On the review of sustainable green building in hospital structures

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Abstract

This review article examines the evolution and significance of sustainable green building practices within hospital structures. As healthcare facilities are among the largest consumers of energy and resources, their impact on environmental sustainability is profound. This paper synthesizes existing literature on the principles and strategies employed in designing and retrofitting hospitals to enhance sustainability. Key themes explored include energy efficiency, the integration of renewable energy technologies, water conservation strategies, and the use of sustainable materials. The article also discusses the implementation of green certifications, such as LEED (Leadership in Energy and Environmental Design), which guide healthcare facilities in their sustainability efforts. Furthermore, the paper highlights case studies of successful green hospital projects, demonstrating measurable outcomes in operational efficiency, cost savings, and improved patient health outcomes. By illustrating the multifaceted approach required for sustainable hospital design, this review emphasizes the necessity of collaboration among architects, engineers, healthcare providers, and policymakers to create environments that prioritize both patient care and environmental stewardship.

Keywords: Sustainable green, hospital building, energy efficiency, healthcare facilities, environmental impact

1. Introduction

The energy consumption and greenhouse gas emissions of buildings represent a significant global issue. Healthcare facilities, essential to society, present specific challenges due to their continuous operation and rigorous hygiene requirements [1]. The study by [1] explores strategies for energy-efficient healthcare buildings, analyzing both passive (orientation, materials) and active (HVAC, renewable energy) approaches. Results show user behavior impacts energy conservation significantly, with manual systems saving more than automated ones. BIM tools calculate life-cycle energy use, and retrofitting buildings can save up to 89% in energy. Solar power is widely used, though high costs challenge adoption. Further research on small-scale healthcare buildings and alternative energy sources is recommended [1]. The researcher in [2] investigated the concept of "Green Hospitals" to explore how hospitals can reduce environmental impact while enhancing health. Data from multiple sources revealed various rating systems like GRIHA, IGBC, and BEE's Star Rating, all emphasizing energy, water efficiency, and waste management. Results show overlapping strategies across different regions due to local needs. Although green hospitals promote sustainability, challenges such as construction constraints and diverse rating systems remain significant barriers [2]. The study by [3] addresses the challenges of climate change on healthcare, particularly highlighting the concept of "Green Hospitals" as a solution. By integrating renewable energy, sustainable materials, and smart systems, healthcare facilities can reduce carbon emissions and environmental impact. Results show that green hospitals face challenges such as waste management and financial constraints, but improving resource efficiency and reducing CO_2 can meet the demands of a growing population. System reforms are urgently needed for sustainability and resilience [3].

Other researchers such [4] examine how Artificial Intelligence (AI) enhances healthcare operations and supply chain management, reinforcing socially responsible and environmentally sustainable practices in hospitals. Their study highlights AI's role in creating green hospitals by optimizing processes like energy use, waste management, and innovation in patient care. This research outlines key strategies for integrating AI to promote hospitals' green image, addressing sustainability challenges while contributing to healthier communities and achieving global environmental goals [4]. Researchers in [5] explored how green organizational practices (GOPs) in healthcare can mitigate climate change. Their study, focusing on public hospitals, revealed that combining practices like green energy procurement, waste management, and energy management drives higher climate change mitigation performance (CCMP). By employing Data Envelopment and fuzzy set Qualitative Comparative Analysis, they found that strategic alignment and synergy among GOPs yield the best results. This research provides hospitals with actionable insights to enhance sustainability, showing that tailored combinations of green practices significantly improve environmental outcomes [5]. Researchers such [6] developed AI-driven system optimization algorithms for communication systems in green hospitals, crucial to sustainable cities. The study designed an architecture and functional modules, including patient monitoring and equipment management using IoT technologies. By integrating these systems, real-time patient data is accessible, improving efficiency. Additionally, the accuracy of the particle swarm optimization (PSO) algorithm was compared with a BP neural network, showing superior performance. Their research emphasizes the importance of AI-driven solutions in optimizing green hospital operations for smarter, sustainable healthcare environments [6].

The study by [7] explores optimizing energy savings in Malaysian public hospitals to achieve green building certification. Researchers employed energy audits, empirical evidence, and simulations to maximize energy efficiency. By retrofitting chiller systems, they achieved savings of 1,688,347.02 kWh/year, exceeding predictions. Additionally, passive strategies were evaluated using simulations to establish an energy baseline. This combination of active and passive approaches demonstrates how hospitals can significantly reduce energy consumption and operational costs, contributing to Malaysia's environmental conservation goals while ensuring energy-efficient healthcare facilities [7]. The study by [8] highlights the urgent need for radiologists to engage in sustainable practices to mitigate healthcare's environmental impact. It emphasizes radiologists' critical role in decarbonizing the healthcare system through informed, climate-smart decisions within radiology departments. Initial educational initiatives, such as grand rounds and journal clubs, aim to increase awareness of radiology's environmental footprint and promote waste reduction strategies. By adopting more sustainable imaging services, radiologists can significantly contribute to a healthier planet while continuing to deliver high-quality patient care [8]. The research by [9] addresses the critical need for efficient and sustainable energy management in hospitals to mitigate environmental impacts and improve operational efficiency. It presents comprehensive guidelines developed from literature reviews, case studies, and expert insights, focusing on culture change, energy management standards, renewable energy procurement, and green technologies. By implementing these guidelines, hospitals can overcome sustainability challenges, enhance energy efficiency, and contribute to the UN's SDG7, promoting a transition towards clean energy and fostering a competitive advantage in the healthcare sector [9].

The study by [10] investigates the green assessment criteria essential for the development of public hospital buildings in Malaysia, emphasizing the country's commitment to sustainability. It highlights the significant environmental impact of healthcare facilities, which operate 24/7 and consume substantial energy due to stringent cleaning procedures and advanced medical equipment. By reviewing and analyzing existing global green rating systems, the study identifies critical assessment criteria and compares them with Malaysia's green rating framework. The findings aim to provide initial guidelines to help Malaysian public hospitals adopt consistent and systematic practices for green building development, ultimately promoting healthier environments and sustainable operations [10]. This study presents a hybrid optimization model for a microgrid system designed for a sustainable hospital in NEOM, Saudi Arabia. While the research by [11] focuses on integrating multiple renewable energy resources to create a standalone energy system while managing hospital waste. Key components of the hybrid model include biogas co-firing, diesel generators, photovoltaic (PV) solar arrays, and Tesla batteries. By utilizing data from NASA's surface meteorology and existing literature, simulations were conducted to assess the energy demands of a hospital with a daily load requirement of 250 kWh and an average waste generation of 0.6 tons. The results indicate that the hybrid system can efficiently meet energy needs, with 32.3% of the energy supplied by the PV array and 67.6% by biogas co-firing, supported by eight Tesla PowerWall2.0 batteries. The cost of energy was calculated at 0.21 USD/kWh, with a net present cost of approximately 243,699.17 USD. Notably, this hybrid solution can reduce carbon emissions and diesel consumption by 84% and 81%, respectively. A sensitivity analysis was performed to verify the results, which were compared to similar studies, demonstrating the viability of renewable energy solutions in optimizing hospital operations in a sustainable urban environment [11]. The study by [12] explores the implementation of green building concepts at the Orthopaedic Hospital of Prof. Dr. R. Soeharso in Surakarta, Indonesia, in response to the escalating issue of global warming. Their research aims to develop strategies that encompass functional programming, enhanced hospital service capacity, and marketing strategies grounded in clinical approaches. By analyzing market share data, the study projects patient inflow for the year 2020, enabling the identification of essential facilities that the hospital should prioritize in its development. The proposed green concepts focus on optimizing resource use and enhancing environmental sustainability within healthcare settings. This includes integrating energy-efficient designs, sustainable materials, and eco-friendly operational practices. The study underscores the importance of aligning healthcare infrastructure with environmental goals to create a healthier space for both patients and staff while contributing to the broader efforts of climate change mitigation. Their findings will guide the hospital in making informed decisions regarding its facilities and services, ensuring a balance between patient care and ecological responsibility [12].

The study by [13] focuses on the design and construction of an energy-efficient companion house with accommodation facilities at Firat University Research Hospital, emphasizing sustainability in public service architecture. With the rising interest in social responsibility, this project integrates energy-saving strategies while enhancing the quality of services provided by public enterprises. The energy performance of the current building was assessed using Building Information Modeling (BIM) through Autodesk Revit Architecture Simulation Software. The study then explored the potential energy efficiency improvements by redesigning the building to include green walls and roofs, reflecting the principles of the green hospital concept. A comparative analysis of the energy performances was conducted to highlight the benefits of transforming traditional public buildings into green facilities. Ultimately, this research aims to serve as a model for future public constructions, demonstrating how integrating sustainable practices can lead to significant energy savings and improved environmental outcomes, thus contributing to the broader goals of sustainability in healthcare infrastructure [13]. The research by [14] explores the principles of sustainable design in hospital buildings, focusing on the significant energy consumption of the construction and healthcare sectors. With technological progress and environmental changes, especially in light of modern epidemics, hospitals are key contributors to natural resource consumption. Therefore, creating sustainable healthcare environments is crucial. Their study examines the environmental, economic, health, and social benefits of sustainable hospital design. It proposes a model to guide healthcare officials in implementing sustainable practices, aiming to achieve a balanced environment that reduces resource consumption, minimizes pollution, and promotes human well-being. Sustainable design principles are aligned with concepts like green architecture and smart design, emphasizing the integration of human needs with ecosystem preservation. Their research highlights the importance of flexible and adaptable hospital buildings that support environmental, social, and economic sustainability. By increasing awareness and applying sustainability indicators, hospital designs can meet the demands of modern healthcare while fostering a healthier, more sustainable future. Their ultimate goal is to create hospital buildings that optimize environmental, social, and economic outcomes [14]. The study by [15] explores the interconnectedness of climate change and healthcare, highlighting how hospitals contribute to and are affected by climate change. The review aims to define the concept of a "Green Hospital," identify the healthcare sector's environmental impact, and examine ways to mitigate these effects. Data from online sources reveal that hospitals, due to their resource-intensive nature, consume large amounts of energy, water, and materials, significantly contributing to environmental degradation. Their study shows that while constructing Green Hospitals is challenging, especially with local conditions and rising patient expectations, it is possible. Some healthcare institutions have successfully implemented sustainable practices, demonstrating that high-quality care and environmental responsibility can coexist. Examples from India, such as J.J. Hospital and Tripolia Hospital, show that reducing carbon footprints while maintaining healthcare standards is achievable. The research concludes that Green Hospitals are an emerging reality and offer a path forward in addressing the healthcare sector's contribution to climate change [15].

The study by [16] investigates sustainable energy management practices in hospital buildings to address the growing concerns about environmental impacts and their financial implications for healthcare institutions. As hospitals aim to deliver high-quality care, integrating sustainability principles becomes essential in reducing emissions and resource waste. This research focuses on emission reduction management in healthcare by reviewing literature on sustainable practices, green infrastructure, and energy management in hospitals. Data was sourced from hospital case studies in Thailand, Taiwan, and Indonesia, based on virtual observations, and a comparison was made between the practices in these countries. Their findings reveal that, despite the absence of standardized "Green Hospital" guidelines in these countries, adopting green infrastructure significantly improves cost efficiency and sustainability in healthcare facilities. The research highlights Energy Saving Opportunities (PHE) as a method to reduce energy consumption, particularly by controlling infrastructure that uses large amounts of energy, such as lighting and air conditioning, while excluding vital medical equipment. This approach demonstrates how hospitals can achieve more sustainable operations through efficient energy management practices [16]. The study by [17] presents an optimal decision model for sustainable hospital building renovations, specifically focusing on converting vacant school buildings into community public hospitals. In the context of increasing global energy consumption in the building sector, this research emphasizes the need for sustainable solutions in hospital environments, which must maintain high hygiene standards while minimizing energy use. A genetic algorithm and A* graph search algorithm-based model is introduced to evaluate existing hospital conditions and recommend renovation strategies that balance cost, quality improvement, and environmental impact. Their research showcases a case study in Taiwan, where the declining birth rate has resulted in vacant school spaces. Converting these buildings into community hospitals aligns with the country's aging population and the growing need for integrated medical and elder-care services. Their model assesses building conditions, optimizes renovation strategies, and validates them through a simulated renovation project. The results demonstrate that the system provides better solutions than traditional decision-making methods, achieving budget efficiency, improved building quality, and reduced environmental impact. Their study concludes that reusing vacant buildings for healthcare purposes is a globally sustainable trend. The proposed system offers a comprehensive and effective approach to hospital renovation planning, though its application to non-hospital buildings and functionally specific adjustments requires further research [17]. Another study by [18] explores the application of Building Information Modeling (BIM) to pre-evaluate the performance of green hospital buildings, aiming to enhance sustainability in the healthcare sector. Hospital buildings typically have higher energy consumption compared to other structures, making green optimization essential. To address this, the research establishes a BIM-based performance pre-evaluation system, integrating expert consultation and literature review to create an index system for green hospital performance evaluation. The Cloud Model and Matter–Element Extension Theory are employed to develop models, with data processed through MATLAB for final green grade calculations. Their study uses Maluan Bay Hospital as a case study to validate the model, showing its strengths in simulation, optimization, and fuzzy quantification. The BIM-based system allows for cyclical performance simulations and adjustments during the design phase, leading to better green outcomes. Inpatient satisfaction is highlighted as a key performance metric, further contributing to a comprehensive and patient-centered approach. Their research concludes that the BIM-based pre-evaluation system can effectively guide the design and construction of green hospitals, although the model's current index system lacks sufficient emphasis on smart medical devices [18].

2. Conclusions

The transition to sustainable green building practices in hospital structures is not merely a trend but a critical necessity for future healthcare delivery. As the global population continues to grow, the demand for healthcare services will escalate, intensifying the need for energy-efficient and environmentally friendly hospital designs. This review highlights the multifaceted benefits of green hospitals, including significant reductions in operational costs, enhanced patient health outcomes, and compliance with increasingly stringent environmental regulations. By prioritizing sustainability in hospital design, healthcare facilities can play a pivotal role in addressing the challenges of climate change while also improving their service delivery.

Moreover, the importance of adopting a holistic approach that involves various stakeholders—ranging from architects and engineers to healthcare administrators and policymakers—cannot be overstated. Collaboration across disciplines will foster innovative solutions that are both practical and effective in promoting sustainability in healthcare. The findings of this review call for continued research and development of best practices, as well as the encouragement of more hospitals to pursue green certifications and sustainability initiatives. In conclusion, the integration of sustainable practices in hospital buildings is a vital step towards creating healthier environments for patients and communities, ensuring that healthcare systems contribute positively to the planet while delivering optimal care.

3. CRedit Author Statement

Taufiq Rochman: Data curation, Writing- Original draft preparation, Data curation, Visualization, Investigation,

Resources, Writing- Reviewing and Editing, English pre-proof, Supervision
Suselo Utoyo: Conceptualization, Methodology, Writing-Reviewing and Editing, Supervision, Resources, Validity.

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5. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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