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Towards a Sustainable Economical Housing Model in the Hot and Dry Region of Egypt

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Abstract

The sustainable economic design aims to meet the need for environmentally sustainable housing that provides thermal comfort without depleting energy and resources. This paper proposes a methodology for achieving an economically sustainable residential model that optimizes energy uses and maximizes resource efficiency to achieve the best environmental performance at the lowest possible economic cost. The theoretical foundation of this research paper explores the relationship between sustainable housing and reducing economic costs and climate-appropriate treatments for residential buildings in hot, dry regions. And in its practical section, the research paper addressed an applied study for evaluating and developing one of the housing models in Egypt's hot, dry region, that is The National Housing Project. By testing the effect of different climate treatments on thermal comfort and the economic cost of using the study model in the long term. This was carried out using the simulation and modeling program (Design Builder) to achieve an economically sustainable residential model that achieves maximum energy and resource efficiency and the best environmental performance at the lowest possible economic cost. To achieve the objectives of this research paper, the study relied on both inductive and deductive methods in the theoretical and analytical aspects and applied those methods using simulation software. The research concludes by extracting the results and proposing appropriate recommendations to reach an economically sustainable housing model in Egypt's hot, dry region.

1. Introduction

The design of economic housing Should focus on three main factors of design; first the economic factor and economic feasibility, secondly the social factor and the attempt to improve the standard of living for residents, and additionally the third factor is environmental which deals with attempting to achieve thermal comfort and climate compatibility. By balancing the relationship between these three factors, an optimal and realistic solution for low-cost environmental housing could be achieved. The economic factor is considered the most important of these three factors, particularly in societies suffering from energy and resource shortages. Working towards an economical environmental solution in the short and long term is one of the most important ways for achieving success in economic housing projects.

2.Research Problem

The research problem lies in the absence of the rules and principles of sustainable design for residential buildings, which has led to dysfunctional buildings from an environmental and economic perspective suffering from a lack of efficiency and an increase in energy consumption, making the residential sector the largest consumer of electricity with 41% of the total consumption of electrical energy in Egypt [1].

3.Research Aims

The main objective of this research is to reach a housing model that achieves maximum energy and resource efficiency and the best environmental performance at the lowest possible economic cost, in addition to:

-Monitoring and identifying sustainable treatments that achieve energy efficiency in the housing sector.
-Studying the relationship between economic cost and achieving thermal comfort in residential buildings.
-Reducing energy consumption in residential buildings over the assumed lifespan.

4.Methodology

The methodology adopted in this research paper relied on the analytical method based on induction and deduction, to gather data and basic theoretical concepts related to the study topic through reviewing previous academic research and studies. It clarified the logical progression to reach an environmentally sustainable and economically efficient housing model and achieve thermal comfort in residential buildings from theoretical perspectives, including:

-Studying the relationship between housing sustainability and cost reduction.
-Identifying sustainable climate solutions suitable for residential buildings in hot and dry regions.

-Studying the economic cost and evaluation methods of climate - solutions.

-Identifying simulation and modeling program (Design Builder), which was selected because it contributes to two areas of building information modeling (BIM), which are energy consumption and sustainability, which are the areas concerned in this study[2]. Moreover, the program's high-performance speed and high-quality results were also considered[3]. The study begins by analyzing the current situation of thermal comfort and energy consumption for the residential model using the simulation program. Then, the impact of integrating climate treatments into the housing model in the study area is studied by determining a set of constants and variables for practical study and determining the effect of each variable on thermal comfort in turn. Then, the effect of the variables with the best impact in parallel is studied. This is followed by studying energy consumption and the economic cost of the proposed model, comparing it to the existing model in terms of thermal comfort, energy consumption, and economic cost over the short and long term. Finally, a set of results are extracted from the research and some recommendations are proposed to help achieve an economic and sustainable housing model that achieves thermal comfort and economic efficiency in Egypt’s hot, dry region.

The study relied on the following to achieve the research objectives:

-Testing the accuracy of the simulation software by validating it and determining the error rate in calculating energy consumption.

-Selecting sustainable design solutions suitable for low-income residents housing based on theoretical studies.

-Calculating the economic cost of operation cost based on prices in September of the base year 2022.

-The impact of artificial lighting on energy consumption in the cooling and heating process was calculated but will not be included in the cost comparison.

The study area and model were chosen for the following reasons:

4.1 Study Area

-Minya Governorate is located in a prominent and central location among the cities of Upper Egypt.

-The climate is extremely challenging, as Minya is one of the most exposed areas in Egypt to significant temperature extremes [4].

-Lack of environmental climate control systems in buildings, especially residential buildings in the city of New Minya.

-The proximity of New Minya city to the researchers’ working area makes it easy to conduct field visits, resulting in more accurate research outcomes.

Based on this, New Minya city has been chosen as the area of study.

4.2Study model

The model of the National Housing buildings was chosen for the following reasons:

- It represents the largest proportion of the total number of housing units for low-income citizens in New Minya city, accounting for 22.5%[5]. It is the highest in number and the largest in electricity consumption[6].

Figure (1) shows National Housing in the Sixth Neighborhood in the City

Figure (1) National Housing in the sixth neighborhood in the city[5]

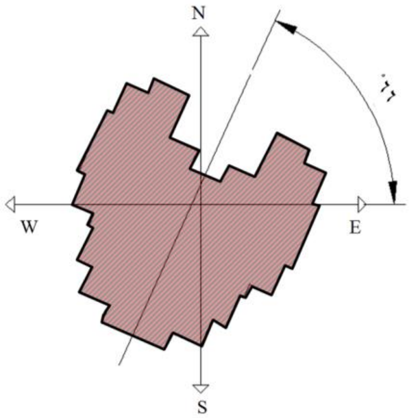

Figure (2) Actual orientation for the case study

The model is located in the sixth district, consisting of 58 residential buildings with one design model, in addition to six residential buildings with another design model. The most frequently repeated building in terms of orientation in the residential area was chosen, as shown in Figure (2). Table (1) shows the indicators and criteria for selecting the study model.

Table (1) Indicators and criteria for selecting the study model[5]

Housing type	sustainability standards		Energy consumption			occupation level			Residential complex		
	unavailable	available	low	middle	high	low	middle	high	small	middle	big

Youth Housing	•				•			•			•
Future Housing	•				•			•			•
Developed economist	•				•			•	•		
National housing	•				•			•			•
Cooperative housing	•		•			•					•
economic housing	•				•		•		•		
social housing	•		•			•					•
-National housing Zahraa Minia city	•		•			•					•

And the proposed methodology was developed by identifying a set of constants and variables as follows:

4.3 Constants of Study:

-The climatic region: New Minya city in the hot dry region of Egypt.
-The model used: a building in the National Housing Project in the Sixth District of New Minya city, which is a unified model for national housing buildings that have been applied throughout the Arab Republic of Egypt without taking into account the climate and site characteristics.
-The average number of users per a housing unit is 5 individuals.
-The economic cost is calculated for the duration of fifty years, which is the assumed lifespan of the building.

4.4Variables of the Improvement Study:

Variables of the improvement study are sustainable architectural climatic treatments suitable for the study's case in the hot dry region.

5. Principles of Economic Design for Sustainable Buildings

Suitable living spaces for humans should provide people with privacy, a sense of ownership, spaciousness for daily activities and basic human needs, and at the same time, operating cost should be appropriate for the purchasing power of the targeted population. Suitability should meet the needs and aspirations of inhabitants while taking into account the constant progression and the continuous development of society as a whole [7]. To understand this, the following concepts of economic sustainability are addressed:

5.1 The Relationship Between Housing Sustainability and Cost Reduction.

While it may appear that sustainable residential buildings require a higher cost than the cost required for traditional housing, the opposite is true[8]. Most sustainable design principles work to reduce the cost of construction and utilization of buildings, especially in large housing development projects, by implementing practical means and using economical materials to Affordable operation cost of houses for inhabitants. Sustainable design principles seek to make housing cost-effective for its users in the long run, including energy efficiency, using renewable energy sources and long-lasting building materials that require less maintenance, along with other principles.

5.2 Sustainable Climate Treatments

A sustainable building is one that achieves integrated quality in terms of environmental performance, social and economic compatibility, and aims to reduce its impact on the environment[7]**.** And this building in the hot, dry region is characterized by the following sustainable climate treatments:

- - Orienting residential buildings so that the vertical axis of the main facade faces north [9].
- - Designing the residential building with an ideal aspect ratio of 1:1.3, which can be increased to 1:1.6 and by creating an internal courtyard, which increases the northern surface areas without affecting the aspect ratio, thus increasing shading on facades and courtyard floors and improving the efficiency of the building[10].
- - Increasing the thickness of exterior walls to reduce the amount of heat transferred through them and the thermal behavior of solar radiation on the wall [11].
- - Insulating roofs and exterior walls to provide thermal comfort for building envelopes and reduce the need for cooling and heating systems.
- - Treating structure openings to reduce heat loads inside building spaces[12], the location of openings should be carefully studied to increase the average air flow rate and air dispersion [13]. Adding sun breakers around the openings helps prevent unwanted sunlight from falling on building facades during hot periods of the year. Sun breakers can be horizontal, vertical, or combined [14].
- - Using white or other light colors will reduce the amount of heat absorbed by the walls. If dark colors are used instead of white, the building surface temperature will vary according to the degree of sunlight reflection, which depends on the orientation of the building[15] .
- - Generating electricity in buildings through the use of solar systems, which are integrated with the building through the outer envelope of the building (roof and exterior walls)

5.3 Economic Feasibility Studies for Housing Projects

Economic feasibility studies for housing projects aim to reach the most appropriate design that achieves the maximum return with the minimum cost. Economics means the balanced relationship between cost and benefit to achieve the overall benefit or the marginal benefit required. The benefit here means achieving the thermal comfort of residents with lower building operating costs. Feasibility studies are a set of tests and estimates prepared to assess the suitability of the building or some of its proposed elements in light of cost expectations and direct and indirect returns throughout the assumed lifespan of the building[16].

6. Cost and Economic Evaluation of Climate treatments

6.1 Climate treatments Cost

Climate mitigation cost is defined as the total amount of money spent on the building starting from the feasibility study, throughout all the stages of project development and finalizing, and up to the expenses needed for utilization and maintenance[17]. The total cost of the building or one of the building's elements is the sum of all the following items:

- Direct cost: It is called direct as it is paid directly by the owner to fund construction or one of its elements and it includes the total sum that the project owner pays from the design stage to the utilization and maintenance stage[18]. It consists of the initial cost and periodic cost.

- Indirect cost: it includes costs that are not paid directly by the owner or user, but their value enters implicitly during the assumed lifespan of the building or one of its elements. It includes the investment cost of turnover, asset depreciation cost, inflation rate cost, taxes, and administrative expenses.

6.2 Concepts for Calculating the Climate Treatments Costs

There are several concepts for calculating climate treatments costs, which are as follows [19]:

- Base year: It is the standardization of the purchasing power of money at a fixed time for cost calculation, and it is usually the year of implementation.

- Profit: earning a profit is the main objective of any economic venture, and this objective must be achieved to ensure the continuation of the project. The profit in residential buildings is to reduce operating costs.

- Break-even point: any economic project has a cost and a profit return. The expenditure of economic projects and their elements are explained earlier. Figure (3) shows the relationship between the cost and profit return for the project. At the beginning of the project, we find that the cost curve starts from the initial cost value and continues to increase with the added periodic and indirect costs. Meanwhile, the profit curve starts from zero and it ascends with time. At a certain period of time, both the cost curve and the profit curve intersect with each other, and this is known as the break-even point. Breaking even means that the building has covered its costs and started to achieve profit [19].

6.3 Methods for Evaluating Climate Treatments

Economic studies have identified more than one method for the economic evaluation of projects, to take action and compare different ideas economically, and conduct economic feasibility studies. Among these methods, we can mention the life cycle cost method [20]. In this method, the total cost of the climate treatment is calculated according to the cost items mentioned earlier, whether direct or indirect, taking into account the following[20]:

-Determine the assumed lifespan of the climate treatment according to the specifications of the materials and performance efficiency.

-The assumed lifespan of the treatment is calculated to be proportional to the assumed lifespan of the building, which is determined to be fifty years. The number of times the treatment is changed is calculated according to this relationship (number of times the treatment is changed = 50/assumed lifespan of the treatment in years).

-Some treatments have an assumed lifespan that is the same as that of the building and are not changed, such as insulation walls and sun breakers.

-The present value for money and the inflation rate should be taken into account, and the base year should be the year of the construction and implementation of climate treatment. If it is necessary to replace the treatment after a certain period of time, the calculation is based on the price in the base year, so as not to combine two values for different times that do not have the same purchasing power in the base year.

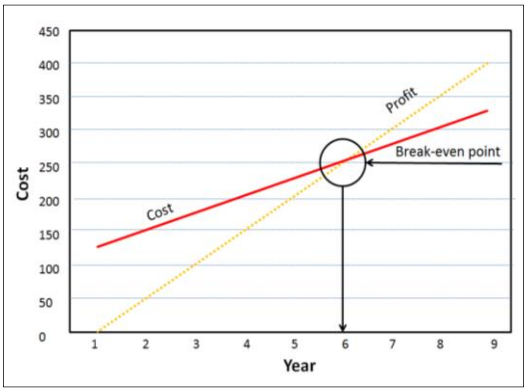

Figure (3) Break-even point in economic projects[19]

7. Simulation and Modeling to Achieve Building Efficienc

In recent years, more advanced tools have emerged that deal with buildings as integrated data and information systems, including information on material quantities and properties, energy performance, lighting efficiency, site characteristics, execution information, and more. This new approach to design is called Building Information Modeling (BIM) and Green Building Information Modeling (BIM Green). It is a digital methodology for modeling building information and data, making changes in design and implementation processes, and directing design towards more sustainable and efficient methods than a few years ago[3].

The Design Builder program is considered one of the important programs in the fields of sustainability and energy consumption, as well as calculating the economic cost of construction buildings and their components, Table (2) shows a comparison of the different programs.

Table (2) Comparison of the uses of BIM software[3]

BIM software	Energy	Sustainability
Autodesk Ecotect Analysis		•
Autodesk Green Building studio		•
Graphisoft EcoDesigner		•
Bentley Hevacomp		•
Design Builder	•	•
Energy Analysis Autodesk	•	
Green Building studio	•	
IES Hevacomp	•	
Tas eQuest	•	

It is a new and advanced program with high flexibility in operations. The program uses the Energy Plus dynamic simulation engine to generate performance data. It is the first comparison program that includes the same environmental surface, and it provides a set of data related to the building's environmental performance, such as energy consumption, HVAC systems, thermal comfort strategies, lighting, summer and winter temperatures, and carbon emissions. The program considers most environmental factors [21]. Figure (4) illustrates the inputs and outputs of the program.

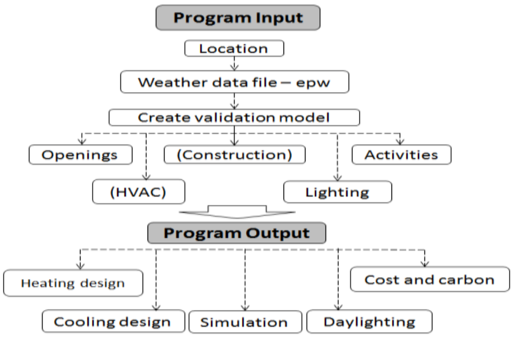

Figure (4) Inputs and Outputs of Design Builder program

8. Climatic Characteristics of The Study Area.

8.1 Thermal Comfort

Indoor environmental comfort factors include thermal comfort and indoor air quality. In addition to having a great positive effect on residents' health, behavior, and productivity, achieving thermal comfort also affects the amount of energy consumption in buildings. Buildings that were not designed to achieve thermal comfort for users require more heating and cooling loads to achieve it, and that in return increases the economic cost of energy consumption and also increases carbon emissions. The thermal comfort zone - except for the hot humid zone - is between temperatures of 20-25.6 degrees Celsius and relative humidity ranging from 20% to 80%, but some do not agree on this as the boundaries of thermal comfort vary from place to place and from one season to another[22].

8.2 Climatic Region

The New Minya city follows the hot and dry climatic region, where Egypt has been divided into three climatic regions as shown in Figure (5). The hot and dry region extends from Cairo to the southern borders of Egypt and includes the parts located west of the Nile River to the western borders, as well as the parts located east of the Nile River to the heights of the Red Sea. This region is characterized by its extremely hot desert climate in the summer, especially as we move southward due to the distance from the sea[22].

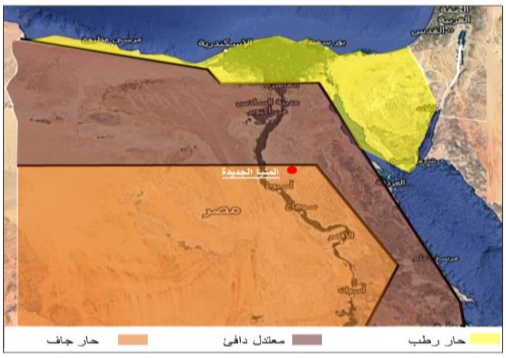

Figure (5) Design climatic regions in Egypt [22]

8.3 Climate Factors

As previously mentioned, climate is one of the most important factors affecting the shape and architectural design of buildings. The study area (New Minya City) is characterized by a continental desert climate. All climate elements are analyzed using the climate file extracted from the Design Builder program, where August has the highest average monthly temperature, while January has the lowest average monthly temperature. The average temperature during the summer months is above the thermal comfort level, while in the winter months, it is below the thermal comfort level. The highest average of solar radiation is in July and August, and the lowest rate is in January and December. The winter months (November, December, January, February, and March) are characterized by strong cold wind blowing in the direction of the north and northwest, which contribute to lowering the temperature of buildings. The summer months (April, May, June, July, August, September, and October) are characterized by strong hot wind that contribute to raising the temperature of buildings.

8.4 Input Parameters in Simulation Program

These parameters were selected as inputs to the program through theoretical study and the Egyptian code for energy consumption[23].

-Floor area per person: This is the share of each person from the floor area of the housing unit, where the area of the housing unit is 63 m2, and the average number of family members is 5, so the floor area per person is 12.6 m2/person.

-Air temperature and relative humidity: The recommended thermal comfort in the hot dry region in Egypt ranges from 21.8 to 30 degrees Celsius, with a relative humidity of 20 to 50% and wind speed of 0.5 to 1.5 m/s[23]

-Fresh air rate: The required natural ventilation rates as shown in Table (3) and Table (4) are averaged to be 4 liters/second/person.

Table (3) Ventilation rates required for various activities [23]

activity (adults)	Required ventilation)rates (l/sec	Metabolic rate
sitting	0.8	100
light work	2.6 :1.3	320 :160
middle work	3.9 :2.6	480 :320
hard work	5.3 :3.9	650 :480
Very hard work	6.4 :5.3	800 :650

Table (4) The minimum required ventilation rate[23]

space	Min (L/sec/person)
Living and sleeping rooms	3
Kitchens and bathrooms	14

-Required illumination intensity: The illumination intensity varies from one space to another in residential buildings as shown in Table (5), the average is 300 lux.

Table (5) the required lighting intensity in residential buildings[23]

Space	(LUX) Illumination intensity level		
	Max	Avg	Min
bedrooms	100	75	50
guest rooms	400	300	200
living rooms	500	300	200
bathrooms	200	150	100
kitchens	400	200	100
Corridors and stairs	200	150	100
Spot lighting	1000	750	50

The other operating details of the model will be presented in tables according to their order in the simulation software (Design Builder). Except for what has been mentioned, the default program settings have been kept.

9. Case study development Proposed

To reach the proposed development for the existing National Housing model, a set of steps were taken as follows:

9.1 Validation of The Simulation Software

Validation of the simulation software was achieved by comparing field measurements of actual electricity consumption and the energy consumption results of the calibrated model using the simulation and modeling software (Design Builder) for a full year of a housing unit in one of the Cooperative Housing buildings in the fourth district in New Minya City. Validation is very important to test software accuracy and detect the percentage of error in the results. The housing unit was selected for two main reasons; first, it had architectural and urban similarities with the National Housing area (the case study) to make the validation realistic and accurate, and second, because energy consumption data for this specific housing unit was available. Figure (6) shows the calibrated model of the housing unit on the Design Builder software window. Calibration was based on actual data collected by the researchers from the residents of the housing unit and entered into the software through its various tabs. A set of tables, data, and graphs were extracted, through which the amount of electricity consumed by the validated model was estimated to be 4494 Kilowatts.

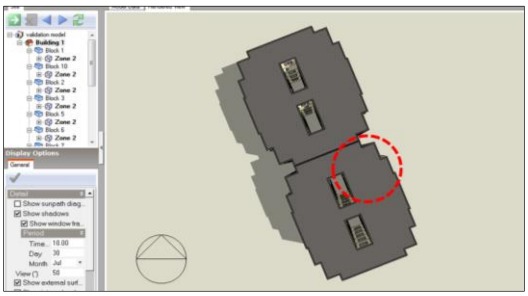

Figure (6) the residential unit calibration model on the program window

Figure (7) shows the comparison between the actual energy consumption of 4740 kWh[6] and the energy consumption of the validated model using the simulation software (Design Builder). Through comparing the two results, it can be concluded that the accuracy of the program is 94.3%, and the percentage of error in the program's results is 1.06, which gives an acceptable indication of the validity of using this program in simulating and calculating energy consumption for buildings.

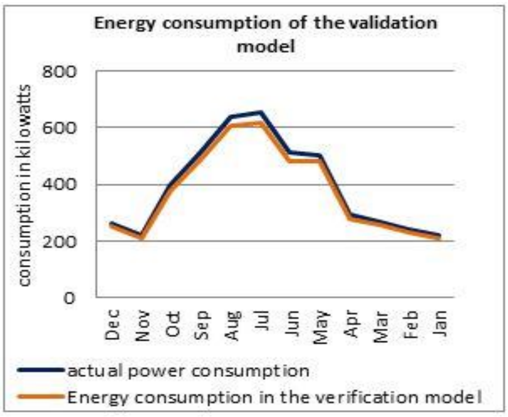

Figure (7)Energy consumption of the validation model

9.2 Standards for selecting climate treatments

The sustainable climate treatments suitable for the project site are selected, and the most suitable ones are preferred for the building's function and economic cost. Climate treatments are selected according to their achievement of thermal comfort as shown in Table (6).

Table (6) the impact of sustainable design treatments on thermal comfort

sustainable treatments	The effect on thermal comfort	
	effective	Ineffective
Northern orientation of the building	•	
External wall thickness	•	
Building materials used	•	
Roof and wall insulation	•	
The height of the floor	•	
Dimensions and location of openings	•	
Use of shading tools	•	
Use light colors	•	

The economic cost is one of the most essential factors for differentiating between climate treatments. Table (7) shows the impact of design treatments on cost items. Some treatments do not affect the cost increase entirely, such as routing and light colors, others affect one or more cost components, and some cost items, such as administrative expenses, taxes, and inflation rate, are generally affected by all stages of construction.

Table (7) the impact of sustainable design strategies on cost

	Initial cost				periodic cost			Indirect cost			
	Create an additional space	Additional structural	fulfillment cost	Design cost	Periodic maintenance	workers and use	Energy and fuel	Capital investment	Asset depreciation	Inflation rate	Taxes and administrative expenses
Northern orientation											
wall thickness	•		•					•	•		•
Building materials			•					•	•		•
Insulation			•		•			•	•		•
The height of the floor			•					•	•		•
Dimensions and location of openings											
shading tools		•	•		•			•	•		•
Light colors											

9.3 Assessment of Thermal Comfort in The Case Study

The current status of the study model was evaluated and the hours of thermal discomfort were determined for the entire year based on natural ventilation only for the entire building and without the influence of industrial ventilation and cooling systems. Figure (8) shows the study model on the program window. The data and parameters for the current situation were entered into the program in the order shown in Table (8). The Design Builder simulation program calculates thermal comfort in different periods and regions according to ASHRAE using the following equation: (Tc = 17.8 + 0.31*To) [24], where To (is the average outside temperature and Tc is the average thermal comfort temperature. Figure (9) shows the hours of discomfort in the building for the current study case, where the maximum hours of discomfort occur in January and August and the lowest rates occur in April and November. The total hours of discomfort in the building (study case) were estimated at 7,116 hours, representing 81% of the thermal discomfort hours during the year.

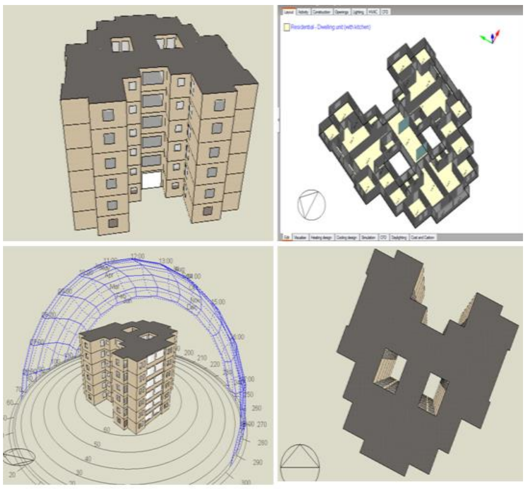

Figure (8) Drawing the study case model using the simulation software

Figure (9) Discomfort hours in the residential building during the months of the year

Table (8) Thermal comfort inputs in the current situation, according to their arrangement in the program

Category	Sub-Category	Item	Input
Activity	Occupancy	Floor area per person	m/person 12.6
		Metabolic rate	Seated quite
		Metabolic factor	1.00
		Occupancy schedule	Residential Occ
		Clothing	Clo/Winter (1.0) Summer Clo/(0.5)
	Environmental control	Fresh air	L/sec-person) (3
Construc-tion	External walls		3 mm interior paint 2 cm cement mortar 12 cm clay brick 2 cm cement mortar 1 cm splatter paint U-Value = 2.143
Opening	Glazing type	3 mm single clear glass With wood frame	U-Value = 5.894 U-Value = 3.633
	Window shading	Shading slats	
Lighting	type	The lighting effect is turned off	
HVAC	HVAC type	There is no air conditioning - only natural ventilation	

9.4 The Energy Required to Achieve Thermal Comfort Mechanically

Considering that the bedrooms and living spaces in the residential unit are air-conditioned with split units to achieve thermal comfort, along with natural ventilation during the periods of thermal comfort, and natural ventilation only for service spaces, and the building is in its current state, this is to calculate the electrical energy consumed to achieve thermal comfort. The data and specifications for this were entered into the simulation program shown in Table (9).

Figure (10) illustrates the energy consumed in the building to achieve thermal comfort for a full year, which is 171950 kWh.

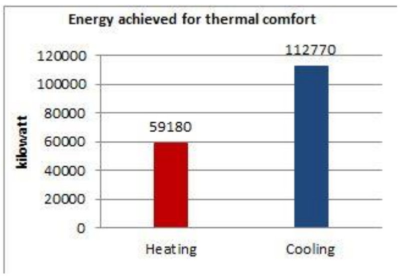

Figure (10) the electrical energy consumed for a year

Based on the electricity consumption rates at the Egyptian Ministry of Electricity, as shown in Table (10), the cost of energy consumption for the entire building is 170804 EGP

Table (9) Thermal comfort inputs, According to their arrangement in the program

Category	Sub-Category	Item	Input
Activity	Occupancy	Floor area per person	m/person 12.6
		Metabolic rate	Seated quite
		Metabolic factor	1.00
		Occupancy schedule	Residential Occ
		Clothing	Clo/Winter (1.0) Summer Clo/(0.5)
	Environmental control	Cooling	24˚
		Heating	22˚
		Fresh air	L/sec-person) (3
		Humidity control	% 20:50
		Outdoor temperature limits	22:28 C
	Other gains	Electrical appliances effect has been turned off	
Construction	External walls		3 mm interior paint 2 cm cement mortar 12 cm clay brick 2 cm cement mortar 1 cm splatter paint U-Value = 2.143
Opening	Glazing type	3 mm single clear glass, With wood frame	U-Value = 5.894 U-Value = 3.633
	Window shading	Shading slats	
Lighting	Lighting type	LED lighting for all interior spaces at night	
HVAC	- Split units for living and sleeping rooms, in addition to natural ventilation in the thermal comfort times. - Natural ventilation of service spaces. - Industrial ventilation for all spaces.		

Table (10) Electricity prices for the year 2022 [6]

grades	Consumption in kilowatts	The price per kilowatt In Egyptian pounds
1	0:50	0.58
2	51:100	0.68
3	0:200	0.83
4	201:350	1.11
5	351:650	1.31
6	651:1000	1.40
7	1000 more than	1.45

9.5 The Effect of Study Variables on Thermal Comfort

The study examines the effect of its variables on thermal comfort using the study model by changing only one variable while keeping all other variables in their current state to achieve the best results that can be obtained from using these variables individually. Then, the variables with the best results are combined to achieve a good average for achieving thermal comfort in the building, as shown in Table (11).

Table (11) the study variables affecting thermal comfort

The main variable	Building Orientation	Buiǐng shape	External wall thickness	Materials	Insulating ceilings and walls	The height of the housing floor	Architectural treatments for windows: window ratio	Sun breakers	Glass type
Sub variables	N	The residential building - the applied study model	12 cm	sandstone	polystyrene	2.7 m	10%	30 cm	Single 3mm
	S		25 cm	limestone	foam vinyl	3.0 m	20%	50 cm	Single 6mm
	E		38 cm	cement bricks	polyethylene	3.3 m	30%	70 cm	Double 6mm
	W		Double wall with void of 10 cm	clay bricks	glass fibers	3.6 m	40%	100 cm	
	45˚N-W				Cellulose		**50%**		
	N-E 45˚								
	S-W 45˚								
	S-E 45˚								

9.5.1 Building Orientation

Slight changes in the hours of thermal discomfort for the entire building were observed compared to the current orientation, as shown in Figure (11). Where the north orientation of the building recorded the lowest value for the annual hours of discomfort with a percentage decrease of 81%, the southwest orientation recorded the highest hours of discomfort with a percentage increase of 83.2% annually. This is due to the flawed, centralized architectural design of the building and the residential units being placed in all directions, as shown in Figure (12).

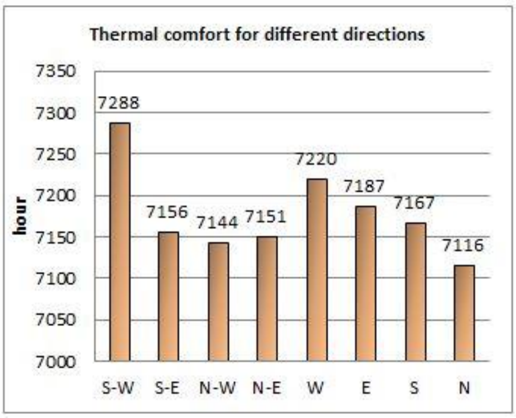

Figure (11) Annual discomfort hours- building orientation

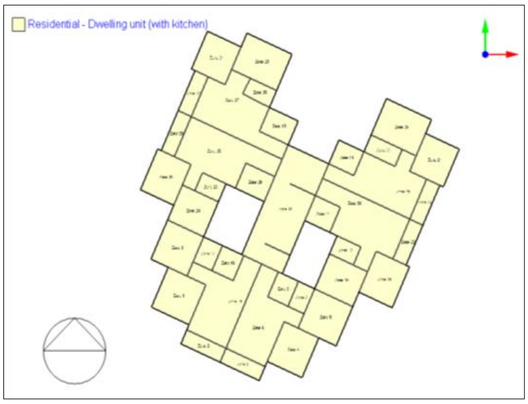

Figure (12) the horizontal section of the model on the simulation software window

9.5.2 Thickness of Exterior Wall

Figure (13) a thickness of 12 cm recorded 81.2% of the annual thermal discomfort hours, while a thickness of 25 cm recorded 81.1%, and a thickness of 38 cm recorded 79.7%. The double wall with an air void recorded 79.4% of the hours, which is 156 hours less than the current situation.

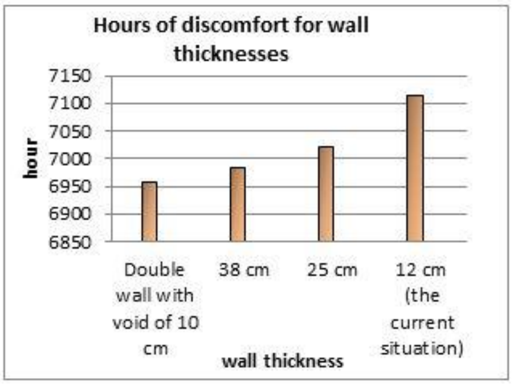

Figure (13) discomfort hours resulting- walls thickness

9.5.3 Building Materials

Figure (14) where that clay brick and sandstone recorded the best results compared to other materials. However, the difference in the thermal comfort hours between the different materials was not significantly impactful.

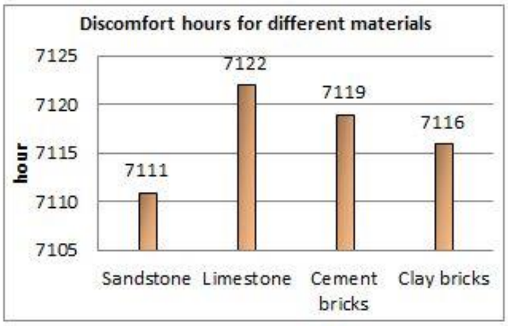

Figure (14) discomfort hours resulting – materials

9.5.4 Insulation of Roofs and Exterior Walls

The results, as shown in Figure (15) indicated that 5 cm thickness of polystyrene provided the best insulation results.

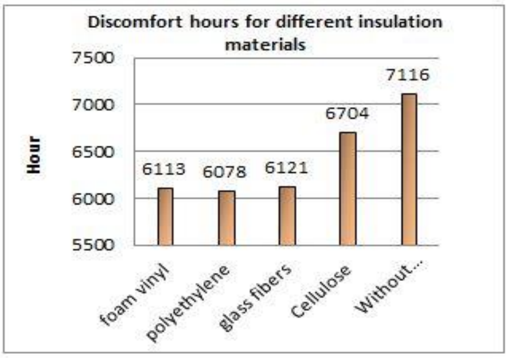

Figure (15) discomfort hours resulting- insulation materials

9.5.5 The height of the housing unit

The results were not significantly affected, as shown in Figure (16).

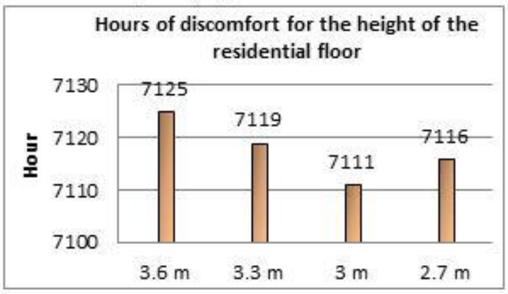

Figure (16) Annual discomfort hours resulting- floor heights

9.5.6 Openings Treatment

Percentage of Windows: A percentage of 20% openings recorded the best results with an 81% reduction in annual discomfort hours, as shown in Figure (17)

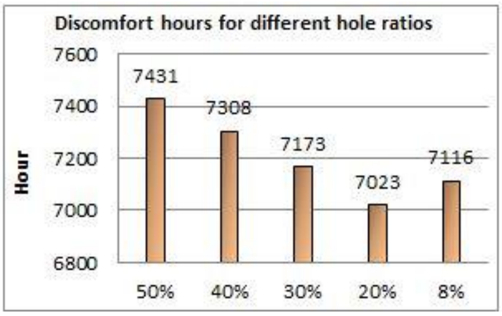

Figure (17) discomfort hours resulting- percentage of openings

-Sun Breakers: The results were as shown in Figure (18), where the best results came from 100-cm sun breakers with a percentage of 79.4% reduction in annual discomfort hours.

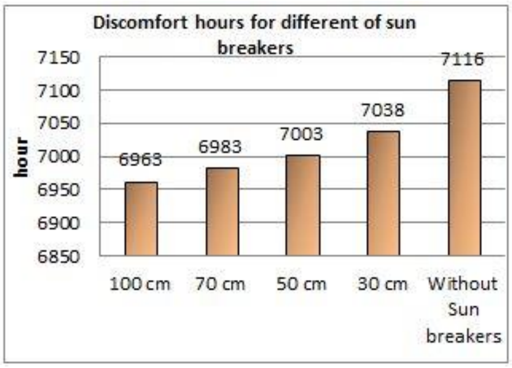

Figure (18) discomfort hours resulting- Sun breakers

-Windows Glass: Figure (19), where double-glazed glass with an intermediate gap recorded better results than single-glazed glass by a difference of 33 hours annually.

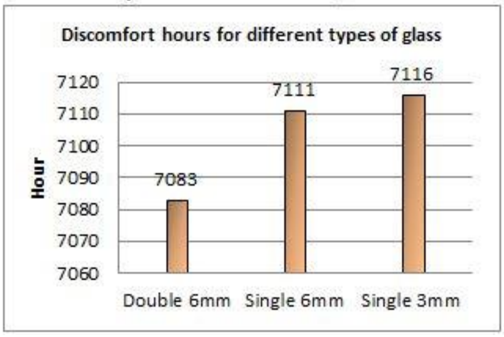

Figure (19) discomfort hours resulting- Type of window glass

9.5.7 Solar Systems

In addition to generating renewable electricity, integrating solar systems into buildings has an impact on thermal comfort, as it blocks sunlight from the surfaces it is mounted on if installed horizontally in a way that allows air movement underneath. Figure (20) illustrates a significant reduction in discomfort hours after insulating the building surface using solar cells.

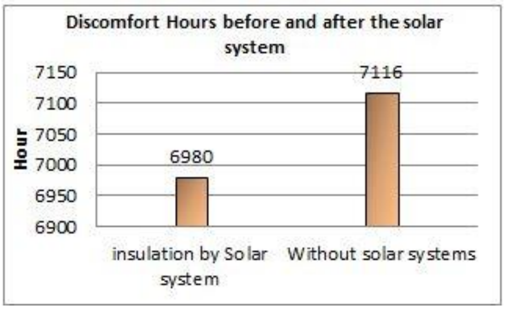

Figure (20) discomfort hours resulting - solar systems

9.6 Solar System and Energy Production of the Proposed Model

Egyptian Electricity Holding Company contracts with specialized companies to install solar systems with contracts lasting 25 years, which is the minimum assumed life span of the solar system. These systems are replaced by 50% after 25 years, and regular maintenance can extend the life of these systems. These systems can achieve the break-even point after 5-6 years of installation and begin to achieve economic gain.

The study model area is 425m2 which accommodates a solar system providing 59.5kWh through one or two inverter devices. Egyptian Electricity Holding Company specifies certain types of inverter devices and does not license the solar system without them. This solar system operates for an average of five hours per day, depending on the intensity of solar radiation. The solar system works all day, and its highest performance happens during solar radiation peak hours from 10 AM to 4 PM. The daily energy production of this system is 297.5 kWh, and the total cost of installing this system is 1,100,000 EGP, with an average cost of 18,400 EGP /kWh. The annual maintenance cost ranges from 15,000 to 20,000 EGP, and thus the cost per square meter of the solar system, including replacement and regular maintenance during the assumed life of the building, is 42436 EGP[25].

9.7 Thermal Comfort and Energy Consumption of the Proposed Model

After studying the previously mentioned variables and extracting the best results for each variable alone. The best results are grouped together to be tested and studied for their effect on thermal comfort. It can be seen that the hours of thermal discomfort have significantly decreased during the year after adding the proposed treatments to the existing national housing building. The hours of discomfort approached zero in March and November.

The energy consumption is calculated for the split AC units in the bedrooms and living rooms only, and natural ventilation is used for service areas. It is shown that the amount of electrical energy consumed after the modification is reduced to 109652 kWh and 97502.4 Egyptian pounds per year. Figure (21) shows the electrical energy required by the building before and after the modification. Figure (22) shows the achieved hours of thermal discomfort with the climate treatments and HVAC system. The hours of thermal discomfort in the building reached very satisfactory results during the year, but they did not disappear completely because the service areas were only naturally ventilated. The program calculates the average hours of discomfort for the entire building.

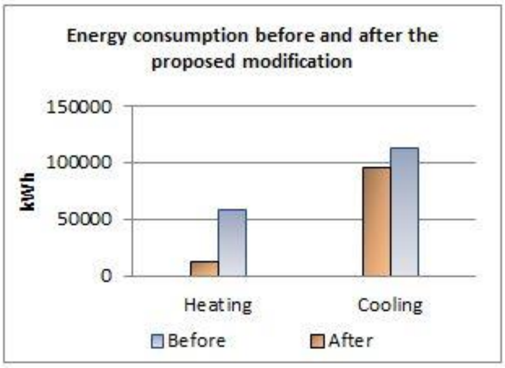

Figure (21) the electrical energy required by the building before and after the modification

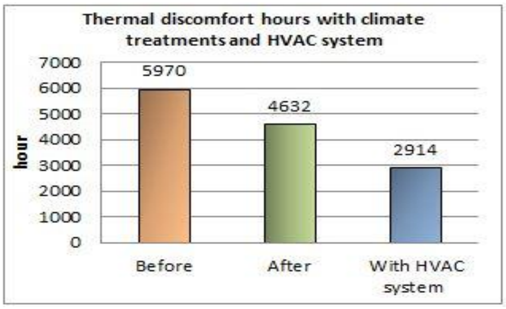

Figure (22) Annual thermal discomfort hours with climate treatments and HVAC system

9.8 The Short-term Economic Cost of The Models

The cost of architectural treatments was calculated using the cost method over the building's lifecycle by calculating the total cost of climate treatment according to the cost items mentioned earlier. Design Builder software calculates the economic cost of construction and architectural items in the building by entering the cost per square meter or per unit depending on the nature of the cost item in different tabs in the software. Figure (23) shows the inputs for calculating costs in the Design Builder program.

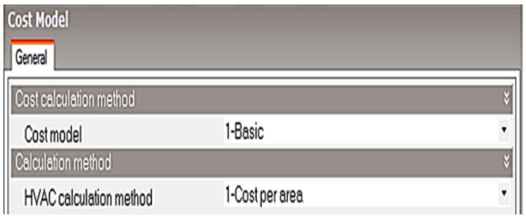

Figure (23) Inputs for cost calculation in the Design Builder program

The following items were taken into account in the cost calculation:

- The total cost of the existing building is EGP 8,152,889 according to the latest tendering conducted by the New Minya City Authority in 2022.
- The cost entered into the simulation program is the total cost (direct and indirect) per square meter or linear meter for the executing items of all sustainable processing works according to the market price in 2022.
- The cost difference between single and double walls was calculated, the same for the single and double glass used Table (12) shows the total cost of the proposed traditional sustainable processing.Table (13) shows the total Cost of Proposed modern Sustainable Treatments.

Table (12) the total cost of the proposed traditional sustainable treatments[26]

Item	Cost per meter (EGP)	Total cost (EGP)
North Orient	0	0
Building shape	0	0
Double wall insulated (polystyrene)	275	438900
Surface insulation (polystyrene)	125	65500
Sun blocks	1500	291600
Double glazing 6 mm	120	24000
Sum	820000	

Table (13) Details of the proposed solar system[25]

Item/modern sustainable treatment	A solar system on the proposed building model
The cost per meter (EGP)	42436
)Cost at the moment (EGP	1100000
The total cost of the item during the assumed life span of the building)(EGP	2525000
The building's annual energy production (kWh)	108587.5

Based on the above, it can be concluded that:

-The cost of the existing model is 8,152,889 EGP.

-The cost of the proposed model equals the cost of the existing model + the cost of the proposed sustainable treatment + the cost of the solar system = 10,007,389 EGP.

Therefore, the cost of the proposed building has increased by 22.77% in the short term.

9.8 The Long-term Economic Cost of The Models

To ensure the economic feasibility of integrating architectural treatments in the proposed model, the economic cost of the added climate architectural treatments over the assumed lifespan of the building, which the economic studies have estimated at around 50 years, must be calculated

-Calculating the total cost of the current model throughout its assumed lifespan by using the following equation:
Total cost =
Building cost + (Energy consumption for the building in the current state * 50 years) (50*170804.16) + 8152889 = = 16693097 EGP
-Calculating the total cost of the proposed model throughout the assumed lifespan of the building: The total economic cost of installing and maintaining the solar system over 50 years is 2,525,000 EGP, and the electricity produced by it is 108,587.5 kWh /year as shown in Table (13) Therefore, the difference between the electricity consumption required for the building after the proposed modification and the electricity produced by the building is as follows:

- Electricity required after modification
 = 109,652 kWh/year
- Electricity produced by solar cells
 = 108,587.5 kWh /year
- Difference in electricity consumption
 = Electricity required after modification - Electricity produced by solar cells = 109,652 - 108,587.5 = 1,064.5 kWh /year.

Based on that, the economic cost of the energy required for the residential units in the building, based on the aforementioned electricity tariff rates, is 617.41 EGP/year. This cost represents 0.6% of the electricity consumed for achieving thermal comfort in the current situation.

Calculating the total cost of the proposed model throughout its assumed lifespan by using the following equation :

Total cost= the cost of the existing building + the cost of the solar system + the total cost of implementing all proposed treatments + (the difference in electrical energy required annually * 50 years)

= 8,152,889 + 2,525,000 + 754,500 + (617.41 * 50 years) = 11,463,259.5 EGP

Thus, it was found that the proposed Treatments reduced the overall cost of the building and its long-term use by 31.3%.

9.10 Results and Achieving the Break-even Point

Through analyzing the study results, it is evident that adding sustainable design treatments to the building reduced the number of hours of thermal discomfort by 77.7%. Consequently, it helped reduce the energy consumption used to achieve thermal comfort by 57% annually. It also increased the economic cost of the building by 22.77% in the short term, but it helped reduce the overall economic cost of the model by 31.3% in the long term.

Any economic project has a cost and a profit return. In the proposed model, the profit is achieved by saving the used electrical energy, as well as converting the building from a consumer of electrical energy to a producer of it.

Table (**14**) shows the cost of the current model and the proposed model during the assumed lifespan of the building. It is clear from the table that the cost of using the current model increases by very large values due to the increase in annual energy consumption, while the cost of using the proposed model increases by a very small percentage due to the transformation of the building from an energy consumer to an energy producer. Figure (24) illustrates the breakeven point between the cost of using the existing model and the proposed model over the long term. From the figure, it is clear that at the beginning of the building's life, the cost curve of using the existing model starts with a lower value than the cost curve of using the proposed model and continues to increase with the presence of energy consumption costs. On the other hand, the cost curve using the proposed model starts with a higher value than the previous curve and increases at a very low rate over time. The two curves intersect at a period of approximately twenty years, which is the break-even point for the models. At that point, the building has covered the added sustainable processing costs and has started to make a profit.

Table (14) the cost of the existing and proposed models over the assumed lifespan of the building

Cost- Time	Existing model cost (EGP)	Proposed model cost (EGP)
present time	8152889	11432389
10 years later	9860929	11438563
20 years later	11568969	11444737
30 years later	13277009	11450911
40 years later	14985049	11457085
50 years later	16693089	11463259

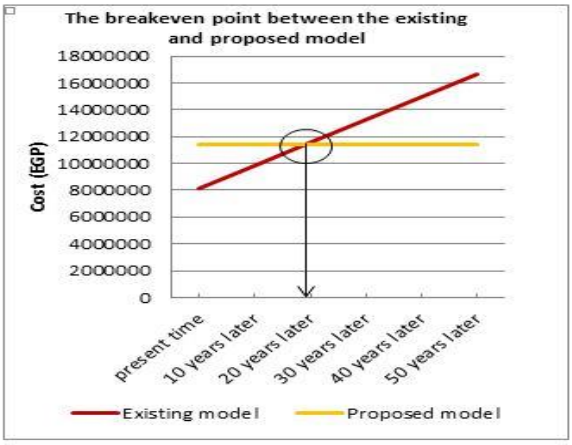

Figure (24) the breakeven point between the existing and proposed mode [23]

10. Results and Recommendations

10.1 Results

[1] Placing the building in a north-facing direction recorded the lowest hours of discomfort by 81% of annual discomfort hours.

[2] The building mass was not situated on the optimal orientation suitable for the hot and dry climate region.

[3] Thermal discomfort hours are inversely proportional to the thickness of the external walls.

[4] Clay brick and sandstone recorded slightly better results compared to other materials in terms of the number of thermal comfort hours.

[5] The polystyrene material recorded the lowest thermal discomfort rate during the year with 69% of the year's total hours, reducing the discomfort hours by 1038 hours annually.

[6] The effect of the height of the housing unit on thermal comfort is very minimal.

[7] 20% opening ratio recorded the best results with 81% of the annual hours.

[8] 70:100-centimeter-deep sun breakers recorded the best results. Also, double-glazed glass with inner gaps recorded better results than single glass in openings.

[9] The amount of electrical energy consumed to achieve thermal comfort in the building decreased by 57% after adding sustainable climate treatments.
The overall economic cost of the proposed model decreased by 31.3% compared to the existing model after adding sustainable design treatments suitable for the type of housing during the assumed lifespan of the building.

10.2 Recommendations

The research has concluded with the following recommendations:

[1] The need to move away from centralized forms in the design of residential buildings.

[2] The thickness of external walls should not be less than 38 cm, and double walls can be constructed with an inner gap to reduce the cost of thick walls.

[3] The necessity of insulating roofs and external walls with high-efficiency insulation materials such as (polystyrene) to reduce heat exchange between the building and its external environment, thus reducing the energy consumption used to achieve thermal comfort in the building.

[4] Increasing the proportion of openings in external walls to 20% of the wall area to improve ventilation and thermal comfort in interior spaces.

[5] The need to install vertical and horizontal sun breakers on the eastern and western fronts, and install horizontal sun breakers only on the southern front to reduce the passage of solar radiation into the interior spaces of the building. The recommended depth of sun breakers should range between 70 to 100 centimeters.

[6] The need to use double-glazed glass instead of single-glazed glass for the windows of residential buildings.

[7] Integrating solar systems into residential buildings to reduce the amount of electrical power consumed from public electricity companies and convert buildings from energy-consuming to energy-producing entities.

11. References

[1] The annual report of the Egyptian Ministry of Electricity and Renewable Energy, 2022.
[2] https://www.designbuilder.co.uk
[3] Tamer Refaat: "Building Information Modeling (BIM) and Green Architecture - A study of using the (Desgin Builder) program as one of the green BIM programs in simulating a residential building in the Fifth Settlement" published research, Engineering Sector Journal of Al-Azhar University, 2018.
[4] Hisham Dawoud Sidqi Badawi: “Change in the Climate Continent in Egypt,” Scientific Research Journal of Arts, Twenty-First Issue of 2020, Part Two.
[5] The New Urban Communities Authority - New Minya City Authority, 2022.
[6] Arab Republic of Egypt, Ministry of Electricity and Renewable Energy, New Minya City Electricity Company, 2022.
[7] Basma Yehia Abdel-Salam: “Evaluating the Climatic Performance of Urban Spaces from the Perspective of Green Architecture Concepts - A Case Study of the Residential Area in New Minya,” Master Thesis, Faculty of Engineering, Minia University, 2017.
[8] Mai Osama Ahmed Mostafa, Magdy Mohamed Kassem, and Mohamed Saad Atwa: "Evaluation of the Sustainable Environment Experience in Egypt", Department of Architecture, Faculty of Engineering, Al-Azhar University, 2016.
[9] Khaled Selim Fajal: "Architecture and Environment in Hot Desert Regions," Al-Dar Al-Thaqafea for publication, Cairo, first edition, p. 31, 2002.
[10] Ahmed Abdel-Montalib Mohamed Ali: “Using simulation to evaluate and improve the thermal performance of residential buildings, a case study of New Assiut City.” Master thesis, Faculty of Engineering, Assiut University, p. 31, 2011.
[11] Mona Awad Abul-Enein, Al-Wazir: “The Role of Facades in Achieving Thermal Comfort Inside Administrative Buildings in Egypt,” PhD thesis, Department of Architecture, Faculty of Fine Arts, Alexandria University, p. 24, 2011.
[12] Abd al-Montalib Muhammad Ali: “Spontaneous Architecture in the South Valley - Between Theory and Application of Desert Architecture,” Al-Safaa and Al-Marwa Press for Printing and Publishing, Assiut, p. 48, 2004
[13] Amal Abdel-Halim Al-Dabaraki: "Natural Ventilation as a Design Approach in Passive Architecture," Master Thesis, Faculty of Engineering, Ain Shams University, p. 52, 1999.
[14] Ahmed Halim Hussein: “The Role of Solar Refractors in Achieving Light Comfort in Educational Spaces, Case Study: Egyptian Educational Buildings "Engineering Research Journal AA90 – AA104, Faculty of Engineering, El Matareya, Helwan University, 2022.
[15] Ahmed Fathy: "The Impact of Modern Technology on the Employment of Alternative Materials in the Interior Architecture Vocabulary" Published research, Heritage and Design Journal, Arab Society for Islamic Civilization and Arts, Volume 2, Issue 12, December 2022.
[16] Bin Sha’a Walid, Almawy Ahmed, Bin Uthaina Bu Hafs: “Economic Feasibility Studies as a Mechanism for the Success of Investment Projects” Al Muntada Journal for Economic Studies and Research, Volume 3, Issue 2, Algeria, 2019.
[17] Othman Abd al-Rahman Mitkes: "The design and planning phases of long-sea bridges by applying value engineering," Ph.D. thesis, Faculty of Engineering, Cairo University, 1997.
[18] Ahmed Ibrahim Othman: “The Value Management Approach between Raising Quality and Reducing Costs,” Master Thesis, Faculty of Engineering, Ain Shams University, p. 53, 2013.
[19] Mohamed Abdel-Fattah Ahmed El-Essawy: "Environmental Design Economics - A Model for Economic Environmental Design and Its Impact on Buildings," Ph.D. Thesis, Faculty of Engineering, Cairo University, 2007.
[20] Abdel-Aziz Mustafa Abdel-Karim: “Feasibility Study and Project Evaluation,” Dar Al-Hamid for Publishing and Distribution, Jordan, 2001.
[21] US Department of Energy, 2019, www.energy.gov
[22] Khaled Selim Fajal: "Contemporary Environmental Architecture" Cairo, first edition, Deposit number in the Book House 2011/17674, 2011.
[23] The Egyptian Code for Energy Efficiency Improvement in Residential Buildings, Part One, 2006.
[24] Jihad Ahmed Hanafi: “Assessing the Possibility of Achieving Energy Efficiency in the Design of High-rise Administrative Buildings in Egypt,” Ph.D. Thesis, Faculty of Engineering, Minya University, p. 175, 2022.
[25] Energy Conservation Department, General Court of Minya Governorate, and Karma Solar Company, Minya Governorate, September 2022 AD.
[26] The Committee for Setting Estimated Values for Projects, Contracts and Bidding Department, New Minya City Authority, New Urban Communities Authority, Ministry of Housing and Urban Communities, September 2022.