INNOVATION AND SUSTAINABILITY
Volume 6, No. 2. 2026
ISSN 2786-5940, e-ISSN 2786-5959
Received: 24.12.2025; Revised: 29.05.2026; Accepted: 25.06.2026; Published: 10.07.2026
Journal homepage: https://inns.com.ua/en

UDC 330.341.1:620.9
DOI: 10.31649/vis/2.2026.61

The impact of energy-efficient architecture as a driver of economic innovation and fiscal resilience in Ghana

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Abstract. This study aimed to investigate energy-efficient architectural design as a strategic instrument of economic policy and innovation, repositioning it to address Ghana's energy crisis by driving economic innovation and fiscal resilience within the building sector. The survey of 120 registered architects in Ghana (quantitative survey) produced 72 valid responses (60.0% response rate). The methods applied included descriptive statistics, Pearson correlation, multiple linear regression and principal component analysis. Factor analysis indicated that there were two main innovation themes Building Envelope/Orientation (64.4% of variance) and Site Condition decisions (9.2% more variance) with good scale reliability (Cronbachs 0.90). The multi-dimensional outcome construct was confirmed with energy performance items loading on one factor, which explained 80.5% of variance. Five predictors of energy performance were identified by regression, which accounted 81.7% of the variance of energy performance; with passive solar ($\beta = 0.510$), natural ventilation ($\beta = 0.373$), site temperature ($\beta = 0.315$), daylighting ($\beta = 0.284$), and site shading ($\beta = = 0.175$) for a standardised regression coefficient. The main barriers are economic and informational: absence of public knowledge (mean = 3.20/4), and client budget (mean = 3.00/4), which are considered to be high barriers. Key conclusions showed that design innovations have the potential to save 25-50 per cent of energy loads in buildings and are also related to productivity of labour, 5-15 per cent. Scenario analysis projected that, with widespread implementation, annual economic benefits would reach 150-300 million dollars, comprising direct fiscal savings (25-50 million), productivity enhancement (15-30 million), green construction investment mobilised (100-200 million), and reduced fuel imports (10-20 million) offsetting 7-13 per cent of the yearly energy deficit

Keywords: sustainable development; productivity gains; green investment; climate-responsive planning; fiscal policy

Introduction

Ghana's persistent and deepening energy crisis represents one of the most significant threats to national economic stability, manifesting not merely as a technical shortfall i n generation capacity but, more fundamentally, as a structural impediment to productivity, public expenditure management, and long-term development. Consequently,

Suggested Citation:
Baabereyir, R.B., Sheitu, A., & Edmund, B. (2026). The impact of energy-efficient architecture as a driver of economic innovation and fiscal resilience in Ghana. *Innovation and Sustainability*, 6(2), 61-73. doi: 10.31649/vis/2.2026.61.

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the cyclical nature of power outages, colloquially termed "dumsor" has disrupted industrial activity, undermined business confidence, and imposed recurrent fiscal burdens on an already strained public budget. In response, policy responses have historically concentrated on expanding supply-side infrastructure, investing heavily in thermal generation and pursuing renewable energy targets; however, these efforts have consistently lagged behind escalating demand, thereby exposing the limitations of a purely supply-oriented approach. Within this context, the building sector emerges as a critical yet underutilised point of intervention.

The ongoing energy crisis in Ghana is causing instability in the economic condition of the country, not as a technical inadequacy, but as a structural hindrance to productivity and fiscal governance. It has led to the existence of electricity sector debt in excess of GH 80 billion (US 5.6 billion) estimated to rise to over US 9 billion by 2026 with cyclical power outages (dumsor) disrupting most industries, undermining business confidence, and plunging the country into recurrent fiscal burdens (Asmah, 2025; Lighting up Accra…, 2025). Nevertheless, the responses have been on supply-side infrastructure expansion but this has failed to keep pace with the rising demand revealing the shortcomings of supply-only-oriented policy. Nevertheless, the building sector as a large electricity user, presents a very important, yet under-tapped demand-side intervention. According to the estimates of the World Bank Group (2025), every dollar spent on energy efficiency will give the US government a return of US 3-5, saving their money. But this potential has not been exploited due to disjointed regulations, inadequate technical integration, and the view of efficiency as an engineering, but not a strategic, economic issue. There are no enforced efficiency requirements in building regulations, so architectural design choices, which shape the long-term energy use, are rarely considered in macroeconomic terms (Built environment critical…, 2024). This alienation of technical practice and economic policy is the main issue: the systematic underestimation of energy-efficient architecture as a source of fiscal resiliency.

Ministry of Finance of Ghana (2025) promoted changes in demand without reasoning to the construction of buildings. G. Tettey *et al.* (2025) also found policy incoherence in renewable transition, but did not consider building codes. Clean Air Task Force (2025), once emphasised the demand-side urgency without quantifying the level of building-level efficiency input. S. Owusu-Mante (2025) analysed the landscape of Ghana's renewable energy transition, concentrating on the creation of the Ministry of Energy and Green Transition as a policy signal. The scientist concluded that institutional coordination remains weak, with disjointed efforts across ministries and limited integration of green skills development, local material supply chains, and building regulations into a coherent strategy. Greater focus was on renewable barriers, as G. James *et al.* (2025) analysed them, and the Energy Commission (2025) demanded increased enforcement of efficiency. The International Energy Agency (2025) worldwide affirmed that efficiency programmes have economic benefits. E. Ochedi & A. Taki (2022) developed a framework approach to energy-efficient residential building design in Nigeria, identifying passive solar strategies, natural ventilation, and site-responsive design as critical interventions in tropical climates. The authors concluded that systematic application of these principles can yield significant reductions in cooling loads and operational energy consumption. J. Allen *et al.* (2022) associated indoor quality with a 5-15% productivity increase but in high-income nations only. The fact that the Ghana has created the Ministry of Energy & Green Transition indicates that this connection has been acknowledged within its policies.

Nevertheless, there is a very big discrepancy between the technical architectural solutions and their expression in the form of conscious economic policy. To empirically determine and measure the effect of architect's design decisions that are energy-efficient (EED) on the energy performance (EP) of buildings in Ghana, and to re-conceptualise these technical results as sources of economic innovation. Practically translate evidences of economic innovation sustainability into coherent policy, industry structure to decrease national energy demand, reduce public sector expenditures and spur green investment to support national energy security, and sustainable development objectives (Tettey *et al.*, 2025). Consequently, an existing large gap is the connection between particular architectural design decisions, and building energy performance that has not been empirically assessed in the Ghanaian professional setting, or converted into economic frameworks involving the correlation of design with minimised government expenditure, increased productivity, and green market stimulation. The purpose of the study was to empirically determine the effect of energy-conscious design on building energy performance in Ghana and redefines these results as quantifiable aspects of fiscal stability, which gives an innovation evidence base of incorporating architectural practice in the national energy policy.

Materials and Methods

The research design used was a quantitative, and cross-sectional survey design to understand the correlation between design decisions of architects, and building energy performance in Ghana. The statistical tools applied include descriptive statistics, Pearson correlation, multiple linear regression, and principal component analysis. Principal Component Analysis (PCA) with Varimax rotation using SPSS. Scale reliability was excellent (Cronbach's $\alpha = 0.90$). The study population was registered architects with good standing registered by the Architects Registration Council of Ghana (ARCG). Out of 850 registered architects on their sample frame; 120 practicing architects were used for the study, as it was determined by R. Krejcie & D. Morgan (1970) sample size determination table, being recommended by L. Kish (1965) for conducting surveys on the professionals. Data cleaning resulted in the retention of 72 complete and valid responses to be analysed and the response rate was 60. They used stratified sampling depending on years of experience (0-5, 6-15, 16 or more years), and primary practice sector (public, private, and academia). The major metropolitan centres with very high, and more constructional projects were used to draw the participants in Accra, Kumasi, and Takoradi.

The work of N. Ahmad *et al.* (2019) was used to develop a structured questionnaire which was piloted on 15 architects to evaluate their clarity, relevance and length. Pilot feedback was taken into consideration with minor wording changes, and the consent of the appropriate respondents was taken, in accordance with the ethical principles of the American Sociological Association (2018), and used solely for academic purposes, and no name was required. The questionnaire included four parts: Section 1 that covered demographic and professional information with six questions: years of experience, sector of practice, highest educational level, type of typical project (residential, commercial, institutional, or mixed use), the number of efficient projects completed with respect to building energy codes, and knowledge of Ghana building energy codes. Section 2 quantified the frequency and priority of 13 individual energy efficient design (EED) decisions rated where 1 = Never Used to 5 = Always Used. These were divided into two: Building Envelope/Orientation Innovations (eight items: building orientation, window to wall ratio, external shading devices, wall insulation, roof insulation, glazing type, building compactness, and thermal mass) and Site Condition Innovations (five items: prevailing wind utilisation, landscaping for shading, vegetation placement, topography adaptation and rainwater harvesting integration). Section 3 measured perceived building energy performance based on five statements with a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). They were as follows: Buildings that I design consume less energy than conventional designs, occupants report lower energy costs, thermal comfort is always well achieved without excessive mechanical cooling, indoor environmental quality (air quality, daylight, acoustics) is just as high as occupant expectations, and post occupancy evaluations indicate high occupant satisfaction with energy performance. Section 4 enumerated 5 possible obstacles to the implementation of energy efficient design on a 4-point scale (1 = Not a Barrier to 4 = Severe Barrier): absence of client demand, increased cost of upfront costs, limited technical expertise of design teams, no enforcement of building energy codes, and no availability of energy efficient materials in the immediate area.

The data were collected within eight weeks by utilising both electronic (Google Forms) and paper-based data, which was gathered at the professional association meetings as well as direct visit to architectural firms in Accra, Kumasi, and Takoradi. A set of information was given to the participants in an information sheet that contained the purpose of this study, and all respondents were informed to give consent. There were anonymity and confidentiality. The results were analysed in SPSS version 26. Three descriptive statistics (means, standard deviations, frequencies) were calculated of respondent characteristics, and design priorities. Pearson product moment correlation coefficients were used to examine bivariate associations between EED decisions, and energy performance. This was followed by multiple linear regression (stepwise entry) to determine the most important predictors of the energy performance with standardised beta coefficients used to determine the relative contribution of each predictor. Before the regression, the assumptions of linearity, normality, homoscedasticity, and multicollinearity were tested with the help of the residual plot and variance inflation factor. All statistical tests were two tailed and the level of significance was 0.05. design. This study has a number of limitations. To begin with, the sample of 72, which is used in this study, is sufficient to perform its statistical analysis, but does not allow generalising it to the whole profession. Once again, the use of self-reported performance of energy instead of quantitative consumption data presents a possibility of response bias. The cross-sectional design, however, only captures associations, but not causality. Research in the future must also include the actual energy consumption in buildings built with the known EED strategies to confirm the self-reported performance indicators.

Results and Discussion

Ghana's energy crisis and the underutilised potential of building energy efficiency

The Energy Crisis in Ghana and the argument in favour of constructing energy efficiency. The power industry in Ghana is in a structural crisis that is spiralling out of control with increasing debt, inefficiencies in operations, and financial burdens that are unsustainable. Clean Air Task Force (2025) asserts that, the energy crisis of Ghana is a debt/inefficiency spiral: the accrued debts of the sector are over GH80 billion (about US5.8 billion), and the amount of money needed to fund it annually is estimated to be US2.23 billion. Combined with S. Owusu-Mante (2025) stated that, performance of Electricity Company of Ghana (ECG) is a major bottleneck, which contributes to Aggregate Technical, Commercial and Collection (ATC&C) losses of up to 40% leading to a monthly shortfall in revenue of US 25.8 million. This leakage in the budget, he argues, is a budget killer to other important investments in the state. The power generation mix of Ghana in the year 2023-2025 is shown in Table 1. Most of the generation is thermal.

Table 1. Ghana's power generation mix: 2023-2025 (GWh)

Source	2023 (Actual)	2024 (Actual)	2025 (Projected)
Hydro	9,187	9,893	10,200
Thermal	14,930	14,524	15,200
Other renewable sources	147	181	250
Total	**24,264**	**25,550**	**25,650**

Source: Ghana renewable electricity: % of total electricity generation (2024), Global Legal Insights (2025) for 2023 data, Electricity Monitor Ghana (2025), M. Afful (2025) and author's projections based on Energy Commission (2025) outlook

Moreover, according to Electricity Monitor Ghana (2025), since 2016, electricity generation has been dominated by thermal power, and its output has been increasing steadily to reach its peak of 14,930 GWh in 2023 and then slightly declines to 14,524 GWh in 2024. This means that, hydropower, which controlled Ghana generation rates between 2000 and 2015 with a share of between 51 and 92%, has been surpassed by thermal over the past few years. According to the International Trade Administration (2025), a significant portion of power generation in Ghana is based on thermal generation (66%), hydro (33%), and renewable sources (1%). Ghana has had limited success in the integration of renewable energy, although its ambitious policy targets have been terribly derailed by the continued failures in implementing them. S. Owusu-Mante (2025) highlighted that, the renewable energy transition states that there is a broader implementation gap: though policy objectives indicate that the non-hydro renewables should take more than 20% of installed capacity, they occupy less than 2%. G. Tettey *et al.* (2025) stated that the absence of effective policy streams hinders development of Ghana, which is aggravated by financing mechanism, and institutional barriers pattern, which the Danish Institute of International Studies (2025) also notes.

Although the need to promote energy efficiency in buildings has been a long-established idea in the global discourse as a pillar of sustainable development, its potential as an economic innovation driver has been little tapped in Ghana. According to A. Salmi *et al.* (2022) building energy efficiency is viewed internationally as one of the keys to sustainable economic development because buildings are a long-term capital infrastructure that lowers operational expenses. Sustainable development as a concept of economic and environmental objectives was put forward by the World Commission on Environment and Development (1987). E. Ochedi & A. Taki (2022) presented major strategies for energy efficiency in buildings and economic innovation, comprising either Building Envelope/Orientation Innovations (e.g., passive solar, natural ventilation) or Site Condition Innovations (e.g., climatic analysis, shading), which is consistent with R. Crawford (2011). However, empirical research from Ghana quantifying the impact of specific energyefficient design (EED) decisions and directly linking them to macroeconomic outcomes is lacking.

Conceptual frameworks:
Design-based performance-based economic innovation

The combination of whole building design approach has turned out to be one of the fundamental principles of sustainable construction operationalisation (Ochedi & Taki, 2022). M. Kashef (2025), the bifurcation of EED decisions is in line with contemporary building science, inspired by holism, and biophilic approach to bioclimatic performance optimisation. According to E. Ohene *et al.* (2024), the above strategies are considered by the existing literature on tropical architecture to be critical resilience to make buildings more tolerant to temperature and power outages, which are also validated by Y. Yang *et al.* (2023). The shift of slender energy metrics to a more socio technological notion of efficiency, connected to occupant wellbeing, and cognitive output is found in the International Energy Agency (2025), The human dimension… (2020), and Y. Yu *et al.* (2024).

Based on modern political economy explanations of the nexus of constraints in Ghana, that deter efficiency expenditures (Clean Air Task Force, 2025; World Bank Group, 2025). Also, EEDs are innovations in a sophisticated construction innovation system, observable in the Global Alliance for Buildings, and Construction (2024). E. Ohene *et al.* (2024) on the contrary confirm the relationship between performance, and economic returns with life cycle cost models, which is that low levelised costs of efficient structures in tropical climates. J. Allen *et al.* (2022) further present strong evidence for the relationship between cognitive functioning, and indoor air quality, as well as thermal comfort based on controlled studies. S. Owusu Mante (2025), and G. Tettey *et al.* (2025) proved the necessity to design green skills, and resources that can motivate local entrepreneurs as an opportunity with a future in the current strategy in Ghana. In the context of the basis of the circular economy and decoupling, P. Albrecht & M. Gravesen (2025) and Ministry of Finance of Ghana (2025) discussed the vulnerability of the fiscal and trade sector in Ghana. The conceptual framework of energy efficient building design strategies, and energy performance of public buildings in Ghana, as shown in Figure 1 reflects Building Envelope/Orientation Innovations, and Site Condition Innovations as the main sources of energy performance in the national context.

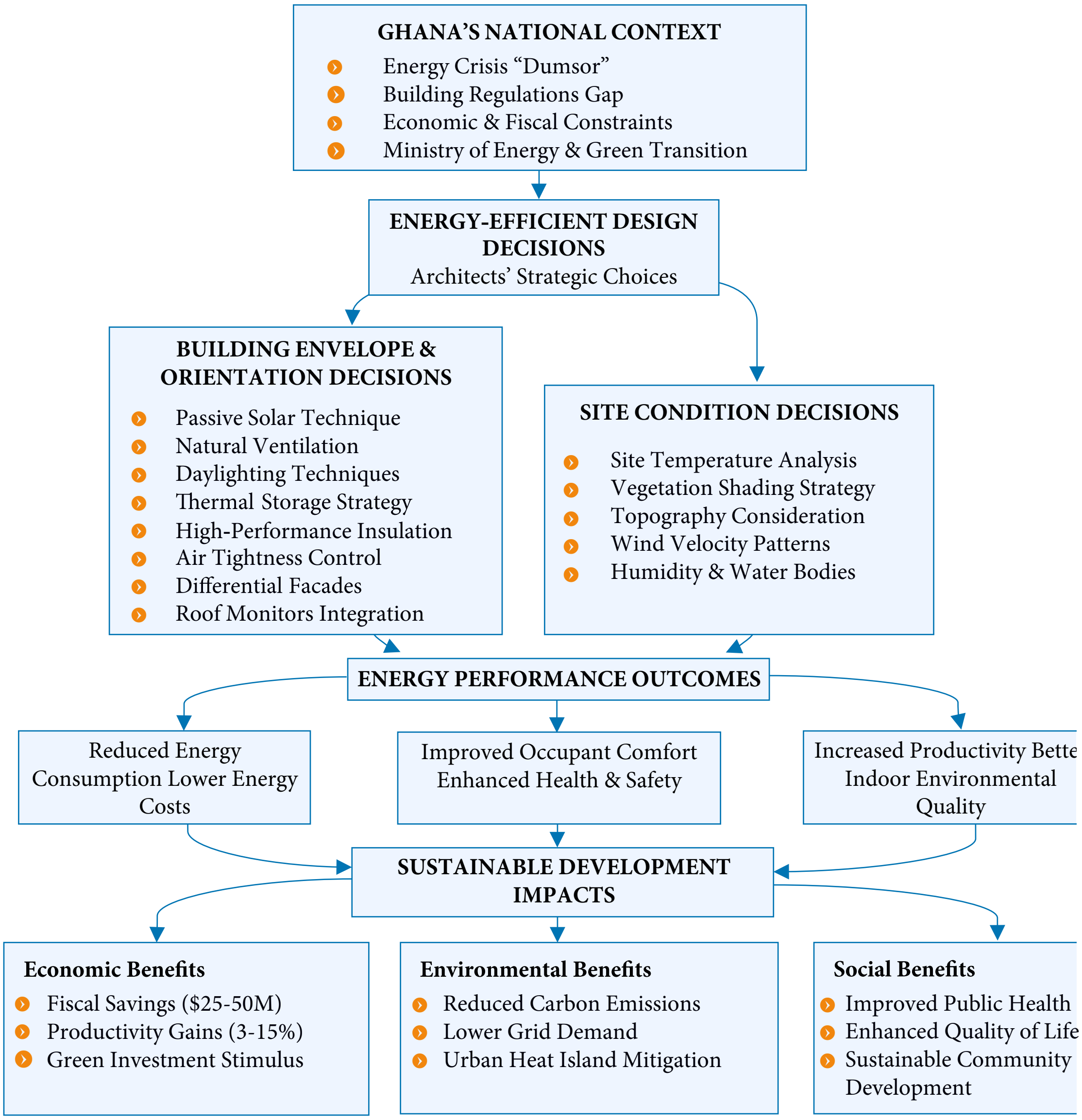

Figure 1. Conceptual framework: Energy efficient design strategies and energy performance
Source: author's elaboration

Figure 2 shows the economic innovation pathway of energyefficient building design in Ghana. The diagram illustrates EEDs leading to energy performance, which bifurcates into Productivity & Fiscal Benefits and Green Market Stimulus, converging on Macroeconomic Resilience.

The Ghana Green Building Code based policy framework of energy efficient building design in Ghana and the EDGE certification system have been shifted to be a regulated market-driven mechanism rather than a voluntary niche approach (Kumar, 2025). According to S. Asuamah Yeboah (2024), it is stipulated that the Government incentives towards sustainable construction in developing countries: Catalysts for change. Drivers of change: Government incentives to promote sustainable construction in developing countries; the evidence shows that this framework successfully transfers environmental targets into economic results that can be measured: Ghana has already achieved one million square metres of EDGE-certified space by 2025 (up from just 40,000 m^2 in 2017). The 100% EDGE certification of the Greenville District Housing Programme which is mandatory is another indication that the regulators have now come to the realisation that green building is a prerequisite towards the provision of public housing.

More importantly, the integration of the framework with local financing that has been epitomised by the SUNREF Ghana programme that deployed the equivalent of the US$30 million in credit lines offered by the Agence Française de Developpement (AFD) as well as the equivalent of the US$2 million in technical assistance offered by the EU Africa Infrastructure Trust Fund which has executed over US $20 million in green energy projects. As it generates an estimated annual reduction of about 139,020 tonnes of CO_2 (SUNREF Ghana Programme ends, advances climate finance and green investment, and low carbon materials, such as the 139,020 tonnes of CO_2 in the world largest Limestone Calcined Clay Cement (LC_3) plant commissioned in Tema with a US $110 million investment which replaces up to 40 percent of traditional clinker and reduces carbon emissions by as much as 40% (Afful, 2025), creates its own reinforcing loop: regulation attracts demand, demand attracts investment, and investment lowers technology costs. Accordingly, some of the main lessons of this analysis are that obligatory certification targets, rather than voluntary guidelines, have triggered market expansion, requiring that codes be coupled with accessible EDGE certification reduces compliance costs incurred by developers, and making codes conditional on their being coupled with accessible EDGE certification further lowers compliance expenses. In the absence of such alignment and ongoing public-private coordination, this framework risks remaining a mere blueprint rather than becoming a lived reality.

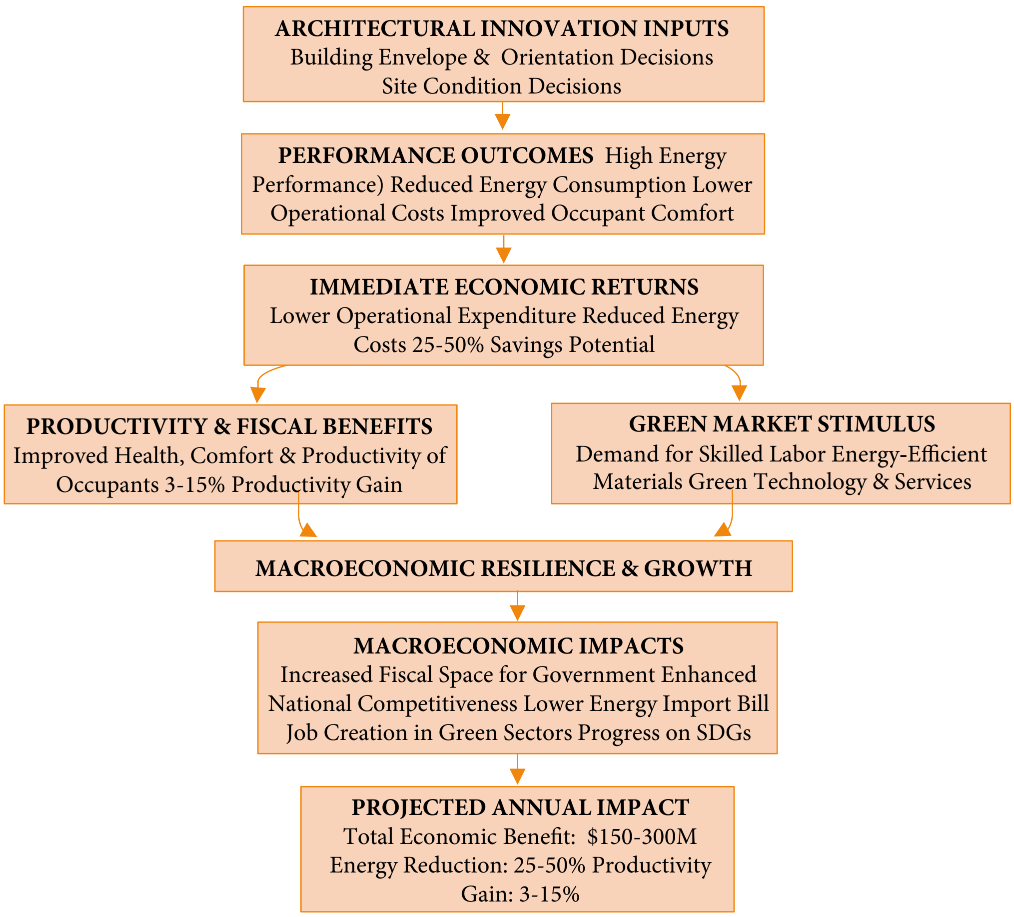

Figure 2. Economic innovation pathway of energy-efficient building design in Ghana
Source: author's elaboration

Results sample characteristics and response rate
A total of 72 valid responses were obtained out of the 120 questionnaires sent out which is a response rate of 60.0. The sample included architects of the following experience levels: 25.0% of 0-5 years, 41.7% had 6-15 years, and 33.3% had 16+ years. In terms of sector, 58.3, 25.0 and 16.7% were in the private practice, the public sector and academia respectively. Principal Component Analysis of energy efficient design decisions. The 13 EED items were subjected to a Principal Component Analysis (PCA) with varimax rotation. The Kaiser Meyer Olkin measure of sampling adequacy = 0.814, and the Test of Sphericity was significant ($\chi^2 = 684.237$, n = 78, p = 0.001). The PCA reduced the 13 EEDs to two components that accounted 73.6% variance. The factor loadings are shown in Table 2.

Table 2. Principal component analysis of energy-efficient design decisions

Component and design decisions	Factor loadings	Variance explained
Component 1: Building Envelope/Orientation (BE/O) Decisions		64.4%
Passive solar technique	0.832	
Provision of natural ventilation	0.815	

Continued Table 2

Component and design decisions	Factor loadings	Variance explained
Daylighting techniques	0.808	
Thermal storage strategy	0.797	
High-performance insulation	0.767	
Air tightness / Infiltration control	0.733	
Differential facades technique	0.695	
Integration of roof monitors	0.641	
Component 2: Site condition (SLC) decisions		9.2%
Temperature of the building site	0.923	
Site shading by vegetation	0.858	
Topography of the building site	0.576	
Wind velocity at the building site	0.597	
Humidity and presence of water bodies	0.539	
Total variance explained		**73.6%**

Source: author's computation

The average scores of the single EED items indicated that, site temperature analysis (mean = 4.64) and passive solar technique (mean = 4.58) and natural ventilation (mean = 4.56) were the most common design innovations used. Nonetheless, Table 3 shows the reliability analysis results of the Cronbach alpha coefficients of the scales (Cronbach's alpha >0.9).

The alpha coefficients of the Cronbach coefficients in Table 3 range between 0.905 and 0.943, which are far greater than the more traditional acceptable test value of 0.70 and the more stringent test value of 0.80 as a good reliability test. These values imply a very high degree of internal consistency of each of the three scales. In particular, the scale of Performance (5 items; α = 0.943) has an excellent internal consistency; that is, the five items covary with each other as well as are reliable in measuring a single construct. The "BE/O" scale (8 items; α = 0.932) and the "SLC" scale (5 items; α = 0.905) also show excellent reliability, with α values above 0.90. Such coefficients are not only acceptable in the context of this study, but are also indicative of very reliable measurement instruments.

These findings warrant considering that each of the scale's measures consistently its intended latent variable without undue measurement error. Further the high alphas, along with the factor loadings obtained elsewhere (as in Table 5), is strong evidence that the scales are both reliable and unidimensional in nature. There is no need to revise the scale or to remove items based on the theory of internal consistency. Table 4 shows Multiple regression analysis, with stepwise multiple regression analysis conducted to identify predictors of energy performance. The model was significant ($F(5,66) = 159.144$, $p < 0.001$), explaining 81.7% of the variance in energy performance (Adjusted $R^2 = 0.817$).

Table 3. Reliability and scale validation test results

Scale	Number of scale items	Cronbach's alpha coefficient
BE/O	8	0.932
SLC	5	0.905
Performance	5	0.943

Source: author's computation

Table 4. Multiple regression results for EEDs predicting energy performance

Predictor variable	Beta (β)	t-value	p-value
Passive solar technique	0.510	7.128	< 0.001
Natural ventilation	0.373	6.595	< 0.001
Site temperature consideration	0.315	4.521	< 0.001
Daylighting technique	0.284	3.885	< 0.001
Site shading strategy	0.175	3.572	< 0.001

Source: author's computation

Again, the Principal Component Analysis for energy performance (PCA) revealed five energy performance items with unidimensional structure, with a single factor explaining 80.524% of the variance (KMO = 0.792, Bartlett's Test = 389.781, $p < 0.001$). Table 5 shows the factor loadings.

Table 5. Principal component analysis for energy performance

Item	Factor loading
Reduced energy consumption	0.945
Less energy cost	0.936
Improves the comfort of occupants	0.922
Improves health and safety of occupants	0.880
Improves the productivity of occupants	0.818

Source: author's computation

The implications of these results to the structure of the scale are quite numerous. The highest loading (0.945) indicates that the item with the highest loading in the factor is Reduced energy consumption, which is also the most central and defining item of the factor, and the lowest loading (0.818) still comfortably exceeds the 0.70 benchmark, demonstrating that it makes a meaningful contribution, which is statistically significant. Importantly, it does not have weak or negative or cross- loadings. The consistently high loadings, therefore, offer strong empirical support of a unidimensional scale format. Such a pattern of results is reliably indicative to show that all the five items converge to measure one single, cohesive latent construct, which can be interpreted as the perceived benefits of energy-efficient design. Thus, it can be safely assumed that the scale can be used as a unidimensional scale with no subscales or items should be deleted. The Constraints to implementation as shown in Table 6 presents mean ratings for five barriers to incorporating EEDs, measured on a 4point scale (1 = Not a Barrier to 4 = Severe Barrier).

Table 6. Constraints to incorporating energy-efficient design decisions

Constraint	Mean rating	Level of barrier
Lack of public awareness of benefits	3.20	High
Client's budget constraints	3.00	High
Lack of skilled labour	2.91	MediumHigh
Lack of access to energyefficient materials	2.82	Medium
Lack of enforcement of compliance during construction	2.77	Medium

Source: author's computation

The primary barriers to energy-efficient construction are not purely technical but are rooted in economic, informational, and regulatory gaps. The highest-rated constraints suggest that demand-side intervention is critical, as overcoming the lack of public awareness and clients' budget constraints requires policies aimed at stakeholder education and strengthening the financial case, for example through incentives, green financing, or lifecycle cost analysis. At the same time, the presence of medium-high to medium barriers related to skills, materials, and enforcement indicates the need for supply chain and workforce development, including investments in training, the expansion of local material supply chains, and the strengthening of oversight mechanisms to ensure that design intentions are properly implemented during construction. Table 7 projects the economic mechanisms, and outcomes associated with each highperformance design innovation.

Table 7. Projected economic potential of high-performance design innovations

Innovation (predictor)	Primary economic mechanism	Shortterm economic outcome	Longterm macroeconomic benefit
Passive solar technique (β = 0.510)	Displacement of purchased electricity for lighting/heating	~ 2540% reduction in lighting/AC load; reduced utility bills	Fiscal space creation; energy security (reduced peak demand)
Natural ventilation (β = 0.373)	Elimination/reduction of mechanical cooling demand	~ 3050% savings on cooling costs; lower HVAC maintenance	Labour productivity gain (515% from improved IAQ); reduced healthcare burden
Site temperature & shading (β = 0.315 & 0.175)	Microclimate moderation to reduce heat island effect and cooling loads	~ 1020% lower cooling energy; extended building lifespan	Urban resilience; ecosystem value (carbon sequestration, biodiversity)
Daylighting technique (β = 0.284)	Direct displacement of artificial lighting	~ 1530% savings on lighting electricity; enhanced visual amenity	Productivity & health (310% improvement in occupant wellbeing and cognitive performance)

Source: author's computation based on beta coefficients and benchmarks from R. Pacheco et al. (2012) and International Energy Agency (2025)

The results substantiate EEDs as powerful economic innovations. The great explanatory power of the model shows that investments in the identified EEDs give significantly predictable returns. The high predictive value of the passive solar (0.510) and the natural ventilation (0.373) highlights the value of climate responsive design as a direct measure of financial savings and productivity increase in government buildings. These innovations provide the space that a government badly needs so that it can more effectively address the existing $2 billion annual energy deficit, and also create a more competent workforce in the government. Table 8 presents a scenario analysis estimating the annual economic benefits of a national public building energy efficiency program.

Table 8. Estimated macroeconomic benefits of a national public building energy efficiency program

Impact category	Key metric	Conservative estimate (annual)	Rationale
Direct fiscal savings	Reduced government energy expenditure	$2550 million	30% energy use reduction across 20% of public building stock
Productivity enhancement	Value of increased public sector output	$1530 million	3% productivity gain from improved comfort/ health
Investment & GDP stimulus	Green construction investment mobilised	$100200 million	Initial capital for retrofits flowing into local sectors
Energy sector & trade	Reduced fuel imports & grid stress	$1020 million	Lowered thermal generation demand
Total potential annual economic benefit	Combined direct & indirect impact	$150300 million	Demandside contribution to mitigating US$2.23 billion annual energy shortfall (Clean Air Task Force, 2025)

Source: author's computation based on Ministry of Finance of Ghana (2025) and Clean Air Task Force (2025)

Table 8 summarises the estimated annual macroeconomic benefits of a national public building energy efficiency program, and disaggregated into the four key impact categories. All estimates are given as lower limits and the overall combined annual benefits have been estimated to be between 150 million and 300 million. The biggest direct fiscal gain is through reduced government spending on energy (25-50 million per year), based on a modelled 3% productivity gain between occupants of the public sector as a result of increased thermal comfort, lighting, and indoor air quality parameters empirically related to higher work output. The largest macroeconomic lever mobilised green construction investment. Mobilised green construction investment (100-200 million yearly) is the most significant macroeconomic lever. This capital inflow is invested in local supply chains (materials, labour, engineering services) providing multiplier effects in terms of GDP and employment.

Moreover, there were decreased fuel imports and gridstess (100-200 million annually). Combined, the total economic benefit of 150- 300million annually, as a demand-side contribution, will help reduce this US 2.23 billion annual energy short fall identified by the Clean Air Task Force (2025). It is noteworthy that all the estimates are characterised as conservative, which means that the actual benefits might be higher, in case a larger percentage of the building stock is retrofitted or energy prices increase. Policy-wise, Table 8 shows that a public building energy efficiency program would yield returns in more than one channel fiscal, productivity, investment, and trade among macroeconomic channels rather than just reducing utility bills. The range format (X-Y million) is the only format that appropriately takes into account uncertainty in uptake rates, energy price volatility, and productivity measurement, but still provides an actionable order-of-magnitude direction to be taken in cost-benefit analysis. The programme has the potential to generate US$150-300 million yearly. Green construction investment (US$100-200 million) is the greatest benefit followed by direct fiscal savings (US$25-50 million), productivity gains (US$15-30 million), and reduced fuel imports (USя$10-20 million). These, combined, can help overcome the US 2.23 billion annual energy deficit in Ghana, which is a macroeconomic demand side strategy with positive fiscal, productivity and trade impacts.

The output of PCA empirically confirms the theoretical bifurcation of the conceptual framework (Fig. 1), as the EED decisions of architects in Ghana concentrate around Building Envelope/Orientation Innovations and Site Condition Innovations. This total variance explained (73.6) is high implying that these two types have most systematic difference in EED practices. Comparison of possible savings on the international and regional level. The projected energy savings in this study (25-50 reduction of building loads) are in line with the results of similar tropical settings. In Tanzania, it was found out that, green buildings are capable of saving between 8 to 57 per cent of the annual energy (Islam *et al.*, 2024). E. Ohene *et al.* (2024) found that, in Ghana alone, passive design strategies had the potential to save 34-35% of energy in different climates against baseline conditions.

A. Khalid & M. Okitasari (2023) also found that, government related barriers are still a serious impediment to the uptake of green building technologies in Ghana. The results find correlation with the regression results of the current study that assigned passive solar technique (0.510), and natural ventilation (0.373) as the most effective predictors of the energy performance. The current study however contrasts the relative economic contribution of each design innovation unlike the past studies, which mainly concentrated on technical feasibility only. Multipliers and creation of employment. Table 8 estimates of economic benefits of between 150-300 million a year are well supported by recent global analysis. The World Bank Group (2025) discovered that, on an investment of one dollar in energy efficiency, can provide a payoff of between 3 and 5 dollars, and can save future energy supply investments by up to \$11.6 billion in power savings to an average middle-income nation by 2050. Notably, the report says that, in 2022, energy efficiency generated the largest number of jobs throughout the energy industry, with nearly 11 million individuals in global companies' workplace in respect of manufacturing, construction, installation, and support services.

For Ghana, this implies that, a national EED program could generate significant formal employment in the construction, and retrofit sectors for dimension which is absents from previous Ghanaian studies. Partnership for Energy efficiency in Buildings (2025) supports this perception by stating that, 80% of the buildings that will be constructed in Africa by the year 2050, will have a one-time chance of generating employment, lessening the use of energy, and enhancing the security of energy by green building. The current researches predicted that mobilised green construction investment in the range of 100-200 million dollars (Table 8) would be directly related to such employment results. Obstacles to adoption: Multiple studies agree. The conclusion that, economic (Primary barriers) and informational (Table 6) are the main obstacles is strongly backed by the latest literature.

In a doctoral thesis on net zero carbon buildings in Ghana, E. Ohene (2024) found a greater initial investment cost to be the greatest obstacle, then unavailability of skilled labour, inadequate regulations, and policies, and public awareness. Similar results were reached by A. Khalid & M. Okitasari (2023), who assert that, government related obstacles are significant that, an efficient communication approaches, regulations backed by the mass, and standards are crucial promotion techniques. Meanwhile, thematic analysis of the green certification barriers in Ghana revealed that, built environment professionals repeatedly mention cost, insufficient awareness, and inadequate enforcement as the barriers to the implementation. This paper concurs with the above authors that, the main challenges are not technical, but informational and economic. This is the agreement of numerous studies with significantly different methodologies, which enhances the argument of specific policy interventions. Economic innovation pathway (Fig. 2).

The regression results empirically support the entire chain illustrated in Figure 2. Figure 2 shows that, EEDs lead to improved energy performance, which then splits into (a) Productivity & Fiscal Benefits and (b) Green Market Stimulus, finally converging on Macroeconomic Resilience. The strong predictive power of passive solar ($\beta = 0.510$), and natural ventilation ($\beta = 0.373$) directly feeds the fiscal savings leg: a 25-50% load reduction translates into lower government utility bills, creating fiscal space. Meanwhile, improved indoor environmental quality supports the 5-15% labour productivity gains documented by the International Energy Agency (2025) and J. Allen *et al.* (2022). The Green Market Stimulus leg is evidenced by estimated \$100-200 million in mobilised green construction investment (Table 8), which would stimulate demand for local materials, skilled labour, and efficient technologies. Thus, Figure 2 is not merely a diagram, it is an empirically grounded causal chain where each link is quantified by the beta coefficients and projected outcomes. The productivity pathway itself is supported by emerging Ghanaian evidence.

An importance-performance analysis of an EDGE-certified office building in Ghana found that, occupants prioritise temperature, air quality, and humidity exactly the IEQ factors improved by passive solar and natural ventilation (Zhong *et al.*, 2023). A.-M. Sadick (2020) found significant differences in job satisfaction and self-reported productivity based on IEQ factors among university employees in a tropical African climate. These findings extend J. Allen *et al.* (2022) controlled-study evidence from high-income countries to Ghana, suggesting similar mechanisms operate across different economic contexts. Finally, the scenario analysis (Table 8) projects annual benefits of \$150-300 million, which would offset 7-13% of Ghana's US\$2.23 billion annual energy sector deficit reported by Clean Air Task Force (2025). This demonstrates that, demand-side efficiency can meaningfully complement supply-side expansions. However, the study acknowledges with G. Tettey *et al.* (2025), and P. Albrecht & M. Gravesen (2023) that, an implementation gap persists: policy goals exist, but are not realised due to weak coordination, fragmented regulations, and insufficient enforcement. The disconnect between technical feasibility and policy implementation mirrors broader regional patterns. In this context, the present study provides the empirical basis quantified beta coefficients and projected macroeconomic benefits to elevate energy-efficient architecture from a technical specialism to a central pillar of national fiscal policy.

Conclusions

The research found that the response rate of 60.0% (72 valid responses out of 120 distributed questionnaires) is reasonable to conduct a professional survey of registered architects in Ghana. They discovered that, the decisions in energy efficient design by the architects are clustered around two empirically validated innovation themes, Building Envelope/Orientation Innovations (explaining 64.4% of the variance) and Site Condition Innovations (explaining another 9.2% of the variance of design strategies). The research determined that, there are five design choices that are statistically significant predictors of building energy performance.

The total amount of variance in the energy performance attributed to passive solar technique ($\beta = 0.510$), natural ventilation ($\beta = 0.373$), site temperature consideration ($\beta = 0.315$), daylighting technique ($\beta = 0.284$), and site shading strategy ($\beta = 0.175$) was 81.7%. The most commonly used design innovations were site temperature analysis (mean = 4.64), passive solar technique (mean = 4.58) and natural ventilation (mean = 4.56). It was further discovered that, the major barriers to adoption are economic, and informational: lack of public awareness (mean = 3.20), and client budget constraints (mean = 3.00) are high barriers, and skilled labour (2.91), material access (2.82), and enforcement (2.77) are medium to medium high. The Scenario analysis estimated that, a national public building energy efficiency programme would result in economic savings of between 150-300 million per annum, in compensation of the estimated 7-13% of the estimated 2.23 billion per annum of the Ghanaian energy sector deficit.

Future research opportunities consist of: more cost benefit analysis in the five most popular design strategies in various building types (schools, hospitals, offices); macroeconomic modelling of the nationwide retrofit programmes using computable general equilibrium models; exploring new financing models like the Energy Service Company, green bonds, and public private partnerships; longitudinal studies of actual energy performance, and productivity results; and cross country research on West Africa to determine the sensitivity of policy and market contexts.

Acknowledgements
None.

Funding
None.

Conflict of Interest
None.

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Вплив енергоефективної архітектури як рушія економічних інновацій та фіскальної стійкості в Гані

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Анотація. Метою цього дослідження було вивчення енергоефективного архітектурного проектування як стратегічного інструменту економічної політики та інновацій, з метою його використання для подолання енергетичної кризи в Гані шляхом стимулювання економічних інновацій та фіскальної стійкості у будівельному секторі. Опитування 120 зареєстрованих архітекторів у Гані (кількісне дослідження) дало 72 дійсні відповіді (рівень відгуку 60,0 %). Використані методи включали описову статистику, кореляцію Пірсона, множинну лінійну регресію та факторний аналіз головних компонентів. Факторний аналіз показав наявність двох основних інноваційних тем: будівельна оболонка/орієнтація (64,4 % дисперсії) та рішення щодо умов майданчика (ще 9,2 % дисперсії) із високою надійністю шкали (Кронбах $\alpha = 0{,}90$). Багатовимірна конструкція результатів була підтверджена, причому показники енергетичної ефективності завантажувалися на один фактор, який пояснював 80,5 % дисперсії. Регресійний аналіз виявив п'ять предикторів енергетичної ефективності, які пояснювали 81,7 % дисперсії: пасивне сонячне опалення ($\beta = 0{,}510$), природна вентиляція ($\beta = 0{,}373$), температура на майданчику ($\beta = 0{,}315$), денне освітлення ($\beta = 0{,}284$) та затінення майданчика ($\beta = 0{,}175$) за стандартизованим коефіцієнтом регресії. Основними бар'єрами виявились економічні та інформаційні: відсутність знань у громадськості (середнє = 3,20/4) та бюджет клієнта (середнє = 3,00/4), що вважаються значними перешкодами. Ключові висновки показують, що інновації у проєктуванні можуть забезпечити економію 25-50 % енергоспоживання будівель, а також пов'язані з продуктивністю праці на 5-15 %. Сценарний аналіз прогнозує, що при широкому впровадженні річні економічні вигоди можуть досягти 150-300 мільйонів доларів, включаючи прямі фіскальні заощадження (25-50 млн), підвищення продуктивності (15-30 млн), залучення інвестицій у зелене будівництво (100-200 млн) та зменшення імпорту палива (10-20 млн), що компенсує 7-13 % річного енергетичного дефіциту

Ключові слова: сталий розвиток; підвищення продуктивності; зелені інвестиції; клімато-адаптивне планування; фіскальна політика