



HOUSING ADAPTATION TO CLIMATE CHANGE: A REVIEW OF RESILIENT ARCHITECTURAL PRACTICES AND RENEWABLE ENERGY SOLUTIONS

¹Benjamin Moral

¹Department of Architecture, Baze University, Abuja, Nigeria

Corresponding author: briggz.mb@gmail.com

Abstract

The built environment is a critical frontier for climate change mitigation and adaptation, with residential buildings accounting for a substantial portion of global energy consumption and greenhouse gas emissions. This paper presents a critical review of contemporary literature (2020-2025) synthesizing advancements in climate-resilient housing through integrated architectural and renewable energy solutions. A systematic analysis of 51 studies examines three core areas: passive and active architectural design for thermal resilience; the role of decentralized renewable energy in enhancing autonomy; and the socio-technical, policy, and governance dimensions of implementation. The present review identifies a paradigm shift from static efficiency toward dynamic, adaptive building systems, highlighting the efficacy of bioclimatic design, smart materials, and AI-driven management. Decentralized solar energy is underscored as fundamental for decarbonization and energy security, though its success depends on supportive policies, community engagement, and equitable finance. Persistent gaps are noted, including the need for holistic lifecycle assessments, scalable models for low-income contexts, and stronger integration of technical and social equity approaches. The review concludes by advocating for a transformative shift toward adaptive, regenerative, and just residential environments.

Keywords: Climate adaptation, resilient housing, renewable energy, architectural design, decentralized systems

1.0 Introduction

The existential threat of climate change manifests acutely in the residential sector, where buildings are simultaneously major contributors to greenhouse gas emissions and highly vulnerable to climate impacts (He, *et al.*, 2025; Piselli, *et al.*, 2025). The built environment is responsible for approximately 36% of global final energy use and 37% of energy-related CO₂ emissions (Woldegiyorgis *et al.*, 2025). This sector faces a dual imperative: drastic mitigation through deep decarbonization and urgent adaptation to protect inhabitants from intensifying heatwaves, storms, flooding, and other climate-induced hazards (Zhou, 2023). Housing, as the most ubiquitous building typology, sits at the heart of this challenge. Climate-resilient housing, therefore, is not a marginal concern but a fundamental

prerequisite for sustainable development, energy security, and social welfare.

The concept of resilience in housing has evolved beyond mere structural robustness to encompass a holistic capacity to anticipate, absorb, adapt to, and recover from climatic shocks and stresses while ensuring continuous energy services and occupant well-being (Janta *et al.*, 2024). This entails a synergistic integration of two core domains: *resilient architectural practices* and *renewable energy solutions*. Architectural practices provide the first line of defense, mediating the relationship between the external climate and the internal environment through design, form, envelope, and material choices (Sommese *et al.*, 2022). Renewable energy solutions, particularly decentralized

systems, offer the means to decarbonize housing operations and ensure energy autonomy during grid disruptions, a key aspect of functional resilience (Okesiji, 2025).

Significant research, as seen in Islam & Meyer (2025), Odebode (2025) and Ajiro-tutu *et al.*, (2025), has proliferated across these domains, yet a critical synthesis that connects architectural adaptation with energy transition in the specific context of housing remains necessary. While numerous studies (Munonye & Ajonye, 2025; Ghobadi *et al.*, 2025; Seo, 2025; Bayeroju *et al.*, 2025; du & Liao, 2025) explore energy-efficient technologies or climate-responsive design in isolation, there is a pressing need to analyze their integrative potential and the real-world socio-technical conditions for their implementation. This review addresses this gap by interrogating the recent literature (2020-2025) through three analytical lenses.

Through this critical review, the paper aims to move beyond descriptive cataloguing of technologies toward an analytical synthesis that reveals patterns, contradictions, and future directions for research and practice. It argues that achieving climate-resilient housing requires a systemic paradigm shift, from viewing buildings as static consumers to dynamic, adaptive, and productive nodes within local energy and ecological systems.

This paper is guided by three core objectives:

1. To critically examine passive and active architectural design strategies, including building form, envelope optimization, smart materials, and bioclimatic principles, employed for thermal resilience and energy efficiency in housing across varied climatic contexts.
2. To evaluate the role, integration pathways, and socio-technical

challenges of decentralized renewable energy systems (e.g., solar PV, hybrid mini-grids) in enhancing climate resilience, energy security, and decarbonization in residential settings, with a focus on vulnerable and off-grid communities.

3. To analyze the policy, governance, financial, and community-level dimensions that enable or constrain the transition to climate-resilient housing, identifying barriers and catalysts for mainstreaming adaptive and renewable energy solutions.

2.0 Methodology

This review adopts a systematic approach to identify, select, and critically analyze relevant academic literature on housing adaptation to climate change, with a focus on resilient architecture and renewable energy. The methodology was designed to ensure transparency, reproducibility, and comprehensive coverage of recent peer-reviewed knowledge.

2.1 Literature Search and Selection

The literature corpus was retrieved from the Scopus database, one of the largest curated abstract and citation databases of peer-reviewed literature. The search was conducted on January 20, 2026. The search strategy employed a structured string combining key terms related to climate adaptation, housing/architecture, and renewable energy within the document title, abstract, and keywords. The specific search string used was:

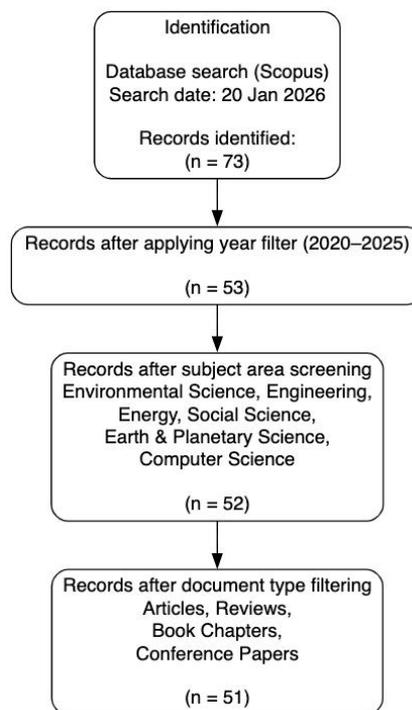
TITLE-ABS-KEY(("housing adaptation" OR "climate adaptation" OR "climate resilient housing" OR "resilient architecture" OR "climate adaptive buildings") AND (climate OR "climate change" OR resilience OR resilient) AND

(architect OR housing OR building* OR dwellings OR residence*) AND ("renewable energy" OR "solar energy" OR "wind energy" OR "green energy" OR "sustainable energy")*)

This initial search yielded 73 documents. To focus on the most contemporary research and innovations, the results were filtered to include publications from the last six years (2020-2025), resulting in 53 documents. To maintain relevance to the interdisciplinary yet

technically grounded nature of the topic, the subject areas were limited to Environmental Science, Engineering, Energy, Social Sciences, Earth and Planetary Sciences, and Computer Science, yielding 52 documents. Finally, the document types were restricted to Articles, Reviews, Book Chapters, and Conference Papers to ensure substantive scholarly contributions, resulting in the final corpus of 51 studies for analysis. This selection process is detailed in the PRISMA flow diagram (Figure 1).

Figure 1: PRISMA Flow Diagram of Literature Selection



2.2 Analytical Framework

The selected 51 studies were subjected to a critical analytical review rather than a descriptive summary. The analysis was structured around the three stated objectives. For each objective, studies were thematically grouped, and their findings, methodologies, and arguments were compared, contrasted, and synthesized. Particular attention was paid to identifying consensus, innovation, contradictions, and gaps in the literature. Analytical themes emerged inductively from

the literature, such as the shift from passive to dynamic envelopes, the centrality of solar energy in decentralization, and the policy-implementation gap. Tables and figures were constructed to synthesize key information (e.g., architectural strategies by climate, renewable energy applications) and to facilitate comparative analysis. This approach ensures the paper provides a synthesized, evaluative perspective on the state of knowledge, moving beyond a simple listing of previous work.

3.0 Critical Review of Resilient Architectural Design Strategies

The first line of defense in climate-resilient housing is the architectural design itself, which can significantly mediate external climatic pressures, reduce mechanical energy demand, and enhance occupant comfort and safety. The reviewed literature demonstrates a sophisticated evolution from traditional passive design to integrated, smart, and material-driven adaptive strategies.

3.1 Bioclimatic Design and Form Optimization

Fundamental to climate adaptation is the alignment of building form and orientation with local microclimates. This principle, long evident in vernacular architecture (Nakhaee, 2022; Sharif *et al.*, 2022), is being recalibrated using advanced simulation tools. Studies emphasize that optimal building geometry is highly climate-specific. For instance, Hong *et al.* (2022) found that in cold climates, an elongated rectangular plan (ratio 1:1.44) with a compact form minimized heat loss, whereas in hot climates, a more square plan was preferable to reduce east-west solar exposure. Similarly, Alabsi and Du (2025) argued for clustered building designs in hot-arid West Asian cities, demonstrating that strategic massing can enhance mutual shading and reduce cooling loads at the neighborhood scale, contributing to urban carbon neutrality.

Building orientation and the strategic placement of cores and atria are critical for controlling solar gain and facilitating natural ventilation. Jaisankar and Gupta (2025), in their pre-design analysis for high-rise buildings, highlighted that shape efficiency (minimizing exposed surface area) must be balanced with space efficiency and solar radiation management. Their work

underscores the necessity of conducting such analyses early in the design process to lock in resilience benefits. Furthermore, urban morphology at a larger scale significantly impacts residential resilience. Najian and Goudarzi (2025), using Computational Fluid Dynamics (CFD), showed that urban density and building configuration in hot-arid cities like Isfahan critically affect pedestrian-level wind flow, which is essential for natural ventilation and outdoor thermal comfort during heatwaves. Poorly planned density can suppress beneficial winds, exacerbating the Urban Heat Island (UHI) effect and increasing cooling energy demand.

3.2 Building Envelope Innovation and Adaptive Materials

The building envelope acts as a dynamic filter between interior and exterior environments. Innovations here are pivotal for resilience. Research highlights two key directions: high-performance static envelopes and dynamic, responsive facades. Static envelope advancements focus on superior insulation, thermal mass, and phase change materials (PCMs). Mistarihi *et al.* (2025), in their review for the UAE's net-zero ambitions, reported that enhanced building envelopes using phase change materials (PCMs) and high-reflectivity coatings could reduce cooling demand by 15-48%. Jaffar & Muthulingam (2025) experimentally demonstrated the effectiveness of macroencapsulated nano-enhanced PCMs (NePCMs) integrated into hollow concrete roofs in hot climates. Their 4% graphene nanoplatelet NePCM reduced indoor surface temperatures by an average of 9.6°C during peak sun, slashing cooling loads by 68% compared to a conventional roof.

The frontier of envelope research, however, lies in adaptability. The concept of the

Climate-Adaptive Building Envelope (CABE) is gaining traction. Oh *et al.* (2024) investigated dynamic photovoltaic integrated shading devices (PVSDs), finding that intelligently controlled, rotating PV panels could double solar energy harvest compared to static shading while simultaneously optimizing daylighting and reducing thermal gain. Sommese *et al.* (2022), in their review of biomimetic envelopes, proposed a "bio-adaptive model," advocating for materials and systems that self-regulate in response to environmental stimuli, much like plant adaptations. Kang *et al.* (2024) further connected envelope strategy to lifecycle carbon, showing that hybrid Cross-Laminated Timber (CLT) constructions with optimized envelopes could reduce greenhouse gas emissions by up to 36%, though their effectiveness varied significantly with climate, sometimes increasing cooling demand in warmer regions, a critical nuance for adaptation planning.

3.3 Smart Systems and AI-Driven Building Management

Resilience is increasingly defined by operational intelligence. The integration of Artificial Intelligence (AI) and the Internet of Things (IoT) transforms housing from a passive shell into a responsive organism. Woldegiyorgis *et al.* (2025) reviewed AI applications in building performance, identifying key domains: energy forecasting, HVAC optimization, and fault detection. They reported that AI-IoT integration could reduce emissions by 21%, with AI-optimized HVAC control saving up to 37% in energy.

Kim *et al.* (2025) provided a compelling case study in tropical Kuala Lumpur, where an AI-driven strategy using high-resolution (5-minute) data and Model Predictive Control (MPC) optimized AC use. Their system achieved a 12,871 kWh monthly energy saving, a 5,913 kg reduction in CO₂, and maintained comfort, directly addressing the "comfort-efficiency trade-off." Similarly, Magraoui *et al.* (2025) demonstrated a simpler smart system: roller shutter control based on solar radiation in Algeria. This low-tech smart intervention reduced heating energy consumption by up to 21% and improved thermal comfort in winter, proving that smart resilience can be achieved at varying levels of technological complexity. The overarching trend is toward predictive, rather than reactive, building management, enhancing both efficiency and resilience to variable weather patterns.

These AI and smart system interventions represent the operational and technological dimension of a holistic resilience strategy. When integrated with the fundamental architectural and material adaptations outlined in Table 1, such as optimized building form, high-performance envelopes, and passive design, they create a synergistic framework for climate-responsive housing. Table 1 synthesizes these key architectural adaptation strategies, categorizing them by primary climatic challenge and linking them to specific technologies and reported performance benefits.

Table 1: Synthesis of Key Architectural Adaptation Strategies by Climatic Challenge

Climatic Challenge	Primary Architectural Strategies	Key Technologies/Materials	Reported Performance Benefits	Selected References
Extreme Heat Cooling Demand	Compact form, minimized E-W exposure, shading, natural ventilation, high-albedo surfaces.	PCMs & NePCMs, reflective coatings, dynamic shading (PVSDs), insulated envelopes.	Cooling load reduction: 15-48% (Mistarihi <i>et al.</i> , 2025); Indoor temp. reduction: up to 9.6°C (Jaffar & Muthulingam, 2025).	Mistarihi <i>et al.</i> (2025); Jaffar Abass & Muthulingam (2025); Oh <i>et al.</i> (2024); Najian & Goudarzi (2025)
Cold Heating Demand	Elongated form (N-S), high insulation, thermal mass, air-tightness, solar gain maximization.	High-performance glazing, super-insulation, CLT, air-tight seals, passive solar design.	Primary energy consumption: 27-68 kWh/(m ² ·y) in Northern EU NZEBs (Borowski <i>et al.</i> , 2025); GHG reduction up to 36% with hybrid CLT (Kang <i>et al.</i> , 2024).	Hong <i>et al.</i> (2022); Borowski <i>et al.</i> (2025); Kang <i>et al.</i> (2024); Magraoui <i>et al.</i> (2025)
Humidity & Rainfall	Elevated structures, breathable envelopes, rainwater harvesting, moisture-resistant materials.	Permeable cladding, natural ventilation designs, raised foundations (stilt houses).	Disaster resilience (post-hurricane), water self-sufficiency.	García (2025); Pareti <i>et al.</i> (2022)
Urban Heat Island & Airflow	Strategic density, wind corridor planning, clustered designs, green infrastructure integration.	CFD modeling for layout optimization, green roofs/walls, permeable pavements.	Improved pedestrian wind comfort, microclimate cooling (up to 1.27°C from vegetation) (Han <i>et al.</i> , 2025).	Alabsi & Du (2025); Najian & Goudarzi (2025); Han <i>et al.</i> (2025); Bellomo & Colajanni (2025)
General Operational Efficiency	Integrated passive design, real-time monitoring, predictive control, adaptive systems.	AI & IoT platforms, MPC, BIM, smart meters, sensor networks.	Energy savings: 10-30% (Mistarihi <i>et al.</i> , 2025); up to 37% for HVAC (Woldegiyorgis <i>et al.</i> , 2025); peak shaving and cost savings.	Kim <i>et al.</i> (2025); Woldegiyorgis <i>et al.</i> (2025); Magraoui <i>et al.</i> (2025)

4.0 Renewable Energy Integration for Housing Resilience and Decarbonization

While architectural strategies reduce energy demand, the decarbonization and energy security of housing fundamentally depend on a shift to renewable energy (RE) sources. The literature strongly emphasizes decentralized or distributed RE systems as key to building climate resilience, particularly for ensuring

continuity of power during climate-induced grid failures and for serving underserved populations.

4.1 Decentralized Renewable Energy Systems as a Resilience Imperative

The vulnerability of centralized grids to extreme weather events, exemplified by Puerto Rico's collapse after Hurricane Maria (García, 2025; López-González, 2025), has

propelled decentralized renewable energy (DRE) to the forefront of resilience thinking. DRE systems, including rooftop solar PV, solar home systems, mini-grids, and small-scale wind or biomass, provide localized generation that can operate independently (in island mode) or interact with the main grid. Okesiji (2025) argues that DRE is a critical pathway to climate resilience in low-income regions, addressing energy poverty for over 733 million people while reducing reliance on fragile centralized infrastructure. Janta *et al.* (2024) formalize this in their energy resilience assessment framework, which expands traditional risk assessment to include "recoverability" and "adaptability," metrics for which DRE systems score highly by providing local energy buffers.

4.2 Solar Energy: The Central Pillar of Residential Decarbonization

Among RE options, solar photovoltaics (PV) are overwhelmingly dominant in the housing context due to their modularity, declining cost, and suitability for integration at the building scale. The literature explores various integration models:

- *Rooftop PV and Building-Integrated PV (BIPV)*: The most direct form of residential RE. Liu *et al.* (2023) discuss integrating PV with nature-based solutions (NBS) like green roofs, creating multifunctional spaces that generate energy, manage stormwater, and mitigate UHI. Slootweg *et al.* (2023), in a GIS study of Amsterdam, quantified the vast rooftop potential for PV, finding 55% of rooftops suitable, capable of powering households post-2030. Their work also highlights the spatial competition and synergy between PV and green roofs, with 42% of roofs

suitable for synergistic combined (EGR-PV) installations.

- *Community Solar and Energy Insurrection*: Beyond individual rooftops, community-scale solar projects are highlighted as models for resilience and energy justice. López-González (2025) documents Casa Pueblo in Puerto Rico, a community *autogestión* (self-management) organization that spearheaded an "energy insurrection" through community-owned solar projects. This model not only provides energy independence but also embodies a decolonial challenge to extractive energy systems, framing resilience as both technical and socio-political.
- *PV-Thermal Hybrid Systems*: For broader energy needs, hybrid systems are explored. Vallati *et al.* (2024) experimentally validated a system combining water-source heat pumps with photovoltaic-thermal (PVT) panels for social housing retrofit in Rome. The PVT panels provided 36% primary energy savings, demonstrating a viable pathway for deep energy retrofits in existing housing stock.

4.3 Hybrid Systems and Supporting Technologies

For full energy autonomy, especially in off-grid areas, hybrid renewable systems are essential. Okesiji (2025) cites cases like Kenya's solar-wind hybrid mini-grids. Bantelay *et al.* (2022) explore hydro-powered pumps for small-scale irrigation, a renewable solution for agricultural resilience that supports rural livelihoods. Furthermore, energy storage is the critical enabler of DRE resilience, allowing solar power generated during the day to be used at night or during

grid outages. While not the primary focus of every housing study, storage is implied as a necessary component of resilient RE systems (Zhou, 2023). The literature also points to the concept of housing as a *prosumer* node within a smart grid. Zhou (2023) envisions a future where distributed energy prosumers,

equipped with PV, storage, and electric vehicles, engage in peer-to-peer energy sharing, creating a resilient and flexible district energy network. This transforms housing from an energy sink into an active participant in grid stability.

Table 2: Applications and Considerations of Renewable Energy Solutions in Housing

RE Solution	Scale / Application	Key Resilience Benefits	Reported Challenges / Barriers	Authors
Rooftop Solar PV / BIPV	Individual homes, apartments.	Energy cost reduction, carbon mitigation, backup power (with storage), grid independence.	Upfront cost, regulatory hurdles (grid connection), roof suitability, need for storage for full resilience.	Slootweg <i>et al.</i> (2023); Liu <i>et al.</i> (2023); Oh <i>et al.</i> (2024)
Community Solar Microgrids	Neighborhoods, rural villages, multi-family complexes.	Enhanced reliability, collective ownership, economies of scale, stronger community resilience.	Complex governance, financing, technical maintenance, policy support often lacking.	López-González (2025); Okesiji (2025); Kwanhi <i>et al.</i> (2025)
Solar Home Systems (SHS)	Off-grid or low-income households.	Basic energy access (lighting, charging), displaces kerosene/diesel, improves health and productivity.	Affordability, quality of hardware, sustainable business/pay-as-you-go models.	Okesiji (2025)
Hybrid RE Systems (e.g., Solar-Wind, PVT)	Stand-alone homes, rural mini-grids, community facilities.	Higher reliability and capacity factor, meets diverse loads (power, heat, water pumping).	Higher system complexity and cost, requires sophisticated control systems.	Vallati <i>et al.</i> (2024); Bantelay <i>et al.</i> (2022); Okesiji (2025)
Integrated RE with Passive Design	Net-Zero Energy Buildings (NZEB), Passive Houses.	Drastically reduces net energy demand, enabling full or high penetration of on-site RE.	Requires holistic, integrated design from outset; performance gap in operation.	Borowski <i>et al.</i> (2025); Hong <i>et al.</i> (2022); Mistarihi <i>et al.</i> (2025)

5.0 Socio-Technical Dimensions: Policy, Governance, and Equity in Housing Adaptation

The technical potential of resilient architecture and renewable energy is necessary but insufficient for widespread transformation. The literature consistently reveals that socio-technical factors, policy,

finance, governance, capacity, and equity, are the primary determinants of successful implementation. This section critically analyzes these enabling and constraining dimensions.

5.1 The Policy-Implementation Gap and Governance Models

A recurrent theme is the disconnect between high-level climate commitments and on-the-ground housing adaptation. D'Onofrio *et al.* (2023) examine Joint Sustainable Energy and Climate Action Plans (SECAPs) in Italian municipalities, finding that while voluntary cooperation among small towns can pool resources and knowledge, success hinges on multi-level governance that connects local action with regional and national support. Iliina and Kohno (2024), analyzing Russia's smart city and energy transition policies, note that digitalization of housing utilities is a state priority, but comprehensive strategies linking this to deep decarbonization and climate adaptation remain underdeveloped.

The case of the UK Committee on Climate Change (CCC), reviewed by Lysack (2020), is presented as a best-practice model for independent oversight, policy accountability, and transparency. Its statutory role in advising on and monitoring carbon budgets has been instrumental in the UK's progress, notably in decarbonizing electricity. This contrasts with contexts where policy is fragmented or voluntary. The need for robust, enforceable building codes that mandate climate resilience features and renewable energy readiness is a clear implication from studies in diverse settings, from the UAE (Mistarihi *et al.*, 2025) to Ethiopia (Bantelay *et al.*, 2022).

5.2 Financing and Economic Barriers

Cost remains a formidable barrier. Anwar *et al.* (2021) show that while passive measures can significantly reduce energy demand in Pakistani homes, the upfront investment is a deterrent. For renewable energy, Okesiji (2025) identifies financial constraints as a

major hurdle to DRE adoption in low-income regions, calling for innovative mechanisms like green bonds, blended finance, and pay-as-you-go solar models. Kwanhi *et al.* (2025), in their review of climate philanthropy, argue that philanthropic funding can be a catalyst for RE transitions in Africa but must be strategically aligned with national policies and focus on building local capacity to be sustainable. The economic case for resilience is often long-term and involves avoided costs from disasters, which is difficult to translate into immediate investment decisions for homeowners or developers.

5.3 Equity, Community Agency, and Just Transitions

Perhaps the most critical dimension emerging from the literature is equity. Climate adaptation risks exacerbating existing inequalities if not deliberately managed. García (2025) notes that post-Hurricane Maria, Earthship-style autonomous housing in Puerto Rico faced barriers related to financing and regulatory approval, potentially limiting access to those with resources. López-González (2025) powerfully frames community-led solar in Puerto Rico as "re-existence," a decolonial practice asserting energy sovereignty against historical extractivism. This highlights resilience as not just a technical state but a social process rooted in community agency.

Albaddawi (2025), in a policy gap analysis in Jordan, finds that while women are mentioned in climate and development policies, concrete mechanisms for their economic empowerment through green energy entrepreneurship are lacking. Similarly, Campbell and Lester (2023) show

that climate-smart agriculture training in Jamaica must be tailored to local contexts and empower farmers with knowledge and resources. These studies underscore that successful housing adaptation requires participatory approaches that engage residents as active agents, not passive recipients, and that explicitly address gender, income, and ethnic disparities.

5.4 Knowledge Gaps and Capacity Building

A lack of technical capacity and localized data is a significant constraint. Pong *et al.*

(2025), surveying Asian farmers in California, found a high need for adaptation information but identified funding and regulatory complexity as major barriers, with a preference for hands-on workshops and farmer-to-farmer learning. This points to the importance of extension services and knowledge co-production. Alariyan *et al.* (2025) and Mohammed *et al.* (2023) stress the need for asset managers and utility companies to develop frameworks to assess climate vulnerability and integrate adaptation into maintenance and planning cycles, a form of institutional capacity building.

Table 3: Key Socio-Technical Barriers and Enablers for Resilient Housing

Dimension	Key Barriers	Potential Enablers & Strategies	Authors
Policy & Governance	Fragmented policies, lack of enforcement, voluntary measures, misalignment across government levels.	Independent oversight bodies (e.g., UK CCC), mandatory resilient building codes, integrated SECAPs, multilevel governance coordination.	Lysack (2020); D’Onofrio <i>et al.</i> (2023); Mistarihi <i>et al.</i> (2025)
Finance & Economics	High upfront capital costs, lack of accessible green financing, perceived risk, split incentives (renter/owner).	Green bonds, subsidized loans, on-bill financing, pay-as-you-go models, carbon pricing, resilience insurance products.	Okesiji (2025); Anwar <i>et al.</i> (2021); Kwanhi <i>et al.</i> (2025)
Equity & Justice	Risk of maladaptation benefiting the wealthy, lack of community voice, gender disparities in access and benefits.	Community-led design and ownership (e.g., energy co-ops), targeted subsidies for low-income households, gender-responsive policy, focus on energy sovereignty.	López-González (2025); Albaddawi (2025); García (2025)
Knowledge & Capacity	Lack of technical skills among builders/designers, insufficient localized climate data, low homeowner awareness.	Training and certification programs, development of decision-support tools (like the RBE method by Moro, 2025), knowledge-sharing platforms, robust extension services.	Pong <i>et al.</i> (2025); Moro (2025); Mohammed <i>et al.</i> (2023)
Social & Behavioral	Resistance to change, undervaluing long-term benefits, comfort vs. efficiency trade-offs, habitual energy use.	Demonstrations (case studies), real-time feedback systems (smart meters), adaptive comfort standards, social marketing campaigns.	Kim <i>et al.</i> (2025); Magraoui <i>et al.</i> (2025)

6.0 Discussion and Synthesis: Toward an Integrative Paradigm for Housing Resilience

This critical review synthesizes a rapidly evolving body of knowledge, revealing a clear trajectory from compartmentalized solutions toward an integrative paradigm for

housing resilience. The analysis across architectural strategies, renewable energy integration, and socio-technical dimensions yields several overarching insights and highlights critical gaps for future inquiry.

6.1 The Convergence of Passive and Active Intelligence

The distinction between passive design and active systems is blurring. The ideal resilient house is not merely a well-insulated box with solar panels on top. It is an integrated system where the building form and envelope (often with dynamic, adaptive properties) drastically reduce energy demand, while on-site renewable generation meets the remaining load. Intelligence, via AI and IoT, optimizes this interaction in real-time, balancing energy production, storage, consumption, and occupant comfort (Kim *et al.*, 2025; Woldegiyorgis *et al.*, 2025). This convergence demands interdisciplinary collaboration from the earliest design stages, as underscored by Jaisankar and Gupta (2025) and Borowski *et al.* (2025).

6.2 Decentralization as a Dual Strategy for Mitigation and Adaptation

The literature firmly positions decentralized renewable energy as a dual-purpose strategy. It is the primary tool for decarbonizing housing operations (mitigation) and a critical infrastructure for ensuring energy security during climate disruptions (adaptation) (Okesiji, 2025; Zhou, 2023). This reframes housing from a problem (a source of emissions) to part of the solution, a node in a resilient, distributed energy network. The cases of Puerto Rico (López-González, 2025; García, 2025) and studies on African mini-

grids (Okesiji, 2025) provide compelling evidence for this approach, particularly for communities on the frontlines of climate change and energy poverty.

6.3 The Primacy of the Socio-Technical Interface

The most consistent finding across the review is that technical solutions, no matter how sophisticated, are futile without conducive social, economic, and governance conditions. The "policy-implementation gap" (D'Onofrio *et al.*, 2023), financing hurdles (Anwar *et al.*, 2021), and equity concerns (Albaddawi, 2025) are repeatedly identified as the primary bottlenecks. Therefore, advancing housing resilience is less a problem of technical innovation, though that remains important, and more a challenge of institutional innovation, financial engineering, and inclusive governance. The bio-adaptive model of Sommese *et al.* (2022) must be complemented by a "governance-adaptive model" that learns and evolves from community practice.

6.4 Critical Gaps and Future Research Directions

Despite advancements, significant gaps persist:

1. *Lifecycle and Systems Thinking*: Few studies adopt a full lifecycle perspective that considers embodied carbon of advanced materials (like NePCMs or CLT) alongside operational savings (Kang *et al.*, 2024 is an exception). Future research must evaluate net resilience benefits across the building's life.

2. *Scalability in the Global South:* While many case studies focus on specific projects in Europe, North America, or Asia, scalable and affordable models for mass housing adaptation in rapidly urbanizing cities of the Global South are under-explored. The work on DRE (Okesiji, 2025) and passive design (Nakhaee Sharif *et al.*, 2022) provides a foundation that needs urgent upscaling.
3. *Resilience Metrics and Evaluation:* Janta *et al.* (2024) propose a framework, but standardized, widely accepted metrics for "housing resilience" that combine technical performance, energy security, and social outcomes are lacking. This hinders comparative analysis and policy evaluation.
4. *Integration of Blue-Green Infrastructure:* The role of nature-based solutions (green roofs, urban trees, water management) within housing plots and neighborhoods is recognized (Liu *et al.*, 2023; Han *et al.*, 2025) but often treated separately from building design. Research on fully integrated bio-climatic housing systems is needed.
5. *Politics of Resilience:* The critical lens applied by López-González (2025), viewing resilience as a contested, political process of "re-existence," is rare but essential. More research is needed on power dynamics, ownership models, and how resilience interventions can challenge or reinforce existing inequalities.

7.0 Conclusion

This review has critically examined the nexus of resilient architectural practices and renewable energy solutions in housing adaptation to climate change. It demonstrates that the field is moving from a focus on static efficiency toward dynamic adaptation, from centralized supply toward decentralized prosumer models, and from purely technical fixes toward integrated socio-technical systems.

The resilient house of the future, as depicted in the literature, is adaptive, intelligent, and productive. It leverages bioclimatic design and smart materials to maintain comfort with minimal energy input, generates its own renewable power, stores it for times of need, and interacts intelligently with the grid and its occupants. However, this vision will remain niche without addressing the formidable socio-technical barriers. Effective policy frameworks like the UK's CCC model, innovative and inclusive financing, community-centered governance, and a relentless focus on equity are the indispensable enablers. Ultimately, adapting housing to climate change is not just a technical construction challenge; it is a profound societal project that touches on energy justice, economic development, and the right to a safe and dignified home in a changing world. Future efforts must therefore be as rigorous in developing participatory processes and equitable policies as they are in perfecting photovoltaic cells or algorithmic controls. By synthesizing these diverse strands of research, this paper provides a consolidated foundation and a clear agenda for researchers, practitioners, and policymakers committed to building homes that are not only shelters from the storm but

active cornerstones of a resilient and sustainable future.

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Generative AI Statement

While AI-powered tools (specifically Grammarly) were used during the preparation of this manuscript to improve grammar, clarity, and punctuation, the critical thinking, literature synthesis, analytical framework, argument development, and overall intellectual content are solely the product of the author's work. The selection, interpretation, and evaluation of all referenced sources were conducted manually by the author.