International Journal of Leading Research Publication (IJLRP)
E-ISSN: 2582-8010 ● Website: www.ijlrp.com ● Email: editor@ijlrp.com

The Implementation of Integrated Energy Management Systems in Healthcare Facilities - Balancing Efficiency and Effectiveness

Simran Sethi[1], Barbara Caemmerer[2]

[1]Student, [2]Supervisor
[1]Specialisation: Leading Green and Digital Transformation

Abstract

This research investigates the challenges and opportunities in energy management within healthcare facilities, focusing on the New Delhi and Gurugram region in India. Utilizing qualitative semi-structured interviews with five healthcare professionals, including anaesthesiologists, dental surgeons, dentists, ENT doctors, and gynaecologists, the study explores their perspectives on energy consumption, technological advancements, regulatory compliance, and societal implications.

The data analysis reveals that healthcare facilities face significant challenges in energy consumption, particularly during the COVID-19 pandemic. The integration of renewable energy sources, optimization of energy storage, and predictive analytics emerges as crucial areas for future research. The theoretical framework emphasizes the interconnectedness of technological innovations, organizational considerations, and regulatory landscapes. Findings suggest that an integrated energy management system, incorporating advanced technologies like IoT sensors and AI-powered analytics, is essential for optimizing energy consumption patterns

At a managerial level, the study emphasizes the importance of conducting cost-benefit analyses, evaluating return on investment, and promoting an energy-efficient culture within healthcare organizations. The societal and environmental implications of healthcare underscore the necessity of regulatory compliance and a shift towards sustainability reporting. In Delhi, several regulatory compliance measures, such as mandatory solar panel installations, are observed in line with national guidelines for green and climate-resilient healthcare facilities. To achieve sustainable and efficient energy management in healthcare facilities, the study recommends a holistic approach that takes into account advanced technologies, organizational culture, and regulatory compliance. The research contributes to the existing literature by providing comprehensive insights into the various aspects of healthcare energy management, paving the way for future research directions and practical implementations.

PART I. LITERATURE REVIEW

Challenges related to energy in Healthcare Facilities

Healthcare facilities face a lot of challenges to energy consumption and with rising stress during the COVID 19 pandemic it became even more apparent. Most notably it was found that energy consumption

at these facilities arises from space heating, cooling, ventilation, steam production, medical equipment usage, lighting, and hot water consumption (Alotaiby and Krenyácz 2023). In fact, some researchers emphasize the importance of energy efficiency in the face of growing energy demand. In Italy, the hospital sector accounts for approximately 35% of the total energy use. Hospitals are described as complex structures due to their size, diverse technologies, and the need for continuous operation (Alfonso et al. 2023). While energy is important for healthcare facilities, implementing efficient energy strategies in this context presents significant challenges, including outdated building structures. Since healthcare facilities conjure up huge electricity bills due to the abovementioned reasons, an efficient way to manage the energy systems is necessary. There have been many proposals in this area, such as variable air volume system, partial use of renewable energy resources, optimization of HVAC systems etc. (Kolokotsa et al. 2012). The rise in operation costs and environmental degradation are important concerns for the adoption of integrated EMS solutions.

Fundamental Principles Underlying Integrated Energy Management Systems

Use of technology, organization restructuring, and regulatory aspects needed to be combined together to provide a framework for the hospital's energy management and be part of the final framework. (Gambarotta et al. 2023) suggested in their study to focus on integrated energy systems, which combine electricity, heating, and gas sectors to enhance system efficiency and incorporate renewable energy sources. It introduces a real-time optimization strategy using Model Predictive Control (MPC) to coordinate various technologies in systems with multiple conversion units and distribution networks. Factors affecting energy consumption in hospitals vary widely, including usage type, building age, insulation, climate, equipment maintenance, and energy management. (Kolokotsa et al. 2012) suggest implementing straightforward energy conservation techniques, which can lead to up to 10% reduction in primary energy consumption. Targeting high-cost energy categories and employing integrated energy management programs are recommended for identifying potential savings. Overall, the literature review suggests that a holistic view is needed which incorporates advanced technologies such as IoT sensors and data analytics, along with organizational structures and behavioral interventions. An interplay between technological innovations and the broader social-economic context is a perspective that needs to be adopted.

Efficiency and Effectiveness in an Energy Management System

In an energy management system, efficiency is related to maximal output from minimal input. Meaning that we need to optimize resource allocation and consumption. The study (Santamouris et al 1994) proposes and evaluates various scenarios for interventions in building envelopes and heating, cooling, and lighting systems to assess the effectiveness of energy conservation techniques. Simulations suggest that an overall 20% energy conservation is achievable. Specific measures include using more efficient heat production and distribution systems (resulting in a 15% reduction in heating consumption for hospitals and 11% for clinics), proper insulation (saving 173 kWh/m2 in hospitals and 103 kWh/m2 in clinics) and employing night ventilation and ceiling fans for cooling (achieving reductions of up to 68% and 56% in hospitals and clinics, respectively). The use of high-efficiency lamps can also cut lighting energy consumption by up to 50%. On the other side, effectiveness relates to the alignment of energy management strategies with organizational goals, sustainability objectives and patient care. In a comparative study on energy benchmarking in healthcare facilities, Li et al. (2021) have introduced

various benchmarking methods such as multiple linear regression (MLR) and generalized additive model (GAM) for assessing energy efficiency in healthcare facilities. The knowledge gained from benchmarking methodologies can aid in evaluating the efficacy of energy management strategies. In 2023, Bera et al. introduced a simulation-based approach to achieve flexibility in healthcare processes, which provides valuable insights. This approach emphasizes flexibility, resource utilization, and adaptive care. These factors align with human behavior and organizational culture considerations for a successful energy management system.

Case Studies in Integrated Energy Management Systems

There are numerous case studies showing that integrated energy management system is the right approach. For example, in South Africa, healthcare institutions are significant energy consumers, with consumption levels per bed ranging from 43–92 kWh per day. The main thermal energy consumers are heating, ventilation, and air conditioning (HVAC) and water-heating systems, both critical to patient health. Hohne et al. (2020) proposes various energy-efficiency initiatives categorized by different levels: conceptual, active, technical, and further improvement, based on the POET framework (performance, operation, equipment and technology efficiency). Potential energy savings range from 50%–70% at the conceptual level, 15%–30% at the active level, 50%–70% at the technical level, and 5%–10% at the further improvement level. In another study by Santamouris et al (1994) an extensive energy audit of 30 healthcare buildings in Hellas, Greece was conducted as part of a National Energy Programme. Various interventions including improvements to the building envelope and heating, cooling, and lighting systems, to achieve energy conservation were proposed. Additionally, the use of high efficacy lamps can reduce lighting energy consumption by up to 50%. The findings provide valuable insights into energy consumption patterns in healthcare buildings and serve as guidelines for future energy-efficient construction. In yet another case study by researchers in Brazil, emphasis on the crucial role of managing energy consumption, utilizing green technologies, and overseeing building installations for environmental performance in hospitals was found to be crucial (Oliveira et al 2021).

Regulations and Compliance

Energy management initiatives should be aligned with national and local standards or regulations. Additionally, specific focus should be given to industry–specific standards. Understanding and navigating these regulatory landscapes is essential for healthcare facilities which want to adopt effective energy management strategies and are willing to remain compliant with legal requirements. For example, Russel and de la Rica (2018) show in their research that decentralization has been a crucial aspect of healthcare reform, particularly through the adoption of mHealth and mobile biosensors for molecular diagnostics. Influential organizations like the World Health Organization, the European Union, and the FDA have advocated for global decentralization in healthcare. Developers of mobile biosensors aim to align with these policies by enabling easy data sharing between patients and providers, and by connecting portable readers with diagnostic tests. This helps to advance new trends and discoveries in the field of healthcare reform.In the future, we may see even more regulation hurdles, for example in another study Bamakan and Ziaeian (2022) introduced integration of blockchain technology in waste management systems which aligns with the environmental sustainability aspect of healthcare facilities. The emphasis on waste recycling and reuse resonates with the broader societal goals,

contributing to a more sustainable healthcare environment. However, this may cause some hurdles with regards to adoption of this new technology.

Technological Advancements

Major advancements in healthcare management systems include AI-powered analytics, integration of advanced sensors, real-time monitoring systems and blockchain technology to optimize energy consumption patterns in healthcare settings. These advancements have paved the way for more innovative solutions to evolve. They offer the potential for real-time insights and adaptive control allowing healthcare facilities energy systems to respond dynamically to fluctuations in demand. In their 2019 study, Dhanvijay and Patil focused on health applications utilizing wireless communication. They placed particular emphasis on aspects such as network setup, infrastructure, and implementation in the healthcare sector. They also addressed privacy and security concerns, identifying areas for further research. Habibzadeh et al. (2020) reviewed the clinical applicability of Healthcare Internet of Things (HIoT), focusing on its key components: sensing, data transmission, and deduction. Dang et al. (2019) examined current trends in IoT-based healthcare systems, as well as the integration of emerging technologies like Big Data Analytics (BDA) and cloud computing in healthcare applications. They also conducted a detailed assessment of privacy and security issues associated with IoT in healthcare. Ray et al. (2019) investigated the relevance of edge computing in IoT-based healthcare systems, providing various use cases for edge-IoT-based healthcare frameworks. They introduced a novel framework for healthcare leveraging edge computing (Junaid et al 2022).In additional review, Lakhan et at. 2022 proposed DNNECTS algorithm framework which introduces advanced technologies like deep neural networks and IoT for energy-efficient partitioning and task scheduling. Such technological advancements are crucial in optimizing energy consumption patterns, aligning with the need for incorporating IoT sensors and data analytics in healthcare energy management. In another paper, Banotra et al. (2023) conducted a study on energy harvesting for IoT devices. Their research is highly relevant to healthcare energy management and provides valuable insights into creating sustainable solutions. The study recommends incorporating renewable energy sources and optimizing energy storage as future research needs for integrated energy management systems.

Human Behavior and Organizational Culture

The human element in healthcare energy management systems is crucial for their success. Fostering a culture of energy efficiency within the staff at these healthcare facilities can save significant portions of their daily energy consumption. Increasing awareness would include training staff in energy conservation and incentivizing them to exhibit these behaviours. For example, García-Sanz-Calcedo et al (2014) performed a study in 70 healthcare centers in Extremadura (Spain) through which they identified that energy management is more effective in smaller buildings compared to larger ones with a higher number of users and medical staff. Larger buildings face challenges in educating a larger workforce on environmental and energy matters, and their operational cost management may be less centralized without a dedicated Center Director. However, larger buildings tend to be more efficient in utilizing renewable energies as their floor area increases. Hence, building size, patient to caregiver ratio and number of staff are essential factors to consider when designing an efficient energy management system. In further analysis, Swarnakar et.al (2023)'s study emphasized critical success factors (CSFs) for

sustainable Lean Six Sigma (LSS) implementation in healthcare. The most important factors for efficient energy management in healthcare facilities were identified as the economic and managerial (E&M) critical success factors (CSFs). A holistic approach incorporating advanced technologies and organizational structures is necessary, and the prioritization method used to identify these CSFs was the best-worst method (BWM). In another novel approach, the paper by Nichols and Strengers (2014) offers a distinct viewpoint on the social behaviors linked with air conditioning and their influence on the highest possible electricity demand. This approach towards health implications aligns with the comprehensive outlook required for the effective management of energy in healthcare facilities, highlighting the correlation between technological advancements and wider socio-economic contexts.

Cost-Benefit Analysis and ROI

The adoption of these energy management systems should be preceded by a cost-benefit analysis. A team of researchers that look into the long-term economic viability of such implementations is necessary. Evaluating the return on investment can help the healthcare facilities to justify capital expenditure while improving the quality of care. For example, the results from the study conducted in Spain (García-Sanz-Calcedo et al) showed that for a healthcare center with an area of 1000 square meters (about twice the area of a basketball court), a potential reduction of 10,801 kWh in energy consumption can be achieved through an average investment of 11,601Euros. This would result in an annual saving of 2961 euros with an average payback period of 3.92 years. Similarly, in a study conducted by Ryan-Fogarty et al. (2016) at Cork University Hospital in Ireland, environmental sustainability efforts were examined. The research revealed a significant 33% decrease in energy consumption following the introduction of an energy management program, which was a collaborative effort with the Irish government's Public Sector Energy Efficiency Program. This initiative focused on educating hospital staff and formulating strategies to mitigate their environmental footprint.

Environmental Sustainability and CSR

According to a study by Senay and Landrigan (2018) there is limited adoption of sustainability reporting withing the healthcare sector due to narrow profit margins, regulatory complexities, and a potential belief that healthcare organizations are already contributing significantly to society. Although it also states that there are strides in this direction through initiatives such as American Hospital Association's Sustainability Roadmap for Hospitals. Another study by Creixans-Tenas (2020) promotes a model that establishes a connection between the social responsibility initiatives undertaken by these hospitals (122 Spanish hospitals studies in the research), their communication practices, and their economic and financial performance. Additionally, the study highlights the mediating role of communication in the relationship between social responsibility and financial outcomes. Therefore, by reducing their carbon footprint and showing a commitment to sustainable operations, healthcare facilities can align themselves with broader societal goals and expectations.

Areas for Filling the Research Gap and Potential Directions

While there has been quite wonderful progress in this direction, there is still a need for understanding and implementing integrated energy management systems. Future research needs to focus on areas such as integration of renewable energy sources, optimization of energy storage solutions, and the development of predictive analytics for energy demand forecasting. Additionally, there is more space for

doing comprehensive studies that consider the unique challenges of different types and sizes of healthcare facilities in new geographical locations.

PART II. CASE DESCRIPTION

Introduction

India's healthcare facilities, especially those in the Delhi NCR (National Capital Region) region, are faced with a double challenge of providing quality healthcare at an affordable cost while managing escalating operational costs, including a growing energy use. This study examines the implementation of EMS within these hospitals as well as a study of the status quo within them, particularly in the cities of New Delhi and Gurugram. In this case study, we take a closer look at how certain healthcare facilities have implemented an EMS system. By conducting a case study interview with doctors and facility managers, this study aims to gain a deeper understanding of the challenges, strategies, and outcomes of integrating EMS in an environment where resources are limited.

Context of the Case

Gurugram and New Delhi are among the most densely populated urban centre in India. Based on Indian Health Public Standards, there should be 3.33 beds per 1000 people, based on which, Gurugram should have 6000 beds, however it only has 1360 beds that are deemed affordable to the middle and lower-middle classes. The annual OPD (outpatient door) inflow, which has 2.8 million in 2017, is expected to grow to 7 million by 2030 (According to Times of India Newspaper article and numbers released by Gurgaon Metropolitan Development Authority - GMDA). In the wake of these growing demands, we want to understand the plan for implementing an energy management system within these healthcare facilities.

Case Selection Rationale

This case study adopts the categorization of a “critical” case due to the criticality of energy management in healthcare facilities, where uninterrupted power supply is crucial for patient care. Additionally, the case is “unusual” given the unique challenges faced by healthcare facilities in these densely populated cities, which may differ from other regions. (Based on Yin’s 2018 categorization). The choice of this case is pivotal in answering the overarching question regarding the successful implementation of EMS in resource-intensive healthcare settings.

Case Boundaries

This case will focus on public and private hospital in New Delhi and Gurugram. It will not include smaller clinics, and healthcare facilities located in rural or less developed areas. The study will primarily focus on the implementation of Energy Management Systems and its impact on energy consumption and operational efficiency. Broader topics such as healthcare policy, infrastructure development, or other non-energy related issues will be considered but only in relation to their direct influence on EMS adoption.

Descriptive Data

The selected healthcare facilities in Gurugram and New Delhi range from medium-sized private hospitals to large government-run medical centres. These facilities serve a diverse patient population including local residents, as well as patients traveling from neighbouring states and even international medical tourists. The hospitals vary in terms of size and specialization, with most of them proving a wide range of services but some focussing on specific speciality (cardiology or orthopaedics). A list of proposed doctors work with the following hospitals:

1. Max Hospital, Delhi NCR
2. Yashoda Hospital Kaushambi, Delhi NCR
3. Artemis Hospitals, Gurgaon
4. Apollo Hospital, Gurgaon
5. Medanta - the Medicity, Gurugram

Justification of Case Choice

Due to the study's geographical focus, New Delhi and Gurugram are chosen as the study's case studies because of their prominence in India's healthcare landscape as well as their unique challenges relating to energy management that the hospitals in these cities face. There are several issues which these cities face such as fluctuating power supplies, increasing energy costs, an increasing educated and energy conscious population and an increased awareness of the environmental impact on the healthcare operations in these cities. Hence, by exploring this area we will be able to find the answers to the question, "How can we achieve a balance between efficiency and effectiveness in the management of healthcare energy resources?"

Interview process and Data collection

To gather intelligent insights, semi-structured interviews were conducted with key stakeholders in the selected hospitals. This includes mostly doctors, but perhaps also some facility managers who have worked and seen the workings of these hospitals. The interview will be guided by some pre-determined questions, covering topics such as motivations for adopting EMS, challenges faced and status quo.

PART III. CASE STUDY PROTOCOL

Justification of Research Design

Statement of Research Question

In this research paper, I would like to explore the topic of how we can achieve a balance between efficiency and effectiveness in the management of healthcare energy resources in resource-intensive settings with a special focus on the hospitals in New Delhi and Gurugram area of India.

Case Selection Rationale

The chosen investigation of healthcare facilities in New Delhi and Gurugram serves as a fitting exploration of the research question for several compelling reasons, aligning seamlessly with Yin's established criteria.

First and foremost, the critical nature of the case is underscored by the indispensable need for uninterrupted power supply in healthcare facilities, where energy management emerges as a pivotal facet of their day-to-day operations. This case, therefore, effectively delves into the criticality of energy management within healthcare settings.

Furthermore, the chosen case stands out as an unusual one due to the distinctive challenges confronted by healthcare facilities situated in densely populated urban centres like New Delhi and Gurugram. These challenges include escalating energy costs, fluctuating power supplies and a progressively energy-conscious population, rendering this case both unique and distinct from other geographic regions.

The study's uniqueness lies in its focus on public and private hospitals in Delhi and Gurugram. By focussing on these locations, the research provides a targeted and concentrated context for examining the implementation of energy management systems within the healthcare sector. As a result, we can gain insight into how such facilities are being run in India.

The selection of hospitals within the study encompasses a diverse range, varying from medium-sized private facilities to large government-run medical centres, serving a broad and varied patient population. This diversity in size and specialization adds to the study's strength by providing a mixed sample for comprehensive analysis.

In the end, the study's focus on energy consumption and operational efficiency is directly relevant to the question. To establish a strong and focused exploration of the research topic, EMS and best practices are investigated within selected healthcare facilities in New Delhi and Gurugram.

Research Quality Criteria

This multifaceted approach has been adopted to ensure construct validity of this research project aimed at managing healthcare energy resources efficiently and effectively in resource-intensive settings. Semi-structured interviews with key stakeholders, including doctors and facility managers in selected hospitals in New Delhi and Gurugram, serve as a primary source of firsthand information. Additionally, an extensive review of reports related to the implementation of Energy Management Systems (EMS) in healthcare facilities, along with an examination of newsletters and training materials provided by the National Accreditation Board for Hospitals & Healthcare Providers (NABH) in India, contributes to a comprehensive understanding of the subject matter. The triangulation of interview data with information gleaned from NABH reports ensures the convergence of evidence, enhancing the construct validity of the findings.

To address internal validity, a rigorous approach involving pattern matching was employed. Themes and patterns emerging from the interviews were systematically compared with those present in reports from the governmental agencies, hospitals and internal and external links. Cross-checking information across different sources, including interviews and reports, ensures the consistency of findings and strengthens the internal validity of the study. This methodological triangulation serves to minimize biases and enhance the credibility of the research outcomes.

The research aims to connect the interview findings with existing theories in the field of healthcare energy management to establish external validity. The insights gathered from the selected interviewees working in different areas of healthcare contribute to the broader body of knowledge in the field, achieved through analytic generalization. The study also includes relevant theories and concepts from

the existing literature to construct a theoretical framework that guides the research process and helps in understanding the implications of the case study findings.

Maintenance of reliable data is achieved through meticulous data management practices. The researcher developed a dedicated database that ensures data integrity and consistency throughout the research process (also available in the Appendix). We report the links between research questions, data sources, types, analysis methods, and findings in a transparent manner, thereby maintaining a clear and reliable chain of evidence. Consistency in data collection and analysis procedures across the case study reinforces the reliability of the study, with a focus on systematic and rigorous data handling throughout the research process.

Sources of Evidence and Approach to Data Collection

Research Proposition (RP) 1

The implementation of integrated energy management systems can lead to significant reductions in energy consumption in healthcare facilities in India such as hospitals and clinics, contributing to both environmental sustainability and cost savings.

To explore the impact of implementation of energy management systems, key data points are crucial. The primary evidence sought is the data on energy consumption in hospitals and clinics, accessible from the Bureau of Energy Efficiency (BEE) in India. To realize the economic impact, consumption figures and estimated energy impact are explored for these areas as compared to the whole country. This shall give us a comprehensive overview of potential financial benefits.

Environmental impact assessments related to energy conservation efforts are sourced from reports on energy efficiency by National Centre for Disease Control (under the Government of India). The report titled “Towards Climate-smart Hospitals” was released with consolidated insights from the National Hospital Energy Consumption Survey in August 2023 and was carried out by the National Programme on Climate Change and Human Health (NPCCHH). It is a pivotal source for understanding broader environmental implications of EMS adoption in healthcare settings.

Research Proposition (RP) 2

The challenges related to energy consumption in India are multi-faceted, focusing on factors such as acute water scarcity and climate change.

To understand the muti-faceted challenges in healthcare facilities, the focus shifts to acute water scarcity and climate change. Data on both is extracted from reliable sources, including the Meteorological Department of India, world bank reports, and Statista. The World Bank’s climate change impact report provides a comprehensive overview of the environmental challenges faced by healthcare facilities.

Additionally, qualitative interview with several doctors gleans insights into their perspectives on the challenges associated with water scarcity and climate change in healthcare facilities. These interviews add a valuable base layer to our understanding, providing real-world experiences and perceptions that contribute to more nuanced analysis. The synthesis of this qualitative data will be incorporated into visual representations such as a word cloud, to showcase the interconnected challenges of water scarcity and climate change in the context of healthcare energy consumption.

Research Proposition (RP) 3

This proposition explores the impact of technological advancements on the healthcare facilities. The IoT sensors, AI-powered analytics and real-time monitoring systems, offer opportunities to optimize the energy consumption patterns in healthcare settings. To support this proposition, reports and case studies from BEE, will provide valuable insights into successful applications of technology for energy optimization.

Qualitative interviews with healthcare professionals, especially those involved in the adoption of advanced technologies, have been conducted. These interviews offer a base layer of understanding, providing first-hand accounts of the impact of AI-powered analytics, IoT sensors, and real-time monitoring systems on energy consumption patterns. The synthesis of these qualitative insights will be presented, highlighting the human aspect of technological integration in healthcare energy management.

Research Proposition (RP) 4

Fostering a culture of energy efficiency among staff is critical for the success of energy management systems in healthcare facilities.

The fourth proposition emphasizes the human element in energy efficiency, focusing on fostering a culture of energy consciousness among healthcare staff. Qualitative interviews with doctors provide us with a base layer understanding of the status quo and gives us insights into the cultural practices that support the idea of energy conservation in healthcare settings. Training records and documentation of energy conservation workshops or programs conducted by NABH (National Accreditation Board for Hospitals & Healthcare Providers) a subsidiary of Quality Council of India provide supplementary evidence to the same.

PART IV. DATA ANALYSIS AND FINDINGS

Introduction and Background

The healthcare sector in India, as much as it is crucial for health, promotion and delivery of health, it also stands as the key emitter of Green-house gases (GHGs). According to the report from Alliance for an Energy Efficient Economy, the climate footprint of the Indian healthcare sector is substantial, amounting to 39 million tons of carbon dioxide equivalent, comparable to the annual GHG emissions from 10 coal-fired power plants. This insight underscores the need for energy efficient practices within healthcare facilities to circumvent their environmental impact.

As a result of this revelation, a series of qualitative semi-structured interviews were conducted. The interview questionnaire was designed to gather insights from healthcare professionals in New Delhi and Gurugram regarding their awareness, experiences, challenges, and perspectives on energy management. The comments from five doctors were collected between December 2023 and January 2024.

Table: Interviewed doctor's overview

Table 1. Overview of Interviewed Doctors

Doctor ID	Specialization	Years in practice	Key points discussed
D1	Anaesthesiologist	More than 17 years	Cost control in premium institutions, challenges in compliance

D2	Dental Surgeon	4 years	Use of solar panels in dental department, challenges in incentives
D3	Dentist	17-18 years	Balancing energy in high-end hospitals, post-COVID impact
D4	ENT Doctor	18 years	Use of solar panels and generators, mandatory solar panel installation
D5	Gynaecologist	20 years	Awareness on lights usage, IoT sensors for water conservation

Table: List of Institutes - Acronyms

Table 2. Here is a list of acronyms used for institutes in this research:

Acronym	Full form
NABH	National Accreditation Board for Hospitals and Healthcare - India
EMS	Energy Management System
BEE	Bureau of Energy Efficiency - India
NPCCHH	National Programme on Climate Change and Human Health - India
AIIMS	All India Institue of Medical Sciences - India
GHG2	Metric tons of indirect CO2 emissions of electricity, power and heat from direct billing of owned or leased facilities.

Energy Management Systems (EMS) Awareness and Implementation

The interviews explored the awareness and experiences of healthcare professionals regarding Integrated Energy Management Systems (EMS) in healthcare facilities.

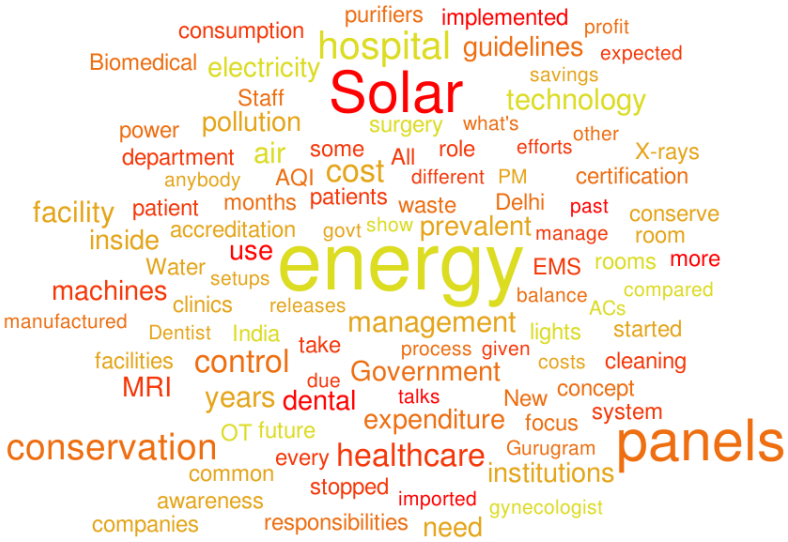


Fig 1. Word-cloud of Responses by Doctors in the Qualitative assessment conducted as a part of this report

The doctors have varying levels of experience, with the highest being 20 years in practice. Most doctors reported Solar panels are commonly used in healthcare facilities for energy conservation. Some also reported that compliance with energy regulations is a concern, especially in premium institutions. Doctor D2 also reported challenges in energy certification. Moreover, the COVID-19 pandemic had amplified the country's reliance on advanced healthcare, emphasizing the need for a sustainable approach in the face of increasing energy consumption. Above you will find a word cloud with keywords extracted from doctors' responses on EMS awareness.

Energy Consumption Challenges

Now diving deeper into the challenges of energy consumption in healthcare facilities by incorporating insights from the Bureau of Energy Efficiency's (BEE) "Energy Efficiency Report" also referred to as *Government Report* in the table below. The BEE report sheds light on the growing energy consumption in the commercial building sector, with a specific focus on hospitals. This information will be integrated with the responses from the interviewed doctors to provide a comprehensive overview.

Table 3. Challenges in Managing Energy Consumption - Combined Insights

Challenges	Insights from Doctors	Government Report
Lack of incentives for energy conservation	Doctor D2 emphasized the need for incentives in energy conservation.	Government emphasizes efficiency enhancement and conservation.
Compliance measures and certification costs	Doctor D1 highlighted challenges in energy pollution certification.	Growing energy consumption in the commercial sector.
Limited technology and training for staff	Doctor D3 discussed the need for technology manufactured in India.	Increased capacity demand due to the growth of the hospital sector.
Cost as a major factor in technology adoption	Doctor D5 stressed on the importance of cost considerations in technology adoption.	Inadequate power system to meet existing and growing demand.

The key findings from the interviews and the analysis of the government report are: Firstly, the lack of incentives for energy conservation is a common concern highlighted by both the doctors and the government report. Compliance measures and certification costs are identified challenges, with the BEE report emphasizing the growing energy consumption in the commercial sector. Some doctors have expressed limited technology adoption due to cost constraints, while the government report emphasized the inadequacy of the power system to meet existing and growing demand. Moreover, cost considerations for technology adoption are echoed by both the doctors and the government report.

And so, the challenges identified by the doctors are not isolated but are part of a broader context outlined by the government report. The imperative for the healthcare sector to contribute to energy conservation becomes even more pronounced when considering the significant strain on the power system and the socially desirable plan of making power available to all.

Technological Advancements

In this section we explore the first-hand experiences of the doctors with the technological advancement such as AI-powered analytics, IoT sensors, and real-time monitoring systems for energy optimization and other technological improvements to the current infrastructure. We also incorporate insights from Bureau of Energy Efficiency's (BEE) book on "Energy Management in Healthcare Facilities".

In the interviews, Doctor D2 mentioned the control of lights by doctors for energy savings, indicating a hands-on approach to energy conservation. On the other hand, Doctor D3 stressed on the need for technology manufactured in India, reflecting a consideration for local production to reduce costs.

The book on "Energy Management in Healthcare Facilities" by BEE highlighted the unique challenges faced by hospitals due to their 24/7 operation and the need for careful control of internal climates. The long-term use of hospital buildings, often exceeding 50 years, necessitates continuous optimization of energy consumption through retrofitting and renovations.

The report underscores that energy-efficiency measures are most effective during new construction, retrofitting or remodelling buildings. The BEE report aligns with Doctor D3's observation on the importance of cost in technology adoption. The report also suggests that it is usually less expensive to introduce additional energy saving measures during retrofitting work, thus minimizing the interference with normal hospital routines.

It also identified *centrifugal chillers* as significant power consumer, in the mechanical system room. The report emphasized the impact of microprocessor-based control systems and hence the improved energy efficiency of chillers. Doctor D5's observation on increased focus on energy conservation post-COVID aligns well with the emphasis on advancements in chiller control technology.

Additionally, Doctor D2's strong emphasis on the need for incentives in energy conservation resonates with the report's recommendation to schedule the installation of energy-saving measures during retro-fitting work to minimize disruptions.

The integration of insights from the BEE's book and doctors' interviews provides a comprehensive understanding of technological advancements in healthcare facility energy management. The observations from the doctors' interviews further highlight the practical considerations and challenges faced in implementing these technologies. The convergence of perspectives emphasizes the importance of embracing advanced technologies, especially during retrofitting and remodelling, to enhance the energy saving aspect in healthcare facilities.

Cultural Aspects and Staff Awareness

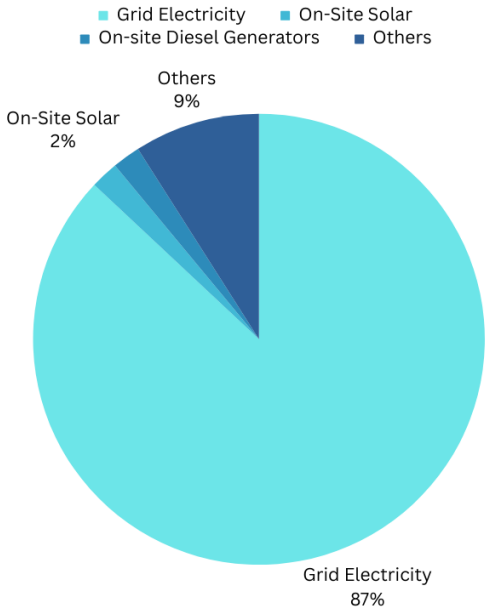


Fig 2. Distribution of hospitals' total primary energy use by energy source (Source: National Hospital Energy Consumption Survey 2023)

In this section, key insights from Doctor's interviews are combined with relevant data from the National Accreditation Board for Hospitals and Healthcare Providers (NABH) and the Bureau of Energy Efficiency's (BEE) best practice guide to explore the cultural aspects and staff awareness regarding energy management in healthcare facilities. The above pie chart shows the reliance of Indian healthcare facilities still being heavily on Grid Electricity.

NABH's Training Initiatives

Three out of five doctors highlighted the role of NABH employees in providing training on energy, water and waste management to the hospital staff. The training involves the use of posters and visuals to generate awareness. NABH standards also encourage hospitals to set up their own key performance indicators to monitor and measure healthcare facility performance related to compliance with Green & Clean Standards.

Energy Audit and Prioritization

BEE's guide emphasized the importance of starting with an energy audit. It would help identify all energy end-uses, estimate energy consumption by each end-use, and determine energy usage in relation to desirable values. The guide suggests prioritizing energy conservation measures based on cost-effectiveness. Economic models are recommended for calculating cost-effectiveness, considering savings throughout the lifetime of the measure. This sits well with the observation from doctor D4 on the increased focus on technology, coupled with NABH's indicators, aligning well with the guide's emphasis on selecting measures with a simple payback method.

The guide also finally highlights the importance of maintenance and follow-up procedures after implementing measures. Doctor D5's emphasis on IoT sensors and upgrading technology aligns well with the guide's recommendations for continuous monitoring of energy usage.

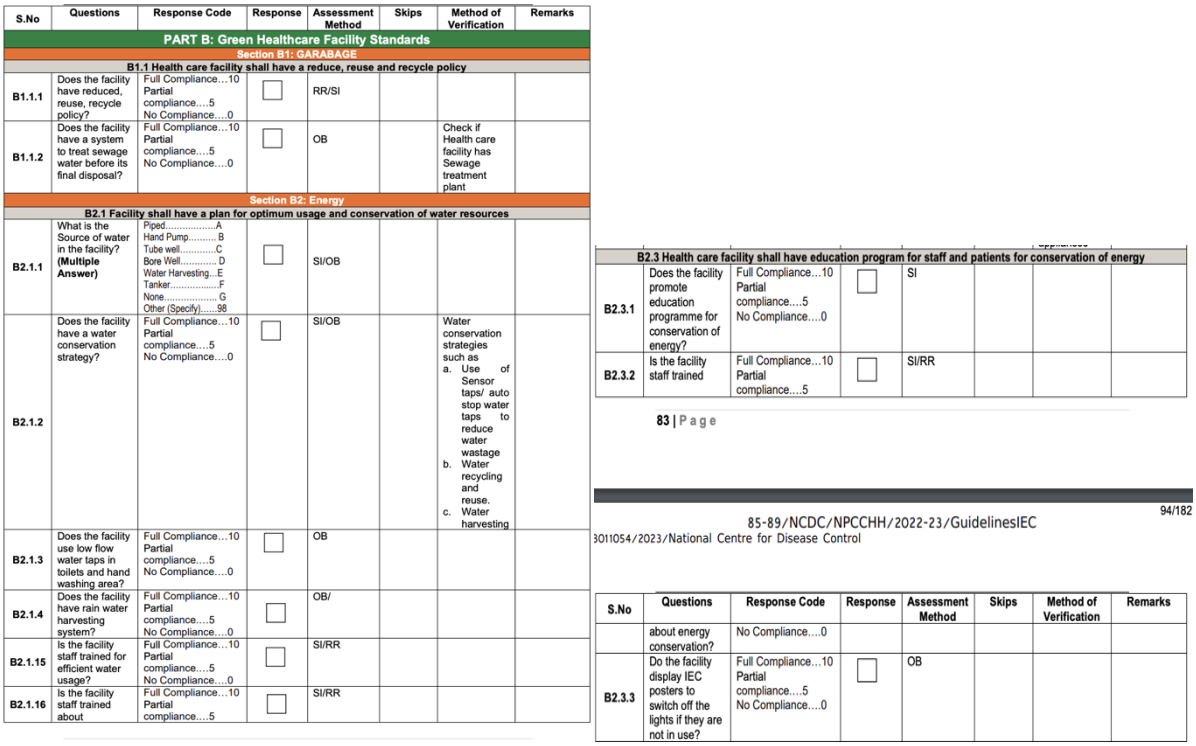
The guide also highlights that everyone's involvement is necessary to achieve the most cost-savings. Staff awareness and involvement are necessary for successful implementation. Doctor D2's mention of training staff for electricity conservation aligns with the BEE's recommendations of involving all staff members in energy-saving efforts.

Regulatory Compliance and Challenges

This section explores how healthcare facilities ensure compliance with national and local energy regulations and the challenges encountered while aligning energy management strategies with regulatory requirements.

Table 4. Regulatory measures and Insights from the interviewed Doctors

Regulatory Measures	Insights from Doctors
Mandatory Solar Panel Installations	Dr D4 highlighted the Delhi government's mandatory solar panel installation requirement.
Energy management council talks and inspections	Dr D3 discussed regular talks and inspections by energy management councils.
NABH accreditation for quality and safety standards	Dr D5 highlighted the requirement for NABH accreditation in hospitals.



S.No	Questions	Response Code	Response	Assessment Method	Skips	Method of Verification	Remarks
PART B: Green Healthcare Facility Standards							
Section B1: GARABAGE							
B1.1 Health care facility shall have a reduce, reuse and recycle policy							
B1.1.1	Does the facility have reduced, reuse, recycle policy?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	RR/SI			
B1.1.2	Does the facility have a system to treat sewage water before its final disposal?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	OB		Check if Health care facility has Sewage treatment plant	
Section B2: Energy							
B2.1 Facility shall have a plan for optimum usage and conservation of water resources							
B2.1.1	What is the Source of water in the facility? **(Multiple Answer)**	Piped……A Hand Pump……B Tube well……C Bore Well……D Water Harvesting…E Tanker……F None……G Other (Specify)…..98	☐	SI/OB			
B2.1.2	Does the facility have a water conservation strategy?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	SI/OB		Water conservation strategies such as a. Use of Sensor taps/ auto stop water taps to reduce water wastage b. Water recycling and reuse. c. Water harvesting	
B2.1.3	Does the facility use low flow water taps in toilets and hand washing area?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	OB			
B2.1.4	Does the facility have rain water harvesting system?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	OB/			
B2.1.15	Is the facility staff trained for efficient water usage?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	SI/RR			
B2.1.16	Is the facility staff trained about	Full Compliance…10 Partial compliance….5	☐	SI/RR			

B2.3 Health care facility shall have education program for staff and patients for conservation of energy							
B2.3.1	Does the facility promote education programme for conservation of energy?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	SI			
B2.3.2	Is the facility staff trained	Full Compliance…10 Partial compliance….5	☐	SI/RR			

83 | Page

94/182

85-89/NCDC/NPCCHH/2022-23/GuidelinesIEC

3011054/2023/National Centre for Disease Control

S.No	Questions	Response Code	Response	Assessment Method	Skips	Method of Verification	Remarks
	about energy conservation?	No Compliance….0					
B2.3.3	Do the facility display IEC posters to switch off the lights if they are not in use?	Full Compliance…10 Partial compliance….5 No Compliance….0	☐	OB			

Figure 3: Questionnaire in NPCCHH's report on "Guidelines on Green and Climate Resilient Healthcare Facilities," released in February 2023

After a careful study of the NPCCHH's report on "Guidelines on Green and Climate Resilient Healthcare Facilities," released in February 2023, it was realised that doctor D4's mention of Delhi government's mandatory installation of solar panels aligns with the NPCCHH's guidelines on renewable energy usage. NPCCHH's report emphasizes green and climate-resilient healthcare facilities. The compliance questionnaire, as shown in Figure, rates facilities as either compliant or non-compliant based on various green measures. Questions cover water conservation, rainwater harvesting, staff training for efficient water usage, usage of renewable energy, energy-efficient lighting, procurement of energy-efficient equipment, optimum use of natural light, use of energy-efficient appliances, and promotion of education programs for energy conservation.

Doctor D3's mention of government officials giving talks on future energy management aligns with NPCCHH's emphasis on climate-resilient healthcare facilities. Doctor D5's emphasis on IoT sensors and technology upgrades is in line with NPCCHH's focus on energy-efficient appliances and equipment

The challenges in implementing energy management strategies were highlighted by doctor D1's comment that compliance measures should be checked only every 6 months. This emphasizes the need for more frequent checking and monitoring to ensure that the healthcare facilities meet the regulatory requirements consistently.

Balancing Efficiency and Effectiveness

Table 5. Insights from the semi-structured interviews of doctors in Delhi-Gurugram area.

Future Perspectives	Insights from Doctors
Focus on digital technology adoption	Doctor D3 emphasized the shift towards digital technology in healthcare.
Increasing awareness and penalties for non-compliance	Doctor D5 stressed the need for penalties for non-compliance to enhance awareness
Increasing efficiency through digital scanning	Doctor D4 discussed the efficiency gains from digital scanning technologies.

Insights from Doctor's interviews

In the interviews, we got some opinions from the doctors on how to balance efficiency and effectiveness in managing healthcare resources. One of the findings is that digital technology adoption and patient awareness are key strategies for balancing efficiency and effectiveness. Also, there is a big role of patient awareness in achieving this balance.

Further Insights

BEE's Energy Efficiency in Hospitals best practice guide outlines three fundamental ways to conserve energy: switching off equipment when not in use, incorporating energy efficiency methods in routine maintenance, and implementing energy-saving measures during hospital refurbishment. Further, BEE emphasizes the integration of energy efficiency measures as part of routine maintenance procedures.

This aligns with doctor D5's mention of sensors in operating theatres that cut off water when not in use, showcasing the integration of energy-saving measures into daily operational practices.

Local Context – New Delhi and Gurugram

In the Figure 4 below you can see the GHG Scope 2 emissions from hospitals all over India. Considering there are around 192 hospitals in New Delhi (Based on data on the website of Delhi Medical Association) and 100 hospitals in Gurugram (Based on data on the website of Government of Gurugram) including public and private hospitals, it amounts to a total of 9174 GHG Scope 2 emissions (in tonne CO2/year) in question. In comparison, we can see that an average annual emission of 3.7 metric tons of CO2 per car is equivalent to annual carbon emissions from a fleet of approximately 2,500 cars.

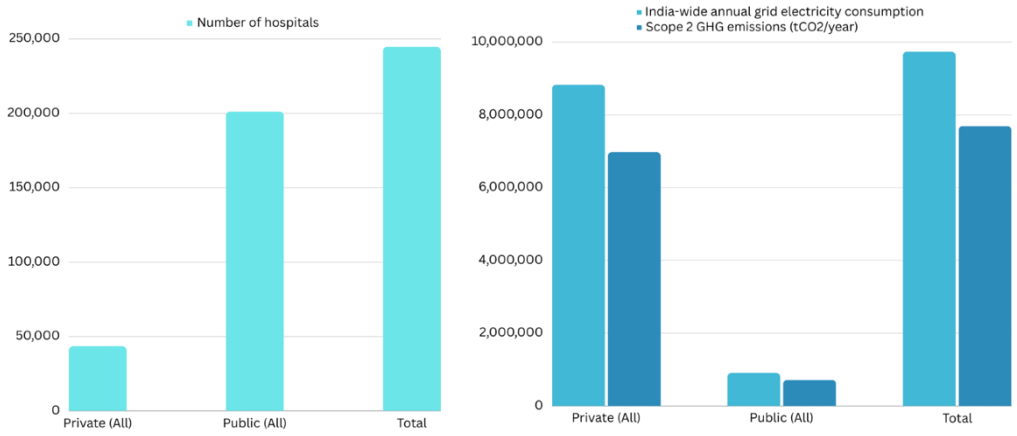


Fig 4. India-wide annual hospital grid electricity consumption and Scope 2 GHG emissions in FY 2019-20 (Source: National Hospital Energy Consumption Survey 2023)

During the interviews one insights that came forth was that the post-COVID era has witnessed an increased focus on healthcare infrastructure, not only in terms of medical preparedness but also in terms of environmental sustainability. Government bodies, such as the Delhi government, had made it mandatory for healthcare facilities to install solar panels, reinforcing a shift towards renewable energy sources. The emphasis on renewable energy aligns with Doctor D1's insights on the potential of renewable energy catching up in the healthcare sector. A table with summarised insights from the interviews is presented below.

Table 6. Insights from the interviewees on local perspectives

Localized factors	Insights from doctors
Delhi government mandates for solar panels	Doctor D4 discussed the Delhi government's mandatory solar panel installation requirement.
Impact of post-COVID changes on costs and efficiency	Doctor D3 highlighted the increased focus on energy conservation post-COVID.

Mandatory Pollution Certificates in Clinics as well as hospitals	Doctor D2 spoke about the mandatory pollution certificate in clinics for operation purposes and to offer best quality of care to the patients

However, challenges in aligning energy management strategies with regulatory requirements persist, as noted by Doctor D2. The government's focus on compliance, while crucial for driving sustainable practices, poses challenges for healthcare facilities in terms of initial costs and implementation hurdles.

PART V. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research study was to investigate the energy management practices in healthcare facilities in New Delhi and Gurugram, India to shed light on the challenges faced by healthcare professionals, technological advances, cultural aspects, regulations compliance, and the local context in which healthcare facilities operate. Although the study has its limitations, the findings provide valuable insights for theoretical, managerial, and societal implications, as well as acknowledging the study's limitations.

Theoretical implications

This study significantly contributes to the existing literature by offering a nuanced understanding of energy management in the healthcare sector, particularly in the Indian context. The theoretical implications can be summarized as follows

1. Integrate various environmental management theories. Including the socio-technical perspectives to analyze the complex interplay between technology, cultural and regulatory factors influencing energy management in healthcare facilities.
2. The post-COVID era saw an increase in environmental sustainability which aligns with resilience theory. This emphasizes the need for healthcare facilities to adapt to changing environmental priorities.
3. The research also highlighted the role of regulatory bodies such as BEE, NABH, NPCCHH in shaping the energy management practices. The mandatory solar panel installation and compliance measures underline the impact of institutional forces on environmental priorities.

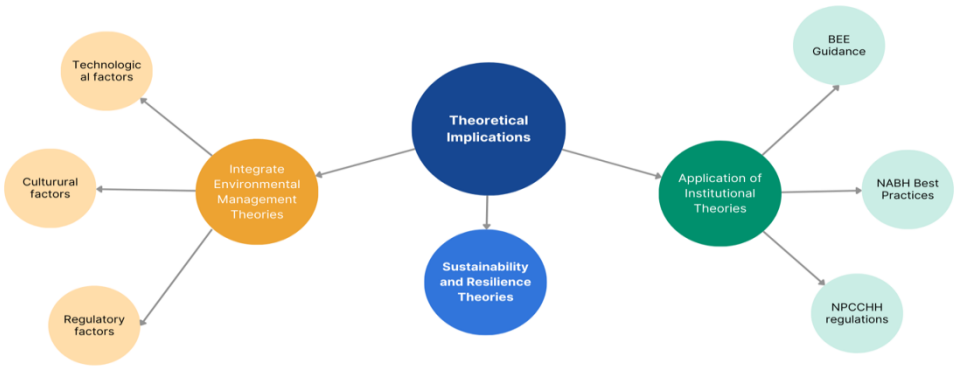


Fig X: Bubble map of theoretical implications gathered by this study

This study aims to contribute to the existing literature by combining diverse perspectives on healthcare energy management. The challenges identified in this study align with previous research (Alotaiby and Krenyácz, 2023; Alfonso et al., 2023), highlighting the persistent struggle of healthcare facilities in managing energy consumption. The proposed theoretical framework above incorporates the role of integrated energy management systems, technological innovations, and organizational considerations (Gambarotta et al., 2023; Kolokotsa et al., 2012). This study builds on Santamouris et al.'s (1994) effectiveness evaluation, emphasizing the importance of aligning energy strategies with organizational goals and sustainability objectives. These contributions advance the understanding of holistic approaches to healthcare energy management

Managerial implications

Some of the managerial level implications are illustrated and listed below:

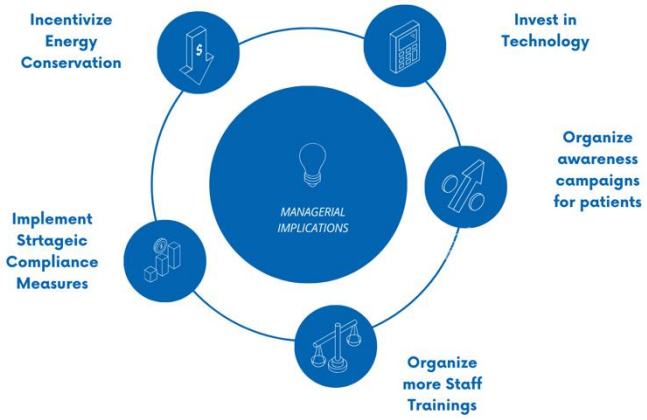


Fig XX: Some implications of actions to be taken on managerial level

1. Healthcare organizations should implement incentive programs to encourage staff to conserve energy due to concerns around lack of incentives.
2. It's advisable for managers to invest in energy-efficient technologies during retrofitting and remodelling. This will not only be cost-effective but also ensure minimal disruption to daily operations
3. The importance of continuous staff awareness programs is highlighted by the role of NABH in providing training. Managers should prioritize training sessions to instil a culture of energy conservation throughout the organization.
4. Healthcare managers should take a proactive approach to regulatory compliance. This involves investing in renewable energy sources to meet requirements and aligning with governmental mandates and global sustainability goals

Organizations and healthcare managers can learn valuable lessons from this study. The study emphasizes the importance of integrating advanced technologies like IoT sensors and AI-powered analytics to optimize energy consumption patterns (Dang et al., 2019). It also underscores the significance of financial viability through cost-benefit analysis and return on investment (García-Sanz-Calcedo et al.,

2014) when implementing energy management systems in order to save costs. Furthermore, the study highlights the critical role of staff awareness and engagement through trainings in achieving energy efficiency goals, emphasizing the significance of human behaviour and organizational culture (García-Sanz-Calcedo et al., 2014; Swarnakar et al., 2023).

Societal or environmental implications

The study highlights the impact healthcare facilities have on environmental sustainability and society. Compliance with regulations, as studied by Russel and de la Rica (2018) and Bamakan and Ziaeian (2022), is crucial for aligning energy management strategies with legal requirements. The study also advocates for healthcare organizations to shift towards environmental responsibility and sustainability reporting, aligning with broader societal expectations (Senay and Landrigan, 2018; Creixans-Tenas, 2020). Moreover, the study has broader implications. The Delhi government's emphasis on renewable energy has a positive impact on environmental sustainability. By adopting solar panels, healthcare facilities contribute to reducing the carbon footprint and align with global climate goals. Additionally, the study reveals that NABH standards are important in ensuring quality and safety in healthcare facilities. This has societal implications by promoting equitable healthcare services with an emphasis on environmental responsibility. The increased focus on energy conservation after COVID-19 presents an opportunity to raise public awareness. Public campaigns can educate individuals about the environmental impact of healthcare facilities and the role they play in supporting sustainable practices.

Limitations of study

Although this study provides valuable insights, it does have some limitations. The study is based on interviews conducted with only five healthcare professionals in specific locations. Therefore, a larger and more diverse sample could offer a more comprehensive understanding of energy management practices in the Indian healthcare sector. Furthermore, the data collection period was limited to 2023-2024, and a more extended timeframe could capture evolving trends and changes in energy management practices. Additionally, the findings may not be entirely generalizable to all healthcare settings in India as regional variations and differences in healthcare infrastructure could impact the applicability of the study's insights. Finally, the study heavily relies on interviews and existing reports, and direct observational data within healthcare facilities could have added depth to the understanding of energy management practices.

Recommendations for Future Research

Here are some suggestions for future research on energy management practices in healthcare facilities:

- Conduct longitudinal studies to track the evolution of energy management practices over time, considering changing regulations, technological advancements, and cultural shifts.
- Compare different states or cities within India to identify unique challenges and best practices related to energy management practices in healthcare facilities.
- Conduct in-depth case studies within healthcare facilities to gain a deeper understanding of the implementation of specific energy-saving measures and their impact.

- Investigate public perceptions and awareness regarding the environmental impact of healthcare facilities, which could be used to develop targeted awareness campaigns.

The research gaps that have been identified propose several directions for future exploration. Researchers should focus on the integration of renewable energy sources, optimization of energy storage, and the development of predictive analytics for energy demand forecasting. Conducting comprehensive studies that consider the unique challenges faced by different healthcare facility types and sizes across various geographical locations will contribute to a more nuanced understanding of effective energy management

DISCLAIMER

I Simran Sethi hereby declare that I am the sole author of this Master's thesis.

I hereby certify that it does not contain material which I have submitted for the qualification for any other degree.

I confirm that I am aware of and understand ESSCA's policy on plagiarism and I certify that all the sources that have been used to write this Master's thesis are explicitly referenced in conformity with the guidelines provided in the programme.

I certify that the data that have been used in this Master's thesis were collected and analysed with conformity of academic integrity standards. I confirm that I'm at ESSCA's disposal to produce the original dataset and the electronic files I used during data analysis.

The views and opinions expressed in this Master's thesis are those of the author and do not necessarily reflect the ESSCA's official policy or position.

Acknowledgements

I would like to express my sincere gratitude to Professor Barbara Caemmerer for her invaluable guidance and unwavering support throughout the process of conceptualizing and writing this research thesis. Her expertise and insights have played a pivotal role in enhancing my understanding of research methodologies and refining the quality of this work.

I am also deeply thankful to ESSCA Business School and all the esteemed professors who have been instrumental in shaping my academic journey during my Masters programme. Their dedication to fostering a conducive online learning environment and imparting valuable knowledge has been instrumental in my growth and development.

This research would not have been possible without the mentorship, encouragement, and academic resources provided by Professor Barbara Caemmerer and the faculty at ESSCA Business School. I extend my heartfelt appreciation for their commitment to excellence in education and for being pillars of support throughout my academic pursuit.

Bibliography

1. Alotaiby, Rana, and Éva Krenyácz. "Energy efficiency in healthcare institutions." *Society and Economy (published online ahead of print 2023)*. doi: 10.1556/204.2023.00013.
2. Alhurayess, S., & Darwish, M. K. (2012). "Analysis of energy management in hospitals". In 2012 *47th International Universities Power Engineering Conference (UPEC)*, Uxbridge, UK (pp. 1-4). doi: 10.1109/UPEC.2012.6398665.
3. Alrbai, Mohammad, Sameer Al-Dahidi, Loiy Al-Ghussain, Hassan Hayajneh, and Ali Alahmer. 2023. "A Sustainable Wind–Biogas Hybrid System for Remote Areas in Jordan: A Case Study of Mobile Hospital for a Zaatari Syrian Refugee Camp." *Sustainability 15, no. 20: 14935*. https://doi.org/10.3390/su152014935.
4. Alfonso, Marino, Paolo Pariso, and Michele Picariello. "Energy use and End-use Technologies: Organizational and Energy Analysis in Italian Hospitals." *International Journal of Energy Economics and Policy 13, no. 3* (2023): 36-45. https://doi.org/10.32479/ijeep.13951.
5. Peng, Z., Zhu, L., Wan, G., et al. "Can integrated care improve the efficiency of hospitals? Research based on 200 Hospitals in China." *Cost Eff Resour Alloc 19, 61* (2021). https://doi.org/10.1186/s12962-021-00314-3.
6. Kolokotsa, Dionysia, Theocharis Tsoutsos, and Sotiris Papantoniou. "Energy conservation techniques for hospital buildings." *Advances in Building Energy Research 6, no. 1* (2012): 159-172. http://dx.doi.org/10.1080/17512549.2012.672007.
7. Gambarotta, Agostino, Riccardo Malabarba, Mirko Morini, Giuliano Randazzo, Michele Rossi, Costanza Saletti, and Andrea Vieri. "Demonstrating a Smart Controller in a Hospital Integrated Energy System." *Smart Energy 12* (2023): 100120. ISSN 2666-9552. https://doi.org/10.1016/j.segy.2023.100120.
8. Santamouris, M., Dascalaki, E., Balaras, C., Argiriou, A., & Gaglia, A. (1994). "Energy performance and energy conservation in health care buildings in Hellas". *Energy Conversion and Management, 35*(4), 293-305. https://doi.org/10.1016/0196-8904(94)90062-0.
9. Hohne, Percy Andrew, Kanzumba Kusakana, and Bubele Papy Numbi. 2020. "Improving Energy Efficiency of Thermal Processes in Healthcare Institutions: A Review on the Latest Sustainable Energy Management Strategies" Energies 13, no. 3: 569. https://doi.org/10.3390/en13030569
10. Oliveira, Karine Borges de, Eduardo Ferro dos Santos, Antonio Faria Neto, Vitor Homem de Mello Santos, and Otávio José de Oliveira. "Guidelines for Efficient and Sustainable Energy Management in Hospital Buildings." Journal of Cleaner Production 329 (2021): 129644. https://doi.org/10.1016/j.jclepro.2021.129644.
11. Russell, de la Rica. "Policy Considerations for Mobile Biosensors." *ACS Sensors 3, no. 6* (2018): 1059-1068. https://doi.org/10.1021/acssensors.8b00289.
12. Dhanvijay, Mrinai M., and Shailaja C. Patil. 2019. "Internet of Things: A survey of enabling technologies in healthcare and its applications." Computer Networks 153: 113-131. https://doi.org/10.1016/j.comnet.2019.03.006.
13. Habibzadeh, H., Dinesh, K., Rajabi Shishvan, O., Boggio-Dandry, A., Sharma, G., and Soyata, T. "A Survey of Healthcare Internet of Things (HIoT): A Clinical Perspective." IEEE Internet of Things Journal 7, no. 1 (January 2020): 53-71. doi: 10.1109/JIOT.2019.2946359.

14. Mutlag, Ammar Awad, Mohd Khanapi Abd Ghani, N. Arunkumar, Mazin Abed Mohammed, and Othman Mohd. "Enabling technologies for fog computing in healthcare IoT systems." Future Generation Computer Systems 90 (2019): 62-78. https://doi.org/10.1016/j.future.2018.07.049.
15. Ray, Partha Pratim, Dinesh Dash, and Debashis De. "Edge computing for Internet of Things: A survey, e-healthcare case study and future direction." Journal of Network and Computer Applications 140 (2019): 1-22. https://doi.org/10.1016/j.jnca.2019.05.005.
16. Dang, L. Minh, Md. Jalil Piran, Dongil Han, Kyungbok Min, and Hyeonjoon Moon. 2019. "A Survey on Internet of Things and Cloud Computing for Healthcare" Electronics 8, no. 7: 768. https://doi.org/10.3390/electronics8070768
17. García-Sanz-Calcedo, Justo, F. López-Rodríguez, and F. Cuadros. "Quantitative analysis on energy efficiency of health centers according to their size." Energy and Buildings 73 (2014): 7-12. doi:10.1016/j.enbuild.2014.01.021.
18. Ryan-Fogarty, Yvonne, Bernadette O'Regan, and Richard Moles. "Greening healthcare: systematic implementation of environmental programmes in a university teaching hospital." Journal of Cleaner Production 126 (2016): 248-259. doi:10.1016/j.jclepro.2016.03.079.
19. Junaid, Sahalu Balarabe, Abdullahi Abubakar Imam, Abdullateef Oluwagbemiga Balogun, Liyanage Chandratilak De Silva, Yusuf Alhaji Surakat, Ganesh Kumar, Muhammad Abdulkarim, Aliyu Nuhu Shuaibu, Aliyu Garba, Yusra Sahalu, and et al. 2022. "Recent Advancements in Emerging Technologies for Healthcare Management Systems: A Survey" Healthcare 10, no. 10: 1940. https://doi.org/10.3390/healthcare10101940
20. Senay E, Landrigan PJ. "Assessment of Environmental Sustainability and Corporate Social Responsibility Reporting by Large Health Care Organizations." *JAMA Netw Open. 2018;1*(4):e180975. doi:10.1001/jamanetworkopen.2018.0975
21. Creixans-Tenas, Judit, Dolores Gallardo-Vázquez, and Núria Arimany-Serrat. 2020. "Social Responsibility, Communication and Financial Data of Hospitals: A Structural Modelling Approach in a Sustainability Scope" Sustainability 12, no. 12: 4857. https://doi.org/10.3390/su12124857
22. Bamakan, Seyed Mojtaba Hosseini, Pooria Malekinejad, and Mehran Ziaeian. "Towards Blockchain-Based Hospital Waste Management Systems: Applications and Future Trends." *Journal of Cleaner Production* 349 (2022): 131440. https://doi.org/10.1016/j.jclepro.2022.131440.
23. Nicholls, Larissa, and Yolande Strengers. "Air-conditioning and Antibiotics: Demand Management Insights from Problematic Health and Household Cooling Practices." *Energy Policy* 67 (2014): 673-681. https://doi.org/10.1016/j.enpol.2013.11.076.
24. Bera, Sasadhar, Pradeep Kumar, and Subhajit Bhattacharya. "A Study on How to Achieve Flexibility in Healthcare Process: A Simulation-Based Approach." *International Journal of Productivity & Performance Management* 72, no. 8 (2023): 2292-2316. doi:10.1108/IJPPM-06-2021-0335.
25. Li, Yongkui, Lingyan Cao, Jiansong Zhang, Yi Jiang, Yilong Han, and Jianjun Wei. "Energy Benchmarking in Healthcare Facilities: A Comparative Study." *Journal of Construction Engineering & Management* 147, no. 11 (2021): 1–15. doi:10.1061/(ASCE)CO.1943-7862.0002183.
26. Banotra, Atul, Sarbani Ghose, Deepak Mishra, and Sudhakar Modem. "Energy Harvesting in Self-Sustainable IoT Devices and Applications Based on Cross-Layer Architecture Design: A Survey." *Computer Networks* 236 (2023): 110011. https://doi.org/10.1016/j.comnet.2023.110011.
27. Lakhan, Abdullah, Qurat-Ul-Ain Mastoi, Mohamed Elhoseny, Muhammad Suleman Memon, and Mazin Abed Mohammed. "Deep Neural Network-Based Application Partitioning and Scheduling for

Hospitals and Medical Enterprises Using IoT Assisted Mobile Fog Cloud." *Enterprise Information Systems* 16, no. 7 (2022): 1–23. doi:10.1080/17517575.2021.1883122.

28. Swarnakar, Vikas, Anthony Bagherian, and A.R. Singh. "Prioritization of Critical Success Factors for Sustainable Lean Six Sigma Implementation in Indian Healthcare Organizations Using Best-Worst-Method." *TQM Journal* 35, no. 3 (2023): 630–53. doi:10.1108/TQM-07-2021-0199.

Appendix A.

Source	**ID**	**Details**	**Notes**
Doctor Interviews	D1	23/12/2023 20 minutes Recorded and transcribed Anaesthesiologist	Premium and medium institutions, energy distribution, solar panels, pollution control, compliance measures
	D2	23/12/2023 20 minutes Recorded and transcribed Dental Surgeon	Integrated EMS, It's implementation, challenges in energy consumption, incentives
	D3	23/12/2023 40 minutes Dentist	Energy management in dental services, cost and effectiveness balance, patient awareness, RCT cost trends
	D4	23/12/2023 15 minutes ENT Doctor	Solar panels, generators, digital programs, robotic surgery, Delhi govt's solar panel mandate
	D5	29/12/2023 15 minutes Gynaecologist	Energy conservation, AQI impact, water conservation, biomedical waste management, future predictions

Company Reports	CR1	Hospital Energy Efficiency Best Practices Guide March 2009 55 pages BEE Link	Guidelines for energy efficiency in hospitals by Bureau of Energy Efficiency
	CR2	Impact Assessment 2021-22 Final Report May 2023 225 pages BEE Link	Impact assessment on energy management
	CR3	Impact Assessment 2018-19 Final Report March 2020 148 Pages BEE Link	Impact assessment on energy management, Bureau of Energy Efficiency final report
	CR4	Guidelines for Green and Climate Resilient Healthcare Facilities February 2023 103 pages NPCCHH Link	Guidelines issued on Green and climate change resilient hospitals by the National Programme on Climate Change and Human Health
Survey Data	HS1	National Hospital Energy Consumption Survey Report 50 pages Link	Insights into hospital energy consumption
Company or Government Website	GWS 1	Gurugram District Official Website - Hospitals	List of government and private hospitals in Gurugram
	CWS 2	Delhi Medical Association - List of Hospitals for Vaccination	List of hospitals for COVID-19 vaccination
Internal Documents	ED1	NABH Accreditation Standards for Hospitals 6th Edition 101 pages January 2024 Link	Draft Accreditation standards for hospitals Draft digital health standards by NABH

	ED2	NABH Digital Health Standards 1st Edition 54 pages April 2023 Link	
External Websites	EWS 1 EWS 2 EWS 3 EWS 4 EWS 5 EWS 6 EWS 7 EWS 8 EWS 9 EWS 10 EWS 11 EWS 12 EWS 13	IBEF - Healthcare Presentation Environment Clearance – Healthcare Statista - India Annual Rainfall Volume World Bank - World Water Day 2022 ScienceDirect - Impact of COVID-19 on Hospitals Express Healthcare - Hospital Energy Consumption AEEE - Survey on Energy Efficiency in Hospitals NCDC - National Health Profile 2019 NCDC - Hospital Energy Consumption Survey Ministry of Statistics - Energy Statistics 2023 IRJET - Hospital Energy Management System BW Healthcare World - CO2 Emission from Indian Hospitals NABH - National Accreditation Board for Hospitals	Presentation on the healthcare industry in India Information on environmental clearance for healthcare projects Statistical data on India's annual rainfall Information on India's efforts to address water needs Article on the impact of COVID-19 on hospitals Report on hospital energy consumption in India Survey report on energy efficiency in hospitals National Health Profile 2019 by National Health Profile Hospital Energy Consumption Survey by National Centre for Disease Control Energy statistics in India for 2023 Article on Hospital Energy Management System Report on CO2 emissions from Indian hospitals Official website of NABH

Interview Guide for the Semi-structured Interviews

Section	Question number	Question text
Introduction	1a	Could you please provide a brief overview of your role and responsibilities in the healthcare facility?
	1b	How long have you been working in the healthcare sector in New Delhi/Gurugram?
Energy management systems (EMS)	3a	Are you familiar with the concept of Integrated Energy Management Systems in general?
	3b	Can you share any experiences or insights regarding the implementation of EMS in your healthcare facility?
Energy consumption challenges	5a	What challenges do you see in managing energy consumption in healthcare facilities in New Delhi/Gurugram?
	5b	How do factors such as building age, insulation, climate, equipment maintenance, and energy management impact energy consumption in your healthcare facility?
Technological advancements	7a	Have you seen the integration of AI-powered analytics, IoT sensors, or real-time monitoring systems for energy optimization in your healthcare setting?
	7b	How do you think these technological advancements can contribute to balancing efficiency and effectiveness in energy management?
Cultural aspects	9a	How would you describe the current culture of energy efficiency among the staff in your healthcare facility?
	9b	Are there specific initiatives or practices in place to foster a culture of energy efficiency?
Regulatory compliance	11a	How does your healthcare facility ensure compliance with national and local energy regulations?
	11b	What challenges, if any, have you encountered in aligning energy management strategies with regulatory requirements?
Balancing efficiency and effectiveness	13a	In your opinion, what is the ideal balance between efficiency and effectiveness in managing healthcare energy resources?
	13b	Can you provide specific examples or strategies that your facility has implemented to achieve this balance?

Local context – New Delhi / Gurugram	15a	Are there any specific challenges or opportunities related to energy management that are unique to the local context of New Delhi or Gurugram?
	15b	How do you think the geographical and socio-economic factors of the region influence energy management practices?
Recommendations and future perspectives	17a	What recommendations would you offer to enhance the efficiency and effectiveness of energy management in healthcare facilities in New Delhi and Gurugram?
	17b	How do you foresee the future of energy management evolving in the healthcare sector, considering technological advancements and regulatory changes?
Closing	19a	Is there any additional information or insights you would like to share regarding healthcare energy management in your facility or region?
	19b	Thank you for your time and participation in this interview.