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Enhancing Energy Performance in Aswan's Residential Buildings Using Thermal Insulation

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Abstract: This study investigates the impact of thermal insulation on energy consumption and carbon emissions in residential buildings in Aswan, a region characterized by extreme summer temperatures. Utilizing the EDGE simulation program, different thicknesses of Extruded Polystyrene (XPS) insulation were applied to external walls and roofs to determine their influence on energy demand and environmental sustainability. The methodology included an assessment of the selected insulation material, simulation of building energy performance under varying insulation thicknesses, and identification of insulation thickness that provides the best balance between energy savings and cost. The results revealed that applying 0.05 m of insulation to the roof and 0.04 m to the walls led to a 6.61 kWh/m² annual reduction in energy use, with a corresponding 0.8 tCO_2e/year decrease in carbon emissions. Additionally, a cost-benefit analysis demonstrated that this insulation strategy reduces cooling energy expenses by approximately 53.35% annually, translating to a financial saving of 11.67 EGP/m^2/year. These findings highlight the critical role of thermal insulation in enhancing energy efficiency and mitigating environmental impact in hot climate zones. By providing insights into the optimal insulation thickness, this study supports sustainable urban development strategies and offers practical guidelines for policymakers and construction professionals in Egypt and similar regions.

Keywords: Thermal Insulation; Thermal Comfort; Energy Consumption; Carbon Emission; EDGE

1. INTRODUCTION

The pursuit of human comfort has significantly increased the use of active cooling systems in buildings, resulting in greater dependence on conventional, fossil fuel-based energy sources. In earlier times, traditional architectural designs employed various passive strategies to regulate heat transfer and reduce energy consumption. However, such techniques have largely been neglected in modern construction practices. Given the growing reliance on mechanical cooling systems, understanding the climatic conditions of specific regions becomes essential when developing effective energy efficiency strategies.

Aswan's climate is characterized by extreme desert conditions, with prolonged, scorching summers and short, mild winters. During the peak summer months, temperatures often exceed 40°C, and occasional heatwaves can cause even higher temperature spikes [1]. The region's low humidity levels intensify the sensation of heat, particularly when cooling winds are absent. In contrast, the winter season remains mild, with average temperatures typically ranging between 10°C and 20°C. The considerable temperature fluctuations between day and night, along with seasonal variations, impose substantial demands on cooling systems to maintain comfortable indoor environments throughout the year. Furthermore, the region is exposed to high levels of solar radiation, with an average of approximately 6 kWh/m²/day [2], which further intensifies the cooling load, particularly in structures with significant sun exposure. The prevailing climate significantly increases the demand for cooling energy, especially in residential and commercial structures, as they seek to balance indoor comfort with efficient energy management [3]. Taken together, these conditions emphasize the urgent need for effective cooling strategies in Aswan's residential buildings. This growing demand for cooling is not limited to Aswan alone but reflects a broader global challenge, as rising temperatures worldwide drive an increasing need for energy-efficient solutions in the built environment. In response to the global challenge of energy consumption and environmental impact, it is essential to evaluate building energy regulations based on their effectiveness in enhancing environmental performance. Over the past decade, the "Green Building" movement has been supported by the development of numerous building performance assessment tools. Among the most recognized green certification systems worldwide is the Excellence in Design for Greater Efficiencies (EDGE) [4]. EDGE stands out as the first certification system that comprehensively addresses both residential and commercial buildings, offering a flexible framework adaptable to various local standards and regulations. EDGE emphasizes that one of the fundamental solutions to reducing energy consumption in residential buildings is improving the thermal properties of the building envelope, thereby enhancing energy efficiency and indoor comfort.

Accordingly, over the past few decades, Egyptian researchers have increasingly focused on developing energy-efficient building envelopes to reduce energy consumption, thereby minimizing the associated environmental impact.

In 2022, research conducted by E. B. Ahmed [5] on the Faculty of Engineering building at El Fayoum University explored strategies to enhance energy efficiency through the application of thermal insulation. Using the DesignBuilder software, four different scenarios were modeled: insulating the roof, implementing a double roof system incorporating a 0.2 m air gap, insulating external walls, and constructing double walls with integrated insulation. The findings revealed that the double roof system with a 0.2 m air gap provided the most significant improvement in energy performance. Regarding wall insulation, the most effective configuration was identified as a single wall outfitted with a 0.07 m thick polyurethane insulation board. Similarly, M. Mosry et al. conducted a study aiming to determine the optimal thermal insulation material for minimizing energy consumption in a five-story educational facility. Their simulation assessed eight types of insulation materials, each tested across thicknesses ranging from 0.02 m to 0.2 m in 0.02 m increments. After evaluating year-round indoor thermal comfort and total energy consumption, Expanded Polystyrene (XPS) emerged as the most efficient insulation option for the building [2]. Moreover, Moraekip conducted in 2023 a case study in Cairo to assess the impact of thermal insulation blocks on residential building energy performance. Using simulation techniques, the study demonstrated that integrating insulation blocks could reduce heat transfer by approximately 41.61% to 65.08%, leading to a reduction in energy consumption ranging from 4.27% to 13.32% [6]. Also, in the same year El shihy et al. evaluated thermal comfort levels in existing Egyptian residential buildings and analyzed issues related to excessive electricity consumption. Using building performance simulations, they found that enhancing thermal insulation reduced electricity consumption for air conditioning systems by approximately **15% to 22%** [7]. Furthermore in 2024, A. Yasser et al investigated the application of sustainable thermal insulation materials in residential buildings in Faiyum. Their comparative analysis between non-insulated and insulated buildings revealed that employing sustainable insulation materials reduced cooling energy consumption by **18% to 25%** and improved indoor air temperatures by **2°C to 3°C**, thus significantly decreasing reliance on active cooling systems [8].

Despite the growing interest in enhancing energy efficiency and improving thermal insulation in residential buildings, a number of critical gaps remain evident in the existing literature. Most previous studies have primarily concentrated on the energy-saving potential of insulation materials, often overlooking the economic feasibility aspects that are essential for informed decision-making by policymakers and homeowners. Additionally, there is a noticeable shortage of research that integrates the EDGE certification framework into the evaluation of building energy performance. These gaps highlight the need for a more holistic approach that considers both technical and economic dimensions within internationally recognized certification systems. So, this study aims to evaluate the impact of thermal insulation materials on cooling energy consumption and carbon emissions in residential buildings in Aswan based on EDGE standards. The research will identify the most suitable insulation thickness for application between walls and on the roof, as well as examine its effects on carbon emissions. This evaluation will provide valuable insights into sustainable cooling strategies for urban areas with high temperatures and energy demands, supporting the development of energy-efficient building practices in Aswan.

2.METHODOLOGY

This research methodology is structured into three main stages, as illustrated in Figure (1). The first stage involves a preliminary investigation of various thermal insulation materials to identify the most suitable option based on their thermal properties and relevance to Egypt's climatic conditions. In the second stage, the selected insulation material is incorporated into a residential building model developed using EDGE simulation software. Multiple simulation scenarios are run by varying the insulation thickness applied to both the walls and the roof. Finally, the third stage includes a cost analysis based on the EDGE results to determine the optimum insulation thickness. This analysis considers both energy savings and the cost of insulation over the building's lifespan, ultimately identifying the most cost-effective and energy-efficient insulation strategy.

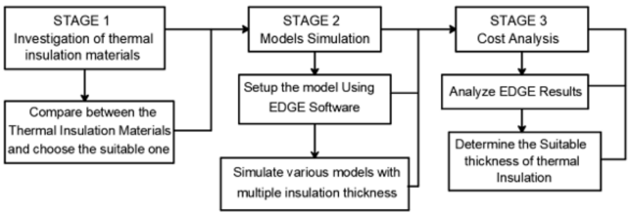

FIG 1. Flowchart of the Research Methodology

2.1INVESTIGATION OF THERMAL INSULATION MATERIALS

In the initial stage of the study, a market survey was conducted to identify the thermal insulation materials commonly available in Egypt. The investigation involved direct engagement with local suppliers, distributors, and construction companies across various regions. The survey results indicated that two primary insulation materials dominate the Egyptian market are XPS and Polyurethane (PU) boards. The selection criteria for the insulation material were based on several key factors: market availability, thermal performance (low thermal conductivity), mechanical strength, moisture resistance, long-term durability, and compatibility with Egypt's hot desert climate. Although PU boards are also available, XPS was chosen as the optimal material due to its superior overall performance and practicality for local building conditions. XPS is a rigid foam insulation product produced through an extrusion process, resulting in a closed-cell structure that offers consistent thermal efficiency and outstanding mechanical strength. Its key advantages over alternatives such as polyurethane include superior thermal conductivity, higher resistance to moisture, and enhanced durability. These properties make XPS particularly effective for use in building envelopes exposed to Egypt's extreme climatic conditions.

Furthermore, XPS demonstrates a low thermal conductivity of approximately 0.025 $W/m^2 \cdot K$, contributing significantly to minimizing heat transfer through walls and roofs. It also possesses excellent long-term performance, maintaining around 90% of its original thermal resistance even after decades of use. With its recyclability, resistance to water absorption, and an expected lifespan exceeding 50 years [9]. XPS requires minimal maintenance under normal conditions and retains its thermal performance with simple periodic inspections [10].

2.2MODELLING THE RESIDENTIAL BUILDING

In this study, a simulation was carried out for a high residential building located in Aswan, designed to host six occupants over a two-story layout totaling 294 m^2. The selection of a high-income housing prototype was based on its typically larger area, greater energy demand, and integration of advanced building technologies, making it a representative model for evaluating the effectiveness of energy-saving strategies such as thermal insulation enhancement. Although the case study targets luxury housing, the findings can offer insights applicable to other residential types given the shared climatic conditions and efficiency targets. The building's energy performance was assessed using the EDGE software. Known for its user-friendly interface and location-specific analysis, EDGE enables rapid estimation of energy consumption, carbon emissions, and potential savings from implementing various design improvements. Version 3.0.0 of the program was employed in this research due to its reliability, speed, and calibration against real-world data, particularly in evaluating the impact of applying XPS to the external envelope and roof. Also, the main inputs to the EDGE simulation include building geometry, climatic location, construction materials, HVAC system specifications, and occupancy details, while the outputs provide estimates of energy use, carbon emissions, and potential savings in both energy and operational costs.

2.2.1MODEL PROPERTIES

The building includes two floors, and rooftop rooms, as illustrated in Figure (2). It features spaces for, reception and dining areas, living rooms, maid room, kitchens, bathrooms, and bedrooms.

(a) Plan of ground floor (b) Plan of first floor (c) Plan of roof rooms

FIG2. Plans of the Residential Building

Table (1) provides additional building specifications required for the simulation. It shows a total building area of 294 m^2, with 4 bedrooms covering a combined area of 64.68 m^2. The kitchen area totals 16 m^2, dining rooms cover 54.62 m^2, living rooms span 29.1 m², bathrooms account for 29.87 m², utility spaces measure 4.60 m², and the balconies cover 68.80 m². Table 2 outlines the façade specifications, including the façade lengths: 29.7 m for the north and south orientations, and 21 m for the east and west orientations. It also details the percentage of façade area exposed to outside air, also it shows that each floor has a height of 3.2 m.

TABLE 1. Specification of the building [11]

Element	**Area (m²)**	**Element**	**Area**	**Element**	**Area**	**Element**	**Area**
Building	294	Bathrooms	29.87	Kitchen	16	Dining Rooms	54.62
Bed Rooms	64.68	Utility	4.60	Balconies	68.8	Living Rooms	29.1

TABLE 2. Façade properties [11]

Façade	**Length (m)**	**Exposed Area**	**Façade**	**Length (m)**	**Exposed Area**
North	13.8	100 %	South	13.8	100 %
East	8.8	100 %	West	8.8	100 %

TABLE 3. Breakdown of Building Loads, Fuel Consumption, and CO_2 Emission Factors [11]

Attribute	**Details**	**Attribute**	**Details**
Load Distribution			
Laundry Usage	Yes	Energy Consumption per Meal	0.65 kWh
Car washing	No	**Fuel Consumption**	
Dishwasher Usage	Yes	Hot Water Heating Fuel	Natural Gas
Domestic Hot Water	Boiler	Cooking Fuel	Natural Gas
Meals per Person	3 Meals/day	**CO_2 Emission Rate ($KgCO_2$/kWh)**	
Onsite Meal Consumption	100 %	Electricity	0.41
Onsite Food Preparation	100 %	Natural Gas	0.18

TABLE 4. Specifications for Water Efficiency Measures, Glass and HVAC [11]

Category	**Details**	**Category**	**Details**
Glass efficiency		**Water Efficiency Measures**	
Glass type	Single layer 8 mm	Shower heads	14 L/min
U – Value, SHGC	3.50, 0.80	Faucets with Aerators	8 L/min
VT	0.70	Single Flush toilets	9 L/flush
Windows frame material	Aluminum	Kitchen Faucets	12 L/min
HVAC Characteristic			
System type		DX – Split system	
Set Cooling temperature		25ºC	
COP		3.16	

2.2.2ANALYSIS OF ENERGY CONSUMPTION

Energy consumption was analyzed by categorizing loads from key household activities such as dishwashing, water heating, laundry, and air conditioning. High-energy tasks like car washing and cooking were assessed for their impact, with cooking alone using 0.65 kWh per meal. Natural gas, used for both hot water and cooking, serves as the primary fuel source. Emission factors are 0.41 kg CO_2/kWh for electricity and 0.18 kg CO_2/kWh for natural gas. Table (3) presents a detailed analysis of the building's energy consumption, fuel use, and CO_2 emission factors.

2.2.3PROPERTIES OF BUILDING GLASS, HVAC, AND WATER EFFICIENCY

To simulate an integrated model using the EDGE tool, it was necessary to gather detailed information about the glass specifications, HVAC system, and water efficiency measures as summarized in Table (4). These parameters were chosen based on common practices in Egypt. For the glass, a single-layer pane with a thickness of 8 mm was used, offering a U-value of 3.50, a Solar Heat Gain Coefficient (SHGC) of 0.80, and a visible transmittance (VT) of 0.70. This selection reduces insulation thickness while allowing sufficient natural light into the building. The HVAC system used is a DX-split unit set to maintain an indoor temperature of 25ºC, in line with the Egyptian Residential Energy Code [12] This system features a Coefficient of Performance (COP) of 3.16, ensuring high cooling efficiency.

Water efficiency measures were also implemented, including flow rate of shower heads, toilets and kitchen faucets.

TABLE 4. Specifications for Water Efficiency Measures, Glass and HVAC [11]

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HVAC Characteristic			
System type		DX – Split system	
Set Cooling temperature		25ºC	
COP		3.16	

2.2.4MATERIAL SELECTION FOR THE MODEL

The energy simulation model for the residential building in Aswan was developed using a detailed representation of the external wall and roof compositions to accurately assess thermal performance and energy consumption. For the external walls, the design consists of multiple layers to enhance insulation and structural stability. The wall assembly includes: internal plaster (density: 2100 kg/m³, thickness: 0.015 m), followed by a clay brick layer (density: 1850 kg/m³, thickness: 0.10 m), then the XPS thermal insulation layer with variable thickness according to the simulation scenarios, followed by another clay brick layer (0.10 m thick), and finally an external plaster layer (0.015 m). This structure ensures effective thermal performance while maintaining durability, as shown in Figure (3).

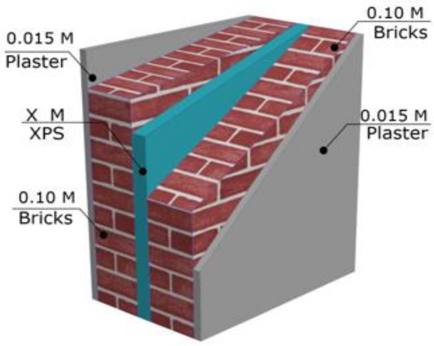
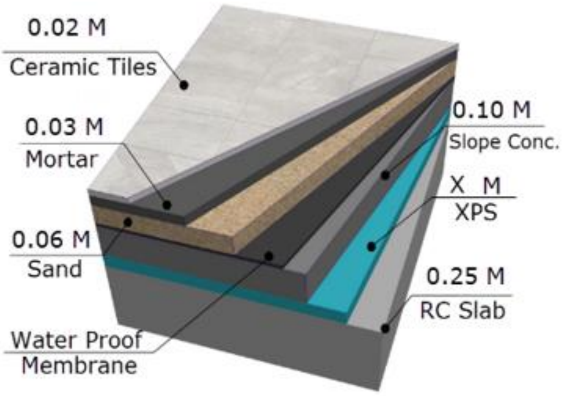


Fig 3. External wall layers[11]

For the roof, the model incorporates a complex layered configuration designed to provide effective thermal insulation and protection against harsh climatic conditions. It includes a reinforced concrete (RC) slab (density: 2500 kg/m³, thickness: 0.25 m) as the primary structural component. XPS insulation is also applied in the roof design, with its thickness varied in the simulation. Additionally, the roof system features a slope concrete layer to facilitate water drainage, covered by a waterproof membrane to prevent water infiltration. To further enhance thermal resistance, layers of sand, mortar, and ceramic tiles are included, contributing to the roof's overall thermal mass and energy performance as shown in Figure (4).



2.3Impact of Insulation Thickness on Energy and Cost

To evaluate the influence of XPS insulation thickness on building energy performance, a series of simulations were carried out by varying the insulation thickness from 0.02 m to 0.10 m in 0.01 m increments for both external walls and the roof. The methodology adhered to the ISO 6946 standard [9], which outlines procedures for calculating thermal resistance (R -values) and thermal transmittance (U-values) of building components. In the simulation process, each wall insulation thickness was systematically paired with each roof insulation thickness to identify the most energy-efficient combination. Initially, for the base case (with no insulation applied), the thermal resistance of each material layer was calculated based on its thickness and heat transfer coefficient (h), following equation (1). Subsequently, the corresponding U-values for both walls and roof were derived according to equation (2). Tables 5 and 6 present the calculated U-values for different insulation thicknesses, illustrating the impact of varying insulation levels on the thermal performance of the building envelope.

$$\mathbf{R = \frac{Thickness}{h}} \qquad \mathbf{Eq.\,(1)}$$

$$\mathbf{U = \frac{1}{\Sigma R}} \qquad \mathbf{Eq.\,(2)}$$

Table 5: Calculated Thermal Conductivity Values for Wall with Varying XPS Insulation Thicknesses [9]

Layer	Thick. (m)	h (w/m^2.k)	R (m^2.k/w)	XPS thick. (m)	U (W/m^2. K)
Internal Air Surface	--	8.13	0.123	0 (Base C)	**1.86**
Internal Plaster	0.015	0.72	0.021	0.02	**0.747**
Clay Bricks	0.10	0.60	0.167	0.03	**0.575**
XPS	0	0.025	0	0.04	**0.467**
Clay Bricks	0.10	0.60	0.167	0.05	**0.394**
External Plaster	0.015	0.72	0.021	0.06	**0.340**
External Air Surface	--	--	0.040	0.07	**0.299**
Total (U)	**1.86 W/m^2. K**			0.08	**0.267**
				0.09	**0.242**
				0.10	**0.220**

Table 6: Calculated Thermal Conductivity Values for Roof with Varying XPS Insulation Thicknesses [9]

Layer	Thick. (m)	h (w/m^2.k)	R (m^2.k/w)	XPS thick. (m)	U (W/m^2. K)
Internal Air Surface	--	8.13	0.123	0 (Base C)	**1.91**
RC Slab	0.25	1.57	0.159	0.02	**0.756**
XPS	0	0.025	0	0.03	**0.580**
Slope Concrete	0.1	1.5	0.067	0.04	**0.471**
Sand	0.06	0.75	0.08	0.05	**0.396**
Mortar	0.03	0.72	0.042	0.06	**0.342**
Ceramic Tiles	0.02	1.6	0.013	0.07	**0.301**
External Air Surface	--	--	0.040	0.08	**0.268**
Total (U)	**1.91 W/m^2. K**			0.09	**0.243**
				0.10	**0.221**

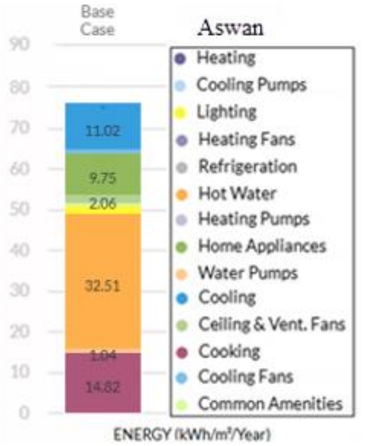
Based on the results of the simulation, the optimal insulation thicknesses for both walls and roofs were determined. The optimal insulation thickness is defined as the point at which the total cost (ECC) is minimized. This total cost includes the cost of electricity consumption (ECO) and the cost of insulation materials (Ic) over the building's estimated lifetime (X) [13]. To accurately estimate insulation costs, direct communications with local suppliers were conducted. Electricity prices (EP) for residential buildings were obtained from the official rates published by the Egyptian Electricity Holding Company (EEHC). The building lifetime was assumed to be 50 years, providing a consistent basis for the evaluation of both energy consumption and insulation investment [14]. The total cost (ECC) was calculated using equation (3).

$$\mathbf{ECC = ECO * Ep + \left(\frac{Ic}{X}\right)} \qquad \mathbf{Eq.(3)}$$

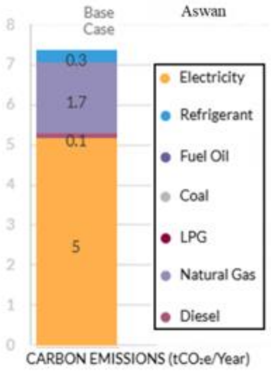
3.RESULTS AND DISCUSSION

3.1ENERGY CONSUMPTION AND CARBON EMISSSION

The simulation results indicate that energy consumption in the residential building in Aswan is distributed across various activities. The breakdown of consumption is as follows: cooking uses 14.82 kWh/m² per year, water pumps 1.04 kWh/m², hot water 32.51 kWh/m², lighting 1.54 kWh/m², common amenities 0.92 kWh/m², ceiling and ventilation fans 2.06 kWh/m², home appliances 9.75 kWh/m², cooling 11.02 kWh/m², and cooling fans 1.37 kWh/m². This results in a total annual energy consumption of 75.03 kWh/m² as shown in Figure (5-a). Also, the carbon emissions were from four sources Electricity (5.00 tCO_2e /year), Diesel (0.10 tCO_2e /year), Natural Gas (1.70 tCO_2e /year) and Refrigerants (0.3 tCO_2e /year) as shown in Figure (5-b).



a) Energy Consumption of the building



b) **Carbon Emission of the building**

FIG 1. **Results of Energy Consumption and Carbon Emission of the building [11]**

These results highlight that cooling and hot water production are the dominant energy-consuming activities, contributing significantly to the building's total carbon emissions of 7.1 tCO_2e per year. Electricity consumption (5.00 tCO_2e) and natural gas usage (1.70 tCO_2e) are the primary sources of these emissions. Given Aswan's extreme summer temperatures, reducing cooling demand through insulation can lead to substantial energy savings and help mitigate carbon emissions by decreasing the reliance on active cooling systems.

3.2 OPTIMUM THICKNESS OF THERMAL INSULATION

The results indicate a significant reduction in energy consumption by applying XPS insulation with varying thicknesses to the external walls and roof of the residential building. Specifically, energy usage decreased from 75.03 kWh/m²/year to 67.51 kWh/m²/year, demonstrating the effectiveness of thermal insulation in reducing energy demand. This reduction is attributed to improved thermal resistance, which minimizes heat transfer through the building envelope, thereby decreasing the need for active cooling.

A detailed analysis of the results, as presented in Table (7), reveals that the optimal insulation thickness was 0.05 m for the roof and 0.04 m for the walls. This configuration achieved the lowest total cost of electricity consumption and insulation material, amounting to 156.30 LE/m²/year. This balance between insulation cost and energy savings was determined through a cost-benefit analysis that evaluated various thickness scenarios.

Furthermore, the optimal insulation setup led to an annual energy savings of 6.61 kWh/m², which corresponds to a carbon emission reduction of 0.8 tCO_2e per year and a reduction in energy consumption cost by 11.67 EGP/m²/year, as illustrated in Figures (6) and (7). These findings highlight the dual benefits of energy cost reduction and environmental sustainability. By decreasing the building's reliance on fossil fuel-based electricity for cooling, the insulation strategy not only enhances energy efficiency but also contributes to lower carbon emissions, supporting sustainable urban development goals in hot climate regions like Aswan.

This analysis underscores the importance of selecting the right insulation thickness to maximize cost-efficiency and thermal performance. The study's findings provide valuable insights for architects, engineers, and policymakers seeking to implement energy-efficient building practices in Egypt and other regions with similar climatic conditions.

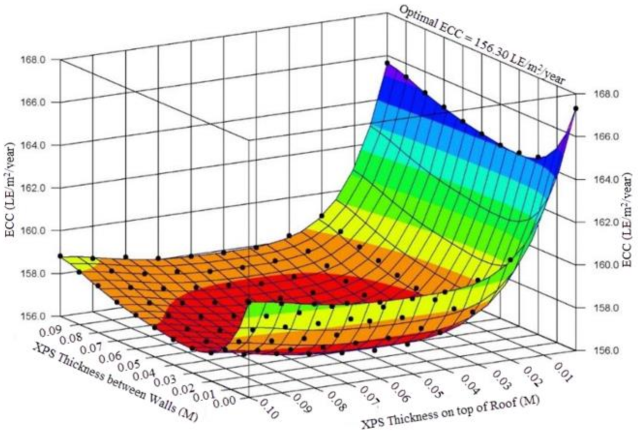
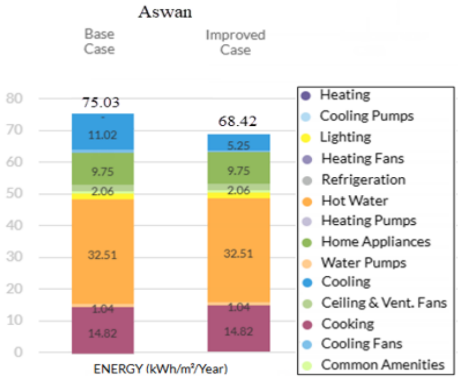
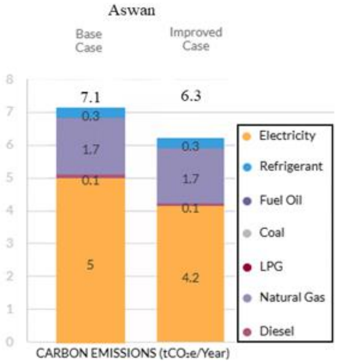


Fig 2. Optimum value of ECC in Aswan [11]



(a)Energy Consumption



(b) Carbon Emissions

FIG 3. Energy Consumption and Carbon Emission of the building[11]

XPS Thickness		**Aswan**									
Wall	**Roof**	**0 m**	**0.02 m**	**0.03 m**	**0.04 m**	**0.05 m**	**0.06 m**	**0.07 m**	**0.08 m**	**0.09 m**	**0.10 m**
0 m	ECO	75.03	71.68	71.17	70.83	70.6	70.44	70.33	70.23	70.15	70.09
	ESA	0.00%	27.04%	31.15%	33.90%	35.75%	37.05%	37.93%	38.74%	39.39%	39.87%
	ECC	167.97	160.67	159.95	159.61	159.51	159.57	159.73	159.92	160.16	160.44
0.02 m	ECO	73.3	69.88	69.36	69.03	68.81	68.67	68.56	68.48	68.38	68.32
	ESA	13.96%	41.57%	45.76%	48.43%	50.20%	51.33%	52.22%	52.87%	53.67%	54.16%
	ECC	164.29	157.49	156.74	156.42	156.34	156.45	156.61	156.85	157.04	157.32
0.03 m	ECO	73.03	69.59	69.09	68.8	68.61	68.43	68.29	68.19	68.12	68.06
	ESA	16.14%	43.91%	47.94%	50.28%	51.82%	53.27%	54.40%	55.21%	55.77%	56.26%
	ECC	164.10	157.26	156.55	156.32	156.31	156.32	156.43	156.62	156.88	157.16
0.04 m	ECO	72.84	69.42	68.96	68.8	68.42	68.26	68.12	68.02	67.93	67.89
	ESA	17.68%	45.28%	48.99%	50.28%	53.35%	54.64%	55.77%	56.58%	57.30%	57.63%
	ECC	164.09	157.29	156.68	156.74	156.30	156.36	156.46	156.65	156.87	157.19
0.05 m	ECO	72.72	69.31	68.83	68.49	68.31	68.15	68	67.9	67.84	67.78
	ESA	18.64%	46.17%	50.04%	52.78%	54.24%	55.53%	56.74%	57.55%	58.03%	58.51%
	ECC	164.24	157.46	156.80	156.46	156.47	156.53	156.61	156.80	157.08	157.36
0.06 m	ECO	72.63	69.23	68.72	68.4	68.18	68.02	67.93	67.83	67.77	67.69
	ESA	19.37%	46.81%	50.93%	53.51%	55.29%	56.58%	57.30%	58.11%	58.60%	59.24%
	ECC	164.45	157.69	156.97	156.67	156.60	156.65	156.87	157.06	157.34	157.57
0.07 m	ECO	72.57	69.18	68.66	68.34	68.13	67.98	67.86	67.77	67.68	67.61
	ESA	19.85%	47.22%	51.41%	54.00%	55.69%	56.90%	57.87%	58.60%	59.32%	59.89%
	ECC	164.73	158.00	157.25	156.95	156.90	156.98	157.12	157.34	157.55	157.81
0.08 m	ECO	72.52	69.11	68.63	68.31	68.08	67.96	67.82	67.71	67.65	67.6
	ESA	20.26%	47.78%	51.65%	54.24%	56.09%	57.06%	58.19%	59.08%	59.56%	59.97%

	ECC	165.03	158.26	157.60	157.30	157.20	157.35	157.45	157.62	157.90	158.20
0.09 m	ECO	72.49	69.08	68.58	68.29	68.06	67.89	67.8	67.67	67.64	67.53
	ESA	20.50%	48.02%	52.06%	54.40%	56.26%	57.63%	58.35%	59.40%	59.64%	60.53%
	ECC	165.38	158.60	157.90	157.67	157.57	157.60	157.82	157.94	158.29	158.46
0.10 m	ECO	72.43	69.05	68.55	68.21	68.01	67.85	67.72	67.66	67.55	67.51
	ESA	20.98%	48.26%	52.30%	55.04%	56.66%	57.95%	59.00%	59.48%	60.37%	60.69%
	ECC	165.66	158.95	158.25	157.90	157.87	157.93	158.05	158.33	158.50	158.83

4. CONCLUSION

This study evaluated the impact of thermal insulation on energy consumption and carbon emissions in residential buildings in Aswan, using the EDGE simulation program. The key findings are:

- Applying XPS insulation with optimal thicknesses of 0.05 m for the roof and 0.04 m for the walls resulted in:
    - Annual energy savings of 6.61 kWh/m².
    - Reduction of 0.8 tCO_2e in carbon emissions per year.
    - 53.35% energy cut on cooling energy, equivalent to 11.67 EGP/m²/year.
- The insulation strategy effectively reduced the need for active cooling, leading to lower electricity consumption and carbon emissions, thus contributing to environmental sustainability.
- The study demonstrated that choosing the optimal insulation thickness strikes a balance between material costs and energy savings, supporting sustainable urban development in Aswan and similar hot climates.
- By providing detailed insights into the relationship between insulation thickness, energy consumption, and cost savings, this research enhances the understanding of thermal insulation's role in improving building energy efficiency.

5. FUTURE STUDIES

Future research should explore the following areas to further enhance the understanding of thermal insulation's impact on energy efficiency:

- Regional Analysis in Egypt: Investigate the effectiveness of XPS insulation in other Egyptian cities with varying climatic conditions, including coastal areas, humid regions, and other desert climates. This would provide a comprehensive understanding of insulation performance across different environmental settings.
- Alternative Insulation Materials: Examine the potential of alternative insulation materials by testing different types such as Polyurethane boards or fiber glass with the same defined thickness to compare their thermal effectiveness, life-cycle cost, and environmental impact against XPS insulation.
- Dynamic Energy Modeling: Utilize dynamic energy modeling tools to simulate real-time energy consumption patterns and improve the accuracy of energy performance predictions.

6. Research Limitation

This study focuses on enhancing the energy performance of residential buildings in Aswan using thermal insulation, with simulations conducted through the EDGE assessment tool. While EDGE provides a robust and widely accepted framework for evaluating energy efficiency measures, it operates within a static simulation environment. Future research could expand on this work by integrating additional simulation methods or empirical field data to further validate and refine the results.

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