*International Journal of Computational and Experimental Science and Engineering (IJCESEN)*

*Vol. 11-No.4 (2025) pp. 4345-4355*
*http://www.ijcesen.com*

***ISSN: 2149-9144***

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**Research Article**

# Improving the Energy Efficiency of Patient Rooms in Hospital Buildings by treating the building envelope in Kafr El Sheikh Governorate, Egypt

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**Article Info:**

**DOI:** 10.22399/ijcesen.5056
**Received :** 1 November 2025
**Accepted :** 1 December 2025

**Keywords**

Energy efficiency
patient rooms
hospital building
thermal insulation

**Abstract:**

Hospitals are among the most energy-intensive buildings due to their continuous operation throughout the year, seven days a week. Patient rooms constitute the largest portion of functional spaces. This study aims to reduce energy consumption in patient rooms in hospitals in Kafr El-Sheikh Governorate, Egypt, while maintaining thermal comfort standards. Given the governorate's hot and humid climate in summer and mild winters, air conditioning and lighting systems consume a significant amount of energy. The research utilizes Design Builder v7.0 software to simulate the thermal performance of patient rooms and test design alternatives (such as insulation materials, glass type). The results of the proposed treatments, which include 25 cm thick brick walls, 6 cm thick thermal insulation, and 6 mm thick double glazing, showed that they effectively reduce energy consumption by between 19.4% and 28.38% in patient rooms.

## 1. Introduction

Hospital buildings are among the world's largest energy consumers. According to ( Liu, D., 2023) [1], energy consumption by hospitals accounts for between 5% and 10% of total energy consumption in the building sector. In hot climates, maintaining a comfortable indoor environment presents a double challenge, given the different thermal needs of patients compared to healthy individuals (Hwang et al., 2007) [2]. Kafr El-Sheikh Governorate has a unique climate (high humidity and temperature), which increases both perceived and latent cooling loads. To achieve green hospitals, rigorous and precise architectural, environmental, and technological solutions and treatments are essential, starting with the design of patient rooms (Taleb, 2016) [3]. Patient rooms constitute the largest portion of the hospital's functional spaces, and their design quality directly impacts patient recovery speed and the efficiency of material and resource utilization. In Kafr El-Sheikh Governorate, hospitals face a challenge in the efficiency of their building envelopes, leading to increased financial burdens due to the electricity consumption of mechanical systems.

## 2. Research Problem:

Increased energy consumption rates in patient rooms at Kafr El-Sheikh hospitals are a result of reliance on mechanical systems and neglect of environmental considerations for the building's perimeter. This also leads to an uncomfortable indoor environment for patients. (Verheyen et al., 2011) [4].

## 3. Research Questions

- How can energy consumption be reduced in hospital patient rooms in Kafr El-Sheikh Governorate?

- How can "efficient architectural design" solutions reduce energy consumption in hospital patient rooms?
-

## 4. Research Objectives

- . Reduce energy consumption and improve energy efficiency in patient rooms by treating the building envelope of the hospital building.
-

## 5. Research Hypothesis

Treating the envelope building of patient rooms in hospitals in Kafr El Sheikh using thermal insulation, 25 cm thick walls, and double glazing improves energy efficiency.

## 6. Research Methodology

The research study uses descriptive analytical methods and the applied methods using simulation. In the theoretical stage, data related to the climate of Kafr El-Sheikh Governorate is collected, along with previous studies that confirm the problem and seek to analyze hospital design standards and patient room treatment requirements in hospitals. Then, the second stage is the selection of a case study of an existing hospital in Kafr El-Sheikh Governorate and the collection of energy consumption data. Then, the third stage is the applied study using simulation with the Design Builder v7.0 program, inputting climate data, creating a model of patient rooms, and drawing results. Then, the recommendations stage is the comparison of results and the selection of the most efficient treatments to improve energy consumption in patient rooms in Kafr El-Sheikh hospitals.

## 7. Literature Review

Studies indicate that balancing energy efficiency with patient thermal comfort presents a significant and complex challenge. (Hwang et al. 2007) [2], in a study of hospital buildings in Taiwan, noted that patients' thermal comfort requirements differ considerably from those of healthy individuals, necessitating precise adjustments to mechanical cooling and heating systems to meet their needs without wasting energy. (Azizpour et al. 2013) [5] also pointed out the need to improve design requirements for thermal comfort in large hospitals in tropical regions to reduce reliance on mechanical cooling and heating systems. (Verheyen et al. 2011) [4] further supported this approach by conducting objective and subjective measurements in patient rooms in Belgium, demonstrating that a patient's perception of the thermal environment directly influences their energy efficiency through the control of windows and mechanical systems used for local cooling and heating .(Mourshed et al. 2012) [6] indicated that work efficiency and the quality of healthcare depend on and are greatly affected by the design factors of the physical environment, which indirectly affects energy consumption rates and patterns. To improve performance rates in hot climates similar to that of Kafr El Sheikh Governorate, (Taleb 2016) [3] focused on enhancing the building envelope performance in UAE hospitals, emphasizing that facade treatments reduce cooling loads and improve the performance of mechanical systems. Within the framework of development strategies, (Buonomano et al. 2014) [7] presented a dynamic analysis of energy performance rates in hospital building renovations, showing that exterior envelope treatments combined with mechanical systems are the most effective in improving energy performance. (Song et al. 2018) [8] discussed innovative technological solutions, specifically phase-change materials (PCMS), as an effective way to reduce thermal loads. They highlighted the role of these materials in improving energy efficiency in buildings through their unique thermal energy storage properties in a comprehensive review. (Jin et al. 2014) [9] demonstrated that placing phase-change materials within wall cavities in the building envelope significantly reduces heat transfer rates and lowers energy consumption under varying climatic conditions. In an applied study on lightweight buildings in Shanghai, (Wang et al. 2020) [10] demonstrated through parametric analysis that wall panels equipped with PCM contribute effectively to energy saving, which can be simulated and applied in patient rooms in Kafr El-Sheikh hospitals to reduce thermal fluctuations resulting from the hot and humid climate.

- **Phase Change Materials (PCMs):**

Phase change materials are materials that store and release large amounts of thermal energy (latent heat) while changing their physical state (from solid to liquid or vice versa) at a specific transition temperature. They are characterized by their ability to absorb heat when the ambient temperature rises above their melting point and release this stored heat when the temperature drops below their freezing point (Song et al., 2018) [8].

- **The concept of how PCM works in hospitals:**

In Kafr El Sheikh's hot climate, these materials absorb heat penetrating the walls during the day, transforming from a solid to a liquid state, thus preventing the patient's room from overheating. At night, when the temperature drops, the material releases this stored heat and returns to a solid state (Ahangari & Maerefat, 2019) [11].

- **Images of PCM Integration in Patient Rooms:**
- These materials are not visible but are integrated into building elements in several ways:
PCM-Infused Gypsum Boards: Replacing ordinary gypsum boards with boards containing micro-particles of the material (Wang et al., 2020) [10].
- Wall Cavities: Placing a thermal shield in the space between bricks to reduce heat transfer (Jin et al., 2014) [9].
- **false Ceilings**: These are integrated into the ceiling tiles to absorb heat generated by lighting and medical equipment.
-

## 8. Types of Inpatient Hospital Rooms: A Comparative Overview

The design of inpatient rooms is of paramount importance to patient care flexibility, impacting outcomes, infection control, privacy, and efficiency. There are two main room types: ward rooms and living quarters, and multi-bed suites.

**1. Single Rooms (Private Rooms)**

Details: It guarantees a room for just one of them, as well as a private bathroom and a bed support area.

**Key Advantages:**

**Infection control measures:** greatly reduce the risk of hospital-acquired infections by maintaining the cleanest medical supplies. (Bracco et al., 2007) [12].

**- Ensuring privacy and dignity:** The possibility of confidential communication between medical staff and family members enhances patient dignity.

**-Improved environmental control:** Patients should have direct control over lighting, temperature, and noise, as well as the presence of windows, which contributes to their satisfaction and quality of sleep**.** (Ulrich et al., 2008) [13].

**-Clinical Flexibility:** allows for its use for various purposes across several levels of service (limited, requiring standard or individual care, such as isolation) and is also used to minimize patient transfer.

**Key Challenges:**

**-Increased costs:** The increased building area and the complex air conditioning and ventilation systems required for each patient will lead to higher costs.

**- Staff workflow:** This may increase the distances traveled by nursing staff, potentially requiring more personnel to maintain the same standard room layout.

-**The isolation of patients:** from others and the lack of roommates leads to feelings of social loneliness or anxiety.

**2. Double Rooms (Semi-Private Rooms)**

Description: A room shared between two patients, usually separated by a separate curtain, and a double toilet.

**Key Advantages:**

**-Resource efficiency of double rooms:** Lower construction costs and less energy consumption per person compared to single rooms.

**-Social support for patients:** Helpful peer support can be provided, reducing feelings of loneliness when roommates get along.

**-Easier patient monitoring:** Allowing the monitoring of two patients from one location can improve nurses' responsiveness.

**Key Challenges:**

**- Privacy violation:** All conversations, visits, and procedures within the hospital are heard and seen without any privacy.

**- Risk of infection:** The risk of infection transmission is higher among patients sharing rooms compared to those in individual rooms.

**- Logistical complexity:** Based on gender, diagnosis, and behavior, careful patient allocation is required, and disagreements often arise regarding control of the internal environment of the rooms, such as temperature, lighting, and television.

**- Disturbance:** activity and Noise from the patient, their visitors, or medical staff may disturb the comfort of other patients**.**

**3. General Wards (Multi-Bedrooms)**

Description: Large, open rooms, easily adaptable to accommodate three or more patients (the most common case is 4 or 6 patients), and containing a central bathroom.

**Key Advantages:**

**-Maximum space and cost utilization:** Lower operating and construction costs per patient bed per room, allowing for optimal use of every available space and thus accommodating many patients.

- **Complete centralized supervision:** Enables highly efficient visual supervision by a limited number of patient staff, ideal for stable, mildly ill patients.

**Key Challenges:**

**-Infection control in triple patient room:** These are extremely challenging indoor environments where outbreaks of multidrug-resistant organisms are common (Stiller et al., 2017) [14] ,(Andersen, B. M. 2019) [15].

**- Stress and Noise:** High noise levels due to continuous activity, increased stress, and sleep disturbances negatively impact patient recovery (Ulrich et al., 2008) [13].

**- Lack of privacy in triple patient rooms:** Privacy is virtually nonexistent, making discussions or sensitive procedures difficult for patients and compromising their dignity.

**-Environmental control in triple patient rooms:** Individual control is impossible. Achieving a balance in ventilation, lighting, and temperature for

all patient beds in the room is a major engineering challenge.

- **Modern Trends and Other Classifications:**

Modern hospitals rely heavily on the design of standardized, single-person acute care rooms, based on scientific evidence demonstrating their effectiveness in infection control and patient-centered care.

**Rooms are also classified according to clinical requirements:**

**- Isolation rooms:** These are single rooms equipped with specialized ventilation systems, either negative pressure for controlled air isolation or positive pressure for protective isolation.

**-Intensive Care Unit (ICU) Rooms:** Larger single rooms designed to accommodate numerous life-support devices and allow 360-degree access to the critically ill patient.

**-Step-Down/Intermediate Care Rooms**: For patients who require more monitoring than a general ward but not ICU-level care.

**9. Case Study: Kafr El-Sheikh Oncology Hospital Project:**

**- Project Description:**

A large-scale project to provide comprehensive care for all cancer cases in the Nile Delta. The project is located on an area of 8,876 square meters in Kafr El-Sheikh City and includes: - 148 beds - 8 operating rooms - Intensive care and recovery rooms occupying an entire floor of the building - 8 patient elevators - The center houses one of the most unique radiology departments in Egypt and the Middle East - A nursing school is attached to the center - It includes a two-level underground parking garage covering the entire site.

Within months, one of the largest and most modern cancer treatment centers in the Middle East will be completed, alleviating people's suffering. [18]

The Kafr El-Sheikh Oncology Center is in the area opposite the Religious Institute, near the Slaughterhouse Square and the Girls' Agricultural School. It is built on an area of 3,400 square meters and consists of the following main buildings:

**1- Building (A),** with an area of 1,400 square meters, consisting of a basement, ground floor, and six upper floors.

**2- Building (B),** with an area of 2000 m², consists of a basement, a ground floor, and three upper floors.

The Kafr El-Sheikh Oncology Hospital building comprises a basement, a ground floor, and six upper floors, distributed as follows:

**- Basement:** Houses the Oncology Radiotherapy Department, including two linear accelerators, a high-dose brachytherapy unit using HDR technology, and a CT scanner. It also includes medical gas storage, warehouses with separate storage areas for logistics services, a central kitchen and staff dining area, a central laundry, a central sterilization unit, and electrical and mechanical engineering services.

**- Ground Floor:** Houses the Oncology Outpatient Clinics with a range of clinics, in addition to the Diagnostic Imaging Department and an Emergency Department for patient stabilization.

**- First floor:** In addition to the endoscopy unit consisting of three operating rooms for different procedures, the chemotherapy department includes two sections; one for children and the other for adult patients. It also contains operating rooms for oncological surgery as well as an intensive care unit for cancer patients.

**- Second Floor:** Houses the central laboratory, a separate section containing the blood bank with storage facilities, and a patient ward.

**- Third Floor:** Includes staff accommodation, administration offices, the Intensive Care Unit lobby, and a patient ward.

**- Fourth and Fifth Floors:** Contain patient wards.

**- Sixth Floor:** Dedicated to the Medical Oncology Intensive Care Unit, including an intensive care lounge, high-level intensive care rooms, and isolation facilities [17].

10. **Analysis of climatic data:**

Analysis of climatic data for the study area in Kafr El-Sheikh Governorate, specifically the accommodation rooms in the Oncology Hospital building in Kafr El-Sheikh Governorate in hot regions:

- **Psychometric chart:**

The psychrometric map illustrates the relationship between temperature and relative humidity on the horizontal and vertical axes, respectively. The thermal comfort zone, with respect to temperature and humidity, as well as occupancy rates, including clothing type and activity level, is defined in Figure (9).

**11. Simulation Methodology:**

The specifications and dimensions of the building are entered into the program, and a model and simulation are created that simulates the reality of the building. This model simulates everything related to energy consumption in the building, as shown in the following model taken from the Design Builder v7.0 program, which is a program that analyses the inputs in the case study.

**12. Discussion of results:**

**First case (base case): -**

**1-** Energy consumption results (base case) with different orientation types for patient rooms in the Kafr El-Sheikh Oncology Hospital, in the case of a 25cm thick red brick wall with 6mm single

transparent glass, and where the simulation results for the (north) orientation are shown in Figure (11):

**2-** Energy consumption results base case (east orientation) for a model of the accommodation rooms in the Oncology Hospital in Kafr El-Sheikh in the case of a wall thickness of 25 cm red brick and 6 mm single transparent glass as shown in Figure (12):

**3-** Energy consumption results for the base case (south orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with a wall thickness of 25 cm (red brick) and 6 mm single-pane clear glass, as shown in Figure (13):

**4-** Energy consumption results for the base case (west orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with a wall thickness of 25 cm (red brick) and 6 mm single-pane clear glass, as shown in Figure (14):

**5-** Comparison of Energy consumption results for the base case with different orientations for the patient room model at Kafr El-Sheikh Oncology Hospital, with 25cm thick red brick walls and 6mm single-pane clear glass, as shown in Figure (15):

**Second case**: Adding 6cm thermal insulation to the 25cm thick walls and 6mm double-pane glazing:

1- Energy consumption results for different orientations of the Kafr El-Sheikh Oncology Hospital patient room model, with 25cm thick red brick walls, 6cm thick thermal insulation, and 6mm double-pane energy-saving glazing, given that the simulation results are for a (north orientation), as shown in Figure (16):

2- Energy consumption results for different orientations (east orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with 25cm thick red brick walls, 6mm thick thermal insulation, and 6mm double-pane energy-saving glass, as shown in Figure (17):

3- Energy consumption results for different orientations (south orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with 25cm thick red brick walls, 6mm thick thermal insulation, and 6mm double-pane energy-saving glass, as shown in Figure (18):

4- Energy consumption results for different orientations (west orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with 25cm thick red brick walls, 6mm thick thermal insulation, and 6mm double-pane energy-saving glass, as shown in Figure (19):

5- Comparison of energy consumption results with different orientation types after proposing treatments for the patient rooms model at the Kafr El-Sheikh Oncology Hospital, in the case of 25cm thick red brick walls, 6mm thick thermal insulation for the walls, and 6mm double-glazed energy-saving glass. As shown in Figure (20): By comparing the energy consumption rate for the base case (west orientation) of 46.91 kWh per m² per year with that of the base case (north orientation) of 43.65 kWh per m² per year, the energy savings rate is 7% for choosing the north orientation for the patient rooms at Kafr El-Sheikh Oncology Hospital.

6- Comparing the energy consumption results with different types of orientation in the base case and after proposing treatments for the patient rooms model in the Oncology Hospital in Kafr El-Sheikh, as shown in Figure (21):

- By comparing the energy consumption rate for the base state (west-orientation, 65.5 kWh per m² per year) with the proposed west-orientation configuration (46.91 kWh per m² per year), the energy savings are **28.38%.** This comparison is based on the selection of appropriate architectural treatments: 25 cm thick red brick walls, 6 cm thermal insulation, and 6 mm double-glazed, energy-efficient glass for the patient rooms at the Oncology Hospital in Kafr El-Sheikh.
- By comparing the energy consumption rate of the base case, north orientation, 54.17 kWh per m2 per year, compared to the north orientation after proposing treatments, 43.65 kWh per m2 per year, the energy consumption savings rates are **19.4%** for choosing the appropriate architectural treatments: 25 cm thick red brick walls, 6 cm thermal insulation in the walls, and choosing 6 mm double energy-saving glass for the accommodation rooms in the Oncology Hospital in Kafr El-Sheikh.



***Figure 1*** *illustrates the research methodology*

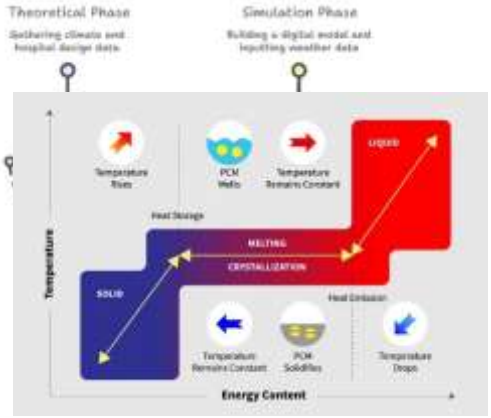



***Figure 2*** *Working of phase change materials [8]*

***Illustration 3*** *The Single Room (Private Room) [20]*



***Figure 4*** *The semi-private patient room [16]*



***Figure 5*** *General Wards (Multi-Bedrooms) [19]*



***Figure 6*** *Oncology Hospital building in Kafr El-Sheikh [17]*

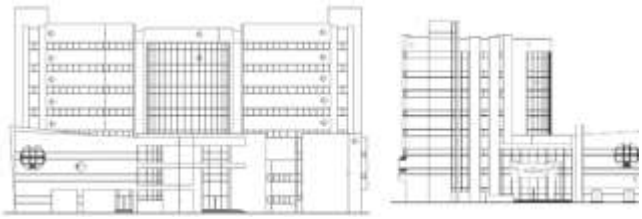


***Figure 7*** *The facades of the Oncology Hospital building in Kafr El-Sheikh.*

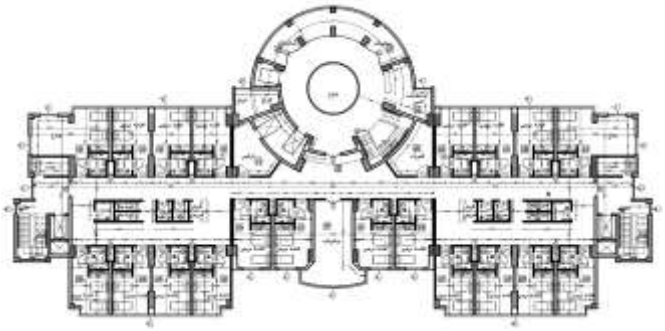


***Figure 8*** *shows the typical plan and includes patient rooms - Kafr El-Sheikh Oncology Hospital building*

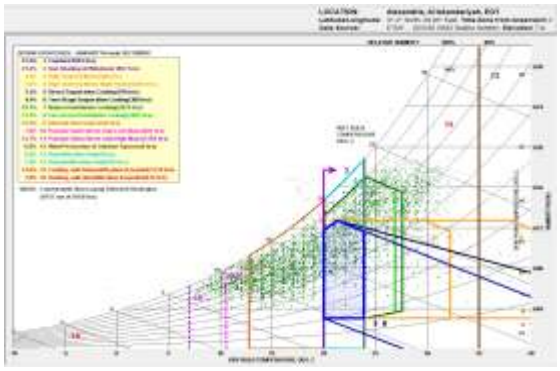


***Figure 9:*** *The psychometric map of Kafr El-Sheikh Governorate.*

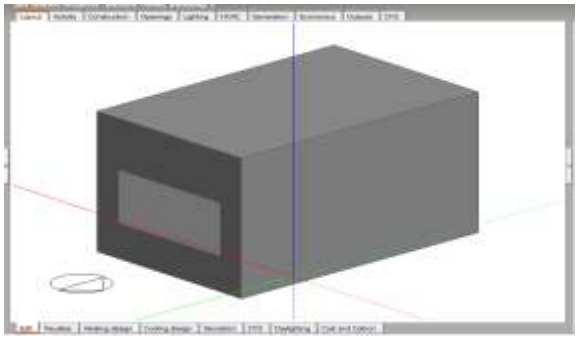


***Figure 10*** *A model of the typical case study model, patient rooms, in the Design Builder v7.0 program.*

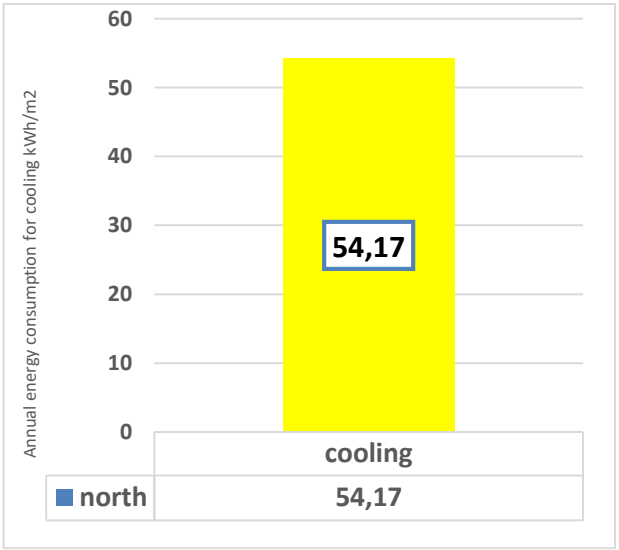



***Figure 11****: Shows the energy consumption results for the foundation case (north orientation) of the model accommodation rooms in the Oncology Hospital in Kafr El-Sheikh in the case of a wall thickness of 25 cm red brick and 6 mm single transparent glass with an annual cooling energy consumption rate of 54.17 kWh per m2.*

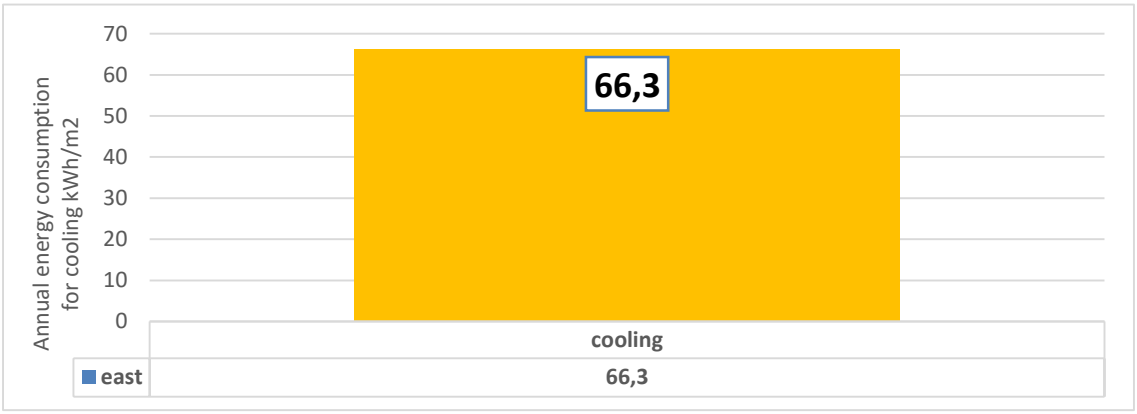



***Figure 12:*** *The energy consumption results for the base case (east- orientation) of a typical inpatient room model at the Kafr El-Sheikh Oncology Hospital, with a wall thickness of 25 cm (red brick) and 6 mm single-pane clear glass, at an annual cooling energy consumption rate of 66.3 kWh per m².*

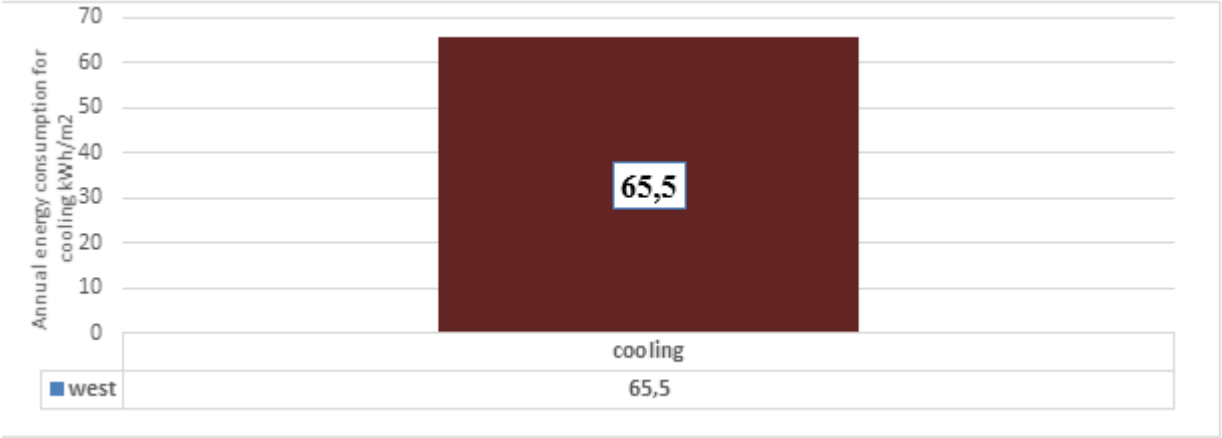



***Figure 13****: The energy consumption results for the base case (south orientation) of the patient rooms model at the Kafr El-Sheikh Oncology Hospital, with a wall thickness of 25 cm (red brick) and 6 mm single-pane clear glass, with an annual cooling energy consumption rate of 64.4 kWh per m².*

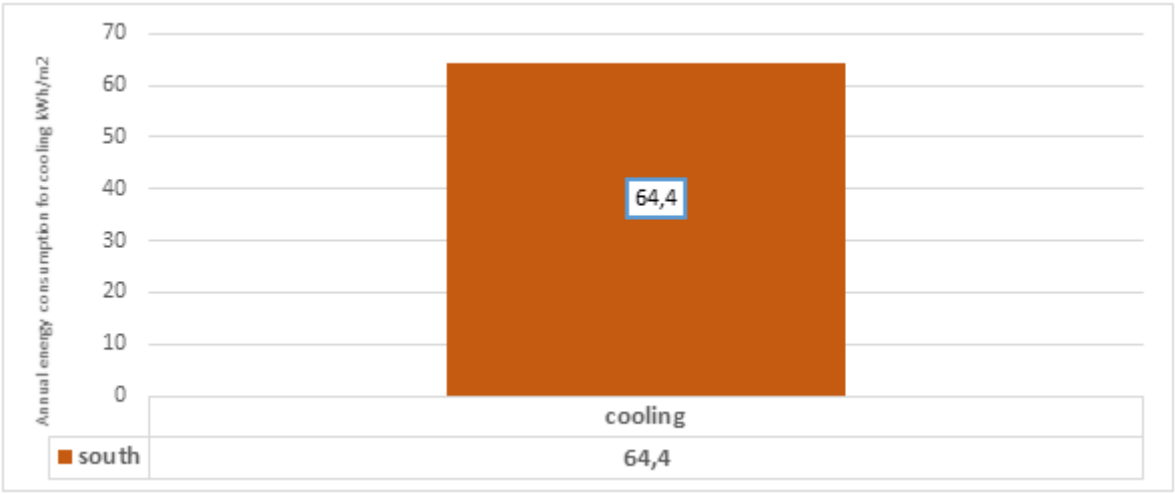



***Figure 14:*** *The energy consumption results for the base case (west orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with a wall thickness of 25 cm (red brick) and 6 mm single-pane clear glass, at an annual cooling energy consumption rate of 65.5 kWh per m².*

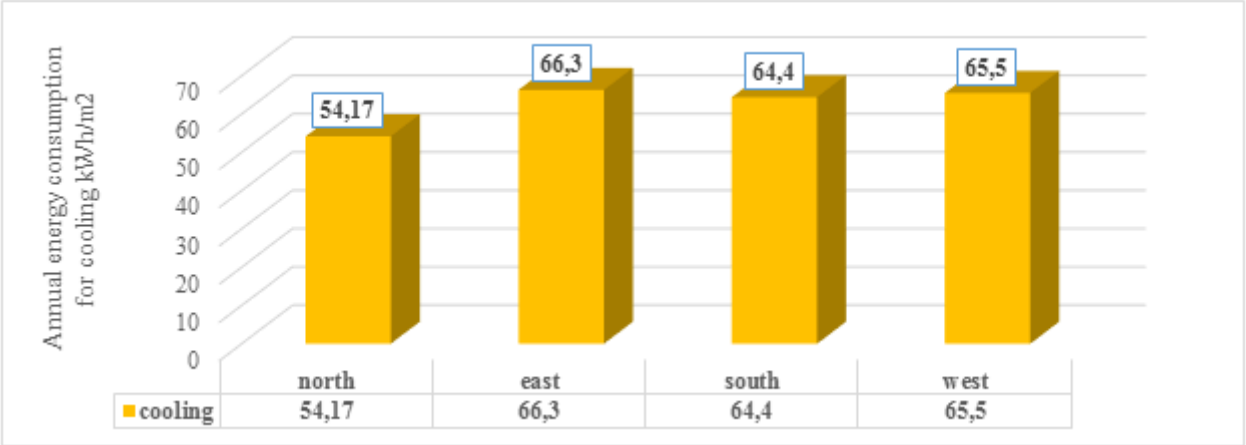



***Figure 15***: *Comparing the energy consumption rate for the West Orientation Base Case (65.5 kWh per m² per year) with the North Orientation (54.17 kWh per m² per year), the energy savings rate is 17.3% for choosing the North Orientation for the Patient Rooms at Kafr El-Sheikh Oncology Hospital.*

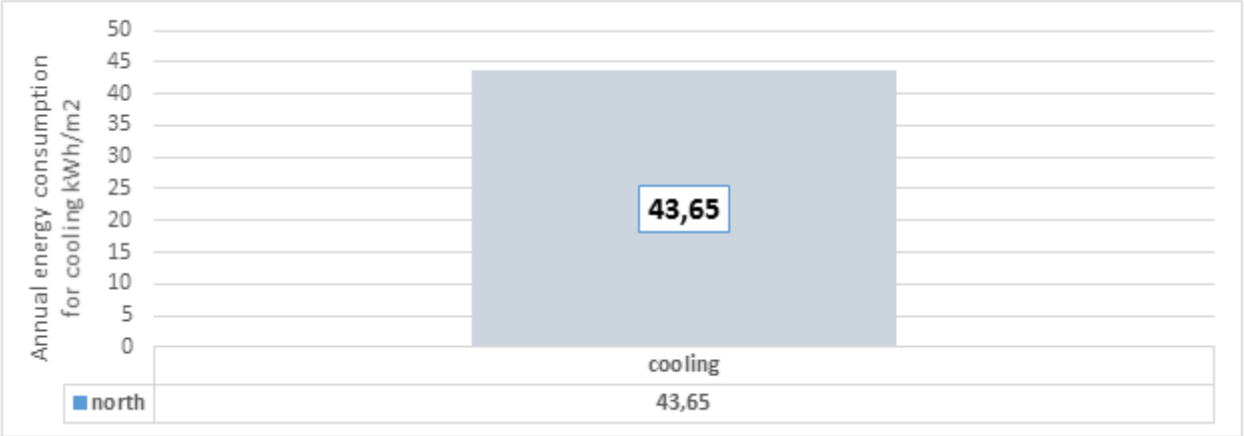



***Figure 16:*** *The energy consumption results for the case (north orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with 25 cm thick red brick walls, 6 mm thick thermal insulation for the walls, and 6 mm single-pane clear glass, with an annual cooling energy consumption rate of 43.65 kWh per m².*

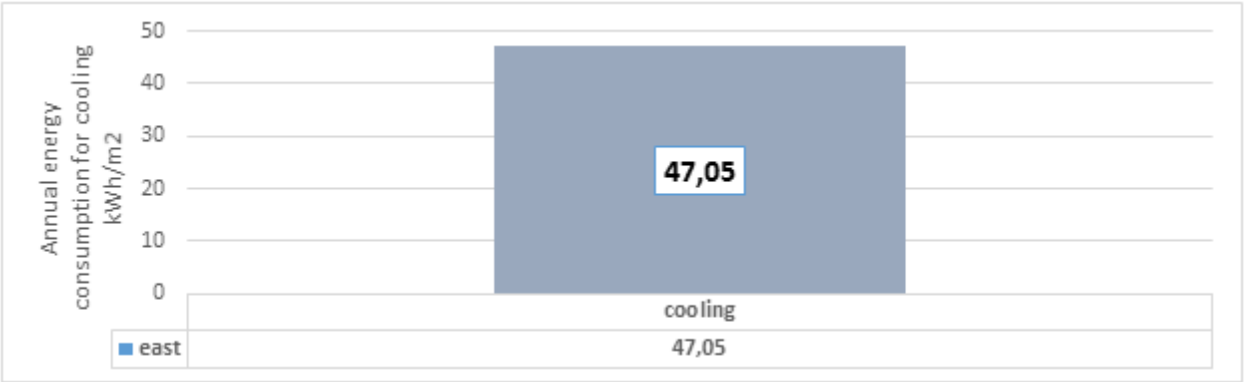



***Figure 17****: The energy consumption results for the (east orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with 25 cm thick red brick walls, 6 mm thick thermal insulation for the walls, and 6 mm single-pane clear glass, with an annual cooling energy consumption rate of 47.05 kWh per m².*

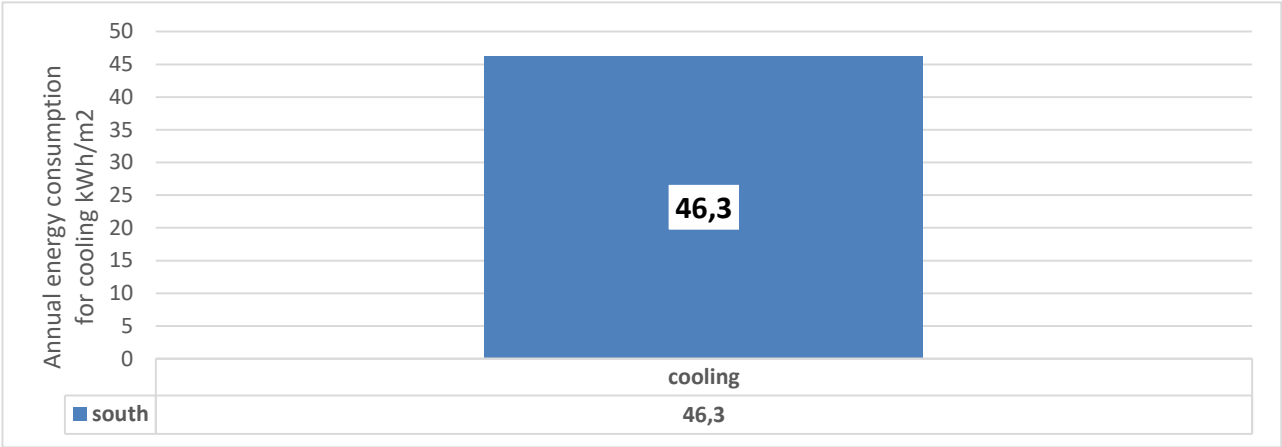



***Figure 18**: The energy consumption results for the case (south orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with 25 cm thick red brick walls, 6 mm thick thermal insulation for the walls, and 6 mm double-pane clear glass, with an annual cooling energy consumption rate of 46.3 kWh per m².*

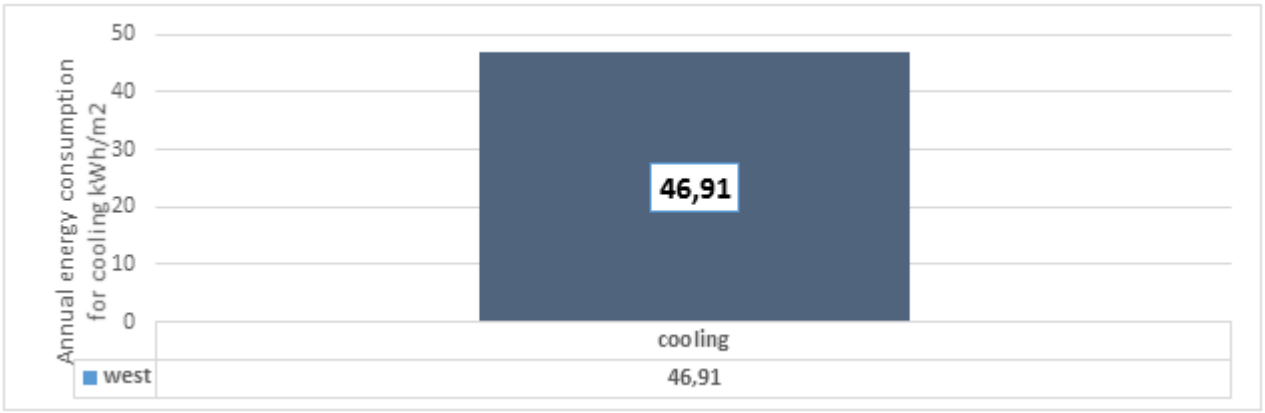



***Figure 19**: The energy consumption results for the (west orientation) of the patient room model at the Kafr El-Sheikh Oncology Hospital, with 25 cm thick red brick walls, 6 mm thick thermal insulation for the walls, and 6 mm single-pane clear glass, with an annual cooling energy consumption rate of 46.91 kWh per m².*

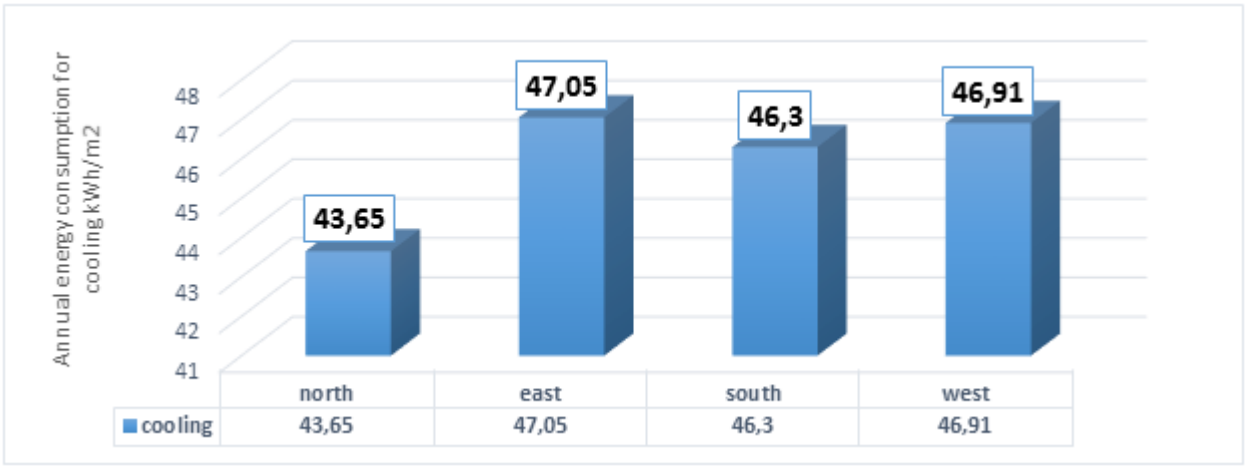



***Figure 20:** Comparison of energy consumption results with different orientation types after proposing treatments for the patient rooms model at the Kafr El-Sheikh Oncology Hospital, in the case of 25cm thick red brick walls, 6mm thick thermal insulation for the walls, and 6mm double-glazed energy-saving glass.*

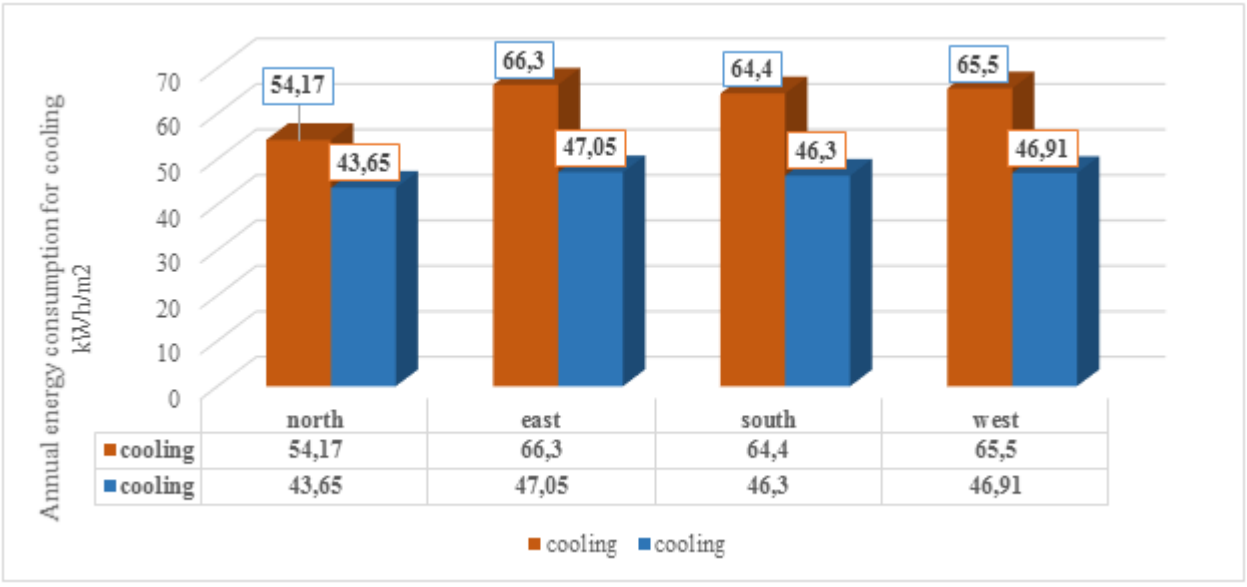



***Figure 21***: *shows Comparing the energy consumption results with different types of orientation in the base case and after proposing treatments for the patient rooms model in the Oncology Hospital in Kafr El-Sheikh.*

## 13. Recommendations:

1- Choose for north-facing orientations for patient rooms in new healthcare buildings. Reason: Although the energy-saving percentage after implementing treatments is slightly lower for north-facing rooms (19.4%) compared to west-facing ones (28.38%), the overall energy consumption is significantly lower with a north-facing orientation. Specifically, energy usage in north-facing rooms stands at 54.17 kWh/m²/year (basic) and 43.65 kWh/m²/year (improved), compared to 65.5 kWh/m²/year (basic) and 46.91 kWh/m²/year (improved) in west-facing rooms.

2- Enforce the mandatory use of energy-efficient architectural treatments. Reason: The proposed measures, including 25cm brick walls, 6cm thermal insulation, and 6mm double glazing, have been shown to effectively reduce energy consumption by 19.4% to 28.38%, regardless of orientation. Require these specifications as he minimum standard for designing and constructing patient and care rooms in hospitals. This is particularly important in hot climates like Egypt. Incorporation into the National Building Code for Healthcare Facilities should be prioritized.

3- Integrating phase change materials (PCM) into the design of the Kafr El-Sheikh Oncology Hospital

4- Making thermal and energy simulation an essential step during the design phase of all new healthcare buildings or renovation projects.

## Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authorsdeclare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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