Evaluating the hospital's resilience by determining the resiliency score of its energy system via related criteria

SETARE PEIROW[1], **FATEMEH RAZI ASTARAEI**[1,*], **AMIR-ALI SAIFODDIN**[1], AND **HOSSEIN YOUSEFI**[1]

[1] *Department of Renewable Energies and Environment, Faculty of New Sciences and Technologies, University of Tehran, P. O. Box: 14399-56191, Tehran, Iran*
[*] *Corresponding author email: razias_m@ut.ac.ir*

Manuscript received 29 January, 2022; revised 20 May, 2022; accepted 06 June, 2022. Paper no. JEMT-2201-1368.

Hospitals are among large-scale buildings with complicated energy system. Due to the significance of the hospital's energy system in treating patients and general health, monitoring its resiliency is a crucial issue. Unfortunately, most of recent hospitals have been designed and developed, disregarding the importance of energy system's resiliency. In this study, the resiliency of a hospital's energy system has been investigated by quantifying the related criteria extracted from Hospitals' Standard books and determining the system's resiliency score. First, a hospital located in Tehran, Iran, has been selected as the case study, and its complicated energy system was modeled with Design-Builder software. Results of the simulation showed that the annual energy consumption of the current system was 3.08 GWh of electricity and 4.23 GWh of gas. Then, the energy system was separated into tiny wards, and the resiliency of each ward was measured using criteria linked to the resiliency of medical facilities by the scoring method. Calculating the weighted mean of the various wards yields the system's overall resiliency. The mean resiliency score of the case study was calculated to be 4.13 (range from 1 to 5), which is considered a good value. However, the hospital's power supply system which contributes the most to the total resiliency grade, owed the lowest score. Consequently, boosting the performance of this system may lead to a major influence on promoting the total energy system's resiliency.

keywords: *Hospital, energy system, design-builder, resiliency, scoring method, resilience criteria.*

http://dx.doi.org/10.22109/jemt.2022.326969.1368

NOMENCLATURE

Sets

i	Ward counter
j	Criteria counter
S_i	Resiliency score of i^{th} ward
S_{ij}	Resiliency score of i^{th} criteria in j^{th} ward
V_i	Weight percent of section i in the overall resiliency score
S_{ni}	Mean normal score of i^{th} unit.
S_{total}	overall resiliency of the energy system

1. INTRODUCTION

Hospitals are among buildings with high energy consumption, due to their vast size and use of diagnostic and therapeutic equipment [1], [2]. The majority of current hospitals were constructed with little regard for energy efficiency[3]. In fact, over the last few decades, hospitals have been designed and developed merely to fulfill the health standards, disregarding the role of the energy system's resiliency on the patient's health [4],[5]. This is due to low energy costs and a lack of political and social attention to the issue of economic and environmental sustainability of human activities. Because the hospital may be expanded and additional medical wards may be constructed, establishing a resilient energy system is critical when expanding and building new facilities.

One of the scientific methods that offer a particular explanation of the concept of sustainability is the theory of resiliency [6] which is the ability of a disrupted system to recover to its previous function [7]. Although the notion of resiliency was previously only employed in psychology and ecology, it has recently been used in other sectors, including energy [8].

Three distinct factors characterize system resiliency: 1) the shock magnitude that the system can endure while remaining in a specific posture. 2) The system's ability to self-organize to some extent. 3) The system's ability to develop adaptive capability[9]. A resilient energy system is durable, compatible, long-lasting, and robust [10]. On the other hand, a system is recognized as a resilient one, if all of its components are deemed to be part of the total system [8].

The following factors should be addressed when assessing an energy system's long-term resiliency [11]:

- Quality, robustness, sustainability, and durability of the system;
- Ease of adaptability and flexibility;
- Using current standards to reduce complexity and simplify design;
- Proper system insulation and appropriate control systems to minimize losses;
- Using long-lasting, durable raw resources;
- Preventing the use of chemicals, toxic and incendiary substances;
- Making safety forecasts.

Several types of research on the issue of energy in hospitals have been published [12]–[17]. Some of these studies that have been conducted to evaluate the long-term sustainability and resiliency of the hospital's energy system are listed below.

Balasubramaniam et al. conducted a research on energy system management to improve micro-grid resiliency when operating in an island state [18]. This research suggests using survivability to boost the flexibility of micro-grids. In this work, survivability refers to minimizing load loss for the duration of the microgrid's operation in an island state following an incident. Micro-grid loads are categorized as critical and non-critical during island operations. The crucial decision is whether non-critical loads are provided after critical loads are delivered or whether more energy is saved for later distribution. This study formulates the task as a nonlinear programming problem. The results are compared with an energy management system-based time analysis program. The theoretical formulation, which is based on numerical data, demonstrates the use of an expanded mathematical framework to boost micro-grid flexibility to minimize critical load loss and maximize the non-critical stored load.

Castro et al. evaluated the sustainability of buildings in the health sector [19]. This study aimed to examine sustainability assessment techniques in health care facilities and to offer to integrate the Sustainable Efficient Design (SED) criteria in the new method of building sustainability assessment. A group of stakeholders validated the relevance of each new suggested indicator using a questionnaire, and the findings were critically examined. After this step, the Analytic Hierarchy Process (AHP) was used to evaluate the questionnaire responses. Generally, the study's recommended strategy was based on fifty-two indicators of efficient sustainable design, containing requirements for designing a sustainable energy system. These indicators were classified into twenty-two categories, which were broken further into five regions.

In a review study, Pantzartzis et al.[20] looked at many elements of sustainability in healthcare equipment. The methodology utilized was as follows: 1. A comprehensive literature review of key aspects related to determining the optimal size and defining the constituents of a sustainable health facility; 2. A systematic evaluation of the sustainability of a case study involving small health care facilities in Italy using evaluation forms obtained from the literature review. The literature review in the article relates to a group of elements that go beyond the idea of efficiency and are connected to four aspects of the environment: environmental, technical, social, and economic issues. According to the article's conclusions, there is insufficient and inconsistent information to identify the long-term sustainability of medical facilities at their ideal scale, and the number of hospital beds is influenced by several factors. As a result, we may remark on the capacity of a medical center's beds by establishing 52 sustainability indicators in the sectors of environment, technological, social, and economical.

Ahmadi et al.[21] developed a hybrid long-term framework to assess the resilience of the energy system based on the concept of drought resilience. New flexibility indicators were proposed in the mentioned study to optimize societal welfare, limiting necessary energy supply, restoring system function quickly, and lowering the overall cost of the energy system following a drought. The suggested model consists of two optimization models based on linear programming and a scenario analysis model based on a mix of back-casting and future-forward techniques, the major goal of which was to quantify and optimize measures of sustainable development in post-drought communities by assessing the energy system's resiliency (as an essential critical infrastructure system). The findings of this study suggested that system resiliency is a useful and valuable issue in energy policy and long-term planning. So, if policymakers emphasize the system resiliency in addition to designing the system for minimum costs, the rate of disruption propagation and system performance reduction would be reduced.

Gargari et al. [22] proposed the preventive maintenance scheduling of multi-energy microgrids to improve system resiliency under uncertain settings. The General Algebraic Modeling System (GAMS) optimization tool was used to perform energy planning and maintenance calculations. An exact model of electricity and natural gas was used to verify the simulation findings. Three distinct examples were explored to demonstrate the effectiveness of the suggested method in a conventional multi-energy micro-grid. Accordingly, using multi-energy micro-grids offered a significant opportunity to increase the system's efficiency in cost, technology, and environmental impact.

The failure of prior studies to handle the hospital energy system as an integrated system is one of their key flaws, which is due to the complexity of modeling and the system's enormous scope. Modeling with Design-Builder software, on the other hand, provides a thorough examination of the hospital's energy system and recommendations for improvements as well. As described above, only a few studies on the subject of evaluating the resiliency of the hospital's energy system have been done recently.

In this research, first, a reference design technique was applied to assess the state of the building's current energy system. The total energy system, with all of its intricacies, is represented as an integrated system in Design-Builder software for this investigation. The software is used to model the building from multiple perspectives, including building physics (materials), building architecture, cooling and heating systems, lighting systems, and so on, and it can simulate all elements of the structure [23]. Then, using the related criteria, the resiliency of various wards of the energy system is assessed, and lastly, the overall resiliency score of the energy system is determined. Following an evaluation of the present system, recommendations will be made to improve the energy system's flexibility and resiliency.

2. METHODOLOGY

This section presents a simulation of hospital's energy system using detailed information of its complicated structures. Then resiliency criteria of different parts of hospital's energy system are introduced and each ward's share in calculating overall resiliency is identified. The resiliency of each ward can be measured using criteria linked to the resiliency of medical facilities

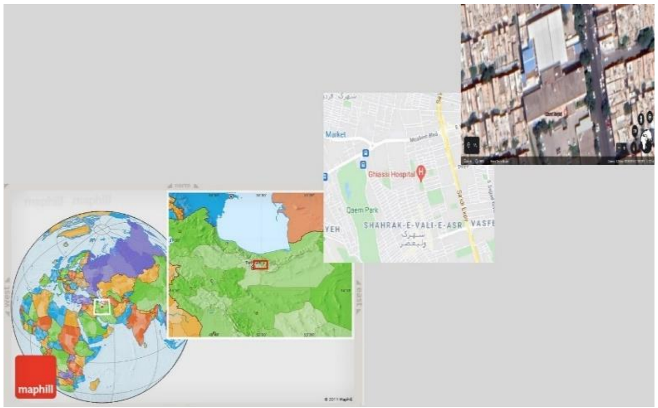


Fig. 1. The location of Ghiasi Hospital in Tehran, Iran.

by the scoring method. Finally, calculating the weighted mean of the various wards yields the system's overall resiliency.

A. Case study

Ghiasi specialized hospital, located in the south western part of Tehran province, Iran (35.69° N, 51.31° E), has been selected for this study (Figure 1). This hospital, with more than 250 beds, has a total area of 17300 square meters. Different diagnostic and therapeutic departments such as laboratories, CT scans, ophthalmology, emergency unit, pharmacy, etc., are located on the ground floor. In contrast, hospital wards, operation rooms, CCU, and ICU departments are located on the higher floors.

B. Hospital's Energy System

In this research, the hospital energy system has been modeled using Design-Builder software (version 6.1.0.006), convenient for modeling different aspects of the building. The software can utilize the climate data files of different cities to calculate the energy input, consumption, and losses for the region that building is located. The modeling engine of the software is Energy-Plus which has been developed by American Energy Department and is considered a highly accurate and capable simulator.

In the first step, the 3D model of the building was drawn in the Design-Builder software. The 3D plans have been generated using the model files, which are in the format of AutoCAD plans. The plan includes the building, its orientation, how doors and windows are built-in, and the different floors' unlike zones (Figure 2).

After drawing the building plan and specifying the activity template of each area, it is necessary to enter the information related to the energy system and building physical specifications in the software. Tables 1-3 include the main assumptions used for modeling in Design-Builder software. After entering the information into the software and running the simulation for one year, the output results are displayed. The acquired findings were tested using hospital energy bills that included exact model usage, and the validation of the obtained results was confirmed with an error of less than 10% [24].

C. Resiliency evaluation

To evaluate the energy system's resiliency, the system must break down into smaller wards. Each ward has a different impact on the system's overall resiliency. As a result, if the total resiliency score of the system is determined as 100, a percentage is assigned to each ward, indicating its importance in determining the overall resiliency of the system. Then, by use of Hospital Accreditation Standards [25], the resiliency criterion for each ward is detected. Finally, the system's total resiliency score could be attained. Table 3 shows how to rate each category. The following are the system's wards that are evaluated for resiliency:

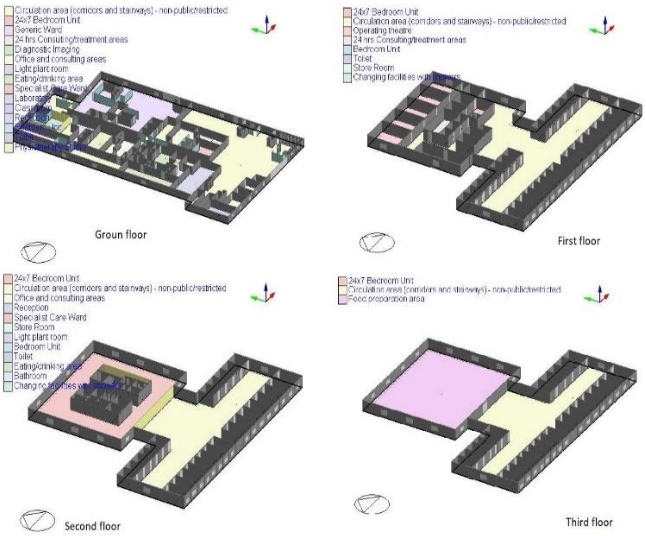


Fig. 2. Plan of hospital floors in Design-Builder.

- Power supply system;
- Lighting system;
- Heating and cooling system;
- Hot water supply system.

D. Weighting method

The weighting method for various parts of the energy system in calculating the model's overall resiliency is defined as follow. The hospital energy system is made up of several wards, each of which contributes differently to providing comfort to patients and personnel, as well as the total energy consumption of the system. As a result, the magnitude of each component's influence should be emphasized when analyzing the system's overall resiliency. Since the hospital power supply system has a direct influence on other aspects of the system, such as lights, electrical equipment, elevators, and the cooling system, this area contributes the most to the overall system's resiliency evaluation. The hospital lighting system, on the other hand, is extremely important and ranks second because it has a direct influence on the treatment staff's performance and patient care. The hospital's cooling and heating system is also crucial since it has a tangible impact on the patients' and employees' thermal comfort, having a coefficient equivalent to the hospital's lighting system. Finally, the third important ward is the hot water supply system.

Table 4 shows the contribution of each component of the energy system to the overall evaluation of resiliency. This table was created by combining expert opinions with a questionnaire and then averaging the findings. The specialists mentioned above include the authorities responsible for hospital safety, environmental health, accreditation, facilities, security and services, and hospital repairs. In order to compute the total resiliency score, the resiliency score of each segment must calculate individually

Table 1. Model specifications (Input data in Design-Builder).

Information	Input value in Design-Builder
Geographical location of hospital	Tehran-Mehrabad
Latitude and longitude	35.69° N , 51.31° E
Building plan	3D design is produced by calling the DXF file
Location of doors, windows, and building spaces	Based on the building plans
Building use	The use of each space is entered (such as laboratory, ward, clinic, and etc.)
Frequency of occupants' presence in each space	It is determined according to the use of each space
Comfort temperature in winter	22-25 °C
Comfort temperature in summer	25-28 °C
Type of HVAC system	Fan coil unit (4-pipe), Air cooled chiller
Hot water consumption	It is determined according to the use of each space
Energy consumption for computers, office supplies, and so on.	It is determined according to the use of each space and the time schedule
Energy required for cooking	The required energy and its source is determined for the food-cooking space (200W/m^2)
Building wall materials and their thickness	Brick walls of thickness 40 cm (based on the intended building features)
Building faćade	Cement faćade of thickness 5 Cm
Quality of sealing	Medium
Type of window	Transparent and double-glazed
Type of lamps	Low standard (15W/m^2)
Type of air-conditioning system	Fan coil unit (4 pipe)- Air cooled chiller
COP of cooling system	2
COP of heating system	0.85
Hot water supply system	Boiler with 85% efficiency
Energy source of cooling system	Electricity
Energy source of heating system	Natural gas
Energy source of hot water supply	Natural gas
Energy source for cooking	Natural gas

Table 2. Thermal properties of the walls.

Inner surface	unit	value
Convective heat transfer coefficient	W/m^2-K	2.152
Radiative heat transfer coefficient	W/m^2-K	5.54
Surface resistance	m^2-K/W	0.13
Outer surface	unit	value
Convective heat transfer coefficient	W/m^2-K	19.87
Radiative heat transfer coefficient	W/m^2-K	5.13
Surface resistance	m^2-K/W	0.04
No bridging	unit	value
U-Value surface to surface	W/m^2-K	0.231
R-Value	W/m^2-K	4.499
U-Value	m^2-K/W	0.222

Table 3. The resiliency criteria-related scores.

Score	1	2	3	4	5
Condition	very weak	weak	average	good	Very good

using the criteria listed above. The following formulation is implemented to compute the system's average resiliency score.

$$S_i = \frac{\sum_{j=1}^{n} S_{ij}}{n} \tag{1}$$

Table 4. The weight percent of different wards in calculating the overall resiliency score.

System	Lighting	Power supply	Heating and cooling	Hot water supply	Total system
Weighted percent	20	50	20	10	100

Where:

- i is the ward counter;
- j is the criteria counter;
- S_{ij} is the resiliency score of jth criteria in ith ward;
- S_i is the resiliency score of ith ward,
- v_i is the weight percent of section i in the overall resiliency score and;
- S_{total} is the overall resiliency of the energy system. Table 5 lists the counters for the various wards of the system.

Table 5. Related counter for different wards.

Related ward	i: each ward's counter
Lighting	1
Power supply	2
Heating and cooling	3
Hot water supply	4

3. RESULTS

A. Simulation with Design-Builder

The following are the results of modeling Ghiasi Hospital's energy system with Design-Builder software for one year. The yearly electricity usage is calculated as 3.08 GWh, and the annual gas consumption is calculated to be 4.23 GWh. So natural gas accounts for 58 percent of the yearly consumption basket, while electricity accounts for 42 percent. Figure 3 depicts the annual energy needed for cooling and heating, hot water consumption, lighting, facilities, and electrical appliances in the building. As displayed in the figure, heating accounts for the largest contribution (GWh 1.91), and electrical equipment accounts for the smallest contribution (GWh 0.86). As a result, the heating system bears the majority of the model's energy burden. The yearly cooling and heating demand of the building is depicted in Figure 4. The annual cooling and heating loads are 1.73 GWh and 1.62 GWh, respectively. The monthly curve of cooling and heating demands is also displayed in Figure 5. A positive sign denotes heat provided to the environment during the cold seasons, while a negative sign denotes heat withdrawn from the environment during the warm seasons. As shown, heating requires a maximum of 462 MWh per month, which occurred in January. The building's largest monthly energy demand for cooling is 456 MWh, which was utilized in July.

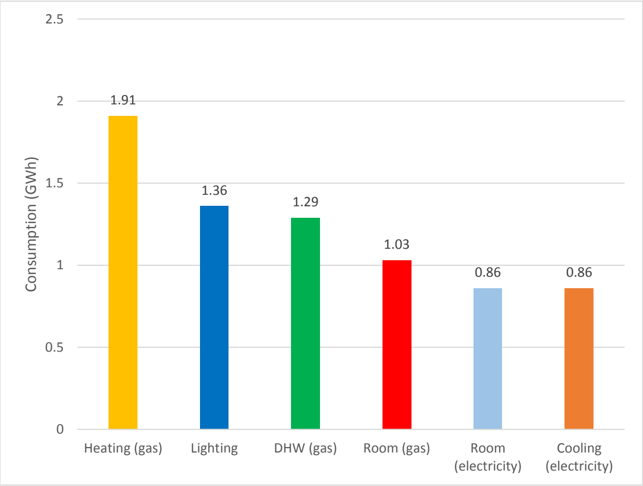


Fig. 3. The energy needed for different consumers per year [24].

B. Results of resiliency evaluation

B.1. The resiliency score of the lighting system

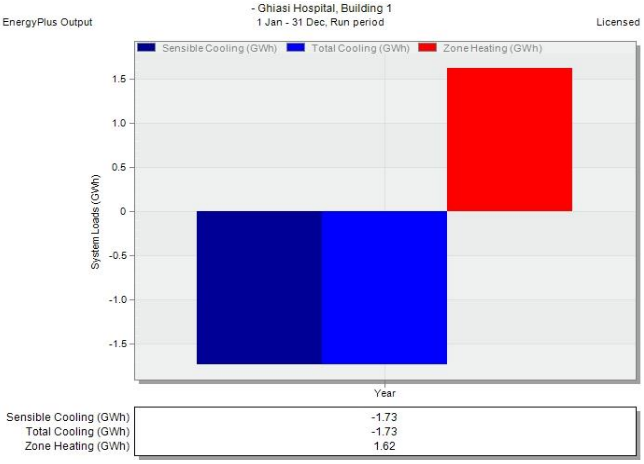
Table6 lists the criteria for the resiliency of the hospital's lighting system as well as ratings for each category. Calculating the mean resiliency score of the lighting section is as below. S1 denotes the mean resiliency score of the lighting unit and Sn1 denotes the mean normal score of this unit.

$$S_1 = \frac{(12 \times 5) + 3 + 1 + 4}{15} = 4.5$$

$$\mathrm{S}_{\mathrm{n1}} = \frac{13.8}{15} = 0.92$$

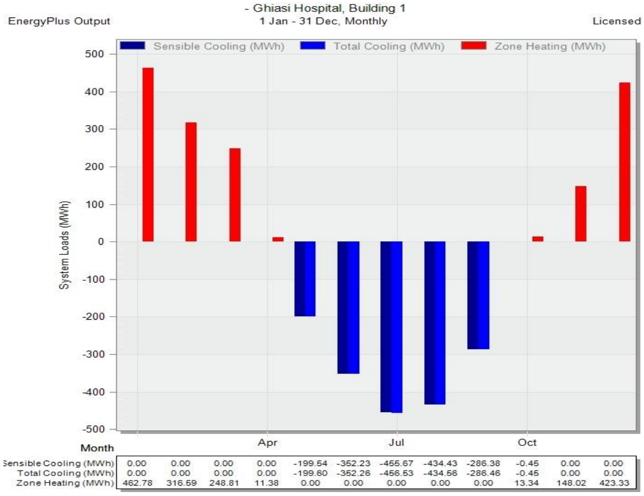
B.2. The resiliency score of the power supply system

The electrical equipment accessible in the hospital is separated into the following groups, as illustrated in Figure 6. This category is according to the practical relevance and the subsequent connection of the equipment's power supply. The hospital's power supply system, according to the previous explanations, is made up of three primary suppliers, including the public power supply, the emergency power supply, and the safe power supply system. The requirements for each supplier are listed in Tables



	Year
Sensible Cooling (GWh)	-1.73
Total Cooling (GWh)	-1.73
Zone Heating (GWh)	1.62

Fig. 4. The building's heating and cooling load per year.



Month			Apr			Jul			Oct		
Sensible Cooling (MWh)	0.00	0.00	0.00	0.00	-199.54	-352.23	-455.67	-434.43	-286.38	-0.45	0.00	0.00
Total Cooling (MWh)	0.00	0.00	0.00	0.00	-199.60	-352.26	-456.53	-434.56	-286.46	-0.45	0.00	0.00
Zone Heating (MWh)	462.78	316.59	248.81	11.38	0.00	0.00	0.00	0.00	0.00	13.34	148.02	423.33

Fig. 5. The bar chart of the rates of cooling and heating for different months of the year.

Table 6. The lighting system resiliency-related criteria and relevant scores.

Explaining the resiliency criteria	score	normalized
The size of the windows should be no more than 20% of the total area of the relevant wall.	5	1
Not glaring the ceiling and wall lighting for the patients	5	1
The artificial light should be a mixture of white and yellow	5	1
Preventing direct sunlight in the internal and general surgery wards	5	1
Possibility of lowering the space's light intensity throughout the day and night	5	1
Existence of a ceiling light cover	5	1
Controlling the light intensity for study, general lighting and examination in the patient's room	5	1
Using a globe or prismatic lamps in the examination and dirty lining ward	5	1
Using rain protection power socket in the toilets	3	0.6
Not using the glossy aluminum louvers for the lights in bedridden wards	5	1
Using safety electricity for the emergency exit and escape corridorsŐ lights with a two-hour support time	1	0.2
The lighting circuits wiring within the steel or PVS pipes with a minimum pipe diameter of 13.5 PG	5	1
Existing protection conductor for all lights	5	1
Using LED and SMD lamps in the lighting system	4	0.8
Summation	68	13.8

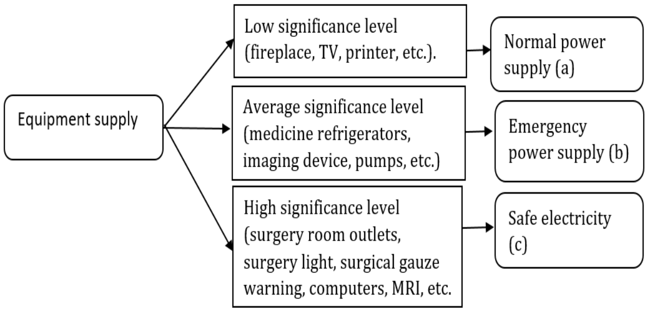


Fig. 6. Types of electrical power supply for hospital equipment.

7 to 9. S_{2c} denotes the mean resiliency score of the emergency power unit and S_{n2c} denotes the mean normal score of this unit.

$$S_{2c} = \frac{(5\times5)+4+1}{7} = 4.28$$

$$S_{n2c} = \frac{6}{7} = 0.85$$

Table 7. Related criteria and the relevant scores of normal power supply.

Explaining the resiliency criteria	score	Normalized
Using an electrical distribution system TN-S[1]	5	1
Using coupling to prevent electric shock	5	1
Built-in design of electrical outlets	4	0.8
Choosing an earth-equipped outlet	5	1
Using an IP standard of electrical outlets fitting to each space	5	1
Protecting outlets circuits using miniature outlets or branch circuit fuses	5	1
Using PVC insulation for rod wires	5	1
The wire's diameter in each section's circuits is based on the relevant standard	5	1
Using a radial system in building wiring	5	1
Summation	44	8.8

Table 8. Related criteria and the relevant scores of emergency power supply.

Explaining the resiliency criteria	score	Normalized
Installing a diesel generator with a minimum height of 160 mm on the foundation.	5	1
securing the generator motor to the foundation using a vibration isolator	3	0.6
Preventing the smoke returning from the diesel generators to the building	5	1
Using a double glaze sheath to pass the exhaust pipe	1	0.2
Using a weight valve at the end of the exhaust	1	0.2
Using a condensate water trap in the horizontal part of the exhaust	1	0.2
Using an automatic weight valve for the air inlet and outlet that open only when the generator is operating	1	0.2
The main fuel storage tank is placed horizontally	1	0.2
Placing the daily fuel tank beside each diesel	5	1
Saving fuel as the rate of system support during one weak	5	1
Summation	28	5.6

Table 9. Related criteria and the relevant scores of safe power supply.

Explaining the resiliency criteria	score	Normalized
Next to each piece of medical equipment or device, a secure power supply is provided.	4	0.8
Safe electricity-powered loads are fed into a separate electrical panel.	5	1
The time it takes for UPS to support is between 10 and 20 minutes.	5	1
A dynamic UPS is used if using a central UPS system	1	0.2
The official computers used in the entire hospital should be connected to the safe electricity	5	1
The safe electricity device is interrupted-based	5	1
Using the bypass switches in the hospitalsÕ UPS apparatuses is required	5	1
Summation	30	6

B.3. Total resiliency of power supply system

The weighted mean method is applied to calculate the average resiliency of the power supply system, because of the important difference between the three mentioned electricity suppliers. According to Figure 5, safe electricity owes the highest importance, emergency power supply has medium significance and normal electricity owes the lowest rank.

In hospitals, normal electricity is usually supplied by the grid, while diesel generators supply emergency power, and UPS batteries supply safe electricity. Emergency power systems are installed to protect life and property from the consequences of loss of primary electric power supply. It is a type of continual power system. This system kick in 10 seconds after an outage while safe power systems immediately transmit electricity. Emergency power systems are designed to be totally independent, which means they have their own conduits and panels.

Typically, equipment with no direct effect on patients' health, such as printers and televisions, is connected to normal power. Equipment that has moderate importance in patients' health such as medicine pumps and refrigerators, are connected to the emergency power system. Finally, equipment of high importance in patients' health, such as MRI, and surgery light, is connected to the safe power system.

Due to the difference in importance of mentioned power suppliers, the weighted average is used to calculate the overall resilience of the energy system. The weight assigned to each supplier is determined considering its importance and based on the opinion of experts. These experts include the authorities responsible for hospital safety, environmental health, accreditation, facilities, security and services, and hospital repairs.

According to experts, the weight of 0.5 for safe power, 0.3 for emergency power, and 0.2 for normal power are assigned in calculating the overall resiliency of the power supply system.

$$S_2 = 0.2 \times S_{2a} + 0.3 \times S_{2b} + 0.5 \times S_{2c}$$

$$S_{2n} = 0.2 \times .99 + 0.3 \times 0.56 + 0.5 \times 0.85 = 0.79$$

B.4. Hospital's thermal comfort resiliency

Table 10 lists the requirements for hospital thermal comfort system resiliency, as well as the scores for each category. S_3 denotes the mean resiliency score of the thermal comfort unit and S_{n3}

Table 10. The related criteria and the relevant score of the hospital's thermal comfort.

Explaining the resiliency criteria	score	Normalized
Instead of using a radiator, using a fan coil or an air conditioner to deliver heat	5	1
Using dust absorbing filter in fan coils	4	0.8
Using a four-pipe and two-coil fan coil	5	1
Not earthly installing the fan coil	5	1
Installing the fan coil inside the stepped ceiling	4	0.8
Disinfecting the fan coils regularly	4	0.8
Installing the access valve on the roof for the fan coil	5	1
Installing wall thermostat for fan coils	3	0.6
Double air handling unit	1	0.2
Existing an additional blower in the hospitalÕs technical-engineering warehouse	5	1
Dual air evacuation suction	1	0.2
Existing an additional suction in the hospitalÕs technical-engineering warehouse	5	1
Using air-conditioning filters in the air handling unit	5	1
Using horizontal distribution system for air distribution	5	1
Using a horizontal distribution system for piping	5	1
Installing soundproofing devices on air distribution ducts if needed	4	0.8
Insulating the internal surfaces of air ducts	3	0.6
Not using channels made of fiberglass material in the ventilation of the surgical ward	5	1
Not using materials whose fibers may enter the interior of the ward with air (such as asbestos) to seal the seam of the ducts	5	1
Summation	79	15.8

denotes the mean normal score of this unit.

$$S_3 = \frac{(5\times11)+(4\times4)+(3\times2)+1+1}{19} = \frac{79}{19} = 4.16$$

$$S_{n3} = \frac{15.8}{19} = 0.83$$

B.5. Resiliency of hot water supply system

Table 11 lists the criteria for the resiliency of the hospital's hot water delivery system, as well as the scores assigned to each criterion. The total resiliency score of the energy system is calculated as below.

Table 11. The related criteria and the relevant score of the hot water supply resiliency.

Explaining the resiliency criteria	Score	Normalized
Not using vertical pipes from the lower or upper floors	5	1
Insulating the hot water pipes	4	0.8
Not passing the horizontal pipes from the stepped ceiling	5	1
Installing stopcocks at the pipe inlet to each ward	4	0.8
Not passing the pipes through the patients' hospitalization space	5	1
Installing a perlator on water harvesting taps	1	0.2
Installing an extension connection to the pipes to use sanitary ware	5	1
Summation	29	5.8

Table 12. The mean and weight score of energy system components.

Type of system	Hot water	Heating and cooling	Lighting	Power supply
The system's weight percent in total resiliency score (Si)	10	20	20	50
Resiliency score (V_i)	4.14	4.16	4.53	3.95
Normal resiliency score (V_{ni})	0.83	0.83	0.92	0.79

$$S_{total} = \frac{S_1\times V_1+S_2\times V_2+S_3\times V_3+S_4\times V_4}{100} = \frac{3.95\times50+4.53\times20+4.16\times20+4.14\times10}{100} = 4.13$$

$$S_{normal-total} = \frac{0.79\times50+0.92\times20+0.83\times20+0.83\times10}{100} = 0.83$$

4. CONCLUSION

In this study, the resiliency of a hospital's energy system has been investigated by quantifying the related criteria extracted from the Hospitals' Standard books. For this purpose, the energy system was separated into tiny wards, and the resiliency of each ward was measured using criteria linked to the resiliency of medical facilities by the scoring method. Calculating the weighted mean of the various wards yields the overall resiliency of the system. It was found that the resiliency score of the lighting, cooling and heating, power supply, and hot water systems are 4.4, 4.16, 3.9, and 4.15, respectively. So, the total resiliency score of Ghiasi Hospital was calculated to be 4.13, which is an acceptable score based on the stated weight for each ward.

In other words, according to the normalized resiliency score, the hospital's energy system is 83% resilient. The findings reveal that the power supply system has the lowest score while it contributes the most to the total resiliency score of the system. Consequently, boosting the performance of this system leads to a major influence on promoting the energy system's resiliency.

The main weakness of the power supply system in the current model is non-compliance with the points related to the resilience of the emergency power system, which is supplied by diesel generators. Several actions need to be taken in order to improve the emergency power supply, such as securing the generator motor to the foundation with a vibration isolator or using a double glaze sheath to pass the exhaust pipe. Setting a weight valve at the end of the exhaust and placing a condensate water trap in the horizontal part is also suggested to promote the system's resilience. On the other hand, the installation of an automatic weight valve for the inlet and outlet air that opens only when the generator is operating can help to increase the system's immunes and resiliency.

Based on the results of this study, implementing the presented method in the article for evaluating hospital's resiliency is an appropriate choice which confirms the mission of hospitals. The attained results of this research can be simplified to the further health centers and hospitals in other places. Applying quantitative evaluation of resiliency to social areas such as hospitals might be an effective method for the regulatory organizations to assess the hospitals' status and identify their strengths and weaknesses. It can be determined from this investigation that numerous factors affect the resilient performance of the energy system. Accurate knowledge of the system requires its division into smaller subsets and evaluating the role of each subset in the overall resilience of the system.

Declaration of competing interest

The authors proclaim that they have no known conflicting financial interests or personal associations that could have appeared to affect the work stated in this paper.

Acknowledgement

The authors would like to acknowledge the Iran International Science Foundation (INFS, Project number: 98003237) for the financial support of this work.

REFERENCES

1. K. Bawaneh, F. G. Nezami, M. Rasheduzzaman, and B. Deken, "Energy consumption analysis and characterization of healthcare facilities in the United States," Energies, 2019, doi: 10.3390/en12193775.
2. M. H. Jahangir, S. A. Mousavi, and R. Asayesh Zarchi, Implementing single- and multi-year sensitivity analyses to propose several feasible solutions for meeting the electricity demand in large-scale tourism sectors applying renewable systems, no. January. Springer Netherlands, 2021.
3. S. Hamed, N. El-Bassiouny, and A. Ternès, "Evidence-Based Design and Transformative Service Research application for achieving sustainable healthcare services: A developing country perspective," J. Clean. Prod., vol. 140, pp. 1885–1892, 2017, doi: 10.1016/j.jclepro.2016.09.161.
4. A. Franco, M. Shaker, D. Kalubi, and S. Hostettler, "A review of sustainable energy access and technologies for healthcare facilities in the Global South," Sustain. Energy Technol. Assessments, vol. 22, 2017, doi: 10.1016/j.seta.2017.02.022.
5. J. García-Sanz-Calcedo, A. Al-Kassir, and T. Yusaf, "Economic and environmental impact of energy saving in healthcare buildings," Appl. Sci., vol. 8, no. 3, 2018, doi: 10.3390/app8030440.
6. R. Phillips, L. Troup, D. Fannon, and M. J. Eckelman, "Do resilient and sustainable design strategies conflict in commercial buildings? A critical analysis of existing resilient building frameworks and their sustainability implications," Energy Build., vol. 146, pp. 295–311, 2017, doi: 10.1016/j.enbuild.2017.04.009.
7. A. Baniassadi, J. Heusinger, and D. J. Sailor, "Energy efficiency vs resiliency to extreme heat and power outages: The role of evolving building energy codes," Build. Environ., vol. 139, no. December 2017, pp. 86–94, 2018, doi: 10.1016/j.buildenv.2018.05.024.
8. Z. I. Rauen, B. Kantarci, and H. T. Mouftah, "Resiliency versus energy sustainability in optical inter-datacenter networks," Opt. Switch. Netw., vol. 23, pp. 144–155, 2017, doi: 10.1016/j.osn.2016.06.003.
9. J. Zou, Q. Chang, X. Ou, J. Arinez, and G. Xiao, "Resilient adaptive control based on renewal particle swarm optimization to improve production system energy efficiency," J. Manuf. Syst., vol. 50, no. September 2018, pp. 135–145, 2019, doi: 10.1016/j.jmsy.2018.12.007.
10. P. P. J. Yang, "Energy Resilient Urban Form: A Design Perspective," Energy Procedia, vol. 75, pp. 2922–2927, 2015, doi: 10.1016/j.egypro.2015.07.592.

11. A. Baniassadi and D. J. Sailor, “Synergies and trade-offs between energy efficiency and resiliency to extreme heat – A case study,” Build. Environ., vol. 132, no. December 2017, pp. 263–272, 2018, doi: 10.1016/j.buildenv.2018.01.037.
12. S. Dursun, E. Aykut, and B. Dursun, “Assessment of Optimum Renewable Energy System for the Somalia–Turkish Training.pdf,” J. Renew. Energy Environ., vol. 8, no. 3, pp. 54–67, 2021, doi: https://doi.org/10.30501/jree.2021.245232.1140.
13. A. González González, J. García-Sanz-Calcedo, and D. R. Salgado, “A quantitative analysis of final energy consumption in hospitals in Spain,” Sustain. Cities Soc., vol. 36, pp. 169–175, 2018, doi: 10.1016/j.scs.2017.10.029.
14. A. Carbonari, R. Fioretti, M. Lemma, and P. Principi, “Managing energy retrofit of acute hospitals and community clinics through EPC contracting: The MARTE project.,” Energy Procedia, vol. 78, pp. 1033–1038, 2015, doi: 10.1016/j.egypro.2015.11.054.
15. C. Shen, K. Zhao, J. Ge, and Q. Zhou, “Analysis of building energy consumption in a hospital in the hot summer and cold winter area,” in Energy Procedia, 2019, doi: 10.1016/j.egypro.2019.01.883.
16. S. M. Vaziri, B. Rezaee, and M. A. Monirian, “Utilizing renewable energy sources efficiently in hospitals using demand dispatch,” Renew. Energy, vol. 151, pp. 551–562, 2020, doi: 10.1016/j.renene.2019.11.053.
17. P. Principi, F. Roberto, A. Carbonari, and M. Lemma, “Evaluation of energy conservation opportunities through Energy Performance Contracting: A case study in Italy,” Energy Build., vol. 128, 2016, doi: 10.1016/j.enbuild.2016.06.068.
18. K. Balasubramaniam, P. Saraf, R. Hadidi, and E. B. Makram, “Energy management system for enhanced resiliency of microgrids during islanded operation,” Electr. Power Syst. Res., vol. 137, pp. 133–141, 2016, doi: 10.1016/j.epsr.2016.04.006.
19. M. de F. Castro, R. Mateus, and L. Bragança, “Healthcare Building Sustainability Assessment tool - Sustainable Effective Design criteria in the Portuguese context,” Environ. Impact Assess. Rev., vol. 67, no. October 2016, pp. 49–60, 2017, doi: 10.1016/j.eiar.2017.08.005.
20. E. Pantzartzis, F. T. Edum-Fotwe, and A. D. F. Price, “Sustainable healthcare facilities: Reconciling bed capacity and local needs,” Int. J. Sustain. Built Environ., vol. 6, no. 1, pp. 54–68, 2017, doi: 10.1016/j.ijsbe.2017.01.003.
21. S. Ahmadi, Y. Saboohi, G. Tsatsaronis, and A. Vakili, “Energy system improvement planning under drought condition based on a two-stage optimization model: The desire for sustainability through the promoting of system’s resilience,” Energy Reports, vol. 7, pp. 3556–3569, 2021, doi: 10.1016/j.egyr.2021.06.010.
22. M. Z. Gargari, M. T. Hagh, and S. G. Zadeh, “Preventive maintenance scheduling of multi energy microgrid to enhance the resiliency of system,” Energy, vol. 221, p. 119782, 2021, doi: 10.1016/j.energy.2021.119782.
23. S. Peirow, F. Razi Astaraei, A. Saifoddin Asl, and H. Yousefi, “Optimal Design, Economic and Environmental Multi-Year Sensitivity Analysis of Hybrid Renewable Energy System for a Complex Load Demand: Hospital,” SSRN Electron. J., 2022, doi: 10.2139/ssrn.4024927.
24. S. Peirow, F. Razi Astaraei, A. Saifoddin Asl, and H. Yousefi, “Optimal Design, Economic and Environmental Multi-Year Sensitivity Analysis of Hybrid Renewable Energy System for a Complex Load Demand: Hospital,” SSRN Electron. J., 2022, doi: 10.2139/ssrn.4024927.
25. National Accreditation Board for Hospitals and Healthcare Providers (NABH), nabh.pdf, 4th edditi. ISQua Accreditation, 2015.