

THE ROAD TO DECARBONIZING PAKISTAN'S CONSTRUCTION SECTOR

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Abstract

Pakistan's building sector consumes over 40% of national energy, yet low-carbon building (LCB) adoption remains critically low. This study identifies key barriers and develops a contextual framework to accelerate LCB implementation. A mixed-methods design was used: a survey of 153 construction professionals and semi-structured interviews with ten industry experts across major urban centers. Based on empirical evidence, the study proposes a Three-Pillar Low-Carbon Building Design (LCBD) Framework: (1) Policy and Regulatory Foundation (mandatory codes, financial incentives, institutional strengthening); (2) Technical Capacity Development (professional training, curriculum reform, knowledge sharing); and (3) Market Transformation (awareness campaigns, demonstration projects, supply chain development). Complementary outputs include passive design templates for 5 and 10 Marla houses, an Energy-to-Mortgage model to improve affordability, and a 10-year implementation roadmap. The study concludes that overcoming Pakistan's regulatory vacuum and capacity deficits requires coordinated action. With mandatory codes, green financing, and systemic educational reform, the construction sector can transition from a major carbon emitter to a cornerstone of sustainable development.

1. INTRODUCTION

The construction sector represents one of the most significant contributors to global greenhouse gas emissions, accounting for approximately 39% of total carbon emissions when operational and embodied carbon are combined [1], [2]. Buildings are responsible for 36% of global final energy consumption and 37% of energy-related CO₂ emissions [3], [4]. As urbanization accelerates globally, particularly in developing nations, the

environmental impact of the built environment continues to intensify [5], [6].

In Pakistan, the building sector consumes over 40% of national energy, with this proportion steadily increasing due to rapid urbanization and economic development [7]. The World Bank projects that Pakistan's urban population will reach 50% by 2030, creating unprecedented pressure on construction infrastructure and energy systems [8]. Pakistan's total energy consumption has grown at an average annual rate of 4.8% over

the past decade, with residential and commercial buildings representing the fastest-growing demand sectors [9].

Low-Carbon Buildings (LCBs) have emerged as a critical solution for mitigating climate change impacts from the construction sector. LCBs are defined as highly energy-efficient buildings that minimize carbon emissions through optimized design, efficient systems, and renewable energy integration [10]. The concept encompasses both operational carbon (from building use) and embodied carbon (from materials and construction processes) [11]. Despite the global momentum toward decarbonization, Pakistan's construction sector remains largely tethered to conventional, energy-intensive practices. Current literature extensively covers LCB adoption in developed economies, yet there is a profound lack of empirical data and contextualized implementation frameworks specifically tailored to Pakistan's unique socio-economic and climatic landscape. The problem is exacerbated by a regulatory vacuum where the absence of mandatory energy codes allows for the proliferation of inefficient building stock. This study addresses this gap by identifying localized barriers and proposing a framework that aligns sustainable construction with the practical realities of the Pakistani market.

This study aims to assess the current state of low-carbon building adoption in Pakistan's construction sector, identify and prioritize the key barriers hindering its implementation, analyze stakeholder perspectives on the associated challenges and opportunities, develop a contextualized implementation framework tailored to Pakistan's unique socio-economic, regulatory, and climatic conditions, and provide evidence-based policy recommendations to facilitate the transition toward low-carbon construction practices.

This research addresses critical gaps in understanding low-carbon building implementation in developing economies, with findings that hold significant theoretical and practical implications. The study informs policy development for Pakistan's construction sector by providing empirical evidence to support regulatory

reforms and incentive mechanisms. It offers actionable guidance for industry practitioners seeking to adopt low-carbon practices within prevailing technical and financial constraints. Furthermore, the findings contribute directly to Pakistan's climate commitments under the Paris Agreement by identifying pathways for emissions reduction in the rapidly growing building sector. The mixed-methods approach employed presents a replicable methodology for similar developing economies confronting analogous barriers to sustainable construction. Finally, this research establishes robust baseline data to enable future longitudinal studies tracking the evolution of low-carbon building adoption over time.

2. LITERATURE REVIEW

Low-Carbon Building Concepts and Evolution

The concept of low-carbon buildings has evolved significantly over the past two decades. Initially focused primarily on energy efficiency, the definition has expanded to encompass a holistic approach including embodied carbon, operational efficiency, and lifecycle impacts [12], [13], [14]. The International Energy Agency defines LCBs as buildings that dramatically reduce energy consumption through integrated design while minimizing carbon emissions throughout their lifecycle [10], [15], [16].

Key principles of low-carbon building design include:

- **Passive design strategies:** Optimizing building orientation, envelope, and natural ventilation to minimize active heating/cooling needs [17]
- **Energy efficiency:** High-performance building systems and appliances that reduce energy consumption [18]
- **Renewable energy integration:** On-site or off-site renewable energy to offset remaining energy demands [19]
- **Embodied carbon reduction:** Material selection and construction methods that minimize lifecycle carbon [11]
- **Smart building technologies:** Automated systems for optimized energy management [20]

Barriers to Low-Carbon Building Adoption

International literature identifies several common barriers to LCB adoption:

Economic barriers: Higher upfront costs, uncertain return on investment, limited access to financing, and lack of economic incentives [21], [22].

Regulatory barriers: Absence of mandatory building codes, weak enforcement mechanisms, fragmented policy frameworks, and bureaucratic complexities [32].

Technical barriers: Limited technical expertise, inadequate professional training, shortage of qualified practitioners, and insufficient research and development [25], [26].

Market barriers: Low consumer awareness, split incentive problems between developers and occupants, limited availability of sustainable materials, and inadequate performance verification systems [27], [28], [29], [30].

Institutional barriers: Resistance to change, fragmented industry structure, lack of coordination among stakeholders, and insufficient knowledge sharing platforms [31].

Core-Shell Passive Design Concept

In Pakistan's hot climate zones, the Core-Shell design approach is suggested as a climate-responsive architectural strategy to reduce cooling energy consumption in residential buildings. This idea divides the building into two thermally different zones. Stairwells, kitchens, bathrooms, and storage areas are examples of service and transitional spaces that make up the core zone. These spaces serve as a buffer against external heat gain because they are less susceptible to thermal discomfort. The shell zone, which surrounds this core, houses main living areas like lounges and bedrooms that are intended to optimize daylighting, natural ventilation, and thermal comfort.

By lowering direct solar heat transfer to occupied areas, this zoning strategy improves the building envelope's thermal performance and is consistent with accepted passive design principles that prioritize energy efficiency and envelope optimization [20]. The method directly validates the study's conclusions that passive design

techniques can dramatically lower a building's energy consumption.

Courtyard Passive Cooling (Southern California Desert Case)

A quantitative analysis of traditional courtyard home designs in the low desert of Southern California was conducted with respect to the natural thermal performance of courtyard areas under summertime peak temperature conditions using indoor and Courtyard environmental monitoring equipment to measure indoor and courtyard air temperature, relative humidity, and solar radiation. The results demonstrated that daytime courtyard air was consistently cooler than both directly adjoining spaces and the outdoor environment. In addition to the other research referenced in this study, the results of this study support findings of other studies that demonstrate courtyard design, specifically design attributes such as courtyard orientation, wall height, and open space, can effectively reduce heat gain and increase occupant comfort without the use of mechanical cooling in hot arid climates [1].

Evapo-Reflective Roof Cooling System

A passive roof system utilizing a combination of reflective materials and evaporative cooling was evaluated in an earlier study for areas with hot arid climates. The roof design consisted of a concrete ceiling, a water pool, and a reflective aluminum plate that utilized an air space for enhanced ambient cooling due to air convection. The simulated results indicated that the indoor air temperature was significantly cooler than conventional roof designs and the night time environment was cooled by means of natural ventilation (wind). The results of this research demonstrate the potential for using a combination of reflective elements, thermal mass, and evaporate techniques to obtain thermal comfort without the use of mechanical heating and cooling systems [2].

Retrofits for Historic Courtyard Housing

New studies have examined retrofitting historic courtyard houses of hot-arid climate with passive cooling strategies such as green roofs, shaded courtyards, and improved wall insulation.

Simulations show measurable improvement in thermal comfort and energy savings; however, purely passive techniques were not always able to achieve all thermal comfort criteria. Hybrid methods providing combinations of different passive techniques showed the best overall balance for providing indoor cooling, controlling humidity levels, and demonstrating that proper design and retrofitting can improve the performance of traditional buildings in harsh climates [3].

Simulation-Based Passive Cooling (Conference Study)

Conference proceedings have presented simulation studies examining passive cooling techniques for hot-arid climates including solar shading, optimization of thermal mass, and natural ventilation. By using parametric simulations, it has been demonstrated that there are several parameters that can greatly impact indoor temperatures, including wall insulation thickness, size of the courtyard, and shading geometry. These studies illustrate the need to utilize multiple techniques in order to maximize cooling performance in hot-arid climates with large daily temperature fluctuations [4].

3. RESEARCH METHODOLOGY

This study employs a mixed-methods research design, integrating quantitative and qualitative approaches to provide a comprehensive understanding of LCB implementation challenges in Pakistan [32]. The research design combines:

- Quantitative survey of construction professionals
- Qualitative interviews with industry experts
- Comprehensive literature review and policy analysis

This triangulation approach enhances validity and provides richer insights than single-method studies [33].

Data Collection Methods

This study employed a mixed-methods design combining quantitative surveys and qualitative interviews to examine low-carbon building implementation in Pakistan's construction sector.

A structured questionnaire was administered to 153 construction professionals (purposively sampled from major urban centers: Karachi 32%, Lahore 28%, Islamabad 21%, other 22%). Respondents included architects (28%), engineers (35%), project managers (22%), and developers (15%), with varying experience levels (<5 years: 25%; 5–10 years: 38%; >10 years: 37%). The survey covered demographics, current practices, barriers (five-point Likert scales), technical knowledge, and policy perspectives.

Complementarily, semi-structured interviews (45–90 min) were conducted with ten industry experts (≥ 10 years' experience), including senior architects (n=3), government officials (n=2), academic researchers (n=2), industry leaders (n=2), and an NGO representative (n=1), exploring barriers, enablers, stakeholder roles, policy recommendations, and future trends.

Quantitative data were analyzed using SPSS (descriptive statistics, ranking analysis, cross-tabulation; Cronbach's $\alpha = 0.87$). Qualitative interview transcripts underwent thematic analysis following Braun & Clarke's six-phase framework. Informed consent and confidentiality were ensured; participants could withdraw at any time. Limitations include geographic focus on urban centers, moderate sample size, self-report bias, and cross-sectional design.

4. Findings and Analysis

Current State of Low-Carbon Building Adoption

Survey results indicate critically low adoption of low-carbon building (LCB) practices in Pakistan's construction sector. Only 7% of respondents had worked on projects explicitly targeting low-carbon performance, while 73% followed conventional practices with minimal sustainability measures. Awareness levels were modest: 66% were "somewhat familiar" with LCB concepts, 21% had a "good understanding" of technical requirements, and 13% had limited or no knowledge.

Barriers to Low-Carbon Building Implementation

Respondents rated 15 potential barriers on 5-point Likert scales (1=Not a barrier, 5=Critical barrier). Table 1 presents the ranked results:

Table 1: Barriers to Low-Carbon Building Implementation

Barrier	No codes	No subsidies	High cost	Low awareness	Low knowledge	Labor shortage	Material scarcity	Unclear ROI	Weak financing	Weak enforcement	Complex certification	Split incentives	Resistance	Few demos	Low R&D
Rank	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mean Score	4.76	4.67	4.59	4.44	4.36	4.27	4.19	4.13	4.04	3.99	3.84	3.77	3.67	3.53	3.44
Std. Dev.	0.48	0.59	0.62	0.72	0.67	0.75	0.78	0.81	0.86	0.88	0.92	0.94	0.99	1.01	1.06

Regulatory and Policy Barriers

The absence of mandatory building codes was ranked as the most critical barrier. As one government official noted, without regulations, developers lack incentive to pursue energy efficiency. Pakistan's existing codes focus mainly on structural safety, with minimal energy performance requirements, creating a regulatory vacuum with no accountability for carbon emissions or energy consumption.

Economic and Financial Barriers

Three economic barriers ranked among the top concerns: lack of financial incentives, high upfront costs (15–25% increase for LCB features), and uncertain ROI. Emerging mechanisms like the Energy-to-Mortgage (E2M) model remain largely undeveloped in Pakistan. As one developer noted, banks do not recognize energy efficiency as adding property value, making the extra cost a pure expense.

Knowledge and Capacity Barriers

Limited awareness, insufficient technical knowledge, and lack of skilled workforce are major capacity gaps. Survey results show 68% of respondents received no formal training in sustainable construction, 72% reported no organizational professional development, and

81% had limited access to technical resources. As a university professor noted, architecture and engineering curricula barely cover sustainable design, leaving graduates without fundamental knowledge of energy-efficient building principles.

Stakeholder Perspectives on Implementation Challenges

Qualitative interviews revealed distinct implementation challenges across stakeholder groups. Government officials cited fragmented agency responsibilities, limited technical capacity, short-term political priorities, and insufficient budgets. Private sector professionals highlighted client unwillingness to pay sustainability premiums, competitive disadvantage of green buildings, short-term profit orientation, and risk aversion to unproven technologies. Academic experts stressed limited local research on climate-appropriate technologies, disconnects between research and industry practice, inadequate research funding, and the need for demonstration projects.

Empirical Validation of Low-Carbon Materials in Pakistan's Climate

A case study evaluated the thermal performance of agro-waste biocomposites as low-carbon insulation in Karachi's hot-humid climate. Steady-state

analysis compared a standard uninsulated 6-inch brick wall (baseline) with the same wall plus a 0.05 m interior layer of agricultural waste-based insulation. Boundary conditions assumed peak summer outdoor temperature of 36 °C, target indoor 24 °C ($\Delta T = 12$ °C), and an HVAC COP of 2.8. Results (based on Fourier’s law) demonstrated that adding biocomposite insulation significantly reduces conductive heat flux and cooling loads, thereby lowering operational energy demand. The accompanying table (Table 1) quantifies thermal conductivity (k-value), assembly U-value, peak heat

gain per m², and corresponding electrical power required to offset the load.

Even shorter version:

A steady-state thermal analysis in Karachi (36 °C outdoor, 24 °C indoor) shows that adding a 0.05 m layer of agro-waste biocomposite insulation to a standard brick wall substantially reduces conductive heat gain and cooling energy demand, as quantified by Fourier’s law and presented in Table 2.

Table 2: Comparative Thermal Analysis of 6-inch Brick vs. Bio-composite-Insulated Assemblies

Metric	Baseline: 6" Brick (No Insulation)	Plaster + palm fibers (6%)	Natural-fiber building materials	Plaster + wood shavings (15%)	Rice husk bio-composites (PBAT/PLA)	Date-palm surface fiber boards	Rice husk-cellulose boards	Cellulose-paper based (generic)	Rice-husk panels via pulping
k-value (W/m·K)	0.8 (Marin-Calvo et al., 2023)	0.19 (Rachedi & Kriker, 2025)	0.1345 (Majumder et al., 2021)	0.099 (Mohammed Badr et al., 2025)	0.08 (Muthuraj et al., 2019)	0.0445 (Raza et al., 2022)	0.0435 (Marin-Calvo et al., 2023)	0.04 (Marin-Calvo et al., 2023)	0.0395 (Rodríguez Neira et al., 2024)
Assembly U-Value (W/m ² ·K)	2.774	1.604	1.366	1.155	1.015	0.674	0.662	0.621	0.615
Peak Heat Gain (W/m ²)	33.29	19.25	16.39	13.86	12.18	8.09	7.95	7.45	7.38
AC Power Required (W/m ²)	11.89	6.87	5.85	4.95	4.35	2.89	2.84	2.66	2.64

Energy Reduction	0.00%	42.20%	-50.80%	-58.40%	63.40%	75.70%	76.10%	77.60%	-77.80%
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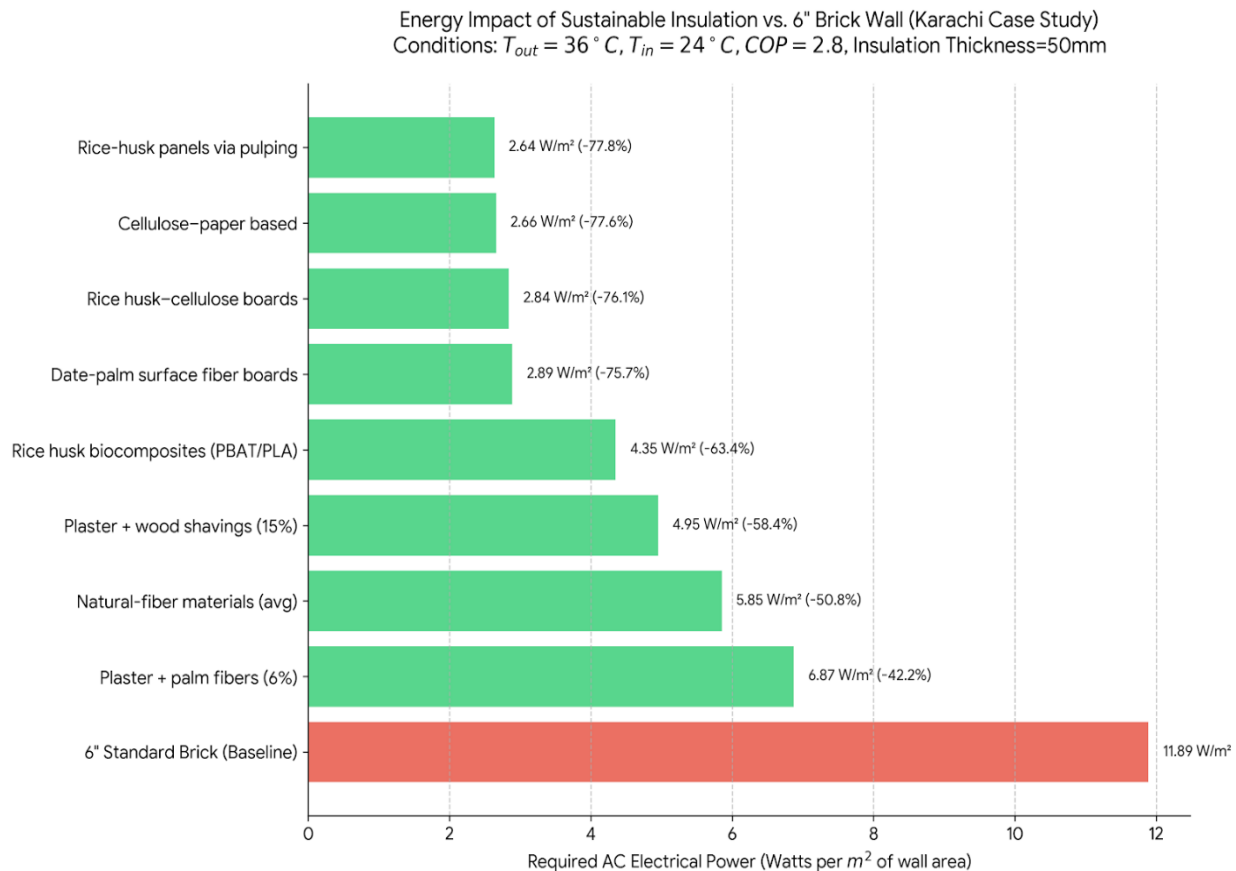


Fig 1. Graphical Representation of Energy Load Reduction

Figure 1 visually represents the required electrical power (W/m^2) to offset the heat gain through each wall assembly. Lower bars indicate higher performance and greater energy savings.

Discussion and Synthesis

Agro-waste bioc-omposites significantly reduce operational cooling energy in hot-humid climates. Even a 6% palm-fiber plaster cut conductive heat gain by 42.2%, while high-performance materials like rice-husk panels and date-palm fiber boards ($k \approx 0.04 W/m \cdot K$) reduced cooling energy by up to 77.8% with just 5 cm of insulation. For Karachi, this translates to lower electricity bills, reduced

peak grid demand, and less reliance on fossil-fuel plants, while also converting crop residues that otherwise cause smog into low-carbon building solutions.

Successful Implementation Factors

Respondents identified five key facilitators for sustainable building projects: strong client commitment (82%), early integration of sustainability goals (76%), access to technical expertise (71%), financial incentives (68%), and visible demonstration projects (63%). As one senior architect noted, sustainability is not significantly more expensive when considered

from the start, but becomes costly when added as an afterthought.

5. PROPOSED FRAMEWORK:

Based on empirical findings and literature synthesis, this study proposes a contextualized Three-Pillar Low-Carbon Building Design (LCBD) Framework specifically tailored for Pakistan's construction sector.

Framework Overview

The LCBD Framework consists of three interdependent pillars: (1) **Policy and Regulatory Foundation** (mandatory building codes, financial incentives, streamlined approvals); (2) **Technical Capacity Development** (professional training, curriculum enhancement, knowledge sharing); and (3) **Market Transformation** (awareness campaigns, demonstration projects, supply chain development).

Pillar 1: Policy and Regulatory Foundation

- Mandatory building codes - Phased implementation: voluntary with incentives (years 1-2), mandatory for public/large commercial projects (years 3-4), and all new construction (year 5+). Key elements include envelope thermal standards, HVAC/lighting/appliance efficiency, progressive renewable energy targets (10-30%), and dual compliance paths.
- Financial incentives - Direct support (capital subsidies of 10-20%, 5-year tax credits, accelerated depreciation), financing mechanisms (green mortgages at 2-3% below market, property tax rebates of 10-25%, revolving retrofit loan funds), and market instruments (feed-in tariffs, carbon pricing, certification fee waivers).
- Institutional strengthening - Establish a National Green Building Council, a Building Energy Efficiency Unit within the Ministry of Climate Change, provincial implementation agencies, and technical committees for local adaptation.

Pillar 2: Technical Capacity Development

- Professional training programs - Short-term: intensive workshops, certification programs, online CPD modules, and

train-of-trainers (target: 5,000 professionals in 3 years). Long-term: mandatory CPD for license renewal, specialized master's programs, and research fellowships.

- Educational curriculum enhancement - University level: mandatory sustainable design courses, interdisciplinary low-carbon studios, and dedicated research centers. Vocational level: green building skills training and certifications for specialized trades (e.g., solar installation, advanced insulation).
- Knowledge sharing and research - Establish a national building energy performance database, design guidelines for different climates, best-practice manuals with local cost data, research funding for context-specific solutions, and an annual conference/publication series.

Pillar 3: Market Transformation

- Awareness and demand creation - Multi-channel campaigns targeting developers (business case), building owners (cost/health benefits), and the public (environmental quality). Strategies include mass media, industry seminars, real estate platforms, and school programs.
- Demonstration projects - Public sector leadership (mandate low-carbon design for government buildings, retrofit flagships, publish performance data) plus competitive grants for innovative pilots. Target: 20 demonstration projects within 5 years, with open-house events and technical tours.
- Supply chain development - Domestic manufacturing incentives (insulation, glazing, solar), technology transfer partnerships, quality standards. Import facilitation (reduced tariffs, streamlined approvals, bulk procurement). Market infrastructure (product directory, testing facilities, distribution networks). A local supplier database is provided in Appendix A.

Implications for Mortgage Financing

The capitalization of energy savings has several implications for housing finance:

- Households residing in energy-efficient buildings can sustain higher mortgage repayments due to reduced operational costs.

- Financial institutions may consider increasing loan eligibility without proportionally increasing credit risk.
- The model introduces a mechanism through which energy efficiency contributes directly to asset affordability.

At a broader scale, this approach has the potential to facilitate the integration of sustainability considerations into mainstream housing finance systems.

Risk Mitigation for Financial Institutions

From a lender's perspective, the E2M model contributes to risk reduction in multiple ways:

Improved Repayment Capacity: Lower utility expenses increase the borrower's net disposable income, thereby enhancing the debt service coverage ratio and reducing the likelihood of default.

Predictability of Savings: Energy savings derived from passive design and efficient systems are relatively stable over time, providing a reliable basis for financial evaluation.

Enhanced Asset Value: Energy-efficient buildings typically exhibit improved market performance, including higher resale values and lower vacancy rates. These factors strengthen the quality of collateral and reduce long-term lending risk.

Empirical Evidence from Literature

Existing literature supports the economic viability of integrating energy efficiency into financial decision-making, particularly in developing economies:

- Studies indicate that although green buildings may involve higher initial costs, lifecycle savings can offset these premiums through reduced operational expenditure [30].
- Empirical evidence suggests that energy-efficient buildings often achieve higher asset values and improved market performance, enhancing their attractiveness as investments [31].
- Research on developing economies highlights the importance of financial innovation in overcoming barriers to sustainable construction adoption [33].
- Recent analyses emphasize that measurable economic returns and incentive

structures are critical drivers for the adoption of low-carbon building practices [14].

These findings collectively reinforce the rationale for incorporating energy savings into mortgage evaluation frameworks.

Policy and Implementation Considerations

Successful E2M implementation requires coordinated support: (1) green mortgage products with preferential rates tied to energy performance; (2) standardized energy performance certification to validate savings; (3) public-private risk sharing (e.g., government guarantees) to reduce lender risk; and (4) integration with the LCBD Framework to strengthen financial incentives and market transformation.

The Energy-to-Mortgage model demonstrates that reductions in household energy consumption can be translated into quantifiable financial value. A 20% decrease in utility expenditure can generate substantial long-term savings, which, when capitalized, enhance mortgage affordability and reduce lending risk.

In the context of Pakistan's construction sector, this model provides a practical mechanism to address one of the primary barriers to low-carbon building adoption—high upfront costs. By aligning economic incentives with sustainability objectives, the E2M approach offers a viable pathway for integrating energy-efficient design into mainstream housing finance.

Implementation Roadmap

The LCBD Framework requires phased implementation over 10 years:

Phase 1: Foundation Building (Years 1-3)

- Develop building codes and technical standards
- Establish institutional structures
- Launch pilot training programs
- Initiate demonstration projects

Phase 2: Scaling Up (Years 4-7)

- Implement mandatory codes for large buildings

- Expand training to reach 10,000+ professionals
- Activate financial incentive programs at scale
- Achieving 50+ demonstration projects

Phase 3: Market Transformation (Years 8-10)

- Universal code compliance for new construction
- Self-sustaining market for low-carbon buildings
- 30% of new construction meeting LCB standards
- Established domestic supply chains for sustainable materials

Application of Passive Design in Residential Buildings

This study suggests useful residential design templates for Pakistan, building on the passive design techniques covered in Section 2.5. For house typologies of five and ten marla, these templates convert theoretical ideas into climate-responsive solutions.

Passive Design Template for 5 Marla Houses

The 5 marla residential plot is an example of a constrained urban typology that calls for small-scale but efficient passive design interventions. In order to reduce solar heat gain from the western facade which has been found to be a major factor in indoor overheating in warm climates, the suggested template takes an East-West orientation

[41]. The building's length along the East-West axis improves indoor thermal conditions by reducing solar exposure.

Natural ventilation is achieved through well-placed openings that allow cross-ventilation in living spaces. A vertical ventilation shaft in the core zone improves air movement through the stack effect. Warm air rises and exits through high openings, which pulls cooler air into the building. This method greatly improves indoor air circulation without needing mechanical systems.

A key innovation in this design is the use of a simple wind catcher system, inspired by traditional Middle Eastern architecture. Located at the roof level, the wind catcher captures prevailing winds and directs them into indoor spaces, thus improving airflow and lowering indoor temperatures. This passive cooling method is well-known for its effectiveness in hot, dry climates and is supported by existing research on passive ventilation systems [20].

The building envelope further contributes to thermal performance through the use of high thermal mass materials such as masonry walls, which absorb heat during the day and release it at night, stabilizing indoor temperatures. Additionally, reflective roofing materials and external shading devices such as overhangs and louvers are employed to reduce solar heat gain. These combined strategies contribute to a substantial reduction in cooling energy demand, consistent with global trends in passive building performance [39].

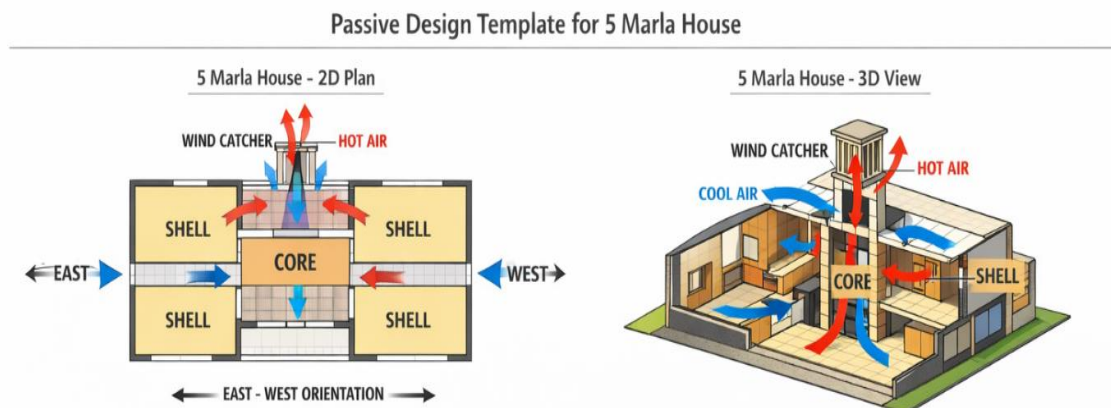


Fig.2 Passive Design Template for 5 Marla Houses

Passive Design Template for 10 Marla Houses

By utilizing a 10 marla residential plot as your base, there's much more room for flexible layout designs, and more opportunities for incorporating advanced, passive design techniques into the layout plan itself. One of the main objectives of this template is to have an internal courtyard (the internal courtyard serves to regulate the local, microclimatic conditions within the building) that will aid to facilitate air movement, natural daylighting and the shedding of heat [20],[41]. During the daytime, the courtyard acts as a thermal sink (absorbing heat), while at night the courtyard acts as a cooling mechanism (releasing heat), thereby increasing the potential to create comfortable indoor conditions [20].

The layout is organized based on a core-shell design, with a central core and habitable spaces surrounding it. This arrangement helps produce air movement similar to the movement of air through an exhaust fan [40]. To assist in creating

this air movement, a double height space in the building will create a greater stack effect than would occur with only habitable space; thus air will naturally rise and exit at the upper portions of the building while drawing in cooler outside air through openings located on the lower sides of the building [20],[39]. The vertical movement of air due to this natural effect greatly improves passive natural ventilation and consequently helps to lower indoor temperatures.

The design further incorporates airflow corridors that align with prevailing wind directions, allowing unobstructed movement of air across the building. This strategy enhances cross-ventilation and ensures consistent air exchange within interior spaces [41]. The combination of courtyard cooling, stack ventilation, and wind-driven airflow creates a highly efficient passive cooling system, making the 10 Marla template significantly more effective in reducing energy demand compared to smaller residential units [39].

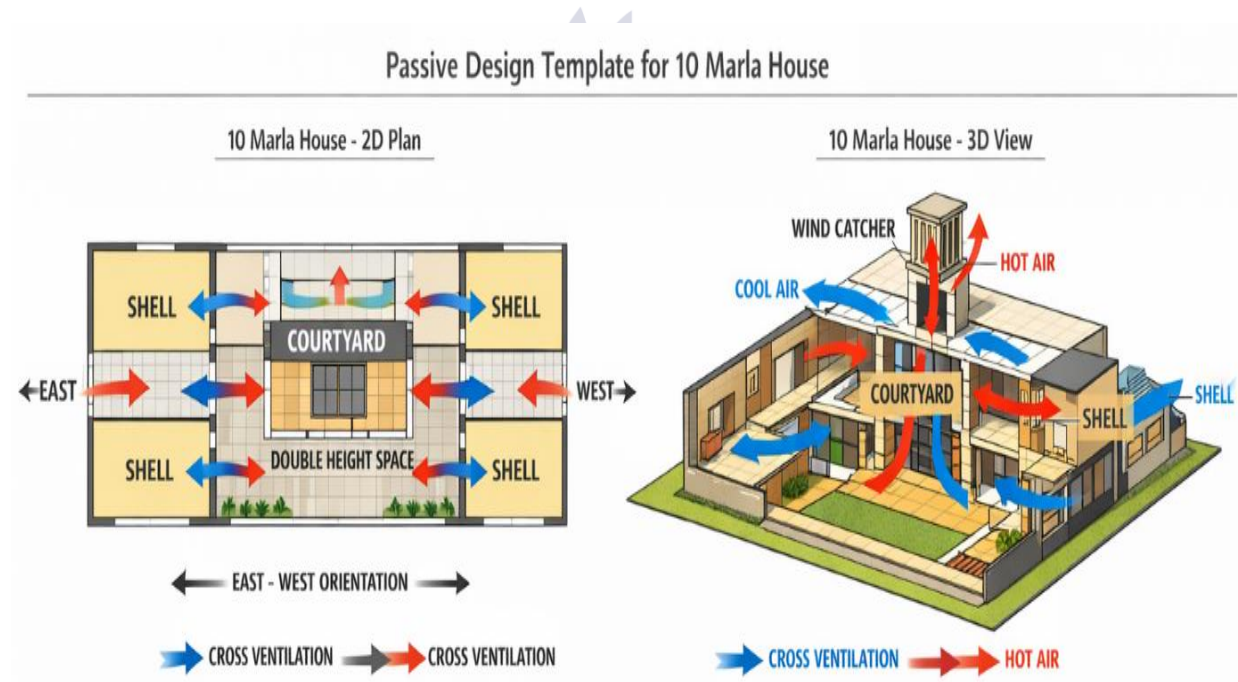


Fig.3 Passive Design Template for 10 Marla Houses

DISCUSSION

Interpretation of Findings

- Finding 1: Regulatory vacuum as primary barrier. The absence of mandatory building codes emerged as the single most critical barrier, with a mean score of 4.76/5. This finding aligns with international research demonstrating that mandatory regulations are essential drivers of market transformation. Without regulatory requirements, economic rationality favors conventional construction despite the documented long-term benefits of low-carbon approaches.
- Finding 2: Economic barriers are multifaceted. While high upfront costs received significant attention, the barrier analysis reveals that a lack of financial incentives (4.67) and uncertain ROI (4.13) are equally important. This suggests that addressing economic barriers requires both reducing costs through incentives and economies of scale and improving financial returns through energy savings and market recognition.
- Finding 3: Capacity gaps are pervasive. The finding that 68% of respondents received no formal training in sustainable construction indicates fundamental gaps in professional education. This capacity deficit cannot be addressed through short-term interventions alone but requires systemic changes to university curricula and continuing professional development systems.
- Finding 4: Technical feasibility is demonstrated. Analysis shows that passive design strategies can achieve 40–77% energy demand reduction in Pakistan's climate zones. This demonstrates that technical solutions, particularly localized agro-waste insulation, exist; the challenge is implementation and supply chain scale rather than technology availability.

6. CONCLUSION & RECOMMENDATIONS

Key Conclusions

LCB adoption in Pakistan is critically low (7% of projects). Systemic barriers span regulatory, economic, technical, and market domains, requiring coordinated interventions. Mandatory building codes are foundational. Technical

feasibility is confirmed (passive design can significantly reduce energy). Financial mechanisms must address upfront costs and limited green financing. The proposed three-pillar LCBD Framework offers integrated guidance for policy, capacity, and market transformation.

Recommendations for Industry

- **Developers:** Integrate sustainability early; use Energy-to-Mortgage (E2M) models.
- **Architects/Engineers:** Prioritize passive techniques (courtyards, wind catchers) and local bio-composites.
- **Financial institutions:** Offer green mortgages (2–3% below market); include energy savings in loan eligibility.

Recommendations for Future Research

This study opens several avenues for future research:

- Longitudinal studies tracking LCB adoption rates and actual post-occupancy performance over time.
- Detailed cost-benefit analysis of specific low-carbon technologies (e.g., solar-reflective paints vs. agro-waste panels) with localized financial modeling.
- Occupant behavior studies investigating how residents interact with passive design features in Pakistan's urban context.
- Life cycle assessment (LCA) of locally available construction materials to quantify the total carbon footprint from "cradle to grave".
- Comparative studies with other South Asian countries to identify transferable policy lessons and regional supply chain opportunities.

Final Remarks

The transition to low-carbon construction in Pakistan is an urgent necessity to meet national climate commitments and ensure future energy security. While the barriers are significant—ranging from a regulatory vacuum to pervasive capacity gaps—the technical feasibility of achieving up to 77% energy reduction through localized solutions provides a clear path forward. By adopting the proposed Three-Pillar LCBD Framework, Pakistan can transform its built

environment from a major carbon source into a cornerstone of sustainable development. Success will require the immediate synchronization of mandatory building codes, innovative green financing, and a systemic overhaul of professional technical education.

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