An Assessment of External Wall Retrofitting Strategies Using GRC Materials in Hot Desert Regions

4 authors:

Ayman Ragab
Aswan University
55 PUBLICATIONS   683 CITATIONS

SEE PROFILE

Mohamed Hssan Hassan Abdelhafez
Aswan University
32 PUBLICATIONS   310 CITATIONS

SEE PROFILE

Omar Hamdy
Faculty of Engineering, Aswan University
28 PUBLICATIONS   377 CITATIONS

SEE PROFILE

Mohammed Alghaseb
University of Ha'il
13 PUBLICATIONS   108 CITATIONS

SEE PROFILE

buildings

Article

An Assessment of External Wall Retrofitting Strategies Using GRC Materials in Hot Desert Regions

Ayman Ragab [1,*], Mohamed Hssan Hassan Abdelhafez [1,2,*], Mabrouk Touahmia [3], Mohammad Alshenaifi [2], Emad Noaime [2], Khaled Elkhayat [2], Mohammed Alghaseb [2] and Omar Hamdy [1]

1   Department of Architectural Engineering, Faculty of Engineering, Aswan University, Aswan 81542, Egypt
2   Department of Architectural Engineering, College of Engineering, University of Hail, Hail 2240, Saudi Arabia
3   Department of Civil Engineering, College of Engineering, University of Hail, Hail 2240, Saudi Arabia
*   Correspondence: ayman.ragab@aswu.edu.eg (A.R.); mo.abdelhafez@uoh.edu.sa (M.H.H.A.)

Abstract: Due to urbanization, population growth, and the consequences of climate change, the usage of energy for cooling has increased considerably in recent years. Passive climate measures, on the other hand, could alleviate the situation by reducing energy use in buildings. This study examined the environmental and financial benefits of utilizing glass fiber-reinforced cement in the external walls of a communal social hub building in New Aswan city, taken an example of the hot desert region. Utilizing Design Builder software, the effect of various outside wall alternatives on cooling energy consumption was explored and analyzed. In addition, a cost–benefit analysis utilizing the simple payback period was conducted to aid decision-makers in selecting the most suitable exterior wall materials for public buildings in hot desert regions. Using cement plaster, cement brick, glass wool, and glass fiber-reinforced cement as an outside wall resulted in a significant improvement rate, according to the data. Compared to a typical wall (cement plaster, cement brick, and cement plaster), it can save up to 41% of energy. In addition, it has the lowest simple payback period value when compared to other examined solutions (10.86 years). In general, the results indicate that glass fiber-reinforced cement walls embedded in thermal insulation materials and incorporated into cement brick walls are more energy-efficient in terms of necessary cooling energy and economic viability.

Keywords: cost-effective energy buildings; glass fiber-reinforced cement; cooling energy; thermal conductivity; simple payback period

1. Introduction

Due to the significant amount of energy required for cooling in Egypt's hot desert regions, the energy consumption of buildings has increased dramatically [1]. Consequently, energy conservation has become a priority in these buildings [2]. Additionally, architects, engineers, and decision-makers focus more on the energy efficiency of buildings [3–8]. This is due to an increase in supply shortage over the past decade. Since the beginning of 2012, the number of power outages in Egypt has increased dramatically. In 2012–2013, the gap between electricity generation and demand was 8.6% [9]. During the summer of 2013, power outages typically lasted 1–2 h per day on average. During the summer of 2014, the average duration of a power outage was between four and six hours per day [2]. The high annual growth rate in energy demand and the increase in per capita energy consumption are likely to continue [10]. To meet energy demands, the energy production capacity should rapidly evolve. In Egypt, where cooling consumes the most energy, it is essential to construct building envelopes that are more suited to the external climate. Recently, architects have used new methods to build public buildings that are different from the old ones, made of two layers of cement plaster with a bricklayer in the middle. The most prevalent new techniques are gypsum board, cement board, and glass fiber-reinforced cement (GRC) walls. These new systems were utilized with or without the

use of insulating materials. In Egypt, GRC has been rarely used as a composite material for prefabricated buildings despite its low cost [11]. However, the initial cost of some types of insulation materials, combined with the absence of regulations mandating their use, has led to the use of these new techniques without insulation materials. As a result, several functional benefits were realized because of the increased interior space in comparison to the conventional exterior walls. In addition, it lacks sufficient heat resistance to prevent heat from entering.

Several previous studies [12–17] have investigated the thermal properties of GRC. For instance, Nagy et al. [18] calculated the thermal conductivity, density, and specific heat capacity of GRC. In this study, GRC material samples were evaluated after 28 days using a Taurus TLP 300 DTX hot plate measuring instrument (TAURUS Instruments AG, Germany) in accordance with EN 12,664: 2001. It was noted that the thermal conductivity values of GRC specimens were lower than those of steel fiber-reinforced concrete. Wang et al. [19] studied the effects of high temperature on the thermal conductivity of GRC. This study revealed that the thermal conductivity is less than that of concrete; the decrement increases with the quantity and length of glass fibers. Temperatures between 400 and 500 °C have the greatest impact on the decrease in thermal conductivity. Temperatures ranging from 500 to 580 °C have the greatest impact on thermal conductivity reduction. There were numerous attempts to improve the thermal properties of the GRC material. Coated or uncoated fiber-reinforced composites are the focus of these efforts. Zhu et al. [20] investigated the effective thermal conductivity of coated/uncoated fiber-reinforced composites with different fiber arrangements. The effective thermal conductivity of fiber-reinforced composites was discovered to be primarily influenced by the thermal conductivity of the fibers and coating layers. The thickness of the coating layer has a significant impact on the thermal conductivities of composites with fibers distributed randomly in space but has no effect on the thermal conductivities of composites with fibers arranged perpendicular to heat transfer. Tuncel et al. [21] conducted a further study in which the thermal performance of GRC composites was enhanced by incorporating a commercial microencapsulated phase change material (PCM) into the composites. The thermal characteristics of composites were enhanced by the incorporation of PCMs, whereas the latent heat capacity and thermal conductivity were increased and decreased, respectively, indicating an improvement. Consequently, PCMs are suitable for enhancing the energy efficiency of GRC composites.

In order to compare the environmental performance of glass fiber-reinforced cement wall panels and kenaf fiber-reinforced cement wall panels, Zhou et al. [16] used kenaf fiber in reinforced cement to create fiber-reinforced cement composites with exceptional mechanical and thermo-physical properties. This study employed a comparative life cycle assessment (LCA) to examine the effectiveness of fiber-reinforced cement wall panels made from kenaf fiber as opposed to traditional glass fiber. Incorporating a small amount of kenaf fiber (2% by mass) into cement composites significantly improved thermal resistance in comparison to GRC panels, as shown by the results. Using a natural fiber (such as kenaf bast fiber) instead of a synthetic fiber (such as glass fiber) to reinforce the cement wall panels can significantly reduce the environmental impact, in terms of both structural and insulating functions. Gandia et al. [22] used recycled glass fiber-reinforced polymer (GFRP) waste in the production of adobe. They discovered that adding 10% GFRP waste produced the best results when compared to adobe without additives, resulting in a 21% reduction in thermal conductivity.

Due to a lack of knowledge on the quantitative benefits of achieving the best thermal conditions and energy efficiency in buildings, GRC walls embedded with insulation materials are still unfamiliar systems that have yet to be widely implemented in Egypt. In the current study, a communal social hub building in a city club complex (New Aswan city) is chosen as the case study because such buildings have been previously constructed without climate-specific factors in mind. Nevertheless, they account for a sizeable portion of electricity consumption, especially for cooling. Consequently, the purpose of this study was to compare the use of GRC walls in public building envelopes as a modern construction

technology alongside the use of traditional brick wall materials. In addition, this study investigates new opportunities for energy savings in these social buildings through the installation of GRC walls with insulation materials embedded within them. It examines the effectiveness of various types of external walls in reducing cooling energy requirements and achieving thermal comfort. The findings of this investigation can be applicable to public structures in Egypt and other places with comparable characteristics.

According to this article, the use of GRC materials in building has environmental and economic benefits. Consequently, researchers in this study concentrated on six different exterior wall materials. They differ from traditional Egyptian walls in this regard. The results of this study could be useful in the hot desert regions of Egypt, particularly in terms of choosing acceptable outside walls for public buildings.

2. Material and Method

Three steps were extensively carried out to determine the effects of different building envelopes on the energy required for cooling in Egypt's hot desert regions:

i. The climatic characteristics of New Aswan city were determined, along with detailed descriptions of the studied building model;
ii. Model validation was performed by comparing measured and extracted simulated data;
iii. A comparison between the investigated building envelope options, in terms of environmental conditions, energy savings, and economic feasibility, was performed.

2.1. Location and Specifications of the Study Case Model

This research was conducted in New Aswan city, which is located 12 km north of the current city of Aswan on the western bank of the Nile. New Aswan is located in the desert zone (24.1° N–32.9° E). This climate is considered BWh according to the Köppen–Geiger climate classification. The annual mean temperature is 25.9 °C. In summer, however, the maximum air temperature exceeds 40 °C. In addition, the average annual precipitation is 1 mm [23]. Following the new urban expansion in New Aswan, it is anticipated that up to one million residents will have access to social housing in the coming years. As a result, the city intended to provide its residents with various social services. The city club complex is one of the social services mentioned. It was designed in numerous Egyptian cities, each with their own distinct characteristics. Figure 1 illustrates the club's location, with the investigated building highlighted.

(a)　　　　　　　　　　　　　　　　　(b)

Figure 1. The investigated building location: (**a**) the location of the city club complex in relation to New Aswan city; (**b**) the intended building on the planned site of the city club complex.

The club consisted of three main buildings in addition to numerous football, basketball, handball, and swimming pool areas. The investigated building was intended to serve as a social hub for a variety of activities. The ground floor, for instance, was destined to be a restaurant. The investigated building had a surface area of approximately 1056 m². The building consisted of three floors and had a rectangular shape. The first and second floors were designed as salons and festival halls, respectively. The roof was utilized as an

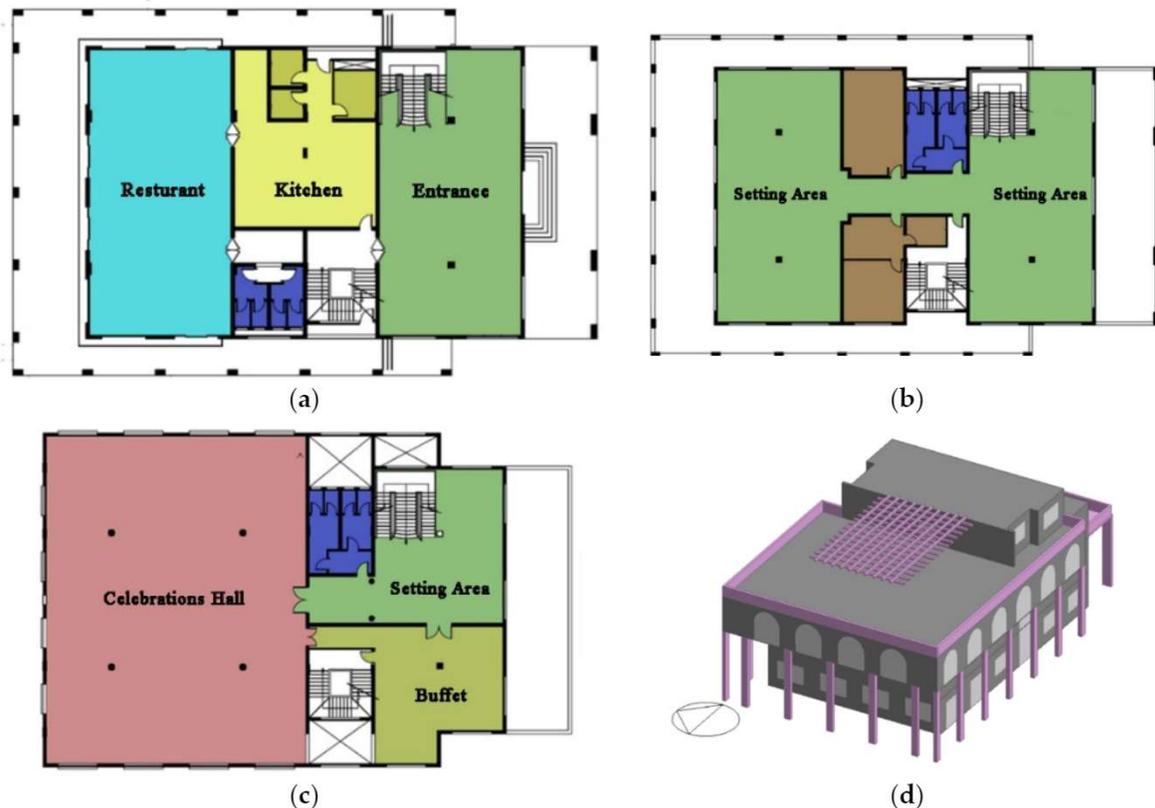open area. Figure 2 displays all the architectural drawings for the building plans and the isometric model.

Figure 2. The building drawings: (**a**) the ground floor; (**b**) the first floor; (**c**) the second floor; (**d**) the isometric model.

2.2. Meteorological Data and Study Framework

This study applied simulation software to assess the impact of various outside wall options. The study used climate data from New Aswan city to represent Egypt's hot desert climate. In addition, the simulation was conducted both with and without air conditioning. Hourly weather data for the year 2021 were obtained from the weather station placed in the Aswan University (Hobo U30). The data were collected as a CSV file that was recently converted by EnergyPlus to a different file format (EnergyPlus weather data file epw), making it compatible with the simulation Design Builder software V5.5.2.007 (Design Builder Software Ltd., London, UK), which is a simulation program with an easy-to-use interface that employs EnergyPlus as its sophisticated simulation engine. It could compute the annual energy required for cooling in each of the options under consideration and assess the thermal condition of each interior space.

The framework of the study is depicted in Figure 3. Modeling, simulation software input, and an economic evaluation were all included in the framework of this study. In this regard, six models represent the proposed exterior wall options that were modeled in the first stage by loading a 2D drawing file in dxf format into the Design Builder software. In the second step, Design Builder was provided with a variety of data, including occupant activities, schedule, construction and openings, and HVAC data. In addition, as stated previously, simulation software was supplied with actual climate conditions gathered from the Aswan University weather station (Hobo U30).
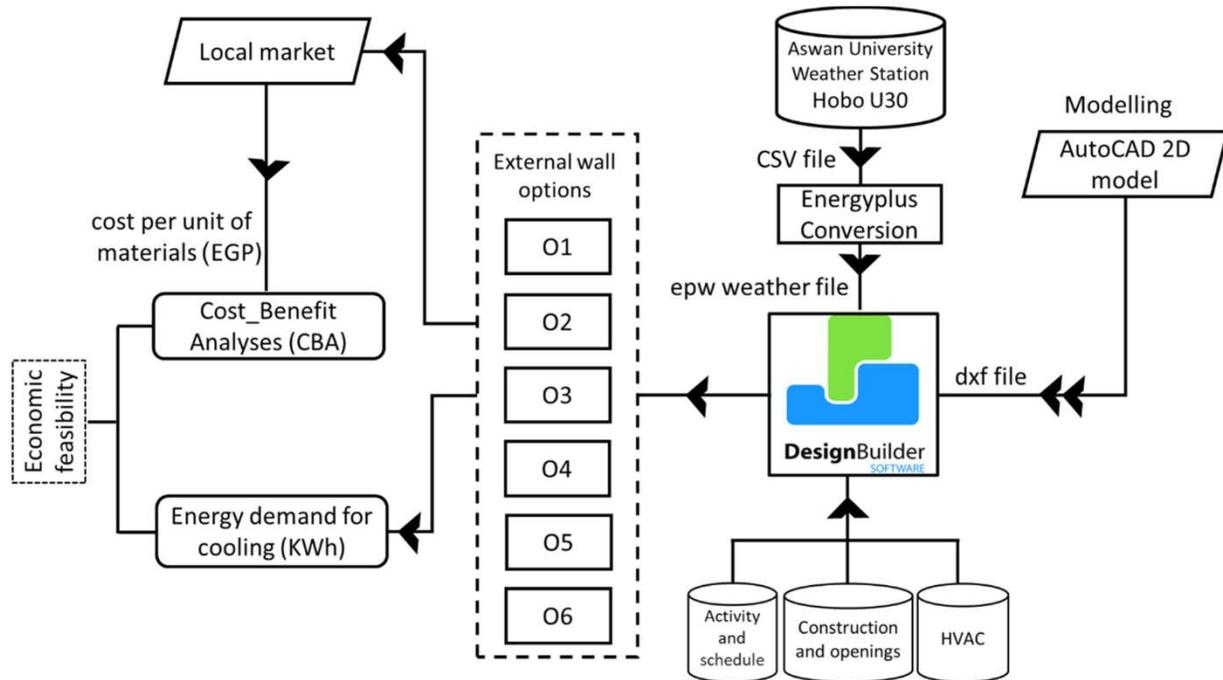
Figure 3. Schematic diagram of the study framework.

The building schedule was established using a set of predetermined activities based on information gathered from the club administration, including occupancy hours and the number of people who had previously entered the building. The building was occupied every weekday during the summer from 9 a.m. to 12 a.m. Even though the club was open for fewer hours during the winter, it was typically busy until 11 p.m. In addition, the building was occupied every day of the year, including in the holidays.

2.3. Model Validation

The Hobo U12 was utilized to measure climate variables, including the air temperature and the relative humidity. On the first floor, measurements were taken in the sitting area. The air temperatures of the first and the last floors were not studied because the first floor was almost entirely affected by ground surface reflection. Moreover, the top floor also was exposed to direct solar radiation [24,25].

Measurements were collected over the duration of the first eight days of July 2021, which represents a typical summer week in New Aswan city. On the other hand, the building was modeled in the simulation software (Design Builder), with consideration of all architectural features, such as the wall and roof openings, as well as the construction details. To make the simulation software more realistic, the building's schedule, activities, and HVAC settings were provided.

The simulation model was validated by comparing the simulation results to measurements, in accordance with ASHRAE guideline 14-2002 [26]. The average inaccuracy of the thermal simulation findings was 14.64%. Table 1 gives details on the simulation input data and assumptions for the studied building. Figure 4 shows a comparison between the simulation and experimental results.

Table 1. The simulation input data and assumptions of the study model.

Item	Specification
Type	Communal social hub
Location	New Aswan city
Floor area (m^2)	1056
NO of floors	3
Floor height (m)	4
Density (people/m^2)	0.2
Windows glazing	Single-glazed (6 mm)
(HVAC)	split air conditioning for each space
Cooling set-point	25 °C
Heating set-point	18 °C

(**a**)
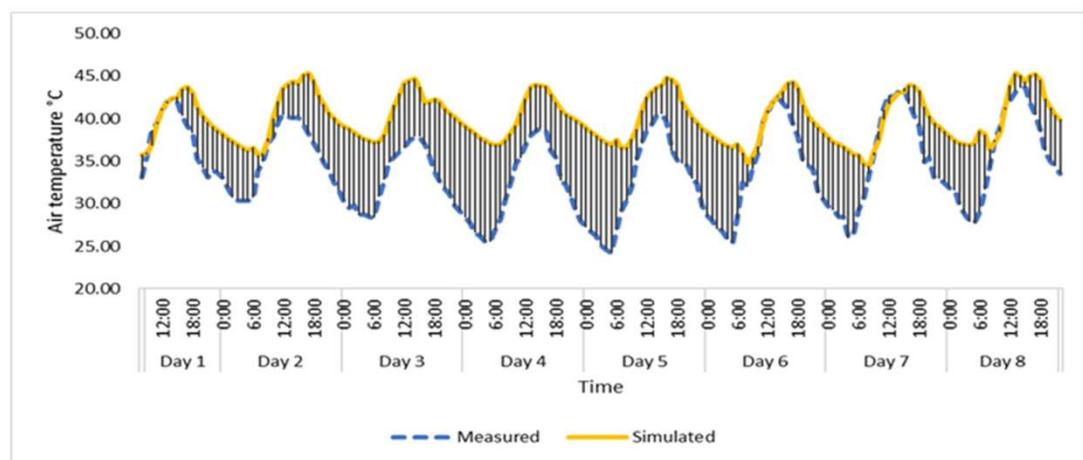
(**b**)

Figure 4. The validation process for the model: (**a**) the weather station at Aswan University (Hobo U30), (**b**) the plotted results for the measured and simulated data.

2.4. Description of the Proposed Wall Options

The study focused on the material layers of the external walls that influence heat transfer from the exterior to the interior spaces. Six options were studied using the Design Builder simulation software to prevent heat gain and to reduce the energy required for cooling in the communal social hub in the city club located in New Aswan city. In Egypt, the first option (O1) was the most popular wall layer. The option (O1) was used as the standard against which other options can be compared. The first option (O1) was developed to generate the second option (O2), consisting of five layers in the following order: cement plaster, cement brick, air cavity, cement brick, and cement plaster. The third option (O3) differed significantly from the previous two. Due to the use of the thinner outermost and innermost layer materials, i.e., glass fiber-reinforced concrete (GRC), it had a small thickness (0.17 m). Glasswool was sandwiched between these two layers. The fourth option (O4) and the third option (O3) differed as the middle layer was made of foam rather than glasswool. (O3) and (O4) generated the fifth (O5) and sixth (O6) options, respectively. In these options, common layering materials such as cement plaster and cement brick were combined with GRC and common insulation materials (e.g., foam and glasswool). The characteristics of the proposed external wall cross-sections are mapped out in Figure 5. In addition, Table 2 displays the thermal properties of the proposed exterior wall options.
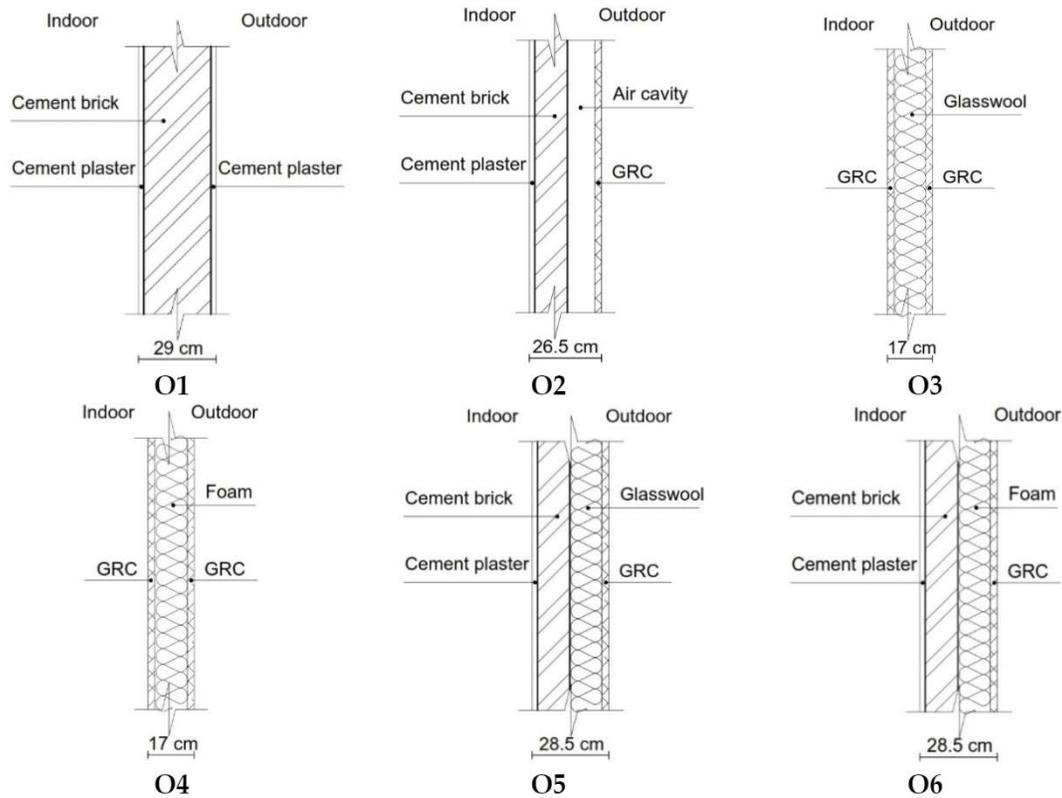
Figure 5. Characteristics of the wall section options.

Table 2. The most important thermal properties of the proposed external wall options.

Material Name	Abb.	Thickness (m)	Density (kg/m³)	Thermal Conductivity (W/mK)	Specific Heat (J/kg K)	Thermal Resistance (m² K/W)	Total Thermal Resistance (R_t) (m² K/W)	U-Value (W/m² K)
Cement plaster		0.02	1762	0.721	840	0.028		
Cement brick	O1	0.25	600	0.752	1000	0.332	0.558	1.793
Cement plaster		0.02	1762	0.721	840	0.028		
Cement plaster		0.02	1762	0.721	840	0.028		
Cement brick		0.12	600	0.752	1000	0.159		
Air cavity	O2	0.1	1000	0.3	1000	0.333	0.575	1.74
GRC		0.025	2000	0.67	1100	0.037		
GRC		0.025	2000	0.67	1100	0.015		
Glasswool	O3	0.12	120	0.03	840	4	4.237	0.236
GRC		0.025	2000	0.67	1100	0.037		
GRC		0.025	2000	0.67	1100	0.037		
Foam	O4	0.12	20	0.035	1400	1.667	3.676	0.272
GRC		0.025	2000	0.67	1100	0.037		
Cement plaster		0.02	1762	0.721	840	0.028		
Cement brick		0.12	600	0.752	1000	0.159		
Glasswool	O5	0.12	120	0.03	840	4	4.386	0.228
GRC		0.025	2000	0.67	1100	0.037		
Cement plaster		0.02	1762	0.721	840	0.028		
Cement brick		0.12	600	0.752	1000	0.159		
Foam	O6	0.12	20	0.035	1400	1.667	4.292	0.233
GRC		0.025	2000	0.67	1100	0.037		

3. Results and Discussion

In order to evaluate the findings of this study, the primary outputs that were obtained will serve as the basis for further investigation in the building that was studied and that correlates to the various design characteristics. These outputs consist of the indoor thermal conditions, the potential energy savings for cooling purposes (kWh), and the economic feasibility of the various proposed options. In the two parts that follow, the implications of each design variable on the outputs were broken down and discussed individually.

3.1. The Effect of Proposed Design Options on the Indoor Thermal Conditions

As stated before, the simulation was conducted both with and without using the air conditioning. In the initial phase of the simulation, air conditioning was not used. The results indicate that all proposed exterior wall construction alternatives were less efficient. All GRC options were compared to the common wall option (O1) based on monthly mean indoor air temperatures. Throughout the year, the indoor monthly mean air temperatures were found to be consistently higher than dry-bulb temperatures (Figure 6). Furthermore, the following notes were observed:

▪ The indoor monthly mean air temperatures were only completely positioned in the thermal comfort zone for three months (January, February, and December). In March and November, only four options provided thermal comfort (O5, O6, O3, and O4).

▪ All alternatives were less efficient without air conditioning. However, among the examined options, O5 and O6 were the most successful.

▪ As previously demonstrated, New Aswan utilized more energy for cooling during the hottest months. Consequently, none of the investigated options could provide thermal comfort without the use of air conditioning, as the majority of passive climate solutions do. This result is consistent with previous studies [27].
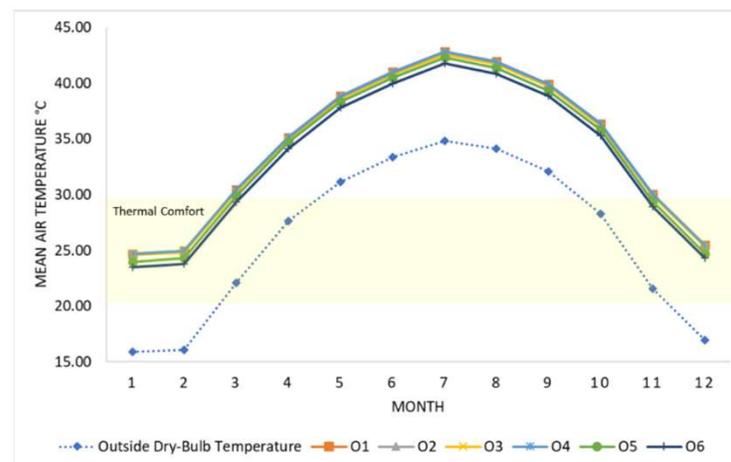

Figure 6. The monthly mean air temperature in the salon in terms of internal thermal conditions without using air conditioners.

Using air conditioner units in the second phase, the impact of the proposed external wall construction options (O1, O2, O3, O4, O5, and O6) on the internal thermal conditions was investigated. In Figure 7, the simulation results, including all studied options for external wall construction building, are presented in two graphs. These graphs are as follows. Subgraph (a) compares the mean air temperature in the salon space on the first floor and with south-west orientation to the dry-bulb temperature for each proposed option. Subgraph (b) shows the improvement rate in the hottest months during the period between April and October. For the reasons stated in the model validation section, the first floor was chosen to be evaluated in terms of air temperature reduction. The obtained air temperature values were taken on 2 July 2021, one of the hottest days of the year [28]. In terms of the average air temperature, the results of the simulations for the six used options can be broken down as follows:

▪ Regarding the mean air temperature inside the investigated building, all studied options showed nearly the same trend, with some options showing a minor improvement in their performance. In addition, the mean air temperature values were lower than the outside dry bulb temperature in all studied options from April to October, while it was higher in the other months.

- All the studied external wall options provided adequate thermal comfort for the occupants throughout the year. The average air temperature ranged from 21.6 °C to 29.1 °C.
- In general, the simulations generated satisfactory results, exhibiting that (O5) has the best thermal performance and monthly energy consumption and, as a result, the best total annual energy cost among other options.
- Following (O5), it was noticed that (O6), (O3), and (O4) demonstrate the best results in terms of the mean air temperature, the monthly energy needed for cooling, and hence the annual energy cost.
- Among the investigated options, (O2) was the least efficient option. It had the highest mean temperature variations of more than 28 °C from May to September.
- Focusing on the months between April and October, compared to outside dry bulb temperature, (O5) improved the mean air temperature by 8.93%, 15.76%, 19.74%, 21.96%, 21.11%, 17.64%, and 10.83% for the months from April to October, respectively.
- In terms of the mean air temperature, (O6) was the second best option, with an improvement rate ranging from 7.84% to 20.79%. (O2) had the lowest improvement rate, with improvements ranging from 2.55% to 16.37%.
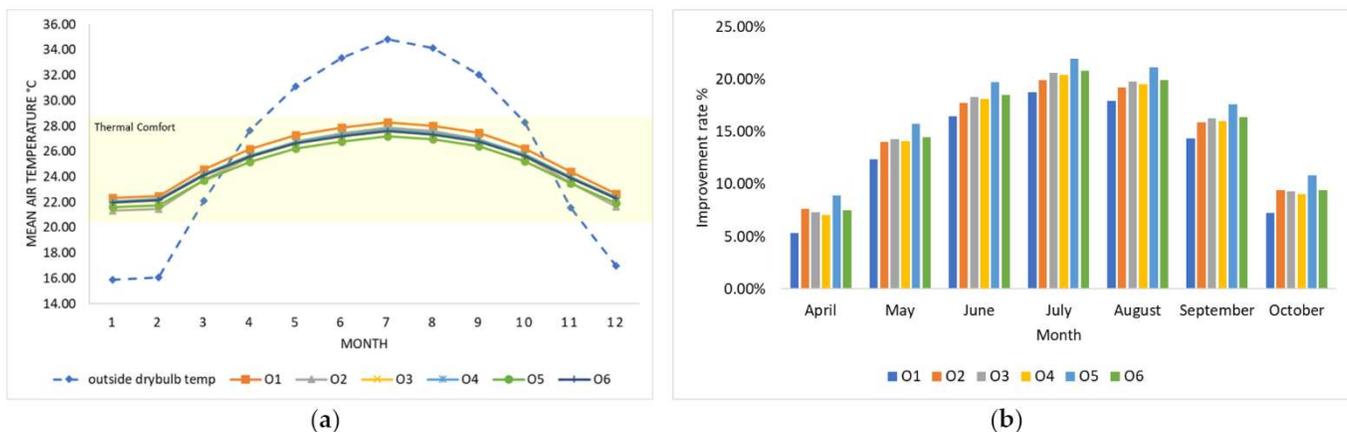

(**a**)   (**b**)

Figure 7. The simulation results in terms of internal thermal conditions using air conditioners: (**a**) the monthly mean air temperature in the salon; (**b**) the improvement rate for the studied options in the hot time of the year.

3.2. The Effect of Proposed Design Options on the Energy Required for Cooling

The results of the energy demand for cooling are shown in Figure 8. It was divided into four subgraphs. Graph (a) shows the monthly energy required for cooling in the investigated external wall options, whereas graph (b) depicts the annual energy consumption (kWh) based on the U value (W/m^2 K). Graph (c) presents the annual improvement rate compared to the common wall cross-section (O1) and recent graph (d) displays the annual energy cost in Egyptian Pounds (EGPs) based on household electricity tariffs. The results show that, as anticipated, the cost increased rapidly in tandem with the increase in energy consumption. Furthermore, it was observed that all of the options under consideration followed a similar trend with noticeably different values. According to monthly results, the most achievements occurred during the summer months. On the other hand, annual cooling energy consumption increased significantly. The simulation results, in terms of the energy required for cooling, can be summarized as follows:

- As presented in Figure 8a, the monthly results show that (O5) performed slightly better than O6 in all months. However, (O2), which presents the integration of GRC and the common brick layer with an air cavity in between, had the worst performance among the options containing GRC material.
- Despite the use of GRC material, the monthly energy required for cooling increased dramatically in the case of (O2). This may be because the U value was high, and there

was a heat trap between the GRC and the common brick layer in the external wall option that lacked ventilation.

- The U value significantly impacted the energy demand for cooling in the studied area, as shown in Figure 8b. With R2 = 0.8961, a clear relationship between the U value and cooling energy demand was discovered. This means that U values could be responsible for more than 89% of the energy consumption for cooling purposes, as they play a key role in reducing heat transfer from the exterior to the interior spaces, lowering the amount of energy required for cooling.

- As shown in Figure 8c, (O1) was used as a benchmark against which the other options were compared. The annual energy needed for cooling in the case of using (O5) was the most efficient option among the studied options, with a 41.21% improvement rate. Then there is (O6), which enhances energy efficiency by 37.96%. (O3) and (O4) performed similarly, with (O3) exhibiting slightly higher efficiency, increasing energy efficiency by 31.24%. Among the options studied, including the reference option (O1), (O2) was the least efficient. With an improvement rate of 9.43%, (O2) was the least efficient advised option.

- As shown in Figure 8d, the amount of energy used for cooling had a greater impact on energy costs (EGP). The best performance was in (O5), which was followed by (O6), (O3), and (O4) in that order.
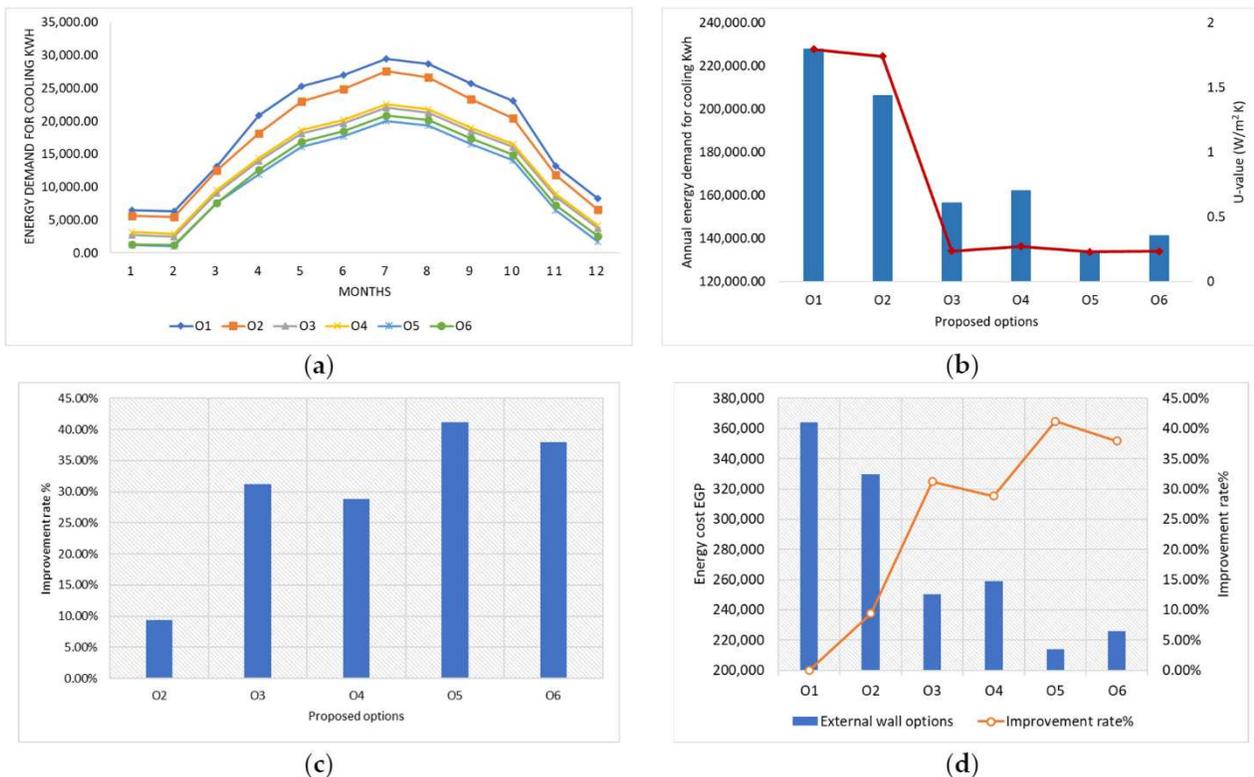

Figure 8. Simulation results in terms of energy required for cooling: (**a**) the monthly energy needed for cooling; (**b**) the annual energy demand for each option; (**c**) the improvement rate for the studied options; (**d**) the annual energy cost per (EGP).

Because of the important and urgent need to minimize building energy consumption, the thickness of thermal insulation materials has steadily increased over time [29,30]. Insulation thickness has steadily increased in some northern European countries. This restriction has significant economic and technical implications. Because of the increased thickness, existing buildings will have less available internal space and will have higher insulation costs. In that context, optimizing the building envelope materials to reduce the interior temperature to keep the thermal comfort inside the building within the acceptable

range remains a key concern associated with reducing the energy required for cooling [31]. This is due to the conductivity of building materials which has a significant impact on heat transfer, particularly through external walls.

Using GRC in conjunction with thermal insulation materials could be a beneficial way to reduce the thickness of external walls, while also minimizing the U value and lowering the amount of energy required for cooling. However, due to the estimated cost, which was higher than the common building envelope, it could not be used in all building types [30]. Moreover, even though the initial cost of the material was higher when using GRC materials, the energy cost may be lower than with a common building envelope. A cost analysis using the simple payback period (SPP) method was used to assess the economic efficiency of each proposed option. This method could aid designers in finding suitable materials for external walls.

3.3. The Cost–Benefit Analyses (CBAs) of Proposed Design Options

Despite the new trend in Egyptian buildings toward passive climate solutions, cost-effectiveness remains a major barrier to implementation. Decision-makers can use cost–benefit analysis (CBA) to weigh up the benefits and drawbacks of various available options in a data-driven manner, allowing them to make complex decisions in a systematic manner. Several methods were previously used to assess the economic feasibility of the available opportunities. A simple payback period (SPP) was used in several papers to assess the proposed alternatives [30,32,33]. The simple payback period (SPP) is a tool used for determining the time required to recoup a financial investment. If that criterion is important to the decision-makers, this type of analysis allows them to compare different options for investment opportunities and select one that returns their investment in the shortest amount of time.

While the study's findings indicate that the proposed GRC walls could save energy, it was also necessary to assess their financial benefits in terms of both energy and cost savings. As a result, a cost analysis (in EGP) was carried out, and the additional investment for each of the five options was calculated. For the proposed options, the main components of the construction cost were calculated. Because of its poor performance in terms of energy savings, (O1) was used as a benchmark. The additional investments, as well as the simple payback period (in years), were calculated as follows [33]:

Additional investment = the total material cost of each proposed GRC walls option − the total material cost of (O2).

$$SPP = \frac{Additional\ investment}{Annual\ energy\ saving}$$

The common wall and GRC options' unit costs (EGP/m^2) were collected from the local market (Arab Contractor Company, Egypt). The prices are stated in Table 3.

Table 3. The cost per unit of materials (source: Arab Contractor Company, Egypt).

Materials	Unit Cost EGP/m^2
Cement plaster	100
Cement brick	500
GRC	2000
Glasswool	50
Foam	100

The total annual energy costs, construction costs, annual savings, and SPP for each option are shown in Table 4. Option 5 (cement plaster, cement brick, glasswool, and GRC) appears to be the most promising in terms of energy conservation. It is the shortest, with an SPP of 10.86 years. In terms of SPP value, (O6) (cement plaster, cement brick, foam, and GRC) comes in second (12.09 years). Because of their energy efficiency, economic viability, and low SPP, adding GRC embedded with glasswool or foam to an external wall would

be the best option among the options compared. Furthermore, (O3) and (O4) seem to be inefficient options due to the high initial cost of GRC material in Egypt.

Table 4. Summary of the cost–benefit analyses (CBAs).

Options	Wall Cost (EGP)	Additional Investment (EGP)	Energy Cost (EGP/year)	Annual Saving (EGP/year)	SPP (year)
O2	2,171,426.4	1,586,811.6	329,698.60	34,342.57	46.21
O3	3,382,414.2	2,797,799.4	250,327.61	113,713.56	24.60
O4	3,424,172.4	2,839,557.6	259,091.88	104,949.30	27.06
O5	2,213,184.6	1,628,569.8	214,036.59	150,004.59	10.86
O6	2,254,942.8	1,670,328	225,842.24	138,198.93	12.09

4. Conclusions

This research looked at the effects of six various options for exterior walls on cooling energy requirements, mean air temperatures, and energy costs. Simulations (Design Builder) and field observations support this study's findings. As a result, the findings show the impact of the diversity of thermal properties for each material on the energy efficiency in buildings. In conclusion, the study presents several remarks, summarized as follows:

- Thermal performance could be improved using a glass fiber-reinforced cement (GRC) material and an insulating material as the third and fourth wall options, rather than using GRC material and cement brick with a vacuum between them. An explanation for this discovery might be found in the second wall option's high U value (GRC material followed by air cavity, cement brick, and cement plaster), as well as a heat trap in the air cavity layer and a lack of apertures in the cross-sectional layers of the wall themselves.
- Embedded GRC materials with insulation materials could improve thermal and energy efficiency while expanding the area of interior spaces due to their thinner thickness compared to conventional exterior walls.
- The fifth wall option (O5), which represents an external wall option with the following layers: (cement plaster, cement brick, glasswool, and GRC), was proven to be the most energy-efficient option in terms of internal thermal conditions and required cooling energy, with an improvement rate of approximately 41.21%. Moreover, the fifth option (O5) was the most economically feasible option among those examined, with a simple payback period of roughly 11 years.

Future research could be conducted to reduce the need for thicker envelopes and suggest novel materials that could reduce the amount of energy needed to cool space while preserving a comfortable temperature for a large number of people.

Author Contributions: Conceptualization, A.R. and O.H.; methodology, M.H.H.A. and A.R.; software, A.R.; validation, M.H.H.A. and O.H.; formal analysis, A.R. and O.H.; investigation, A.R. and O.H.; resources, M.A. (Mohammed Alshenaifi) and E.N.; data curation, M.A. (Mohammed Alshenaifi), K.E. and E.N.; writing—original draft preparation, A.R.; writing—review and editing, M.H.H.A. and M.T.; visualization, M.A. (Mohammed Alghaseb) and K.E.; supervision, M.H.H.A. and A.R.; project administration, M.H.H.A.; funding acquisition, M.H.H.A. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1.　AbdelAzim, A.I.; Ibrahim, A.M.; Aboul-Zahab, E.M. Development of an energy efficiency rating system for existing buildings using Analytic Hierarchy Process–The case of Egypt. *Renew. Sustain. Energy Rev.* **2017**, *71*, 414–425. [CrossRef]
2.　Mahmoud, A. The Influence of Buildings Proportions and Orientations on Energy Demand for Cooling in Hot Arid Climate. *SVU-Int. J. Eng. Sci. Appl.* **2022**, *3*, 8–20. [CrossRef]
3.　Ahmad, R.M.; Reffat, R.M. A comparative study of various daylighting systems in office buildings for improving energy efficiency in Egypt. *J. Build. Eng.* **2018**, *18*, 360–376. [CrossRef]
4.　Alsaadani, S. A statistical review of a decade of residential energy research in Egypt. *Energy Rep.* **2022**, *8*, 95–102. [CrossRef]
5.　Aly, A.M.; Hassn, M.H.; Abdel Rady, Y.R.; Mohammed, A.T. The effect of using nano-materials in external openings on energy consumption in hot desert climate. JES. *J. Eng. Sci.* **2020**, *48*, 468–477. [CrossRef]
6.　Calise, F.; Cappiello, F.L.; Vicidomini, M.; Song, J.; Pantaleo, A.M.; Abdelhady, S.; Shaban, A.; Markides, C.N. Energy and economic assessment of energy efficiency options for energy districts: Case studies in Italy and Egypt. *Energies* **2021**, *14*, 1012. [CrossRef]
7.　Mahmoud, A.R.A.; Aly, A.M.; Hassan, M.H. Evaluating the Thermal Performance of Urban Spaces in Aswan City "A Case Study of Saad Zaghloul Street. *J. Eng. Sci.* **2015**, *43*, 766–782. [CrossRef]
8.　Ragab Abdel Radi, A. The impact of phase change materials on the buildings enegy efficiency in the hot desert areas the annexed rooms of the traffic building in new aswan city as a case study. *J. Eng. Sci.* **2020**, *48*, 302–316. [CrossRef]
9.　Dabaieh, M.; Wanas, O.; Hegazy, M.A.; Johansson, E. Reducing cooling demands in a hot dry climate: A simulation study for non-insulated passive cool roof thermal performance in residential buildings. *Energy Build.* **2015**, *89*, 142–152. [CrossRef]
10.　Radwan, A.F.; Hanafy, A.A.; Elhelw, M.; El-Sayed, A.E.H.A. Retrofitting of existing buildings to achieve better energy-efficiency in commercial building case study: Hospital in Egypt. *Alex. Eng. J.* **2016**, *55*, 3061–3071. [CrossRef]
11.　Fahmy, M.; Mahdy, M.M.; Nikolopoulou, M. Prediction of future energy consumption reduction using GRC envelope optimization for residential buildings in Egypt. *Energy Build.* **2014**, *70*, 186–193. [CrossRef]
12.　Poděbradská, J.; Černý, R.; Drchalová, J.; Rovnaníková, P.; Šesták, J. Analysis of glass fiber reinforced cement composites and their thermal and hygric material parameters. *J. Therm. Anal. Calorim.* **2004**, *77*, 85–97. [CrossRef]
13.　Abdi Moghadam, M.; Izadifard, R.A. Effects of steel and glass fibers on mechanical and durability properties of concrete exposed to high temperatures. *Fire Saf. J.* **2020**, *113*, 102978. [CrossRef]
14.　Sakthivel, M.; Vijayakumar, S.; Ramnath, B.V. Investigation on Mechanical and Thermal Properties of Stainless Steel Wire Mesh-Glass Fibre Reinforced Polymer Composite. *Silicon* **2018**, *10*, 2643–2651. [CrossRef]
15.　Xiao, X.; Hu, S.; Zhai, J.; Chen, T.; Mai, Y. Thermal properties and combustion behaviors of flame-retarded glass fiber-reinforced polyamide 6 with piperazine pyrophosphate and aluminum hypophosphite. *J. Therm. Anal. Calorim.* **2016**, *125*, 175–185. [CrossRef]
16.　Zhou, C.; Shi, S.Q.; Chen, Z.; Cai, L.; Smith, L. Comparative environmental life cycle assessment of fiber reinforced cement panel between kenaf and glass fibers. *J. Clean. Prod.* **2018**, *200*, 196–204. [CrossRef]
17.　Blazy, J.; Blazy, R.; Drobiec, Ł. Glass Fiber Reinforced Concrete as a Durable and Enhanced Material for Structural and Architectural Elements in Smart City-A Review. *Materials* **2022**, *15*, 2754. [CrossRef]
18.　Nagy, B.; Nehme, S.G.; Szagri, D. Thermal properties and modeling of fiber reinforced concretes. *Energy Procedia* **2015**, *78*, 2742–2747. [CrossRef]
19.　Wang, W.C.; Wang, H.Y.; Chang, K.H.; Wang, S.Y. Effect of high temperature on the strength and thermal conductivity of glass fiber concrete. *Constr. Build. Mater.* **2020**, *245*, 118387. [CrossRef]
20.　Zhu, C.Y.; Gu, Z.K.; Xu, H.B.; Ding, B.; Gong, L.; Li, Z.Y. The effective thermal conductivity of coated/uncoated fiber-reinforced composites with different fiber arrangements. *Energy* **2021**, *230*, 120756. [CrossRef]
21.　Tuncel, E.Y.; Pekmezci, B.Y. Performance of glass fiber-reinforced cement composites containing phase change materials. *Environ. Prog. Sustain. Energy* **2019**, *38*, e13061. [CrossRef]
22.　Gandia, R.M.; Gomes, F.C.; Corrêa, A.A.R.; Rodrigues, M.C.; Mendes, R.F. Physical, mechanical and thermal behavior of adobe stabilized with glass fiber reinforced polymer waste. *Constr. Build. Mater.* **2019**, *222*, 168–182. [CrossRef]
23.　Hess, D.; Tasa, D. *McKnight's Physical Geography: A Landscape Appreciation*; Prentice Hall: Upper Saddle River, NJ, USA, 2011; p. 688.
24.　Mahmoud, H.; Ragab, A. Impact of Urban Geometry on Cooling Loads in Egypt: Case study: A social residential compound in New Aswan City. In Proceedings of the 2020 9th International Conference on Power Science and Engineering (ICPSE), London, UK, 23–25 October 2020; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2020; pp. 71–75. [CrossRef]
25.　Mahmoud, H.; Ragab, A. Urban geometry optimization to mitigate climate change: Towards energy-efficient buildings. *Sustainability* **2020**, *13*, 27. [CrossRef]
26.　ANSI/ASHRAE. *ASHRAE Guideline 14-2002 Measurement of Energy and Demand Savings*; ASHRAE: Atlanta, GA, USA, 2002; Volume 8400, p. 170.
27.　Abd Elrady, A.R.; Hassan, M.H. Conservation of morphological characters as an approach to thermal comfort. In *Vernacular Architecture: Towards a Sustainable Future*; CRC Press: Boca Raton, FL, USA, 2014; pp. 15–20. [CrossRef]
28.　Sameh 2014, S.H.; Kamel, B. A framework to promote energy efficiency as a solution to the energy problem in Egypt. *Energy Power Eng.* **2017**, *9*, 187. [CrossRef]

29. Pacheco Torgal, F. Introduction to nano- and biotech-based materials for energy building efficiency. In *Nano and Biotech Based Materials for Energy Building Efficiency*; Springer International Publishing: Berlin/Heidelberg, Germany, 2016; pp. 1–16. [CrossRef]

30. Abdelrady, A.; Abdelhafez, M.H.H.; Ragab, A. Use of insulation based on nanomaterials to improve energy efficiency of residential buildings in a hot desert climate. *Sustainability* **2021**, *13*, 5266. [CrossRef]

31. Mahmoud, A. Investigating the Impact of Different Glazing Types on the Energy Performance in Hot Arid Climate. *J. Adv. Eng. Trends* **2022**, *42*, 69–84. [CrossRef]

32. Ragab, A.; Abdelrady, A. Impact of green roofs on energy demand for cooling in egyptian buildings. *Sustainability* **2020**, *12*, 5729. [CrossRef]

33. Abdul Mujeebu, M.; Ashraf, N.; Alsuwayigh, A. Energy performance and economic viability of nano aerogel glazing and nano vacuum insulation panel in multi-story office building. *Energy* **2016**, *113*, 949–956. [CrossRef]