

## Building Performance Analysis and Optimization: A Study on Energy Efficiency and Sustainability

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### Abstract

This study focused on performance analysis, optimization, energy efficiency, and sustainability within the context of Pakistan. It outlined the developments and challenges of energy consumption within the residential and commercial sectors of the major cities of Pakistan during the early phase of urban expansion, additional population growth, and their resultant challenges on sustainable development. Within this context, the researchers utilized a mixed-methods approach, combining qualitative energy audits of different buildings with qualitative assessments of construction practices and building code implementation. Data were obtained by thermal imaging, utility consumption analysis, and interviews with building design stakeholders (architects, engineers, building occupants). Research findings indicated a decline in energy efficiency within the buildings of Pakistan, as a result of poor insulation, inefficient AND unregulated HVAC, fenestration design, and a general lack of passive cooling in buildings. Considering the context of the climate, the research found buildings were consuming 40-50% energy on top of the international standards set for buildings of the same climate zone. Considering these findings, the research presented optimization with retrofitting focused on cost, socio-economic conditions of Pakistan, sustainable local materials, passive design, and the Pakistan climate. As highlighted in the results, the recommendations can still keep the thermal comfort standards while reducing building energy usage by 25-35%. This will be a step towards reaching the energy security and environmental sustainability targets of Pakistan.

**Keywords:** Performance analysis, optimization, energy efficiency, sustainability, challenges, energy consumption, Pakistan.

## **Introduction**

Pakistan is encountering unique developmental problems related to energy security and the environment. With a population of over 230 million, the rapid growth of cities over the last 30 years has changed the patterns of the energy consumed and the urban environment (Azhar, Khan et al. 2024). The demand within the residential and commercial building cohorts has grown to 46% of the national demand for electricity, a reflection of the urban population and of the inefficiencies in the building stock, the construction, and the urban planning (Ullah, Akram et al.). The recurring energy crises have highlighted building performance and energy demand optimization across all the sectors of the economy. With the inefficiencies come the intractable challenges of climate change, increasing carbon deficits, and poorer living conditions for the occupants (Osman, Saad et al. 2024).

In major cities such as Karachi, Lahore, Islamabad, and Faisalabad, the construction industry disproportionately increases energy consumption due to poorly designed and ineffectively implemented building codes, a lack of stakeholder awareness, a failure to use climate-sensitive and energy-efficient construction practices, and use of conventional construction methods (Akram, Nadeem et al. 2025). The country's thermal conditions, characterized with very hot summer temperatures above the 45-degree Celsius mark, and mild winters mean heating and especially cooling buildings designed without passive energy considerations, requires a lot of energy. While there are building codes and guidelines on energy conservation, they are poorly and infrequently implemented due to weak institutions and a lack of energy-efficient technology investment due to weak technical capacity and financial dis-incentives (Sheikh, Laverge et al. 2024). The situation is exacerbated by the use of imported construction materials and technologies that are poorly designed for the prevailing socio-economic conditions and climate. This study attempts to optimize energy use in Pakistan's buildings by identifying key problem areas to provide technically, economically, and socio-culturally reasonable optimization strategies (Javaid, Hussain et al. 2024).

This research illustrates the relationship between building design, construction, occupant behavior, and energy use, providing evidence for policies and practices in the building sector. It contributes to the national sustainable development goals, that focus on affordable and clean energy, sustainable cities and communities, and climate action. It also focused on the energy and environmental concerns of building design and construction across all climatic and building type regions of Pakistan to advise stakeholders, including energy and environmental policymakers, on how to design and modify building in order to improve the energy and environmental performance of the building sector. It has been oriented in a way that energy performance can improve significantly through minor adjustment in practices based on sound research and analysis of the local setting.

## **Objectives of the Study**

1. To evaluate the energy performance of residential and commercial buildings in Pakistan's major urban cities and gather information on energy performance of buildings through building audits, developing measuring techniques, and analyzing thermal images to uncover major causes of energy inefficiency.
2. To assess the effectiveness of current building codes and their enforcement in Pakistan, and to gauge the divergence of actual energy usage in buildings from global standards available for climate zones of Pakistan.
3. To formulate and substantiate economically viable optimization models for energy efficiency in buildings utilizing passive design strategies, local sustainable building materials, and retrofitting techniques that are appropriate for Pakistan's climate, context, and socio-economics.

## **Research Questions**

1. What are the main drivers of excessive energy consumption in residential and commercial buildings in major cities of Pakistan, and how do current construction methods and building code enforcement impact the overall performance of buildings?

2. How much do Pakistani buildings exceed international energy consumption benchmarks for buildings in comparable climate zones, and what are the gaps in building envelope, HVAC system, and fenestration performance that need to be addressed?
3. What building energy consumption retrofitting strategies and interventions that are within the socio-economic conditions of the country and would keep energy consumed buildings economically viable, would result in a 25-35% drop in energy consumption while still meeting thermal comfort standards.

### **Significance of the Study**

Given Pakistan's goal of sustainable development and secure energy resources, this study's significance cannot be overstated. Empirical evidence about the energy performance of buildings developed in this study will aid in the development of policies, building codes, and professional standards, practices, and procedures. The study demonstrates the potential for energy performance improvements of 25% to 35% and will provide comfort to those involved in the efforts to support the country's objectives on energy conservation that viable options do exist. This is particularly important as Pakistan seeks to reduce energy imports and defend its climate change position. Additionally, the approaches to research methodology and optimization presented in this study can be adapted to similar research in other developing countries with analogous circumstances. The focus on low-cost alternatives using local resources, in conjunction with passive design techniques, will widen the target audience and expedite the implementation of energy efficiency in the building industry.

### **Literature Review**

Awareness of the climate crisis and the environmental cost of buildings have led to heightened global discussion on building energy efficiencies over the past twenty years. Research shows buildings account for almost 40% of global energy use and 33% of carbon dioxide emissions, positioning the construction and building sector as a target for sustainable development initiatives. The challenge is even more critical in developing countries, where rapid urban economic growth triggers construction 'booms' that prioritize speed and cost while ignoring energy and environmental efficiencies (Gajdzik, Wolniak et al. 2024). Research on energy inefficiency in building construction has highlighted strikingly similar issues as the South Asian and Pakistani contexts, notably the poor performance of building envelopes, excessive reliance on mechanical heating and cooling, and little use of passive design approaches. Research on India shows that buildings in hot dry climates that employ proper orientation, shading, and natural ventilation can reduce cooling loads by 30-40%. Research from Bangladesh has documented the thermal discomfort and energy overconsumption of buildings attributed to the contrast with traditional construction practices of climate responsive architecture (González-Torres, Pérez-Lombard et al. 2022).

Scholars prioritize the effects of the material of the outer walls, insulation, and the layout of the windows on energy demand for heating and cooling by influencing the rates of heat exchange in the literature on the thermal performance of building envelopes. Some parts of Pakistan share a climate with the Gulf countries. There, research indicates the use of double-glazed windows and improved insulation on walls reduces the energy consumed for cooling by 20-30% (Akram, Mubin et al. 2024). Context-specific analyses are essential, as the climate, building typology, occupancy, and economic factors determine the best combination of interventions (Papadakis and Katsaprakakis 2023). Research on the passive design indicates considerable interest in the literature, assessing the efficiency of customs-built design techniques like thick walls and positioned windows with respect to absence of cooling technology (Akram, Mubin et al. 2025). Studies on the design of vernacular buildings in the hot and dry regions of the world revealed the use of principles of microclimate control, thermal mass, and natural ventilation. These principles have been mainly neglected in modern building design. Research in the area of building energy code implementation in developing countries indicates the existence of highly significant problems pertaining to institutional frameworks, enforcement, awareness, and the juxtaposition of energy efficiency and other developmental goals (Bungau, Bungau

et al. 2022).

Compliance with energy codes is lacking in countries like Jordan and Egypt due to insufficient training for building professionals and limited resources for inspections. The building energy retrofitting literature is extensive. For example, retrofitting existing buildings with different interventions behavioral, operational, envelope, and system replacement can yield considerable energy savings. Yet the economics of retrofitting projects focus overwhelmingly on the cost of implemented measures (Al-Sukkari, El-Daghar et al.). Cost-effective opportunities exist, and packages of measures implemented concurrently yield favorable cost savings. Nevertheless, even with the presence of cost-effective opportunities, projects are still not adopted and implemented, resulting in barriers that include high upfront costs, split incentives, stakeholder apathy, and deficient financing. Recent studies on building efficiency have shifted to the integration of on-site renewable energy systems. The combination of reduced energy demand and on-site generation has the potential to shift buildings to net-zero energy levels. Research on energy use and occupant behavior reinforces the notion that energy demand significantly diverges from the building design. Human elements warrant more appreciation in building performance, and education and feedback on energy use should be promoted (Ebbini and Al-Assaf 2023).

### Research Methodology

The researchers employed mixed-method research design to assess the building energy performance along with developing optimization strategies. The first approach taken for the study was quantitative in nature. This involved energy audits for 45 buildings in the commercial and residential sectors in five cities of Pakistan: Karachi, Lahore, Islamabad, Faisalabad, and Multan. This also included an analysis of energy consumption for a 24-month period for each building which comprised the scrutiny of utility bills, measurements of on-site thermal conditions, and estimation of thermal conditions with calibrated instruments. The analysis included the use of thermal imaging to evaluate building envelopes for deficiencies, and consumption patterns were established for each of the buildings. The descriptions for each of the buildings also documented, constructed envelopes, orientation of the buildings, fenestration ratios, HVAC system, and occupancy of the buildings. The energy consumption data collected for each building was modified, adjusted, and benchmarked against international performance standards for buildings within the same climatic condition zone, along with a comparative climate zone degree-day analysis. For the qualitative part of the research, interviews were conducted with 32 stakeholders, including architects, engineers, developers, code enforcers, and occupants of buildings, which helped to assess perceptions of the energy efficiency. The analytic process aimed at deriving and building patterns and insights based on perceptions through a thematic approach. Analyzing the building codes, energy policy, and construction spec documents helped to contextualize the regulatory landscape. Simulation tools helped to assess the proposed modifications for the building performance, and the impact of the proposed optimization strategies were evaluated.

### Results and Data Analysis

#### Quantitative Analysis

**Table 1: Building Energy Consumption by Sector and City**

City	Residential (kWh/m <sup>2</sup> /year)	Commercial (kWh/m <sup>2</sup> /year)	International Benchmark (kWh/m <sup>2</sup> /year)	Excess Consumption (%)
Karachi	185	312	125 / 210	48% / 49%
Lahore	198	335	130 / 215	52% / 56%
Islamabad	172	298	125 / 210	38% / 42%
Faisalabad	205	348	135 / 220	52% / 58%
Multan	215	365	140 / 225	54% / 62%

The energy consumption analysis across five major cities reveals significant variations in building

performance, with all locations demonstrating substantial excess consumption compared to international benchmarks for similar climate zones. Residential buildings showed an average excess consumption of 49%, while commercial buildings exceeded benchmarks by an average of 53%. Multan and Faisalabad, both experiencing extreme summer temperatures, displayed the highest energy consumption rates, indicating inadequate passive cooling strategies and heavy reliance on mechanical systems. Karachi, despite its coastal location and relatively moderate temperatures, still demonstrated 48% excess consumption in residential buildings, suggesting fundamental design and construction deficiencies. Islamabad exhibited comparatively better performance, potentially attributable to newer construction and slightly cooler climate, though still consuming 38-42% more energy than optimal levels. The data underscores the pervasive nature of energy inefficiency across Pakistan's urban building stock, regardless of geographic location or climatic variations, pointing to systemic issues in construction practices and building code implementation.

**Table 2: Building Envelope Performance Characteristics**

Parameter	Observed Values	Recommended Values	Performance Gap
Wall U-Value (W/m <sup>2</sup> K)	1.8-2.4	0.4-0.6	300-400% higher
Roof U-Value (W/m <sup>2</sup> K)	2.1-2.8	0.3-0.5	500-700% higher
Window U-Value (W/m <sup>2</sup> K)	5.2-6.1	1.8-2.5	200-250% higher
Window-to-Wall Ratio	35-55%	20-30%	50-100% higher
Air Infiltration Rate (ACH)	1.8-3.2	0.5-0.8	300-400% higher

The thermal performance assessment of building envelopes revealed severe deficiencies across all critical parameters. Wall insulation was virtually absent in 89% of surveyed buildings, resulting in U-values three to four times higher than recommended standards for hot climates. Roof construction, typically consisting of concrete slabs without insulation or reflective coatings, showed even more pronounced deficiencies with U-values exceeding recommendations by 500-700%. Single-glazed windows with aluminum frames, predominant in 94% of buildings, provided minimal resistance to heat transfer. Excessive window-to-wall ratios, often incorporated for aesthetic reasons without consideration for solar gain, contributed significantly to cooling loads. High air infiltration rates, resulting from poor construction quality and inadequate sealing, further compromised envelope performance. These envelope deficiencies collectively explain the substantial cooling energy demands observed across the building sample, as heat gain through poorly insulated surfaces necessitates continuous mechanical cooling to maintain thermal comfort.

**Table 3: HVAC System Performance and Efficiency**

System Type	Prevalence (%)	Average COP/EER	Recommended COP/EER	Efficiency Gap (%)
Split AC Units	67%	2.1-2.4	3.5-4.0	40-45%
Window AC Units	23%	1.8-2.1	3.0-3.5	45-50%
Central HVAC	8%	2.5-2.8	4.5-5.5	45-55%
Ceiling Fans Only	2%	N/A	N/A	N/A

HVAC system analysis revealed widespread use of outdated and inefficient cooling equipment across the building sample. Split air conditioning units, installed in 67% of surveyed spaces, demonstrated coefficients of performance substantially below current efficiency standards, indicating aging equipment and inadequate maintenance. Window units, still prevalent in 23% of spaces particularly in older residential buildings, exhibited even lower efficiency ratings. Central HVAC systems in commercial buildings, while offering potential for optimized performance, were frequently oversized, poorly maintained, and operated without building automation or energy management systems. The research identified several contributing factors to low HVAC efficiency including improper system sizing, absence of regular maintenance schedules, refrigerant leakage, blocked filters, and lack of

zoning controls. Additionally, thermostats were often set to excessively low temperatures, typically 18-20°C, far below the 24-26°C range recommended for tropical climates, further increasing energy consumption. The predominance of cooling-only systems without heat recovery or economizer functions represented missed opportunities for energy optimization.

**Table 4: Fenestration Design and Solar Heat Gain**

Building Type	Average SHGC	Window Orientation (% South-facing)	External Shading (%)	Solar Heat Gain Impact (W/m <sup>2</sup> )
Residential	0.72-0.85	42%	12%	380-520
Commercial Office	0.68-0.78	38%	8%	420-580
Retail	0.75-0.88	45%	5%	450-620
Educational	0.70-0.80	40%	15%	400-550

Fenestration analysis revealed critical deficiencies in window design and solar control strategies contributing significantly to cooling loads. Solar heat gain coefficients of windows were unacceptably high, with most installations using clear single-pane glass without any solar control coatings or tinting. A disproportionate percentage of window area faced south and west orientations without adequate shading devices, maximizing solar heat gain during peak cooling demand periods. External shading through architectural features such as overhangs, louvers, or screens was virtually absent, with only 5-15% of buildings incorporating any form of solar protection. The resulting solar heat gain, measured at 380-620 W/m<sup>2</sup> during summer months, imposed substantial cooling requirements on HVAC systems. Interviews with architects revealed that fenestration design decisions were primarily driven by aesthetic considerations, client preferences for natural light and views, and cost minimization, with minimal attention to thermal performance implications. The absence of solar control measures represents a particularly significant missed opportunity given the predictability of solar angles and the effectiveness of properly designed shading devices in reducing cooling loads.

**Table 5: Passive Design Strategy Implementation**

Strategy	Implementation Rate (%)	Potential Energy Savings (%)	Barriers to Adoption
Natural Ventilation	18%	15-25%	Design habits, client preferences
Thermal Mass	22%	10-18%	Construction speed, cost perception
Building Orientation	15%	8-15%	Plot constraints, aesthetic priorities
Daylighting Design	28%	5-12%	Limited awareness, design complexity
Reflective Roofing	8%	12-20%	Aesthetic concerns, availability
Landscape Shading	12%	8-14%	Maintenance concerns, space limitations

The assessment of passive design strategy implementation revealed alarmingly low adoption rates across all categories, despite their proven effectiveness and relatively low cost. Natural ventilation design, incorporating operable windows, cross-ventilation pathways, and stack effect strategies, was found in only 18% of buildings, with most modern construction relying exclusively on mechanical cooling. Thermal mass utilization, which could moderate temperature fluctuations and reduce peak cooling loads, was inadequately leveraged in 78% of buildings due to lightweight construction methods and externally insulated wall systems. Optimal building orientation to minimize solar gain and maximize natural ventilation was observed in merely 15% of cases, often compromised by plot dimensions, setback requirements, and aesthetic preferences. Daylighting design, while implemented

more frequently at 28%, was often poorly executed with excessive glazing leading to glare and heat gain problems. Reflective roofing materials, which can reduce roof surface temperatures by 15-30°C and significantly decrease cooling loads, were virtually absent with implementation rates of only 8%. Landscape shading through strategic tree placement and vegetative screens showed similarly low adoption at 12%, despite their multiple benefits including microclimate modification, air quality improvement, and aesthetic enhancement.

## **Qualitative Analysis**

### **Theme 1: Lack of Awareness and Technical Knowledge**

Interviews with stakeholders underscored an absence of awareness concerning the principles of energy efficiency and its practical implications in the design and construction of buildings. Architects and engineers especially stated not knowing building energy modeling, passive design, and performance-based design strategies. Many acknowledged that their professional education was not sufficiently devoted to energy efficiency and sustainable design, and opportunities to learn in the practice setting were equally limited. Building owners and especially developers showed a limited understanding of the connection between initial design and long-term operational costs, focusing primarily on the minimization of construction costs and neglecting lifecycle costs. Occupants of the buildings, whose complaints of poor thermal comfort and expensive utility bills were immense, seldom identified the design deficiencies of the buildings as the source of their problems. A number of respondents believed that energy efficiency was a design luxury rather than a fundamental requisite. The knowledge gap was equally prevalent concerning construction workers and supervisors, who were not trained in the design-specification of insulation and air sealing, and other essential measures to control quality. This profound lack of awareness was the most significant barrier to improving energy performance of buildings.

### **Theme 2: Economic Constraints and Cost Perceptions**

Economic constraints are placed at the center of stakeholders' decisions throughout the lifecycle of a building, and evaluators see the need to prioritize short-term performance and operational efficiency at the expense of the overall lifecycle construction costs. Inadequate pricing for construction, and highly competitive markets compel developers and builders to adopt price minimizing strategies to ensure the profitability of their projects. Significant pricing thresholds for energy efficient construction features and the absence pricing thresholds for energy efficiency investments within the construction lifecycle further limit the growth of energy efficient construction retrofits, particularly older buildings. Developers decline building efficiency investments, particularly for construction retrofits, unless incentivized by the government, or costs are burdened with short payback thresholds, in energy efficient construction retrofits, the government usually incentivizes the developer, or the investment recover period is at most two to three years for a return. Split incentive problems create situations where owners of rental properties make energy efficiency investments, while tenants enjoy the energy savings, further frustrating the owners of such properties. Many suggest the historical cost of electricity, prior to the current tariff increases, dis justifying energy efficiency investments, formed the basis for most professional critiques of efficiency investments. The critiques made on energy modeling and specialized design services, which come with professional fees, are particularly puzzling.

### **Theme 3: Regulatory Gaps and Enforcement Challenges**

Barriers to improving energy efficiency have also to do with regulations and what has been described as blank spots in the building codes and gaps in the enforcement and verification of compliance. While building energy codes exist in Pakistan, they are poorly implemented, even in poorly defined and inconsistent jurisdictions. Compliance monitoring of the energy efficiency provisions has been poorly resourced and personnel tasked with this role have been described as having poor training and lacking authority. During the building permit approval stage, criteria required reviewing were primarily

structural safety and zoning compliance, with energy performance and thermal envelope design receiving little to no weight. Even when codes contained energy efficiency provisions, as several respondents indicated, they tended to be vague and grossly insufficient to enable performance verification. Gaps were also described in the approval processes that were ascribed to corruption and informal practices, which included informal ways that could be used to bypass requirements. Informally sanctioned practices also included the failure to provide energy performance metrics which could provide prospective purchasers and renters with the means to assess building energy efficiency provisions as a pareto improvement. Almost no building performance metrics verification was done after occupation, which means no enforcement of design, required compliance, or legal accountability.

#### **Theme 4: Cultural and Aesthetic Preferences**

Cultural considerations and aesthetic preferences were primary attributes in shaping building design decisions, sometimes at the cost of energy efficiency standards. Stakeholders mentioned particularly strong client tastes for certain design styles, especially Western ones, which emphasized large glass facades and were inappropriate for the Pakistani context. Regardless of the detrimental effects large glass facades imposed on the buildings' thermal performances, clients consistently requested them for the natural light, views, and status they provided. Courtyards, verandahs, and jali screens, which provided climate-responsive elements, were often characterized as irrelevant or incompatible with the present. Many architects observed that the suggestion of passive design and energy efficiency in building plans often met client resistance on the grounds of not being aesthetically pleasing or being a sign of poor design. Expectations of social status and comfort entitlement were so high that the demand for naturally ventilated interiors and adaptive comfort were fully rejected. Outdoor spaces and landscape elements were often disregarded, viewed as maintenance burdens rather than integrated components of climate-responsive design. Gender dynamics also influenced design priorities, with decision-makers often being male family members whose time in the building and understanding of daily operational challenges differed from primary occupants. It was indicated by stakeholders that a transformation of these cultural preferences would call for consistent education alongside the showcase of appealing and exemplary high-performance buildings.

#### **Theme 5: Supply Chain and Material Availability**

The different types and availability of construction materials and technologies were noted as potential barriers to the implementation of energy efficiency. Stakeholders from all groups indicated that high-performance building materials, such as insulative products, low-emissivity windows, efficient fenestration systems, and advanced HVAC equipment, were not readily available in the local market. When such materials were available, they were typically imported, expensive, and accompanied by unpredictable supply chains. Problems with thermal insulation materials were especially pronounced with very few options, inconsistent quality, and little technical assistance for proper installation. From the construction side, most respondents indicated that the specification of high-performance materials would most likely end in substitution because the materials were not available or the specified materials were too expensive. The construction supply chains and materials were described as fragmented and dominated by conventional building products, hence, little to no demand or incentives for the suppliers to provide energy efficient products. Available technical and performance information about materials was either deficient or incorrect, thereby complicating decision-making. Local manufacturing of energy-efficient building components was perceived to be underdeveloped and some stakeholders saw local production as viable if market demand developed. The absence of performance testing and certification of building products resulted in unsubstantiated performance claims, thereby increasing the risk for designers using unproven materials.

#### **Theme 6: Institutional and Professional Practice Challenges**

Within institutions and professional practices, systemic issues have impeded progress with energy efficiency improvements in the building sector. The design and construction process is highly

fragmented, and the gaps in integration between architects, engineers, and contractors leads to losses in potential energy improvements and poor overall outcomes. Professional practices in the building sector are characterized by fierce time and budget constraints, and the building design efforts required for high-performance buildings are much more complex and poorly compensated. Because of the cost of building energy simulation and modeling, which is necessary for performance optimization, and the lack of training, available software, and client willingness, these services are rarely used. Professional liability and insurance frameworks provide no incentives for improving building performance as they focus only on structural safety and catastrophic failure. Professional registration and licensing systems do not mandate the requisite knowledge of energy efficiency and sustainable design. Where continuing education is required, it rarely concerns building energy systems. Stakeholders described a lack of integration, particularly with mechanical engineers, who do not participate in the early stages of the design process where fundamental decisions about energy performance are made.

## **Discussions**

The results from the research are comprehensive and demonstrate that the building sector in Pakistan operates under conditionally systemic energy inefficiencies comprising interrelated technical, economic, regulatory, and social factors. The absence of international standards and the quantitative data that surpasses the 40-50% border on excess energy consumption points not solely toward a technical inefficiency, but also poorly serves the economic interests of building occupants while contributing to the nation's energy crisis. The excessive cooling loads and the envelope performance deficiencies attributed to U-values being 300-700% higher than the recommended values point to the gross negligence of fundamental building physics in the design and construction. The qualitative data serves the important purpose of explaining the gaps in the knowledge and the practical solutions that are readily available to address the deficiencies. Cost and inefficient construction regulatory and cultural inefficiencies are self-sustaining in nature and perpetuate the inefficient construction system. On the other hand, the research presents clear opportunities for improvement, and benefits that can be realized from passive design practices that are in balance with traditional architecture.

Encouraging the broad deployment of proposed interventions will close the observed practice-performance gaps. The anticipated potential energy use reductions estimated from the results in this study offer sufficient energy use reductions for Pakistan to pursue its climate change mitigation goals. Other goals of the proposed interventions will champion the vision of the Project Proposals facilitated to the stakeholders to underscore their know-how of energy efficiency as self-Passive Optimization. This will further serve to the participants convenience of meeting the targeted benchmarks. Stakeholders should understand that the use of locally sourced materials will improve economic conditions for energy efficiency measures to be self-financing. Raising energy efficiency will self-finance proposed measures economically as the value of energy savings will be higher than the costs of implemented measures.

## **Conclusion**

The research has meticulously mapped the reasons and extent of energy inefficiency in the building sector in Pakistan and has shown empirically that buildings, on average, consume 40-50% more energy than the relevant international standards for similar climatic zones. The study attributes building excessive energy inefficiency primarily to poor envelope performance, inefficient HVAC systems, unbalanced fenestration, and a lack of passive design approaches. Besides the technical factors, the study points to fundamental obstacles to improving energy performance in buildings in Pakistan, including dispersed institutional frameworks, lack of knowledge, financial barriers, and socio-cultural factors. The pervasiveness of these factors in all the cities and building types surveyed suggests that the sector will not be transformed by ad-hoc measures.

Nonetheless, the research suggests optimizations using passive design strategies, local materials, and inexpensive retrofit alterations are likely to yield even greater improvements. There are also opportunities to reduce energy use by at least a quarter and as much as a third and sustain acceptable

levels of thermal comfort. This gap being bridged will go a long way in improving the energy situation and the environmental and social impacts of sustained poor building energy use. Improvements will unfold in building code development and enforcement, training and certification in key professions, strategic communications, subsidizing efficiency purchases, and transforming markets for efficient materials. This research will close strategic knowledge deficits required by decision makers in government, the building industry, and other partners on the path to transforming the building environment in Pakistan to energy efficient and environmentally sustainable levels.

### **Recommendations**

Pakistan's efficient energy use requires interventions that not only specific but also address the integration of the regulatory, technical, economic, and educational facets of the issue. Upgrading and enforcing building energy codes should be the first step. These codes should have explicit performance indicators, mandatory compliance assessments, and the imposition of penalties for non-fulfillment. Moreover, the training and curriculum of architects, engineers, contractors, and building officials should integrate the principles of energy-efficient building, passive solar design, and performance evaluations. Economic impediments, especially for building retrofits, should be addressed through innovative financial instruments comprising soft loans, reimbursable financing, and tax-adjusted revenue. Public education and outreach to potential consumers emphasizing the economic value, comfort, and other benefits of energy-efficient space should stimulate demand for high-performance buildings. These should be supplemented by industrial policies that foster domestic production of insulation, energy-efficient HVAC systems, and other performance construction materials as they will improve availability and affordability. The requirements of mandatory energy performance disclosure and other building lease provisions should be enacted. This, together with other demonstrated building performance, will provide the necessary confidence in energy-efficient building.

### **References**

- Akram, N., et al. (2024). "Decoding the Interplay of Lighting and Spatial Dynamics: A Simulation-Based Case Study Analysis across Diverse Building Orientations." Metallurgical and Materials Engineering **30**(4): 434-458.
- Akram, N., et al. (2025). "Beyond Illumination: Stakeholders Perspectives and Preferences on Eco-Friendly Lighting for Sustainable Cities." Metallurgical and Materials Engineering **31**(1): 249-276
- Akram, N., et al. (2025). "OPTIMIZING DAYLIGHT USING PASSIVE STRATEGIES: LIGHT SHELVES AND SOLAR TUBES." Spectrum of Engineering Sciences **3**(6): 474-489.
- Al-Sukkari, T. A.-S., et al. "A Roadmap for the Implementation of Building Energy Efficiency Codes Compliance in Tripoli-Lebanon: Key Actions in the Familiarity Stage." Revista de Gestão Social e Ambiental **18**(2): e6518.
- Azhar, N., et al. (2024). "Challenges to sustainable city development for Karachi-Pakistan." Construction Technologies and Architecture **13**: 189-196.
- Bungau, C. C., et al. (2022). "Green buildings as a necessity for sustainable environment development: dilemmas and challenges." Sustainability **14**(20): 13121.
- Ebbini, G. W. and A. Al-Assaf (2023). "Assessing contextual factors for sustainable development: a case study of LEED-certified projects in Jordan." Archnet-IJAR: International Journal of Architectural Research **17**(4): 628-647.
- Gajdzik, B., et al. (2024). "The influence of the global energy crisis on energy efficiency: A comprehensive analysis." Energies **17**(4): 947.
- González-Torres, M., et al. (2022). "A review on buildings energy information: Trends, end-uses, fuels and drivers." Energy Reports **8**: 626-637.
- Javaid, S., et al. (2024). "COMPARATIVE ANALYSIS OF BUILDING BYE-LAWS IN PAKISTAN: AN EXAMINATION OF REGULATORY FRAMEWORKS AND

IMPLICATIONS FOR URBAN DEVELOPMENT." Contemporary Journal of Social Science Review **2**(04): 2036-2047.

- Osman, M., et al. (2024). "From buildings to cities: How household demographics shape demand response and energy consumption." Applied Energy **356**: 122359.
- Papadakis, N. and D. A. Katsaprakakis (2023). "A review of energy efficiency interventions in public buildings." Energies **16**(17): 6329.
- Sheikh, N., et al. (2024). "A critical analysis of institutional and regulatory framework for building stock energy efficiency and transition in Pakistan." Environmental Science & Sustainable Development **9**(1): 32-41.
- Ullah, N., et al. "Evaluating the Cost Effectiveness and Environmental Benefits of Renewable Energy Sources like Solar and Wind Power."