INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Energy Efficiency in Healthcare Buildings: A Systematic Comparative Review of Building Performance, Regulatory Frameworks, and Retrofit Strategies in the United Kingdom and Selected Developing Economies

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DOI: https://doi.org/10.51244/IJRSI.2026.1307000198

Received: 20 July 2026; Accepted: 25 July 2026; Published: 06 August 2026

ABSTRACT

Healthcare buildings are among the most energy-intensive facilities due to their continuous operation, stringent environmental requirements, and reliance on complex building services. Improving their energy efficiency is essential to achieving global decarbonisation goals. This study presents a comparative analysis of energy efficiency in healthcare buildings in the United Kingdom and Kenya, focusing on building performance, regulatory frameworks, and retrofit strategies. A systematic review of peer-reviewed literature, policy documents, technical reports, and case studies was undertaken to evaluate energy use, carbon emissions, regulatory approaches, and energy-efficiency interventions. The findings reveal that UK healthcare buildings generally achieve higher energy performance through stronger regulatory frameworks, greater investment, and wider adoption of advanced technologies. In contrast, healthcare facilities in Kenya face challenges including limited funding, ageing infrastructure, and constrained technical capacity. However, the study identifies several cost-effective measures, including LED lighting upgrades, HVAC optimisation, energy management systems, and solar photovoltaic installations, that can significantly improve energy performance in resource-constrained settings. The study contributes an integrated framework linking building performance, regulation, and retrofit strategies, providing practical recommendations for policymakers, facility managers, and building services engineers seeking to enhance healthcare building sustainability and support decarbonisation objectives.

Key words: Energy efficiency, Renewable energy, Hospitals retrofit, Healthcare buildings, Sustainable healthcare infrastructure

INTRODUCTION

sector is a major contributor to global energy consumption and carbon emissions. Among building types, healthcare facilities are particularly energy intensive due to their continuous operation, strict indoor environmental requirements, and reliance on energy-demanding systems such as heating, ventilation and air conditioning (HVAC), medical equipment, lighting, and sterilisation processes [1]. Consequently, improving energy efficiency in healthcare buildings is essential for reducing operational costs and supporting decarbonisation objectives. Many countries have introduced policies and programmes to improve the energy performance of public-sector buildings. The United Kingdom has made significant progress through initiatives such as the National Health Service (NHS) Net Zero Strategy, public-sector decarbonisation funding, and increasingly stringent building energy regulations [2]. These measures have supported the adoption of technologies including building energy management systems, high-efficiency HVAC systems, LED lighting, improved insulation, and renewable energy technologies. In contrast, healthcare facilities in many developing economies face challenges including limited. The building investment, ageing infrastructure, weak regulatory enforcement, and unreliable electricity supplies, often resulting in inefficient energy use and higher operating costs [3]. Despite these constraints, growing healthcare demand and rising energy costs have increased the need for more sustainable and efficient healthcare infrastructure. Although substantial research has been conducted on building energy efficiency and retrofit technologies, comparative studies that integrate building performance, regulatory frameworks, and retrofit strategies across developed and developing countries remain limited [4]. There is a lack of research examining the transferability of energy-efficiency strategies from the United Kingdom to developing-country contexts such as Kenya, where financial, institutional, and technical conditions differ significantly [5]. This study addresses this gap by conducting a comparative analysis of healthcare building energy efficiency in the United Kingdom and selected developing economies, with particular focus on Kenya. The analysis is structured around three interconnected themes: building energy performance, regulatory and policy frameworks, and retrofit strategies [6]. Through this integrated approach, the study evaluates the suitability of established UK practices for resource-constrained healthcare environments and identifies practical measures capable of improving energy performance and supporting decarbonisation objectives. The aim of this study is to compare energy efficiency in healthcare buildings in the United Kingdom and selected developing economies [7]. Specifically, the research evaluates energy performance indicators, examines regulatory frameworks, assesses retrofit strategies, and develops evidence-based recommendations for prioritising energy-efficiency interventions in developing-country healthcare facilities. By linking technical, regulatory, and operational perspectives, the study contributes to the growing body of knowledge on sustainable healthcare infrastructure and provides practical guidance for policymakers, facility managers, and building services engineers seeking to improve energy performance while maintaining healthcare service quality [8].

RESEARCH DESIGN

This study adopts a systematic comparative review design to examine energy efficiency in healthcare buildings, using the United Kingdom as a benchmark and Kenya as the principal developing-country case. The review also draws on relevant evidence from other developing economies where this provides broader contextual understanding of the technical, financial, institutional, and regulatory challenges affecting healthcare-building energy performance. The analysis focuses on three interconnected dimensions: building energy performance, regulatory frameworks, and retrofit strategies. A systematic review approach was selected because evidence on healthcare-building energy efficiency is dispersed across engineering, energy, healthcare, sustainability, policy, and infrastructure literature. The approach enables the identification, evaluation, and synthesis of existing evidence without requiring the collection of primary building-performance data or the use of building-energy modelling and simulation software. Accordingly, this study does not generate new simulated energy-performance results. Instead, it synthesises and comparatively interprets findings reported in existing academic studies, policy documents, technical reports, and documented healthcare-building case studies. The research is qualitative in design and relies primarily on secondary data. The United Kingdom is used as a benchmark because of its comparatively mature regulatory environment, established healthcare sustainability policies, institutional capacity, and relatively advanced adoption of energy-efficiency and decarbonisation technologies. Kenya is examined as the principal developing-country case because its healthcare sector illustrates challenges associated with constrained investment, ageing infrastructure, technical-capacity limitations, and electricity-supply reliability, while also demonstrating opportunities for practical interventions such as solar photovoltaic systems and energy-management improvements. Evidence from other developing economies is incorporated where relevant to identify common contextual challenges and to assess whether retrofit strategies may have wider applicability beyond Kenya. The comparative analysis is structured around three analytical themes. The first examines building energy performance, including energy use intensity, electricity and thermal energy consumption, HVAC performance, lighting efficiency, renewable-energy integration, energy monitoring, and greenhouse-gas emissions. The second examines regulatory and policy frameworks, including building-energy regulations, healthcare sustainability policies, energy-efficiency standards, environmental assessment schemes, institutional responsibilities, enforcement mechanisms, and available funding support. The third examines retrofit strategies, including building-envelope improvements, insulation, HVAC optimisation and replacement, LED lighting, building energy-management systems, renewable-energy technologies, energy monitoring, and operational-management measures. The analysis uses thematic synthesis and structured comparative analysis rather than statistical meta-analysis or computer-based energy simulation. Evidence extracted from the selected literature is coded according to the three analytical themes and subsequently compared across the United Kingdom, Kenya, and, where relevant, other developing-country contexts. Comparative tables and matrices are used to identify similarities, differences, recurring barriers, successful interventions, and potentially transferable strategies. This research design is appropriate for the study objectives because it enables the integration of technical, regulatory, financial, and institutional evidence within a single analytical framework. It also reflects the practical reality that comparable primary energy-performance datasets are not consistently available across healthcare facilities and national contexts. The study therefore aims to synthesise reported evidence and identify contextually appropriate strategies rather than produce new building-performance predictions.

SYSTEMATIC REVIEW APPROACH

A systematic literature search was conducted to identify evidence relating to energy efficiency in healthcare buildings, with particular emphasis on the United Kingdom, Kenya, and relevant developing-country contexts. The search focused on three principal themes: building energy performance, regulatory frameworks, and retrofit strategies. The literature search was conducted using Scopus, Web of Science, ScienceDirect, PubMed, and Google Scholar. These databases were selected because they provide coverage of research in building engineering, energy efficiency, healthcare infrastructure, sustainability, energy management, environmental policy, and public-sector decarbonisation [9]. In addition to peer-reviewed academic literature, relevant government publications, policy documents, technical guidance, and reports from recognised international organisations were examined to capture regulatory and implementation evidence not always available in journal publications. The search strategy used combinations of predefined keywords and Boolean operators, including energy efficiency and healthcare buildings, Hospital energy consumption and energy performance, hospital and "energy retrofit, healthcare facilities and building regulations, green hospitals and sustainability, hospital and solar photovoltaic, healthcare building and building energy management system, United Kingdom and hospital energy efficiency, Kenya and hospital energy efficiency, and developing countries and healthcare building energy efficiency[10]. The review primarily considered publications published between 2010 and 2025 to capture recent developments in healthcare-building energy efficiency, sustainability policy, and retrofit technologies. Earlier publications were included where they provided important theoretical, methodological, historical, or regulatory context. Backward and forward citation tracking was also used to identify additional relevant publications not retrieved through the initial database searches [11]. The search and screening process resulted in 550 identified records. Following the removal of 90 duplicate records, 460 records underwent title screening. of these, 180 proceeded to abstract screening, 70 were assessed through full-text review, and 50 studies and relevant supporting sources were included in the final evidence base. The selection process was organised according to a staged screening procedure involving identification, duplicate removal, title screening, abstract screening, full-text assessment, and final inclusion [12].

PRISMA-BASED LITERATURE SEARCH AND SCREENING PROCESS

This systematic review was conducted in accordance with the Preferred reporting items for Systematic Reviews and Meta-Analyses (PRISMA) framework diagram 1 to ensure transparency, reproducibility, and methodological rigour. The review process consisted of four stages: identification, screening, eligibility assessment, and inclusion. During the identification stage, literature searches were undertaken in Scopus, Web of Science, ScienceDirect, PubMed, and Google Scholar. Searches were conducted between January and March 2026 using combinations of predefined keywords related to healthcare buildings, energy efficiency, hospital energy consumption, retrofit strategies, building regulations, renewable energy, and sustainable healthcare infrastructure. Boolean operators (AND, OR) were employed to refine search results and improve relevance. Additional records were identified through backward and forward citation tracking of key publications and through a review of policy documents and reports from government agencies, healthcare organisations, and international institutions. The database searches initially yielded 550 records. Following the removal of 90 duplicate records, 460 publications remained for title screening. Titles were screened against the predefined inclusion criteria, resulting in the exclusion of studies primarily focusing on non-healthcare buildings, healthcare service delivery without building-energy considerations, or unrelated sustainability topics. Following title screening, 180 studies were retained for abstract review. During abstract screening, publications were assessed for relevance to the three themes of this review: healthcare-building energy performance, regulatory frameworks, and retrofit strategies. Studies that lacked sufficient methodological detail, were unrelated to healthcare buildings, or did not address energy-efficiency issues were excluded. This process resulted in 70 studies proceeding to full-text assessment. The full-text review evaluated each study against the eligibility criteria. Attention was given to methodological quality, relevance to the research objectives, availability of full-text access, and the extent to which studies provided evidence relating to building performance, regulatory mechanisms, or retrofit interventions. Twenty studies were excluded at this stage because they did not provide sufficient evidence relevant to the study objectives, lacked methodological transparency, or duplicated findings reported elsewhere. Consequently, 50 studies and supporting sources were included in the final evidence base for analysis and synthesis

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Study Selection Criteria

Following the literature search, a structured study selection process was undertaken to identify publications that aligned with the objectives of this review. The selection procedure was guided by predefined inclusion and exclusion criteria to ensure the quality, relevance, and consistency of the evidence incorporated into the comparative analysis. Studies were considered eligible if they focused on energy efficiency in healthcare buildings, including hospitals, clinics, and other healthcare facilities, and examined one or more of the key themes of this review: building energy performance, energy consumption, regulatory frameworks, or retrofit strategies. Eligible studies investigated the United Kingdom, selected developing economies, or provided comparative evidence relevant to these geographical contexts [13]. The review included peer-reviewed journal articles, conference proceedings, government reports, policy documents, and publications from recognised international organisations published in English between 2010 and 2025. Seminal studies published before 2010 were included only when they contributed essential theoretical, methodological, or policy context. Studies were excluded if they focused solely on non-healthcare buildings, addressed healthcare service delivery without considering building energy performance, lacked sufficient methodological information, or consisted of editorials, opinion articles, book reviews, newsletters, or duplicate publications. Non-English publications and studies with inaccessible full texts were also excluded to maintain consistency and ensure the reliability of the review [14]. The study selection was conducted through a three-stage screening process. Initially, duplicate records retrieved from multiple databases were identified and removed. Subsequently, the titles and abstracts of the remaining publications were screened to assess their relevance to the research objectives. Finally, the full texts of potentially eligible studies were reviewed against the predefined selection criteria before inclusion in the final dataset. This systematic screening process reduced the risk of selection bias and ensured that only studies directly relevant to the comparative assessment of healthcare building energy efficiency were retained [15]. Priority was given to studies employing rigorous research methodologies, comprehensive datasets, and clearly reported findings. Official publications from government agencies and international organisations were also prioritised for the assessment of regulatory frameworks and policy initiatives because they provide authoritative and up-to-date information on energy efficiency standards and implementation practices. The final selection of studies formed the evidence base for the subsequent data extraction, thematic synthesis, and comparative analysis of building energy performance, regulatory frameworks, and retrofit strategies in the United Kingdom and selected developing economies.

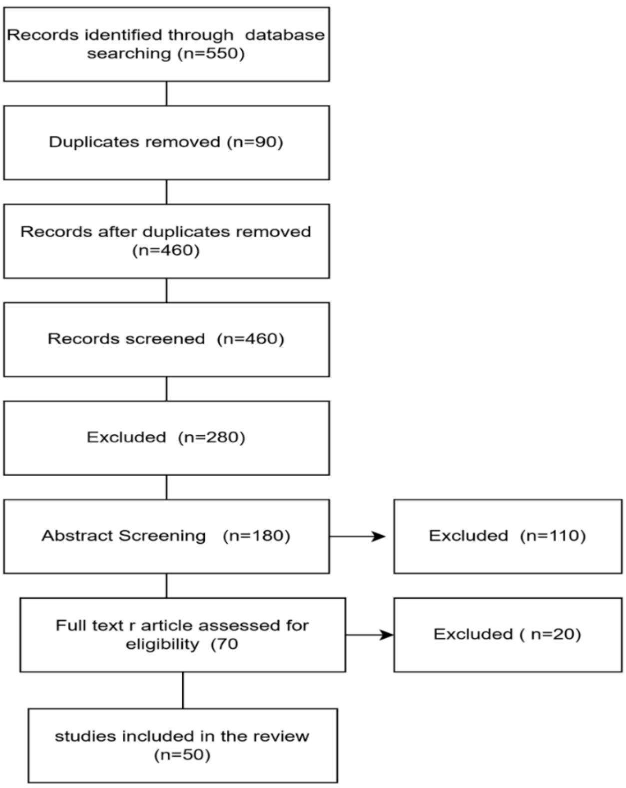

Diagram 1: Prisma flow diagram illustrating the identification, screening, eligibility assessment, and inclusion of studies used in the systematic review.

Screening Stage	Number of Studies
Records identified	550
Duplicates removed	90
Title screening	460
Abstract screening	180
Full-text review	70
Included studies	50

Table 1 Prisma study selection process

QUALITY ASSESSMENT

To improve the reliability and robustness of the review findings, all eligible studies were subjected to a structured quality assessment process. Each publication was evaluated against four criteria: methodological rigour and clarity, relevance to healthcare-building energy efficiency, quality and completeness of reported data, and the reliability of conclusions and recommendations. Studies that satisfied at least three of these criteria were retained for inclusion in the final review. Priority was given to publications from peer-reviewed journals, government agencies, healthcare organisations, and recognised international institutions due to their higher credibility and reliability. This quality assessment process helped minimise potential bias, ensure the inclusion of high-quality evidence, and strengthen the overall validity of the study's findings and conclusions.

Data Extraction

Data extraction was conducted using a structured and standardised approach to ensure consistency and transparency throughout the review process. Following the selection of eligible studies, relevant information was systematically extracted into a data matrix. For each study, bibliographic details, study location, healthcare-facility type, building characteristics, energy-performance indicators, regulatory frameworks, and reported retrofit measures were recorded. Where available, quantitative data such as energy use intensity (EUI), annual energy consumption, carbon emissions, energy savings, and operational costs were also collected [16]. The extracted data were organised into three thematic categories aligned with the study objectives. The first category, building energy performance, included energy consumption patterns, HVAC performance, lighting efficiency, renewable-energy integration, and greenhouse-gas emissions. The second category, regulatory frameworks, covered building regulations, energy-efficiency standards, healthcare sustainability policies, certification schemes, and governance mechanisms influencing healthcare-building performance [17]. The third category, retrofit strategies, included interventions such as HVAC upgrades, LED lighting, building energy management systems (BEMS), insulation improvements, renewable-energy technologies, and energy-monitoring systems [18]. The extracted evidence was reviewed to identify recurring themes, similarities, and differences across the selected countries. Comparative tables and narrative summaries were developed to evaluate the effectiveness of regulatory approaches and retrofit measures under different economic, climatic, and institutional conditions. To minimise errors and ensure consistency, all data were extracted according to a predefined protocol, and any uncertainties were resolved through further examination of the original sources [19]. The resulting dataset formed the basis for the thematic synthesis and comparative analysis presented in the Results and Discussion sections.

Data Synthesis and Analysis

Following data extraction, the selected studies were coded and synthesised using a thematic analysis approach to identify key patterns and trends within the evidence base. The extracted information was organised into three analytical themes: building energy performance, regulatory and policy frameworks, and energy retrofit strategies. Comparative matrices were subsequently developed to facilitate cross-country comparisons between the United Kingdom and Kenya, enabling the identification of similarities, differences, implementation barriers, enabling factors, and transferable best practices. Due to significant variations in study design, reporting methods, climatic conditions, and healthcare-building characteristics across the selected literature, a statistical meta-analysis was considered inappropriate. Therefore, a narrative synthesis approach was adopted to integrate and interpret the findings, allowing for the development of evidence-based conclusions and recommendations regarding energy efficiency improvements in healthcare buildings.

COMPARATIVE ANALYSIS

A comparative analysis approach was employed to examine similarities, differences, and emerging patterns in energy efficiency practices within healthcare buildings across the United Kingdom and selected developing economies [20]. The analysis was structured around the three key themes established during the data extraction process: building energy performance, regulatory frameworks, and retrofit strategies. This framework enabled a systematic evaluation of how variations in technological development, economic conditions, climatic characteristics, institutional capacity, and policy environments influence energy efficiency outcomes in healthcare facilities. The comparison of building energy performance focused on variations in energy consumption patterns, energy use intensity (EUI), carbon emissions, operational efficiency, and the performance of key building systems, including heating, ventilation and air-conditioning (HVAC), lighting, and energy management systems. Where comparable quantitative data were available, performance indicators were examined to identify differences in energy efficiency levels and the factors contributing to improved or reduced building performance. The analysis of regulatory frameworks examined differences in national policies, building energy codes, healthcare facility standards, sustainability guidelines, and regulatory enforcement mechanisms. Attention was given to the extent to which policy frameworks support energy-efficient healthcare infrastructure, including the role of mandatory standards, certification schemes, government initiatives, and institutional governance structures [21]. The comparison considered how mature regulatory environments in developed contexts, such as the United Kingdom, differ from the evolving policy frameworks and implementation challenges commonly observed in developing economies. The assessment of retrofit strategies compared the effectiveness and applicability of energy improvement measures implemented in healthcare buildings. This included evaluating interventions such as building envelope upgrades, insulation improvements, HVAC optimisation, LED lighting systems, renewable energy integration, building energy management systems (BEMS), and smart monitoring technologies [22]. The analysis considered not only energy savings and carbon reduction potential but also economic feasibility, technological availability, maintenance requirements, and suitability within different national contexts. A thematic synthesis approach was adopted to interpret the findings from the selected studies and identify common trends, successful practices, and barriers to implementation. Comparative matrices were developed to organise evidence across countries and highlight transferable strategies that could support energy efficiency improvements in healthcare buildings. The analysis also recognised contextual differences, including variations in climate, healthcare infrastructure quality, financial resources, energy costs, and technical expertise, which influence the feasibility and effectiveness of energy efficiency measures [23]. Through this comparative framework, the study aims to identify lessons from the United Kingdom's established approaches while examining how selected developing economies are addressing energy efficiency challenges within healthcare infrastructure. The findings provide a basis for understanding adaptable strategies and policy recommendations that can support sustainable, low-carbon healthcare buildings across diverse global contexts.

RESULTS AND DISCUSSION

The reviewed literature reveals significant differences in healthcare-building energy performance between the United Kingdom and developing economies. These differences are influenced by variations in infrastructure quality, regulatory enforcement, investment levels, technological adoption, and operational management practices. Although healthcare facilities worldwide have high energy demands due to continuous operation and specialised services, energy-use efficiency varies considerably across national contexts. Healthcare buildings in the United Kingdom generally demonstrate better energy performance due to long-term investment, comprehensive energy regulations, and structured sustainability programmes across the NHS estate. Many

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

facilities have adopted Building Energy Management Systems (BEMS), high-efficiency HVAC systems, LED lighting, improved insulation, and renewable-energy technologies, contributing to reduced energy consumption and lower carbon emissions. In contrast, healthcare facilities in developing economies often experience lower energy efficiency because of ageing infrastructure, inadequate maintenance, limited capital investment, and unreliable electricity supply. Dependence on diesel generators, poor thermal performance of building envelopes, and inefficient building services frequently result in higher operating costs and increased greenhouse-gas emissions. HVAC systems remain the largest contributors to energy consumption in healthcare buildings. UK hospitals generally operate more efficient and automated systems supported by regular maintenance and performance monitoring, whereas facilities in developing economies often rely on outdated equipment with limited automation. Similarly, LED lighting and intelligent lighting controls are widely adopted in the UK but remain less common in many developing countries because of financial constraints. Renewable-energy integration is also more advanced in the UK, supported by government funding and policy incentives. However, the literature highlights significant potential for solar photovoltaic systems in developing economies, particularly where unreliable grid supply affects healthcare operations. Combined with battery storage, these technologies can improve both energy efficiency and energy security. The review further demonstrates that several energy-efficiency measures are transferable across different healthcare settings. Cost-effective interventions such as LED lighting upgrades, HVAC optimisation, improved maintenance practices, basic energy-management systems, and staff awareness programmes can provide meaningful energy savings with relatively modest investment. Overall, the evidence indicates that healthcare-building energy performance is shaped not only by technology but also by governance, regulatory maturity, investment capacity, and operational management. While the United Kingdom has established a mature framework for improving healthcare-building efficiency, developing economies can achieve substantial improvements through the phased adoption of cost-effective retrofit measures supported by stronger policies and targeted investment.

Indicator	UK	Developing Countries
Energy Use Intensity (kWh/m²/year)	350–550	500–900
HVAC share of electricity	45–55%	50–65%
LED adoption	High	Moderate-Low
Building Energy Management Systems	Common	Rare
Renewable Energy	Moderate	Low
Diesel Generator Dependence	Low	High

Table 2 Comparison of Energy Performance Indicators between the UK and Developing Countries [4]

The comparative analysis presented above identifies broad differences in energy performance between healthcare buildings in the United Kingdom and developing economies. However, practical implementation of energy efficiency measures varies considerably depending on institutional capacity, financial resources, regulatory support, and technological availability. To illustrate how retrofit strategies have been implemented in real healthcare environments, two case studies are presented. The first examines a leading National Health Service (NHS) hospital in the United Kingdom, while the second highlight experiences from developing economies. Together, these case studies demonstrate how different combinations of energy management, building retrofits, and renewable energy technologies can improve operational efficiency, reduce carbon emissions, and enhance the resilience of healthcare facilities under diverse economic conditions. To complement the comparative analysis presented above, a case study from the United Kingdom is provided to illustrate how energy efficiency measures have been implemented in practice within a major NHS hospital. The case demonstrates how regulatory support, strategic investment, and integrated energy management systems can improve building performance while maintaining high standards of patient care. It also provides practical lessons that may be adapted for healthcare facilities in developing economies.

CASE STUDY 1: GUY'S AND ST THOMAS' NHS FOUNDATION TRUST, UNITED KINGDOM

Guy's and St Thomas' NHS Foundation Trust are one of the largest healthcare providers in the United Kingdom, operating Guy's Hospital, St Thomas' Hospital, Evelina London Children's Hospital, and several community healthcare facilities. The Trust has been actively implementing energy efficiency and decarbonisation measures to support NHS Net Zero targets

ENERGY EFFICIENCY INTERVENTIONS

The Trust has implemented a comprehensive range of energy-efficiency initiatives, including the installation of solar photovoltaic (PV) systems and battery storage across healthcare sites, the deployment of building energy management and monitoring systems, upgrades to low-carbon heating infrastructure, modernisation of ageing energy assets, and continuous monitoring of building energy performance to reduce energy consumption and carbon emissions. In 2026, the Trust installed solar PV systems at five community healthcare facilities with support from a £667,000 grant from Great British Energy [24].

Measure	Result
Annual financial savings	Approximately £57,000/year
Carbon reduction	About 50 tonnes CO_2/year
Solar electricity contribution	Up to 50% of annual site electricity demand at selected facilities
Battery storage integration	Installed at three sites

Table 3 Reported outcomes of the intervention

In addition, the Trust entered a strategic partnership to replace ageing energy infrastructure with low-carbon heating and energy systems. The programme aims to lower energy consumption, improve resilience, reduce emissions, and decrease operating costs without requiring upfront NHS capital expenditure. The Guy's and St Thomas' case demonstrates how regulatory support, investment mechanisms, and advanced energy management practices enable healthcare facilities to achieve significant energy and carbon reductions [25]. The combination of renewable energy generation, efficient building services, and digital energy monitoring aligns with the findings presented in Table 1, where UK hospitals exhibit high adoption of Building Energy Management Systems (BEMS), extensive LED deployment, and increasing renewable energy integration.

CASE STUDY 2: MAKUENI COUNTY REFERRAL HOSPITAL, KENYA

Makueni County Referral Hospital is one of the largest public healthcare facilities in rural Kenya, serving approximately 500 patients daily. Like many healthcare facilities in developing economies, the hospital historically experienced high electricity costs and dependence on an unreliable electrical grid.

ENERGY EFFICIENCY INTERVENTION

In 2024, the hospital implemented a solar photovoltaic (PV) energy system to reduce operational costs and improve energy security. The project was designed to supplement grid electricity, reduce diesel generator dependency, and enhance service reliability [26].

Measure	Result
Annual solar generation	288 MWh/year

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VII July 2026

Contribution to electricity demand	30–33%
Annual financial savings	KSh 7 million/year (≈ £40,000)
Monthly energy bill before project	KSh 1.8 million
Monthly energy bill after project	KSh 1.1–1.2 million
Monthly savings	KSh 600,000–700,000

Table 4 Measured outcomes

The Kenyan experience illustrates that renewable energy represents one of the most practical retrofit options for healthcare facilities in developing economies [27. Unlike many capital-intensive building-envelope upgrades, solar PV installations can provide immediate reductions in electricity expenditure while improving resilience against power interruptions. The findings support the conclusions of this study that renewable energy integration, combined with basic energy management improvements, offers a high-impact and cost-effective pathway for improving healthcare building performance in resource-constrained settings [28].

Indicator	Guy's and St Thomas' NHS Trust (UK)	Makueni County Referral Hospital (Kenya)
Main Intervention	Solar PV, BEMS, low-carbon heating, energy infrastructure upgrades	Solar PV installation
Renewable Energy Contribution	Up to 50% at selected sites	30–33% of electricity demand
Annual Financial Savings	£57,000/year	KSh 7 million/year
Carbon Reduction	50 tCO_2/year	Significant reduction through reduced grid and generator use
Regulatory Environment	Strong NHS Net Zero and UK energy regulations	Emerging policy framework
Transferability	High technical sophistication	Appropriate for resource-constrained settings

Table 5 Comparative Summary [28]

COMPARATIVE ANALYSIS OF REGULATORY FRAMEWORKS

The regulatory environment plays a critical role in improving energy efficiency within healthcare buildings by establishing minimum performance standards, encouraging sustainable building practices, and facilitating investment in low-carbon technologies. The comparative analysis reveals considerable differences between the United Kingdom and Kenya in terms of regulatory maturity, enforcement mechanisms, and policy support for sustainable healthcare infrastructure. In the United Kingdom, healthcare buildings operate within a comprehensive regulatory framework that includes Building Regulations Part L, the NHS Net Zero Strategy, the Public Sector Decarbonisation Scheme, the Energy Savings Opportunity Scheme (ESOS), and BREEAM sustainability assessment standards [29]. These policies establish mandatory energy performance requirements and provide financial support for energy efficiency and decarbonisation projects. Consequently, UK healthcare organisations have increasingly adopted energy-efficient technologies, renewable energy systems, and building energy management systems to meet national carbon reduction targets. In contrast, Kenya has made significant progress through the Energy Act 2019, national energy efficiency strategies, and renewable energy policies [28]. However, enforcement remains less comprehensive than in the UK due to financial constraints, limited technical capacity, and competing infrastructure priorities. Although renewable energy adoption is increasing, many healthcare facilities continue to experience challenges associated with inadequate funding, ageing infrastructure, and unreliable electricity supply. The findings indicate that stronger regulatory enforcement and dedicated funding mechanisms have contributed significantly to the higher energy performance observed in UK healthcare buildings. Developing economies can benefit from adapting regulatory approaches that incentivise energy-efficient healthcare infrastructure while recognising local economic and institutional constraints [30].

Aspect	United Kingdom	Kenya
Building Energy Regulations	Comprehensive and mandatory	Emerging and developing
Enforcement Mechanisms	Strong	Moderate
Healthcare Sustainability Policies	NHS Net Zero Strategy	National Energy Efficiency Strategy
Funding Mechanisms	Extensive government support	Limited funding availability
Renewable Energy Incentives	Well established	Growing
Building Certification Systems	BREEAM	Limited application

Table 6 Comparison regulatory frameworks

COMPARATIVE ANALYSIS OF RETROFIT STRATEGIES

Energy retrofit measures provide a practical means of reducing energy consumption in existing healthcare facilities. The reviewed literature indicates that the effectiveness of retrofit measures varies according to building condition, climate, available funding, and technical capacity. Low-cost measures such as LED lighting replacement, equipment scheduling optimisation, preventive maintenance, and staff awareness programmes consistently demonstrate favourable payback periods and significant energy savings. These interventions are particularly suitable for healthcare facilities in developing economies where capital resources are limited. Medium-cost measures include building energy management systems (BEMS), variable speed drives, occupancy controls, and HVAC optimisation strategies [31]. These technologies improve operational efficiency and facilitate continuous monitoring of building performance. High-cost measures such as building envelope upgrades, insulation improvements, renewable energy installations, and complete HVAC replacement offer substantial long-term benefits but require significant upfront investment. Despite these challenges, solar photovoltaic systems have demonstrated strong potential in both developed and developing healthcare settings due to declining technology costs and increasing energy prices [32].

Retrofit Measure	Typical Energy Savings (%)	Cost Level	Suitability for Developing Economies
LED Lighting	10–20	Low	High
HVAC Optimisation	15–30	Medium	High
Building Energy Management System	5–15	Medium	Medium
Insulation Upgrades	10–25	Medium	Medium

Solar PV Systems	15–35	Medium-High	High
Full HVAC Replacement	20–40	High	Low-Medium

Table 7 Comparative assessment of retrofit measures [12]

The analysis suggests that LED lighting, HVAC optimisation, and solar photovoltaic installations offer the most practical balance between cost and energy savings for developing economy healthcare facilities. The energy-saving ranges represent reported values identified in the reviewed literature and should not be interpreted as standardised predictions applicable to all healthcare buildings.

COST-BENEFIT ANALYSIS OF RETROFIT OPTIONS

A simplified cost-benefit assessment indicates that retrofit priorities should be based on both expected energy savings and investment requirements. Low-cost measures such as LED lighting, HVAC optimisation, and staff energy-management practices generally require limited capital investment and can provide relatively rapid financial returns. Building energy management systems (BEMS) require greater initial investment but can provide longer-term benefits through improved monitoring, control, and maintenance. Solar photovoltaic (PV) systems generally involve higher upfront costs but can reduce electricity expenditure and improve energy resilience, particularly where grid electricity is unreliable. Table 7 summarises the relative economic attractiveness of the main measures.

Retrofit measure	Initial cost	Expected benefit	Payback potential	Suitability
LED lighting	Low	Energy and maintenance savings	Short	High
HVAC optimisation	Low–Medium	Reduced cooling/heating demand	Short–Medium	High
BEMS	Medium	Improved monitoring and operational control	Medium	Medium–High
Solar PV	Medium–High	Lower electricity costs and improved energy resilience	Medium	High
HVAC replacement	High	Substantial long-term energy savings	Medium–Long	Medium

Table 8 Comparative cost-benefit assessment of retrofit measures

The assessment suggests that resource-constrained hospitals should prioritise low-cost measures with rapid returns before progressing to capital-intensive interventions. However, actual payback periods depend on local energy prices, building conditions, system size, operating patterns, and available financing. Therefore, project-specific financial analysis is recommended before implementation.

DISCUSSION

The findings indicate that healthcare buildings in the United Kingdom generally achieve better energy performance than those in developing economies, largely due to stronger regulatory frameworks, greater investment capacity, and wider adoption of advanced energy-management technologies. While healthcare facilities worldwide face similar operational demands, differences in policy support, funding availability, and technical capacity significantly influence energy-efficiency outcomes. A key finding is the importance of regulatory frameworks and energy-management practices in driving efficiency improvements. UK policies, including Building Regulations Part L, the NHS Net Zero Strategy, ESOS, and the Public Sector Decarbonisation Scheme, have encouraged investment in low-carbon technologies and energy-efficient building systems. In contrast, developing economies often face barriers related to limited funding, weaker enforcement, and inadequate technical resources. The review also highlights the value of Building Energy Management Systems (BEMS), HVAC optimisation, and renewable-energy technologies. Real-time monitoring systems improve operational efficiency and maintenance practices, while solar photovoltaic installations offer significant opportunities to reduce operating costs, lower emissions, and enhance energy security. These benefits are particularly important in regions affected by unreliable electricity supplies. Importantly, several low-cost and transferable retrofit measures were identified, including LED lighting upgrades, HVAC optimisation, basic energy management systems, and staff energy-awareness programmes. Such interventions can deliver meaningful energy savings and are well suited to resource-constrained healthcare facilities. This review is limited by its reliance on secondary data and the uneven availability of comparable energy-performance information across countries. Research should prioritise primary performance monitoring, post-retrofit evaluations, and detailed economic assessments, including life-cycle costs and payback periods. Future studies should also examine how hospital type, building age, climate zone, occupancy patterns, and healthcare service demand influence energy performance and the effectiveness of retrofit measures. Further studies should also examine the long-term impacts of renewable-energy systems, battery storage, and smart-building technologies across different healthcare settings and climatic conditions.

CONCLUSION

Healthcare buildings are among the most energy-intensive facility types, making energy efficiency a critical component of sustainable healthcare infrastructure. This study compared healthcare-building energy efficiency in the United Kingdom and Kenya by examining building performance, regulatory frameworks, and retrofit strategies. The findings indicate that UK healthcare facilities generally achieve higher energy performance due to stronger regulatory support, greater investment capacity, and wider adoption of advanced energy-management technologies, whereas Kenyan facilities face challenges associated with limited funding, ageing infrastructure, and unreliable energy supply. Despite these differences, several retrofit measures were identified as effective and transferable across both contexts. LED lighting, HVAC optimisation, building energy management systems, and solar photovoltaic installations offer practical opportunities to reduce energy consumption, lower operational costs, and support decarbonisation objectives. The case studies further demonstrate that energy-efficiency improvements can deliver measurable financial, operational, and environmental benefits while enhancing healthcare-service resilience. The study concludes that improving healthcare-building sustainability requires a combination of effective policy frameworks, targeted investment, energy-management practices, and renewable-energy integration. Future research should focus on primary performance data, long-term post-retrofit evaluation, and detailed economic assessments to support the development of context-specific and financially viable energy-efficiency strategies for healthcare facilities.

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