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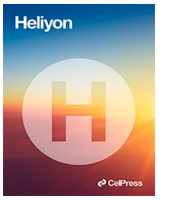

Research article

Green hospitals face to climate change: Between sobriety and resilience

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A B S T R A C T

Climate change poses a critical challenge to global health, influencing social and environmental determinants such as housing, air and water quality, and food security. This article explores the profound impact of climate change on health, projecting an additional 250,000 annual deaths from various climate-related diseases between 2030 and 2050. Healthcare systems significantly contribute to global carbon emissions. The concept of the "Green Hospital" is introduced as a paradigm shift in healthcare, focusing on optimizing resource efficiency and minimizing environmental impact. This concept encompasses renewable energy integration, natural lighting, sustainable materials, green roofs, and smart building management systems. Several challenges remain major, such as medical waste management, water conservation, chemical use, pollution, and plastic usage in healthcare settings. Moreover, obstacles to green hospital initiatives should be resolved, including system redundancy, regulatory compliance, operational demands, financial constraints, and cultural resistance. Conclusively, an urgent reformation of healthcare systems is needed to align with eco-friendly and sustainable practices, highlighting the necessity to reduce CO^2 emissions and manage resources and waste more effectively to meet the evolving health needs of a growing and aging global population.

1. Introduction

The influence of climate change extends to the social and environmental factors that determine health, including safe housing, clean air and water, and sufficient food. It is projected that climate change will cause an additional 250,000 deaths annually from malnutrition, malaria, diarrhea, and heat-related stress between 2030 and 2050. The expansion of transportation, food choices, and energy options can lead to better health by reducing greenhouse gas emissions. Climate change has already caused various health problems, including death and illness due to extreme weather events, disruption of food systems, increased prevalence of zoonotic and foodborne illnesses, and vector-borne and waterborne diseases, as well as mental health issues. Furthermore, climate change undermines several social determinants of good health, including access to healthcare, equality, and livelihoods. This ongoing crisis is the most significant threat to global health, and healthcare professionals worldwide are already addressing its effects. A report published by The Shift Project in 2021 [1] revealed that the French health sector contributes to more than 46 million tons of CO2 emissions, which represents almost 8 % of the total emissions in France. This includes the purchase of medical equipment and medicines, as well as patient and staff transportation and food. In the UK, the National Health Service (NHS) emits 18 million tons of CO2 annually, accounting for almost a quarter of the total emissions coming from the public sector [2,3]. In the US, total gas emissions from healthcare organizations increased by 6 % from 2010 to 2018 [4,5]. Moreover, the global market for medical waste management is

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expected to grow from an estimated USD 6.8 billion in 2020 to USD 9 billion by 2025 [6]. The healthcare industry is lagging on environmental issues, with excessive energy consumption and weak waste management being the main contributors. Urgent action is required to address this. The pursuit of green development stands as a paramount challenge, arguably the most significant, of the 21st Century. This crucial importance of sustainable development was acknowledged much earlier, dating back to the United Nations Conference on the Human Environment held in Stockholm in 1972. The hospital can contribute to maintaining the good health of the population by managing its carbon emissions effectively and adopting an eco-friendly action plan [7]. As healthcare professionals, our responsibility is not only to treat but also to prevent diseases. This requires a green/eco-friendly management of our healthcare system.

1.1. Green hospital

The concept of a "Green Hospital" encompasses various interpretations. The Office of the Federal Environmental Executive views it as an approach that optimizes the efficiency of a building's energy, water, and material usage, while minimizing its impact on human health and the environment. This encompasses the entire life cycle of the building, from its location to design, construction, operation, maintenance, and eventual dismantling [8]. The United States Environmental Protection Agency (EPA) describes green buildings as structures created and processes used that are both environmentally responsible and resource-efficient throughout the building's life cycle. This includes considerations from the site location to design, construction, operation, maintenance, renovation, and even deconstruction. This approach not only focuses on traditional aspects like economy, utility, durability, and comfort but also emphasizes sustainable or high-performance building practices [9]. Healthcare Without Harm characterizes a green and healthy hospital as one that actively reduces its environmental impact and aims to eliminate its contribution to disease burden. Such a hospital acknowledges the interplay between human health and the environment, incorporating this understanding in its governance, strategy, and operations. It addresses local needs through environmental action and practices primary prevention by engaging in efforts to foster community environmental health, health equity, and a green economy [10,11]. Thus, green healthcare is conceptualized as a multifaceted system that focuses on restoring, managing, and optimizing human health through ecological principles. This approach is designed to be sustainable in terms of environment, economy, and society over an indefinite period. It aims to operate in harmony with both the human body and the natural world, ensuring that it does not disproportionately or unfairly impact any key component of the healthcare system [12]. Often synonymous with sustainable healthcare, this concept emphasizes delivering healthcare services in a way that is environmentally considerate. It seeks to not only promote health but also positively influence the community at large [13, 14].

Green health systems are based on the following ten components [15]:

1. Leadership through education, goal setting, accountability, and incorporating these priorities in all external relations and communications,
2. Substituting harmful chemicals with safer alternatives,
3. Reducing, treating, and safely disposing of healthcare wastes,
4. Implementing energy efficiency and clean renewable energy generation,
5. Reducing hospital water consumption and supplying potable water,
6. Improving transportation strategies for patients and staff,
7. Reducing food waste and the environmental footprint while improving patient and worker health by making changes in hospital service menus and practices,
8. Reducing pharmaceutical pollution and developing safer pharma,
9. Taking advantage of green buildings to develop safer, more resilient, greener, and healthier building products and systems.
10. Changing purchasing habits in ways that reduce environmental and human rights impacts.

1.2. Search strategy

PubMed Medline, Web of Science, Google Scholar, IEEE Xplore, and Scopus databases were used for the research, with only articles in English language, using the following terms: "green hospital", "eco-friendly hospital", and "climate change".

1.3. State-of-the-art infrastructure

The state-of-the-art infrastructure of the eco-friendly hospital is a testament to innovative design and construction techniques that prioritize sustainability and environmental stewardship.

1.4. Renewable energy sources

The hospital integrates renewable energy sources into its infrastructure, such as solar panels and wind turbines [16]. These clean energy systems generate electricity to power various operations within the facility, reducing reliance on traditional energy grids and minimizing greenhouse gas emissions. The hospital strategically places solar panels on rooftops and utilizes open areas to harness maximum solar energy. Wind turbines, carefully positioned, capture wind power to supplement the energy needs of the hospital [17].

1.5. Natural lighting and ventilation

The hospital maximizes the use of natural lighting and ventilation to reduce energy consumption and create an efficient healing environment [18]. Large windows and skylights are strategically placed throughout the building to allow ample natural light to penetrate the interiors, reducing the need for artificial lighting during the day [19]. The hospital also incorporates intelligent shading systems to optimize natural light without compromising patient comfort or privacy. Furthermore, the design of the hospital prioritizes cross-ventilation and utilizes natural airflow patterns to minimize the reliance on mechanical ventilation systems [20].

1.6. Sustainable materials and construction

The eco-friendly hospital prioritizes the use of sustainable materials and construction practices. During the construction phase, the project adheres to green building standards, such as using locally sourced, eco-friendly materials and minimizing waste generation [12]. The building materials are carefully selected to ensure low embodied energy, recyclability, and minimal environmental impact. This focus on sustainable construction not only reduces the environmental footprint but also creates a healthier indoor environment for patients and staff [11].

1.7. Green roof and gardens

The hospital incorporates green roofs and gardens into its infrastructure, providing multiple benefits [13]. Green roofs improve energy efficiency by reducing heat transfer and providing natural insulation. They also absorb rainwater, reducing stormwater runoff and supporting the overall water management system. Additionally, these green spaces create a therapeutic environment, promoting healing and well-being for patients, while also contributing to biodiversity conservation within the urban setting [14].

1.8. Smart building management systems

To optimize energy efficiency and monitor environmental conditions, the hospital employs state-of-the-art smart building management systems [21]. These systems utilize advanced sensors and automation technology to control lighting, heating, cooling, and ventilation systems based on occupancy and ambient conditions. The integration of these systems ensures optimal resource utilization, minimizes energy waste, and enables real-time monitoring and adjustment for improved sustainability performance [22,23].

1.9. Initiatives for a green hospital

1.9.1. Medical waste

According to a report published in 2021 by The Shift Project think tank, poorly treated medical waste poses a threat to more than half of the world's population, exposing them to environmental, labor, or public health hazards [24]. Medical waste can be poorly managed due to various reasons, such as lack of awareness of the health risks associated with it, insufficient training in proper waste management, lack of infrastructure, energy or appropriate regulations, or poor enforcement of existing regulations. Additionally, greenhouse gas emissions and air pollution can result from the transportation and incineration of medical waste using fossil fuel vehicles, inappropriate incineration technologies, or incineration of unsuitable materials. Suppliers should also be held accountable for the materials used and the channels of waste disposal. Non-hazardous materials such as cardboard, paper, glass, plastics, and food, which constitute 85 % of medical waste, can be recycled and should be separated from hazardous waste to reduce disposal costs [25]. Although reducing waste is crucial for a more sustainable future, hospitals have a high dependence on single-use plastics and disposable items due to fundamental infection control measures. However, there could be other ways to reduce waste in hospitals too, despite the use of some products that cannot be changed or reused in a sterile hospital environment.

1.9.2. Water

Water is crucial not only for keeping the environment clean, but also for promoting good health in patients by allowing them to stay hydrated and maintain proper hygiene practices. Proper sanitation of water is a critical issue, as wastewater may contain harmful chemicals that need to be removed. To address this issue, some health facilities have implemented on-site wastewater treatment systems, such as biodigestion systems, that can remove harmful chemicals and generate methane gas, which can be utilized as a source of fuel within the facility [26]. Moreover, an essential aspect of the hospital's infrastructure is its advanced water conservation systems. Rainwater harvesting techniques are employed to collect and store rainwater from roofs and open areas. This water is then treated and used for non-potable purposes, such as irrigation, flushing toilets, and cooling systems. Additionally, the hospital implements greywater recycling systems to treat and reuse water from sinks, showers, and laundry facilities. These measures significantly reduce the hospital's water consumption and promote responsible water management practices.

1.9.3. Chemicals use

Chemicals are commonly used in healthcare settings, including for cancer treatment and disinfection. However, the use of chemicals can pose risks to both human health and the environment. For example, medical devices containing mercury are still used in some facilities. By addressing the use of chemicals and the associated risks, healthcare facilities can better protect the health of patients and those living in the surrounding area [27].

1.9.4. Hospital pollution

Ambient air pollution, caused mainly by burning fossil fuels, results in approximately 4.2 million deaths annually, and its impact on health is intensified by climate change [28]. Healthcare facilities can contribute to ambient air pollution through the on-site combustion of fossil fuels, incineration of medical waste, procurement of energy from fossil fuel sources, and the purchase of goods produced and transported using fossil fuels. The transportation systems of facilities and patient and staff transportation also contribute to air pollution related to transportation, which produces smog and poor air quality, negatively impacting human health. Strategies such as transportation planning and procurement that reduce air pollution and associated greenhouse gas emissions, and switching to cleaner fuels and cooking technologies can help reduce indoor air pollution [29]. Therefore, it is worth considering incorporating telemedicine into the health system, which has been shown to be associated with a significant reduction in the carbon intensity of ambulatory visits [30].

1.9.5. Plastic

In healthcare, single-use plastics serve important purposes, but they often end up being wasted or overpackaged. Innovative solutions can be explored, such as creating surgical intervention packs instead of individually wrapped products. Recycling facilities can be introduced in hospitals and waiting rooms to minimize the amount of waste that goes to landfills, but it's essential to provide clear labelling to ensure that people know which items can be recycled. Reusable sharps bins can replace disposable ones that have been incinerated, reducing the need for single-use plastics [31].

1.9.6. Food products

A sustainable healthcare facility should prioritize reducing the consumption of meat and increasing the intake of fruits and vegetables for patients. The use of antibiotics in cattle feed to increase yields is a common practice that can lead to the development of superbugs, which can be harmful to human health. Local breeds of cattle that are fed natural green fodder should be preferred if meat is to be included in patients' diets. Additionally, meat production requires a high amount of water, with 1 kg of meat protein taking up to 7900 L of water, compared to 4650 L for 1 kg of vegetable protein, except for milk. By reducing the consumption of meat, healthcare facilities can help conserve water resources. Furthermore, vegetarian diets are known to have health benefits [32]. To minimize meat consumption, healthcare facilities can consider introducing vegetarian options in their menus [33].

1.9.7. Cleaning products

The cleaning products commonly used in hospitals can be detrimental to the health of vulnerable patients such as fetuses, newborns, and elderly individuals, due to the harmful chemicals they contain. To promote the development of sustainable healthcare facilities, it is crucial to prioritize the use of environmentally friendly cleaning products. Moreover, hospitals often purchase furniture and equipment that is coated with special chemicals to prevent fire hazards. However, it is well known that these chemicals can have negative effects on patients and the hospital environment. Therefore, there should be a greater focus on eco-friendly furniture options that are free of harmful chemicals [34].

1.9.8. Financial impact for healthcare systems

Gwyneth et al. [35] showed in US that a quality improvement initiative in an operating room transitioned to a waterless surgical scrub, saving $2233 per year and 2.7 million liters of water annually. Moreover, another initiative through proper waste management led to annual savings of $694,141 and a 30 % reduction in medical waste [35]. Hospitals also reported savings through energy efficiency, reusing single-use devices, and waste management. For example, energy-efficient practices in operating rooms can save $25,000 annually per room, and the average hospital has about 11 operating rooms. Additionally, reusing single-use devices saved another hospital $2.5 million annually. Managing waste streams effectively, including recycling, can also result in significant cost savings [35].

The NHS's investment in public sector decarbonization is expected to save £650 million per year. Over 30 NHS healthcare facilities secured £329 million for energy-efficient innovations, which is estimated to save 1 million tons of carbon. Examples include the use of LED lighting and solar power, with savings amounting to hundreds of thousands of pounds annually in energy costs at specific hospitals [36].

Between 2005 and 2013, a study [37] on energy consumption was conducted in 12 hospitals and 70 healthcare centers in Spain, constructed from 1980 to 2005. This study, carried out through audits by the Extremadura Energy Agency between 2005 and 2012, indicated potential energy savings in healthcare buildings. Buildings smaller than 5000 m^2 without beds could save up to 8.60 kWh/m2 annually, costing around 1.55 €/m2. For larger buildings over 5000 m^2 with beds, the savings could reach 6.88 kWh/m2 per year, equating to an expense of 1.25 €/m2 [37]. In a study by Vanhoudt et al. [38], a hospital in Belgium demonstrated the potential to save up to 71 % in primary energy consumption by utilizing thermal energy storage combined with a heat pump, as opposed to traditional gas-based boilers and water chillers. Additionally, Yun et al. (2012) [39] found that deviations in occupancy patterns from a building's initial design can lead to increased energy use for lighting, with a potential for up to 50 % energy savings through adjustments.

1.9.9. Barriers and obstacles to green hospital

Creating a green hospital faces numerous obstacles, including:

1. **System Redundancy**: Hospitals must have backup systems to ensure continuous operation during emergencies, which often requires additional resources.

2. **Regulatory Compliance**: Adherence to health, safety regulations, and building codes can sometimes restrict the adoption of sustainable practices in healthcare settings.
3. **Extended Operational Hours**: Hospitals operate 24/7, leading to increased resource consumption and challenges in implementing energy-saving measures.
4. **Infection Control**: Stringent protocols for infection control can conflict with environmentally friendly practices.
5. **Ventilation Requirements**: Hospitals need more frequent air exchanges compared to standard office buildings to maintain a sterile environment.
6. **Accreditation and Licensing**: Meeting various central, state, and accreditation standards can limit the ability of facilities to choose environmentally sustainable options.
7. **High Energy and Water Consumption**: Healthcare facilities consume significantly more energy per square foot than typical commercial buildings and use between 80 and 150 gallons of water per bed each day.
8. **Large Waste Generation**: Hospitals produce approximately 0.5 Kg of hazardous waste per bed daily.
9. **Chemical Usage**: The use of hazardous chemicals for cleaning, disinfection, sterilization, disease treatment, and research pose environmental risks.
10. **Building Life Cycle**: While hospital exteriors have a long lifespan, interiors often require renovations every few years, impacting sustainability.
11. **Financial Constraints**: The high cost of implementing green technologies can be a deterrent for many healthcare facilities.
12. **Lack of Awareness**: A general lack of awareness about the benefits and practices of sustainable healthcare can hinder its adoption.
13. **Technological Limitations**: Current technology may not always offer sustainable alternatives that meet the specific needs of healthcare facilities.
14. **Cultural Resistance**: Resistance to change within the organizational culture of hospitals can impede the adoption of green practices.
15. **Supply Chain Issues**: Limited availability of sustainable materials and products can restrict green hospital initiatives.

2. Conclusion

Climate change is one of the most pressing and complex challenges of our time. To preserve our planet's ecosystem, we must drastically reduce our net carbon dioxide (CO2) emissions, better manage our resources, and better manage our waste, while continuing to meet the health needs of a growing and aging population. Every gesture counts.

CRediT authorship contribution statement

Alexandre Vallée: Conceptualization, Validation, Writing – original draft.

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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