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Photovoltaic cells as a mechanism to enhance efficiency and balance energy in hospitals (Case Study: Hurghada General Hospital)

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ABSTRACT

The research expresses the developmental trend towards rationalizing and improving energy efficiency as one directions of Egypt's Vision 2030. The study specifically focuses on the energy efficiency and neutrality of hospitals, which are among the most important and energy-consuming sectors. This is achieved through an inductive study of the relationship between the guidelines for designing hospitals and green health facilities and the concept of energy-neutral hospitals, as one objectives of this guide, Which is characterized by the balance between produced and consumed energy using solar cells (photovoltaic), which are considered the primary technology for generating renewable energy in buildings. This is followed by a study of models of local hospitals that consider energy conservation and the analysis of energy efficiency and conservation strategies, as well as solar energy systems, and their application to a local hospital using a simulation program to identify the main opportunities and challenges facing the establishment of energy-neutral hospitals, especially in Egypt. The research concluded that solar cells can achieve energy efficiency in hospitals, and their efficiency increases by producing energy when installed at a 20-degree tilt on a horizontal surface. Energy production doubles when they are installed on horizontal surfaces at an appropriate tilt angle and southern facades. Thus, solar cells are considered one of the essential means to achieve an energy-neutral hospital according to sustainable future visions.

1. Introduction

Egypt's future vision is moving towards adopting renewable energy solutions. The construction industry and its role in promoting sustainable development is one of the strategic goals of sustainable development in Egypt. Energy-neutral buildings consider the requirements of sustainable development, making them more sustainable by implementing programs and mechanisms that contribute to rationalizing and enhancing energy consumption efficiency. Photovoltaic cells are among the most important tools for harnessing technological capabilities to apply and produce energy from renewable energy sources, which have seen tremendous developments in recent years, making them

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more efficient. Hospitals play a leading role in adopting these technologies due to their contribution to reducing carbon emissions and environmental pollution. In this context, photovoltaic cells emerge as a sustainable solution to meet the energy needs of hospitals, reducing their reliance on traditional energy sources, where hospitals are the fourth largest consumers of energy in the category of public buildings. Energy consumption items in hospitals include heating and cooling systems, which represent the largest portion of energy consumption in hospitals to maintain temperature and humidity in operating rooms, intensive care units, and patient rooms. Following these in consumption are ventilation systems, especially in areas that require central air conditioning, in addition to lighting systems, which need continuous lighting, especially in corridors. This is alongside electrical elements and medical equipment, which also consume large amounts of energy.[1] Previous literature that dealt with the same field of study has focused on the importance of sustainable design through the use of environmentally friendly building materials, building orientation, and the application of thermal insulation techniques , such as:

- Emerging Trends in Green Healthcare Building Design of Saudi Arabia: A Sustainable Approach - Safeer Ahmad -this study shows how important architectural features are in enhancing the use of water, air, light, and some new approaches that reduce the negative impact, such as solar energy, proper waste management, and telemedicine. A SWOT analysis determines the strength of the availability of government support, whereas financial and civic awareness is a threat. It is noted that green health system practices in Saudi Arabia are on an upward trajectory.
- Strategic frameworks for sustainability and corporate governance in healthcare facilities; approaches to energy-efficient hospital management: The research developed three integrated conceptual strategic frameworks for managing hospitals and healthcare facilities towards energy efficiency, green hospital initiatives, and corporate governance. The research also outlined the concepts of green hospitals and energy efficiency management systems and best practices based on the conclusions drawn from the investigated case studies.
- Hospitals' Energy Efficiency in the Perspective of Saving Resources and Providing Quality Services through Technological Options - A Systematic Literature Review: 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 solar power systems optimizing.

Based on the above, there are many challenges to energy generation, and the feasibility of applying photovoltaic cells in buildings as a minimum requirement to achieve energy-neutral buildings has not been clarified, especially at the local level in Egypt, despite the high solar radiation it enjoys. Therefore, this study addresses the possibility of using photovoltaic cells as an effective tool to balance the increasing energy needs of hospitals with environmental responsibility, evaluating their benefits, identifying the challenges they may face, and the opportunities associated with applying photovoltaic cells in hospitals, to maximize energy efficiency as one directions of Egypt's Vision 2030.

1.1. Problem of the Study:

The effectiveness of using photovoltaic cells as one of the sustainable technological techniques to achieve a balance between energy generation and consumption in hospitals by integrating solar cells into the building envelope elements of the hospital, with a focus on analyzing the opportunities and challenges to enhance energy efficiency in local hospitals.

1.2. Aims of the Study

The research aims to clarify the outcomes of using photovoltaic cells to rationalize energy consumption and its impact on one of the local hospital models (case study: Hurghada General Hospital) using a measurement and simulation program, Design Builder.

1.3. Methodology

The research relies on the inductive-analytical approach to study the impact of environmental strategies represented by photovoltaic cells to achieve energy-neutral hospitals. This is done by examining the concept and standards of energy-neutral buildings and hospitals, the most important local systems for evaluating green hospitals, and energy reduction strategies in hospitals. It also involves studying solar energy systems and the extent of applying the energy-neutral hospital approach in Egypt. (Figure 1)

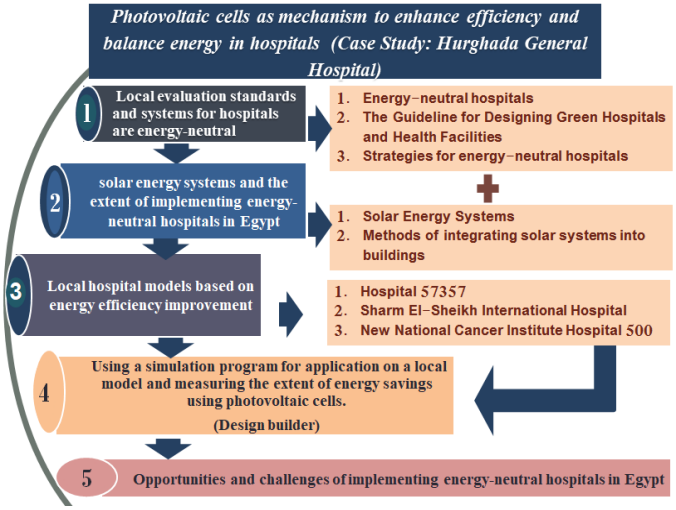


Figure 1: Methodology

2. Local evaluation standards and systems for hospitals are energy-neutral.

2.1. Energy-neutral hospitals

It is one types of healthcare facilities that represent an energy-efficient building, producing all the energy it consumes over the year by integrating renewable energy sources with the building and site. Energy-neutral hospitals refer to the use of operational energy only in the buildings and do not include the building's embodied energy.

The "Energy Efficiency Code" is considered a reference for designing net-zero buildings, as it provides the minimum requirements for architectural design, electrical and mechanical systems to reduce energy consumption and improve thermal performance. The three-step strategy for net-zero energy buildings begins with reducing energy consumption, then reusing energy, and finally compensating for the consumed energy through renewable energy sources to achieve a balance in energy consumption for the net-zero energy building. This type is concerned with balancing the energy consumed during the building's operational phase, and the focus in the design and operation of the building is on methods to reduce energy consumption [2] (Figure 2).

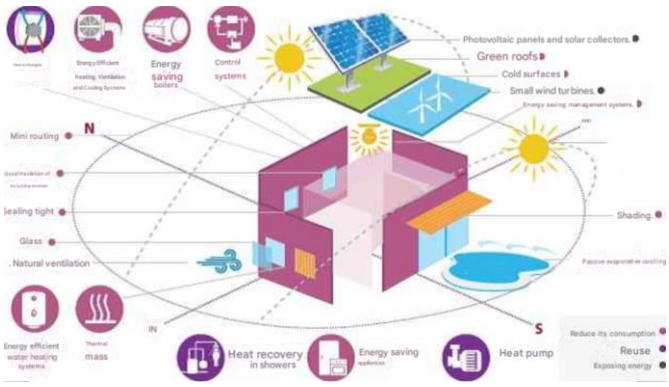


Figure 2: Measures to reduce, reuse, and offset energy consumption to achieve a net-zero energy building. [3]

Hospitals are the largest and most costly operational units within healthcare systems, consuming anywhere from 50 to 80% of the resources in these systems. The demand for integrated patient care and demographic and epidemiological changes has led to an increase in healthcare expenditures. [4] Green-built hospitals can achieve a significant reduction in their carbon footprint through the use of existing energy-efficient technologies and renewable energy sources appropriate to the region. Climate change is a major concern for most hospitals. Hospitals could also include solar panels, wind turbines, or even geothermal systems to change their efficiency along with energy-conserving HVAC systems and better insulation. Partial cost savings achieved by these programs in operating expenses and reducing GHG emissions tend to assist in achieving the financial viability of the hospitals. [5]

2.2. The Guideline for Designing Green Hospitals and Health Facilities

The Green Hospital and Health Facility Design Guidelines issued by the National Housing and Building Research Center in Egypt in 2019, which consider the design phase for new hospitals, include 7 main items (sustainable site, energy efficiency, water efficiency, materials and resources, indoor environmental quality and creating a healing environment, management and operation, renewal, innovation, and creativity). The energy efficiency item aims to improve energy consumption efficiency in the mechanical and electrical systems applied in the accredited hospital and ensure that these systems are suitable for their intended requirements (Table 1). It includes the highest evaluation score of 35 points out of a total of 156 evaluation points and contains 3 mandatory conditions and 10 basic requirements. The mandatory conditions include:

- Achieving the minimum for rationalizing energy consumption.
- Documentation of energy recording and monitoring.
- Limiting the negative effects on the ozone layer. [6]

The guideline for one criterion for accrediting a healthcare facility as a sustainable green facility includes that the healthcare facility should adopt solutions for transitioning to clean and renewable energy. The key terms (transition to clean and renewable energy) aim to improve energy consumption efficiency in healthcare facilities. Transitioning to clean and renewable energy sources such as solar energy, wind energy, biogas, and green hydrogen can

significantly reduce greenhouse gas emissions and protect public health from the numerous effects of climate change. The shift from fossil fuels to clean and renewable energy brings with it much health, environmental, and economic benefits. [7]

Table 1
Mandatory conditions and basic requirements for energy consumption efficiency [8]

	No	Item	Points
Mandatory conditions	1	Achieving the minimum for energy consumption rationalization	Mandatory condition
	2	Documentation, recording, and monitoring of energy	Mandatory condition
	3	Reducing the negative effects on the ozone layer	Mandatory condition
basic requirements	1	Rationalizing energy efficiency	4
	2	Strategies for processing the outer shell	3
	3	Energy efficiency of equipment and devices	3
	4	Vertical transportation means within the building	3
	5	Limiting the occurrence of energy peak periods	3
	6	Using new and renewable energy systems	4
	7	Internationally permissible negative effects	3
	8	The simplicity of the design and the ease of operation and maintenance.	4
	9	The optimal preference between energy efficiency and indoor climate quality	4
	10	Primary energy and carbon emissions for the construction and operation of the hospital	4
		total	35 Points

2.3. Strategies for energy-neutral hospitals

Achieving building balance aims to start from the design phase or at any stage before occupancy by implementing the three-step strategy in net-zero energy buildings. This involves reducing energy consumption, then reusing energy, and finally compensating for the consumed energy through renewable energy sources. Computer simulation programs or energy modeling tools are used to predict the amount of energy consumption in the building. [9]

1. Energy reduction strategies

- **Site selection**: The site is carefully chosen to reduce the cost of transporting materials and physical energy during the construction and operation process, ensuring it is close to public transportation networks and near energy distribution networks, including renewable energy sources. [10]

- **Building Envelope**: Roofs and walls with low thermal transmittance, low thermal permeability (U-value), and high thermal resistance (R-value) should be used. Better thermal insulation values can be achieved either by selecting materials with low conductivity or by increasing the thickness of the wall and roof. [11] And one of the most important factors in the design of the building envelope is :

- Properly sealing the building and avoiding cracks around openings and at the intersections between panels, walls, and joints in the building envelope. [12]
- Insulating the building with exterior cladding materials and junctions, the building is insulated as a barrier to thermal flow. [13]
- Insulation using double or triple glazing, considering the solar heat gain coefficient and the visible light transmittance, and using window and door frames made of materials with a low U-value to reduce heat loss. [14]
- Using light colors for paints and reflective materials on building facades and using thermal paint. [15]

- **Building orientation:**

• Choosing the orientation of the part responsible for energy production in the building towards the sun, considering the northern orientation for the largest percentage of external facade surfaces, reducing the area of southern facades, and typically using sunshades to mitigate direct sunlight.
• Construct buildings with rectangular shapes and allow sunlight to heat the building's roof when heating is needed, and reduce the number of windows on the eastern and western sides to minimize the need for cooling and heating. Photovoltaic panels are placed on the main facades facing south, and surrounding elements are orientated for shading.

- **Shading:** For external pathways, pedestrian areas, and building shading, it is preferable to use movable vertical or horizontal shading devices, which can be removed during the cold seasons to allow sunlight to enter the building.

- **Ventilation and natural lighting :**

- Outside air crosses between the gaps, allowing air movement from one side to the other due to the difference in air pressure. The more natural light that enters the building; the less artificial lighting is used, which reduces electricity consumption. This can be achieved by choosing glass with high visible transmittance values while considering shading elements in tropical climates.[16]

- Using a skylight system equipped with solar optical devices on the building's roof to control direct solar heat absorption and daylight illumination factor, and utilizing skylights while reducing the use of side windows to ensure light distribution.

- Prismatic shapes are installed on skylights equipped with solar optical devices to reflect sunlight, convert it into fine light rays, and distribute natural light so that the building is free from glare and reduces the use of air conditioning units.
- Confirm the presence of landscapes with comprehensive photovoltaic tools in the southern lighting areas to reduce glare, minimize solar heat gain, and increase natural lighting.

• **The thermal mass** should have a low solar heat absorption coefficient, and the use of insulating materials such as reflective materials to reduce thermal bridges, in addition to air gaps, is one of the insulation methods.

• **The use of green roofs** through plant covers and green surfaces to reduce the heat transmitted or absorbed by the building.

• **Cooling and heating** using solar energy is a renewable energy technology where the electric water heater operates automatically, and the higher efficiency types should be chosen for the neutral building. [17]

• **Control systems and energy-efficient devices**, such as thermostats and central control systems to maintain a constant cooling temperature, which increases energy savings. Additionally, setting times to turn the system on and off. Smart devices and systems, along with motion sensors related to lighting, heating, and cooling that are highly energy-efficient, are used, and tools are installed to measure the energy level in the building to assist in reviewing the control of temperature, humidity, and lighting systems through the building management system. [18]

2. Energy reuse strategies

• There are strategies and techniques for reusing energy in various energy applications by utilizing the residual energy from heating or cooling processes to reduce the required energy. According to the Green Hospitals Guide, transitioning to clean and renewable energy sources such as solar energy, wind energy, biogas, and green hydrogen can significantly reduce greenhouse gas emissions. Additionally, it can rationalize energy use and save the facility at least 5% of its total annual consumption by using alternative and renewable energy sources, connecting the facility to different energy sources to regulate the use of available energy sources and increase consumption efficiency. [19] Such as using solar panels connected to the electricity and water grid to reduce the energy required to heat or cool air or water again. [20]

3. Energy compensation

• The third step, after implementing energy reduction and reuse measures, is to compensate for the remaining consumption to achieve a balanced state for the energy-neutral building. This is done through various energy-generating technologies, such as solar panels to generate electricity from renewable energy and smart sensors and autonomous control systems to automatically adjust temperature and lighting according to actual needs. Solar collectors for heating are also combined with regular updates and maintenance of these systems.

3. Solar energy systems and the extent of implementing energy-neutral hospitals in Egypt

3.1. Solar Energy Systems

There are three major ways to convert solar energy into usable and controllable energy for humans: photovoltaic solar energy, thermal solar energy, and photovoltaic energy.

1. Photovoltaic solar energy: Sunlight is used in the building instead of using electrical energy for lighting. It can be utilized through openings and windows or by collecting sunlight in optical fibers that are passed through the ceilings of buildings, allowing daylight to travel through them.
2. Thermal solar energy: The idea of converting solar energy into thermal energy relies on using a means to absorb solar radiation, and this means solar collectors. There are many types of solar collectors that differ in their composition and the way they are used in building design so that they fit the design and become part of it.
3. Photovoltaic Energy: It consists of thin cells and wafers of purified silicon to which small amounts of other materials are added (Figure 3). When sunlight falls on the wafers, electrons produce small amounts of electricity. Therefore, many cells are assembled to generate usable amounts of electrical energy... Photovoltaic cells are used in all building elements (roofs (Figure 4), courtyards, facades, and walls; integration of photovoltaic cells with shading devices [21] (Figure 5).

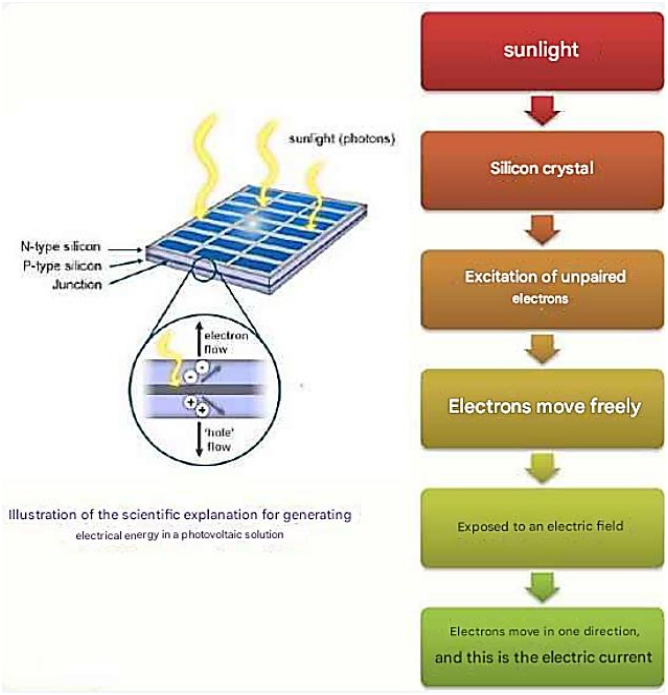


Figure 3: Illustrative diagram of the method used for generating electrical energy using photovoltaic cells. - [22]

Figure 4: Applications of photovoltaic systems (stations installed on building rooftops) - [23]

Figure 5: Applications of photovoltaic systems for covering parking–[24]

3.2. Methods of integrating solar systems into buildings

The systems are installed on the rooftops of buildings according to the available space, which provides flexibility in orientation. There are several methods for integrating them with horizontal surfaces, [25] including: (Figure 6)

1. Inclined solar units designed for horizontal surfaces: They are inclined panels at a fixed angle that are mounted on supporting structures, which in turn are fixed on the surfaces.[26]

Figure 6:Installation of solar cells on horizontal and inclined surfaces [27]

2. Horizontal solar units: They help increase the thermal insulation of the building due to the insulating material they contain, and this type is used in the rehabilitation of old roofs because it does not require complex mechanical installation methods. [28] Solar units used as natural overhead lighting: They are used to covering large spaces with horizontal or sloped surfaces. When using sloped surfaces, solar panels are placed in the direction that receives the maximum amount of solar energy, which is often the southern direction, while the northern side is opened to receive natural light. Therefore, the larger sloped roofs are directed towards the south, and the smaller sloped roofs are directed towards the north. When using horizontal surfaces, transparent or semi-transparent solar panels are used to allow daylight to enter. In this case, the effect of this type appears in the interior design, especially in central courtyards and the main hall when using double-layered glass in their composition. (Figure 7)

Figure 7: Installation of solar cells with top lighting - [29]

3. Solar units designed for rooftop gardens: These are units with fixed inclined structures that are rust-resistant. The structure is designed to rise 40 cm above the ground, and a metal plate is placed under a light layer of soil to secure the solar panel structures. Thus, only the supporting structure with the solar unit is visible above the ground surface.

4. Solar units designed for folded surfaces using thin-film solar technology and curved surfaces come in two types: (Thin-film solar unit applications : its flexibility and

floatability, which can replace traditional exterior finishing materials characterizes this type of solar unit. It is lightweight, has good waterproof insulation, and is also applicable on inclined and horizontal surfaces. It is available in the form of units with specific dimensions or as rolled coils that can reach a width of 1.5m and a length of 0.12m. It is dark blue , and some types have the feature of slightly reflecting the colors of the solar spectrum when direct sunlight falls on Curved surfaces : Curved surfaces can be designed using traditional solar units arranged in a curved manner. [30] (Figure 8)

Figure 8: Installation of solar cells on curved roofs-[31]

5. Installation of solar cell systems in facades: Building facades consist of walls, doors, windows, canopies, and more. Solar cell technologies have provided many options for the types of surfaces that can be used for such purposes. One way to integrate solar units with facades is:

- Curtain walls: These are facades integrated with solar units and are usually exposed to ventilation. They are suitable for design solutions that integrate with solar units, such as using glazed solar units, and bonding materials are used between the gaps to close the voids. [32]

- Vertical walls with external cladding: solar panels cover the entire facade of the building or part of it, and sometimes they serve as a second layer over an inner first layer that contains insulating materials. Water-resistant materials are used to prevent condensation. (Figure 9)

Figure 9: Installation of solar cells on curtain walls-[33]

- Facades with sloped walls: The sloped wall can either be an added curtain wall or the building's wall can be sloped, with the solar units attached as an external cladding. (Figure 10)

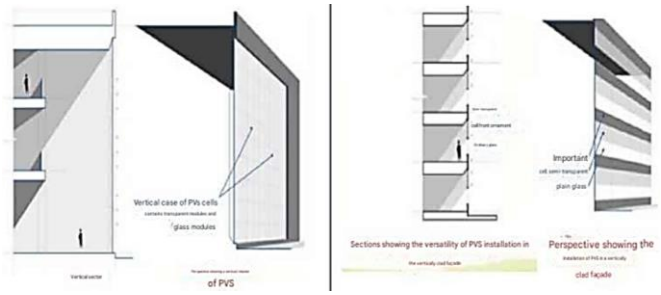


Figure 10: Solar cell units- [34]

- Curved walls: Solar panels can be used to create facades with curved shapes. [35]

4. Local hospital models based on energy efficiency improvement

Models of local hospitals that rely on improving energy efficiency: Green and energy-neutral hospitals are the future of healthcare. They provide environmental, economic, and health benefits by adopting a range of practices, and a selection of hospitals renowned for their environmental success and certified both internationally and locally as green hospitals rely on improving energy efficiency, reducing consumption, utilizing solar energy, and implementing diverse ecosystems.

4.1. Hospital 57357

The hospital has installed a solar power station, which helps reduce electricity consumption and lower carbon dioxide emissions, in line with Egypt's 2030 plan. The 57357 garage is powered by solar energy and serves the hospital's electric vehicles that transport its supplies. It also offers electric car charging services for a fee, which generates revenue for the hospital. [36] (Figure 11)

Figure 11: Solar panels at 57357 Hospital-[37]

4.2. Sharm el-Sheikh International Hospital

The hospital has been equipped with a water desalination and purification station to collect wasted water and use it for irrigating the green areas within the hospital. Solar panels are used to generate clean and renewable energy. There is a mechanism to control all external lighting units, and 100% of fluorescent lamps have been replaced with LED lamps to save energy. Additionally, there is an electric car charging

station, and modern energy-saving technologies are used in transportation within the hospital, along with a designated bicycle parking area, reducing carbon emissions. [38] (Figure 12)

Figure 12: Solar panels at Sharm El Sheikh International Hospital- [39]

4.3. The new 500 500 National Cancer Institute Hospital

A green hospital, where the design of the 500 500 hospital adopts green healthcare concepts, helping to achieve many accomplishments, including reducing water and energy consumption, achieving savings, and increasing efficiency, in addition to documenting the use of new and renewable energy generation systems, minimizing the negative interactions between the site and the surrounding environment, maintaining environmental balance, creating a suitable healing environment, and improving indoor air quality to enhance public health and the safety of patients and staff. [40] (Figure 13)

Figure 13: New National Cancer Institute Hospital 500-500- [41]

5. Using a simulation program for application on a local model and measuring the extent of energy savings using photovoltaic cells.

A building can be constructed entirely and integrated with building elements (photovoltaic windows) to estimate and evaluate the energy efficiency of the building. The design or renovation of the hospital building is an important factor for evaluation and the necessity of applying the Green Hospital Guide to identify the best energy consumption in existing hospital buildings, relying on one of the most important environmental elements (solar cells). The main objective of the simulation is to evaluate the thermal performance of the hospital building and to confirm the impact of photovoltaic cells on thermal comfort and energy consumption through the analysis of orientation and the distribution of solar cells on the building's exterior. These dimensions were chosen due to their importance and impact on energy consumption. The Design Builder software was used to create a simulation model for one of the local public hospitals to measure energy consumption and energy production using a fixed type of photovoltaic cells and a fixed tilt angle, applying them in different locations on the hospital's exterior and comparing the energy production results in different usage alternatives (horizontal, vertical, and inclined).

5.1. Design Builder v.7.0.2.006 program

The Design Builder program was used to measure energy consumption efficiency in the hospital using photovoltaic cells. Building inputs were included for the case study, which can be used to create a simulation in the program and measure through it. The program was chosen based on many features that help evaluate the environmental performance of buildings, as it provides an accurate three-dimensional model of the building, simulates the behavior, and analyses the performance of the existing building. The program supports sustainability standards and is certified by global green assessment systems, such as LEED and BREEAM. It also supports sustainable building technologies, such as the use of renewable energy, photovoltaic cells, heating and cooling systems, and insulating materials. In addition to the ease of use of the program and its integration with other design software such as Revit and AutoCAD, which facilitates data exchange, it features a drawing screen that allows the building to be input as a virtual reality, and the climatic data for Egyptian cities is available in the program's database.

5.2. Description and reasons for choosing to build - Integrated Photovoltaics (BIPV) in construction

They are photovoltaic materials used to replace traditional building materials in some parts of the building's exterior, such as the roof, skylights, or facades. They are increasingly being incorporated into the construction of new buildings as the primary or supplementary source of electricity generation [42], and the optimal orientation of the solar cells is determined to calculate the required area of the solar cells. The trend towards using Building-Integrated Photovoltaics (BIPV) and integrating them with buildings as a source of renewable energy began, initially placing them on rooftops. They then became capable of being integrated with most parts of the building envelope, featuring flexible and attractive architectural designs with functional and aesthetic dimensions. They are considered sustainable architectural systems that enhance the environmental performance of buildings. [43]

5.3. Description and reasons for selecting the study sample

The general hospital in Hurghada was chosen because the city of Hurghada, located in the Red Sea Governorate, has immense potential for solar energy exploitation due to its distinguished geographical location and the abundance of sunlight throughout the year. Hurghada was selected as the study sample site because it recorded the highest monthly average of total solar radiation in Egypt during June 2022, reaching 30.6 mega joules/m² at the Hurghada meteorological station [44], with an average solar radiation of (kJ/M² 220802.6) per day throughout the year [45], making it an ideal environment for generating electricity from solar energy. (Figure 14)

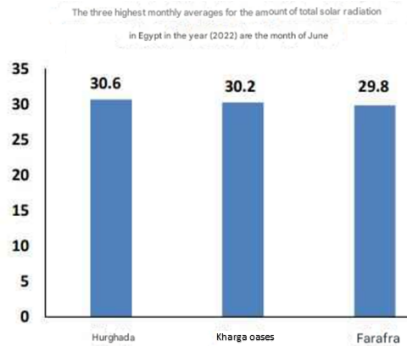


Figure 14: The top three monthly averages of total solar radiation in Egypt in 2022 - [46]

5.4. Simulation Method

A model of the hospital was created with an approximate area of 1100 m² using the Design Builder program according to the area found on Google Maps (Table 2). Energy produced was measured by distributing the photovoltaic cells in different locations within the hospital. The measurement was conducted with a fixed system throughout the year over the entire building surface. The photovoltaic cells were installed on the flat parts, and the circular parts were not used, with a horizontal surface area of 880 m² and a southern facade area of 880 m². The type of solar system used (BIPV) was fixed, with a tilt angle for the solar cells of 20 degrees for the solar panels, measured in (KWH/M²) for electrical energy (Table 3).

Table 2
Hospital Data and Study Sample Inputs for the Design Builder Program [47] - Researcher.

Inputs		Design builder Program
Total area	Hurghada General Hospital in the city of Hurghada, Egypt, with an approximate area of 1100m2.	
Building orientation	The longest side of the mini is orientated northwest.	

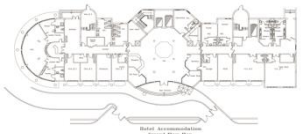
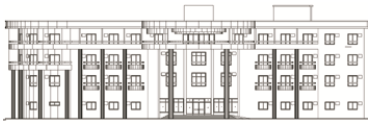
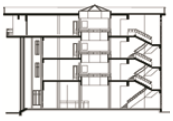
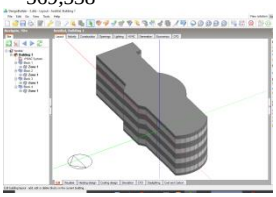
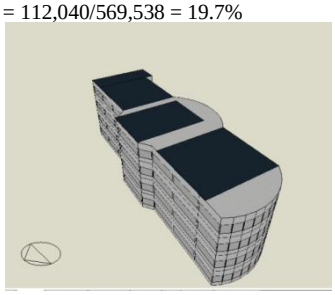
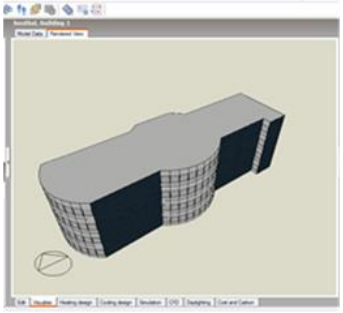
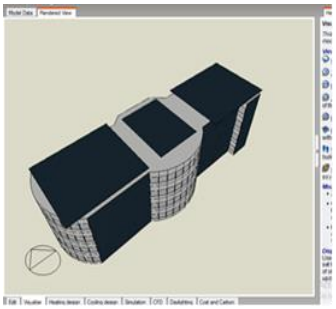
Inputs		Design builder Program
Longitude and latitude	Longitude 33.27 and latitude 27	
	ground floor	repeated floor
		
	Main elevation	section
		
	Energy consumption KWH	Production of solar cells
The current state of energy usage In the hospital	569,538 	0%
		Energy consumption was not reduced in the current state of the hospital as photovoltaic cells were not used, and thus, energy was neither compensated for nor produced to lower energy consumption.

Table 3
A comparative study of the locations for integrating photovoltaic cells in the hospital and the energy production levels of each using the Design Builder program - Reference: The researcher

Outputs	Design builder Program	Results
Installing solar panels on a horizontal surface area of 880 m2 produces energy (112,040 kWh).	The percentage of energy consumption savings = 112,040/569,538 = 19.7% 	The photovoltaic cells produced approximately 19.7% of energy consumption when used horizontally on the building's roof only.
Installing solar panels on the vertical southern facade (880 m2) generates energy. (122,012 kWh)	The percentage of energy consumption savings = 122012/569,538 = 21.5% 	The photovoltaic cells produced approximately 21.5% of energy consumption when used on the building's roof.
Installing solar panels tilted	The percentage of energy consumption savings = 241,407/569,538 = 42.4%	The photovoltaic cells produced

on the horizontal surface and vertically on the southern facade with an area of 1900 m2 at an angle of tilt for the solar panels (20 degrees for the solar panels on the horizontal surface only) produces energy. (241,407 kWh)



approximately 42.4% of the energy consumption when used at a 20-degree angle on the building's roof and perpendicular to the southern facade of the building. Therefore, it has the highest percentage of energy production and is considered one of the essential elements for transforming the hospital into a net-zero energy hospital.

The analysis of the use of photovoltaic cells at the hospital, with a fixed area on both the horizontal surface and the southern facade, resulted in the production and compensation of approximately 19.7% of the hospital's energy consumption on the horizontal surface and approximately 21.5% of the hospital's energy consumption on the vertical southern facade. By utilizing multiple locations, whether on the building's roof with a 20-degree tilt angle or on the southern facade of the building with the same fixed area of solar cell surfaces on the hospital, approximately 42.4% of the hospital's energy consumption is compensated and balanced (Figure 15).

Therefore, the use of photovoltaic cells is considered one of the most effective solutions for producing more than a third of the hospital's energy consumption. Their use is essential as a minimum for implementing solar cell systems in the hospital to achieve energy balance with the hospital's consumption. Consequently, this leads to a net-zero energy hospital, which is one of the fundamental approaches to conserving and rationalizing energy consumption and enhancing its efficiency in hospital buildings, especially in areas with high solar radiation, such as the Red Sea region.

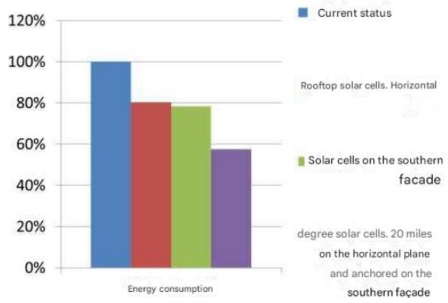


Figure 15: Comparison of energy consumption in the current situation and with the installation of solar panels - researcher

6. Opportunities and challenges of implementing energy-neutral hospitals in Egypt

Energy-neutral hospitals are considered a sustainable solution to address energy challenges, and there are numerous opportunities for their implementation in Egypt due to the country's year-round solar radiation and the potential to harness it using photovoltaic cells, despite some challenges and obstacles.

6.1. The major opportunities

- The presence of multiple regions with high solar radiation and the availability of vast areas for the construction of solar power plants, which helps in energy production using photovoltaic cells

- Targeting energy efficiency improvement with strategic goals and national future visions, establishing energy efficiency codes, a green building rating system in Egypt, and a guideline for green hospitals and healthcare facilities.

- Solar energy can be relied upon, and solar panels can be installed on the roofs and facades of hospitals to generate electricity, which can be stored in batteries for use. Solar cells can provide hospitals with energy independence.

- Energy efficiency in hospitals can be improved by using energy-saving devices, energy-efficient lighting, thermal insulation, and temperature control systems. Many government policies and initiatives aim to encourage investment in renewable energy to balance energy in hospitals. The transition to green hospitals creates new job opportunities in the fields of renewable energy, waste management, and maintenance.

- Solar panels can generate a significant portion of the energy hospitals need, greatly reducing electricity consumption, lowering carbon emissions, and minimizing pollution, which improves air quality and the environment surrounding the hospital.

6.2. The major challenges

- Using renewable energy to offset energy consumption without considering the implementation of energy efficiency strategies.

- The high costs of installing renewable energy systems and the lack of knowledge and understanding of the advantages of energy-neutral buildings

- There is no local reference framework that includes methods for designing and constructing energy-neutral buildings.

- Energy efficiency codes are available, but they are not mandatory for buildings; therefore, most existing buildings do not meet the minimum energy efficiency standards.

- Lack of skills and experience, construction and operation practices, and inaccurate energy consumption estimates in the field of net-zero buildings.

- Legislation must be developed to encourage the adoption of green and sustainable buildings.

- The process of transforming hospitals into green hospitals requires significant investments in technology and infrastructure.

- The difficulty of integrating new technologies with existing systems and infrastructure in hospitals.

- Solar panels require sizeable areas for installation, and it may be difficult to provide these spaces in some hospitals.

- Climate changes affect the efficiency of solar systems, necessitating the presence of energy storage systems or backup power sources.

- The need to conduct comprehensive feasibility studies before deciding to install solar energy systems, determining energy needs, and assessing climatic factors.

7. Results

- Based on the analytical study using the simulation program, it has been revealed that the analysis of using photovoltaic cells in the hospital with a fixed area on both the horizontal surface and the southern facade produces and compensates for approximately 19.7% of the hospital's energy consumption on the horizontal surface and compensates for approximately 21.5% of the hospital's energy consumption on the vertical southern facade. By utilizing multiple locations, whether on the building's roof at a 20-degree tilt angle or on the southern facade of the building with the same fixed area for the solar cell surfaces on the hospital, approximately 42.4% of the hospital's energy consumption can be compensated for. ،Therefore, the use of photovoltaic cells is considered one of the most effective solutions for producing more than a third of the hospital's energy consumption. Their use is essential as a minimum for implementing solar cell systems in the hospital to achieve energy balance with the hospital's energy consumption. Consequently, this leads to a net-zero energy hospital, which is one of the fundamental approaches to conserving and rationalizing energy consumption and enhancing its efficiency in hospital buildings, especially in areas with high solar radiation, such as the Red Sea region.

- The analytical study of buildings produced a vision of the feasibility of applying photovoltaic cells in the hospital and their direct relationship with the implementation of energy-neutral hospitals

- The use of photovoltaic cells in the hospital does not lead to repetitive designs and standardized solutions, but rather results in energy balance at varying rates depending on the design and according to the project's conditions and the climatic region it belongs to. It was found that photovoltaic cells need to be applied in hospitals, activated, and developed to implement the energy neutrality approach to create harmony between the building and the environment. They are one of the green applications and do not conflict with the environment, benefiting from technology.

- The green hospital trends, in their essence, contain the environmental trends of energy-neutral hospitals, making them a reference for innovation and adaptation for environmentally compatible construction. The Green Hospitals Guideline relies on environmental conditions and includes most of the determinants of global systems in accordance with the environmental conditions in Egypt, in addition to environmental determinants suitable for construction in Egypt.

- Dependence on the formation of photovoltaic cells as part of the building without causing any damage to its Energy-neutral hospitals are a type of healthcare facility that represents an energy-efficient building producing all the energy it consumes over the year, usually by integrating on-site renewable energy sources through three steps in energy-neutral buildings: reducing energy consumption, then reusing energy, and finally compensating for energy through renewable energy sources.

- The most important local program towards achieving energy-neutral hospitals is the guidelines for the design of green hospitals and health facilities issued by the National Centre for Housing and Building Research in Egypt in 2019, which consider the design phase for new hospitals and needs to be developed to be suitable for energy-neutral hospitals by presenting various technologies and treatments.

- The "Energy Efficiency Code" is considered a reference for the design of neutral buildings, as it provides the minimum requirements in architectural design and electrical and mechanical systems to reduce energy consumption and improve thermal performance.

- The three-step strategy for net-zero energy buildings begins with reducing energy consumption, then reusing energy, and finally compensating for energy through renewable energy sources.

- There are multiple technologies that generate energy using these sources, such as using solar panels to absorb

solar radiation and utilize and control it, whether photovoltaic solar energy or solar thermal energy.

- There are various methods to integrate the installation of systems on building rooftops according to the available space, providing flexibility in orientation. There are several ways to integrate solar panels with horizontal surfaces, including tilted solar units designed for horizontal surfaces, heat-insulating solar units in a horizontal position, solar units used as natural ceiling lighting, solar units designed for rooftop gardens, curved surfaces, and the installation of solar cell systems on facades (curtain walls, vertical walls with external cladding, facades with slanted walls, and walls with curved shapes**)**

- The most important applications in hospital models rely on improving energy efficiency (installing a solar power station, using solar panels to generate clean energy, and designing the building to provide good natural ventilation).

- The abundance of high solar radiation regions in Egypt and the availability of vast areas for constructing solar power plants help in producing energy using photovoltaic cells.

- Energy efficiency in hospitals can be improved by using energy-saving devices, thermal insulation, temperature control systems, and renewable energy to offset energy consumption by implementing energy efficiency strategies.

- The available space on the building rooftops must be divided to determine the production capacity of the solar panels and to select the appropriate location for the solar panels to obtain the maximum solar radiation.

- Roof coverage: installing solar panels on parking garage roofs to generate energy using the shade to protect cars from heat in hospitals, and installing electric vehicle charging stations in hospital parking lots using solar energy.

- The high costs of installing renewable energy systems, lack of knowledge about the advantages of net-zero energy buildings, and the absence of a local reference framework that includes design and implementation methods for net-zero energy buildings are considered some of the biggest challenges in relying on renewable energies. Additionally, energy efficiency codes are not mandatory for buildings, and there is a lack of skills and expertise in maintaining solar panels, as well as in construction and operation practices for energy consumption in buildings.

- Educational programs lack awareness about the importance of neutral buildings, how to achieve them, and the benefits that result from them.

- Investors and institutions should be encouraged to adopt measures and applications for neutral buildings.

- Developing models for simulation programs and strong specifications applicable at the local level, including construction materials, inspection, and operation before building implementation, and reviewing the design, inspection, and operation procedures for the systems, must be implemented.

- Using renewable energy to offset energy consumption without considering the implementation of energy efficiency strategies.

- The high costs of installing renewable energy systems and the lack of knowledge and understanding of the advantages of energy-neutral buildings

- The absence of a local reference framework that includes methods for designing and constructing energy-neutral buildings

- Lack of skills and experience, construction and operation practices, and inaccurate energy consumption estimates in the field of net-zero buildings

- The process of transforming hospitals into green hospitals requires significant investments in technologies and infrastructure.

- Targeting energy efficiency with strategic goals and national future visions, establishing energy efficiency codes, the green building rating system in Egypt, and the guidelines for green hospitals and health facilities.

- Solar panels can provide hospitals with energy independence.

- Many government policies and initiatives are directed toward encouraging investment in renewable energy, and the shift to green hospitals creates new job opportunities in the fields of renewable energy, waste management, and maintenance.

8. Recommendations

Architectural recommendations

- A comprehensive study of the site and climatic conditions, solar radiation analysis, shadow study, and precise evaluation of the hospital's electrical loads are required to determine the type and size of the solar system needed. This will help design the most suitable solar system in terms of tilt angle, panel orientation, available surface area, and surface design to install the maximum number of solar cells.

- Adopt thermal insulation technologies, natural ventilation, energy-efficient lighting, and regular

maintenance, connect the solar system to the electricity grid, and use an intelligent energy management system to monitor and improve the solar system's performance.

- The appropriate type of solar panels should be selected according to the climatic conditions and the available surface area.

- Hospitals should be converted into energy-neutral buildings to reduce costs, implement environmental sustainability, decrease carbon emissions, and preserve the environment.

- Smart control systems should be implemented using building management systems to collect and analyze data, make decisions about operating various systems, and use sensors to gather data on temperature, lighting, and air humidity to make decisions about operating different systems.

- Devices with low energy consumption should be selected, and workers and patients should be educated on the importance of energy conservation.

- There should be collaboration with engineers specialized in architecture and solar energy to ensure the design and implementation of an effective system.

- Providing references and journals for the latest research and developments in the field of solar energy, wind energy, and other renewable energy sources, and studying projects that have already been implemented in the field of energy-neutral hospitals to identify best practices and potential challenges they may face.

- Legislation should be developed to encourage the adoption of green and sustainable buildings, and comprehensive feasibility studies should be conducted before deciding to install solar energy systems, determining energy needs, and assessing climatic and financial factors.

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