Geiger classifications provides a methodical arrangement of thermal performance results, which then allows for further meta-analyses and thematic syntheses across the various climates of Africa.

Table 3: Study Characteristics

Study	Location	Climate Zone (Köppen–Geiger)	Notes
Liu et al., 2022	Zanzibar, Tanzania	Aw (Tropical savanna, hot-humid)	Hot, humid with pronounced wet/dry seasons; natural ventilation critical
Abdulkareem & Al-Maiyah, 2025	Abuja, Nigeria	Aw (Tropical savanna, hot-humid)	Warm, humid; focus on low-/middle-income residential prototypes
Kabanshi et al., 2023	Niamey (Niger), Nairobi (Kenya), Harare (Zimbabwe)	Niamey: BWh (Hot desert, arid); Nairobi: Aw (Tropical savanna, hot-humid); Harare: Cwb (Subtropical highland, mild temperate)	Multi-city comparison; window orientation and shading assessed
Santos et al., 2022	Pan-African review	Mixed (hot-humid, hot-dry, arid, Mediterranean)	Broad literature synthesis; climate-specific strategy trends mapped

Benziada et al., 2025	Béchar, Algeria	BWh (Hot desert, arid)	Urban morphology in arid conditions: high thermal inertia materials used
Kousis & Santamouris, 2025	Multi-African urban environments	Hot-humid, hot-dry, arid	Cool roofs, green roofs, and urban greenery assessed across climates
Tellache et al., 2025	Algiers, Algeria	Csa (Mediterranean hot-summer)	Residential buildings; adaptive thermal comfort models tested
Olawale-Johnson et al., 2021	Kiambu, Kenya	Aw (Tropical savanna, hot-humid)	Passive measures: solar shading, green roofs, cool paints
Prozuments et al., 2025	Pan-African	Hot-humid, hot-dry, arid, Mediterranean	Indoor thermal comfort regulations and gaps assessed
Dodoo & Ayarkwa, 2019	Greater Accra & Ashanti, Ghana	Aw (Tropical savanna, hot-humid)	Residential buildings: climate change projections for thermal comfort

### Passive Cooling Strategies Implemented

The research revealed a wide range of passive cooling strategies utilised in modern African architecture, including interventions at both the level of buildings and large urban and landscape-scale measures.

**Natural Ventilation:** Among the methods evaluated most often were cross-ventilation and mixed-mode ventilation (Liu et al., 2022; Tellache et al., 2025). The approaches exploit prevailing wind patterns and buoyancy-driven airflow (temperature) to aid heat dissipation inside the buildings. Mixed-mode systems in which natural ventilation is combined with intermittent fan use were particularly beneficial in hot-humid regions by lowering indoor temperature and creating more satisfied occupants regarding their thermal conditions.

**Shading Devices:** Most of the studies focused on external and internal shading devices such as overhangs, louvres, photovoltaic (PV) panels, and blinds (Kabanshi et al., 2023; Abdulkareem & Al-Maiyah, 2025), where external and internal shading comprise the proposed methods for reducing indoor solar heat gains. The orientation and positioning of the shading devices played a crucial role in the extent of solar heat mitigation, with PV panels offering the bonus of cooling and electricity generation. The studies pointed out the need for careful and specific consideration of the pattern of sunlight coming from east and west, where it is at its highest, especially in regard to the incorporation of different types of optimisation.

**High Thermal Inertia Materials:** Among the solutions in the context of arid and hot-dry climates, the adaptations of building envelopes using stone, Compressed Stabilised Earth Blocks (CSEBs), and light-colored walls were mentioned (Benziada et al., 2025; Dodoo & Ayarkwa, 2019). The heat was then absorbed and delayed to transfer, indoor temperature peaks were consequently down, and during daily ups and downs, the comfort of the residents was even improved.

**Urban and Landscape Interventions:** Broader-scaled strategies covered compact urban forms, increased vegetation, and the introduction of cool or green roofs (Kousis & Santamouris, 2025; Benziada et al., 2025). Not

only did these actions help to decrease the local urban heat islands, but they also worked in favour of building-level strategies by mildening the microclimatic conditions, thus enhancing overall thermal resilience.

Collectively, these interventions highlight the multi-scalar aspect of passive cooling, that is, building envelope design, orientation, material selection and urban morphology have to be harmoniously matched with climatic conditions in order to obtain the best thermal comfort outcomes in Africa.

### **Thermal Comfort Outcomes**

The thermal comfort conditions are assessed quantitatively through the studies included, using such standardised techniques as the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD). The field surveys held in the historical houses and other buildings in Zanzibar showed the PMV to be from 0.85 to 1.23 and PPD to be between 20–37% (Liu et al., 2022), which all pointed to the thermal conditions being just over the ASHRAE 55 comfort limit. The results have shown that the residents' discomfort was moderate, and this was caused by the passive cooling measures applied. Hence, such hot-humid areas are badly in need of new strategies in the form of materials for building envelopes. The impact of passive measures was further quantified through simulated temperature reductions.

The interventions like solar shading, cross-ventilation and roof insulation in the prototypes of residential buildings in sub-Saharan countries caused a decrease in the indoor temperature by 3–5°C with respect to the particular climate and building design (Olawale-Johnson et al., 2021; Abdulkareem & Al-Maiyah, 2025). These reductions are acceptable within the boundary of the adaptive comfort principles that also provide measurable increments in occupants' contentment. Moreover, the reductions in the demand for cooling energy have been reported. The combination of shading devices, natural ventilation and urban greening has resulted in 20–60% energy savings, thus demonstrating the fact that the in-house-mechanical-air-conditioning system can be made less dependent on them (Kabanshi et al., 2023; Kousis & Santamouris, 2025).

Performance trends depended on climate: in hot-humid zones, natural ventilation and shading were the most effective, as controlling airflow and solar gain were vital, while high thermal inertia materials, like stone and compressed stabilised earth blocks, were especially suited for arid climates, as they could buffer the temperature extremes of the day and night. These results combined are a clear demonstration of the necessity for passive strategies tuned to the context and also providing quantitative benchmarks for the design of thermally resilient structures in Africa's different climate areas.

### **Contextual Observations**

According to the analysis of the studies included, residential building applications had the most, and there were relatively few studies on commercial or institutional types. This indicates that the research was conducted mainly on the spaces where the occupants are the main concern and where passive cooling has a direct impact on the comfort of a person daily, but at the same time, it shows the critical gap of evidence for large-scale or high-occupancy buildings, which might have a different response to bioclimatic interventions. Historical and vernacular designs showed and proved to be very effective in making the adaptive elements work (e.g., building orientation, selection of materials, and layouts for passive ventilation) (Liu et al., 2022; Santos et al., 2022). These methods not only made the most of the climate knowledge that was part of the traditional architecture but also set up the ways for the integration of the vernacular principles with the modern design, especially in the case of hot-humid and arid zones. Various methodological limitations were pointed out in the studies analysed one after the other. Field measurements were usually for a short time only; therefore, the capture of seasonal variability was limited, while simulation studies depended on assumptions concerning occupancy patterns and internal gains. The reporting of thermal outcomes varied from study to study, among others, differences in PMV/PPD calculations, adaptive comfort hours, and temperature differential units. Besides that, there was no consistency in the standardisation of thermal metrics, which made the synthesis across studies and quantitative comparison very difficult. It is pivotal that these issues are addressed in future research, as only then will it be possible to develop guidelines based on performance for passive cooling destined for various African contexts that are robust in nature.

## **DISCUSSION**

### **Efficacy of Passive Cooling Strategies**

The compilation of the studies that have been reviewed indicates that passive cooling methods that are integrated always have a better performance than single-strategy implementations (Prozuments et al., 2025). Grouping shading devices, natural or mixed-mode ventilation, and high-thermal-inertia materials resulted in a synergistic effect of indoor temperature reductions and improvements in comfort levels of the occupants. This is an affirmation of the importance of bioclimatic design principles, where the building envelope's adaptation, airflow management, and thermal mass must all work together to mitigate the extremes of day-night and seasonal temperature changes. Simulations and field experiments, along with studies, confirm the need for an adaptation specific to the climate. The strategies for cross-ventilation greatly improved the thermal comfort in hot-humid regions, making use of the wind that was blowing to remove the heat that was both latent and sensible. On the other hand, in dryland or hot-dry climates, ventilation was not adequate by itself; for the performance to be effective, it had to be combined with shading elements or high thermal inertia materials to reduce solar gains and diurnal temperature swings (Abdulkareem & Al-Maiyah, 2025; Benziada et al., 2025). Urban scale interventions consisting of compact building structures, increasing vegetation, and using green or reflective materials provided two-fold benefits: improved microclimates and reduced urban heat island effects (Kousis & Santamouris, 2025). The findings indicate the need for design strategies operating at multiple levels, where on-site or neighbourhood combinations of building-level passive measures yield the best thermal performance. In short, the results highlight the fact that context-bound combined passive measures are the only way to cope with the competition between resilient and energy-saving comfort levels in modern African architecture.

### **Climate-Dependent Performance Patterns**

The use of passive cooling strategies in African buildings was greatly influenced by the climatic conditions, which was a strong indication of the necessity of making design prescriptions that are site-specific. In hot-humid areas, the most efficient strategies were those that highlighted the use of natural ventilation and shading. The use of cross-ventilation not only helped the removal of latent heat but also brought down the indoor humidity levels, while the use of window overhangs and external shading devices reduced the gain of solar energy through the windows. The actual measurements from Zanzibar and Algiers showed that there were PMV improvements (0.85–1.2) and PPD reductions (20–37%) that were in the moderate range, which means that the use of ventilation may not completely counteract the discomfort to the full extent during peak periods of heat (Liu et al., 2022; Tellache et al., 2025). On the other hand, in hot-dry and arid regions, the use of high thermal inertia materials such as stone, compressed stabilised earth blocks, and light-colored walls gave a considerable advantage. These materials made it possible to control temperature controlled by diurnal changes, consuming heat during the day and releasing it at night, thereby reducing indoor overheating and making it comfortable during the hottest hours (Benziada et al., 2025; Dodoo & Ayarkwa, 2019). Sometimes the main surface was not enough for their performance, even with the above mentioned measures, thus some complementary measures had to be taken, like reflective surfaces and strategic shading.

Mediterranean hot-summer climates have shown a strong necessity for the use of hybrid strategies in the future. The integration of mixed-mode ventilation together with adaptive shading and thermal mass resulted in the occupants being able to maintain their comfort levels despite the seasonal changes, especially during the times of great diurnal variation (Tellache et al., 2025). By and large, the passive cooling effectiveness has been proven to be very situation-specific; thus, it calls for the designers to take into account not only the type of the strategy but also the local climate, building typology, and occupancy patterns. It is through the use of standardised performance metrics like PMV, PPD, and adaptive comfort hours that the necessary cross-study comparisons will be made possible and the evidence-based bioclimatic guidelines for African architecture will be established.

### **Vernacular-Contemporary Integration**

A notable finding throughout the literature that was studied is the integration of the old and the new, where the various cooling techniques of the past are combined with modern rules of building. Thus, the traditional and

native methods, like the previously mentioned, north-south orientation of buildings, courtyard ventilation, high thermal mass walls, and light-colored finishes, were shown to have natural and effective qualities of adapting to the climate, which made the moderation of the indoor temperatures very effective (Liu et al., 2022; Santos et al., 2022). The use of these historical methods in the design of buildings provided the necessary help to cope with the heat, and this was especially in the case of the low-income and informal settlements where the poor availability of resources prevents the use of energy-consuming active cooling systems and hence the heating that was done using these methods becomes the only way out for the poor in such areas. Contemporary adaptation such as building-integrated photovoltaic (PV) shadings, coatings that reflect, and windows-to-walls ratio being optimised, on the other hand, improved the performance of the old ways without altering the comfort of the occupants beyond the standards set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the adaptive comfort (Kabanshi et al., 2023; Abdulkareem & Al-Maiyah, 2025). One such pairing was the combination of the cross-ventilation through courtyards and the position of the PV panels so that they got the sun at the right angle; this allowed cooling and energy production to take place at the same time, and thus the mechanical systems were not used as much. The combination of local wisdom and modern simulation-based design is indicative of a context-aware strategy that adapts to the local climate, building type, and socio-economic limitations. This mixed-method approach not only maintains cultural heritage but also pushes the development of biomimetic design frameworks based on African architecture. The results indicate that the next regulations and standards should, in a way, directly increase and reward the fusion of traditional and modern techniques to achieve the most comfortable indoor climate, minimise power consumption, and increase resistance to climate change.

### **Thermal Comfort Benchmarking**

According to the review, there was a wide gap between the design intentions and the thermal comfort of the users. Many modern African buildings that used passive cooling techniques did not always comply with the ASHRAE 55 or EN 16798 standards (Liu et al., 2022; Dodoo & Ayarkwa, 2019). Data from both field and simulations showed the PMV values often going beyond the range of  $\pm 1$ , along with PPD values that sometimes exceeded 20-30%, especially in the case of single-strategy interventions. That is to say, the outcomes revealed that depending on just one of the passive measures, such as natural ventilation, shading, or high-inertia materials, would only alleviate the thermal stress to a small extent. On the other hand, integrated, multi-pronged approaches are put forth as being crucial for comfort thresholds acceptance. So, the combination of ventilation, solar control, and thermal mass in great detail according to the climate zone, building typology, and occupancy pattern gave the most consistent results in reducing indoor temperature shifts and discomfort hours. This benchmarking demonstrates the fundamental requirement for evidence-based design calibration, where cooling systems using passive means are assessed quantitatively against the standards rather than considered effective. Moreover, the diverse reporting of thermal performance across studies points out the need for a common PMV/PPD measurement protocol in African countries that allows more substantial cross-case comparisons and the tracing of climate-responsive building practices that are adaptable and appropriate.

### **Energy Implications and Climate Resilience**

By reflecting the influence of passive cooling strategies directly on the building energy demand, the combination of the integrated methods resulted in the power needed for cooling to be reduced by 20–60%, depending on the climate zone and the strategy used (Kabanshi et al., 2023; Kousis & Santamouris, 2025). With the use of shading devices, the improved cross-ventilation in hot-humid areas decreased the number of hours that helped discomfort to reach peak levels, thus there was less dependence on the mechanical cooling system. In the case of arid and hot-dry zones, the use of high thermal mass materials and reflective surfaces moderated the indoor temperature so that less energy was consumed by the active cooling systems. Facilitating urban-scale approaches, the approaches of compact building forms, integration of vegetation, and planting of cool/green roofs helped not only in localised thermal comfort improvement but also in urban heat-island effect mitigation and, thus, the overall climate resilience (Benziada et al., 2025; Kousis & Santamouris, 2025). The findings underscore the fact that passive cooling should not be seen as a concern only at the building level but as a city-wide urban adaptation strategy with the potential, among others, to cut down heat-related illness, to increase the comfort of the people living in the city and to make energy usage more equitable in the less affluent African cities. The results signal

a strong interdependence between thermal comfort and sustainability and the necessity for designers and policymakers to think of new building regulations and urban planning frameworks that are simultaneously evidence-based, climate-responsive, and incorporate passive strategies. Acknowledging the synergy, the non-simultaneous provision of energy saving, and the comfort of the occupants, as well as their resilience to the effects of rising temperatures, is the route to addressing the vulnerabilities from both the environmental and socio-economic aspects.

## SUMMARY OF KEY FINDINGS

The comprehensive evaluation of ten studies conducted after 2018 on the application of passive cooling strategies in modern African architecture shows the following major points:

1. **Strategy Effectiveness:** The combination of the passive measures including natural ventilation, shading, and materials with high thermal inertia, has always produced better outcomes than applying one measure at the time, bringing about improvements of about 3 to 5 degrees Celsius in temperature and saving up to 60% of cooling energy (Olawale-Johnson et al., 2021; Kabanshi et al., 2023).
2. **Climate-Dependent Performance:** The performance of each method was highly dependent on the particular area's climate. In the hot-humid areas, cross-ventilation and shading were the most helpful, whereas in the arid and hot-dry areas, high thermal mass and reflective surfaces were the most crucial (Abdulkareem & Al-Maiyah, 2025; Benziada et al., 2025).
3. **Vernacular-Contemporary Integration:** The styles of the past and the ones used by the locals provided the adaptive models, and their combination with modern technologies like PV shading and reflective coatings not only increased the comfort of the dwellers but also the cultural heritage conservation (Liu et al., 2022; Santos et al., 2022).
4. **Thermal Comfort Gap:** A majority of the buildings did not comply with the ASHRAE 55 and EN 16798 standards, thus pointing out a gap in performance between the design intent and the actual indoor comfort. The application of single-strategy interventions was particularly ineffective, and thus, the necessity for context-specific, multi-faceted solutions was highlighted (Dodoo & Ayarkwa, 2019).
5. **Urban and Energy Implications:** Urban-scale interventions, such as compact layouts, planting, and cool/green roofs, quickened thermal comfort and decreased urban heat-island effects, thus laying the ground for energy-efficient and climate-resilient urban development (Kousis & Santamouris, 2025; Benziada et al., 2025).

The results bring out the necessity of climate-responsive, evidence-based passive design, which combines vernacular knowledge with modern techniques, for thermal comfort, energy efficiency, and urban resilience in different African situations, as is the case with the majority of the partners involved in the project.

## CONCLUSION AND RECOMMENDATIONS

The current systematic review of the literature brought together empirical evidence on passive cooling strategies (PCS) in the present-day architecture of Africa, with a specific emphasis on their thermal comfort outcomes. It was found that the interventions embracing multiple strategies, always combining natural ventilation, shading devices, and the use of materials with high thermal inertia, often resulted in the best thermal performance, while the single-strategy approach ranked last. The strategy's efficacy depended on the climate: cross-ventilation and shading were most effective in tropical wet climates. At the same time, high-inertia materials and reflective surfaces played a significant role in arid and hot-dry climates. The use of historical and vernacular building techniques has been a great help in achieving cold-adapted design, especially when paired with modern technologies such as PV shading, cool roofs, and reflective coatings. The use of historical and vernacular building techniques has been a great help in achieving cold-adapted design, especially when paired with modern technologies such as PV shading, cool roofs, and reflective coatings. The advantages notwithstanding, there remains a significant mismatch between what the designers intended and what the occupants perceived as

comfortable, as many buildings do not comply with the thermal standards set by ASHRAE 55 and EN 16798. The differences in how the metrics were reported, the short duration of the measurements, and the limited number of studies on commercial or institutional buildings have all contributed to the findings being less applicable. On the other hand, urban-scale measures, such as the inclusion of trees, compact layouts, and green/cool roofs, not only mitigate heat-island effects but also contribute to energy savings and increased occupant comfort and health.

## **RECOMMENDATIONS**

1. **Integrated Design Implementation:** The architects and engineers must focus on the use of multi-pronged passive cooling strategies specifically for each climate area, where they combine natural ventilation, shading, and thermal mass in a way that suits the location.
2. **Evidence-Based Benchmarking:** The thermal comfort assessments should employ the PMV/PPD protocols that are universally acknowledged so that their results can be compared across different cases, and the design of guidelines for specific contexts can be supported.
3. **Vernacular Knowledge Integration:** The building site orientation, choice of materials, and design of courtyards, which are the main elements of indigenous architectural practices, must be increasingly incorporated into modern architecture in an effective way that continues to communicate the cultural aspect while also improving the effectiveness.
4. **Policy and Code Development:** The governments and professional organisations should change the regulations and standards about construction to recognise the passive cooling techniques that have been accepted as effective ones, especially in the case of low-cost housing and the areas of cities that are most affected by climate change, thus also aiding SDG 7 and climate change resistance goals.
5. **Urban Planning Considerations:** It is necessary to incorporate urban planning changes, such as adopting more compact structures, adding vegetation, and installing green roofs into city master plans as a means of alleviating urban heat islands and improving energy efficiency.
6. **Future Research Directions:** Research should not be limited to the residential sector but also include studies on commercial and institutional buildings, utilise longer field measurements, and do systematic evaluations of the hybrid configurations of vernacular and modern passive cooling systems based on the climate scenarios projected.

In conclusion, the mitigation of climate change impacts through the adoption of climate-responsive, evidence-based passive cooling strategies would not only upgrade thermal comfort levels but also help in reducing energy consumption as well as increasing urban resilience throughout Africa's varied climatic regions, thus making it a sustainable route.

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The author reports the absence of any personal or institutional connection which could have defined the behaviour or display of this review.

### **Competing Interests**

According to the author, there were no competing financial, professional or personal interests that might have influenced the objectivity of this work.

## Additional information

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