

# Energy efficiency in healthcare institutions

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Received: January 29, 2023 • Revised manuscript received: May 2, 2023 • Accepted: June 8, 2023

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## ABSTRACT

The Environmental Protection Agency classifies healthcare as one of the leading energy-consuming industries. Extensive energy is needed around the clock in healthcare institutions for lighting, ventilation, and operating medical equipment. However, there is a growing concern over the sustainability of energy utilization by healthcare institutions worldwide. This narrative review thus seeks to examine energy efficiency and utilization in healthcare institutions and energy management and conservation techniques and make recommendations for future optimal usage. The paper notes that healthcare institutions use different quantities of energy from diverse sources, including hydropower, biomass, solar energy, and wind power. However, energy consumption varies from one institution to another, with the number of beds and intensity of healthcare operations, with an average of 0.27 MWh m<sup>-2</sup>. Moreover, this review also identified various techniques and measures to enhance energy efficiency, such as the variant refrigerant flow technology and the combination of renewable energy sources with diesel generators to reduce the cost of electricity. Overall, healthcare institutions need energy management systems such as automated energy monitoring technologies, to check the systems' efficiency. The same techniques can also help Middle Eastern healthcare institutions with efficient energy utilization. Ultimately, the literature review aims to introduce an approach that focuses on reducing site-level consumption of energy while increasing the quality of the energy used and hence, helping reduce energy costs while conserving the environment.

## KEYWORDS

healthcare institutions, energy conservation, energy efficiency, energy management

## JEL-CODES

I10, I19, Q40, P18

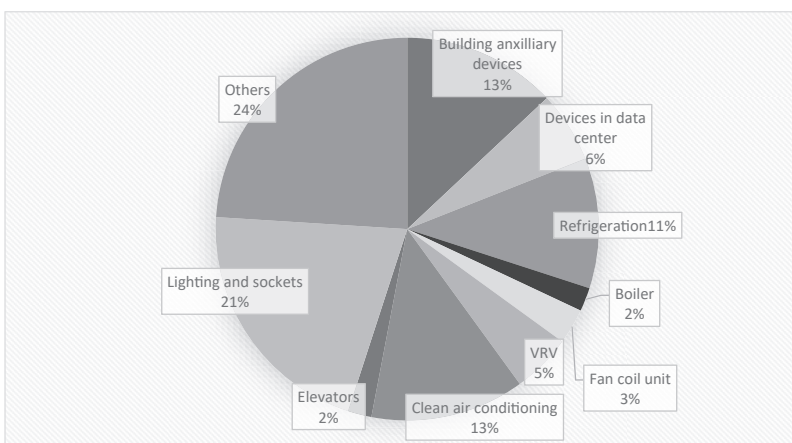
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## 1. INTRODUCTION

Healthcare institutions like hospitals are complex organizations requiring excessive amounts of energy to ensure continuity of service provision (Zaza et al. 2022). Healthcare institutions are subdivided into several functioning departments, each recording different energy consumption rates. For example, Johnson (2010) noted that in the United States, healthcare facilities included physicians' offices, clinical laboratories, outpatient and inpatient centers, and general medical and surgical hospitals, among others. Each facility needs substantial energy for services and activities such as medical scanning and the sterilization of surgical tools by radiation. For example, medical institutions in the USA account for 10.3% of the total energy consumption of the healthcare sector. Such massive energy consumption in medical institutions contributes to increasing environmental pollution levels, among other emissions and increasing carbon footprints in the atmosphere (Teke – Timur 2014). Notably, energy consumption in healthcare institutions arises from space heating, cooling, ventilation, steam production, equipment usage, lighting, cooking, and domestic hot water.

The size of healthcare facilities, such as hospitals, is a critical predictor of energy usage in healthcare institutions (García-Sanz-Calcedo 2014). Efforts have been made to ensure their sustainability by establishing alternative energy sources and environmentally friendly energy uses to minimize the emissions of greenhouse gases. This paper discusses the literature on energy consumption management, sustainability, and efficiency in healthcare organizations under two thematic areas: hospital energy consumption and energy management, efficiency, and energy conservation strategies in hospitals (Fig. 1).

There is a global power problem due to increasing concerns about global warming. Sources of power are under scrutiny to eradicate fossil fuels which emit greenhouse gases. Studies have



**Fig. 1. Electricity consumption in hospitals**

Source: Shen et al. (2019: 8).



established mechanisms to reduce energy consumption in all sectors while maintaining and enhancing efficiencies. In healthcare institutions, for example, insufficient energy means the loss of more lives and increased errors. Machines are taking over human labour to ensure effectiveness and efficiency, and as technology is incorporated into medical institutions, energy is a primary necessity. However, technology comes with unprecedented drawbacks, particularly in energy management. Therefore, there is a need to identify the best methods to promote efficiency and effectiveness while educating consumers about power consumption and improving the immediate environment. The present literature review identifies the causes of intensive energy consumption in healthcare facilities and proposes reliable energy management methods. The study investigates energy consumption in private and public hospitals under secondary and tertiary categories in different climatic zones (globally). These levels may vary depending on the country; in the United States, for example, the secondary and tertiary categories include Level I, II, III, IV, or V, which are defined by the kinds of resources available, and the number of patients admitted annually (McClure et al. 2020). Similarly, the study disregards categorization in terms of adult and pediatric facilities and brackets them as one entity under the two major categories, that is, secondary and tertiary healthcare facilities. The primary objective of energy efficiency and strategic thinking lies in reducing site-level energy consumption while increasing the quality of the energy used. The interventions discussed aid in reducing carbon emissions at healthcare institutions since efficiency drives sustainability.

## 2. REVIEW METHODOLOGY

This literature review was conducted through electronic database search engines. All relevant articles related to the topic were included in the study based on specific criteria. The identified research articles were scrutinized, organized, and discussed under two key sub-topics: energy efficiency and utilization in healthcare institutions and energy management, conservation strategies, and hospital techniques. Similarly, the literature reviews included articles from different regions and continents to establish a general viewpoint regarding the topic under investigation. The search was also carried out on national government and healthcare websites across the globe. The healthcare databases used were PubMed, ProQuest, Science Direct, World Health Organization, and CINAHL.

Other websites and corporate websites included in the search were [healthmanagement.org](https://www.healthmanagement.org), eHealth4everyone, Research Gate, the U.S. National Institute of Health, and the National Department of Energy. Also, a manual data search was conducted on Google Scholar as a reference list of other relevant peer-reviewed articles. The investigation aimed to identify research articles on energy consumption and management in healthcare institutions. Importantly, articles written and published within the last ten years were prioritized for attaining the objectives of the present literature review. Nonetheless, other essential studies published more than ten years ago were incorporated to reinforce the conclusions and the final findings of the most recently selected articles. The research concentrated on studies focusing on healthcare institutions and was based on secondary data to formulate conclusions.



### 3. THEMATIC OUTCOMES FROM LITERATURE: ENERGY CONSUMPTION, MANAGEMENT, SUSTAINABILITY, AND EFFICIENCY IN HEALTHCARE ORGANIZATIONS

This section presents an exposition about the thematic outcomes from literature under two main topical areas. The first thematic outcome is energy efficiency and utilization in healthcare institutions. Under this section, three sub-elements are covered: the impact of healthcare facility design and the nature of hospitals on energy consumption; the impact of climatic zones on energy consumption in hospitals; and the implication of intensive energy consumption in hospitals for climate change. The second thematic outcome focuses on energy management, conservation strategies, and techniques in hospitals.

#### 3.1. Energy efficiency and utilization in healthcare institutions

**3.1.1. Impact of healthcare facility design and the nature of hospitals on energy consumption.** Healthcare institutions like hospitals are the most energy-intensive buildings, and the healthcare industry represents a substantial portion of total commercial building energy consumption in the United States (García-Sanz-Calcedo 2014). Whereas hospitals have several unique features that promote higher energy use, researchers, knowledge designers, and operators have a broad recognition concerning the reduction of energy consumption while maintaining economic benefits to the healthcare industry. Gatea et al. (2020) say that healthcare services are housed in facilities ranging from tertiary care hospitals with extensively technical facility characteristics calling for the specific infrastructure of the offices and other critical departments. Most hospitals globally use electricity and natural gas as their primary sources of energy (Congradac et al. 2012). In China, for example, Ji et al. (2019) document that the two primary sources of energy are utilized in almost all medical institutions. Most research notes that as the size of the hospital increases, the number of beds per room increases; therefore, power consumption increases as the number of beds grows per hospital. Hospitals with more patient beds record higher energy consumption than those without beds (Tang et al. 2016). The problem of energy use generally attracts a lot of attention, particularly concerning efficiency and the underlying benefits of climate change (Cygańska et al. 2021). In modern healthcare institutions, increased energy consumption triggers a continuous increase in electricity costs and the depletion of natural gas, which generate significant environmental outcomes (Bujak 2010). According to Cygańska and Kludacz-Alessandri (2021), the determinants of energy consumption in Polish hospitals include the size of the healthcare facility and the medical activities carried out on the hospital premises; however, a multivariate backward stepwise regression analysis pointed out climate zones as a moderating variable in energy consumption in most Polish healthcare institutions. A similar study by Alhurayess et al. (2012) showed that electricity and heat consumption were directly proportional to the number of beds, doctors, and medical operations performed in any given medical facility.

Similarly, the number and size of the intensive care units and the operating theatres add additional power consumption. Another class is attributed to the hospital's medical activities and general operations. Medical products can be traced by several metrics, including admission or discharge, days of admission, and the total number of patients per day (Silvestro et al. 2017). Energy use in a healthcare institution tends to increase with the number of medical services



provided. Most studies on energy consumption in hospitals have focused on energy usage at a micro level, putting together energy demands and room features in buildings (Cannistraro et al. 2017).

Additionally, previous studies have stressed that healthcare institutions' primary predictors of energy consumption include the size or facility area, the nature (type) of the services, the number of patients, and the employees (Bagnasco et al. 2017). A study conducted in Spain focused on determining sources of high energy consumption among Spanish banks; the results showed that energy usage was directly proportional to the number of employees, the total number of energy-consuming devices, and the size (area) of the banking premises (Gonzalez et al. 2018). An analogous study was conducted among twenty Spanish hospitals (García-Sanz-Calcedo et al. 2019). The study calculated energy efficiency indicators that were a function of several factors, including the building's total size, the number of employees, and the number of hospital beds. According to a Brazilian study, energy consumption variability resulted from hospital size, location, and the number of patient beds in the healthcare facility (Bawaneh et al. 2019).

Similarly, the complexity of the services offered by the hospital contributed to increased energy consumption while providing energy standards coupled with the efficiency of the medical equipment (Čongradac et al. 2012). Other significant studies, including García-Sanz-Calcedo et al. (2019) and Wang et al. (2016), attributed the energy consumption in healthcare institutions to the hospital's activity indicators, represented by the total number of annual discharges, operations, hospitalizations, rescue operations, laboratory tests, endoscopy, and births. Regardless, studies focusing on the impact of hospital activity on energy consumption are infrequent.

Importantly, Morgenstern et al. (2016) established that the number of surgical operations is a critical factor in defining power consumption levels because surgery requires a lot of resources, including energy-intensive equipment. Also, advanced medical facilities conduct complex surgical operations requiring expensive equipment, advanced operational systems, critical life-support systems, and sterilization procedures (Dadi et al. 2022).

A critical factor affecting energy consumption is the degree of medical device use, particularly in areas directly associated with treatment and diagnostics (Szklo et al. 2004). The demand for electricity in hospitals is rising due to the introduction of sophisticated digital medical equipment and devices. A dramatic observation of the association between energy consumed during inactivity and usage hours is evident. When not in operation, CT scanners, linear accelerators, and MRI scanners need 64, 36, and 47% of their weekly energy consumption, respectively (García-Sanz-Calcedo et al. 2019; Ma et al. 2022). Many researchers have associated high energy consumption in healthcare institutions with environmental and climatic factors and geographic location (Dadi et al. 2022; Esmaeili et al. 2011). However, in the U.S., massive energy consumption in healthcare facilities is directly attributed to the number of hospital admissions, the region of the hospital, climatic conditions, and the characteristics of medical equipment and activities in any given hospital (González González et al. 2018; Hijo et al. 2015; Kauko et al. 2014). Dadi et al. (2022) maintain that too much energy is directed towards medical and monitoring equipment, diagnostics, outdoor and indoor lighting, air treatment, summer air conditioning, and computerized and security systems.



**3.1.2. Impact of climatic zones on energy consumption in hospitals.** Climatic zones are critical in determining energy consumption among Chinese hospitals (Ji – Qu 2019). According to the findings of Ji and Qu (2019), among 100 Chinese hospitals, statistics indicate a significant disparity in energy use in four selected climatic zones. Hospitals in hot summer and warm winter regions register annual electricity consumption of  $140.7 \text{ KWh m}^{-2}$ , and this value is reduced by about 67.9%, translating to  $45.2 \text{ KWh m}^{-2}$  in cold areas. The study underlined that yearly electricity usage is higher in hot summer and warm winter regions due to increased air conditioning system use (Wang et al. 2016).

Regardless, larger hospitals in warmer climatic regions indicate more energy consumption, and hospitals in hotter climatic zones use higher energy than those in the coldest areas (Hijjo et al. 2015). The highest energy consumption costs are observed at specialist hospitals using energy-intensive x-rays, tomographs, or the most sophisticatedly equipped surgical theatres. Operating theatres prove to be the largest determinant in increased energy consumption and the high cost of electricity in Poland (Silvestro et al. 2017). Most of the literature highlights three main characteristics defining energy consumption in healthcare institutions (Dadi et al. 2022; Gatea et al. 2020; González González et al. 2018). The first feature regards the capacity of a hospital, which is determined by the size or total area of the hospital rooms and the number of patient beds in each room. In hot areas, there is a need for increased power use; the most researched energy use predictors include the climatic zone or the location of the hospital. The climatic zone of a hospital determines the lighting conditions and the thermal limits. All the three factors above affect overall energy usage regardless of performance and must be accounted for in energy planning in the healthcare industry (Alhurayess – Darwish 2012). Other studies have highlighted weather conditions as a substantial predictor of high hospital energy consumption. Studies agree that climatic conditions significantly influence energy consumption in healthcare facilities (Cygańska – Kludacz-Alessandri 2021). According to Aunión-Villa et al. (2021), climate affects energy consumption in several ways due to non-linear energy consumption patterns in response to weather and climate change (Zaza et al. 2022). For instance, increased air conditioning demands more energy in hot or warm environments.

Likewise, in warmer climatic zones, reduced heating demands lower the need for natural gas, electricity, and oil (Shen et al. 2019). A study in the United States by Wang et al. (2014) concluded that energy consumers in warmer climates and geographic locations depend more on electricity than other available energy sources, such as natural gas. Additionally, in winter, the same consumers use less heating fuel; in summer, cooling systems increase electricity bills (Shen et al. 2019).

While there is agreement between the findings of most researchers in different countries, the energy consumption levels are relatively different. For instance, a study by Gatea et al. (2020) showed that in a Spanish hospital for standard operating conditions, energy consumption was  $0.27 \text{ MWh m}^{-2}$ ,  $9.99 \text{ MWh/worker}$ , and  $34.61 \text{ MWh/bed}$ , which is less compared to energy consumption in United States hospitals. The geographic location directly influences energy use in Spanish hospitals but does not rely heavily on the number of hospital admissions like in American healthcare facilities (Moghimi et al. 2014). In Malaysia, hospital energy consumption in hot climatic regions is relatively high, therefore calling for measures to address the surging energy costs (see Table 1). Among Malaysian healthcare facilities, extensive energy consumption is associated with conditioning, lighting, equipment, and lifts (Moghimi et al., 2014).



**Table 1.** Total natural gas and electricity consumption in Malaysian hospitals

	2005		2006		2007	
	Gas m <sup>3</sup>	Electricity kWh <sub>e</sub>	Gas m <sup>3</sup>	Electricity kWh <sub>e</sub>	Gas m <sup>3</sup>	Electricity kWh <sub>e</sub>
Jan	15,425	119,609	14,865	119,646	10,942	101,860
Feb	16,280	111,796	15,117	101,869	9,080	90,173
Mar	12,032	123,534	8,301	100,094	6,742	100,851
Apr	7,547	115,311	4,651	90,764	4,129	100,263
May	–	145,400	–	125,495	–	131,010
Jun	–	173,074	–	161,528	–	151,893
Jul	–	199,793	–	183,475	–	182,431
Aug	–	167,507	–	149,253	–	135,655
Sep	249	148,720	46	146,588	0	122,263
Oct	4,734	115,820	1,874	96,117	1,094	99,902
Nov	5,518	114,779	8,001	91,039	10,251	83,736
Dec	21,976	115,315	12,446	93,779	10,946	98,858
<b>Total</b>	<b>83,761</b>	<b>1,650,658</b>	<b>65,301</b>	<b>1,459,647</b>	<b>53,184</b>	<b>1,398,895</b>

Source: Moghimi et al. (2014: 106).

Nonetheless, in Malaysian healthcare, for example, where the primary energy source is electricity with a supply of close to 75% of the total hospital consumption, the average annual electricity consumed by the hospital was 44,637,966 kWh, of which 63% was used by air conditioning systems and 17% by lighting. This consumption rate is higher than estimated by the Malaysian rating systems and standards, which recommend an average of 200 kWh m<sup>-2</sup> year<sup>-1</sup> for hospitals (Moghimi et al. 2014). Ultimately, much attention has been shifted towards climatic zones as a critical predictor of energy consumption in significant hospitals globally.

Thermal energy is primarily used in air conditioning and heating of medical rooms, sanitary water production, kitchen services, laundry, and sterilization procedures. Energy consumption in hospital premises for these purposes in several states accounts for around 41% of total consumption (Dadi et al. 2022). However, as mentioned by Silvestro et al., (2017) and reinforced by Wang et al. (2016), energy use may vary from one country to another, with examples of Spain (23%), Japan (25%), China (23%), UK (39%), Brazil (50%), Switzerland (47%) with the United States and Canada recording the heaviest annual electrical and thermal energy use per gross floor space for a standard hospital (Congradac et al. 2014). Elsewhere, Rohde et al. (2015) determined the energy and usage patterns of medical equipment used in hospitals in Norway, finding that the daytime energy intensity of installed medical equipment alone was closing at 90 kWh m<sup>-2</sup> per year. Conclusively, climatic zones promote excessive energy consumption in healthcare institutions, regardless of the size or nature of the hospital.



**3.1.3. The implication of intensive energy consumption in hospitals for climate change.** According to Mihut et al. (2018), thermal comfort in a building has a higher priority than efficiency, yet energy efficiency implementation defines the nature of thermal comfort. The literature points out that a building consists of multiple zones, compounding heat transfer and balance among the zones (Chen et al. 2014). However, the electrical load in one zone tends to increase owing to the differences in the neighboring zones' thermal characteristics, which arise from diverse occupancy. A German study revealed that hospitals emit the most potentially toxic gases into the atmosphere (González González et al. 2018). The study also showed that German hospitals' annual heat generation per hospital bed needed an energy input of over 17,000,000 MWh. Such high consumption is the main contributor to global environmental hazards due to the increased emissions of toxic gases. Similar discoveries were made in Taiwan, where the installation of heating ventilators and air conditioning systems is the primary predictor of energy consumption (Chen et al. 2014). Energy consumption in healthcare institutions can, however, be reoriented to ensure less consumption and more sustainable healthcare facilities if the proper procedures and strategies are put in place by energy-controlling agencies and related policymakers (González González et al. 2018).

## 3.2. Energy management, conservation strategies and techniques in hospitals

Healthcare institutions such as hospitals incur colossal energy bills, raising a concern that researchers, technologists, and policymakers need to prioritize. The increased development of information and computerization has played a critical role in the automatic control and management of human activities in all sectors. Numerous strategies and interventions have been proposed to reduce energy consumption in healthcare facilities. The methods aim to restructure healthcare power consumption by focusing on hospital building designs, room facilities, and other power-intensive activities (Kolokotsa et al. 2012). Most of the techniques proposed include control algorithms and the combination of different types of actuators and sensors for optimizing various sub-systems, which may consist of ventilation, lighting, the cooling and the heating; use of alternative water sources, enhanced Hybrid Automatic Voltage Control (HAVC) systems; renewable energy and green building initiatives (Kolokotsa et al. 2012; Papadopoulos 2016).

Čongradac et al. (2014) categorized the available ways of increasing energy efficiency into two classes. These classes include controls at the level of the room and the level of the entire object. Moreover, intelligent control in a single room can be focused on room heating, lighting, and ventilation. This method of managing energy consumption is related to ventilation control through monitoring carbon (IV) oxide concentration levels in the HAVC system and the room. Equally, such interventions can improve humidity and reduce room heating by controlling external blinds (Čongradac et al. 2014; Papadopoulos 2016).

Čongradac et al. (2014) suggest that building modeling be simplified so that the entire architecture is measurable and consists of known figures of values that include object dimensions and the total space, room types, and average temperatures, among other factors (Santamouris 2012). The previous strategy aimed to increase the usability of the buildings while allowing for verification, validation, and the practical uses of the buildings, what the authors refer to as 'the object.' As proposed by Čongradac et al. (2014), the most suitable method of energy saving in a hospital is installing a thermostat, meaning heating is reduced while cooling is

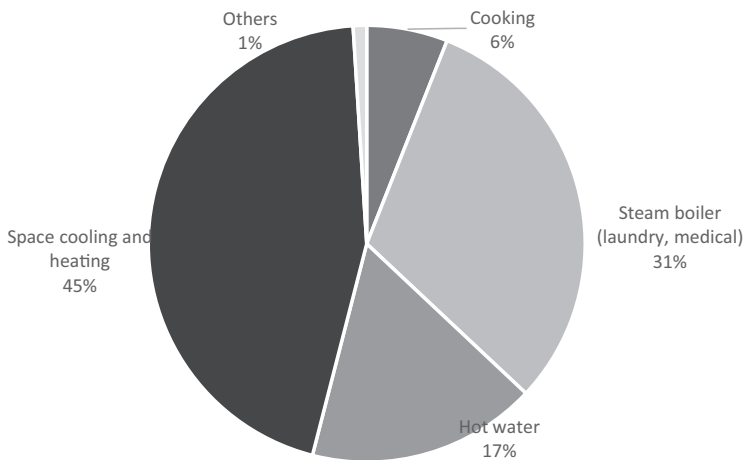




increased, which saves close to 10% of the total energy used in heating. Other methods of saving energy in a hospital, as proposed by Kolokotsa et al. (2012), include time schedules, timers, and heating curves to calculate energy savings for the entire building. The methods' implementation is cost-efficient and has simple procedural steps (Kolokotsa et al. 2012; Papadopoulos 2016).

Notably, healthcare facilities are energy intensive owing to the necessity of increased micro-climatic control, contemporaneity, strict set limits for humidity and temperature, the need for air conditioning within the patient rooms, and exceptional facilities within the hospital like the operation of scanners and theatrical equipment (Ascione et al. 2013). Hence, there is a need to focus on energy-saving approaches that can be achieved by improving the thermal and physical features of the building. Ascione et al. (2013) proposed that energy consumption in healthcare institutions can be minimized by reevaluating the HVAC systems. The HAVC method is effective in reducing energy consumption, as evident at the National Institute for Cancer Treatment 'G. Pascale' in the Mediterranean region (Ascione et al. 2013). The system improves the indoor comfort of patients and hospital employees while reducing energy demands from organic or fossil fuels. The entire design encompasses all the components of the building, starting with the external walls, which are designed to reduce the overall thermal transmittance by approximately  $2.86 \text{ W m}^{-2}\text{K}$ . In comparison, windows have been designed with air cavities and metal frames, allowing adequate ventilation with approximately  $3.2 \text{ W m}^{-2}\text{K}$  thermal transmittance. This approach enables the buildings to use less energy to ventilate rooms in all climatic and weather conditions (Fig. 2).

In hot areas, the heating system is redesigned and replaced with fossil fuel instead of electricity to reduce energy usage in heating and cooling. The central heating system consists of four gas boilers rather than electric coils. All four boilers produce nearly 8,024 kW of energy (Gaspari and Fabbri, 2017). This amount of power provides steam used in the heating plant, with each steamer producing 2,000 kW of thermal energy and DHW circuits using dedicated exchangers. Such orientation allows the heating system's exchangers to send hot water to the



**Fig. 2. Gas consumption in hospitals**

Source: Shen et al. (2019: 8).



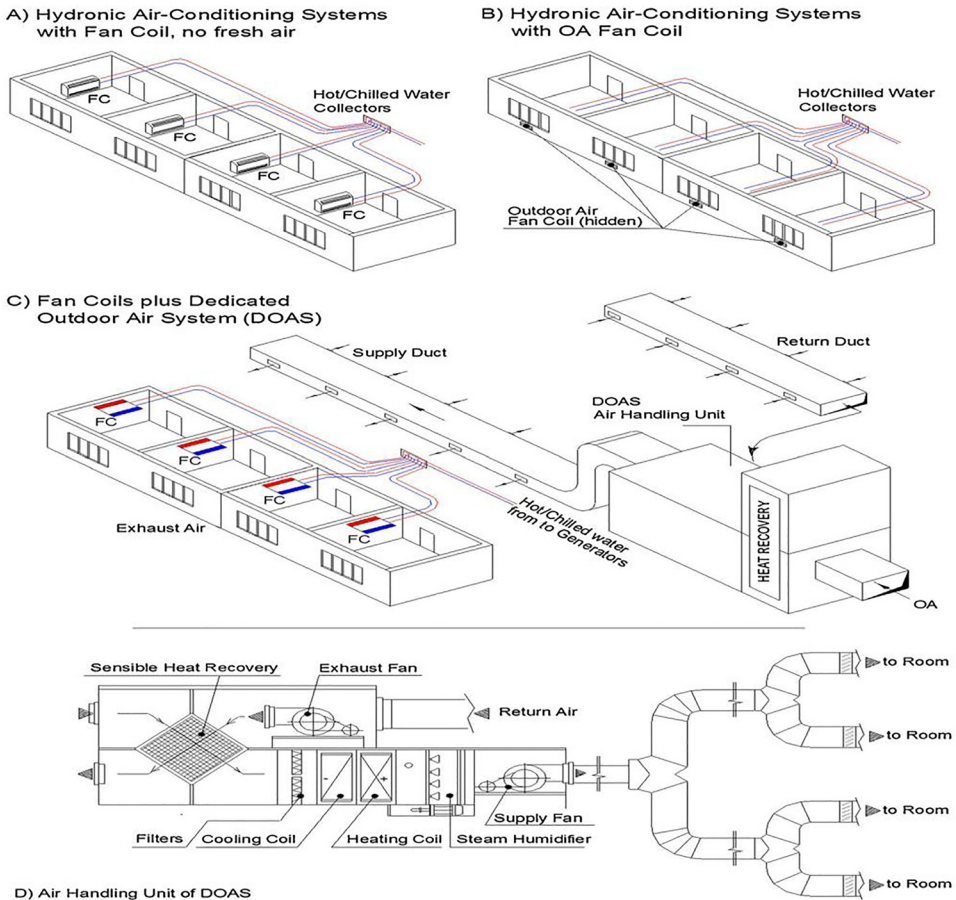
distribution loop, which helps serve all the utilities for the entire hospital building's heating space. For cooling purposes, cold water production is partly centralized and initiated by two chillers; refrigerators are also installed to run fan coils (Ascione et al. 2013). HAVC systems reduce annual power consumption in refurbished buildings. In hot areas, the heating system is redesigned and replaced with fossil fuel instead of electricity to reduce energy usage in heating and cooling. The central heating system consists of four gas boilers rather than electric coils. All four boilers produce nearly 8,024 kW of energy (Gaspari et al. 2017). This amount of power provides steam used in the heating plant, with each steamer producing 2,000 kW of thermal energy and DHW circuits using dedicated exchangers. Such orientation allows the heating system's exchangers to send hot water to the distribution loop, which helps serve all the utilities for the entire hospital building's heating space. For cooling purposes, cold water production is partly centralized and initiated by two chillers; refrigerators are also installed to run fan coils (Ascione et al. 2013). HAVC systems significantly reduce annual power consumption in refurbished buildings compared to the old design of healthcare facilities (Ascione et al. 2013; Gaspari – Fabbri 2017; see also Fig. 3).

The sustainable development model aims to ensure that managers of healthcare facilities effectively implement strategies that minimize costs incurred by hospitals while allowing efficient and effective use of the available resource (Rodríguez et al. 2021). Nonetheless, the implementation of sustainable development focuses on essential issues like patient logistics, energy and water efficiency, effective waste management programs in healthcare facilities, source reduction approaches, and green purchasing. Such techniques allow healthcare institutions to contribute towards enhancing sustainable development in the healthcare sector. Hospital managers should involve organizational stakeholders to achieve energy savings, improve hospital waste efficiency management, conserve water, and monitor other general expenditures. The involvement calls for appropriate training of hospital staff and increasing energy-saving awareness (Rodríguez et al. 2021). A proposal by the World Health Organization concerning the Healthy Building Initiative contributes to a crucial improvement in sustainable healthcare development, particularly in healthcare systems (Rodríguez et al., 2021).

Optimizing energy efficiency within hospitals and healthcare facilities is a primary issue in the energy conservation field (Rodríguez et al. 2020). However, despite the available robust technologies, several barriers hinder the vertical development of sustainable and energy-saving interventions. These barriers include but are not limited to economic incentives, appropriate technology, and insufficiently enforceable regulations and laws from policymakers and local authorities (Rodríguez et al. 2021). Other barriers include technical ones related to inadequate information and knowledge and technological irreconcilability. The incompatibility of upcoming energy technologies with the present building becomes a critical obstacle to installing modern energy-saving systems such as HAVC (Wang et al. 2016). In Chinese public hospitals, Wang et al. (2016) recommended that hospital builders deploy best practices and employ demonstrable energy-efficient building projects that reduce high energy demands. Policymakers in China need relevant laws to moderate the pricing laws while providing alternative energy sources like installing biogas plants for efficient hospital waste management or recycling, reducing greenhouse gas emissions (Tong 2020).

Currently, the green building concept is the societal consensus. Applying energy conservation and management systems is critical for establishing and constructing green hospitals (Mihut et al. 2018). This approach requires the integration of information technology and





**Fig. 3. Simulated heating, cooling ventilation, and air-conditioning systems**  
 Source: Ascione et al. (2013).

energy management. Most industries have shifted attention towards the green concept for energy management, sustainability, and reduced energy costs (Sahamir et al. 2019). Green hospitals call for restructuring buildings to save water, electricity and other resources. Pan et al. (2018) proposes a model for establishing green hospitals where the system aims to improve energy supply reliability, progress operation management levels and equality, shorten power failure times, and apprehend the intelligent power supply system. The strategic project named the hospital electric energy management system entirely relies on the theory and application of green building concepts. The proposed system incorporates several functions and setups to guarantee safe transmission, distribution, and use of electrical energy, but the power supply system has to satisfy particular power quality requirements (Tong 2020). Depending on the actual situation of the hospital premises and the national power standards for the Chinese power systems, the proposed technique monitors the most critical parameters of the power supply



system. The system monitors the operational status of the analog output of the low-voltage distribution system. Every individual analog quantity is effectively reflected. The analog quantity includes three-phase voltage on the incoming line, three-phase current on the incoming line, transformer temperature, significant line harmonics, system active power, reactive power and apparent power, system active power, reactive power, system frequency and system power (Liu et al. 2016).

Moreover, the hospital electric management system effectively monitors all stage quantities of the low-voltage power distribution system, safely, reliably, and automatically, like switching signals and position signals of circuit breakers. The model provides safe, reliable, economical, efficient, and scientific energy use. With the development of green hospitals, hospital's electric energy management system can play a critical role (Huo 2021).

García-Sanz-Calcedo (2014) established a direct relationship between energy consumption and the number of healthcare users. Furthermore, the amount of energy used daily in a hospital directly correlates with the hospital's size and design. Therefore, García-Sanz-Calcedo (2014) suggested optimizing the building floor and argued that appropriate planning of the architectural infrastructure is a critical element in meeting energy efficiency necessities. There is a pressing need to minimize the amount of unnecessary space within a hospital building to reduce energy consumption. The strategy can be achieved by building designers by reducing hallways and other unnecessary passageways, which accounts for approximately 20% of power consumption in healthcare facilities. Designing small buildings for the healthcare industry to control power consumption sets new challenges for reducing the number of services, employees, and patients (Johnson 2010).

The concept of the green hospital has been adopted in American hospitals as well, but with less efficiency (García-Sanz-Calcedo 2014). Green building initiatives are essential to reducing environmental pollution from hospital waste. Johnson (2010) mentions that the United States medical industry produces nearly two million tons of waste annually, with harmful gas emissions into the atmosphere and contributing to global warming. The green policy aims to reduce energy usage. An example of such a hospital is Dell Children's Medical Center in Austin, Texas, with over five courtyard healing gardens characterized by native plants. As per Johnson (2010), other green policies include recycling hospital waste, using highly recyclable materials in construction, and establishing ponds that capture runoff water from buildings. The U.S. Green Building Council's LEED silver standard is critical in ensuring healthcare institutions adhere to green policies (Billanes et al. 2018; Hendron et al. 2013).

Billanes et al. (2018) state that maintaining the general concept of bright green buildings does fit hospital buildings, given that procedural guidelines are followed in renovating energy-efficient healthcare facilities. Therefore, Billanes et al. (2018) proposed the establishment of a bright green building that uses both technology and processes to create a safe, healthy, and comfortable facility, enabling productivity and well-being for its beneficiaries (Chías et al. 2017; Lee et al. 2019). Bright green buildings are energy efficient since they adopt sustainable designs and standards to allow for indoor air quality, minimize energy consumption and carbon emissions, and provide reliable power. The initiative enables the installation of renewable energy systems like wind turbines and solar P.V. storage to replace diesel and electricity (Hijjo et al. 2015).

Teke and Timur (2014) proposed a more advanced energy-saving model incorporating HAVC technology. The system requires the use of energy-efficient motors and variable-speed drive systems. The system improves energy savings and reduces power consumption,



particularly in HAVC systems in healthcare organizations. Notably, the proposed plan contains a water-cooled chiller instead of individual designs. The central system consists of an air conditioning system that utilizes equipment to distribute the cooling media to exchange heat while supplying air from one point to another in the hospital building (Teke – Timur 2014).

Similarly, the HAVC system includes a boiler heating unit; the ventilation unit consists of fans, and the cooling unit consists of a chiller. Both cooling and heating are used in different weather conditions. The heating function is used in cold weather or climates, and the cooling unit is used in warm weather and hot climates, which addresses the issue of excess power consumption due to the challenges of climatic zones (Teke – Timur 2014: 225).

Wang et al. (2016) argue that retrofit projects are based on consolidated and simplified methods, including surveys, energy consumption estimates, predesign, related benefit estimation, final design, construction, and effectively achieved energy-saving assessments. The analyses are often made difficult by heterogeneous and incomplete reference data. For example, calculation tools are based on standard climate files, which, because of climatic fluctuations, can also give values significantly different from the periods considered experimental references. Therefore, it is recommended that the construction of hospital buildings be built on HAVC models with clear guidelines for recycling and using solar energy to replace hydroelectric power and natural gas as primary energy sources.

Energy management in healthcare organizations calls for close monitoring from the organization's management team. According to García-Sanz-Calcedo et al. (2017), the organization needs to undertake maintenance audits to determine if the management of the actions conducted in the hospital building is adequate and to anticipate future demand trends. Silvestro et al. (2017) illustrate that maintenance and frequent monitoring of energy consumption while filtering out unnecessary energy use stimulated an average annual decrease of approximately 20% in the demand for corrective maintenance with a yearly saving of 500 MWh in energy consumption. Also, the report demonstrated a reduction in the emission of greenhouse gases giving an average saving of 75,000 euros year<sup>-1</sup>, without additional costs or extra investment (García-Sanz-Calcedo – Gómez-Chaparro 2017).

The establishment of alternative water sources enhances hospital energy savings, as demonstrated by (Silvestro et al. 2017). Alternative sources may include desalination water plants that use less energy than the standard water treatment procedures in hospitals. The literature directs that reclaiming onsite alternative water sources decreases the need for offsite desalinated water, decreasing energy consumption, particularly for irrigation water end use, unlike water features, which are energy intensive even for an onsite system. The more water used, the better the energy ratio (Seguela et al. 2017b). This element highlights the advantage of using onsite alternative water sources to minimize desalinated water and energy waste (Seguela et al. 2017a). In addition to alternative water sources, hospitals are directed to use renewable and solar energy for daily operations, which proves cost-effective (Kantola et al. 2013; Nourdine et al. 2021).

## 4. CONCLUSIONS AND RECOMMENDATIONS

Healthcare facilities are among the most energy-intensive of all commercial buildings. The literature shows that hospitals need enormous energy to keep them functioning and deliver the quality patient services they desire. However, the most life-saving equipment and critical



rooms are the key contributors to excess power consumption. Increased number of patients, building size, number of employees, climatic conditions, and building design are the most underlined determinants of power consumption in healthcare institutions. In addition to power consumption, the literature emphasizes environmental hazards caused by healthcare institutions, including poor waste management and the release of greenhouse gases into the atmosphere. Many hospitals' current energy consumption rates can be minimized by adopting robust techniques and policies. For instance, most of the literature proposes adopting the green concept, which allows for the establishment of sustainable and energy-efficient hospitals. Proper waste management, adoption of advanced HAVC systems, recycling waste materials, use of recyclable materials in construction, use of alternative energy and water sources, and use of a renewable energy source are among the leading proposals to reduce power consumption in healthcare institutions. Conclusively, many efforts and strategies have been established to overcome the energy consumption challenges in hospitals, such as insufficient funds and improper management, slowing the adoption and implementation of the interventions. Today, few hospital buildings have adopted green building technology, implying that policymakers and authorities must invest more in establishing environment-friendly healthcare institutions.

From environmental and energy standpoints, and under the issue of energy efficiency in healthcare institutions, healthcare facilities need to reduce unnecessary spaces within the hospital building to reduce power consumption. Furthermore, hospital premises need to firmly adhere to the policies governing environmental conservation through renewable energy sources and invest more in solar energy. Through recycling and proper waste disposal, hospitals can reduce the emission of greenhouse gases into the atmosphere.

The literature directs that healthcare facility managers must stress energy management as it is more effective in reducing energy usage, particularly in small hospital buildings. Therefore, concerning energy efficiency management in public governance, health centers with similar features and equipment should have directors effectively manage the operational costs of the building. Ultimately, the green building concept tends to transform all healthcare organizations regarding energy efficiency and sustainability. Healthcare organizations need to consider renovating hospital buildings to meet the standards of green building initiatives for managing energy consumption and the environment.

Shen et al. (2019) provide unique and applicable energy-saving approaches in healthcare institutions. For instance, the authors argue that hospitals need to find better ways to control air conditioning systems' energy use. Notably, the fresh air volume of the central air-conditioning system is constant in most large healthcare facilities; thus, it is impossible to adjust the new air volume according to the actual flow of people. Therefore, there is a pressing need to change the air supply amount according to the indoor carbon dioxide level to save energy consumption for fresh air treatment. Similarly, there is no distinction between a 24-h operation and operating time-only operation in the air-conditioning and hot and cold-water transmission and distribution systems. Therefore, the hot and cold water in the main pipe require 24 h of continuous circulation, resulting in a waste of water pump energy. Reasonable divisions must be made according to usage conditions, like outpatient service and office work, which are only operational during working hours.

As noted by García-Sanz-Calcedo (2014), Cygańska and Kludacz-Alessandri (2021), and Alhurayess and Darwish (2012), lighting systems consume more energy in hospitals. Shen et al. (2019) propose a more robust method of minimizing such energy waste. According to



the researchers, the lighting of the medical building is mainly controlled by the personnel in each functional area, and the lighting control circuit in the public space is integrated. It cannot be adjusted according to the needs of the sub-regions. It is recommended to use multiple channels to control the lighting in each public area independently, to re-arrange the illumination in well-lit spaces, and to use light sensors to automatically to achieve energy savings. In addition, it is found that garage lighting is always on for 24 h, even when no car enters the garage. Besides, in the open area, the lights are turned on during the day, wasting energy. Therefore, it is paramount to use a microwave induction system. A light sensing system is applied to the outdoor lighting of the garage, and the lighting is automatically powered off in the daytime. Conclusively, the literature review has detailed reliable energy efficiency and strategic thinking interventions that minimize the site-level consumption of energy while increasing the quality of the energy used. The interventions discussed aid in reducing carbon emissions at healthcare institutions and illustrate that efficiency drives sustainability, which is critical for the management of healthcare institutions.

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