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PASSIVE ENERGY SAVING THROUGH THERMAL RETROFITTING OF EXISTING GOVERNMENT OFFICE BUILDING ENVELOPES - CASE STUDY FOR OFFICE-RESEARCH BUILDING IN CAIRO, EGYPT

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ABSTRACT

Egypt used several million kilowatts per hour of electrical power in 2023. According to 2022 data, public utilities and agencies used 15% of Egypt's power. Most of Cairo's government buildings built in the 50th and the 60th of the last century are composed of reinforced concrete structure skeletons, flat concrete roofs, and burnt brick exterior and interior walls. At that time, building energy efficiency was not a priority. Thus, uninsulated building envelopes were built. Nowadays, renovating buildings requires increasing energy efficiency. Previous research showed that lack of thermal insulation in roofs, walls, window solar heat gain, and window frames thermal bridging increases heating and cooling costs. The current research aims to enhance existing buildings energy saving by improving thermal insulation of its envelope components. The existing research building in Cairo was assessed for environmental factors to accomplish the research goal. The research used a three-dimensional (3D) terrestrial laser scanner to assess building facades for creating an environmental study model. The research used the building office top floor construction as a comparative environmental simulation using (Design builder® version6 software) as a base case for yearly energy consumption due to heating and cooling loads, followed by improving the thermal insulation of each building element individually in the base environmental model and comparing its effect on annual energy saving percentage, then applying all of the best annual energy saving building envelope element thermal insulation retrofitting techniques to the improved building model. The research results showed that improving roof thermal insulation saves 33.5% of the yearly top floor total electrical energy, 12% for exterior walls, 0.75% for window glazing, and 1.56 % by retrofitting window frames. Applying all of the best energy-saving thermal insulation retrofit techniques to the whole structure saved 31% of annual energy consumption.

Keywords: energy saving, building envelope, thermal insulation, thermal comfort zone, and 3D terrestrial laser scanner.

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1. INTRODUCTION

Conservation of energy in the building industry is a primary focus throughout the process of renovating existing structures. The Egyptian National Climate Change Strategy (NCCS) 2050 summary report states that the Egyptian Ministry of Electricity and Renewable Energy has implemented several steps to raise the proportion of new and renewable energy to 42% of the total electrical energy generated by 2035 [1]. Two strategies can maximize energy efficiency in the building sector: actively, by generating electricity from renewable resources such as installing photovoltaic solar panels on the rooftop, building the south façade and heating water using solar water heaters, or passively, by optimizing daylighting and enhancing the thermal insulation of the building's envelope. Retrofitting the thermal insulation of an existing building's envelope is a passive way for energy conservation. This research study focuses specifically on enhancing the thermal insulation of the building envelope and conserving energy by achieving indoor human thermal comfort while minimizing the use of heating and cooling electric energy. Although other retrofit categories such as improving mechanical and electrical systems are also important for the building's energy saving, they are not the main focus of this study. Building envelope serves as a protective barrier between the inside environment and outside environmental factors, such as external temperature, wind, rain, and humidity. Thermal comfort, indoor air quality, acoustic comfort, and visual comfort are all aspects of human comfort in an indoor setting [2]. The ISO 77730 defines thermal comfort as the state of mind that reflects happiness with the thermal environment. Six primary elements determine thermal comfort. Environmental parameters include air temperature, relative humidity, wind speed, and radiant temperature. Individual factors: attire and metabolic rate. Meanwhile according to ASHREA Standard 55[3], thermal comfort conditions in summer range between the temperature 25 - 27℃ and 21 - 26℃ in winter. The relative humidity is between 10% - 80%.

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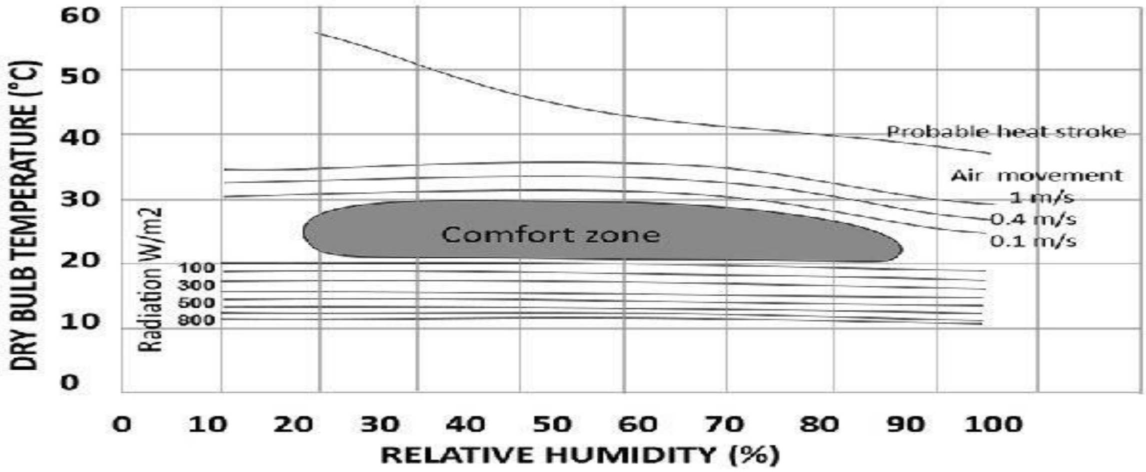

Figure-1. Olgyay's bioclimatic chart [4].

Figure-2. Annual temperature range according to Cairo’s International Airport weather file [5].

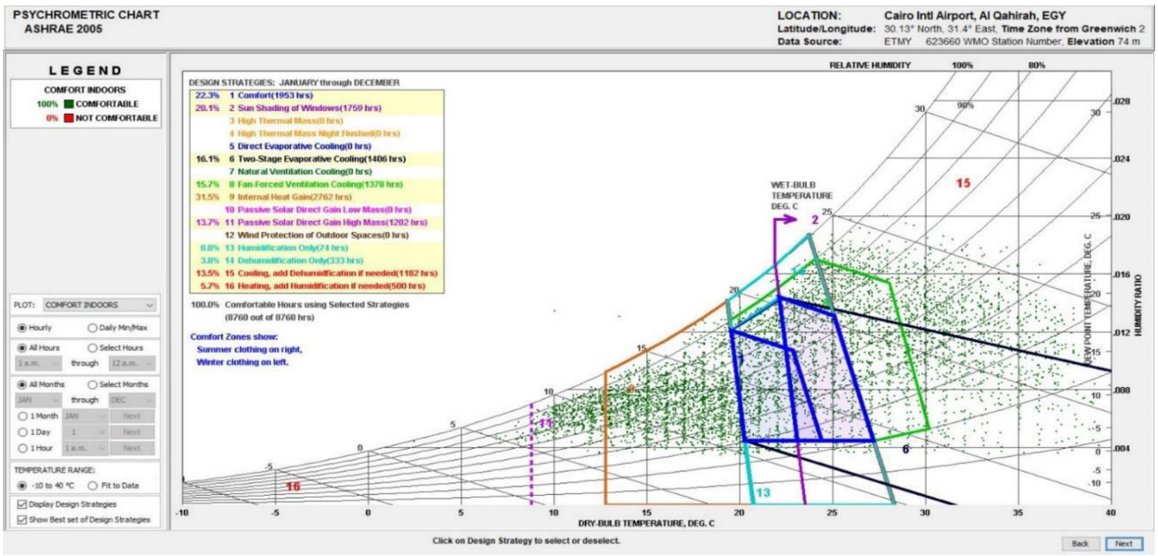

Figure-3. Cairo’s temperature-humidity comfort zone [5].

Exceedance hours refer to the number of hours within a certain period when the environmental conditions in an inhabited indoor space are not within the comfort zone. Egypt is situated in North Africa, a mostly arid tropical area, except for its northern sections, which fall within the Mediterranean climatic moderate zone. The climate of Cairo is characterized by high temperatures and a lack of rainfall during the summer months, with humidity levels ranging from 49% to 61%. In the winter months, humidity levels are typically around 59% to 61%. [6].

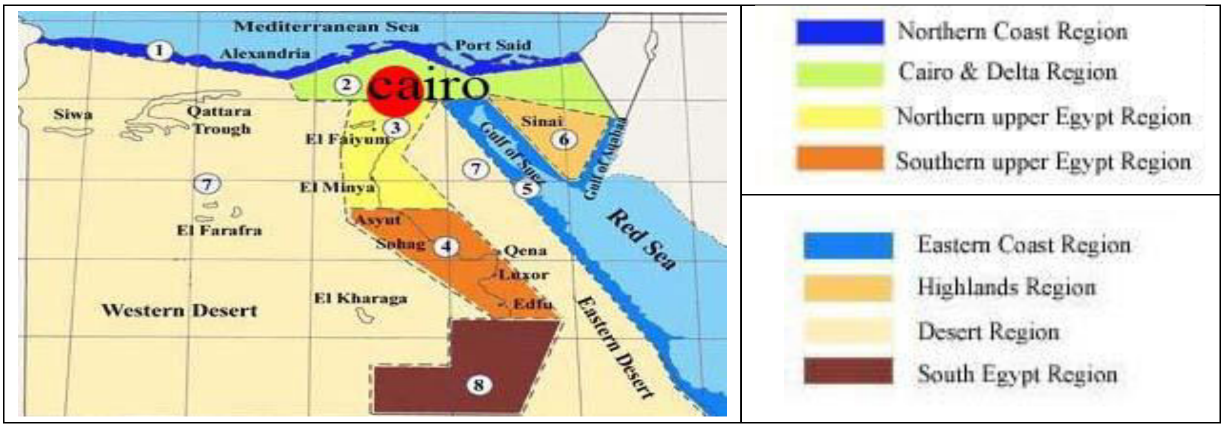

Figure-4. Classification of climatic zones in Egypt according to HBRC [7].

The optimal temperature requirements of a structure are determined by the specific meteorological conditions of its location, which might vary across different regions worldwide. Furthermore, the energy requirements for heating and cooling are in direct opposition in hot temperature areas compared to cold climate regions, even within the same nation. Figure-3 displays the optimal temperature and humidity range in the Cairo, Egypt area [5].

In response to the growing importance of energy conservation in the building industry in Egypt, the Egyptian government has introduced "The Egyptian Code for Energy Efficiency in Buildings for Commercial and Residential Buildings" as a comprehensive manual for architects and engineers involved in the design and repair of structures [7]. Furthermore, another specification titled "Thermal Insulation Work Specifications" was published to provide detailed information on the thermal properties and applications of different insulation materials that are now accessible in the Egyptian building market [8]. Prior research has been conducted on a worldwide scale in the field of upgrading building envelopes to improve their thermal insulation and achieve energy savings. The studies included several architectural structures situated in varying climatic environments. The primary techniques for upgrading the energy efficiency of building envelopes include the addition of thermal insulation layers to the solid components of the façade, improving the thermal performance of windows by modifying their frame design and material, using glass types with low heat gain, and incorporating shade features. While solar water heaters are considered a part of building envelope retrofitting components, they are not yet within the scope of the ongoing study. Eldarwish *et al.* [9] studied the architectural properties and capacities of thermal cladding components for an office building located in Cairo, Egypt, were researched. The study shows that using basic retrofit techniques, such as wall insulation, window glazing, solar shading, and air tightness, may result in an average energy consumption reduction of 33%. Abdel Salam *et al.* [10] during a study that was done in 2023 demonstrated the significance of using energy modelling methods to enhance the efficiency of building envelopes. By doing a detailed analysis of a currently operational educational facility situated in Cairo, Egypt. The research demonstrated that the inclusion of climate-appropriate thermal insulation led to an 18% reduction in air conditioning power use and an 8.1% drop in overall building energy consumption. The use of glazing material suitable for the environment led to a reduction of 21% in air conditioning power consumption, as well as a notable drop of 9.7% in the overall energy consumption of the structure. (Hamed, R. E.) 2023 [11] conducted a study indicating the use of Phase Change Materials (PCM) in building envelopes. The research findings showed that the application of (PCM) enhances the comfort, safety, and efficiency of buildings. Additionally, it results in reduced energy consumption, minimized greenhouse gas emissions, and decreased overall energy usage. The study findings indicate that the most efficient method for constructing energy-efficient building envelopes involves incorporating suspended phase change materials (PCM) into various construction elements inside the built-in envelope systems. These elements include internal walls, floor levels, ceiling layers, opening glass, and rooftop alterations. In 2017, (Abdul Mujeebu *et al*), [12], demonstrated the significance of Nanotechnology in enhancing the thermal insulation of building envelopes. The research findings indicated that by implementing nano vacuum insulated panels in walls and roofs, as well as nanogel glazing in windows, a collective reduction of around 18% in yearly energy consumption of the building could be achieved within the temperature range of 19–27°C. Furthermore, the usage of nanogel glazing alone resulted in a 16% reduction. During a study done by Seghier *et al.* in 2021[13], the researchers offered a technique called retrofitting building information modeling (RBIM) seeking to obtain a balanced design that minimizes both the overall thermal transmittance value (OTTV) and the cost of retrofitting. William, M. A., *et al*. [14] have shown the significance of using dynamic simulation to analyze building performance. They used this approach to investigate an educational building in Cairo, Egypt. The research seeks to identify the most efficient retrofitting option for a building's exterior by considering criteria such as thermal insulation efficacy, cost, and environmental impact. The research found that the use of Extruded polystyrene insulation (XPS) with a thickness of 25 mm leads to a 16% reduction in Heating, Ventilation, and Air-Conditioning (HVAC) energy consumption and an 8% reduction in total energy consumption. In a case study conducted by Faggal *et al*. (2019) [15], the researchers used sophisticated simulation techniques using Design Builder® software to analyze a residential building in New Cairo City. The study found that altering the kind of glass used in the building may lead to a reduction in yearly energy consumption of up to 18.8%. A study conducted by Djedjig *et al*. (2017) [16], focused on investigating the effects of a novel green wall system on the energy efficiency of buildings in hot climates, specifically on the enhancement of the building envelope's thermal performance. The research demonstrated that the implementation of the cutting-edge green wall system resulted in a significant reduction of up to 37% in the yearly energy consumption of the building. In addition, comparison research conducted by (Y. He *et al*.) [17] in the Shanghai region demonstrated the thermal and energy efficiency of green roofs and cool roofs. The research forecasted the impact of several roof designs on the energy efficiency of a public building. The study simulation findings showed that the implementation of a green roof resulted in a reduction of cooling and heating loads on the top level by 3.6% and 6.2% respectively. The implementation of a cool roof has the potential to decrease the cooling demand by 3.6% and simultaneously raise the heating load by 10.4%. In research conducted by Dionysios I. Kolaitis *et al* in 2013 [18], a comparative evaluation was carried out on residential Greek buildings constructed in the 1980s. The study focused on the efficient retrofitting of interior and outdoor thermal insulation systems. The research showed that both exterior and interior thermal insulation designs have a substantial impact on reducing overall energy consumption. Specifically, external insulation surpasses the internal insulation configuration by 8%. Internal insulation provides a shorter return time compared to exterior insulation since it necessitates about 50% less initial expenditure. During the process of retrofitting existing buildings utilizing 3D laser scanners and simulation software for building environmental assessments could significantly reduce the time and effort required to upgrade existing building envelopes. One can use a 3D laser scanner to evaluate the current state of an existing building envelope. This information can serve as the foundation for environmental studies, particularly for structures that do not have construction blueprints or have undergone changes to their building façade over time. By using a laser scanner to capture facade recordings, it is possible to produce 3D drawings with enhanced precision and reduced labor [19, 20, 21, 22]. When compared to traditional surveying techniques, laser scanner technology provides a higher level of information in the form of a 3D model, while significantly reducing the amount of labour needed. In research done by Nap (2022) [23]. Terrestrial laser scanner systems have become widely popular for three-dimensional (3D) modelling. This is because they can operate in difficult or hazardous environments, protecting the safety and welfare of users and researchers, especially in expansive construction. In addition, Marzouk and El-Bendary (2022) [24] use 3D laser scanning technology to oversee gas turbine power plants. However, it affirms the possibility of using other technology, such as laser scanning, to document the condition of deteriorating monuments or structures. In addition, Moyano *et al*. (2022) [25] used a terrestrial laser scanner to generate very precise three-dimensional depictions of large-scale buildings. Arjmand *et al*. (2023) [26] state that the incorporation of 3D laser scanners into different software platforms enables precise assessment of building quality via the capture of point cloud data. As a result, this promotes sustainability in the building industry. The current research study primarily evaluates the practicality of using laser scanner technology to conduct 3D surveys and document the façade of government buildings. This information will be used as the basis for planning the installation of solar photovoltaic components.

2. METHODOLOGY

The research study starts by choosing an existing office-factory research facility situated in Cairo, Egypt, for an energy performance application study, mostly due to the availability of its data. A 3D laser scanner was used to assess the current structure of the building's exterior, while a laser meter was used to measure the dimensions of the building's interior areas. A baseline simulation model was constructed using data from a field survey. The yearly electrical energy results were then compared to the actual electrical consumption of the building on-site to verify the model. For the study, Design builder® Ver 6, a building energy modeling simulation tool based on Energy Plus software is funded by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO). The software was used to measure the building's total annual electrical energy consumption, as well as the heating and cooling energy required to achieve the desired thermal comfort temperature for occupants. The study is conducted using Cairo’s airport weather file. The simulation model, which compares energy use, bases itself on the current state of building construction. Using Design builder® software, a modified basic 3D model was done to create an energy experimental model for the top-level office-factory research building. The top floor was chosen for the primary thermal simulation to investigate the impact of roof insulation on thermal heat uptake. During the study building envelope components were classified into two categories: opaque elements, such as exterior walls and the building roof, and transparent elements, such as operable windows and fixed glass panels. Throughout the energy

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simulation process, many scenarios were tested for retrofitting the thermal insulation of various building envelope components, including the roof, exterior walls, and external windows. These scenarios were tested separately on a top-floor environmental model. Other sources of interior heat gain, such as lighting and equipment, were kept constant throughout the simulation. To determine the yearly percentage of electrical energy saved, the annual energy consumption of each retrofitted element scenario was compared to the annual energy consumption of the base model. Building envelope elements retrofitting methods in the scope of the study are shown in Table-1.

Table-1. Thermal insulation enhancement retrofitted elements.

Roof:	External walls:	Windows:
• Thermal insulating roof tiles • Roof insulation material	• Internal cladding • Double internal wall • Thermal insulation cladding • External cladding • Thermal insulation panels	• low-e window film • low-e glass • color glass • window shading • window frames

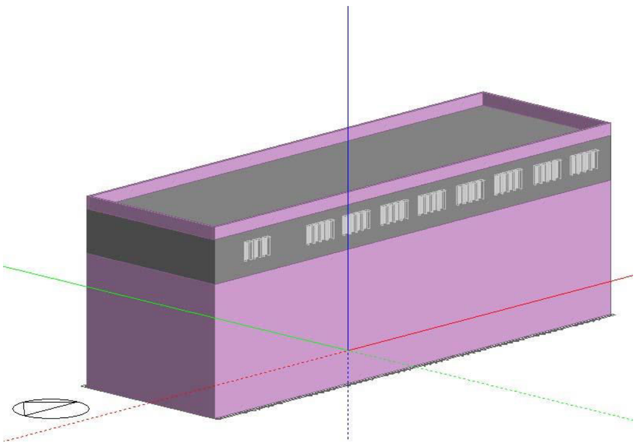

Figure-5. Building simulation energy simulation top floor model.

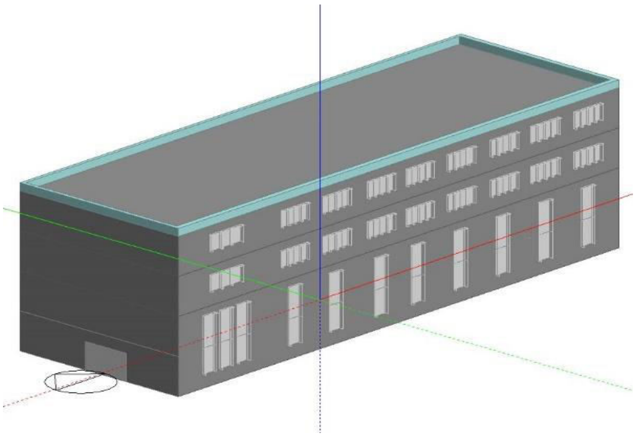

Figure-6. Building energy simulation model.

2.1 Experimental Building Description

The Engineering Research Institute and Renewable Energy is one of the buildings of the National Research Centre, constructed in 1956 situated in Cairo, Egypt was selected as an illustrative example of a mixed-use research office-factory government building situated in a hot dry region. The building coordinates are 30° 02′ 08″ N and 31° 12′ 14″ Figure-7. The building operates on weekdays from 8:00 AM to 4:00 PM. The building is composed of a non-airconditioned research factory on the ground floor with an internal clear height of 9.30 m. The first floor is a mezzanine in the factory area, and the second and third floors house laboratories and office spaces. Each of the second and third floors has 8 offices facing south measuring 4.88 m by 7.25 m, and 5 offices facing north measuring 4.88 m by 5 m. Additionally, there is a conference room on the end side of the building, with dimensions of 10.84 m by 15.75 m, facing West. Each office area accommodates four researchers and is equipped with a 2.5 HP split air-conditioning. The middle corridor is not air-conditioned. The illumination of all interior areas is by ceiling surface-mounted fluorescent bulb units measuring 120 cm X 30 cm. The building plan is rectangular and has an area of 853 square meters. The building has two long sides facing the North and South directions. Although the building has an external total height of 20 m and is located in a research building complex, it is surrounded by four wide streets that reduce the impact of surrounding buildings' shadows casting on its façade. The architectural blueprints for the structure were not accessible, thus the interior areas of the building were surveyed using laser measuring devices. Using a 3D laser scanner, the 3D model cloud was created to serve as a base for studying the building envelope. This model accurately depicts the solid wall areas as well as window placements and dimensions Figure-8.

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Figure-7. Engineering research institute and renewable energy location.

Figure-8. Engineering research institute and renewable energy 3D laser scanner survey 3D point cloud model.

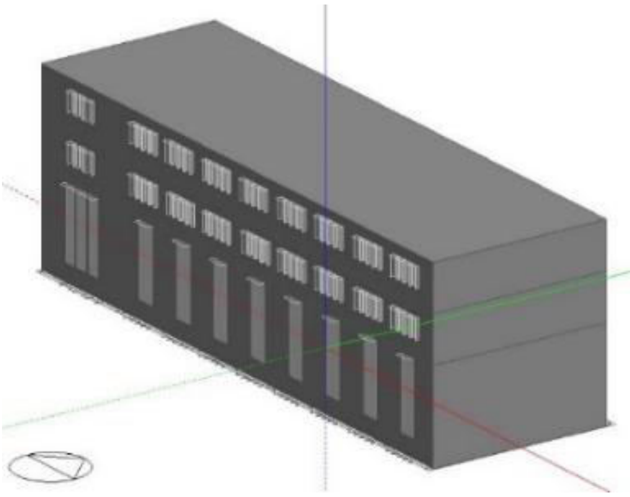

Figure-9. Illustrates an environmental simulation building model created by design builder software based on a 3D point cloud model.

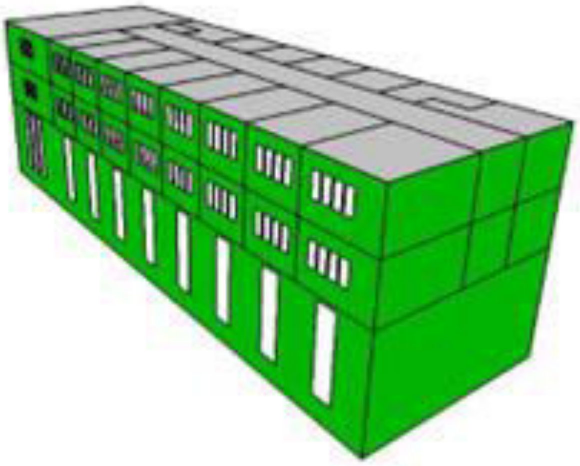

Figure-10. Engineering research institute and renewable energy environmental model.

Based on the building 3D cloud model created by 3D laser scanner the existing building facades were done as a base for the solid and glass area analyses. Table-2 represents building facade area analyses.

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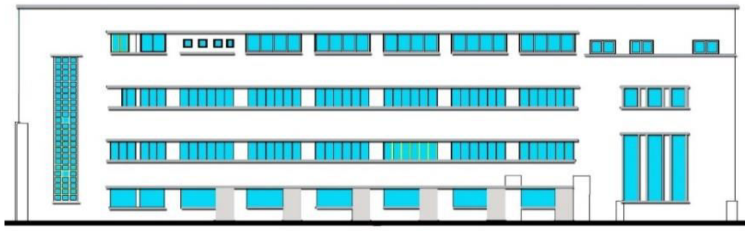
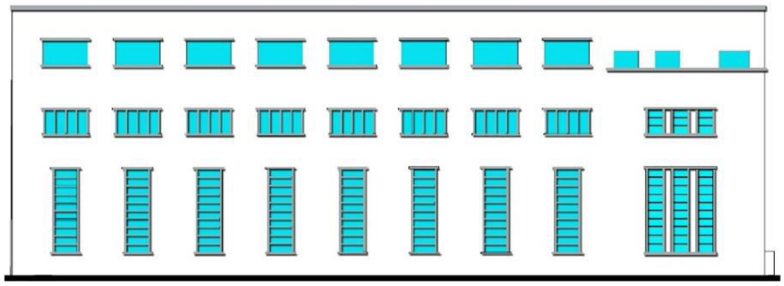
Table-2. Building Façades area analyses.

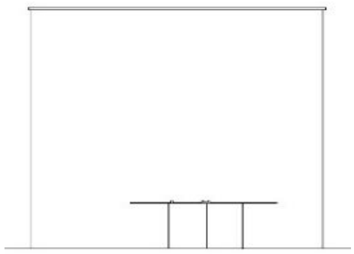
North elevation	**Total façade area m²**	**Solid wall area m²**	**Glazing area m²**	**Window-to-wall ratio**
Length 56.5 m Height 20 m.	**1033**	**841.5**	**191.5**	**18.50 %**



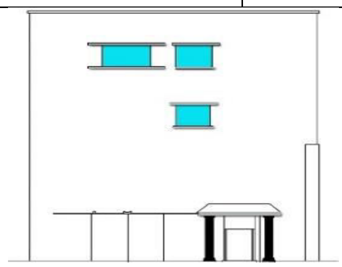
South elevation	Total façade area m²	Solid wall area m²	Glazing area m²	Window-to-wall ratio
Length 56.5 m Height 20 m	1033	851.4	181.6	17.50 %



West elevation	Total façade area m²	Solid wall area m²	Glazing area m²	Window-to-wall ratio
Length 16.25 m Height 20 m.	327	318.7	8.30	2.5%
East elevation	Total façade area m²	Solid wall area m²	Glazing area m²	Window-to-wall ratio
Length 16.25 m Height 20 m.	327	318.7	0	0 %



West elevation



East elevation

The research study concentrated on the experimental model top floor plan representing an air-conditioned office space for the energy consumption simulation as the ground floor factory and mezzanine floor are nonairconditioned spaces.

Figure-10 illustrates the existing building's top floor plan; Figure-11 illustrates the building's top floor environmental simulation model created by using Design Builder software. Top floor envelope analyses are represented in Table-3 considering the floor element as a block component to eliminate its effect on the external envelope analysis. Meanwhile, Table-4 shows the experimental building current construction materials to be a base case for comparison of the annual electrical energy consumption rate (the research study is based on the use of electrical energy as a main source for building heating and cooling purposes) with the thermal insulation enhancement retrofitted elements. All other heat sources such as building occupants, equipment, and lighting were unified during the simulation.

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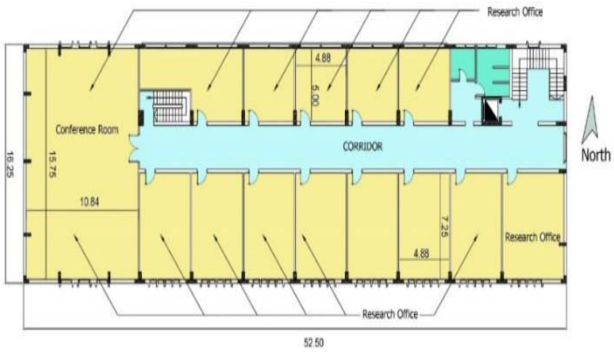

Figure-11. Building top floor plan.

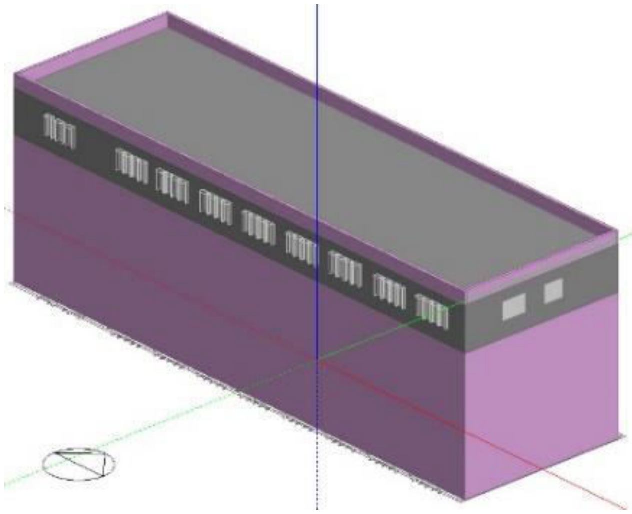

Figure-12. Top floor environmental simulation model.

Table-3. Existing building top floor window-to-wall ratio.

Top Floor Building Façades description (does not include roof parapet area)				
	Total façade area m²	**Solid wall area m²**	**Glazing area m²**	**Window-to-wall ratio**
North elevation	274	225	49	21 %
South elevation	274	222	52	23.40 %
West elevation	79	70.7	8.30	11%
East elevation	79	79	0	0 %

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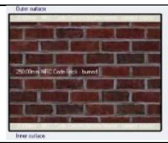
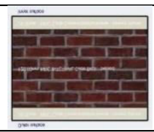
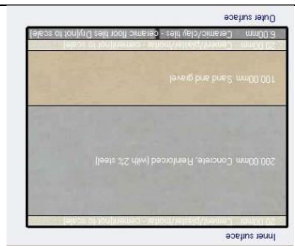
Table-4. Existing building construction materials.

Building Envelope Elements	Construction layers	Total Model Section Thermal Resistance Rt Value (m²K/W)
Building Roof	• 2 Cm concrete tiles • 2Cm cement/plaster/mortar • 6Cm Sand • 10Cm concrete medium-density • 2Cm damp-proof membrane • 20Cm reinforced concrete • 2Cm Internal Cement Plaster	1.025 Egyptian Code Recommendation [3] (Rt Max = 2.26 m² C°/W) 
External walls - white color white cement plaster	• 2 Cm external cement plaster • 25 Cm thick burned brick wall • 2 Cm internal cement plaster	1.060 Egyptian Code Recommendation [3] (Rt Max = 1 m² C°/W) 
Internal partitions	• 2 Cm internal cement plaster • 12 Cm thick burned brick wall • 2 Cm internal cement plaster	1.060 
Intermediate Floors	• 6 MM Ceramic • 2 CM cement mortar • 10 CM sand • 20 CM reinforced concrete slab	0.30 
External windows	• No thermal break Aluminum frame • 6 MM single clear glass	0.17
External doors	• Uninsulated steel sheet door	0.17
Internal doors	• Wood cladding	0.580

A prime energy simulation is done for the building's top floor which consists of 13 research offices and a conference hall. Table-5 shows the results of the environmental model simulation for the top floor study, accounting for heat gain and heat from the thermal resistance values of the existing building envelope components (used as a baseline for comparison).

Table-5. Building top floor (Existing construction) simulation study results.

Measurement Item	Results								
	Total annual electric energy consumed kWh	Total annual electric energy consumed per Square Meter kW/mt²	Annual Heating Energy kWh	Annual Heating Energy per Square Meter kW/mt²	Annual Cooling Energy kWh	Annual Cooling Energy kWh	No. Of discomfort hours	Percentage of discomfort hours	Annual CO2 Emissions Kg
Base Line	35894	42	503	0.6	64387	75.4	2735	31 %	21690

Top floor total annual energy consumed in kWh:
Electrical energy 35894 kWh

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2.2 Suggested Building Thermal Resistance Enhancement Retrofitting Methods

- Building roof

It is recommended by "Egyptian code to improve the efficiency of energy use in buildings" [7] that the roof thermal conductivity U-value for heavyweight construction 20 Watt/m² for airconditioned commercial buildings located in Cairo and delta zone. For flat concrete slabs in the Cairo-Delta region the total thermal resistance (Rt = 2.26 m² C°/W). The two following equations represent the mathematical calculation of materials' thermal resistance.

U=1/Rt Where: U = Total thermal conductivity Rt = Total thermal resistance Material thermal resistance = thickness / (area x thermal conductivity).	R t = L/ k. A Where: K is the material conductivity [W/m². K] L is the plane thickness [m] A The plane area [m²]

- Changing roof tiles

The experimental study building is located in Cairo which is a hot region, energy use is more for cooling purposes than for heating. The Energy Star Program, initiated in 1992 by the U.S. Environmental Protection Agency (EPA), aims to diminish the release of greenhouse gases by endorsing energy-efficient goods, residences, and structures. Solar reflectivity (SR) is a numerical value ranging from 0 to 1.0. According to Energy Star criteria for low-slope roofs, a value of 0 indicates complete absorption of solar energy, while a value of 1.0 shows complete reflectance. It is recommended to use a color value of 0.65 or higher initially and a value of 0.50 or above after three years [27]. To reduce the amount of cooling needed for the top floor experimental model simulation, it was determined that replacing the current grey concrete tiles (0.37) with white roof tiles that have a greater solar radiation reflectance (0.65) would be beneficial. The model roof tile scenario utilizes white-colored tiles that are both typical and various varieties of polyurethane-insulated roof tiles. Table-6 and Figure-12 shows the annual energy conservation rates and percentages achieved by using various thermal insulation roof tiles.

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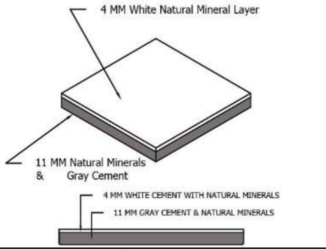
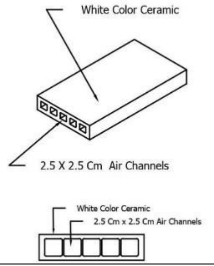
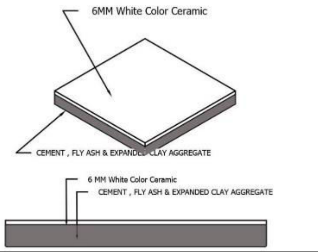
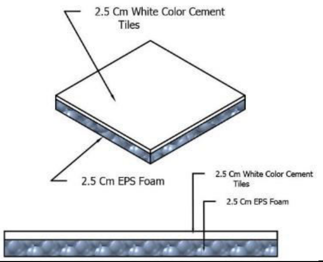
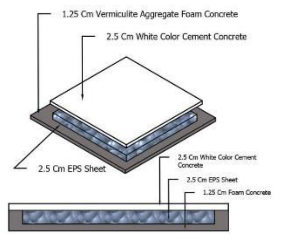
Table-6. Annual energy saving percentages reached by using thermal insulating tiles.

Size mm	**Roof Tile Type**		**Slab Thermal Resistance R Value (m²K/W)**	**Roof Annual Heat Gains kWh**	**Annual Energy kWh**	**Annual Energy Saving Percentage**
250 X 250 X 15		* 4mm White natural mineral. *11 mm natural mineral & gray cement	1.026	700.9	35877	0.04%
130 X 270 X 34		*6mm White color Ceramic. *34mm Cement fly ash & expanded clay aggregate.	1.06	965.94	32122	10.5%
300 X 300 X 40		* 6mm White color ceramic. *34mm Cement, fly ash, expanded clay aggregate	1.22	873.01	29908	16.6%
300 X 300 X 50		*2.5 cm White cement. * 2.5 cm EPS Foam.	1.903	247.67	26430	26.3 %
300 X 300 X 60		*2.5 cm White color cement concrete. * 2.5 cm EPS Sheet. *1.5 cm Vermiculite aggregate foam concrete.	1.916	461.62	26437	26.3%

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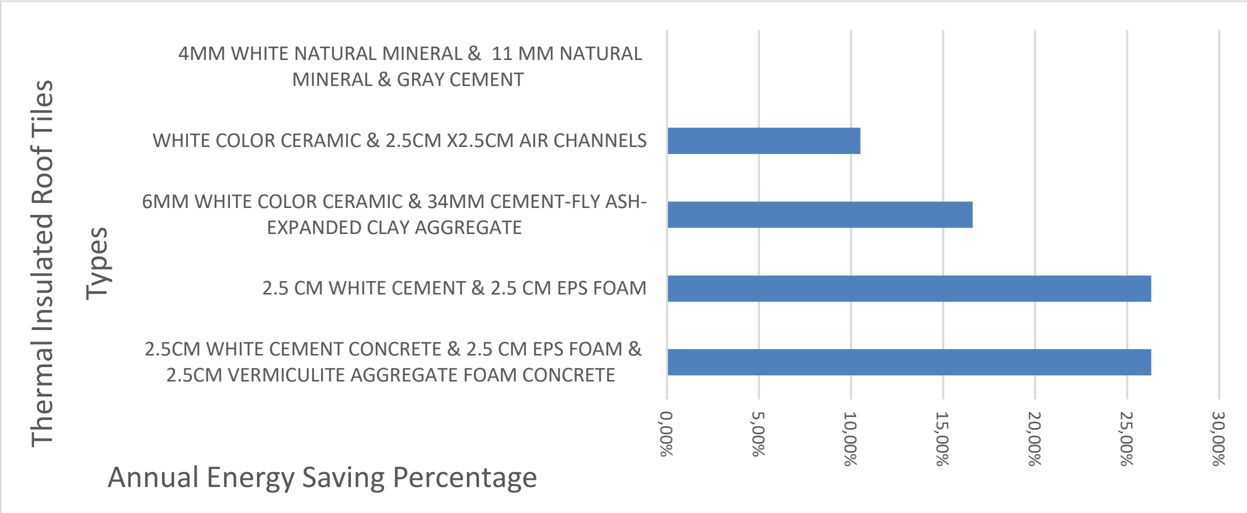

Figure-13. Annual energy saving percentage by applying thermal insulated roof tiles.

The environmental simulations for the different types of thermally insulating roof tiles showed that the composite roof tile with a 2.5-cm-thick white cement top layer, a 2.5-cm-thick extruded polystyrene layer, and a 1.5-cm-thick vermiculite concrete layer had the highest total slab thermal resistance value of 1.916 m^2 - K/W. This particular tile also led to a 26.3% reduction in energy consumption compared to the base model simulation.

Despite the thermally insulated tile leading to yearly energy savings, the overall R-value of the slab section falls below the minimum standards set by the Egyptian code for flat concrete slabs in the Cairo-Delta region (Rt = 2.26 m^2 C°/W). This implies that one must combine thermally isolating roof tiles with another method of roof insulation.

- Adding roof insulation: The second approach to retrofitting involves improving the roof's thermal resistance by adding more layers of thermal insulation. The thermal insulation options being investigated in the research study include solid polyurethane boards, expanded polystyrene boards, expanded perlite mortar, and vermiculite mortar. The comparative approach included using a consistent layer thickness to accurately assess the thermal insulation properties of each material. The material density and thermal resistance values used in the research were based on the Egyptian specifications for thermal insulation work items. Table-7 represents the annual electrical energy saving percentages resulting from applying various types of roof thermal insulating materials to the building simulation model. Meanwhile, Figure-13 illustrates the roof surface inside face conduction heat transfer rate by use of various roof thermal insulating materials and Figure-14 illustrates the roof thermal insulation layers' annual electrical energy saving percentage.

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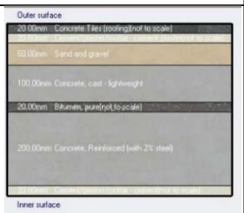
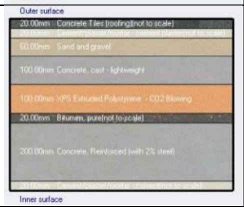
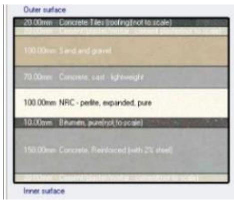
Table-7. Annual electrical energy saving percentages by using roof thermal insulating layers.

	Roof added thermal insulating material & thickness	**Roof Layers Section**	**Roof**	**Total Energy Annual Consumption kWh**	**Annual energy saving percentage**
	Without thermal insulation		heat gain 5893.09 kW Total Slab R-Value 1.025 m²K/W	35894 Base comparative Consumption value	0 %
	10 Cm thick extruded polystyrene boards CO2 density 40 Kg/m³ U value 0.33 Watt/m C° [8]		heat gain 1501 Kw Total Slab R-Value 2.414 m²K/W	24917	30.5 %
	10 cm thick Solid polyurethane Boards density 40 Kg/M³ U value 0.27 Watt/m C° [8]		heat gain 1019 KW Total Slab R-Value 4.440 m²K/W	23878	33.5 %
	10 cm perlite Mortar density 610 Kg/M³ U value 0.11 Watt/M C° [8]		heat gain 4366 Kw Total Slab R-Value 1.699 m²K/W	30527	15 %
	10 cm Vermiculite mortar density 900 Kg/m³ U value 0.303 Watt/m C°[8]		heat gain 6248 Kw Total Slab R-Value 1.120 m²K/W	34890	2.7 %

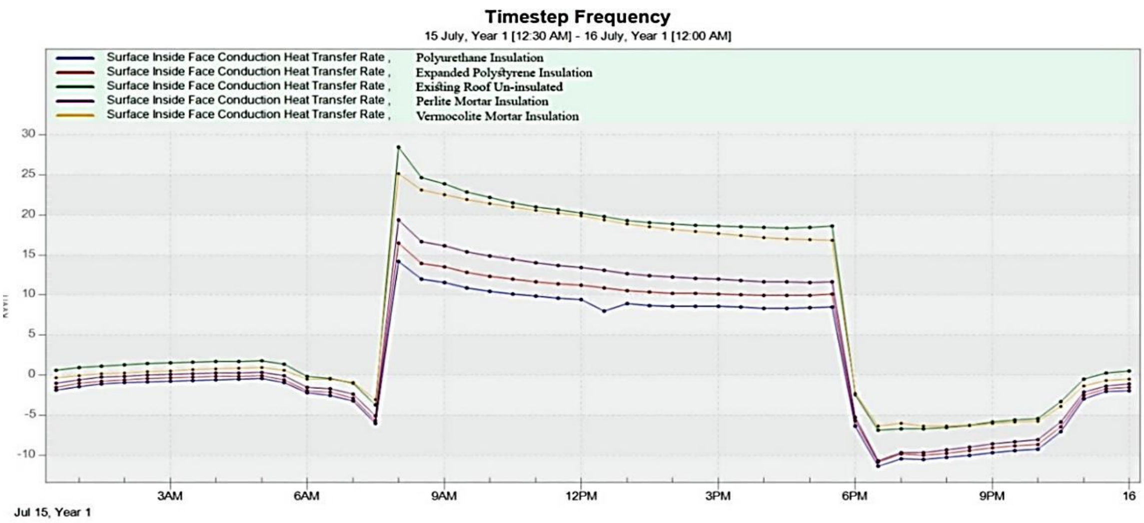


Figure-14. Roof surface inside face conduction heat transfer rate by use of various roof thermal insulating materials.

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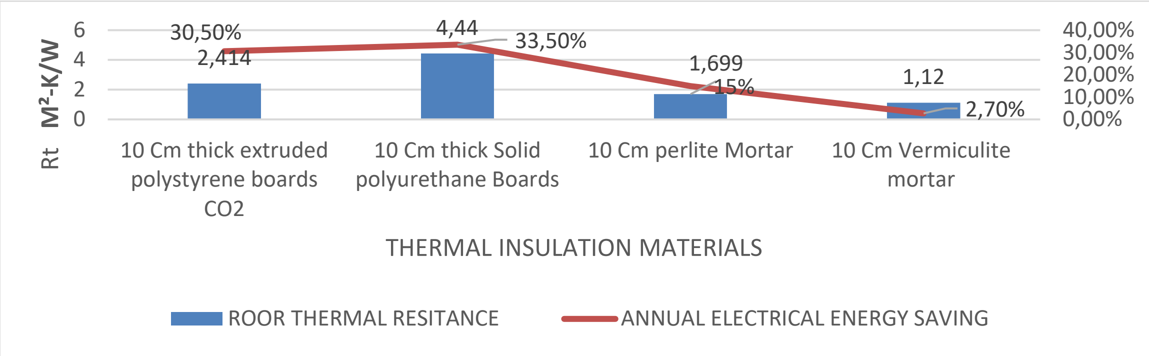

Figure-15. Roof thermal insulation layers annual energy saving percentage.

- Retrofitting Building Exterior Walls

Enhancing the thermal insulation properties of existing buildings outside walls reduces the amount of energy needed for heating and cooling purposes. That is by impeding the heat transfer by conduction to and from the building interior spaces. Based on thermal insulation material location, building exterior walls retrofitting process is categorized into two primary approaches. The first approach is to apply thermal-insulating coating on the internal side of the exterior wall and the second approach is to apply thermal-insulating coating on the exterior side of the external wall. Figure-15 displays a range of techniques used to upgrade the outer walls of buildings.

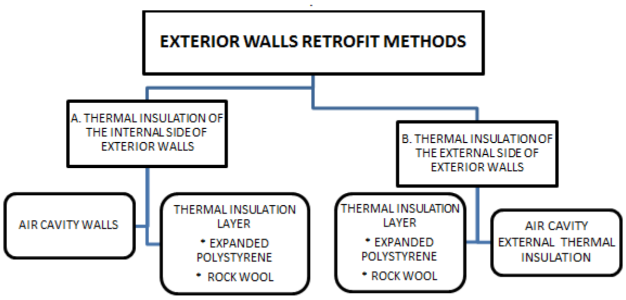

Figure-16. Exterior wall's thermal insulation retrofit methods.

A. First approach - thermal insulation from the internal side of exterior walls

The first approach for retrofitting building exterior walls, and the least expensive approach is to add a thermal insulating layer from the inside side of the structure. Various alternatives are evaluated for interior building insulation layers, such as cavity walls, expanded polystyrene layers, and rock wool layers. All of these solutions often include a 15-mm gypsum board covering layer. According to the "Egyptian code to improve energy use efficiency in buildings," the maximum accepted overall thermal transmittance (OTTV) value for walls in the Cairo and Delta regions should not be more than 90 W/m^2. Additionally, it recommends specific thermal resistance (R-value) for external walls of heavyweight construction based on their orientation and color as shown in Table-8.

Table-8. External wall's thermal resistance requirements according to Egyptian code to improve the efficiency of energy use in buildings.

Walls orientation	Color	Thermal resistance R-value (m² C°/W)
North	Bright	0.6
North East / North West	Bright	0.7
East / West	Bright	0.9
South East /South West	Bright	0.8
South	Bright	0.7

The internal annual heat gains from the existing exterior walls amount to -1790.78 KW, resulting in an annual energy usage of 35894 KW/h. The proposal involves applying thermal insulation layers to the interior surface of the existing building's exterior walls. The walls consist of a 2 cm layer of cement plaster, a 25 cm layer of burnt brick, and an additional 2 cm layer of cement plaster. This surface's basic thermal conductivity U value is 1.874 (W/m²-K). Three scenarios were conducted as shown in Table-9.

Scenario No. 1 An air cavity wall is created by attaching a 12-cm plastered burnt brick wall to the inside of the exterior building wall, leaving a 10-cm gap between the two walls. This gap serves as a thermal barrier between the existing wall and the additional wall. This scenario entails a 22 cm increase in wall thickness on the internal side of the current exterior walls.

Scenario No. 2 The process involves the use of expanded polystyrene boards. The insulation is achieved by affixing 10 cm-thick expanded polystyrene boards to the inner surface of the outside wall of the building, followed by a layer of 1.5 cm-thick gypsum plasterboard. This scenario involves increasing the wall thickness on the internal side of existing exterior walls by an additional 11.5 units.

Scenario No. 3 involves the use of unbonded rockwool. A 10 cm thick layer of unbonded rock wool

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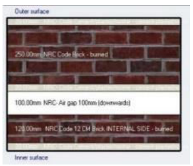
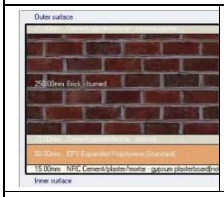
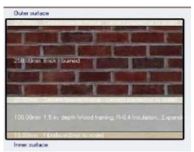
creates the insulation. A 1.5-cm-thick layer of cement, plaster, or mortar-gypsum plasterboard covers the interior side of the exterior building wall, followed by a 1.5-cm-thick layer of gypsum plasterboard. This scenario involves increasing the wall thickness on the internal side of existing exterior walls by an additional 11.5 units.

Table-9. Building external walls thermal insulation enhancement from the indoor side.

Scenario No. 1_ Air cavity wall				
	*2.5cm Cement plaster mortar. *25 cm thick burned brick. *2.5cm Cement plaster mortar. *10 cm air gap *12 cm thick burned brick *2.5cm Cement/plaster/mortar	Wall annual heat gain -1790 Kw wall Thermal Resistance Rt Value 1.837m²-K/W	Annual Electric Energy Consumption 35851 kWh	Annual Energy Saving Percentage 0.12 %
Scenario No. 2_ Expanded polystyrene boards Insulation				
	*2.5cm Cement plaster mortar. *25 cm thick burned brick. *2.5cm Cement plaster mortar. *10cm thick Expanded polystyrene *1.5cm thick Cement/plaster/mortar-gypsum plasterboard	Wall annual heat gain -1790 Kw wall Thermal Resistance Rt Value 2.54 m²-K/W	Annual Electric Energy Consumption 35851 kWh	Annual Energy Saving Percentage 0.12 %
Scenario No. 3_ Unbonded Rockwool Insulation				
	*2.5cm Cement plaster mortar. *25 cm thick burned brick. *2.5cm Cement plaster mortar. *10cm thick Unbonded Rockwool *1.5cm thick Cement/plaster/mortar-gypsum plasterboard	Wall annual heat gain -1790 Kw wall Thermal Resistance Rt Value 3.28 m²-K/W	Annual Electric Energy Consumption 35851 kWh	Annual Energy Saving Percentage 0.12 %

In all three scenarios, the total thermal resistance (Rt-value) was higher than the minimum requirement for external walls set by the "Egyptian code to improve the efficiency of energy use in buildings" for all four wall orientations. However, the environmental simulation results showed that the annual electrical energy savings were less than 0.12%.

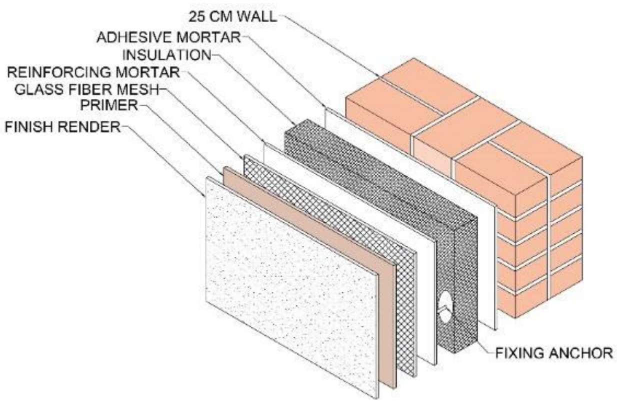


Figure-17. Thermal insulation layers fixed with fixing anchor.

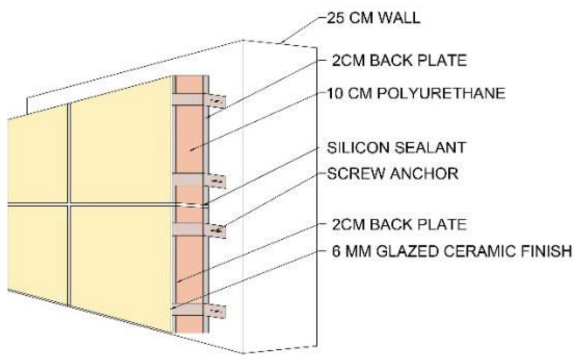


Figure-18. Thermal insulation layers fixed with metal frame.

B. The second approach is thermal insulation of the external side of exterior walls

There are two methods to add thermal insulation layers to the exterior walls of an existing structure. The first method involves using a fastening anchor to minimize the thermal bridge effect, as illustrated in Figure-16. The second method involves attaching a metal frame to the external side of the wall, as shown in Figure-17. The present investigation conducted two scenarios to examine the attachment of exterior thermal insulation as shown in Table-8.

Scenario No. 1 The process entails applying a layer of polystyrene thermal insulation to the exterior wall surface. The process begins with the addition of a cement

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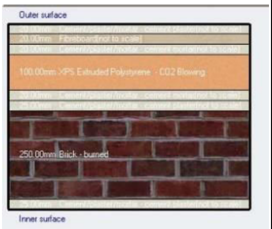
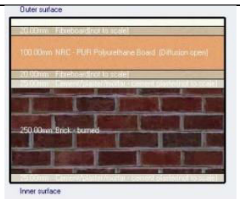
adhesive mortar layer, secured with metal fixing anchors. To provide weather protection for the polystyrene layer, an additional layer of adhesive mortar is added, followed by fiberboard and glass mesh primer, and finally finished with acrylic plaster render.

Scenario No. 2 Polyurethane composite cladding tiles consist of a fiberboard with a polyurethane layer in the Centre. Metal angles and anchor bolts secure these tiles to the outside wall. The spaces between the tiles are filled with mastic silicon filler.

Table-10. Building external walls thermal insulation enhancement from the outdoors side.

Scenario No. 1	**10 Cm Polystyrene Thermal Insulation Layer**			
	*2 Cm Plaster finish *2Cm Cement/adhesive/mortar *2 Cm Fiberboard *10 Cm XPS – CO2 Blowing *2 Cm Cement/adhesive/mortar *2.5Cm Cement plaster mortar. *25 Cm thick burned brick. *2.5Cm Cement plaster mortar.	Wall annual heat gain -1790 Kw wall Thermal Resistance Rt Value 3.818 m^2K/W	Annual Electric Energy Consumption 35851 kWh	Annual Energy Saving Percentage 0.12 %
Scenario No. 2	**10 Cm Thick Polyurethane composite cladding tile**			
	*2 Cm Fiberboard *10 Cm polyurethane board *2 Cm Fiberboard *2.5Cm Cement plaster mortar. *25 Cm thick burned brick. *2.5Cm Cement plaster mortar.	Wall annual heat gain -14910 Kw	Annual Electric Energy Consumption 35699 kWh	Annual Energy Saving Percentage 0.54 %

Although the total thermal resistance (Rt-value) in the two Scenarios exceeded the minimum Rt-value requirement of the external walls mentioned in the “Egyptian code to improve the efficiency of energy use in buildings” in the four wall orientations the environmental simulation results showed that the annual electric energy saving did not exceed 0.12%. Figure-18 illustrates the building's south elevation annual inside face heat transfer rate.

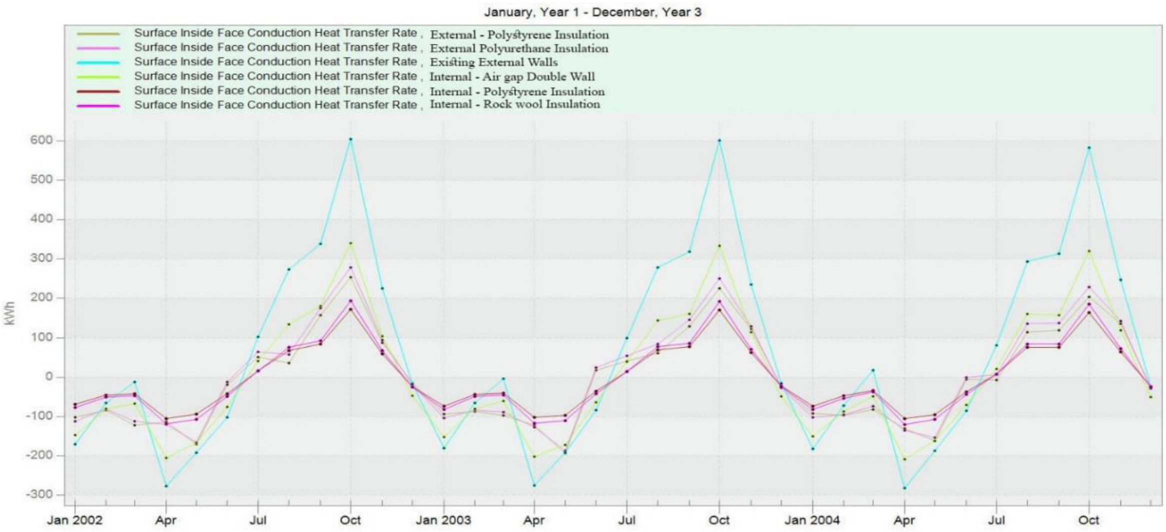


Figure-19. South Elevation Annual inside Face Heat Transfer Rate.

- Retrofitting windows

Windows plays an important role in building energy saving, although it saves lighting energy as is the main source of natural lighting it consumes cooling energy as is one of the heat gain sources. Retrofitting window thermal insulation methods should balance between solar heat gain and the rate of light transmitted especially in office buildings. Figure-19 illustrates windows' thermal insulation retrofitting methods.

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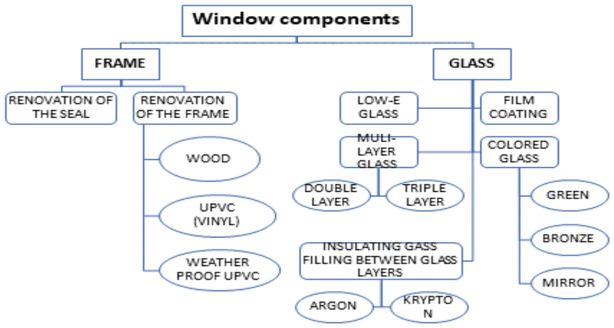

Figure-20. Windows thermal insulation retrofit methods.

- Lowering solar heat gain coefficient (SHGC) **of windows**

One of the retrofit methods examined in the present study is reducing the solar heat gain coefficient. The Solar Heat Gain Coefficient (SHGC) is a numerical value that represents the amount of solar radiation that passes through window glass panels. A lower numerical value indicates a reduced capacity for heat transmission through the window. The solar heat gain coefficient (SHGC) is measured on a scale from 0 to 1, with typical values ranging from 0.25 to 0.8. In hot climates where the cooling load is the main concern, it is advantageous to decrease the solar heat gain coefficient (SHGC) of windows to minimize energy consumption for cooling during summer days. Noting that the size of the window influences the SHGC value. In terms of cost, the first stage of retrofitting windows involves the installation of low-e window film. The next stage involves modifying the glass type, color, reflectivity, or a combination of these factors. The final step involves altering the material of the window frame. The current research study simulation compares the daylight illuminance rate and solar heat gain coefficient (SHGC) of the current glass type (6 mm clear) with other thermal resistance glass types under investigation. This comparison serves as a baseline for evaluating the impact of different glass types on daylight illuminance. Figures 20 and 21 show the current level of daylighting intensity on the top floor workplaces. Meanwhile, Figures 22, and 23 illustrate the solar radiation direction during summer and winter days.

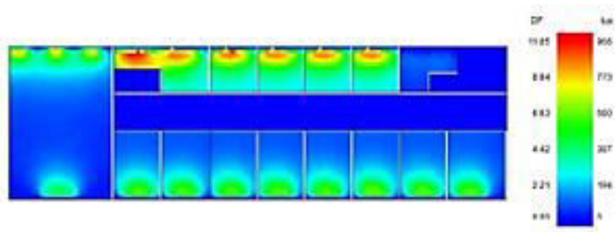

Figure-21. Summer Day June 15 - Time 10 Am Existing building illuminance distribution map.

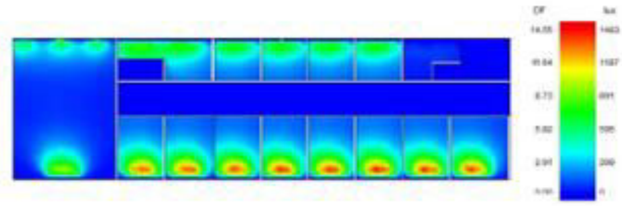

Figure-22. Winter Day December 31 - Time 10 Am Existing building illuminance distribution map.

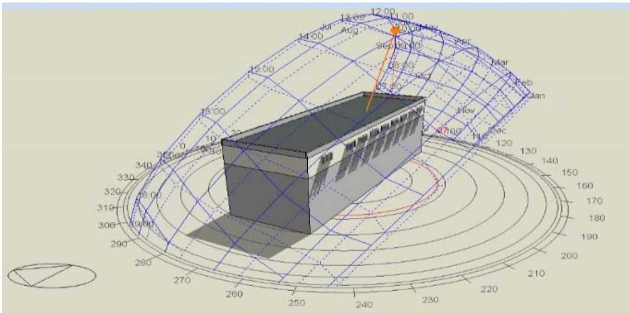

Figure-23. Summer Day June 15 - Time 10 Am Solar rays' direction.

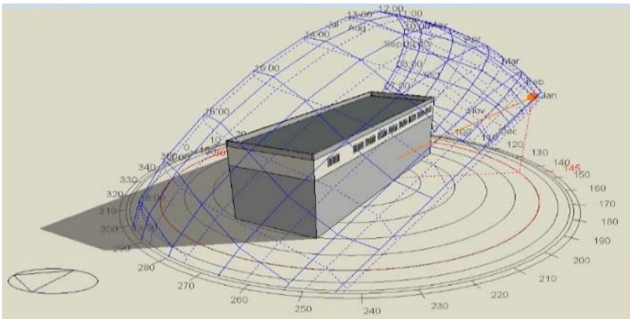

Figure-24. Winter Day December 31 - Time 10 Am solar rays' direction.

A. Low-e glass film

One of the cost-effective methods for enhancing the thermal insulation of existing windows is to lower its glazing solar heat gain coefficient (SHGC) by applying a low-e coating film to the inside side of the glass. Figure-24 illustrates the Low-e film (SHGC) reduction method. Hot, dry regions benefit from reducing the glass solar heat gain coefficient (SHGC) to save cooling energy, while cold regions benefit from using high (SHGC) glazing to save heating energy.

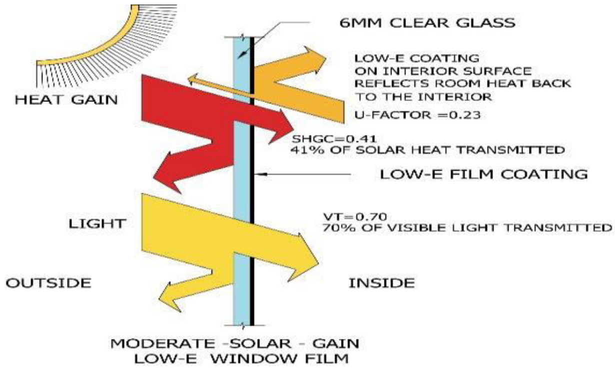

Figure-25. Low-e film (SHGC) reduction method.

B. Low-e glass panels

Cost-wise, the second step in retrofitting existing windows is changing their glazing type by using either low-e clear glass, color glass, or reflective glass. For office buildings daylight illuminance is of great importance, replacing window glass decision is to compromise between the visible light transmittance rate (LT) and its solar heat gain coefficient (SHGC). Table-11 shows various windows retrofit methods using 6 mm clear glass and its related rate of annual energy consumption, Table-12 shows the annual energy consumption related to the use of various colors of single layer 6 mm glass. Meanwhile, Figure-24 illustrates study glass types and their related annual electrical energy-saving percentages.

Table-11. Various window retrofitting methods use 6 mm clear glass.

	Existing Building	**Low e Glass**	**Double Layer**	**Double Layer low e glass**	**Triple layer air gap**	**Triple layer glass low e film (55)**
Layers Number	**Single layer 6mm clear glass**	**Single layer 6mm clear glass low e (e2=.2)**	**Double Layer 6mm clear glass 6mm air gap**	**Double Layer 6mm clear glass low e (e2=.1) 6mm air gap**	**Triple layer 6mm clear glass 25mm air gap for mid pane blinds**	**Triple layer 6mm clear glass low e film (55) 6mm air gap**
Solar Heat Gain Coefficient (SHGC)	0.810	0.72	0.7	0.626	0.604	0.306
Light transmission (LT)	0.881	0.811	0.781	0.721	0.696	0.455
U value (W/m²k)	5.778	3.779	3.094	1.772	1.910	1.211
Annual energy consumption (kWh)	35894	35849	35856	35848	35861	35837
Energy Saving Percentage	0%	0.125%	0.10%	0.13%	0.9%	0.15%

Table-12. Shows annual energy consumption for single layer 6 mm color glass.

	Single layer 6mm green color glass	**Single layer 6mm bronze color glass**	**Single layer 6mm tint reflective color glass**	**Double Layer 6mm clear glass low e (e2=.2) 13mm argon gas**	**Triple layer 3mm clear glass 10mm space krypton gas**
Solar Heat Gain Coefficient (SHGC)	0.623	0.62	0.354	0.635	0.685
Light transmission (LT)	0.749	0.53	0.181	0.721	0.738
Annual Glass heat gain kw (AGHG)	-8576	-8582	-8519.18	-8295.00	-8295.11
U value (W/m²-k)	5.778	5.778	5.067	1.689	1.546
Annual energy consumption (kWh)	35624	35636	35684	35714	35718
Annual energy saving percentage	0.752 %	0.71 %	0.60 %	0.51 %	0.49 %

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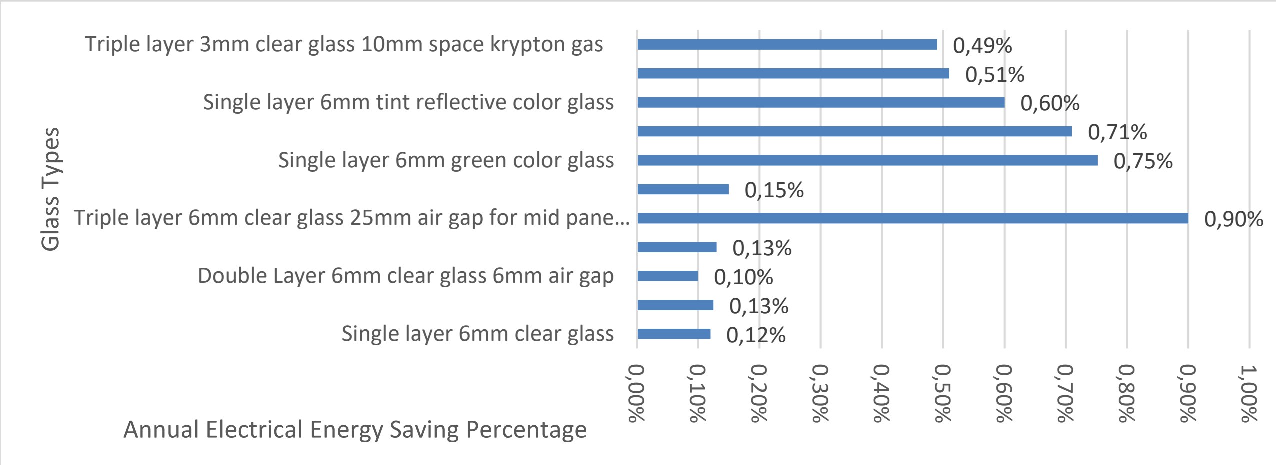
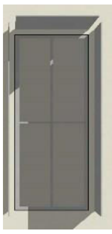


Figure-26. Study glass types and their related annual electrical energy saving percentages.

C. Window solar shading

The third step of retrofitting existing windows involves installing shades to minimize the amount of direct solar radiation that reaches the window glazing area. The permanent committee for preparing the "Egyptian code to improve the efficiency of energy use in buildings" [7] mentions that the building envelope must meet certain requirements. These include not having a minimum or maximum solar heat gain coefficient (SHGC) for the total window area percentage to the total north-facing wall area, and providing enough shade for the glass. The window opening for the south-oriented wall should be between 20% and 30%, with a ratio of 0.8. Additionally, the minimum shaded glass area should be 10%, measured specifically during the morning hours from 9:00 a.m. to 5:00 p.m. on September 21st. The south windows on the existing structure's office levels are the same size. The sill height is 1.5 m, the width is 0.65 m, and the height is 1.75 m. The area is 1.134 square m. All windows have a top overhang that extends 0.45 m from the window wall. Additionally, there are two concrete side louvers with a width of 0.1 m and a projection of 0.3 m from the window wall. The current window shading exceeds the glass area specified by the code. Therefore, there is no need to install any further window shades, as shown in Table-13.

Table-13. Shows the percentage of existing glass-shaded areas on an hourly basis during September 21st.

September 21st morning hours	**9:00 Am**	**95 %**	**Glass shaded percentage**	**9:00 Am**	**12:00 Pm**	**2:00 Pm**	**5:00 Pm**
	10:00 Am	75 %					

D. Retrofitting window frames

The study building currently uses silver color non-weatherproof aluminum window frames, paired with 6 mm plain glass. The techniques for retrofitting the window frames of the building are as follows: building energy simulation after replacing the window frame material with a higher thermal resistance material, such as wood or unplasticized polyvinyl chloride (UPVC). Additionally, further window energy efficiency improvement can be accomplished by using thermal break frame sections and by employing frame fixation methods that reduce thermal bridging. Table-14 illustrates the experimental building's annual energy-saving percentage by changing window frame materials. Meanwhile, Figure-25 shows the effect of window frame type on annual electrical energy saving.

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Table-14. Shows annual energy saving percentage related to various window frame materials.

Type of window frame	Thermal Resistance R-Value (m²K/W)	Thermal conductivity U-Value (W/m²K)	Annual electricity consumption (kWh)	Annual Energy Saving Percentage
Aluminum frame with no thermal break (base of comparison)	0.170	5.881	35894	0 %
Aluminum frame with thermal break	0.199	5.014	35630.40	0.74 %
Unplasticized polyvinyl chloride (UPVC) with no thermal break	0.405	2.467	35627.95	0.75 %
Unplasticized polyvinyl chloride (UPVC) with thermal break	7.0	0.139	35600.1	0.81 %

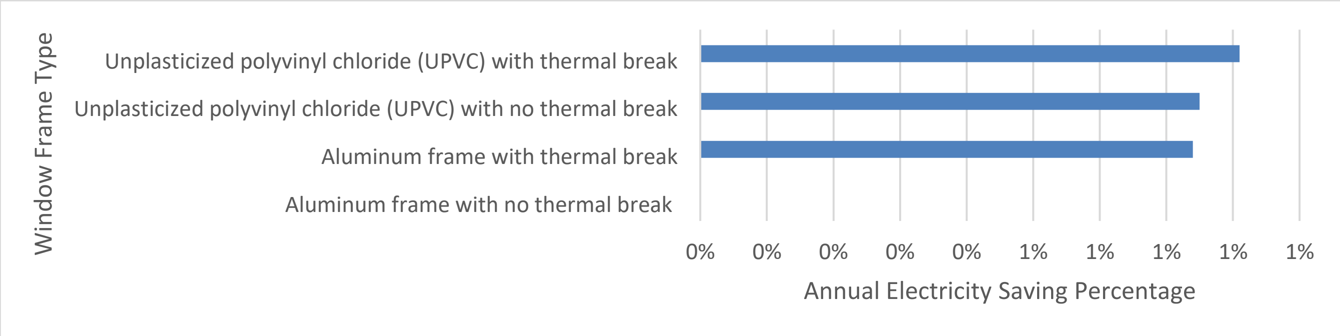

Figure-27. Effect of window frame type on energy saving.

The current research is based on a comparison of annual electrical energy simulation comparison between the existing building top floor current construction thermal insulation situation considering the electrical energy consumed for heating and cooling purposes by unifying other internal heat sources and building top floor annual electrical energy simulation after thermal insulation retrofitting for each building envelope individually to show its effect on the annual electrical energy saving percentage Table-14 summarizes total building energy saving percentages resulting from energy model simulation affected by different building elements retrofit methods.

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Table-15. Summarizes building electrical energy saving resulting from different element retrofit methods.

	Annual electrical energy consumed	**Total energy saving**
Existing building model (base of comparison)	35894 kWh	0 %
Retrofit measure		
A. Improving Roof Thermal Insulation		
1. Roof Thermal Tiles (layers)		
* 4mm White natural mineral. *11 mm natural mineral & gray cement	35877	0.04 %
*2.5 cm White cement. * 2.5 cm EPS Foam.	26430	26.3 %
*2.5 cm White color cement concrete. * 2.5 cm EPS Sheet. *1.5 cm Vermiculite aggregate foam concrete.	26437	26.3 %
*6mm White Color Ceramic. *34mm Cement fly ash & expanded clay aggregate	32122	10.5 %
* 6mm White color ceramic. *34mm Cement, fly ash, expanded clay aggregate	29908	16.06 %
2. Adding Roof Insulation Layers		
10 Cm mortar of Expanded perlite particles	27770	22 %
10 Cm mortar of Vermiculite particles	34615	3.5%
10 Cm thick Solid polyurethane boards	24842	31 %
10 Cm thick extruded polystyrene boards CO2	25533	28 %
B. Improving External walls Thermal insulation		
1-Adding thermal insulation layers to external walls - internal side		
Adding to existing wall layers of • 10 cm air gap. • 12 cm thick burned brick • 2.5cm Cement/plaster/mortar	35851	12 %
Adding to existing wall layers of • 10 cm thick Expanded polystyrene • 1.5 cm thick cement/plaster/mortar-gypsum plasterboard	35851	12 %
Adding to existing wall layers of • 10cm thick Unbonded Rockwool • 1.5cm thick • Cement/plaster/mortar-gypsum plasterboard	35858	12 %
2-Adding thermal insulation layers to external walls - External side		
Adding to existing wall layers of • 2 cm Cement/adhesive/mortar • 10 Cm XPS – CO2 Blowing • 2 cm Cement/adhesive/mortar • 2 Cm Fiberboard • 2 Cm Plaster finish	35858	12 %
Adding to existing wall layers of • 2 Cm Fiberboard • 10 Cm polyurethane board • 2 Cm Fiberboard • 2 Cm Plaster finish	**35699**	0.54 %
C. Improving Thermal Insulation Of Glazing		
Base Model - Single layer 6mm clear glass	35894	

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Single layer 6mm clear glass low e (e2=.2)	35849	0.125 %
Double Layer 6mm clear glass 6mm air gap (e2=.2)	35856	0.105 %
Triple layer 6mm clear glass 25mm air gap for mid pane blinds	35861	0.091 %
Triple layer 6mm clear glass low e film (55) 6mm air gap	35837	0.518 %
Single layer 6mm green color glass	35624	0.75 %
Single layer 6mm bronze color glass	35636	0.71 %
Double Layer 6mm clear glass low e (e2=.2) 13mm argon gas	35714	0.51 %
Triple layer 3mm clear glass 10mm space krypton gas	35718	0.49 %
D. Retrofitting window frame type		
Base Model - Aluminum frame with no thermal break	35894	
Aluminum frame with thermal break	35894	0.74 %
Unplasticized polyvinyl chloride (UPVC) with no thermal break	35627	0.75 %
Unplasticized polyvinyl chloride (UPVC) with thermal break	35600	0.81 %

By applying energy model simulation, a comparison of the yearly heat gain for the current building top floor envelope construction materials, with the yearly heat gain for the retrofitted building top floor envelope construction materials are shown in Figures 26 and 27.

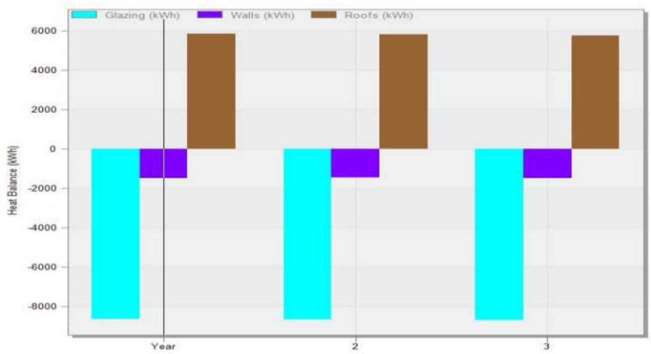

Figure-28. Existing top-floor building model heat balance results in Roof, Walls, and Glazing.

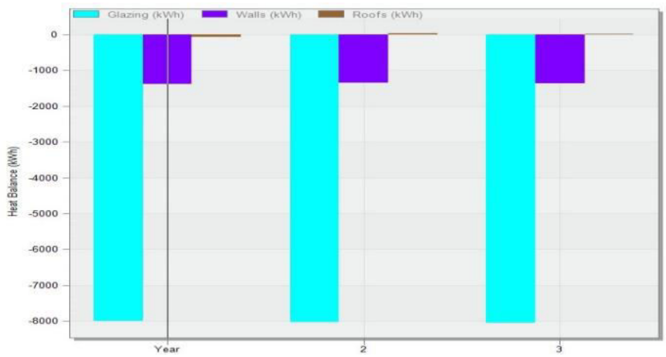

Figure-29. Retrofitted top-floor building model heat balance results in Roof, Walls, and Glazing.

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Table-16. Comparison between existing building envelope & retrofitted building envelope heat gain.

Existing Building Envelope Element Heat Gain		**Retrofitted Building Envelope Element Heat Gain**	
Roof	5868 Kw	Roof	-60.28 Kw
External walls	-1465 Kw	External walls	-1380 Kw
Windows	-8631 Kw	Windows	-7993 Kw
Total Heating Capacity	36.630 Kw	Total Heating Capacity	27.710 Kw
Total Cooling Load	329.63 Kw	Total Cooling Load	270.25 Kw
annual electrical energy consumption 35894 kWh		annual electrical energy consumption of 23344 kWh	
Discomfort hours **2735** (hrs)		Discomfort hours 2196 (hrs)	

3. RESULTS

By comparing the annual electrical energy consumption of the top floor of the experimental existing building through an environmental simulation model and the annual energy consumption of a similar model that incorporates different methods of thermal insulation retrofitting the roof, external walls, and windows, each element underwent individual thermal insulation retrofitting. The research was able to determine the most efficient techniques for thermal insulation retrofitting each element and measuring its impact on the annual electric energy saving. It was noted that:

- retrofitting the roof with thermal insulation tiles by replacing the existing grey cement tiles with white tiles that consist of the 2.5-cm-thick bottom layer made of extruded polyurethane and a 2.5-cm-thick top layer made of white cement can result in a 26.6% reduction in the building's top floor's annual energy consumption.
- Installing a 10-cm-thick layer of solid polyurethane boards as thermal insulation on top of the damp-proof membrane for the concrete roof reduces yearly energy usage by 31%.
- Incorporating thermal insulation layers using various techniques and materials on either the internal or exterior side of the building's external wall, it is possible to reduce the annual electrical energy consumption for the top floor of the building by 12%.
- Changing glazing material, colors, and number of layers the research simulation model showed that using a single sheet of 6 mm green glass results in 0.75% energy savings. This is due to the presence of fixed south elevation windows with overhangs and side lovers in the existing building which provide sufficient shading amount to conserve energy.
- Replacing uninsulated aluminum window frames with unplasticized polyvinyl chloride (UPVC) frames that include a thermal break can reduce the annual electrical energy consumption by 0.81%.

4. RECOMMENDATIONS:

- A field survey has to be done for existing governmental buildings that do not fulfill the “Egyptian code to improve the efficiency of energy use in buildings” and make a plan for its renovation.
- Some retrofit techniques such as low-e colored glass might affect human visual comfort so the decision to replace existing glass should compromise solar heat gain with light transmittance rate.
- Develop new building envelope energy-saving retrofit techniques, and study the applicability of new thermal insulation materials in various Egyptian climatic regions.
- Enhance continuous updating of the Egyptian “Specifications of thermal insulation” with new thermal insulation materials and application techniques.
- Issue new legislation that includes the necessity of applying the “Egyptian code to improve the efficiency of energy use in buildings” during the process of renovating existing Egyptian governmental buildings.
- Include environmental simulation software training for undergraduate architecture students.
- Support training activities in the field of building energy saving and advanced thermal insulation retrofitting technology for architects as a continuous learning requirement.
- The current research did not include environmental factors such as rain and wind in building envelope energy saving study and retrofitting cost measures. Further studies can be made taking these factors into consideration.

5. LIST OF ABBREVIATIONS

NCCS	National climate change strategy
PCM	Phase change materials
RBIM	Retrofitting building information modeling
OTTV	Overall thermal transmittance value
EPS	Expanded polystyrene foam
XPS	Extruded polystyrene
DOE	U.S. Department of Energy's
BTO	Building Technologies Office
EPA	U.S. Environmental Protection Agency
SR	Solar reflectivity
SHGC	Solar heat gain coefficient
LT	Light transmittance rate
AGHG	Annual Glass heat gain
UPVC	Unplasticized polyvinyl chloride

6. DECLARATIONS

a) Availability of data and material
"Availability of data and materials"
The datasets generated during the current study are not publicly available due to their being inside the government region but are available from the corresponding author upon reasonable request.
b) Competing interests
"Not applicable"
c) Funding
"Not applicable"
d) Authors' contributions
"Not applicable"
e) Acknowledgements

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