IJARASEM

ISSN: 2395-7852

International Journal of Advanced Research in Arts, Science, Engineering & Management

Volume 10, Issue 2, March 2023

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 6.551

International Journal of Advanced Research in Arts, Science, Engineering & Management (IJARASEM)

| ISSN: 2395-7852 | www.ijarasem.com | Impact Factor: 6.551 |Bimonthly, Peer Reviewed & Referred Journal|

| Volume 10, Issue 2, March 2023 |

The Impact of Sustainable Design Features on Hospital Energy Consumption and Carbon Emissions

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ABSTRACT: The construction industry (CI) has a significant impact on the environment and on climate change due to the emission of greenhouse gases like carbon dioxide. Globally accepted Sustainable Development Goals (SDG), specifically SDG 7 (Access to Affordable, Reliable, Sustainable and Modern Energy for All), SDG 9 (Industry, Innovation and Infrastructure), and SDG 11 (Sustainable Cities and Communities) stress the responsible utilization of energy in various industries, including construction. The CI uses almost half of the world's produced energy. Therefore, this research presents insights into the efficient use of energy in the building sector and shows how energy efficiency can be achieved by altering different parameters and components like orientation, materials, glazing, and HVAC systems through a case study of a hospital building in Green Building Studio (GBS). This paper also aims to use the Building Information Modelling (BIM) approach to make environmentally sustainable decisions to reduce energy waste in projects. Initially, beneficial factors of BIM on green buildings were identified in the literature and later ranked, based on expert opinions collected using a set of questionnaires. Average Index was used for data analysis. The identified benefits were validated by conducting energy analyses on a hospital model through 3D BIM. It was concluded that a substantial share of energy cost, carbon dioxide (CO_2), and electricity can be saved using this approach. It was determined that a quick and sustainable design process, improved energy efficiency, enhanced building performance, and provision of better design alternatives are the key benefits of the adoption of BIM by such projects. A Cronbach's alpha value of 0.822 was obtained, which further validates the results. The proposed approach may lead future structures to be sustainable and enriches the culture of energy-efficient green buildings.

KEYWORDS: sustainable, hospital, consumption, carbon, emissions, green buildings, communities, industry, infrastructure

I.INTRODUCTION

Due to their large building volume and their continuous operation, hospitals are considered to be among the most energy-intensive building units, with a highly negative impact on the environment [1,2]. The constant human activity that takes place in these buildings and the numerous people who are working or moving into these structures make proper energy management a necessity. Furthermore, energy management in hospitals is an important factor since its mismanagement leads to an increase in operating costs, a negative environmental impact, and a decrease in competitiveness [3]. However, the medical devices used in intensive care units (ICU), surgery rooms, imaging units, and furnaces also require large amounts of energy for smooth functioning. Nevertheless, the largest energy consumption in hospital units comes from heating, cooling, lighting, and hot water, which are usually covered by the cogeneration of electricity, gas, and oil and, in some cases, by photovoltaic solar panels [4,5,6,7]. Governments and hospital administrations are looking for economical energy solutions that will subtractively work in addressing the high prices that they pay to secure energy, in order to reduce operating costs [8,9,10]. In this regard, investment projects to promote energy efficiency are activated by the public or private sectors and also, sometimes, through public–private partnerships [10]. These energy activities are usually undertaken by energy service companies [10]. The complex and continuous operation of the existing hospitals may not allow extensive, quick, and easy interventions; however, the "green health" of the patients, combined with the actual need to save energy resources, require dynamic interventions [11]. It is a difficult equation that requires a deep knowledge of the existing hospital upgrade techniques, along with the search for new methods through scientific research that will provide a reliable solution for energy upgrades and saving resources. The BIM (building information model) has opened up new possibilities in terms of the technical design and construction management of hospital facilities [12,13,14,15]. By means of its application, we gain early warnings that help to deal effectively with design mismatches [16,17,18]. The BIM

methodology, applied at the different levels of 6D and 7D, addresses multidimensional problems that cannot be dealt with in a practical way [19,20]. The environmental performance of hospitals, including the goal of energy efficiency, should be achieved through a holistic approach, with a commitment to continuous improvement and responsible use by the human factor [21]. Following this holistic approach, de Oliveira et al. [3] considered sustainable buildings, cultural change, prudent energy consumption, the usage of energy from renewable sources, energy management standards, green technologies, and social responsibility programs to be necessary factors in public policies. Only a few studies link the energy performance of hospitals to the end users such as hospital employees, patients, and visitors; therefore, it is necessary to incorporate user perceptions into the final design [22].

The energy crisis that erupted after Russia's invasion of Ukraine and the energy cuts seen in many sectors of economic and social activity have made the need for better energy performance in hospitals more urgent. At the same time, it gave scientific research a starting point for finding new approaches to hospitals' energy efficiency issues. [23,24,25]This systematic literature review responds to the call for greater research interest in finding solutions for energy efficiency in both new and old hospitals, saving resources, and improving the quality of the services offered. Through the selection of 185 studies published between 2012 and 2021, the present review aims to capture the existing knowledge related to strategies for energy efficiency in hospitals via technology choices, saving resources, and identifying the relationship between energy efficiency and the quality of the services provided. These sub-objectives feature dimensions such as the examination of energy upgrades regarding the different forms of renewable energy sources, the development of cogeneration systems in hospitals in relation to photovoltaic units, and the role of the environment and climate conditions in the selection of efficient resource-saving systems. Furthermore, it explores to what extent the existing surveys capture the full range of hospital facility types, the public and private sectors, and small-sized and large-sized hospital units. It also includes a comparison of the energy efficiency of hospitals based on their field of expertise, as well as the comparative specialisms among them. The major aim of this process was the extraction of data for tracing convergences and divergences.[26,27]

II.DISCUSSION

"The design of eco-friendly, energy-efficient, green construction projects has been gaining attention in all quarters, from the construction of private homes, office buildings, to large buildings such as hospital complexes. In the health sector, the so-called "Green Hospital" is a concept that is beginning to redefine how healthcare facilities are built to protect the environment while saving human lives.The greater the amount of energy consumed in a hospital, the greater the release of toxic wastes to the environment, causing damage which may put human lives at risk of other diseases and death.[28,29,30]The shift to constructing sustainable healthcare facilities is largely centered on reducing the carbon burden in hospitals while ensuring that the occupants - staff and patients - are kept safe.More and more hospital administrators are beginning to involve architects in incorporating green concepts into hospital design. In fact, according to a report by SBI Energy, green building renovations will experience a significant increase.Hospitals utilize more resources and produce more waste materials than most other commercial buildings of a similar size. Healthcare facilities in the country consume more than 315 gallons of water per bed every day and an average US hospital consumes 103.600 Btu of natural gas per square foot annually.In a typical healthcare centre, lighting, water heating, and space heating account for more than 65% of the energy consumption. Therefore, it remains essential for the construction of healthcare facilities to involve incorporation of green designs and concepts into the process to reduce the impact on the environment, cut down operational costs, and increase energy efficiency.[31,32,33]Hospital administrations have teamed up with designers, architects and construction companies to achieve the Leadership in Energy and Environmental Design, also called LEED. LEED is a system developed by the United States Green Building Council to rate a building and certify it as "green" based on design, construction, and operations of the building.[34,35]

Green Hospital Initiatives

Core measures adopted for green buildings include the use of energy-efficient lighting systems and medical equipment and use of tech-enhanced renewable energy systems. In addition to using energy more efficiently, hospitals are looking at how to create designs that allow more daylight exposure and natural ventilation into the environment.Improving the air quality is an essential component of designing the green hospital. Hospitals are exploring efficient ways of reducing the air content of toxins and contaminants across all corners of the building.The California Pacific Medical Center (CPMC), for instance, has initiated several design features to achieve a green working environment. One of such features is the use of a low-flow plumbing system in a bid to save three million gallons of water every year for the state of California, which many experts

have said may experience a long period of drought.CPMC also has a design initiative to capture rainwater from the roof and use it to irrigate the landscaping, a measure, which they say, would save 180,000 gallons of drinkable water every year.[36,37,38] In addition, the collected rainwater will also be used to operate cooling towers which the hospital uses for their air conditioning system.For energy efficiency, CPMC has implemented a number of green design initiatives to achieve energy consumption at a level, 14 percent less than that of the average US hospital. Some of these design features include use of high-efficiency windows, super insulated roofs, use of sensors which automatically turn the lights off or on in a room depending on whether it is occupied.In addition to these, the patient rooms have been redesigned to allow more exposure to natural light and ventilation.The Children's Hospital of Pittsburgh, a division of the University of Pittsburgh Medical Center, has also adopted ways to cut energy consumption and minimize environmental pollutants in two of its buildings for which it received the LEED certification.The Children's Hospital achieved this structural shift largely by using green materials and design in place of conventional systems. Some of the adopted green designs include systems for monitoring carbon dioxide levels in the atmosphere, use of certified wood products, use of renewable materials in its research building, water-efficient landscaping, minimizing on-site light pollution, elimination of hydrochlorofluorocarbons (HCFCs) and halons, and use of local and regional construction material to reduce transport burden.In addition, the hospital implemented designs that increased exposure to natural light. Operations in the hospital were also modified in the light of the green initiative. The hospital noted that having their daily operational activities meet the requirements of a green building was equally as important as implementing green design initiatives[39,40,41].Some of the operational best practices adopted by the hospital to make it sustainable include the use of nontoxic cleaning chemicals and microfiber mops, discontinuation of use of mercury-containing solutions and medical devices, and use of paper products made from recycled material.The hospital also established a recycling program for lab chemical wastes of toxic solutions, as well as for paper, plastic waste, light bulbs, batteries, and cardboard.

The Benefits of Green Buildings

There is a growing body of evidence supporting the establishment of these initiatives in the design and construction of building projects. On a large scale, these green design and operational initiatives help in achieving a number of global goals including addressing climate change, driving economic growth, and creating sustainable communities.The World Green Building Council groups the benefits of green buildings into three - environmental, economic, and social benefits.According to a report by the council, green buildings in Australia which received the "Green star certification" by the Green Building Council of Australia led to a 62% reduction in greenhouse gas emissions when compared with the average Australian building. On a global level, green buildings will save as much as 84 gigatonnes of carbon dioxide by 2050.Green building also offers a lot of economic benefits globally, on a country level, and on a building level. Some of the benefits include cost savings on utility bills, lower costs of construction, a higher property value for estate developers, and job creation. Building owners note, as reported in a report by Dodge Data & Analytics, that green buildings - whether newly constructed or renovated - created a 7 percent increase in asset value compared to traditional buildings.Socially, the green building offers a number of benefits to occupants.[42,43,44] Studies have shown that workers in green buildings reported a 101 percent improvement in cognitive scores. In addition, employees in green buildings with well-ventilated offices reported sleeping an average of 46 minutes more every night.As healthcare evolves and administrators and providers explore strategies to promote better health care and lower administrative costs, constructing or renovating hospitals using green building design initiatives remains one of the core strategies, which no doubt has immense benefits not only for the hospital and immediate environment but for the world at large."[45,46,47]

III.RESULTS

While many of the concepts behind sustainable design practices stem from the 1987 World Commission on Environment and Development's report titled, "Our Common Future," they have evolved significantly since that time. Integrating sustainable concepts, technologies,[53,54,55,56] and products into hospital design is more critical than ever as global economies try to manage and reduce the impact of climate change. According to a study published in The Lancet Planetary Health, the healthcare industry is responsible for upwards of 10 percent of all carbon emissions worldwide. To reduce that statistic, we must decrease the impact healthcare projects have on the consumption of natural resources and the emission of carbon into the atmosphere.

How do we achieve this goal without compromising patient safety or hygiene? There are several areas to consider during the planning and design phase,[48,49,50] where a thoughtful and conscientious effort is required to opt for the most sustainable options while keeping patients and staff in mind.[51,52]One of the most significant challenges that building

owners and architects face when implementing sustainable design features in a hospital is cost. Materials used for sustainable design features such as heat-reflecting roofs, insulated tinted glass, and eco-atriums can be more expensive compared to less viable alternatives. But with the energy saved, the costs will be offset in the long run[10,11,12].

By focusing on details such as building orientation, sustainably-sourced materials, better water systems, and increased daylighting, architects can design hospitals that are mindful of the environment, while continuing to improve patient wellness, recovery time, and staff retention rates.Reducing hospital emissions is challenging. However, when designers focus on approaches that minimize embodied carbon and reduce energy consumption, powerful results can be realized.One recent example of this approach in action is the new Stamford Hospital in Stamford, Conn., which was the largest LEED for Healthcare project in the U.S. [1]at the time of its certification, and the first LEED for Healthcare project in Connecticut. The design also focused on the patient-centric philosophy of the Planetree model to address the hospital's goal to personalize, humanize, and demystify healthcare.The project's design team looked at multiple angles to improve the performance and efficiency of Stamford Hospital by leveraging LEED and other sustainability guidelines:

Materials: Embodied carbon is a term that explains the carbon footprint of a given material. It measures the greenhouse gases released through each step in the supply chain, from the time the material is extracted to the time it is installed in a building. While sustainability favors modernizing structures to preserve the carbon in an existing building, this isn't always possible to meet the growing needs of patients and staff. As a solution, the Stamford Hospital design team ensured that 59 percent of building materials were sustainably-sourced.[2,3,4,5]
Additionally, designers focused on reducing mercury, lead, and cadmium throughout the building from plumbing systems to electrical wiring. Fifty-two percent of the furniture and medical furnishings used met strict LEED criteria. As part of evaluating furniture and furnishings for the hospital, strict attention was also given to avoiding urea-formaldehyde, heavy metals, hexavalent chromium, stain-resistant chemicals, and added microbial treatments.[6,7,8,9,10]

Energy Reduction: Reducing energy is an essential goal for every healthcare project. In a typical healthcare facility, lighting, water heating, and space heating account for more than 65 percent of the overall energy consumption. Natural light helps reduce the need for electrical illumination to lower energy costs. Planting trees around the building can help reduce sunlight at peak hours of the day to keep hospital interiors cooler. For the Stamford Hospital project, the designers took advantage of a new efficient central plant. They specified LED lighting and a high-performance building envelope, including a green roof, which resulted in an overall energy reduction of 12.49 percent. [11,15]

Waste Management: Many of the materials secured by a hospital ultimately become waste that produces emissions that contain significant air pollutants, including particulate matter, metals, acid gases, and nitrogen oxides. By maximizing future flexibility with shell space, modular casework such as headwalls and nursing stations, and future parking garage possibilities in the Stamford Hospital, sources of future waste were minimized. During construction, the contractor reduced generated waste and strategically recycled to divert 86 percent of construction waste away from landfill. The lower disposal costs dramatically reduced the project's impact on the environment.[12,13,14]
Healthcare facilities in the country consume upwards of 315 gallons of water per bed every day. In the case of Stamford Hospital, designers specified the use of low-flow plumbing fixtures in public restrooms and patient rooms to realize a reduction in water use of 31percent.[16,17,18,19,20] Sub-meters were installed for more substantial water-use sources.The medical equipment uses either a closed-loop system or minimizes the use of water for cooling via dryvacuum pumps, air-cooled compressors, and digital x-ray equipment.When designing a hospital for greater sustainability, it's advantageous to use the natural elements whenever possible. Using sustainable materials and creating a more efficient, high performing environment positively affects staff and patients. Renewable architecture seeks to bring into existence and replenish resources rather than exhaust them. With sustainable design principles in place, building owners and architects can collaborate with hospital staff to take actions that better affect the environment while keeping the needs of patients front and center.[21,22,23,24]

Implications

Energy issues have gained space on the agenda of governments and business managers worldwide and have become an important topic in debates on environmental sustainability due to global warming, the risk of the depletion of nonrenewable sources, and the significant growth per capita energy consumption and global reliance on fossil fuels .[25,26,27,28]

Global warming and the risk of the depletion of non-renewable sources are directly related to the production of electricity. Electricity is generated from thermoelectric, hydroelectric, wind, solar, and nuclear plants, among others. However, global patterns of electricity production are predominantly based on thermoelectric plants, which use the burning of fossil fuels (considered nonrenewable sources) and generate negative impacts on the environment, harming both air and water quality. The burning process of these fuels expels greenhouse gases and particulate materials that contribute to global warming, acid rain, and respiratory diseases (Silva et al., 2018). Air pollution is one of the most important problems that modern urban life brings nowadays. Every year, thousands of people are affected by air pollution, and it even causes deaths . It is reported that approximately 6.5 million people die every year due to causes of air pollution .[29,30]

Hydroelectric dams produce considerable amounts of methane, carbon dioxide, and nitrous oxide, which are all greenhouse gases. Three factors are responsible for the production of these gases in hydroelectric plants: the decomposition of trees affected by the flooding of areas used in the construction of reservoirs; the action of primary algae that emit carbon in gaseous form in the plants' lakes/reservoirs; and the accumulation of nutrients brought by rivers and rain in dammed areas that are decomposed by the primary algae, leading to a constant renewal in the production of these gases .[25,26,27,28]

Meanwhile, the significant growth in energy consumption is related to the intensification of the use of technologies, which are highly dependent on energy consumption, and to population growth .Among the biggest energy consumers are hospitals . They are complex organizations, have significant economic, social, and environmental relevance, and are large consumers of energy due to their operations being carried out 24 h a day; they also have a lot of high-powered electronic equipment to support clinical procedures that need intense and continuous heating, water, ventilation, steam, air temperature and humidity control, and powerful lighting. In addiction hospital require highly controlled indoor environments, this makes them energy intensive buildings with complex and varying specifications for their functions and operations .[31,32,33,34]

Hospitals have only recently considered these issues related to energy consumption in the context of environmental sustainability, unlike many other types of organizations that have been including them for some time in their business models . Furthermore, sustainability issues have become increasingly important in all their environmental, social, and economic aspects . One of the main challenges that needs to be overcome by hospitals in this regard is energy management, based on environmental sustainability, that is used as a strategic means of achieving competitiveness and is focused on energy efficiency . Energy efficiency encompasses policies, strategies, and technologies designed to reduce energy consumption, pollutant gas emissions, and costs . Therefore, efficient energy management in hospitals has the potential to improve energy efficiency.[35,36,37,38]

However, hospitals are among the most difficult organizations to design, build, and operate . Energy management in hospitals deals with different specifications and needs for each area. The area of intensive surgery, for example, requires high energy demand and strict controls on environmental conditions, such as ventilation, heating, and lighting, while administrative sectors use equipment with less energy demands[39,40] . The particularities of these areas represent yet another ingredient that must be considered and presents challenges both in the design of electrical installations and in the efficient management of energy in . Other challenges to be overcome regarding energy management in hospitals are the urgent need to decrease energy consumption without decreasing the quality of health care, high energy-related operating costs, most patients' lack of awareness of rational energy consumption, and the need for high levels of investment in technologies with greater energy efficiency .Due to the importance and potential benefits of overcoming these challenges in relation to contributing to the competitiveness of hospitals and to the preservation of the environment, several scientific initiatives and projects have been developed to incorporate elements of environmental sustainability in the management of energy in such organizations .[35,36,37,38] Among them, the Global Agenda of Green and Healthy Hospitals presents ten objectives that must be adopted by hospitals that enable them to operate in an environmentally sustainable way, among which the management of energy (under the prism of sustainability) stands out . Ryan-Fogarty et al. (2016) investigated environmental sustainability initiatives at the Irish Cork University Hospital. The study identified a 33% reduction in

energy consumption after implementing an energy management program in partnership with the Irish government's Public Sector Energy Efficiency Program. This program was aimed at training hospital employees and developing action plans to reduce their environmental impacts. Weimann and Patel (2017) carried out a case study at the African university hospital Groote Schuur and found a 5.7% decrease in electricity consumption due to the reduction of inefficiencies in their boiler system. This project reduced the consumption of coal and water and consequently reduced the emission of polluting gases. Khahro et al., (2021) studied the use of Building Information Modeling (BIM) and Green Building Studio (GBS) technologies in the design, construction, and operation of green buildings to make energy simulations by changing different parameters and components such as solar orientation, materials, glass, and HVAC systems of a hospital building, and reported a reduction in energy costs and carbon dioxide (CO2) emissions.[41,42,43,44]

These initiatives and studies have presented recommendations and relevant experiences on energy management in hospitals, showing some promising results. However, they have not elaborated on which energy management techniques were developed, or how, to achieve these results. In addition, most hospitals still face difficulties in developing solutions for the sustainable use of energy [45,46,47,48]Therefore, the present study deepens and extends our understanding of these initiatives and studies, with the aim of contributing to overcoming the recurring challenges in the efficient and sustainable management of energy in hospitals.As may be expected, Brazilian hospitals are also facing considerable difficulties in sustainable energy management. They are major energy consumers, representing 10.6% of the country's total electricity consumption . Brazil has 45.3% of its energy matrix made up of renewable sources, being represented predominantly by hydroelectric plants (66.6%) (EPE, 2019). Even so, the cost of energy is 30% above the world average, with 31% of this price being due to taxes . Thus, high energy consumption in Brazilian hospitals also entails high operating costs.In 1985 the Brazilian government started the National Program for Energy Conservation to fight against electric energy waste. The actions concerned with this Program contribute to increase the energy efficiency of goods and services, developing habits and knowledge on energy-efficient consumption, and mitigating negative impacts on the environment. It promotes actions in several segments of the economy, including building. Specifically in this segment, this Program aims, through energy efficiency recommendations, to improve the efficiency of lighting, air conditioning, and motors for hydraulic pumps in commercial, residential, and public buildings [49,50,51]Despite this Program, there is still a lack of laws and incentives, which is one of the significant barriers in adopting energy efficiency measures in Brazil.Considering this scenario, the research question that guided the development of this work is how energy management can be made more efficient and environmentally sustainable in hospitals. To address this question, the objective of this work is to propose guidelines for the efficient and sustainable management of energy in hospitals, elaborated based on the review of the scientific literature and on the results of six the case studies in Brazilian hospitals. In addition to the identification of good practices and difficulties related to energy management, these case studies served to acclimate the authors in relation to the processes and the hospital organizational environment, thus making the guidelines more feasible and appropriate to this universe.The results of this article scientifically contribute to the deepening and expansion of previous works on the theme and to the formation of a block of knowledge on efficient and sustainable energy management in hospitals that will allow the development of research more appropriate to the reality of these organizations. The results of this article also contribute in an applied way to the preservation of the environment and to increasing the competitiveness of hospitals by proposing guidelines for their energy management.[45,46,47,48]

IV.CONCLUSIONS

The increasing global consumption of energy and its negative impacts on the environment has been an issue discussed both by academics and practitioners, including in the health sector. [51,52,53,54]Hospitals are major consumers of energy, which leads to increased operating costs, decreased competitiveness, and negative environmental impacts. Energy management in hospitals must be understood as a way to contribute to environmental sustainability and as a way to improve competitiveness. Therefore, the objective of this paper is to propose guidelines for efficient and sustainable energy management in hospitals, developed based on the literature review, the challenges faced and the good practices of sustainable energy management in the hospitals studied, the cross analysis of the case studies, and the authors' expertise. [55,56]As a result, the eight proposed guidelines are related to culture change, energy consumption management, energy management standard, purchase of renewable energy, green technologies, sustainable hospital buildings, social responsibility programs focused on energy use, and sustainable energy public policies. These guidelines contribute in an applied/managerial way to help managers of public and private hospitals overcome the challenges of energy management and contribute to UN's SDG7 due to its potential to improve energy efficiency and environmental performance, therefore,

being a movement towards clean energy. This study also theoretically/scientifically contributes to the academic debate since the empirical findings found in the hospitals studied and the proposition of guidelines deepen and expand the key elements identified in the literature on efficient energy management in hospitals, providing the basis for developing new research on the subject.[53,54]

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