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Global Energy Regulations for Sustainable Buildings: Comparative Strategies and Adaptation Pathways for Saudi Arabia

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Abstract. This study investigates international regulatory frameworks governing building energy efficiency, focusing on their structure, objectives, and implementation mechanisms. The research identifies commonalities such as performance-based codes, energy labeling systems, financial incentives, and voluntary certifications by comparing policies in the United States, Japan, the United Kingdom, Germany, and the European Union. These elements are analyzed for their applicability to Saudi Arabia, where Vision 2030 mandates a transition toward environmental sustainability and reduced carbon emissions. Since the building sector accounts for over 80% of the Kingdom's electricity consumption, developing integrated and enforceable energy regulations is a strategic and environmental priority. The study recommends a hybrid regulatory model combining mandatory benchmarks with lifecycle-based assessments and market-driven incentives. Contextualizing global best practices within the Kingdom's climatic and economic conditions, the findings contribute to formulating adaptive, forward-looking building energy policies for sustainable urban development in Saudi Arabia.

1. Introduction

The transition toward sustainable development has elevated the importance of green buildings as a central component in global strategies to reduce energy consumption and mitigate climate change [1]. Among various sectors, the building sector represents a substantial share of global energy use and associated carbon emissions [2]. According to the International Energy Agency, buildings accounted for approximately 30% of global final energy consumption and 27% of energy-related CO_2 emissions in 2021, underlining the sector's potential to contribute significantly to national and international energy efficiency targets [3].

Major economies have recently introduced ambitious policy frameworks to improve buildings' energy performance [4]. China, for instance, committed to reducing energy intensity by 16% between 2011 and 2015 under its 12th Five-Year Plan [5]. Under the 14th Five-Year Plan, it promotes carbon-neutral buildings as part of its dual-carbon goals. The United States has revised fuel and building energy standards through initiatives like ASHRAE 90.1 and the Energy Policy Act, aiming for 30% greater energy efficiency than baseline codes [6]. The European Union, under its Energy Efficiency Directive (2012/27/EU), initially targeted a 20% improvement by 2020, later increasing its ambition to 32.5% by 2030. Japan's Top Runner Program and national energy conservation plans seek to reduce electricity consumption by at least 10% by 2030 [7].

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Global energy demand has shown a persistent upward trajectory since the 1970s, only briefly interrupted by economic downturns such as the early 1980s recession [8]. Today, energy consumption in the building sector continues to rise, driven by urbanization, population growth, and increasing expectations for thermal comfort, particularly in rapidly developing regions [9]. Numerous studies indicate that even a 10% improvement in building energy efficiency could yield disproportionately large environmental and economic benefits due to the sector's high operational energy use and long lifecycle impacts [10].

This study aims to analyze international regulatory frameworks and policy systems related to green building development, focusing on their structure, scope, and implementation mechanisms. Through a comparative review of regulations from leading countries in sustainable architecture, the research seeks to derive lessons and strategies that may be adapted to regional contexts. Specifically, this study closely aligns with the priorities outlined in Saudi Arabia's Vision 2030, emphasizing environmental sustainability, energy diversification, and adopting advanced technologies in the built environment. As Saudi Arabia undergoes rapid urban expansion, particularly in high-profile developments such as NEOM, The Line, and Qiddiya, the demand for energy-efficient buildings becomes increasingly critical. The Kingdom's commitment to reducing 278 million tons of CO_2 equivalent by 2030 and increasing renewable energy to 50% of total generation necessitates robust building regulations and strategic policy frameworks. By contextualizing international best practices within the unique climatic, economic, and policy conditions of Saudi Arabia, this study contributes to the development of an evidence-based roadmap for sustainable building regulation in the Kingdom.

2. Literature Review

2.1. Energy Regulations for Green Buildings in Each Country

Globally, countries have adopted diverse regulatory and incentive frameworks to enhance energy efficiency in the built environment, each tailored to their socio-economic contexts, energy policies, and climate commitments [11]. These regulatory approaches often integrate mandatory codes, voluntary certification systems, financial incentives, and performance disclosure mechanisms to drive compliance and promote market transformation (Table 1).

In the United States, the energy regulatory landscape for buildings is characterized by a combination of federal guidelines and state-level adaptations [12]. Notably, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) certification is one of the most widely adopted voluntary green building standards, with over 100,000 certified projects globally as of 2023 [13]. Additionally, the Home Energy Rating System (HERS) developed by RESNET enables performance benchmarking through standardized energy modeling. These tools are often linked with financial incentives, tax rebates, and mortgage products, such as energy-efficient mortgages (EEMs), to stimulate demand for green buildings. Moreover, the Energy Star program, jointly administered by the EPA and DOE, offers market differentiation for energy-efficient buildings, contributing to a more transparent and active real estate market [14].

In Japan, the foundation of energy regulation in the building sector was established with the Energy Conservation Act of 1979, in response to the oil crisis of the 1970s [15]. The Act has since evolved through successive amendments to incorporate performance-based energy codes and obligatory reporting. Japan introduced the Top Runner Program to promote the most energy-efficient technologies, and mandates energy performance labeling for buildings under the Building Energy Efficiency Act of 2015. These measures are supported by extensive maintenance protocols and continuous monitoring practices to enhance long-term building performance. The country also mandates disclosure of energy-saving measures during construction permitting, reinforcing accountability in the design and planning phases.

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The United Kingdom has implemented a robust regulatory framework integrating energy performance metrics into real estate transactions [16]. Since 2007, it has been mandatory to issue Energy Performance Certificates (EPCs) for all new constructions and the sale or rental of residential and non-residential buildings [17]. These certificates are based on the Standard Assessment Procedure (SAP)—initially introduced in 1995 and most recently updated as SAP 10.2 in 2022—which calculates a building's predicted energy use, carbon emissions, and heating costs (UK BEIS, 2022). EPCs serve as a regulatory tool and a driver of market awareness by providing consumers with transparent, comparable energy data.

Germany has long been a pioneer in energy efficiency regulation, with its policy trajectory shaped by the energy crises of 1973 and 1979 [18]. The country enacted the Energy Saving Ordinance (EnEV) in 2002, which was later integrated into the more comprehensive Building Energy Act (GEG) in 2020 [19]. This legislation consolidates various directives into a unified regulatory framework governing building energy requirements, encompassing thermal insulation, energy demand calculations, and renewable energy integration. A central element of the system is the mandatory issuance of Energieausweise (Energy Performance Certificates), which are required for building construction, renovation, or sale. Germany's approach also incorporates lifecycle-based assessments and supports deep retrofitting through national funding programs such as the KfW Efficiency House standards.

Countries have developed unique tools and legal instruments to foster energy-efficient buildings [20]. While the scope and enforcement mechanisms vary, common elements include performance certification, regulatory mandates, and market-based incentives. These frameworks aim to reduce operational energy use and increasingly emphasize embodied carbon, whole-building lifecycle performance, and user behavior—principles essential to shaping the future of sustainable architecture.

Table 1. Energy Regulations for Green Buildings in Each Country

Country	Regulation	Categories	Contents
United States	LEED (Leadership in Energy and Environmental Design), HERS (Home Energy Rating System), Energy Star	Voluntary certification, performance rating, incentives	LEED provides multi-tiered certification for green buildings; HERS measures energy efficiency of residential buildings; Energy Star labels energy-efficient buildings and appliances. Financial incentives include tax credits and energy-efficient mortgage products.
Japan	Energy Conservation Act (1979), Building Energy Efficiency Act (2015), Top Runner Program	Mandatory regulation, performance labeling, and technology benchmarking	Establishes mandatory energy standards for buildings; requires energy performance disclosures; Top Runner identifies the most efficient technologies and sets performance baselines. Labels and reporting are required at the design and construction stages.
United Kingdom	Energy Performance Certificate (EPC), Standard Assessment Procedure (SAP)	Mandatory disclosure, performance modeling	Since 2007, EPCs have been required for all new, sold, or rented buildings. SAP methodology assesses energy usage, emissions, and cost. Recent updates include SAP 10.2, which better reflects real-world performance.
Germany	Energy Saving Ordinance (EnEV), Building Energy Act (GEG 2020)	Mandatory regulation, performance certification, and retrofit support	Unified legal framework for thermal insulation, energy demand, and renewable energy integration. Requires Energieausweis (energy certificate) for new and existing buildings. Supports retrofitting through KfW Efficiency House subsidies.

3. Methodology

This study adopts a comparative qualitative research methodology to analyze international regulatory frameworks governing energy efficiency in the building sector. The approach involves reviewing policy documents, legal frameworks, and third-party certification systems from selected countries, including the United States, Japan, the United Kingdom, Germany, and the European

Union. Key sources include government publications, international treaties (e.g., UNFCCC, Kyoto Protocol), peer-reviewed Q1 journal articles, and technical reports from authoritative organizations such as the International Energy Agency (IEA) and the United Nations Environment Programme (UNEP).

The analysis focuses on three primary dimensions: (1) the regulatory scope and legislative evolution of each country's energy policy in the building sector; (2) the objectives and enforcement mechanisms embedded within each framework; and (3) the presence of incentive structures designed to exceed baseline compliance. A matrix-based comparison was used to systematically identify these frameworks' similarities, differences, and potential adaptability to emerging contexts, particularly in Saudi Arabia, which is undergoing a rapid shift toward sustainability under Vision 2030. The insights derived aim to support policymakers, architects, and urban planners in formulating contextually relevant energy regulations and incentive-based green building strategies in the Gulf region.

4. Analysis

4.1. Regulations and Objectives

The initial framework for managing energy consumption in buildings emerged as part of the broader international response to climate change, notably through the United Nations Framework Convention on Climate Change (UNFCCC) adopted at the Rio Earth Summit in June 1992. At that stage, energy efficiency in buildings was promoted primarily through non-binding recommendations and voluntary guidelines among member nations. However, a significant shift occurred with adopting the Kyoto Protocol, which came into legal force in February 2005. This agreement introduced binding greenhouse gas (GHG) emission reduction targets for developed countries, converting earlier recommendations into enforceable obligations under international law.

The Kyoto Protocol marked a pivotal moment in aligning building energy efficiency with climate policy. Participating countries were required to quantify emissions reductions across various sectors, including the building sector, which contributes nearly 39% of global carbon dioxide emissions when operational and embodied carbon are considered (IEA & UNEP, 2022). The implementation of the Protocol led to the formulation of national and regional regulatory instruments focused on setting performance standards, establishing reporting mechanisms, and introducing economic incentives for energy-efficient design, construction, and operation.

These policies have evolved into integrated energy management frameworks combining mandatory baseline regulations with market-based instruments. Many countries have adopted hybrid systems where minimum energy performance standards (MEPS) are legally enforced. At the same time, financial incentives and voluntary certifications (e.g., LEED, BREEAM, HQE) encourage stakeholders to exceed minimum requirements. For instance, the European Union's Energy Performance of Buildings Directive (EPBD), initially adopted in 2002 and amended several times since, mandates all new buildings to be "nearly zero-energy buildings" (nZEB) and requires member states to establish long-term renovation strategies (EU, 2018).

Moreover, integrating incentive-based schemes, such as tax deductions, green finance, carbon credit markets, and subsidy programs, has strengthened policy effectiveness by offering flexibility and market stimulation. In essence, energy regulations have transitioned from purely environmental considerations to a dual-purpose strategy: mandating compliance to reduce emissions while incentivizing innovation and investment in sustainable building practices.

This trajectory of regulatory development illustrates a maturing global consensus that energy management in buildings must be addressed through a combination of legally binding frameworks, economic instruments, and performance-based targets. These strategies are environmental imperatives and key enablers of energy security, technological progress, and long-term economic resilience.

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Table 2. Regulations and Objectives in Each Country

Country/Region	Regulation Name	Objective
Global	UNFCCC (1992), Kyoto Protocol (2005), Paris Agreement (2015)	Establish international legal and voluntary frameworks to reduce greenhouse gas emissions, including the building sector.
European Union	Energy Performance of Buildings Directive (EPBD, recast 2018)	Achieve nearly zero-energy buildings (nZEB), mandate energy certificates, and promote long-term renovation strategies.
United States	Energy Policy Act (2005), Energy Independence and Security Act (2007)	Improve energy efficiency standards for federal and commercial buildings; support green building incentives.
Japan	Energy Conservation Act (1979, revised 2015)	Mandate rational energy use in buildings; require performance labeling and promote efficient technologies.
United Kingdom	Climate Change Act (2008), EPC regulations under Building Regulations Part L	Legally bind carbon reduction targets and improve building energy performance through standardized assessments.
Germany	Building Energy Act (GEG 2020)	Consolidate energy-saving measures; enforce performance-based standards for both new and existing buildings.

4.2. The relationship between Regulations and Building Energy

The relationship between national regulations and building energy performance reflects each country's evolving commitment to environmental preservation, energy security, and sustainable urban development. In the case of Japan, the regulatory foundation lies in the Energy Conservation Act, first enacted in 1979 and significantly revised to respond to global climate concerns and domestic energy needs. The Act is part of a broader legislative framework that includes the Basic Energy Policy Act and the Basic Energy Plan, which collectively aim to ensure a stable energy supply, reduce greenhouse gas emissions, and reform industrial energy consumption through the principles of safety, environmental sustainability, and market efficiency. According to Japan's Ministry of Economy, Trade and Industry (METI, 2021), the building sector accounts for over 30% of total national energy consumption. In response, the "Guidelines for Design, Construction, and Maintenance of Residential Buildings" define quantitative performance metrics for insulation, window glazing, building orientation, mechanical systems, and HVAC specifications. These metrics serve as criteria for energy-saving housing and are enforced through performance labeling and mandatory disclosures in the design and construction process.

In the United Kingdom, the regulatory architecture for building energy efficiency is codified within a hierarchy of laws encompassing the Climate Change Act (2008), Building Regulations Part L, and energy-specific legislation related to electricity and gas. The UK's approach integrates energy performance standards into residential and non-residential buildings through the Energy Performance Certificate (EPC) and the Standard Assessment Procedure (SAP). These tools enable a standardized evaluation of energy use and CO_2 emissions. In line with its legally binding net-zero carbon emissions target by 2050, the UK government has established adaptive regulatory pathways combining minimum energy efficiency thresholds with flexible compliance methods. These include acceptable solutions, retrofit incentives, and green finance mechanisms supporting new construction and deep retrofitting. The system promotes equitable carbon reduction across all building types and user groups, ensuring a broad applicability that fosters user participation in eco-friendly building transitions (BEIS, 2022).

Regulatory initiatives in the United States have been federally and locally driven. The national LEED (Leadership in Energy and Environmental Design) certification program, developed by the U.S. Green Building Council, has emerged as a dominant voluntary standard. LEED certification integrates energy performance targets with carbon footprint reduction, indoor environmental quality, and lifecycle cost efficiency. Studies indicate that LEED-certified buildings consume 25–30% less energy and emit 34% less CO_2 than conventional buildings (Azhar et al., 2011; USGBC, 2023). Additionally, jurisdictions such as Washington, D.C., have enacted mandatory policies,

notably the Green Building Act, which requires adherence to high-performance standards in planning, construction, and operational phases of public and private buildings. The Act also mandates the creation of a Green Building Fund and oversight through an advisory board, thereby institutionalizing the monitoring and evolution of green practices in the building sector.

In Germany, sustainability policy in the built environment extends beyond individual structures to address the urban scale. The country's Building Energy Act (GEG 2020) integrates previous regulations (EnEV, EEWärmeG) into a comprehensive legislative framework that covers energy performance, thermal insulation, and renewable energy requirements. What distinguishes Germany is the multi-criteria sustainability assessment system developed by the German Sustainable Building Council (DGNB). The DGNB certification encompasses ecological, economic, socio-cultural, functional, and technical performance indicators and process quality. This holistic framework positions sustainability as a technical goal and a societal and environmental commitment. According to DGNB (2022), over 6,000 buildings have been certified, with evidence showing lifecycle cost reductions and improved urban quality in certified districts.

These case studies demonstrate that national energy regulations are increasingly sophisticated, interlinking mandatory compliance, performance-based assessments, and user-oriented incentive schemes. Whether through Japan's technically prescriptive approach, the UK's adaptive carbon-reduction frameworks, the U.S.'s combination of certification and municipal mandates, or Germany's systemic integration of sustainability metrics at both building and urban scales, each model exemplifies how regulation can drive meaningful reductions in energy consumption while enhancing building quality and user experience.

5. Discussion: Implications for the Saudi Arabian Context

Saudi Arabia is undergoing a transformative shift toward sustainability, driven by its national development blueprint—Vision 2030—which positions environmental stewardship, energy diversification, and urban innovation at the center of its agenda [21]. As part of this vision, the Kingdom has pledged to reduce 278 million tons of CO_2 equivalent by 2030 and increase the share of renewable energy to 50% of electricity generation [22]. However, given that the building sector accounts for over 80% of total electricity consumption, primarily due to the intensive use of air conditioning systems in residential and commercial spaces, developing robust energy regulations for buildings is both an environmental necessity and a strategic priority [23].

Drawing on the international frameworks examined in this study, there are critical lessons for Saudi Arabia's regulatory pathway [24]. The mandatory and performance-based approaches in countries like Japan and Germany demonstrate the importance of technical standards for insulation, glazing, passive design strategies, and HVAC efficiency [25]. Meanwhile, the United Kingdom's use of Energy Performance Certificates (EPCs) and long-term renovation strategies illustrates the effectiveness of integrating building performance transparency with user incentives [26]. These strategies are particularly relevant for Saudi Arabia, where introducing the Saudi Building Code (SBC) and the Mostadam certification system has laid the foundational infrastructure for performance-based design and construction.

However, unlike contexts with mature retrofit markets and climate-responsive urban forms, Saudi Arabia faces unique challenges, including extreme desert temperatures, high per-capita energy consumption, and rapid urbanization driven by mega-projects such as NEOM, Qiddiya, and The Line [27]. Therefore, regulatory adaptations must account for climatic zoning, local construction practices, and energy pricing structures. Furthermore, as demonstrated by the U.S. and German experiences, the success of any regulatory system depends on a complementary ecosystem of financial incentives, data transparency, and institutional capacity. This may involve linking energy performance to mortgage rates, utility tariffs, and digital building permit systems via innovative city platforms in Saudi Arabia. To advance national objectives, Saudi Arabia should adopt a hybrid model integrating mandatory performance benchmarks (e.g., minimum U-values,

solar reflectivity, air tightness) with market-based tools (e.g., green loans, EPC ratings, tax incentives). Additionally, a shift toward lifecycle-based assessments, including embodied carbon calculations and post-occupancy evaluations, would align the Kingdom's regulatory trajectory with global best practices. Embedding these measures in future iterations of the SBC and urban planning guidelines would ensure that energy regulations are enforceable, contextually adaptive, socially inclusive, and technologically progressive.

6. Conclusion

This study systematically examined the global evolution of energy regulations in the building sector, highlighting how diverse countries have implemented frameworks to enhance energy efficiency and reduce environmental impact. The research identified common strategies such as performance-based codes, mandatory energy labeling, financial incentives, and voluntary certification systems like LEED and DGNB through a comparative analysis of regulatory models in the United States, Japan, the United Kingdom, Germany, and the European Union. These international examples demonstrate that successful energy regulations enforce compliance, stimulate market transformation, support technological innovation, and foster public participation in sustainability.

The implications of these findings are particularly relevant to Saudi Arabia as the Kingdom advances its Vision 2030 goals, including reducing 278 million tons of CO_2 emissions and transitioning to 50% renewable energy. Given that buildings account for the majority of electricity consumption in the country, the development of integrated regulatory frameworks is imperative. Lessons from international best practices underscore the importance of combining mandatory energy performance standards with incentive mechanisms tailored to local climatic and socio-economic conditions. By embedding lifecycle-based assessments, post-occupancy evaluations, and digital permit systems into future iterations of the Saudi Building Code and the Mostadam certification system, Saudi Arabia can chart a proactive and adaptive path toward a low-carbon, high-performance built environment. This study thus contributes to the ongoing discourse on sustainable urban development and provides a policy-relevant foundation for future regulatory innovations in the Gulf region.

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