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Review

Hospitals' Energy Efficiency in the Perspective of Saving Resources and Providing Quality Services through Technological Options: A Systematic Literature Review

Maria Psillaki [1], Nikolaos Apostolopoulos [2,*], Ilias Makris [3], Panagiotis Liargovas [2], Sotiris Apostolopoulos [4], Panos Dimitrakopoulos [3] and George Sklias [4]

1 Department of Economics, University of Piraeus, 18534 Piraeus, Greece
2 Department of Management Science and Technology, University of the Peloponnese, 22100 Tripoli, Greece
3 Department of Accounting and Finance, University of the Peloponnese, 24100 Kalamata, Greece
4 Department of Economics and Business, Neapolis University Pafos, Pafos 8042, Cyprus
* Correspondence: anikos@uop.gr

Abstract: The effects of climate change, in combination with the recent energy crisis, have brought the energy efficiency issues of hospitals markedly to the fore. Hospitals are considered among the most energy-intensive buildings, which is why they have become a top priority for governments wishing to upgrade their energy efficiency. Given the critical nature of the work of hospitals and the model of healthcare provision (nursing cover 24 h per day, 7 days a week) it is very hard to achieve energy cuts. The international literature shows that the energy efficiency of hospitals is a complex process that requires further research. This need is covered by the present systematic literature review, which captures the existing knowledge on energy monitoring strategies, assessment, and upgrading through technology, resources-saving strategies, and the relationship between energy efficiency and the quality of the service provision, while also identifying future research considerations and the potential for supporting researchers' work. Additionally, this study adds aggregated data to the literature, as far as the energy performance of buildings is concerned, and allows investors to have data exported from energy surveys at their disposal. At the same time, it suggests the further exploration of alternative energy technologies, based on all renewable energy sources rather than only solar power systems. This highlights the need for a comparative examination of hospitals with different climatic and socio-economic environments, to better determine what technologies effectively serve the energy needs of each region. Finally, this survey considers it necessary to connect the energy efficiency of hospital units with the awareness of the management and workforce in the saving of energy resources. Due to the fact that most studies are oriented toward the energy performance of very large-sized hospitals, it is suggested that in the future, the research lens should also be focused on the smaller private and public sectors' health units.

Keywords: hospitals; energy upgrade; energy performance; energy efficiency

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1. Introduction

Due to their large building volume and their continuous operation, hospitals are considered to be among the most energy-intensive building units, with a highly negative impact on the environment [1,2]. The constant human activity that takes place in these buildings and the numerous people who are working or moving into these structures make proper energy management a necessity. Furthermore, energy management in hospitals is an important factor since its mismanagement leads to an increase in operating costs, a negative environmental impact, and a decrease in competitiveness [3]. However, the medical devices used in intensive care units (ICU), surgery rooms, imaging units, and furnaces also require large amounts of energy for smooth functioning. Nevertheless, the largest energy consumption in hospital units comes from heating, cooling, lighting, and hot water, which are usually covered by the cogeneration of electricity, gas, and oil and, in some cases, by photovoltaic solar panels [4–7]. Governments and hospital administrations are looking for economical energy solutions that will subtractively work in addressing the high prices that they pay to secure energy, in order to reduce operating costs [8–10]. In this regard, investment projects to promote energy efficiency are activated by the public or private sectors and also, sometimes, through public–private partnerships [10]. These energy activities are usually undertaken by energy service companies [10]. The complex and continuous operation of the existing hospitals may not allow extensive, quick, and easy interventions; however, the "green health" of the patients, combined with the actual need to save energy resources, require dynamic interventions [11]. It is a difficult equation that requires a deep knowledge of the existing hospital upgrade techniques, along with the search for new methods through scientific research that will provide a reliable solution for energy upgrades and saving resources. The BIM (building information model) has opened up new possibilities in terms of the technical design and construction management of hospital facilities [12–15]. By means of its application, we gain early warnings that help to deal effectively with design mismatches [16–18]. The BIM methodology, applied at the different levels of 6D and 7D, addresses multidimensional problems that cannot be dealt with in a practical way [19,20]. The environmental performance of hospitals, including the goal of energy efficiency, should be achieved through a holistic approach, with a commitment to continuous improvement and responsible use by the human factor [21]. Following this holistic approach, de Oliveira et al. [3] considered sustainable buildings, cultural change, prudent energy consumption, the usage of energy from renewable sources, energy management standards, green technologies, and social responsibility programs to be necessary factors in public policies. Only a few studies link the energy performance of hospitals to the end users such as hospital employees, patients, and visitors; therefore, it is necessary to incorporate user perceptions into the final design [22].

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

Aggregated data are a valuable tool for investors in the field of energy efficiency and saving resources in the context of buildings. At the same time, this suggests a revision of the research agenda and captures the priorities needed for further research. After the introductory note, this literature review presents the theoretical background and illustrates the factors that contribute to the need for further investigation of the issue of energy efficiency in hospitals. The third section presents the methodology through a flow chart. In the fourth section, we lay out our findings from the literature on the energy efficiency of hospitals through technological options, the saving of resources, and the quality upgrade of the services offered. The fifth part outlines possible future research avenues as they emerged from our analysis of the examined aspects. The final part of this article presents our conclusions.

2. Theoretical Background

The effects of climate change, combined with the COVID-19 pandemic and the energy crisis, the latter being as a result of Russia's invasion of Ukraine, have given a new starting point to the energy transition and the conservation of energy resources. States with high energy dependence on third-party countries, such as EU member states, accelerated the processes of energy transition and oriented their financial tools in research and innovation for the development of sustainable energy technologies [23]. At the same time, they proceeded to implement policies moving toward saving energy resources, and they also invested in the energy efficiency of buildings through building upgrade programs [24]. Energy-saving retrofitting of buildings is receiving attention from governments worldwide, due to the aging building stock [25]. The urgent need to reduce energy consumption while decreasing greenhouse gas emissions occupies a major research interest [26]. The building sector is responsible for 40% of energy consumption and 36% of greenhouse gas emissions, which is why the energy upgrade of buildings is a global priority [25,27,28].

Various studies have shown that existing energy upgrade programs do not present clear strategies to reduce carbon and often do not effectively address the complexity of the issue [29]. There are many complex obstacles; therefore, research and innovation are required to address them [30,31]. The research interest in the sustainable renovation of buildings is also of particular interest [26]. The research approach showed that there is no specific solution for the energy upgrading of buildings that suits all contexts, which is why different policies and standards are used that are constantly being improved in light of new research findings [29]. The energy upgrading of buildings and especially of large building facilities, such as hospitals, is a complex process that requires a combination of research-based energy sources because otherwise it could lead to a reduction in social suitability [29]. The energy upgrading of hospitals, which are admittedly energy-intensive buildings, contributes to saving resources, reducing the environmental footprint, and upgrading the quality of their services, as well as supporting national health systems [32,33]. In this regard, additional research is required for energy upgrades of the building infrastructure, due to the urgency imposed by the energy crisis, in combination with the energy transition plans and the development of methods for saving resources [26,31,34]. Recent studies have shown that a holistic examination of the factors affecting the complexity of upgrading buildings is quite insufficient, which is why further research is needed to increase the benefits of the energy-efficient retrofitting of buildings [35,36].

The energy efficiency of large-sized buildings such as hospitals cannot rely only on building upgrades and the use of energy from the cogeneration of different energy sources. There are still many more factors that cannot be ignored, such as the use of all renewable energy sources and not only photovoltaic solar panels, as well as the energy culture of the management, staff, patients, and visitors in hospitals [21]. A holistic approach is needed that links green building retrofit technologies with the prudent use of energy, management standards, and social responsibility programs for energy issues [3]. Under this holistic approach, there are aspects that need further research in order to achieve an effective design that incorporates the energy efficiency of the hospital, the qualitative development of its operations, and the requirements of its end users [22]. Many scholars have focused on the environmental performance of hospitals and the environmental impact that they generate; however, these studies have revealed the mitigation aspects of specific facilities and, therefore, are not optimal, according to Ryan-Fogarty [21]. Public policies for building energy performance, especially concerning hospitals, differ from country to country, as well as from region to region, and factors such as cuts in public expenditure prevent the implementation of important energy-efficiency projects [37]. In this regard, ways of removing financial, institutional, and technological barriers represent an issue that requires further research.

3. Methodological Approach

The main objective of this literature review is to identify and examine articles that are directly related to aspects of the energy upgrading of hospitals, in order to evaluate the existing findings and identify future research paths. The research agenda will be shaped, based on the study and mapping of the existing knowledge on energy upgrading in hospitals and the saving of resources. Based on theoretical and empirical articles, this systematic review, following a methodological approach [38], will reveal research aspects and interactions among the various thematic areas [39]. Compared to other methods of analysis, a systematic literature review employs methods that enhance the reliability of the findings and, at the same time, reduce the biases [40]. The design and organization of the systematic literature review for the evaluation of the existing studies regarding hospital energy upgrades, in terms of the quality of the offered services, saving resources, and technological options [41], was carried out through an examination of published articles in the 2012–2021 period. In order to form a safety net of quality articles, only peer-reviewed journal articles were selected [42,43]. The ScienceDirect, Scopus, EBSCOhost, Web of Science, MDPI, SAGE, and WILEY databases were used to find articles relevant to our topic. Keywords were used and combined according to the objectives of the research, such as "Hospitals—Energy efficiency", "Hospitals—Energy saving", "Hospitals—Energy consumption", "Hospitals—Energy refurbishment", "Hospitals—Energy resources", "Hospitals—Energy resources", "Hospitals—Saving resources", and "Hospitals—Energy upgrade". Then, the above combinations were also combined with the keywords "Healthcare", "Healthcare services quality", and "Healthcare provision".

The procedure was followed as illustrated in Figure 1. After checking the reliability of the results in relation to the framework established for the literature review [44], the final count yielded 185 relevant articles.

Figure 1. Literature review flowchart on the energy upgrading of hospitals.

The vast majority of the research in the field of energy efficiency in healthcare units focuses mainly on the energy-upgrading strategies of hospitals through the use of specific technologies, written from an engineering point of view. However, through an extensive literature review, a research gap in the field of energy upgrading was identified, in regard to economic parameters and the quality of life of both employees and patients, along with a similar research gap concerning the resources and financial tools required for the energy upgrading of hospitals. Trying to bridge that gap, we proceeded to an extensive literature review regarding the benefits of the energy upgrading of hospitals and the ways that this could be achieved, highlighting the economic dimension, as no other similar bibliographic research exists on that issue. Thus, we grouped the papers into specific categories that combined, directly or indirectly, the economic impact and the energy upgrading of hospitals and healthcare units, including strategies for energy monitoring, evaluation, and upgrading through technological options, saving resources, the main obstacles, policy measures, the state funding programs provided, energy management in hospitals, energy performance, and service quality, the economic feasibility of hospital renovation strategies and financing, and obstacles to upgrading hospitals. These issues were then grouped into three main homogenous categories: articles with strategies on energy monitoring, evaluation, and upgrading through technological options (GEUH1), articles with resource-saving content (GEUH2), and, finally, articles that feature energy efficiency and service quality topics (GEUH3). All three categories are presented from an economic perspective of efficiency and sustainability.

The distribution of the selected studies, according to the year of publication and the GEUH categories per year, are shown in Figure 2. Most of the research on the energy upgrading of hospitals was conducted in 2016 and 2017.

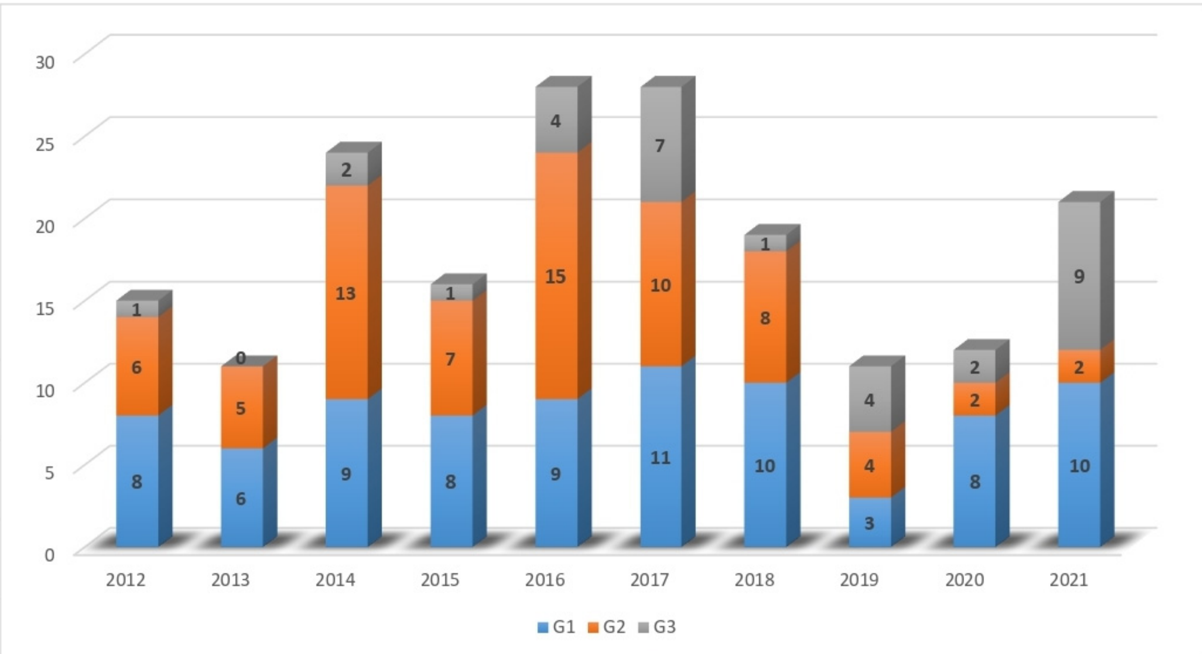

Figure 2. Distribution of selected studies by year of publication and the three category Groups (2012–2021).

Figure 3 illustrates the number of papers in terms of the conducted research, shown according to country.

Figure 3. Visual capture of the examined 185 articles (the studies refer to 39 countries) on a global map image.

The selected studies of the three categories were subjected to content analysis [45,46]. The content analysis supported the thematic analysis [47], as reflected in Table 1 followed by Table 2 which it highlights the most cited papers of the present literature review.

Table 1. Classification and characteristics of the energy upgrade features of hospitals.

THEMES/GROUPS	Energy Upgrade Features in Hospitals	Examples/Source
Strategies for energy monitoring, evaluation, and upgrading through technological options (GEUH1)	• Energy design • Energy management • Alternative technologies options • Use of different sources of energy • Renovations	[8] [48] [49] [50]
Saving resources (GEUH2)	• Strategies for energy saving and efficiency • Energy-saving and preservation techniques • Improving the cost of energy resources • Factors taken into account in energy saving	[51] [52] [53] [54]
Energy performance and the quality of services (GEUH3)	• Energy conservation and healthcare • Green operation related to services' quality and end-user requirements • Improvement of health and comfort by reducing energy use • Patient safety and energy efficiency	[22] [55] [56] [57]

Table 2. The most frequently cited papers in each Energy-Upgrade Hospital Group category.

Group Category	Paper	Journal	Cites
GEUH1	[58]	AE	128
	[59]	NRG	113
	[60]	EP	101
	[61]	ECaM	85
GEUH2	[62]	AE	130
	[63]	NRG	124
	[64]	AE	124
	[65]	E&B	93
GEUH3	[55]	IE&H	82
	[22]	JOCP	45
	[21]	JOCP	42
	[66]	ATE	32

4. Findings

Following the categorization described in Section 3, in this section, we summarize the main research points for each group, as presented in the relevant literature.

5. GEUH1: Strategies for Energy Monitoring, Evaluation, and Upgrading through Technological Options

Non-residential buildings, such as health services and hospital buildings, contribute to energy consumption and cause a negative environmental impact, either due to the age of the buildings, their poor level of energy efficiency, and other factors [67], or due to system faults [68]. Retrofitting hospitals and other strategic buildings is a very challenging issue, both because of their complex articulation and the need to maintain acceptable operational levels and quality of service [69], not only for the main buildings but also for companion houses with accommodation facilities [70]. By following certain strategies for energy efficiency, hospitals can succeed in achieving an adequate reduction of their primary energy consumption [71]. The optimal size of healthcare building stock is critical for the implementation of successful energy efficiency plans [72]. Bakar et al. [73] proposed the energy efficiency index (EEI) as an indicator to track the performance of energy consumption in a building. Other measures include the categorization of healthcare facilities [74] or comparisons of the building layout of comprehensive clinics versus the layouts for inpatient buildings [75]. An intelligent energy management system (IEMS) must be in place in order to harvest the benefits of improving all the related subsystems, while at the same time ensuring the operation of the hospital under extreme conditions, e.g., after a natural disaster [76,77]. Energy efficiency and indoor air quality in healthcare applications and particularly in surgical operating theatres are important features in modernized designs [78], since enclosed thermal zones must be maintained under stringent hygrothermal conditions [79].

Sustainable management in hospitals must be carried out through a comprehensive execution plan, using methodologies such as BIM (building information modeling) and laser tools [14,80–83]. In Europe, for example, more than 80% of the buildings were built before 1990 and, in general, do not have documentation regarding the building in BIM format [80], taking into account the end users' rationales [84]. One of the least widely used aspects of BIM (building information modeling) is the ability to obtain an energy model of the building using the BIM methodology known as BIM 6D. This digital information model enables simulating the real energy behavior of the building and improvements in the building's lighting systems, both natural and artificial, in particular daylight conditions.

In this way, the BIM 6D simulation allows us to make design and operational decisions for the building, not only in the case of new buildings that must, in accordance with current legislation, be NZEB (nearly zero-energy building)-compliant but also for the rehabilitation of existing buildings. Particularly in the case of buildings for healthcare purposes, BIM 6D permits an exhaustive analysis of the energy impact of said rehabilitation, guiding it toward an improvement in energy and light efficiency, which, in turn, provides greater quality and comfort in the use of sustainable buildings [85]. Optimal energy management practices must deal with uncertainties in energy generation and demand [86,87]. Hence, the development of reliable forecasting methods is an important priority of research into electric energy systems [88]. Carbonari et al. [89] recommended improvement strategies that include better insulation in building envelopes, the enhancement of mechanical and lighting equipment, the use of renewable energy, and better regulation of electrical systems. Considerable technical efficiency potential also exists for elevators and escalators for these types of buildings and for air-conditioning systems as well [78].

Among the most important parts of electricity consumption in such buildings are the heating, ventilation, and air conditioning (HVAC) systems [90], the magnetic resonance imaging (MRI) unit [91], and, in some cases, the lighting [92,93]. Evaluation of the energy demand of such systems has become a self-evident measure for planning and optimizing non-residential buildings [94–96]. Dezfouli et al. [97] proposed the application of Variable Speed Drives VSDs in the HVAC system because of the large amount of energy and money that can then be saved, while Rahman et al. [8] proposed another alternative chiller system for that purpose.

The increasing attention to issues such as visual comfort and energy efficiency that characterize the architecture of the 21st century has led to the development of innovative, affordable, high-performance dynamic glazing systems, aimed not only at reducing heat loss but also at controlling the incoming solar radiation [98]. All over the world, several energy-efficiency measures based on existing and new technology systems have been proposed as strategies to reduce the high energy demand and energy costs in hospitals [99–104].

The ability to switch between different energy sources is a crucial advantage for the optimal fulfillment of the energy demand [105]. One example is the cogeneration method, which is commonly recognized as one of the most effective solutions for achieving the increasingly stringent requirements in primary energy consumption reduction and greenhouse emissions reduction, including in hospitals [4,106,107]. However, the method is influenced by uncertainties on both the optimal size of the unit and the annual total cost [61]. Other examples are the CHP (combined heat and power) and CCHP (combined cooling, heating, and power) techniques, which have also been viewed as particularly attractive investments as they result in primary energy conservation and the reduction of the emissions of greenhouse gases [59,108,109]. However, the energetic and economic benefits and the optimal CHP capacity depend on several factors [49,110]. Thus, the generated GHG emissions reductions could be rather low in specific cases, relative to the alternatives [111]. The advantages of high energy efficiency and low emission for solid oxide fuel cells in hospitals make the technology a promising prime mover for CCHP systems [58,112–114].

On the contrary, Facci et al. [115] concluded that the optimal economic management of CCHP plants does not, in general, lead to lower energy consumption and lower pollutant emissions, due to the multiple uncertainties in the optimal design of distributed energy resources (DER) systems. The expected energy, economic, and environmental benefits may not be achieved and a deficit in the energy supply may occur if those uncertainties are not handled properly [116]. Even though hospitals have high operating costs and energy consumption, they have the potential to access a large amount of renewable energy in the form of solar, wind, and human energy, which is not fully considered in hospital designs [117]. In spite of that lack, various studies have proposed new and compatible methods for covering the above gap, as well as identifying the fittest solutions to address these issues [50,118–125].

The increased need for energy efficiency has led to specific policy measures by governments worldwide, providing the motivation for new systems and policies regarding energy management, such as in the United States [48,126,127], Italy [128], Japan [60], China [109], Malaysia [8,129], Saudi Arabia [130], and South Africa [131].

6. GEUH2: Resources Saving

The aim of energy efficiency is to use less energy to provide the same service. In hospitals, energy efficiency offers a powerful and cost-effective tool to reduce greenhouse gas emissions, fuel consumption, and running costs [64,132–134], which are estimated to be relatively high [51]. After all, energy-efficient hospitals have the potential to significantly impact the overall energy profile [135]. According to the EU "Energy Performance of Buildings Directive" recast (i.e., 2010/31/EU and 2012/27/EU), the existing building stocks represent one of the most promising potential sectors for achieving energy savings, and the energy retrofits of such buildings should pursue "cost-optimal levels" [136].

A prerequisite for the determination of savings is the accurate calculation of energy consumption, followed by the application of different methods of intelligent control for energy savings [137,138]. Several efficient indexes have been developed, aiming to achieve energy savings in hospitals and other public buildings [139–141]. The use of benchmarking in the management of healthcare facilities enables comparisons between hospitals [52]. Their energy consumption varies in terms of facility use (general, psychiatric, health center, etc.), the constitution year and the status of the building envelope, the insulation level, the climatic zone, the age and level of maintenance of the mechanical equipment, and the level of energy management [2]. For example, electrical energy costs (EEC) are higher in surgery-focused hospitals, or in the departments of imaging and radiotherapy, while the wards, day clinics, and certain other departments have lower average consumption intensities [142]. In line with that, Christiansen et al. [143] claimed that only isolated areas of the hospital, namely, intensive care units, are actually working around the clock, while even operating theaters have very steady activity patterns. Thus, the utilization times will eliminate wasted standby energy consumption. Differences in energy consumption have also been underlined between hospitals in different climate zones [53,144]. Differences have also been identified relative to the type and the age of the buildings [145,146], and appropriately combining these different building types into energy-demand groups can lead to supply-friendly energy-demand patterns [147]. The challenge today is to succeed in creating energy efficiency, even from older buildings and equipment. Prada et al. [148] tried to transform two relatively old, energy-inefficient hospitals into energy-efficient and intelligent buildings, reducing greenhouse gas emissions and primary energy consumption by using renewable energy. The improvement of the existing air condition systems in hospitals is necessary for energy savings [149,150]. The installation of movable exterior window shading in hospitals offers low heating and cooling demands, especially in tropical locations [151,152]. Fernández et al. [153] concluded that a cost reduction is also obtained by choosing the appropriate contracted capacities in each of the time periods of the electric supply tariff.

New, possibly applied technologies that feature innovative mechanical systems are recognized as offering very effective solutions to achieve the increasingly stringent requirements in primary energy saving and, at the same time, to reduce costs [6,7,154–159]. Wu et al. [160] emphasized, however, that the potential for energy-saving and CO_2 emission reduction for such equipment as the CCHP systems in mild climate zones is smaller than that in other climate zones. Furthermore, in regions with an absence of natural gas, combined with the high price of LS (low sulfur) fuel, those systems' solutions are weak from an economic point of view [161]. The feasibility study by Pagliarini et al. [162] of a trigeneration plant in a large hospital in Parma highlighted the fact that the primary energy-saving (PES) index is inadequate when sizing some of the above methods. Undoubtedly, energy price is one of the most important factors determining the economic performance of the distributed energy supply network [163]. Zheng et al. [164] proposed a feed-in tariff policy that can contribute to both the energy and economic performance related to those systems, but not without causing potential heat and cold conflicts.

Congradac et al. [165] assessed the possibilities for increasing energy efficiency in hospitals, concluding that when the savings are known in advance, the decisions regarding the installation and the costs of necessary work and equipment are much easier. Studies on a large number of hospitals and healthcare centers that were conducted in Europe, the United States, and in many other places all over the world found that through appropriate energy management, along with the installation of new technological systems, implementation of specific innovative techniques, and development of other modern energy retrofit interventions, it is possible to reduce energy consumption and save resources and money [54,72,166–170].

The installation of energy-efficient technologies, such as cogeneration modules and absorption chillers, is beneficial to achieve minimum annual costs through energy saving [62]. Trigeneration and other systems of producing energy have also been proposed by many surveys. Decentralized electricity production through trigeneration systems can save primary energy if these systems operate with a high energy utilization factor (EUF) [171]. Romero et al. [172] concluded that the optimization of energy efficiency can be achieved by consuming low-priced natural gas, operating the gas engines at full load to generate electricity, and selling all this electricity back to the provincial grid, while Arabkoohsar and Andresen [173] proposed a new configuration of a bifunctional solar-assisted absorption chiller that efficiently meets the heating demands of the chiller. Taseli and Kilkis [5] employed a trigeneration system, operating with biogas at an optimum fuel share with natural gas, for retrofitting a 900-bed university hospital, succeeding in achieving a large reduction in CO_2 emissions over a ten-year period. Furthermore, Calise et al. [174] analyzed a trigeneration system serving a hospital, showing that the electricity load tracking (ELT) mode control strategy can achieve better efficiency and profitability.

Several policy measures for energy efficiency in hospitals are presented in the literature for many countries globally, such as the UK [175], Brazil [176], China [177,178], Australia [179], Malaysia [63,180,181], and Turkey [182].

7. GEUH3: Energy Performance and Quality of Services

The quality of the services being provided is an issue of major importance for every healthcare unit. As a result, an energy efficiency strategy should always find a balance between energy saving and improved service quality for patients, healthcare personnel, and accompanying persons [183,184]. Data for the OECD countries, China and India, show that health care, on average, accounts for 5% of the national CO_2 footprint [185], even if it may look as though an "inelastic" demand for energy exists, a significant potential for energy and cost savings is possible with the accurate identification of the final energy consumption [186]. Good management of energy resources, related to the environmental impact, is an important issue to bear in mind, an aim that will improve people's quality of life and the country's competitiveness [187].

García-Sanz-Calcedo et al. [188], in a study of 13 hospitals over ten years, concluded that the number of annual discharges, the number of emergency operations, and the number of hospitalizations are strictly correlated with energy consumption. A good indoor environment in healthcare units directly affects health and comfort, as sick and vulnerable occupants (and other persons) spend most of the day indoors [189]. Thus, the good indoor environmental quality (IEQ) requirements that deal with indoor air quality (IAQ), thermal comfort, and lighting and acoustics are all important objectives [190]. With advances in technology, almost eighty percent of the number of operations that used to be performed in acute care facilities are now performed on an outpatient basis, that is, day surgery. Thus, it is necessary to provide realistic energy performance benchmarks [191–193] that are attainable for each typology within the specific sector.

Hospitals can produce part of their energy from renewable energy sources (RES) for cost reduction and by implementing a demand-dispatch energy program for using

RESs efficiently, along with decreasing energy costs and enhancing residents' safety, while maintaining the comfort of patients and surgeons at the same time [56,194–196]. In order to achieve a green healthcare system, however, a deep knowledge of its strengths and weaknesses is needed, as well as of its internal dynamics [11].

On the contrary, there are some surveys reporting the opposite results, with some green hospitals (14 leadership in energy and environmental design (LEED) hospitals) presenting higher-than-average operating expenses; they also demonstrate higher revenues from inpatients, on average [197]. Manika et al. [198] examined the impact of an environmental sustainability intervention in the healthcare industry, concluding that beyond a strategy of cost-saving, the intervention was perceived to benefit the organization, hospital employees, and patients (i.e., indirectly, through TLC energy-saving actions).

Hospital lighting design should find a balance between visual performance, visual comfort, and energy efficiency [57]. With the proper motivation for staff and their families, significant potential for energy savings exists [199]. However, the use of natural light and ventilation must take into account the building's orientation [22]. The indoor quality of air is vital for all healthcare buildings [55]. However, the different window sizes and types of glazing affect heating, cooling, and lighting energy demand in a hospital patient's room [200]. Lan et al. [201] found that passive solutions to ventilation could be used effectively in a patient hospital ward. The indoor environment of a mechanically ventilated hospital building controls infection rates and also affects the patient's healing process [202]. El-Maghlany et al. [66] tested a retrofit scheme for improving the thermal performance of air conditioning systems in intensive care units, yielding important savings in power consumption. Carnero and Gomez [203] presented an innovative multicriteria model, applied to a variety of electric power distribution systems responsible for supplying electrical energy to critical areas of the health care organizations, ensuring the best quality of care for the patient. Furthermore, Squire et al. [204] concluded that flexible, adaptable interventions can be used within hospitals during infection outbreaks to mitigate healthcare-associated infections.

8. Discussion and Future Research

Global energy consumption is expected to triple by the year 2050; therefore, timely investments should lead to the reduction of greenhouse gas (GHG) emissions, integration of renewable energy sources (RES), and increase in energy efficiency [205]. The widely accepted importance of energy efficiency in the building sector is continuously being acknowledged by the engineering and research community [206,207]. Enforcing energy-related requirements during the design or retrofit phase of a building is a key driver for implementing energy efficiency measures that will not only bring substantial CO_2 savings and reduced energy bills but will also ensure more comfortable occupant conditions, more employment opportunities, and increased energy security [208–210]. The World Health Organization, and comparable reports from several countries, agree that hospitals are responsible for a large part of commercial energy consumption [211] and CO_2 emissions [212], much higher than those of office and school buildings [65], because of their 24-hour activity [213] and the need to ensure thermal comfort, air quality, and visual comfort for their patients [214]. It is, thus, desirable to minimize energy consumption and to promote the use of renewable energy resources and other resources more friendly to the environment [215]. These are crucial factors in the case of hospitals [9].

This research attempts to provide answers regarding those factors related to energy efficiency in healthcare units, highlighting both their environmental and economic impact. Through a systematic review, we seek to capture the existing knowledge on hospitals' energy efficiency, the prospect of resource savings, and the provision of quality health services via technological options by identifying research gaps and suggesting future research paths. Based on those issues, the main findings of the specific literature review can be summarized as follows:

- Even though the body of the literature is quite extensive, many surveys approach energy efficiency either exclusively or mainly from the environmental or the technical point of view, and less in terms of the cost efficiency of those aspects. Thus, more research is needed on the economic impact of energy efficiency in large buildings and hospitals. In this research, we attempted to identify most of those research topics, providing up-to-date knowledge on that issue; however, more research focused on that area of energy saving and efficiency is needed, in order that such systems can be more easily adapted by governments all over the world.
- Most studies are limited to single hospital units in various countries, examining aspects of hospital energy upgrading and saving resources. If hospital units were comparatively examined, then the different elements in energy performance and management could have been identified. The orientation of this research is proposed to comparatively examine hospital units with different climatic conditions and in different cultural and socio-economic environments, in order to highlight the role of the environment and climatic conditions in the selection of an energy-efficient system in hospital units to save resources. This research would contribute to a better understanding of what the most relevant energy needs are for each geographical area, in order to establish an optimal cost for each of the solutions chosen. It is also necessary to compare the hospital units in urban centers with those in rural areas where the environmental conditions are different.
- A similar issue is identified relative to the type of healthcare unit. Because hospitals differ, based on the services they offer and the diseases that they specialize in treating, they also have different energy needs. Their operation also differentiates them in terms of energy costs. Therefore, future research must also take this factor into account when examining ways of increasing the energy efficiency of hospitals, reducing energy costs, and upgrading their services. Further research comparing different types of hospitals based on their specialization is still needed.
- The majority of the research has been conducted in very large-sized hospitals that have a large number of beds and much less has been conducted in the smaller hospital units that are numerically most common, without examining whether they consume less energy in relation to their size. Many studies have focused on large-sized public hospitals, while small private hospitals, health clinics, rehabilitation centers, and hemodialysis centers are outside the research framework. In this study, many different studies have been included for both large and smaller healthcare units in rural as well as metropolitan areas.
- Regarding the issue of saving energy resources, most research is oriented to the cost–result relationship and less to the environmental footprint that hospitals leave, as well as to the energy awareness of hospital staff and patients. It is unclear how operations and staff actions affect and impact energy use in hospitals. The research specification of methods to increase the energy behavior of hospital staff and patients, in combination with saving resources, due to energy upgrading is deemed necessary. Additionally, further research on energy efficiency in relation to costs, environmental impact, and the satisfaction of hospital employees and patients is also needed.
- Our survey of the existing literature shows that most of the published research deals with the energy upgrading of hospitals with cogeneration applications. They mostly refer to combinations of electricity, gas, and oil and less to renewable energy sources. Even when the focus is on renewable energy sources, it is limited to energy generated by photovoltaic installations. There are only a few studies on hospital energy efficiency using other forms of renewable energy, such as wind, aerothermal, geothermal, hydrothermal, hydroelectric, or biomass-based energy production, wastewater treatment, and other biological sources. This is a topic that requires further research, especially relative to large-sized healthcare units.

9. Conclusions

The energy crisis has made it even more imperative to conduct further research into the improvement of the energy efficiency of buildings, such as energy-intensive hospital buildings. At the same time, the developing health sector needs to conserve resources and upgrade the services offered by reducing its energy costs through the discovery and implementation of alternative energy technologies. This systematic literature review captures the existing knowledge and identifies future research paths, aiming to help researchers to study those aspects that have not yet been sufficiently illuminated and attempting to highlight the economic impact of energy efficiency policy in healthcare units. Through that process, the contribution of the implementation of energy-upgrading policies is underlined, the existing gaps in the international literature are identified, and guidelines for future work in specific research fields are provided. More specifically, this research work proposes the further study of alternative energy technologies, in combination with systems based on all renewable energy sources and not only on photovoltaic systems, in order to deal with high energy consumption and identify resource savings with the smallest possible environmental footprint. This suggests the need for a comparative examination of hospital units with different climatic and socio-economic environments to better reflect energy needs and to identify what technologies best serve them, to orient future research in all hospitals of any size, and to link any upgrade with the degree of awareness necessary in management and staff in terms of saving energy resources. Beyond identifying future research pursuits, this systematic literature review responds to the call for greater research into building energy efficiency. It adds summarized data to the international literature on this subject and enables investors to have at their disposal the aggregated data of energy research in the field of energy efficiency and saving resources. Furthermore, some policy implications are highlighted in this research, not only from the environmental point of view but also relative to the economic implications of such policies and the quality of the services provided, necessitating an overall energy-upgrading strategy focused on large buildings with high energy consumption, such as hospitals and healthcare units.

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References

1. Gatea, A.; Batcha, M.F.M.; Taweekun, J. Energy efficiency and thermal comfort in hospital buildings: A review. *Int. J. Integr. Eng.* **2020**, *12*, 33–41.
2. Kolokotsa, D.; Tsoutsos, T.; Papantoniou, S. Energy conservation techniques for hospital buildings. *Adv. Build. Energy Res.* **2012**, *6*, 159–172. [CrossRef]
3. De Oliveira, K.B.; dos Santos, E.F.; Neto, A.F.; de Mello Santos, V.H.; de Oliveira, O.J. Guidelines for efficient and sustainable energy management in hospital buildings. *J. Clean. Prod.* **2021**, *329*, 129644. [CrossRef]
4. Nagao, H.; Uemichi, A.; Yamasaki, Y.; Kaneko, S. Proposal of a decision scheme for installing a cogeneration system considering disaster risks. *Appl. Therm. Eng.* **2017**, *114*, 1414–1423. [CrossRef]
5. Taseli, B.K.; Kilkis, B. Ecological sanitation, organic animal farm, and cogeneration: Closing the loop in achieving sustainable development—A concept study with on-site biogas fueled trigeneration retrofit in a 900-bed university hospital. *Energy Build.* **2016**, *129*, 102–119. [CrossRef]

6. Muccillo, M.; Gimelli, A.; Sannino, R. Multi-objective optimization and sensitivity analysis of a cogeneration system for a hospital facility. *Energy Procedia* **2015**, *81*, 585–596. [CrossRef]
7. Alexis, G.K.; Liakos, P. A case study of a cogeneration system for a hospital in Greece. Economic and environmental impacts. *Appl. Therm. Eng.* **2013**, *54*, 488–496. [CrossRef]
8. Rahman, N.M.; Lim, C.H.; Fazlizan, A. Optimizing the energy saving potential of public hospital through a systematic approach for green building certification in Malaysia. *J. Build. Eng.* **2021**, *43*, 103088. [CrossRef]
9. Acampa, G.; Liberanome, D.; Kalogeras, G.; Koulamas, C.; Kalogeras, A. Energy Management in Hospitals: Evolution of a Methodology. In *Values and Functions for Future Cities*; Mondini, G., Oppio, A., Stanghellini, S., Bottero, M., Abastante, F., Eds.; Springer: Cham, Switzerland, 2020; pp. 21–35.
10. Carbonara, N.; Pellegrino, R. Public-private partnerships for energy efficiency projects: A win-win model to choose the energy performance contracting structure. *J. Clean. Prod.* **2018**, *170*, 1064–1075. [CrossRef]
11. Chías, P.; Abad, T. Green hospitals, green healthcare. *Int. J. Energy Prod. Manag.* **2017**, *2*, 196–205. [CrossRef]
12. Pikas, E.; Koskela, L.; Sapountzis, S.; Dave, B.; Owen, R.B. Overview of building information modelling in healthcare projects. In Proceedings of the Global Health Infrastructure-Challenges for the Next Decade: Delivering Innovation, Demonstrating the Benefits–4th Annual Conference of the Health and Care Infrastructure Research and Innovation Centre, HaCIRIC-Health and Care Infrastructure Research and Innovation Centre, Manchester, UK, 26–28 September 2011; pp. 286–298.
13. Uddin, M.N.; Wang, Q.; Wei, H.H.; Chi, H.L.; Ni, M. Building information modeling (BIM), System dynamics (SD), and Agent-based modeling (ABM): Towards an integrated approach. *Ain Shams Eng. J.* **2021**, *12*, 4261–4274. [CrossRef]
14. Khahro, S.H.; Kumar, D.; Siddiqui, F.H.; Ali, T.H.; Raza, M.S.; Khoso, A.R. Optimizing energy use, cost and carbon emission through building information modelling and a sustainability approach: A case-study of a hospital building. *Sustainability* **2021**, *13*, 3675. [CrossRef]
15. Wen, Q.; Li, Z.; Peng, Y.; Guo, B. Assessing the effectiveness of building information modeling in developing green buildings from a lifecycle perspective. *Sustainability* **2020**, *12*, 9988. [CrossRef]
16. Pereira, V.; Santos, J.; Leite, F.; Escórcio, P. Using BIM to improve building energy efficiency–A scientometric and systematic review. *Energy Build.* **2021**, *250*, 111292. [CrossRef]
17. Lu, K.; Jiang, X.; Tam, V.W.; Li, M.; Wang, H.; Xia, B.; Chen, Q. Development of a carbon emissions analysis framework using building information modeling and life cycle assessment for the construction of hospital projects. *Sustainability* **2019**, *11*, 6274. [CrossRef]
18. Eguaras-Martínez, M.; Vidaurre-Arbizu, M.; Martín-Gómez, C. Simulation and evaluation of building information modeling in a real pilot site. *Appl. Energy* **2014**, *114*, 475–484. [CrossRef]
19. Montiel-Santiago, F.J.; Hermoso-Orzáez, M.J.; Ershadi, M.; Jefferies, M.; Davis, P.; Mojtahedi, M. Implementation of Building Information Modelling in infrastructure construction projects: A study of dimensions and strategies. *International Journal of Information Systems and Project Management.* **2021**, *9*, 43–59.
20. Pezeshki, Z.; Ivari, S.A.S. Applications of BIM: A brief review and future outline. *Arch. Comput. Methods Eng.* **2018**, *25*, 273–312. [CrossRef]
21. Ryan-Fogarty, Y.; O'Regan, B.; Moles, R. Greening healthcare: Systematic implementation of environmental programmes in a university teaching hospital. *J. Clean. Prod.* **2016**, *126*, 248–259. [CrossRef]
22. Wood, L.C.; Wang, C.; Abdul-Rahman, H.; Abdul-Nasir, N.S.J. Green hospital design: Integrating quality function deployment and end-user demands. *J. Clean. Prod.* **2016**, *112*, 903–913. [CrossRef]
23. European Commission. *Proposal for a Directive of the European Parliament and of the Council Amending Directive (EU) 2018/2001 on the Promotion of the Use of Energy from Renewable Sources, Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency*; COM(2022) 222 final; European Commission: Brussels, Belgium, 2022.
24. European Commission. *EU Solar Energy Strategy*; COM(2022) 221 Final; European Commission: Brussels, Belgium, 2022.
25. IEA. *Perspectives for the Clean Energy Transition: The Critical Role of Buildings*; International Energy Agency: Paris, France, 2019. Available online: https://www.iea.org/reports/the-critical-role-of-buildings (accessed on 11 July 2022).
26. Jensen, P.A.; Thuvander, L.; Femenias, P.; Visscher, H. Sustainable building renovation–strategies and processes. *Constr. Manag. Econ.* **2022**, *40*, 157–160. [CrossRef]
27. GlobalABC. Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector. 2019. Available online: www.globalabc.org (accessed on 18 July 2022).
28. Wuni, I.Y.; Shen, G.Q.P.; Osei-Kyei, R. Scientometric review of global research trends on green buildings in construction journals from 1992 to 2018. *Energy Build.* **2019**, *190*, 69–85. [CrossRef]
29. Alabid, J.; Bennadji, A.; Seddiki, M. A review on the energy retrofit policies and improvements of the UK existing buildings, challenges and benefits. *Renew. Sustain. Energy Rev.* **2022**, *159*, 112161. [CrossRef]
30. Hu, M.; Nippala, E.; Kallioharju, K.; Pelsmakers, S. Monte Carlo simulation approach to understand the cost variance for energy retrofit projects: Comparative study of Finland and the United States. *Constr. Manag. Econ.* **2022**, *40*, 207–222. [CrossRef]
31. Wade, F.; Visscher, H. Retrofitting at scale: Accelerating capabilities for domestic building stocks. *Build. Cities* **2021**, *2*, 800–911. [CrossRef]
32. Serghides, D.K.; Thravalou, S.; Dimitriou, S.; Kyprianou, I. Energy performance of healthcare facilities in 3 climatic zones in Cyprus. *Renew. Energy Environ. Sustain.* **2022**, *7*, 16. [CrossRef]

33. Dimoudi, A.; Kantzioura, A.; Toumpoulides, P.; Zoras, S.; Serghides, D.; Dimitriou, S.; Dorri, A. The energy performance of hospital buildings in the South Balkan region: The prospects for zero-energy hospitals. In *Sustainable Energy Development and Innovation*; Sayigh, A., Ed.; Springer: Cham, Switzerland, 2022; pp. 757–763.
34. Morkunaite, L.; Pupeikis, D.; Jurelionis, A.; Fokaides, P.A.; Papadopoulos, A. An Analytical Model for the Impact of Building Control and Automation Upgrade on Space Heating Energy Efficiency. *Buildings* **2022**, *12*, 1074. [CrossRef]
35. Coşkun, A.; Selçuk, S.A. Global Research Trends on Energy Efficient Retrofitting in Existing Buildings. *Period. Polytech. Archit.* **2022**, *53*, 35–56. [CrossRef]
36. Zhang, H.; Hewage, K.; Karunathilake, H.; Feng, H.; Sadiq, R. Research on policy strategies for implementing energy retrofits in the residential buildings. *J. Build. Eng.* **2021**, *43*, 103161. [CrossRef]
37. Lee, M.K.; Park, H.; Noh, J.; Painuly, J.P. Promoting energy efficiency financing and ESCOs in developing countries: Experiences from Korean ESCO business. *J. Clean. Prod.* **2003**, *11*, 651–657. [CrossRef]
38. Webster, J.; Watson, R.T. Analyzing the past to prepare for the future: Writing a literature review. *MIS Q.* **2002**, *26*, 13–23.
39. Thorpe, R.; Holt, R.; MacPherson, A.; Pittaway, L. Using knowledge within small and medium-sized firms: A systematic review of the evidence. *Int. J. Manag. Rev.* **2005**, *7*, 257–281. [CrossRef]
40. Satalkina, L.; Steiner, G. Digital entrepreneurship and its role in innovation systems: A systematic literature review as a basis for future research avenues for sustainable transitions. *Sustainability* **2020**, *12*, 2764. [CrossRef]
41. Kitchenham, B.; Charters, S. *Guidelines for Performing Systematic Literature Reviews in Software Engineering*; EBSE Technical Report; Citeseer: Gaithersburg, MD, USA, 2007.
42. Apostolopoulos, N.; Ratten, V.; Stavroyiannis, S.; Makris, I.; Apostolopoulos, S.; Liargovas, P. Rural health enterprises in the EU context: A systematic literature review and research agenda. *J. Enterprising Communities People Places Glob. Econ.* **2020**, *14*, 563–582. [CrossRef]
43. Podsakoff, P.; MacKenzie, S.; Bachrach, D.; Podsakoff, N. The influence of management journals in the 1980s and 1990s. *Strateg. Manag. J.* **2005**, *26*, 473–488. [CrossRef]
44. Xiao, Y.; Watson, M. Guidance on conducting a systematic literature review. *J. Plan. Educ. Res.* **2019**, *39*, 93–112. [CrossRef]
45. Apostolopoulos, N.; Ratten, V.; Petropoulos, D.; Liargovas, P.; Anastasopoulou, E. Agri-food sector and entrepreneurship during the COVID-19 crisis: A systematic literature review and research agenda. *Strateg. Change* **2021**, *30*, 159–167. [CrossRef]
46. Weber, R.P. *Basic Content Analysis*; Sage: London, UK, 1990; p. 49.
47. Phillips, W.; Lee, H.; Ghobadian, A.; O'Regan, N.; James, P. Social innovation and social entrepreneurship: A systematic review. *Group Organ. Manag.* **2015**, *40*, 428–461. [CrossRef]
48. Burpee, H.; Loveland, J.; Helmers, A. *Targeting 100! Advanced Energy Efficient Building Technologies for High Performance Hospitals: Executive Summary*; No. DOE-UW-0003849-1; Univ. of Washington: Seattle, WA, USA, 2015.
49. Gimelli, A.; Muccillo, M. Optimization criteria for cogeneration systems: Multi-objective approach and application in an hospital facility. *Appl. Energy* **2013**, *104*, 910–923. [CrossRef]
50. Cristóbal-Monreal, I.R.; Dufo-López, R. Optimisation of photovoltaic–diesel–battery stand-alone systems minimising system weight. *Energy Convers. Manag.* **2016**, *119*, 279–288. [CrossRef]
51. Teke, A.; Timur, O. Assessing the energy efficiency improvement potentials of HVAC systems considering economic and environmental aspects at the hospitals. *Renew. Sustain. Energy Rev.* **2014**, *33*, 224–235. [CrossRef]
52. González, A.G.; García-Sanz-Calcedo, J.; Salgado, D.R. A quantitative analysis of final energy consumption in hospitals in Spain. *Sustain. Cities Soc.* **2018**, *36*, 169–175. [CrossRef]
53. Cygańska, M.; Kludacz-Alessandri, M. Determinants of electrical and thermal energy consumption in hospitals according to climate zones in Poland. *Energies* **2021**, *14*, 7585. [CrossRef]
54. Teke, A.; Timur, O. Overview of energy savings and efficiency strategies at the hospitals. *Int. J. Econ. Manag. Eng.* **2014**, *8*, 242–248.
55. Melikov, A.K. Advanced air distribution: Improving health and comfort while reducing energy use. *Indoor Air* **2016**, *26*, 112–124. [CrossRef]
56. Mohammadpour, A.; Anumba, C.J.; Messner, J.I. Integrated framework for patient safety and energy efficiency in healthcare facilities retrofit projects. *HERD: Health Environ. Res. Des. J.* **2016**, *9*, 68–85. [CrossRef]
57. Alzubaidi, S.; Soori, P.K. Energy efficient lighting system design for hospitals diagnostic and treatment room—A case study. *J. Light Vis. Environ.* **2012**, *36*, 23–31. [CrossRef]
58. Zheng, C.Y.; Wu, J.Y.; Zhai, X.Q. A novel operation strategy for CCHP systems based on minimum distance. *Appl. Energy* **2014**, *128*, 325–335. [CrossRef]
59. Moradi, M.H.; Hajinazari, M.; Jamasb, S.; Paripour, M. An energy management system (EMS) strategy for combined heat and power (CHP) systems based on a hybrid optimization method employing fuzzy programming. *Energy* **2013**, *49*, 86–101. [CrossRef]
60. Kong, X.; Lu, S.; Wu, Y. A review of building energy efficiency in China during "Eleventh Five-Year Plan" period. *Energy Policy* **2012**, *41*, 624–635. [CrossRef]
61. Urbanucci, L.; Testi, D. Optimal integrated sizing and operation of a CHP system with Monte Carlo risk analysis for long-term uncertainty in energy demands. *Energy Convers. Manag.* **2018**, *157*, 307–316. [CrossRef]
62. Carvalho, M.; Lozano, M.A.; Serra, L.M. Multicriteria synthesis of trigeneration systems considering economic and environmental aspects. *Appl. Energy* **2012**, *91*, 245–254. [CrossRef]

63. Isa, N.M.; Das, H.S.; Tan, C.W.; Yatim, A.H.M.; Lau, K.Y. A techno-economic assessment of a combined heat and power photovoltaic/fuel cell/battery energy system in Malaysia hospital. *Energy* **2016**, *112*, 75–90. [CrossRef]
64. Ascione, F.; Bianco, N.; De Stasio, C.; Mauro, G.M.; Vanoli, G.P. Multi-stage and multi-objective optimization for energy retrofitting a developed hospital reference building: A new approach to assess cost-optimality. *Appl. Energy* **2016**, *174*, 37–68. [CrossRef]
65. Ma, H.; Du, N.; Yu, S.; Lu, W.; Zhang, Z.; Deng, N.; Li, C. Analysis of typical public building energy consumption in northern China. *Energy and Buildings* **2017**, *136*, 139–150. [CrossRef]
66. El-Maghlany, W.M.; ElHefni, A.A.; ElHelw, M.; Attia, A. Novel air conditioning system configuration combining sensible and desiccant enthalpy wheels. *Appl. Therm. Eng.* **2017**, *127*, 1–15. [CrossRef]
67. Giretti, A.; Vaccarini, M.; Casals, M.; Macarulla, M.; Fuertes, A.; Jones, R.V. Reduced-order modeling for energy performance contracting. *Energy Build.* **2018**, *167*, 216–230. [CrossRef]
68. Cheung, H.; Braun, J.E. Empirical modeling of the impacts of faults on water-cooled chiller power consumption for use in building simulation programs. *Appl. Therm. Eng.* **2016**, *99*, 756–764. [CrossRef]
69. Gaspari, J.; Fabbri, K.; Gabrielli, L. A study on parametric design application to hospital retrofitting for improving energy savings and comfort conditions. *Buildings* **2019**, *9*, 220. [CrossRef]
70. Balo, F.; Sua, L.S.; Polat, H. Green Hospitals and Sustainability: Case of Companion House of a Research Hospital. In *Green Energy and Infrastructure*, 1st ed.; Stagner, J., David, T., Eds.; CRC Press: Boca Raton, FL, USA, 2020; pp. 63–92.
71. Sala, M.; Alcamo, G.; Nelli, L.C. Energy-saving solutions for five hospitals in Europe. In *Mediterranean Green Buildings & Renewable Energy*; Sayigh, A., Ed.; Springer: Cham, Switzerland, 2017; pp. 1–17.
72. García-Sanz-Calcedo, J. Analysis on energy efficiency in healthcare buildings. *J. Healthc. Eng.* **2014**, *5*, 361–374. [CrossRef]
73. Bakar, N.N.A.; Hassan, M.Y.; Abdullah, H.; Rahman, H.A.; Abdullah, M.P.; Hussin, F.; Bandi, M. Energy efficiency index as an indicator for measuring building energy performance: A review. *Renew. Sustain. Energy Rev.* **2015**, *44*, 1–11. [CrossRef]
74. Ahmed, T.M.; Rajagopalan, P.; Fuller, R. A classification of healthcare facilities: Toward the development of energy performance benchmarks for day surgery centers in Australia. *HERD Health Environ. Res. Des. J.* **2015**, *8*, 139–157. [CrossRef] [PubMed]
75. Shi, Y.; Yan, Z.; Li, C.; Li, C. Energy consumption and building layouts of public hospital buildings: A survey of 30 buildings in the cold region of China. *Sustain. Cities Soc.* **2021**, *74*, 103247. [CrossRef]
76. Gomes, M.G.; Rodrigues, A.M.; Natividade, F. Thermal and energy performance of medical offices of a heritage hospital building. *J. Build. Eng.* **2021**, *40*, 102349. [CrossRef]
77. Kyriakarakos, G.; Dounis, A. Intelligent management of distributed energy resources for increased resilience and environmental sustainability of hospitals. *Sustainability* **2020**, *12*, 7379. [CrossRef]
78. Khalil, E.E. Energy Efficient Hospitals Air Conditioning Systems. *Open J. Energy Effic.* **2012**, *1*, 1–7. [CrossRef]
79. Buonomano, A.; Montanaro, U.; Palombo, A.; Santini, S. Temperature and humidity adaptive control in multi-enclosed thermal zones under unexpected external disturbances. *Energy Build.* **2017**, *135*, 263–285. [CrossRef]
80. Da Casa, F.; García, R.; Echeverría, E.; D'Amico, F.C.; Nope, A.; Domínguez, P.; Chías, P. BIM for Sustainable Management in Existing Hospitals. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *503*, 012004. [CrossRef]
81. Da Silva, P.P.F.; Neto, A.H.; Sauer, I.L. Evaluation of Model Calibration Method for Simulation Performance of a Public Hospital in Brazil. *Energies* **2021**, *14*, 3791. [CrossRef]
82. Marmo, R.; Nicolella, M.; Polverino, F.; Tibaut, A. A methodology for a performance information model to support facility management. *Sustainability* **2019**, *11*, 7007. [CrossRef]
83. Di Giulio, R.; Turillazzi, B.; Marzi, L.; Pitzianti, S. Integrated BIM-GIS based design for high energy efficiency hospital buildings. *TECHNE-J. Technol. Archit. Environ.* **2017**, *13*, 243–255.
84. Wu, Q.; Ren, H.; Gao, W.; Ren, J. Modeling and optimization of distributed energy supply network with power and hot water interchanges. *Appl. Therm. Eng.* **2016**, *94*, 635–643. [CrossRef]
85. Montiel-Santiago, F.J.; Hermoso-Orzáez, M.J.; Terrados-Cepeda, J. Sustainability and Energy Efficiency: BIM 6D. Study of the BIM Methodology Applied to Hospital Buildings. Value of Interior Lighting and Daylight in Energy Simulation. *Sustainability* **2020**, *12*, 5731. [CrossRef]
86. Rezvan, A.T.; Gharneh, N.S.; Gharehpetian, G.B. Optimization of distributed generation capacities in buildings under uncertainty in load demand. *Energy Build.* **2013**, *57*, 58–64. [CrossRef]
87. Rezvan, A.T.; Gharneh, N.S.; Gharehpetian, G.B. Robust optimization of distributed generation investment in buildings. *Energy* **2012**, *48*, 455–463. [CrossRef]
88. Bagnasco, A.; Fresi, F.; Saviozzi, M.; Silvestro, F.; Vinci, A. Electrical consumption forecasting in hospital facilities: An application case. *Energy Build.* **2015**, *103*, 261–270. [CrossRef]
89. Carbonari, A.; Fioretti, R.; Lemma, M.; Principi, P. Managing energy retrofit of acute hospitals and community clinics through EPC contracting: The MARTE project. *Energy Procedia* **2015**, *78*, 1033–1038. [CrossRef]
90. Alotaibi, B.S.; Lo, S.; Southwood, E.; Coley, D. Evaluating the suitability of standard thermal comfort approaches for hospital patients in air-conditioned environments in hot climates. *Build. Environ.* **2020**, *169*, 106561. [CrossRef]
91. Esmaeili, A.; McGuire, C.; Overcash, M.; Ali, K.; Soltani, S.; Twomey, J. Environmental impact reduction as a new dimension for quality measurement of healthcare services: The case of magnetic resonance imaging. *Int. J. Health Care Qual. Assur.* **2018**, *31*, 910–922. [CrossRef]

92. Chen, X.; Chen, Y.; Zhang, M.; Jiang, S.; Gou, H.; Pang, Z.; Shen, B. Hospital-oriented quad-generation (HOQG)—A combined cooling, heating, power and gas (CCHPG) system. *Appl. Energy* **2021**, *300*, 117382. [CrossRef]
93. Nwanya, S.C.; Sam-Amobi, C.; Ekechukwu, O.V. Energy performance indices for hospital buildings in Nigeria. *Int. J. Technol.* **2016**, *7*, 15–25. [CrossRef]
94. Al-Ghamdi, S.G.; Bilec, M.M. Green building rating systems and whole-building life cycle assessment: Comparative study of the existing assessment tools. *J. Archit. Eng.* **2017**, *23*, 04016015. [CrossRef]
95. Christiansen, N.; Kaltschmitt, M.; Dzukowski, F.; Isensee, F. Electricity consumption of medical plug loads in hospital laboratories: Identification, evaluation, prediction and verification. *Energy Build.* **2015**, *107*, 392–406. [CrossRef]
96. Ascione, F.; Bianco, N.; De Masi, R.F.; Vanoli, G.P. Rehabilitation of the building envelope of hospitals: Achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates. *Energy Build.* **2013**, *60*, 125–138. [CrossRef]
97. Dezfouli, M.M.S.; Moghimi, S.; Azizpour, F.; Mat, S.; Sopian, K. Feasibility of saving energy by using VSD in HVAC system, a case study of large scale hospital in Malaysia. *WSEAS Trans. Environ. Dev.* **2014**, *10*, 15–25.
98. Casini, M. Smart windows for energy efficiency of buildings. *Int. J. Civ. Struct. Eng.* **2015**, *2*, 273–281.
99. Samsudin, S.S.A.; Shaari, A.M.; Abdullah, K.; Batcha, M.F.M. Potential of Utilizing Solar Chimney as an Energy Efficiency Measure in Malaysian Hospitals. *CFD Lett.* **2020**, *12*, 90–99. [CrossRef]
100. Shariatzadeh, O.J.; Refahi, A.H.; Rahmani, M.; Abolhassani, S.S. Economic optimisation and thermodynamic modelling of SOFC tri-generation system fed by biogas. *Energy Convers. Manag.* **2015**, *105*, 772–781. [CrossRef]
101. Law, Y.L.E.; Dworkin, S.B. Characterization of the effects of borehole configuration and interference with long term ground temperature modelling of ground source heat pumps. *Appl. Energy* **2016**, *179*, 1032–1047. [CrossRef]
102. Kantola, M.; Saari, A. Renewable vs. traditional energy management solutions–A Finnish hospital facility case. *Renew. Energy* **2013**, *57*, 539–545. [CrossRef]
103. Balali, A.; Valipour, A. Prioritization of passive measures for energy optimization designing of sustainable hospitals and health centres. *J. Build. Eng.* **2021**, *35*, 101992. [CrossRef]
104. Moghimi, S.; Bakhtyar, B.; Azizpour, F.; Sopian, K.; Lim, C.H.; Mat, S.; Salleh, E. Maximization of energy saving and minimization of insulation cost in a tropical hospital: A case study in Malaysia. *WSEAS Trans. Environ. Dev.* **2013**, *9*, 105–115.
105. Noussan, M.; Jarre, M. Multicarrier energy systems: Optimization model based on real data and application to a case study. *Int. J. Energy Res.* **2018**, *42*, 1338–1351. [CrossRef]
106. Silveira, J.L.; de Queiroz Lamas, W.; Tuna, C.E.; de Castro Villela, I.A.; Miro, L.S. Ecological efficiency and thermoeconomic analysis of a cogeneration system at a hospital. *Renew. Sustain. Energy Rev.* **2012**, *16*, 2894–2906. [CrossRef]
107. Isa, N.M.; Tan, C.W.; Yatim, A.H.M. A comprehensive review of cogeneration system in a microgrid: A perspective from architecture and operating system. *Renew. Sustain. Energy Rev.* **2018**, *81*, 2236–2263. [CrossRef]
108. Mago, P.J.; Luck, R. Prime mover sizing for base-loaded combined heating and power systems. *Proc. Inst. Mech. Eng. Part A J. Power Energy* **2012**, *226*, 17–27. [CrossRef]
109. Kayo, G.; Hasan, A.; Siren, K. Energy sharing and matching in different combinations of buildings, CHP capacities and operation strategy. *Energy Build.* **2014**, *82*, 685–695. [CrossRef]
110. Gimelli, A.; Muccillo, M.; Sannino, R. Optimal design of modular cogeneration plants for hospital facilities and robustness evaluation of the results. *Energy Convers. Manag.* **2017**, *134*, 20–31. [CrossRef]
111. Howard, B.; Modi, V. Examination of the optimal operation of building scale combined heat and power systems under disparate climate and GHG emissions rates. *Appl. Energy* **2017**, *185*, 280–293. [CrossRef]
112. Jing, R.; Wang, M.; Brandon, N.; Zhao, Y. Multi-criteria evaluation of solid oxide fuel cell based combined cooling heating and power (SOFC-CCHP) applications for public buildings in China. *Energy* **2017**, *141*, 273–289. [CrossRef]
113. Jing, R.; Wang, M.; Wang, W.; Brandon, N.; Li, N.; Chen, J.; Zhao, Y. Economic and environmental multi-optimal design and dispatch of solid oxide fuel cell based CCHP system. *Energy Convers. Manag.* **2017**, *154*, 365–379. [CrossRef]
114. Yang, G.; Zheng, C.Y.; Zhai, X.Q. Influence analysis of building energy demands on the optimal design and performance of CCHP system by using statistical analysis. *Energy Build.* **2017**, *153*, 297–316. [CrossRef]
115. Facci, A.L.; Andreassi, L.; Martini, F.; Ubertini, S. Comparing energy and cost optimization in distributed energy systems management. *J. Energy Resour. Technol.* **2014**, *136*, 032001. [CrossRef]
116. Yang, Y.; Zhang, S.; Xiao, Y. Optimal design of distributed energy resource systems based on two-stage stochastic programming. *Appl. Therm. Eng.* **2017**, *110*, 1358–1370. [CrossRef]
117. Sameh, H.H.; Omar, E.M.; Ezz El-Dein, N.M. Criteria for evaluating the saving and production of energy in hospitals "nursing units". *Int. J. Eng. Res. Technol* **2019**, *12*, 670–678.
118. Dufo-López, R.; Pérez-Cebollada, E.; Bernal-Agustín, J.L.; Martínez-Ruiz, I. Optimisation of energy supply at off-grid healthcare facilities using Monte Carlo simulation. *Energy Convers. Manag.* **2016**, *113*, 321–330. [CrossRef]
119. Kahwash, F.; Barakat, B.; Taha, A.; Abbasi, Q.H.; Imran, M.A. Optimising Electrical Power Supply Sustainability Using a Grid-Connected Hybrid Renewable Energy System—An NHS Hospital Case Study. *Energies* **2021**, *14*, 7084. [CrossRef]
120. Pradhan, A.K.; Kar, S.K.; Mohanty, M.K. Off-grid renewable hybrid power generation system for a public health centre in rural village. *Int. J. Renew. Energy Res.* **2016**, *6*, 282–288.
121. Zhao, B.Y.; Li, Y.; Wang, R.Z.; Zhao, Z.G.; Taylor, R.A. A universal method for performance evaluation of solar photovoltaic air-conditioner. *Sol. Energy* **2018**, *172*, 58–68. [CrossRef]

122. Buonomano, A.; Calise, F.; Ferruzzi, G.; Palombo, A. Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings. *Energy* **2014**, *78*, 555–572. [CrossRef]
123. Buonomano, A.; Calise, F.; Ferruzzi, G.; Vanoli, L. A novel renewable polygeneration system for hospital buildings: Design, simulation and thermo-economic optimization. *Appl. Therm. Eng.* **2014**, *67*, 43–60. [CrossRef]
124. Rasouli, M.; Akbari, S.; Simonson, C.J.; Besant, R.W. Energetic, economic and environmental analysis of a health-care facility HVAC system equipped with a run-around membrane energy exchanger. *Energy Build.* **2014**, *69*, 112–121. [CrossRef]
125. Song, I.H.; Lhee, J.H.; Jeong, J.W. Energy efficiency and economic analysis of variable frequency drive and variable pitch system: A case study of axial fan in hospital. *J. Build. Eng.* **2021**, *43*, 103213. [CrossRef]
126. Zhang, J.; Cho, H.; Knizley, A. Evaluation of financial incentives for combined heat and power (CHP) systems in US regions. *Renew. Sustain. Energy Rev.* **2016**, *59*, 738–762. [CrossRef]
127. Zhang, J.; Cho, H.; Luck, R.; Mago, P.J. Integrated photovoltaic and battery energy storage (PV-BES) systems: An analysis of existing financial incentive policies in the US. *Appl. Energy* **2018**, *212*, 895–908. [CrossRef]
128. Principi, P.; Roberto, F.; Carbonari, A.; Lemma, M. Evaluation of energy conservation opportunities through Energy Performance Contracting: A case study in Italy. *Energy Build.* **2016**, *128*, 886–899. [CrossRef]
129. Rahman, N.A.; Zaki, N.M.; Husain, M.A. Implementation of Sustainable Energy Management Programme in Hospital Langkawi. *Int. J. Civ. Eng. Technol* **2019**, *10*, 1241–1253.
130. Balabel, A.; Alwetaishi, M. Toward Sustainable Healthcare Facilities: An Initiative for Development of "Mostadam-HCF" Rating System in Saudi Arabia. *Sustainability* **2021**, *13*, 6742. [CrossRef]
131. Orosz, M.; Altes-Buch, Q.; Mueller, A.; Lemort, V. Experimental validation of an electrical and thermal energy demand model for rapid assessment of rural health centers in sub-Saharan Africa. *Appl. Energy* **2018**, *218*, 382–390. [CrossRef]
132. Aziz, M.S.I.; Harun, H.; Ramli, A.S.I.; Azmi, A.M.; Dahlan, N.Y.; Zailani, R. Energy Efficiency Initiatives for A Hospital Building in Malaysia. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2021**, *88*, 145–155.
133. Fraile, J.C.; San-José, J.; González-Alonso, A. A boiler room in a 600-bed hospital complex: Study, analysis, and implementation of energy efficiency improvements. *Energies* **2014**, *7*, 3282–3303. [CrossRef]
134. Basken, B.; Galloni, P. Successful Low-cost Energy Management Implementation in Healthcare Facilities. *Energy Eng.* **2014**, *111*, 35–50. [CrossRef]
135. Burpee, H.; McDade, E. Comparative analysis of hospital energy use: Pacific Northwest and Scandinavia. *HERD: Health Environ. Res. Des. J.* **2014**, *8*, 20–44. [CrossRef] [PubMed]
136. Capozzoli, A.; Piscitelli, M.S.; Neri, F.; Grassi, D.; Serale, G. A novel methodology for energy performance benchmarking of buildings by means of Linear Mixed Effect Model: The case of space and DHW heating of out-patient Healthcare Centres. *Appl. Energy* **2016**, *171*, 592–607. [CrossRef]
137. Iadanza, E.; Turillazzi, B.; Terzaghi, F.; Marzi, L.; Giuntini, A.; Sebastian, R. The STREAMER European Project. Case study: Careggi hospital in florence. In Proceedings of the 6th European Conference of the International Federation for Medical and Biological Engineering, Dubrovnik, Croatia, 7–11 September 2014; Springer: Cham, Switzerland, 2015; pp. 649–652.
138. Čongradac, V.; Prebiračević, B.; Jorgovanović, N.; Stanišić, D. Assessing the energy consumption for heating and cooling in hospitals. *Energy Build.* **2012**, *48*, 146–154. [CrossRef]
139. Thongkaw, S.; Assawamartbunlue, K. Energy utilization index and benchmarking for a government hospital. *Agric. Nat. Resour.* **2012**, *46*, 298–304.
140. Zorita, A.L.; Fernández-Temprano, M.A.; García-Escudero, L.A.; Duque-Perez, O. A statistical modeling approach to detect anomalies in energetic efficiency of buildings. *Energy Build.* **2016**, *110*, 377–386. [CrossRef]
141. Teke, A.; Timur, O.; Bayındır, K.Ç. Development and testing of an energy saving tool–Suitability analysis with case study. *Int. J. Electr. Power Energy Syst.* **2016**, *77*, 59–69. [CrossRef]
142. Morgenstern, P.; Li, M.; Raslan, R.; Ruyssevelt, P.; Wright, A. Benchmarking acute hospitals: Composite electricity targets based on departmental consumption intensities? *Energy Build.* **2016**, *118*, 277–290. [CrossRef]
143. Christiansen, N.; Kaltschmitt, M.; Dzukowski, F. Electrical energy consumption and utilization time analysis of hospital departments and large scale medical equipment. *Energy Build.* **2016**, *131*, 172–183. [CrossRef]
144. Rajagopalan, P.; Elkadi, H. Energy performance of medium-sized healthcare buildings in Victoria, Australia-A case study. *J. Healthc. Eng.* **2014**, *5*, 247–260. [CrossRef] [PubMed]
145. Gordillo-Orquera, R.; Muñoz-Romero, S.; Arcos-Aviles, D.; Chillón, R.; Lopez-Ramos, L.M.; Marques, A.G.; Rojo-Álvarez, J.L. Convex programming and bootstrap sensitivity for optimized electricity bill in healthcare buildings under a time-of-use pricing scheme. *Energies* **2018**, *11*, 1454. [CrossRef]
146. Tulsyan, A.; Dhaka, S.; Mathur, J.; Yadav, J.V. Potential of energy savings through implementation of Energy Conservation Building Code in Jaipur city, India. *Energy Build.* **2013**, *58*, 123–130. [CrossRef]
147. Chung, M.; Park, H.C. Comparison of building energy demand for hotels, hospitals, and offices in Korea. *Energy* **2015**, *92*, 383–393. [CrossRef]
148. Prada, M.; Prada, I.F.; Cristea, M.; Popescu, D.E.; Bungău, C.; Aleya, L.; Bungău, C.C. New solutions to reduce greenhouse gas emissions through energy efficiency of buildings of special importance–Hospitals. *Sci. Total Environ.* **2020**, *718*, 137446. [CrossRef]
149. García-Sanz-Calcedo, J.; Gómez-Chaparro, M. Quantitative analysis of the impact of maintenance management on the energy consumption of a hospital in Extremadura (Spain). *Sustain. Cities Soc.* **2017**, *30*, 217–222. [CrossRef]

150. Ji, R.; Qu, S. Investigation and evaluation of energy consumption performance for hospital buildings in China. *Sustainability* **2019**, *11*, 1724. [CrossRef]
151. Cesari, S.; Valdiserri, P.; Coccagna, M. Mazzacane, Energy savings in hospital patient rooms: The role of windows size and glazing properties. *Energy Procedia* **2018**, *148*, 1151–1158. [CrossRef]
152. Dutta, A.; Samanta, A.; Neogi, S. Influence of orientation and the impact of external window shading on building thermal performance in tropical climate. *Energy Build.* **2017**, *139*, 680–689. [CrossRef]
153. Fernández, M.A.; Zorita, A.L.; García-Escudero, L.A.; Duque, O.; Moríñigo, D.; Riesco, M.; Muñoz, M. Cost optimization of electrical contracted capacity for large customers. *Int. J. Electr. Power Energy Syst.* **2013**, *46*, 123–131. [CrossRef]
154. Teke, A.H.M.E.T.; Zor, K.A.S.I.M.; Timur, O.Ğ.U.Z.H.A.N. A simple methodology for capacity sizing of cogeneration and trigeneration plants in hospitals: A case study for a university hospital. *J. Renew. Sustain. Energy* **2015**, *7*, 053102. [CrossRef]
155. Çakir, U.; Comakli, K.; Yüksel, F. The role of cogeneration systems in sustainability of energy. *Energy Convers. Manag.* **2012**, *63*, 196–202. [CrossRef]
156. Costa, A.; Fichera, A. A mixed-integer linear programming (MILP) model for the evaluation of CHP system in the context of hospital structures. *Appl. Therm. Eng.* **2014**, *71*, 921–929. [CrossRef]
157. Ahn, H.; Rim, D.; Freihaut, J.D. Performance assessment of hybrid chiller systems for combined cooling, heating and power production. *Appl. Energy* **2018**, *225*, 501–512. [CrossRef]
158. Pizzolato, A.; Donato, F.; Verda, V.; Santarelli, M.; Sciacovelli, A. CSP plants with thermocline thermal energy storage and integrated steam generator–Techno-economic modeling and design optimization. *Energy* **2017**, *139*, 231–246. [CrossRef]
159. Feng, L.; Jiang, X.Z.; Chen, J.; Ma, Y.; Shi, L. Time-based category of combined cooling, heating and power (CCHP) users and energy matching regimes. *Appl. Therm. Eng.* **2017**, *127*, 266–274. [CrossRef]
160. Wu, Q.; Ren, H.; Gao, W.; Ren, J. Multi-criteria assessment of combined cooling, heating and power systems located in different regions in Japan. *Appl. Therm. Eng.* **2014**, *73*, 660–670. [CrossRef]
161. Biglia, A.; Comba, L.; Fabrizio, E.; Gay, P.; Mannini, A.; Mussinatto, A.; Aimonino, D.R. Reversed Brayton cycle for food freezing at very low temperatures: Energy performance and optimisation. *Int. J. Refrig.* **2017**, *81*, 82–95. [CrossRef]
162. Pagliarini, G.; Corradi, C.; Rainieri, S. Hospital CHCP system optimization assisted by TRNSYS building energy simulation tool. *Appl. Therm. Eng.* **2012**, *44*, 150–158. [CrossRef]
163. Wu, Q.; Ren, H.; Gao, W.; Ren, J. Multi-objective optimization of a distributed energy network integrated with heating interchange. *Energy* **2016**, *109*, 353–364. [CrossRef]
164. Zheng, C.Y.; Wu, J.Y.; Zhai, X.Q.; Wang, R.Z. Impacts of feed-in tariff policies on design and performance of CCHP system in different climate zones. *Appl. Energy* **2016**, *175*, 168–179. [CrossRef]
165. Čongradac, V.; Prebiračević, B.; Petrovački, N. Methods for assessing energy savings in hospitals using various control techniques. *Energy Build.* **2014**, *69*, 85–92. [CrossRef]
166. Sánchez-Barroso, G.; González-Domínguez, J.; García-Sanz-Calcedo, J. Potential Savings in DHW Facilities through the Use of Solar Thermal Energy in the Hospitals of Extremadura (Spain). *Int. J. Environ. Res. Public Health* **2020**, *17*, 2658. [CrossRef] [PubMed]
167. Radwan, A.F.; Hanafy, A.A.; Elhelw, M.; El-Sayed, A.E.H.A. Retrofitting oexisting buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt. *Alex. Eng. J.* **2016**, *55*, 3061–3071. [CrossRef]
168. Kramer, L.; Rizzo, V. Development of a Comprehensive Energy Evaluation Program For a Medical Center in the Northeast: A Case Study. *Energy Eng.* **2015**, *112*, 57–79. [CrossRef]
169. Rohde, T.; Martinez, R. Equipment and energy usage in a large teaching hospital in Norway. *J. Healthc. Eng.* **2015**, *6*, 419–434. [CrossRef]
170. Marshall, B.; Rashid, F. The Ottawa Hospital Energy Management Program. *Energy Eng.* **2013**, *110*, 65–80. [CrossRef]
171. Do Espirito Santo, D.B. An energy and exergy analysis of a high-efficiency engine trigeneration system for a hospital: A case study methodology based on annual energy demand profiles. *Energy Build.* **2014**, *76*, 185–198. [CrossRef]
172. Romero, A.; Carvalho, M.; Millar, D.L. Application of a polygeneration optimization technique for a hospital in Northern Ontario. *Trans. Can. Soc. Mech. Eng.* **2014**, *38*, 45–62. [CrossRef]
173. Arabkoohsar, A.; Andresen, G.B. Supporting district heating and cooling networks with a bifunctional solar assisted absorption chiller. *Energy Convers. Manag.* **2017**, *148*, 184–196. [CrossRef]
174. Calise, F.; d'Accadia, M.D.; Libertini, L.; Quiriti, E.; Vicidomini, M. A novel tool for thermoeconomic analysis and optimization of trigeneration systems: A case study for a hospital building in Italy. *Energy* **2017**, *126*, 64–87. [CrossRef]
175. Morgenstern, P.; Raslan, R.; Huebner, G. Applicability, potential and limitations of staff-centred energy conservation initiatives in English hospitals. *Energy Effic.* **2016**, *9*, 27–48. [CrossRef]
176. Dos Santos, J.B.; Jabbour, C.J.C. Critical factors to be considered when planning the implementation of environmental improvements and energy saving. *J. Energy S. Afr.* **2013**, *24*, 22–29. [CrossRef]
177. Luo, S.; Li, H.; Mao, Y.; Yang, C. Experimental research on a novel sun shading & solar energy collecting coupling device for inpatient building in hot summer and cold winter climate zone in China. *Appl. Therm. Eng.* **2018**, *142*, 89–99.
178. Wang, T.; Li, X.; Liao, P.C.; Fang, D. Building energy efficiency for public hospitals and healthcare facilities in China: Barriers and drivers. *Energy* **2016**, *103*, 588–597. [CrossRef]

179. Bertone, E.; Sahin, O.; Stewart, R.A.; Zou, P.X.; Alam, M.; Hampson, K.; Blair, E. Role of financial mechanisms for accelerating the rate of water and energy efficiency retrofits in Australian public buildings: Hybrid Bayesian Network and System Dynamics modelling approach. *Appl. Energy* **2018**, *210*, 409–419. [CrossRef]
180. Ludin, N.A.; Junedi, M.M.; Affandi, N.A.A.; Ibrahim, M.A.; Sopian, K.; Teridi, M.A.M.; Haw, L.C. Energy efficiency action plan for a public hospital in Malaysia. *Alam Cipta* **2019**, *12*, 73–79.
181. Moghimi, S.; Azizpour, F.; Mat, S.; Lim, C.H.; Salleh, E.; Sopian, K. Building energy index and end-use energy analysis in large-scale hospitals—Case study in Malaysia. *Energy Effic.* **2014**, *7*, 243–256. [CrossRef]
182. Karakasli, E.; Oztop, H.F.; Hepbasli, A. Performance assessment of a polyclinic heating and cooling system in a hospital building. *Int. J. Exergy* **2016**, *21*, 70–86. [CrossRef]
183. Sawyer, L.; Kemp, S.; James, P.; Harper, M. Assessment of a Nurse Led Energy Behavior Change Intervention in an NHS Community Hospital Ward. *Energies* **2021**, *14*, 6523. [CrossRef]
184. Nourdine, B.; Saad, A. About energy efficiency in Moroccan health care buildings. *Mater. Today Proc.* **2021**, *39*, 1141–1147. [CrossRef]
185. Wu, R. The carbon footprint of the Chinese health-care system: An environmentally extended input–output and structural path analysis study. *Lancet Planet. Health* **2019**, *3*, 413–419. [CrossRef] [PubMed]
186. García-Sanz-Calcedo, J.; Al-Kassir, A.; Yusaf, T. Economic and environmental impact of energy saving in healthcare buildings. *Appl. Sci.* **2018**, *8*, 440. [CrossRef]
187. Chaichaloempreecha, A.; Winyuchakrit, P.; Limmeechokchai, B. Long-term energy savings and GHG mitigations in Thailand's building sector: Impacts of energy efficiency plan. *Energy Procedia* **2017**, *138*, 847–852. [CrossRef]
188. García-Sanz-Calcedo, J.; Gómez-Chaparro, M.; Sanchez-Barroso, G. Electrical and thermal energy in private hospitals: Consumption indicators focused on healthcare activity. *Sustain. Cities Soc.* **2019**, *47*, 101482. [CrossRef]
189. Ma, N.; Aviv, D.; Guo, H.; Braham, W.W. Measuring the right factors: A review of variables and models for thermal comfort and indoor air quality. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110436. [CrossRef]
190. Jain, N.; Burman, E.; Stamp, S.; Shrubsole, C.; Bunn, R.; Oberman, T.; Davies, M. Building performance evaluation of a new hospital building in the UK: Balancing indoor environmental quality and energy performance. *Atmosphere* **2021**, *12*, 115. [CrossRef]
191. Ahmed, T.M.; Rajagopalan, P.; Fuller, R. Experimental validation of an energy model of a day surgery/procedure centre in Victoria. *J. Build. Eng.* **2017**, *10*, 1–12. [CrossRef]
192. Bhatia, A.; Singh, H.R. Energy performance assessment of a multi super specialty hospital building in composite climate zone in India: A case study. *Mater. Today Proc.* **2021**, *47*, 3024–3028. [CrossRef]
193. Papantoniou, S.; Kolokotsa, D.; Kalaitzakis, K. Building optimization and control algorithms implemented in existing BEMS using a web based energy management and control system. *Energy Build.* **2015**, *98*, 45–55. [CrossRef]
194. Aziz, M.A.; Mat, S.; Wajid, N.; Sharif, M.K.A. Retrofit Design And Optimization Of PVT-ASHP Plant In Tropical Healthcare Facility. *Int. J. Environ. Sci.* **2021**, *6*, 465–476.
195. Vaziri, S.M.; Rezaee, B.; Monirian, M.A. Utilizing renewable energy sources efficiently in hospitals using demand dispatch. *Renew. Energy* **2020**, *151*, 551–562. [CrossRef]
196. Briller, D.L. Patients and Urgency: Strategies for Designing Sustainable and Energy-efficient Hospitals For the 21st Century. *Energy Eng.* **2014**, *111*, 22–80. [CrossRef]
197. Sadatsafavai, H.; Walewski, J.; Taborn, M. Comparison of a sample of green hospitals with non-green hospitals with respect to operating expenses and patient revenue. *J. Green Build.* **2014**, *9*, 163–188. [CrossRef]
198. Manika, D.; Gregory-Smith, D.; Wells, V.K.; Comerford, L.; Aldrich-Smith, L. Linking environmental sustainability and healthcare: The effects of an energy saving intervention in two hospitals. *Int. J. Bus. Sci. Appl. Manag.* **2017**, *11*, 32–55.
199. Safranek, S.; Wilkerson, A.; Irvin, L.; Casey, C. Using occupant interaction with advanced lighting systems to understand opportunities for energy optimization: Control data from a hospital NICU. *Energy Build.* **2021**, *251*, 111357. [CrossRef]
200. Cesari, S.; Valdiserri, P.; Coccagna, M.; Mazzacane, S. The energy saving potential of wide windows in hospital patient rooms, optimizing the type of glazing and lighting control strategy under different climatic conditions. *Energies* **2020**, *13*, 2116. [CrossRef]
201. Lan, L.; Tushar, W.; Otto, K.; Yuen, C.; Wood, K.L. Thermal comfort improvement of naturally ventilated patient wards in Singapore. *Energy Build.* **2017**, *154*, 499–512. [CrossRef]
202. Fabbri, K.; Gaspari, J.; Vandi, L. Indoor thermal comfort of pregnant women in hospital: A case study evidence. *Sustainability* **2019**, *11*, 6664. [CrossRef]
203. Carnero, M.C.; Gómez, A. Maintenance strategy selection in electric power distribution systems. *Energy* **2017**, *129*, 255–272. [CrossRef]
204. Squire, M.M.; Munsamy, M.; Lin, G.; Telukdarie, A.; Igusa, T. Modeling hospital energy and economic costs for COVID-19 infection control interventions. *Energy Build.* **2021**, *242*, 110948. [CrossRef] [PubMed]
205. Radulovic, D.; Skok, S.; Kirincic, V. Cogeneration–investment dilemma. *Energy* **2012**, *48*, 177–187. [CrossRef]
206. Koulamas, C.; Kalogeras, A.P.; Pacheco-Torres, R.; Casillas, J.; Ferrarini, L. Suitability analysis of modeling and assessment approaches in energy efficiency in buildings. *Energy Build.* **2018**, *158*, 1662–1682. [CrossRef]
207. Calama-González, C.M.; León-Rodríguez, Á.L.; Suárez, R. Daylighting and energy performance evaluation of an egg-crate device for hospital building retrofitting in a Mediterranean climate. *Sustainability* **2018**, *10*, 2714. [CrossRef]
208. Economidou, M. Energy performance requirements for buildings in Europe. *REHVA J* **2012**, *92*, 16–21.

209. Dascalaki, E.G.; Balaras, C.A.; Gaglia, A.G.; Droutsa, K.G.; Kontoyiannidis, S. Energy performance of buildings—EPBD in Greece. *Energy Policy* **2012**, *45*, 469–477. [CrossRef]
210. Bagade, S.D.; Rampure, P.B. Optimized Design of Diesel Generators Based Chilled Water Cooling System for Intelligent Hospitals and Hotels. *Int. J. Innov. Technol. Explor. Eng.* **2020**, *9*, 1649–1656. [CrossRef]
211. Machado, C.; Scavarda, A.; Zhao, F.; Kipper, L. A proposal of an energy saving technology framework for the hospital. *Chem. Eng. Trans.* **2015**, *45*, 241–246.
212. García-Sanz-Calcedo, J. Study of CO2 emissions from energy consumption in Spanish hospitals. *Vibroengineering Procedia* **2019**, *26*, 46–51. [CrossRef]
213. Thinate, N.; Wongsapai, W.; Damrongsak, D. Energy performance study in Thailand hospital building. *Energy Procedia* **2017**, *141*, 255–259. [CrossRef]
214. Papadopoulos, A.M. Energy efficiency in hospitals: Historical development, trends and perspectives. In *Energy Performance of Buildings*; Springer: Berlin/Heidelberg, Germany, 2016; pp. 217–233.
215. William, M.A.; El-Haridi, A.M.; Hanafy, A.A.; El-Sayed, A.E.H.A. Assessing the Energy Efficiency improvement for hospitals in Egypt using building simulation modeling. *Eng. Res. J.* **2019**, *42*, 21–34.