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Retrofitting Existing Residential Buildings for Energy-Efficient Indoor Cooling in Tropical Climates: A Framework for Affordable Climate Adaptation

Michelle Ijato Ajene
Federal University of Technology, Minna, Nigeria.
Corresponding Author: michelleajene@gmail.com
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Abstract

For buildings already built in a tropical climate, rising cooling demand and temperatures are leading to thermal challenges. Many home dwellings are poorly protected from direct heat from the sun and are unable to cool themselves sufficiently, making them more likely to rely on fans and air-conditioning. In this research, the empirical evidences concerning retrofit measures to enhance the indoor cooling conditions, reduce cooling-energy demand and improve the climate adaptation of the existing residential buildings in tropical climates were reviewed. The literature search was done systematically following the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA 2020) guidelines. Literature searches were conducted in major academic search databases and included citation searching, and a specific search using African data. Context such as climatic conditions, retrofit measure, thermal outcomes, energy performance, affordability and climate adaptation value were assessed for the studies that were eligible. The 12 empirical studies that were used for the core synthesis were comprised of nine studies conducted in African countries and three studies conducted in Asian countries. The results indicated that reflective roofs consistently reduced the indoor heat, with the cool roof treatments and external roof covers also showing a beneficial effect, depending on building and climatic conditions, whereas shading, insulation and suitable ventilation also gave further benefits. There were also some retrofit packages that showed potential for saving energy and improving indoor conditions that cost less. The effectiveness of ventilation was less consistent, however, and passive ventilation methods were less effective under some future climate scenarios. Based on these results, an affordable climate responsive retrofit framework was developed for building assessment, heat sources identification, prioritisation of interventions, selection of affordable retrofit packages, assessment of renovation performance and evaluation of climate-resilience. The framework is an evidence-based process to enhance current residential buildings, whilst taking into consideration household resources and changing climatic conditions.

Keywords: Residential Retrofit; Tropical Climate; Thermal Comfort; Indoor Overheating; Cooling Energy; Climate Adaptation.

Introduction

In tropical climates, expanding demand for cooling in the house is combined with higher outside temperatures, which are becoming a real challenge for houses. Ventilation openings (windows, walls and roofs) with inadequate protection from external condition can intensify the effect of high temperatures, strong solar radiation and high humidity inside buildings. Previous research on residential buildings in tropical climates has reported that the indoor environment of these buildings can exceed the acceptable temperature comfort level, both in the day and night (Aderinsola et al., 2025; Gamero-Salinas et al., 2020). This situation gets worse in urban areas of high population density, where urban heat can increase ambient temperatures and limit the natural heat removal opportunities (Gonzalez-Longo & Mohd Sahabuddin, 2019).

The more heat there is inside, the more reliance on fans and air-conditioning. With projected rise in temperature and access to cooling, global residential cooling demand is expected to grow significantly affecting electricity demand and household expenditure (Falchetta et al., 2024; International Energy Agency, 2018). The potential for high cooling costs and intermittent electricity services may be especially important for low-income and middle-income households, who may not be able to keep their indoor conditions acceptable.

The challenge is with existing residential buildings, as it is very costly and practically unrealistic to replace the building with new energy efficient housing. Retrofitting offers an alternative as a means to enhance the thermal performance of existing buildings. Data from tropical climates suggests that interventions like reflective roofing, external shading, insulation and smart ventilation can lower the heat and cooling-energy demand in the building interiors (Tuck et al., 2020; Tong et al., 2019; Chung-Camargo et al., 2024). There is also additional evidence from African studies that relatively simple interventions can have a positive effect in low-income residential areas (Onyenokporo & Ochedi, 2019; Wilby et al., 2021; Kimemia et al., 2020). The effectiveness and cost of these measures, however, will depend on the building and the climatic conditions. This means there is a need for a solution that helps practitioners and households identify, prioritise and combine appropriate retrofit solutions for the current needs for cooling, household resources and future heat exposure.

Statement of the Problem

Old buildings in tropical climates are being threatened by rising temperature with the possibility of indoor overheating. Many dwellings have roofs, windows, walls and ventilation systems that offer only partial protection against solar heat and high outdoor temperatures leading to extended periods of high indoor temperatures and increased reliance on fans and air conditioning. A rise in cooling demand also leads to higher household electricity demand and financial strain with high electricity expenses or seasonal shortages.

There has been research on a variety of solutions for enhancing indoor conditions, such as the use of reflective roofs, insulation, shading, window and facade modifications, and ventilation. The available evidence, however, is spread throughout various climates, building types and research methods. Some of the studies highlight the thermal comfort, others the energy use, cost or single retrofit actions. There is limited research on consideration of these factors together. This constraint is especially crucial in African homes, where many reside in old structures and might not

have the resources to undertake extensive renovations.

The problem is not actually the lack of possible retrofit measures, but the lack of a comprehensive basis for determining which retrofit measures should be prioritised for existing residential dwellings based on their thermal benefits, energy impacts, cost, ease of retrofit and potential to decrease exposure to future heat. If not, families or practitioners can invest in options which does not solve the primary causes of indoor heat or that are too costly. There is therefore a need for a systematic synthesis of empirical evidence to determine the relative value of interventions available and to provide a basis for affordable retrofit framework for a resilient climate.

Purpose of the Study

This research aims to systematically synthesize empirical evidence on retrofit measures in reducing cooling-energy demand and improving the cooling environment in existing residential buildings in tropical climates. The study explores the thermal, energy, cost, implementation and climate adaptation consequences of the options available, specifically focusing on available evidence from residential contexts in Africa. The findings are used to develop an evidence-based framework for assessing the existing dwellings, prioritising appropriate retrofit measures, identifying affordable packages for interventions, and evaluating them for their performance in current and future hot environments.

Research Questions

1. What are the building conditions that lead to overheating and cooling-energy demand in existing residential buildings in tropical climate?
2. What retrofit measures have been reported to improve the indoor thermal conditions and decrease cooling-energy demand in existing residential buildings in tropical and similar hot climates?
3. What evidence is available to support the cost-effectiveness and feasibility of retrofit options, especially in residential conditions in Africa?
4. How can thermal performance, energy savings, affordability, implementation feasibility and climate resilience be integrated into a framework for prioritizing retrofit measures in existing tropical residential buildings?

Significance of the Study

The study is important as it examines the practical challenge of how to improve the thermal situation in existing dwellings without the assumption that household will be able to either replace their home or renovate. The scope of the study to integrate evidence on thermal performance, cooling-energy demand, cost, and climate adaptation offer a more robust framework for residential retrofit decisions than those that examine individual retrofit measures.

The framework can help identify measures for households, especially those with limited budgets, to address major sources of heat indoors without unnecessary expenditure. The framework offers a structured approach for building professionals to evaluate existing dwellings and choose retrofit solutions based on building conditions, but not necessarily the same solution for all dwellings. The findings enable policy makers and housing programmes to provide evidence for residential improvement programmes, energy saving programmes and climate adaptation programmes.

The study is also of relevance to the African context as there are residential studies from Nigeria, Ghana, Uganda, South Africa, Kenya and The Gambia included in the evidence base. This enhances the relevance and applicability of the results in environments where mechanical cooling may be limited by

overheating, by energy cost, or by house conditions and/or the reliability of electricity supply. The study provides an evidence-based framework to link the energy efficiency of residential buildings to thermal comfort, affordability and climate adaptation for retrofitting existing housing in the tropics.

Literature Review

Buildings in tropical climates face high thermal stress on a daily basis due to the high ambient temperature, humidity and minimal opportunity for natural diurnal cooling. A high temperature in indoor air can be maintained for a long period of time under these conditions, making occupants more dependent on the use of fans and air conditioning systems to achieve adaptive thermal comfort level. Various field studies and systematic reviews have found that the temperature of existing residential buildings is above the recommended comfort zone during both day and night, which resulting in high cooling load for the occupants (Aderinsola et al., 2025). The natural cooling capacity can be lowered as well and the time of indoor thermal exposure can be extended because of urban heat island effect and dense concentrations of residential buildings. This is a potential increase in demand for cooling, which puts strain on electricity systems and household budgets, especially where electricity is not reliable or energy costs constrain household consumption.

The efficiency of the building envelope and ventilation systems are two factors that greatly affect the indoor overheating conditions of existing tropical dwellings. The roof is a major source of solar heat gain because of its direct exposure to solar radiation. If roofs are poorly insulated, or have a high solar absorptance, they can reach high surface temperatures, which in turn will increase the conductive and radiant heat transfer into the occupied space. Previous studies conducted in residential buildings have found an increase in the number of hours spent outside thermal comfort levels with an increase in roof exposure and a decrease in the number of hours spent outside thermal comfort levels with an improvement in roof protection (Gamero-Salinas et al., 2020). Window and facade windows also influence heat gains within the building. The high window to wall ratios and high solar heat gain coefficients allows for a significant penetration of direct and diffuse solar radiation into the interior spaces, especially on east and west facing facades. In Singapore, maximum indoor air temperature of up to 44°C was reported in residential buildings located near west facing facades on sunny afternoons when the windows are closed. It was found that opening windows, and reducing window-to-wall ratio, had measurable impacts on indoor temperature (Tong et al., 2019).

Moreso, thermal storage can be enhanced using heavyweight construction materials which can extend the period of time for which the building is exposed to heat. Concrete, brick, rock, and other materials absorb heat during the day, and then release it at night when the outdoor temperatures drop. When natural ventilation is not sufficient, temperatures inside the house may stay high at night and this is reflected on one-sided ventilation, the urban form and the low indoor air speed in high-rise social housing which restrict heat dissipation. In such environment, the operative temperature was observed to be above 29°C and relative humidity was greater than 70% (Gonzalez-Longo & Mohd Sahabuddin, 2019). Furthermore, the effects of insulation degradation, improper seals, building component deterioration and deterioration of materials in older residential buildings can reduce the thermal performance of the building envelope. These deficiencies illustrate that, not only climatic factors contribute to thermal discomfort but also building factors contribute to thermal discomfort that can cause overheating to occur even when outdoor temperatures are not at their peak.

Energy efficient retrofit strategies can be used to address these modes of heat gain by incorporating solar control, thermal insulation, and upgrading the ventilation and cooling systems. In particular, roof related interventions are necessary, as roofs receive a significant amount of solar radiation, and can

contribute a fair amount of heat to the interior of the houses. Research indicates that cool roofs and reflective roof coatings have been shown to greatly reduce heat-stress exposure. Cool-roof retrofits in hot climates have been seen to decrease the heat stress exposure by up to 91% in informal settlements and increase the number of comfortable hours by up to 21% in detached houses (Nutkiewicz et al., 2022; Ukey & Rai, 2024). If conventional roofing solutions are cost prohibitive, an external roofing solution can provide similar benefits and costs less. In one case, high density polyethylene nets placed in attic spaces have been shown to achieve a convective heat flux reduction of around 70-80%, and up to 88% in rooms below the nets (Tuck et al., 2020). Another measure to reduce conductive heat transfer is roof insulation, which can be especially effective when used along with reflective roof surfaces.

Other methods of reducing heat gains include window treatments and solar shading. Window film technology can help reduce solar heat gain, and low solar heat gain glass can help control solar gain through the window. Exterior shading devices like louvres, vertical fins and overhangs can provide shade to the building envelope. These are especially useful for the east- and west-facing side facades where low angle solar rays are hard to manage with only internal shading systems. Low-solar-heat-gain glazing (SHG) and low-conductivity external walls (LEW) are the most effective ways to enhance the building performance. The level of energy savings generated by energy retrofit packages through combined passive retrofit, however, depends on climatic conditions, and energy savings ranging from about 30% to more than 60% (Perera et al., 2024).

Envelope related interventions can further be enhanced with improvements in ventilation to aid removal of indoor heat. Increased ventilation by cross-ventilation, purposeful placement of windows, ceiling fans and controlled night time air flow can promote air movement and help to remove heat that may have been trapped in building materials. These measures will be most effective when the outdoor temperatures are low enough to permit meaningful heat exchange during the night. In addition, efficient mechanical cooling systems can be used in combination with passive cooling solutions to meet residual cooling requirements. The passive measures are undertaken to reduce the cooling load that mechanical services need to address, thereby increasing the overall energy efficiency. Systematic evaluations of retrofit practices in the tropics repeatedly reveal that passive interventions play an important role in successful retrofit strategies. Improvements to roof solar control, roof insulation, shading systems and ventilation improvements are often cited as important actions to improve thermal comfort and reduce cooling loads (Gupta & Deb, 2023; Chung-Camargo et al., 2024).

The effectiveness of retrofit measures is not a guarantee for implementation. Feasibility and cost are critical issues that can affect decisions to invest in energy-efficient upgrades to current housing. Whole-house retrofits can be daunting to households owing to cost, limited financing options, inability to predict payback periods and disruption caused by renovations. The problems associated with these are especially important in low and middle-income households, where housing improvement needs to vie for household resources with other household expenditures. As the findings in Lagos have shown, there can be considerable improvements made without an inordinate investment of money in the passive retrofit. Using the simulation, less expensive retrofit combinations were identified that resulted in a maximum of energy savings of 46.3% and improved indoor comfort, with specific reference to retrofit measures available to lower income groups (Onyenokporo & Ochedi, 2019).

An incremental retrofit approach can be considered as an alternative to large scale retrofit projects as the household can take the steps one at a time as they become available. This strategy allows for the use of each intervention by the occupants while costs are distributed over time. Passive shading, optimizing natural ventilation, and sealing the envelope can be implemented before more costly technologies are considered to reduce cooling loads at an early stage. Passive strategies generated a reduction in energy

use intensity of between 48-50% and the addition of a small%age of renewable energy technologies presented a transition towards a net zero energy use archetype, with pay-back periods reported between 6-10 years (Ohene et al., 2022). Findings indicate that retrofit planning should take into account the order of interventions, especially when multiple interventions are being planned. Simple treatments, such as reflective roof treatments, simple external shading devices and ceiling insulation are other ways of reducing heat gains that require little disruption and have low installation costs compared to full building envelope replacement. In addition, a financial benefit may be realized through retrofitting benefits from bringing a project to fruition when reducing operational energy costs are measurable.

Energy conservation is not the only aspect of residential retrofitting. Existing homes may find themselves in an environment that they were not built for as the temperatures get warmer and extreme heat events occur more often. In such situations, passive retrofit measures can help increase the thermal performance of the building envelope and decrease external heat gains to improve the capacity of buildings to provide thermal comfort inside. A systematic review of retrofit interventions in various climatic regions revealed that passive interventions were able to increase the resilience of a residential building through the reduction of heat gains and increase in its ability to regulate indoor temperature (Hulathdoowage et al., 2024).

Some targeted envelope improvements, reflective surfaces, and nighttime ventilation are shown to be of particular benefit in reducing indoor heat exposure when outdoor exposure is high. The relationship between retrofit and climate adaptation is even more important in areas where electricity is not dependable. Minimizing heat gain through the walls of buildings decreases the cooling needs and the electricity consumption of households in order to maintain thermal comfort. Reduced household energy consumption can also result from the reduced cooling requirements but in tropical climates, passive cooling solutions are not always sufficient to negate the need for active cooling. Future climate projections show that passive retrofit measures can significantly lower danger of overheating, although mechanical cooling systems may still be needed in warmer climates as temperatures rise (Liyanage et al., 2024). Under such circumstances, cooling technology and renewable energy systems can be used to supplement the passive cooling systems, and by effectively satisfying the remaining cooling needs, energy consumption and greenhouse gas emissions can be reduced. The adaptation value of retrofitting is thus not just in terms of immediate reduction of exposure to indoor heat, but also in improving the ability of the existing residential buildings to withstand future climatic conditions.

The general conclusion is that indoor overheating in tropical houses is due to the combination of the external climatic conditions and inadequate building envelope performance, solar control and ventilation. In all of the available evidence, roof solar control, roof insulation, shading systems, and ventilation improvements are consistently cited as major retrofit solutions, and efficient mechanical cooling systems and renewable energy technologies are recommended as solutions to the cooling demand that remains after implementing passive retrofit solutions. These measures are effective and feasible under various conditions including building properties, climate, household economic resources, and constraints for implementing measures. Though, residential retrofitting is more than picking technically effective technologies.

Methodology

Study Design

This study used a systematic literature review to synthesise empirical evidence on energy-efficient retrofit measures to enhance indoor thermal environment in existing residential buildings in tropical climates. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020)

statement were followed in reporting the review. The study aimed to identify, appraise and synthesise the existing empirical evidence on the issue of residential overheating, passive cooling, cooling-energy demand, affordability and climate adaptation, which called for a systematic review. Given the significant methodological differences across the studies identified (field monitoring, controlled experiments, building-performance simulations), the evidence was analysed in a narrative and thematic way, rather than a statistically-based meta-analysis. The outcome was an empirical basis to develop an affordable climate responsive retrofit framework.

Search Strategy

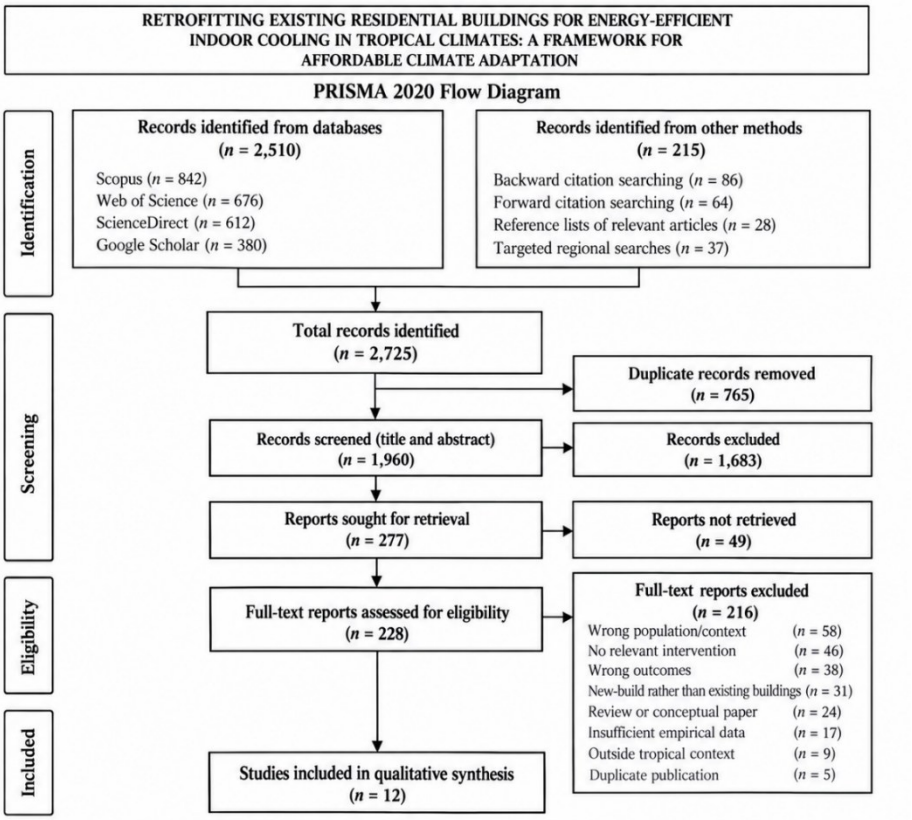
An evidence-based search was conducted and used to identify peer-reviewed studies from 2000 to 2026. Searches were carried out across Scopus, Web of science, ScienceDirect and Google scholar, along with backward and forward citation searching. A focused search for African evidence was also carried out to enhance the representation of residential retrofit research from Africa. The search strategy spanned four conceptual areas: (1) residential buildings, (2) retrofit interventions, (3) thermal and energy performance, and (4) tropical or hot climates. The following terms were used in the search: "residential building", "existing building", housing, dwelling, retrofit, "energy retrofit", "passive retrofit", "thermal comfort", overheating, "indoor temperature", cooling energy, cooling demand, "passive cooling", tropical, "hot-humid", and "tropical climate". African terms such as Nigeria, Ghana, Kenya, Uganda, South Africa, The Gambia and Burkina Faso were also used in African searches.

Table 1: Search Strategy and Eligibility Criteria

Component	Specification
Databases	Scopus, Web of Science, ScienceDirect, Google Scholar
Supplementary search	Backward and forward citation searching; targeted African search
Publication period	2000-August 2026
Building	Existing residential buildings, dwellings, houses, apartments and residential typologies
Climate	Tropical, hot-humid, tropical savanna, tropical monsoon and comparable hot climates
Intervention	Roof modification, reflective roofs, insulation, shading, glazing, ventilation, passive cooling and combined retrofit
Study design	Field studies, experiments, monitoring, calibrated simulation and parametric simulation
Outcomes	Thermal comfort, indoor temperature, overheating, cooling energy, energy consumption, cost, payback and adaptation
Inclusion	Peer-reviewed English-language primary studies meeting the above criteria
Exclusion	New-build studies without retrofit relevance, non-residential studies, reviews, conceptual papers, HVAC-only studies and studies without measurable outcomes

Study Selection

Pre-screening involved the consolidation and the elimination of duplicate records. Titles and abstracts were screened for eligibility based on the outlined criteria and then potentially relevant studies were subject to full-text evaluation. Special focus was put on identifying research focusing on existing residential buildings or housing conditions relevant to retrofit, as opposed to research surrounding new building construction. In the core synthesis, any studies that did not have immediate applicability to existing housing were not included in studies of newly constructed prototypes. Reviews and systematic reviews were also not included as primary evidence but were included for context and cited in the search for the literature. Reasons for exclusion at the full text stage were documented for transparent reporting in accordance with the PRISMA guidelines.



Note: Records identified from databases (n = 2,510) and other methods (n = 215) were combined and screened together after removal of duplicates. The flow diagram follows the PRISMA 2020 guideline.

Data Extraction and Quality Appraisal

The study characteristics, country, climate, building type, study design, intervention, comparator and outcomes were recorded using a structured extraction framework. Thermal outcomes were indoor or operative temperature, thermal comfort, overheating and heat-index measures, while energy outcomes were cooling load, energy consumption, and energy-use intensity. Capital cost and operational savings, along with payback period, were also derived, if available. Data on future climate exposure, electricity dependence and passive resilience was collected to evaluate adaptation potential.

Study design was used as a criterion for methodological quality. The sampling, duration of monitoring, measurement procedures, intervention specification, conditions used for comparison, and reporting of results were evaluated in field and experimental studies. The assessment of the simulation studies was based on baseline-building representation, climate data, model validation, calibration, and assumptions and sensitivity analysis.

Data Synthesis and Framework Development

In view of the diversity of the evidence, a thematic synthesis of findings was carried out under the headings: roof solar control, insulation, shading and facade interventions, ventilation, efficient mechanical cooling, and integrated retrofit packages. Subsequently, interventions were compared in terms of five criteria which are thermal effectiveness, energy saving potential, affordability, feasibility of implementation and climate resilience. These criteria were the basis of a retrofit prioritisation matrix, developed based on the evidence. The framework that was proposed was informed by the resulting synthesis, beginning from building and climate assessment to identifying the dominant heat-gain

pathways through retrofit prioritisation, selection of affordable packages, evaluation of performance, and assessment of climate-resilience. The framework is therefore not fixed and does not reflect a rank ordering of retrofit technologies, but rather a synthesis of empirical evidence.

PRISMA Reporting

A PRISMA 2020 flow diagram was used to present the study-selection process. The final diagram reports the actual numbers of records identified, duplicates removed, records screened, full texts assessed, exclusions and studies included following completion of the database searches. This will help to ensure transparency and reproducibility of the review process while also adhering to the requirements in PRISMA 2020 for reporting the review.

Results

Study Selection and Characteristics of the Evidence

The review identified 12 studies that met the criteria for inclusion in the main evidence synthesis. The studies included residential buildings and housing types in tropical and hot climates, with nine studies carried out in Africa, and three studies in Asia. The African studies were carried out in Nigeria, Ghana, Uganda, South Africa, The Gambia and Kenya, and the Asian studies in Malaysia and Singapore. Field measurements and controlled experiments and computer-based building assessment were used to conduct the studies. Several studies used more than one method.

The type of building, the measures of intervention and outcome differed across the studies. The buildings comprised low-income housing, informal housing, rural dwelling, terrace houses and other residential buildings. The most common interventions were roof improvements and then ventilation, insulation, shading and window and facade changes. Combinations of interventions were studied in some instances, and individual interventions in others.

Table 2. Characteristics and Quantitative Evidence of Included Studies

Study	Location	Building context	Method	Intervention or focus	Baseline performance	Post-intervention / change	Energy performance	Capital cost	Payback
Onyenokporo and Ochedi (2019)	Nigeria	Existing residential building in hot-humid Lagos	Building energy simulation	Low-cost retrofit packages involving roof, wall, window and shading measures	Reference operative temperature: **30.3°C**; annual electricity use: **10,576.37 kWh**; cooling load: **23,205.37 kWh/year**	Package 2 reduced operative temperature to **28.27°C**; Package 3 to **27.3°C**. Maximum reduction from reference: approximately **3°C**	Package 2: **37.6%** reduction in annual electricity use; Package 3: **46.3%** reduction	Package 2: **₦49,134**; Package 3: **₦422,310**	Package 2: **0.085 years**; Package 3: **0.733 years**
Adaji et al. (2019)	Nigeria	Low- and middle-income residential buildings	Field measurements and occupant surveys	Existing building characteristics and occupant adaptation	Indoor conditions ranged across the surveyed households; study focused on measured thermal comfort and adaptive responses rather than a retrofit baseline	No post-intervention retrofit condition reported	No retrofit energy reduction reported	Not reported	Not reported
Wilby et al. (2021)	Ghana	47 living rooms in eight low-income communities	Field monitoring	Roof type, ceiling insulation, fans and tree shade	Indoor temperature ranged from **22.4–45.9°C** in Accra and **22.2–43.0°C** in Tamale	Tree shade reduced very hot days by about **12 days/year** and very hot nights by about **15 days/year**. Ceiling insulation was associated with **6.9°C lower daytime** temperature but **1.4°C higher nighttime** temperature	Not reported	Not reported	Not reported

Study	Location	Building context	Method	Intervention or focus	Baseline performance	Post-intervention / change	Energy performance	Capital cost	Payback
Ohene et al. (2022)	Ghana	Existing two-storey residential building	Parametric building-energy simulation	Natural ventilation, sun shading, daylighting, envelope measures and solar PV	Annual EUI: **136–138 kWh/m²/year**	Passive retrofit measures reduced EUI to **68–70 kWh/m²/year**	Approximately **48–50% reduction** in total energy demand	Detailed retrofit costs reported in study; solar PV assessed separately	Solar PV payback: **6–10 years**
Kebir et al. (2022)	Uganda	Low-resource mud-hut and semi-permanent rural dwellings	SketchUp and EnergyPlus simulation	Passive cooling and daylighting packages	Baseline electrified mud-hut and semi-permanent dwelling scenarios	Package-specific results varied by dwelling type	Mud-hut package: **31% annual energy reduction**; semi-permanent package: **47% annual energy reduction**	Selected measures ranged from approximately **US$36–US$642 per homestead**, depending on dwelling and package	Mud-hut package: **4 years 9 months**; semi-permanent package: **2 months**
Kimemia et al. (2020)	South Africa	Informal housing structures	Controlled experiment	Cool roof coating	Uncoated structure used as control	Mean daily maximum temperature reduced by up to **4.3°C**; minimum temperature reduced by about **2.2°C**	Not reported	Not reported	Not reported
Gamero-Salinas et al. (2021)	Honduras	Apartment-type residential buildings in tropical cities	3,840 thermal simulations	Natural ventilation, wall absorptance, solar heat-gain control and semi-outdoor spaces	Overheating assessed using **hours of exceedance (He)** and **indoor overheating degree (IOD)** under current and future climates	Passive strategies significantly reduced overheating risk; natural ventilation and wall absorptance were among the most influential factors	Energy reduction not reported as a primary quantitative outcome	Not reported	Not reported
Jatta et al. (2021)	The Gambia	Experimental residential houses	Field experiment	Increased ventilation through screened windows and doors	Houses with no or limited screened openings used as comparison	Screened windows and doors reduced indoor temperature by **0.6°C (95% CI 0.5–0.7°C)**	Not reported	Not reported	Not reported
Abong'o et al. (2026)	Kenya	40 rural houses	Randomised field intervention study	Cool roof, cross-ventilation and mat ceiling	Control houses provided the comparison condition	Cool roof reduced daytime Heat Index by **3.3°C** and nighttime Heat Index by **2.4°C**	Not reported	Not reported in the accessible study summary	Not reported
Tuck et al. (2020)	Malaysia	Existing terrace house in hot-humid climate	Field experiment and thermal assessment	HDPE roof cover, ventilation and insulation	Existing roof condition used as comparison	Roof cover reduced convective heat flux by approximately **70–80% in the attic** and **88% in the room**; whole-day operative-temperature acceptability improved by **10%**	No direct annual energy reduction reported; roof cover had **zero operational energy consumption**	Described as low-cost; specific capital cost not reported in the accessible results	Not reported
Tong et al. (2019)	Singapore	Naturally ventilated residential buildings	Experimental field measurements	Façade orientation, window-to-wall ratio, external shading and openings	Four residential sites with different façade characteristics	Indoor air temperature varied according to façade orientation, WWR, shading and openings	Not reported	Not reported	Not reported
Murtyas et al. (2024)	Malaysia	Two-storey terrace house	EnergyPlus simulation under present and future climates	Eight passive cooling measures including shading, insulation, solar reflectivity and night ventilation	Present baseline indoor temperature: approximately **26–31°C**; annual cooling load: approximately **25.0 kWh/m²**	Passive measures increased the fraction of time meeting thermal comfort requirements by **5.8–55.6 percentage points** under present conditions; future baseline temperature projected at **29–36°C**	Passive measures reduced cooling load by approximately **3–8%** under current conditions; one high-reflectivity	Not reported	Not reported

Study	Location	Building context	Method	Intervention or focus	Baseline performance	Post-intervention / change	Energy performance	Capital cost	Payback
							wall option reduced it to about **2 kWh/m²**, an **8% reduction**		

Table 3. Critical Appraisal of Included Studies Using CASP

Study	Study design	CASP appraisal tool	Study validity	Methodological rigour	Clarity of results	Relevance to review	Overall appraisal
Onyenokporo and Ochedi (2019)	Quantitative simulation study	CASP quantitative appraisal	Yes	High	Clear	High	Strong
Adaji et al. (2019)	Cross-sectional field study	CASP Cross-Sectional Studies Checklist	Yes	High	Clear	High	Strong
Wilby et al. (2021)	Field monitoring study	CASP observational appraisal	Yes	High	Clear	High	Strong
Kimemia et al. (2020)	Experimental study	CASP experimental appraisal	Yes	High	Clear	High	Strong
Jatta et al. (2021)	Experimental field study	CASP experimental appraisal	Yes	High	Clear	High	Strong
Ohene et al. (2022)	Building-energy simulation study	CASP quantitative appraisal	Yes	High	Clear	High	Strong
Kebir et al. (2022)	Building-energy simulation study	CASP quantitative appraisal	Yes	High	Clear	High	Strong
Tuck et al. (2020)	Experimental retrofit study	CASP experimental appraisal	Yes	High	Clear	High	Strong
Tong et al. (2019)	Experimental field study	CASP experimental appraisal	Yes	High	Clear	High	Strong
Gamero-Salinas et al. (2021)	Thermal simulation study	CASP quantitative appraisal	Yes	High	Clear	High	Strong
Murtyas et al. (2024)	Thermal simulation study	CASP quantitative appraisal	Yes	High	Clear	High	Strong
Abong'o et al. (2026)	Randomised field intervention	CASP Randomised Controlled Trial Checklist	Yes	High	Clear	High	Strong

The African studies provided evidence from various housing conditions and climatic setting. In Nigeria, Onyenokporo and Ochedi (2019) discovered that low-cost retrofit packages enhance indoor environment and energy consumption in the building could be lowered by up to 46.3% per year. Adaji et al. (2019) revealed that the quality of low-income residential buildings had a strong correlation with thermal comfort conditions inside the buildings. The results suggest that an assessment of the building, and a movement towards improvement, should start before a specific technology is chosen.

The extent of heat exposure in low-income homes has been recorded in Ghana by Wilby et al. (2021), where houses with low-income residing in them were found to be hot. The improvements that include ventilation, shading and building envelope could result in a reduction of energy demand by about 48%-50% as reported by Ohene et al (2022). The study by Kebir et al. (2022) in Uganda also demonstrated that passive cooling improvements can be evaluated in conjunction with financial costs and savings.

Evidence from Southern and West Africa also indicated the need for relatively simple roof interventions. Kimemia et al. (2020) reported a decrease in maximum indoor temperature up to 4.3°C after applying cool roof coatings. A similar study led by Jatta et al. (2021) revealed that roof reflectivity had an impact on the indoor temperature of experimental houses in The Gambia. However, Jatta et al. (2021) demonstrated that this did not yield the same amount of benefit across all situations when the ventilation was increased. The Kenyan research by Abong'o et al. (2026) also confirmed 40 rural house dwellings, with cool roofs providing greater reduction in heat exposure than the evaluated ventilation strategy.

Effects of Retrofit Interventions

The most consistent improvement was seen with roof interventions. Advanced reflective materials, cool roofs and external roof covers lessened solar heat gain in houses. After installing an external roof cover, they observed a 70-80% reduction in roof space heat transfer and up to 88% reduction in room below heat transfer (Tuck et al. 2020). Roof improvements were also seen to decrease the heat exposure of the indoor environment in Nigeria, South Africa, The Gambia and Kenya. The findings indicate that roof treatment is one of the most appropriate initial interventions in the event of poor roof protection and limited financial resources.

Insulation reduced roof and ceiling heat transfer, but was effective to varying degrees depending on the building and the climate. The findings were not in supportive for insulation without taking ventilation and the ability of the building to dissipate the accumulated heat during the night into account. Heat also was decreased through the use of shading and window treatments on exposed facades. The Singapore study showed that the window size, facade orientation and window opening affected the inside temperature of the buildings, thus window and shading improvements should be tailored to the specific orientation and exposure of each building.

Ventilation yielded less reproducible results. A few studies argued that ventilation can eliminate excess indoor heat, especially when the outside air temperature is favourable. However, findings from The Gambia and Kenya indicated that ventilation did not always bring about significant improvements. This discovery means that ventilation must be done after taking into account the temperature and humidity of the outdoors, wind, and the openness in the layout.

Retrofit Prioritisation

The evidence was presented to make comparisons on retrofit measures based on thermal improvement, reduction in energy use, cost, ease of installation, and ability to provide protection during periods of high heat or insufficient electricity. Table 4 shows the result of the prioritisation.

Table 4. Evidence-Informed Retrofit Prioritisation Matrix

Retrofit measure	Thermal benefit	Energy benefit	Affordability	Ease of implementation	Heat resilience	Priority
Reflective or cool roof	High	High	High	High	High	Very high
External roof cover	High	High	High	High	High	Very high
External shading	High	Medium to high	High	High	High	Very high
Roof or ceiling insulation	High	High	Medium	Medium	High	High
Natural ventilation	Medium to high	Medium	High	Medium	High	High, depending on conditions
Efficient ceiling fans	Medium	Medium	High	High	Medium	High
Window or facade modification	Medium to high	Medium to high	Medium to low	Medium	Medium to high	Medium to high
Efficient air conditioning	High	Medium	Medium to low	High	Low during power interruptions	Medium
Solar energy with efficient cooling	Indirect	High	Low	Medium	High	Medium

The findings suggest that priority for retrofit should not be determined by the reduction of indoor temperature only. Roofs with reflective properties, external roof coverings and shading have a high thermal effect and require little installation effort with relatively low costs. These measures are thus

appropriate first steps for low-income families. Insulation, ventilation, window improvements and other measures then can be determined based on the identified deficiencies in each building.
Also, it seems that there is no universal solution to be applied to all residential buildings as findings from these studies showed that ventilation effectiveness was variable depending on the study, and passive measures were less effective as projected future climate changes. The findings therefore, support a step-by-step approach in which the building is evaluated first, the main sources of indoor heat are identified, appropriate measures prioritised and the chosen package assessed regarding thermal performance and energy consumption, cost and future heat exposure. This evidence formed the basis of this proposed affordable climate responsive retrofit framework.

Proposed Affordable Climate-Responsive Retrofit Framework

The proposed framework can be considered a structured approach for enhancing indoor thermal environment for current residential buildings, taking into account the household budget and future heat exposure. The framework has been based on evidence obtained from the review, especially the consistent results from the evidence on roof heat gain, solar exposure, ventilation, insulation, cooling-energy demand and the cost of retrofit measures. The approach does not prescribe a single intervention for all dwellings, but instead starts by calculating the overall building and its local climate. This approach acknowledges that the cause of overheating varies from building to building, and that the most cost-effective solution is not necessarily the same for each household.

Assessing Building and Climatic Conditions

The first step is to evaluate the existing building. This assessment focuses on roof materials and condition, wall structure, windows, orientation, shading, ventilation openings, and ceiling structure and materials that store heat. In addition, household occupancy and the presence of a fan or air-conditioning is assessed. The local environment including temperature, humidity, sunshine and wind are taken into account along with the information available about future temperature rise. The aim is to identify the entry points of heat into the structure, how heat travels through the structure and why it stays in. The assessment is used to determine what sections of the building need attention.

Identification of the Main Sources of Heat

The second stage identifies the main causes of excessive indoor heat. A leaky roof may be the main problem in one house, whereas large, uncovered windows and insufficient cross-ventilation could be a problem in another. The results obtained from the assessment are then used to determine the most important heat sources. This prevents homes from investing in a solution to a smaller issue, where the primary resource being addressed remains the same.

Prioritisation of Retrofit Measures

The third stage is to prioritise potential improvements based on their potential for reducing indoor heat, their potential for electricity savings, cost, and how easily they could be installed and would retain their value if electricity is not available during periods of peak outdoor temperatures or if the temperature rises indoors. The research evidence in this study suggests that reflective roofs, external roof cover and external shading are the highest priority measures that can be implemented that do not involve extensive alteration to the building. Roof or ceiling insulation, improved ventilation and efficient ceiling fans are installed depending on the condition of the dwelling. Solar exposure of openings may warrant window or facade improvements.

Selection of an Affordable Retrofit Package

The fourth phase involves transforming the prioritised measures into a workable package. Selection takes into account the financial resources of the household, availability and cost of construction materials, skills of construction workers in the area, the time required for installation, and the amount of disruption that the job can cause. Low-cost measures are used first particularly if they can deal with a significant source of heat. The costlier enhancements are only added when the anticipated benefit outweighs the additional cost. This sequential strategy enables households to make gradual improvements to their buildings, rather than having to renovate all at once. It also helps to minimize the cost of investing in costly measures before simpler measures are tested.

Assessment of Thermal, Energy and Financial Outcomes

At this stage, it is determined if the chosen measures are adequate. The assessment takes into consideration the changes in indoor temperature, the number of hours of excessive heat, thermal comfort, and the need for fans and/or air-conditioners. Where data exist, changes in electricity consumption and household cooling expenditure are also included. The expected savings are calculated and compared to the cost of the retrofit to make a financial decision. The package is reassessed if the improvement is not feasible within the budget provided and other options are chosen.

Climate-Resilience Assessment

The last stage is whether or not the retrofit will keep occupants safe as the outdoor temperature rises. Special attention is given to measures that can limit heat, but do not use electricity on a continuous basis, since they can continue to protect during power outages. Efficient equipment can be installed to achieve the rest of the cooling requirement when mechanical cooling is still required and minimise electricity consumption. It does not assume, therefore, that passive mechanisms will eliminate the need for mechanical cooling in all tropical homes.

The framework is not a set of improvements to be completed but rather an ongoing decision process. If the chosen package is not considered as being “optimal” in terms of benefits, the findings of the thermal, energy and financial assessment will bring the process back to the prioritisation stage. This process connects building conditions, household resources and exposure to future climate in one retrofit decision pathway. It offers practical guidance for taking cost-effective actions that can mitigate indoor heat, decrease cooling-energy consumption, and enhance the ability of current residential structures to withstand rising temperatures.

Discussion of Findings

The results show that the interaction between roof exposure, facade and window properties, lack of shading, limited ventilation and the storage capacity of building materials are clearly linked to overheating in existing houses in tropical climates. In the studies analyzed, heat gain was a key consistent factor for the roof. The studies conducted in Nigeria, South Africa, The Gambia, Kenya and Malaysia revealed that reflective roof treatments, cool roof coatings and external roof covers could significantly mitigate heat exposure of the interior. Tuck et al. (2020) found that the heat transfer was reduced by about 70 to 80% in the roof space and up to 88% in the room below after installing an external roof cover. Kimemia et al. (2020) also reported up to 4.3°C decreases in the maximum indoor temperature after the cool roof coating. The results validate priorities given to roof intervention if the roof is a significant source of heat gain.

The evidence also demonstrates that a reduction in indoor temperature can be achieved without mechanical cooling being the sole method of cooling. Onyenokporo and Ochedi (2019) have reported that low cost retrofit packages for Lagos can enhance the indoor thermal conditions and cut down the annual energy consumption by up to 46.3%. The energy savings of around 48% to 50% due to the various building envelope, shading and ventilation improvements were also reported by Ohene et al. (2022) in a housing building in Ghana. This is significant, because a decrease in the amount of heat that is gained into a house will decrease the electricity needed for cooling. Retrofit's benefits are not only in terms of thermal comfort, but also energy use in the home.

The findings relating to ventilation are more subject to caution. Although ventilation is a method for removing accumulated heat, its effectiveness depends on outside conditions, building orientation, the opening arrangement, and the timing of ventilation. Jatta et al. (2021) found that there was no uniform improvement in the indoor conditions associated with an increase in ventilation, and Abong'o et al. (2026) found that cool roofs had a more pronounced effect than the cross-ventilation intervention tested. The findings show that it cannot be assumed that ventilation has the same priority as roof or shading measures. The suitability should be determined based on the characteristics of the particular dwelling and the local climate.

It was also concluded in the review that the key to the success of residential retrofit is affordability. Effective interventions do not necessarily have to be scalable. Homes with restricted income may be able to invest in a more modest upgrade, such as a new window, rather than a larger project. The findings from Nigeria, Ghana and Uganda suggest that low-cost solutions can deliver tangible improvements and can be part of a broader retrofit initiative (Onyenokporo & Ochedi, 2019; Ohene et al., 2022; Kebir et al., 2022). This fosters an incremental solution where simple solutions can be applied in the first instance and more expensive solutions considered when funds are available.

The findings also provide conclusive evidence on the need to consider retrofit as a climate adaptation solution. As temperatures rise outside, existing housing can start to become exposed to even more excessive indoor heat. This exposure can be decreased with passive measures, even without continuous use of electricity, especially during power outages. However, future climate assessment evidence shows that passive measures would not be enough for all future scenarios (Murtyas et al., 2024). Thus, mechanical cooling is still applicable when the passive cooling methods do not provide the required inside climate. Mechanical cooling is not the answer to passive cooling, but rather minimizing the heat load in the building and using efficient equipment to provide the rest of the cooling.

The proposed framework addresses these findings, making retrofit selection a building-specific decision. It starts with an assessment of the dwelling and climate, seeks to determine the primary sources of indoor heating, ranks possible interventions, recommends a package that can be afforded by the household, considers thermal, energy and financial outcomes, and lastly evaluates the package of interventions under different scenarios of future heat exposure. This approach fills a gap identified across the literature, where thermal performance and energy use, cost and climate adaptation are yet to be examined all together (Chung-Camargo et al., 2024; Liyanage et al., 2024). The framework thus offers a foundation to link these considerations into a single retrofit decision-making process.

Recommendations

Residential retrofit programmes should be initiated by examining the building, and not the technology, in tropical climates. Prior to making intervention decisions, roof condition, exposure to solar radiation, windows, shading, ventilation, and ceiling construction and heat-storing materials should be assessed. This will save on the costs of measures that will not address the primary source of heat indoors.

Early consideration should be given to reflective roof treatments (cool roofs), external roof covers where heat gain is significant. They can be easily installed and have been proven to have a thermal benefit, making them an attractive choice for homes with limited financial capacity. Where there is a high level of solar exposure or conductive heat transfer, external shading and roof/ceiling insulation should be taken into account, in addition to roof improvements. Ventilation should be introduced based on local outside conditions and the placement of openings and should not be considered as a "sweep of the magic wand" solution.

Staged implementation of retrofit programmes is also recommended. Where they can make a difference in reducing heat gain, low-cost measures should be implemented first. High-cost interventions such as window replacement and mechanical cooling should be considered following an evaluation of the impact of lower cost interventions. Household financing schemes and locally available materials, in addition to financial support, can enhance the accessibility of retrofit measures for low income and middle classes.

Existing housing should be taken into account building regulations and housing improvement programmes in tropical areas with regard to overheating and cooling-energy. Special attention should be given to low-income areas where inhabitants might not have access to air-conditioning and where a lack of power can aggravate exposure to indoor heat. Future temperature increases should also be taken into account when providing retrofit guidance to ensure the investments made today will be beneficial in the future.

Limitations of the Study

The studies included varied widely in climate, type of building, intervention, length and outcome measures of the studies. This variation made it impossible to make a direct comparison of all of the intervention effects, and a meta-analysis was inappropriate. The findings therefore offer comparative evidence and do not give a single indication of the effectiveness of retrofits.

Secondly, much of the evidence was generated from computer-based evaluations of buildings. While these studies can be helpful in determining possible energy and thermal results, the conclusions reached rely on assumptions made regarding the factors of weather, occupancy, ventilation, building materials and cooling usage. A lower number of measurements were taken in the field and fewer in controlled experiments, giving more evidence of the actual performance.

Third, while the review contained significant African evidence, the studies available were focused in a few countries. Data from Nigeria, Ghana, Uganda, South Africa, The Gambia and Kenya provides insight to the conditions in Africa's residential areas, but cannot be assumed to be representative of the wider tropics of Africa. Retrofit performance may vary across regions as a result of variations in construction materials, household income, climate, and electrical services, as well as cultural differences.

Fourthly, there was unequal reporting on economic information. Some of the studies evaluated energy performance but did not give details of retrofit costs, financing conditions for the house and long-term savings. Therefore, the prioritisation matrix proposed should not be interpreted as an economic ranking of the available options, but rather as evidence informed assessment of their cost.

Lastly, the proposed framework is a synthesis of available evidence and it has not yet been evaluated in a prospective manner across various residential building types. It should thus be evaluated in terms of its practical use when applied in a real dwelling in various tropical climate zones, especially in the low-income communities.

Conclusion

This systematic review showed that significant heat exposure levels can occur indoors in existing houses in tropical climates, due to the heat gain through the roofs, solar gain through the facade and windows, poor shading, limited ventilation, and heat accumulation within the building materials. The reviewed studies further indicate that specific retrofit activities have the potential to enhance indoor conditions and lower cooling-energy use. Reflective roofs, cool roof treatments and external roof covers demonstrated very consistent benefits and insulation and shading and ventilation also benefitted system specific to the building characteristics.

The findings show that affordability is important to consider along with the thermal and energy performance when a retrofit decision is taken. Easy-to-implement interventions can make a significant difference with low cost, and can be done prior to more expensive interventions. This evidence also indicates that a passive approach can enhance the resilience of the home to greater frequency of heat and electricity outages, yet mechanical cooling may still be required under extreme conditions of climate today and in the future.

The proposed low-cost climate responsive retrofit plan integrates these findings by acting as a focal point for the building assessment, heat source identification, prioritisation of interventions, selection of affordable retrofit packages, performance assessment and climate resilience assessment. It is based on the notion that the priority for retrofit should be based upon interaction between building condition, expected thermal and energy benefits, household resources, requirements for retrofit, and heat exposure in the future. The framework thus offers an evidence-based guidance to retrofit existing residential buildings, while taking into account the financial and climatic context in which retrofit decisions are taken.

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