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A sustainable approach to healthcare: Implementing the hierarchy of controls in green hospital initiatives

Dr. Rahul Srova, Archana Shahi
Department of Hospital and Healthcare Administration, United College of Engineering and Research, Baba Farid University of Health Sciences, Faridkot, Punjab, India

Abstract
Introduction: Sustainability in healthcare has become increasingly important as hospitals seek to reduce their environmental footprint while maintaining high standards of patient care. With the global push towards environmentally responsible practices, healthcare institutions are now embracing "green" initiatives to minimize waste, conserve energy, and promote sustainable practices within their operations. This article explores various green hospital initiatives, their benefits, challenges, and their impact on healthcare systems.
Objective: This study aims to investigate the principles and practices of green hospitals, assess their environmental and economic benefits, identify the obstacles to their widespread adoption, and explore possible solutions, while also discussing case studies of hospitals adopting green innovations.
Material and Methods: A comprehensive literature review was conducted to gather information on green hospital initiatives, their definitions, and the specific practices involved. Existing case studies and research articles were analyzed to identify successful examples and challenges healthcare organizations face. The review focused on publications from reputable academic journals, industry reports, and government documents. The analysis of case studies and research articles provided valuable insights into the practical implementation of green hospital initiatives, including the effectiveness of various strategies, the challenges encountered, and the potential benefits. By examining successful examples, it was possible to identify best practices and learn from the experiences of others. Additionally, studying the challenges faced by healthcare organizations helped to understand the barriers that may impede the widespread adoption of green hospital initiatives.
Conclusions: Green hospital initiatives offer a promising approach to addressing the environmental impact of the healthcare sector while providing significant benefits. By implementing energy-efficient practices, reducing waste, conserving water, and using sustainable materials, healthcare organizations can contribute to a more sustainable future. However, overcoming initial costs, lack of awareness, and regulatory barriers is essential for the widespread adoption of green hospital practices. Continued research and collaboration among healthcare providers, policymakers, and sustainability experts are crucial to drive progress in this area.

Keywords: Green hospitals, sustainability in healthcare, energy efficiency, waste reduction, environmental impact

Introduction

The concept of sustainability has emerged as a critical concern across industries including healthcare. Healthcare plays an important role in addressing environmental challenges like significant carbon emissions, waste production, and resource consumption. Hospitals rely on medical devices like MRI machines, CT scanners, surgical equipment, Heating, cooling, lighting, and ventilation systems which consume a lot of energy, and cause significant increases in operational costs. Hospitals also require a large quantity of resources like water for cleaning, sterilization, and patient care. Also, It requires chemicals like cleaning agents, and disinfectants which can cause adverse effects on the environment, if not handled properly. Hospitals also generate a significant amount of waste like medical wastes including needles, syringes, human body fluids, and pharmaceutical wastes like expired medicines. All these can cause harmful effects on the environment, if not disposed of effectively. As stated by Eckelman *et al.* (2016) [1], the healthcare sector is also responsible for acid rain, greenhouse gas emissions, smog formation, criteria air pollutants, stratospheric ozone depletion, and carcinogenic and non-carcinogenic air toxics. Chung *et al.* (2019) [2] estimated that healthcare contributes to around 8% of the nation's greenhouse gas emissions.

In response, healthcare institutions are adopting green initiatives, which can integrate sustainability into healthcare operations and also reduce hospital waste which can cause harm to the environment. In the end, it will help in reducing environmental footprints and increase patient outcomes, resulting in benefits to the hospital. Chung *et al.* (2019) [2] also stated by measuring and controlling the environmental impact of healthcare, improved healthcare quality, efficiency, and reduction of unintended consequences can be achieved. So, there is a need for healthcare institutions to shift towards eco-friendly models to ensure a healthy environment for future generations.

Research Aim

This study aims to investigate the principles and practices of green hospitals, assess their environmental and economic benefits, identify the obstacles to their widespread adoption, and explore possible solutions, while also discussing case studies of hospitals adopting green innovations.

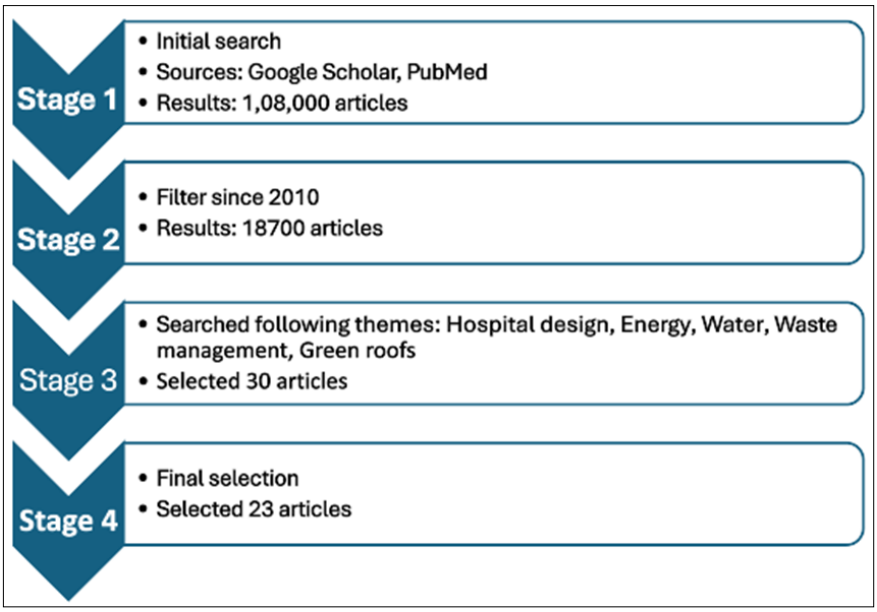


Fig 1: illustrates the rigorous methodology employed in this study, encompassing a systematic four-stage process of initial search, time frame screening, particular themes screening, and final selection

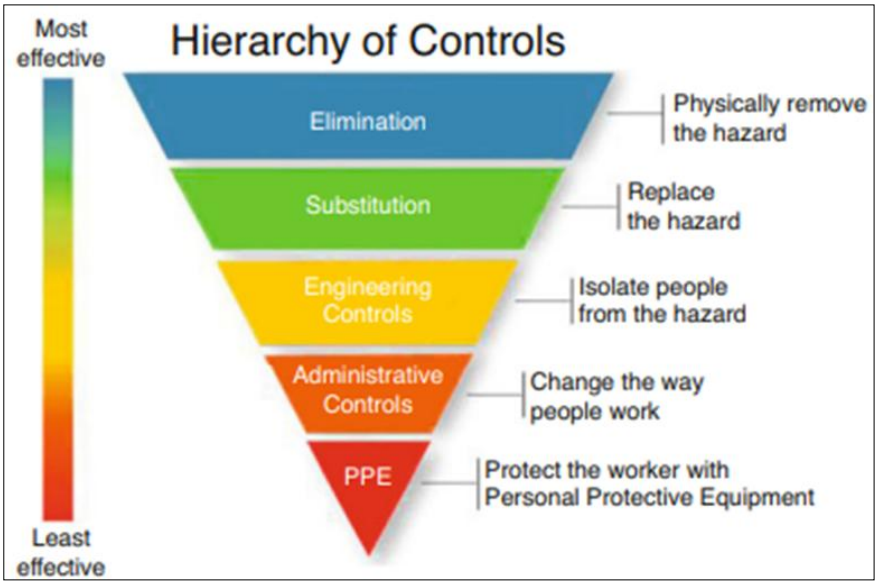
Methodology

The study has focused on secondary data collection by reviewing the existing literature, and case studies from reputable sources within the field of environmental sustainability and healthcare management. Databases such as PubMed, Google Scholar, and Scopus were utilized to gather scholarly articles from 2010 onwards to ensure relevance and current applicability.

The selection of the articles was made as follows:

Discussion

To achieve sustainability, hospitals can adopt a Hierarchical control model to set benchmarks and easily track their progress. This model was originally introduced by the CDC and the National Institute for Occupational Safety and Health in 2015 to prevent occupational hazards among employees. Shahi *et al*. (2023) proposed implementing this model in hospitals for the prevention of healthcare-associated infection (HAI). Hospitals can also apply this model to sustainability efforts.



Source: Shahi *et al.* (2023)

Fig 2

Elimination

It can include

- **Eliminate inefficient plumbing systems:** Remove old, high-flow faucets, showerheads, and toilets that consume excessive water.
- Eliminate energy-inefficient equipment like outdated HVAC systems, incandescent lighting, and inefficient medical devices.
- Eliminate unnecessary single-use products like non-essential disposable items like plastic cutlery, single-use water bottles, and excessive packaging.
- Remove traditional roofing materials that trap heat and contribute to the urban heat island effect.
- Eliminate complete reliance on mechanical ventilation systems

Substitution
can include
- Substitute traditional plumbing fixtures with water-efficient alternatives.
- Substitute fossil fuel-based energy sources with renewable energy.
- Substitute single-use plastics with biodegradable or reusable materials.
- Substitute traditional roof materials with energy-efficient alternatives like green roofs.
- Substitute municipal water for non-potable uses with harvested rainwater.
- Substitute mechanical ventilation with passive cooling and natural airflow.

Engineering controls
can include
- Upgrade to energy management systems: Install building automation systems (BAS) that regulate lighting.
- Implement centralized waste segregation and treatment systems.
- Integrate rainwater catchment into green roofs for efficient harvesting and irrigation.
- Install greywater recycling systems.
- Design hospital buildings that enhance natural airflow.

Administrative controls
can include
- Creating a budget to fund initiatives for going green.
- Take the initiative to seek help from the government.
- Establish maintenance schedules for green roof
- Implementing strict guidelines for waste segregation

PPE
Can Include
- Ensure workers handling hospital waste, including recyclable and compostable materials, wear appropriate PPE to avoid exposure to harmful substances.

To validate our proposed hospital sustainability model, we will conduct a comprehensive literature review to identify and analyze existing research, and case studies that support the effectiveness and feasibility of our model.

Hospital design: In recent years, the concept of sustainability has grown among industry professionals and businesses. It includes the design, construction, and operation of structures that minimize their environmental impact and operational costs without compromising their quality.
Healthcare institutions have begun adopting these techniques to enhance their environmental responsibility and operational efficiencies. As stated by Wu *et al*. (2011), There are more than six green building rating systems used internationally. Each rating system emphasizes different aspects of sustainability, but all fall into six basic categories: energy efficiency, water efficiency, site and environmental impact, indoor environment quality, material conservation, and facility management and operations.
The hospital heavily depends on energy to operate essential medical devices such as CT and MRI machines, air conditioning, and other equipment. The hospital designs play an important role in achieving sustainability. The first thing that can be taken is to apply a white elastomeric coating or cool dyes on the exterior of the building. As shown by Dias *et al*. (2014) [5] and Azarnejad *et al*. (2017) [6], It can significantly reduce the annual cooling load of the building by a maximum of 40% and decrease the maximum temperature to about 5 °C. In contrast, in the winter week, the minimum temperature decreased between (0.8 °C and 1.5 °C). It will help in reducing the energy consumption of the hospital for air conditioning, especially in hot regions.
Also, the hospital needs airborne infection isolation rooms with mechanical ventilation to minimize the cross-infection risk. These mechanical negative pressure isolation rooms are very expensive to build and operate as they require high energy to run this mechanical ventilation. This problem can be solved by adopting natural ventilation in hospitals. The CDC recommended 12 ACH (air changes per hour) ventilation rate for effective to reduce the risk of airborne infections. The natural ventilation system can provide ventilation rates significantly higher than the CDC recommended as shown by Qian *et al*. (2010) [7]. It will reduce our complete dependence on mechanical ventilation systems.

Energy Efficiency: Hospitals have a significant opportunity to reduce their environmental footprints and operation costs through various energy efficiency measures. Hospitals can do energy audits to identify insufficiencies and set benchmarks to track progress.
Hospitals can reduce their dependence on state electricity by shifting towards renewable energy like solar power and replacing traditional lighting with energy-efficient and smart lighting that turns off automatically when the area is unoccupied. Proper maintenance of HVAC systems and the introduction of modern advanced energy efficient HVAC systems can help in achieving sustainability as shown by Doulabi *et al*. (2024) [8]. Almannaei *et al*. (2023) [9] also highlight that solar panels can promote a significant phase to sustainability and cost efficiency in the hospital.
Another impactful adaptation that aligns with these categories that a hospital can adopt is green roofs. Green roofs not only contribute to environmental sustainability but also provide therapeutic benefits for patients by offering them solace, respite, and opportunities for physical and occupational therapy. Also, these gardens can reduce noise pollution by nearly 40 decibels, as mentioned by Saha *et al*. (2022).
Keung *et al*. (2019) [11], highlight that green roofs improve air quality, and provide insulation to the building resulting in the lower temperature of the building and cutting down the cost of providing air conditioning. It enhances the energy efficiency of the hospital.
Pouya *et al*. (2017) [12], show that more than 95 percent of cadmium, copper, lead, and a portion of zinc can be taken out of the rainwater, which prevents their distribution into groundwater. Also, it contributes to clean air by filtering and binding dust particles as well as naturally filtering airborne toxins. It also helps to reduce the urban heat island effect resulting in lower temperatures of building. As Teston *et al*. (2018), highlight the potential for rainwater savings and economic feasibility in public buildings, the rainwater taken out from green roofs can be stored and used at hospitals for cleaning, and washrooms, which will enhance the water efficiency of the hospital. Hospitals can also adopt water-recycling toilets based on onsite electrochemical wastewater treatment, as demonstrated by Subramani *et al*. (2024) [14].

Also, growing fresh fruits and vegetables can partially fulfill the demand for food in the hospital, as shown by Saha *et al*. (2017) [15], and reduce the environmental impacts associated with long-distance food distribution and losses as shown by Kulak *et al*. (2013) [16].

Waste management: The hospitals produce large amounts of medical waste every day. According to Cesaro *et al*. (2017) [17], The term medical waste refers to the residues that originate from healthcare activities and medical procedures performed in hospitals, clinics, laboratories, veterinary clinics, and research centers. WHO (2014) also included household waste produced out of healthcare procedures realized at home in the medical waste. Inadequate disposal of this waste can cause adverse effects on the environment and can also increase the risk of disease transmission to the person in contact with this waste, as mentioned by Graikos *et al*. (2010) [19].

Most frequent exposures involve contact with sharp needles, infectious agents, and hazardous substances. About 65% of these exposures occur in the ward itself due to improper segregation and handling of waste, as noted by Akpieyi *et al*. (2015) [20]. Mohee *et al*. (2015) [21] stated that around 90% of hospital waste is similar to domestic waste and only 10% is considered infectious, including cotton, gloves, sharp needles, pathogenic wastes, pharmaceutical wastes, and chemical wastes. Galtier *et al*. (2002) [22] mentioned around 15-20% as infectious in total the hospital waste. Sadia *et al*. (2020) [23] mentioned that improper waste management is also associated with water pollution, air pollution, soil/land pollution, and radioactive pollution in surrounding areas. It also mentioned that Waste segregation should be done at the earliest opportunity at the point of origin. The hazardous waste should not be allowed to mix up with the non-hazardous waste. Waste should be put in separate colored-coded and labeled bags/ containers. These color codes vary from hospital to hospital and country to country. The container should not exceed three-quarters of its capacity. The bag used for hospital waste collection should be tied tightly at the neck. The garbage bin should be cleaned and disinfected regularly. Waste should be stored in a room within the health care facility. It should be inaccessible to animals, insects, and birds and should not be situated near water bodies, fresh food stores, or food preparation areas. Normally, waste should not be stored for more than 24 hours. Waste should be transported by a designated trolley. There should be separate corridors/lifts in hospitals to carry and transport the waste. Transportation should be done in a sealed container to ensure leakage. The vehicles should be cleaned and disinfected daily with disinfectant.

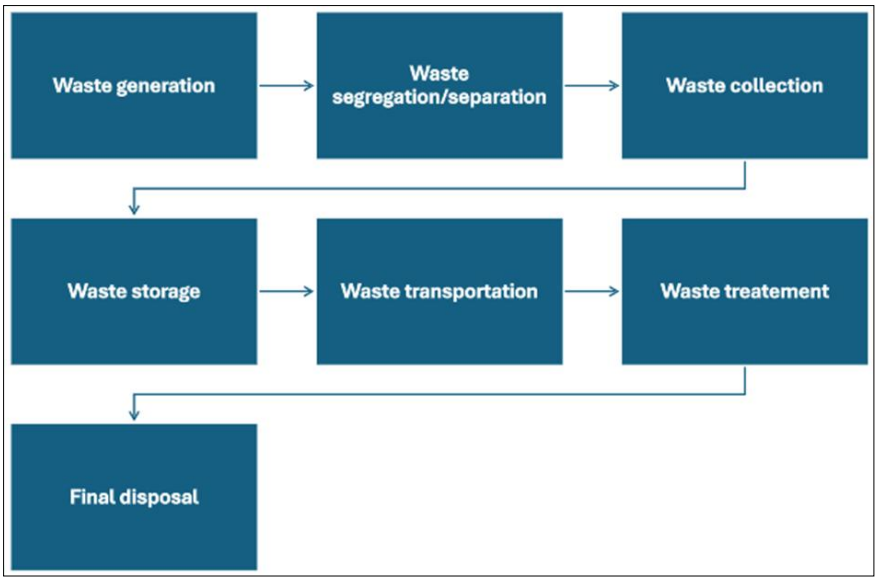
Sadia *et al*. (2020) [23] further highlighted the importance of clear waste management plans, staff training, and adequate resources for effective medical waste management in hospitals.

Hamid *et al*. (2022) [24] mentioned that it is significant to wear personal protective equipment during waste collection, transportation, and storage by all the staff concerned to reduce infection.

Cat	Type of Container	Type of waste	Treatment/ Disposal options
	Non-chlorinated plastic bags	(a) Human Anatomical Waste (b) Animal Anatomical Waste (c) Soiled Waste (d) Expired or Discarded Medicines (e) Chemical Waste (f) Micro, Biotechnological and other clinical lab waste (g) Chemical Liquid Waste	Incineration or Plasma pyrolysis or deep burial
	Non-chlorinated plastic bags or containers	Contaminated Waste (Recyclable) tubing, bottles, intravenous tubes and sets, catheters, urine bags, syringes (without needles) and gloves	Autoclaving/ microwaving /hydroclaving and then sent for recyling
	(Translucent) Puncture, Leak, tamper proof containers	Waste sharps including Metals	Auto or Dry Heat Sterilization followed by shredding or mutilation or encapsulation
	Cardboard boxes with blue colored marking	Glassware	Disinfection or autoclaving, microwaving, hydroclaving and then sent for recycling

Source: Deva *et al*. (2019) [25]

Fig 3: Color coding for hospital waste management



Source: Sadia *et al.* (2020)

Fig 4: Flow diagram showing HWM steps

Challenges: Doulabi *et al*. (2024) [8] also highlighted several challenges and barriers in transitioning to green practices, along with their solutions. Some of these include

- **High Initial Investment:** Many hospitals have limited budgets and financial resources. It is harder to allocate funds for energy efficiency projects.
- **Resistance to Change:** Resistance to change an be significant in such hospitals, where established practices and traditional methods are deeply ingrained.
- **Lack of Awareness:** Lack of awareness about the benefits of green practices and energy efficiency among hospital staff and administrators.
- **Maintenance and Reliability:** It may be a concern for some hospitals about the proper maintenance and reliability of these initiatives.

Solutions

- **Cost:** Hospitals can implement energy-saving projects in phases, that can help to manage costs. Government grants and financial incentives can be provided to support green initiatives.
- **Resistance to Change and Lack of Awareness:** Proper education and training about the benefits of green practices can be provided to increase awareness and acceptance.
- **Maintenance and Reliability:** Pilot projects help hospitals test new technologies before full adoption, while ongoing training ensures proper maintenance.
- Along with it, support from hospital leadership is crucial. Administrators can champion sustainability initiatives and allocate resources to support these efforts.

Case Studies

- **The Healing Garden at Good Samaritan Regional Medical Center in Phoenix, Arizona:** As shown by Pouya *et al*. (2017) [12]**,** In 1996 a healing garden was incorporated into the medical center in Phoenix, Arizona. It is used by patients who are waiting for an appointment and tests and inpatients to enjoy a coffee, by hospital staff for lunch, and by hospital physicians for group meetings. It also offers a unique approach for allowing patients to exercise for cardiac rehabilitation and a hidden monitoring device in the tree canopy allows cardiac patients to continue to be monitored while exercising outdoors by health workers ensuring patient safety.
- **Dell Children's Medical Center of Central Texas, Austin, Texas:** As shown by Doulabi *et al*. (2024) [8], Dell Children's Medical Center is the world's first hospital to achieve LEED Platinum certification, exemplifying sustainable design and energy efficiency. It adapted multiple sustainability designs like energy-efficient materials and systems, including high-performance windows and reflective roofing, on-site solar panels, and implemented rainwater harvesting and low-flow fixtures to reduce water use, resulting significant reduction in energy and water use and providing enhanced indoor environmental quality and patient comfort.

Conclusion

Green hospitals offer significant environmental benefits by reducing energy, waste, and water consumption. To overcome challenges and promote wider adoption, healthcare organizations need ongoing research, collaboration, and support from policymakers.

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