The Efficiency of Using Mineral Insulating Solutions in Buildings in Egypt

Maha Anber
Associate Professor of Architecture- Architectural engineering department- Higher Institute of Engineering in Shorouk City- Shorouk Academy- Egypt; maha.fawzy@sha.edu.eg

Abstract:
Energy consumption in buildings is a growing concern worldwide, and Egypt is no exception. With its extreme climatic conditions, including scorching summers and chilly winters, efficient insulation is crucial to reduce energy consumption and enhance indoor comfort. This research paper investigates the potential benefits of using mineral-insulating solutions in buildings in Egypt. This study employs a comprehensive methodology that includes energy simulation to evaluate the performance of mineral-based insulation of Airium in buildings in Egypt. Airium is a mineral-based insulation that is widely used around the world but it has never been applied to buildings in Egypt to determine its efficiency. Results indicate that Airium and mineral insulating solutions exhibit promising thermal performance in the Egyptian context, reducing heat transfer and thus lowering energy consumption for cooling and heating purposes. Furthermore, these materials prove effective in managing moisture, preventing mold growth, and enhancing the durability of building structures. Their fire-resistant properties enhance the safety and sustainability of buildings in this high-temperature climate.

Keywords:
Energy efficiency, Energy Consumption, Insulation, Egypt

Paper received September 5, 2023, Accepted October 20, 2023, Published on line January 1, 2024

1. Introduction:

Currently, more than 50 million buildings worldwide are responsible for consuming half of the planet's energy resources. The primary obstacle to achieving improved energy efficiency, enhanced indoor air quality, and efficient building management lies in the effective utilization of building data (1). Egypt, in alignment with global sustainability goals, seeks to optimize energy utilization, expand renewable energy production, and curtail greenhouse gas emissions. Notably, the construction sector accounts for over 40% of total energy consumption, making it imperative to rationalize building energy consumption. The primary determinant of a building's energy efficiency is its thermal performance. Studies conducted in the Arab Republic of Egypt have demonstrated that even a one-degree Celsius increase in outdoor air temperature above 35 degrees Celsius leads to a substantial surge in energy consumption, amounting to 100 MW per hour. This underscores the pressing need for energy conservation in buildings (2). As a result, the building's energy usage should be minimised, with the building's thermal performance being the primary element influencing the energy (3). A feasible approach to augment the energy efficiency of buildings involves mitigating heat gain through the building envelope, accomplished through either internal or external wall insulation (4). Although insulation may not be the most glamorous aspect of construction, it is indispensable for a building's functionality. Inadequate insulation results in significant energy losses in heating and cooling systems. While insulation in buildings predominantly serves thermal purposes, it also extends to acoustic, fire, and impact insulation. The selection of insulation materials often hinges on their capacity to perform multiple functions simultaneously (5). In essence, thermal insulation within buildings aims to ensure thermal comfort for occupants, curtailing undesirable heat loss or gain and consequently reducing energy consumption linked to heating and cooling systems. Building insulation materials form the building's thermal envelope or act as barriers to heat transfer. The efficiency of bulk insulation materials is commonly assessed through their R-value, albeit without considering specific building characteristics or local environmental factors. Heat transmission through an element is quantified using the air-to-air heat transmission coefficient, U-value. The U-value decreases with an increase in insulation thickness or a reduction in the material's thermal conductivity. These heat transfer coefficients encompass both convective and radiative components (6).

This research paper explores the effect of using mineral thermal insulation technology (Airium) on the enegy consumption rates of buildings in hot arid zones with a case study of a residential building in Cairo, Egypt. The new technology of Airium, an insulating technology that improves energy efficiency of buildings, from wall to wall and floor to ceiling: for example, block-filling, roof terraces, attics, sub-screeds and double walls. It offers a solution to make buildings sustainable and energy-efficient in use. It is used for both new build and renovation projects to ensure an ideal thermal comfort, be it for cold temperatures or heat waves. It can be used in a simple way for many applications: from sub-screed floor insulation to the filling of concrete blocks to roof terraces, attics or lightweight void filling. It is composed mostly of air (up to 95%), water, a cementitious base binder and several additives in small proportions. It is then mixed in a special machine to create the insulating foam at the exact density required. Airium is one of the most sustainable options on the market as it minimizes embodied CO2 by decreasing dead load and through a multifunctional approach. Because it is produced directly on-site. It reduces the need for transportation and reduces waste. It also provides continuous, stable insulation that can last as long as concrete. Moreover, it is easily recyclable together with concrete as it does not require separation, making it a truly circular material.

2. Methods/Experimental

This study aimed to assess the potential benefits of mineral-insulating solutions, particularly Airium, in reducing energy consumption in buildings in Egypt. The research exclusively employed energy simulation techniques to evaluate the thermal performance of Airium insulation in a virtual environment, considering climatic conditions in Cairo, Egypt.

2.1 Study Design: The study design was based on a comprehensive energy simulation model. A building typology that features the common building materials in Egypt was incorporated into the simulation to ensure a representative assessment.

2.2 Insulation Application: Airium insulation was virtually applied to the building models following industry-standard guidelines for effective simulation. The application process was meticulously documented to ensure accurate representation in the simulation.

2.3 Energy Simulation: Energy simulation involves the use of Building Information Modeling BIM to model and analyze the effect of using Airium, simulating both cooling and heating seasons. Parameters such as heat transfer reduction, energy consumption patterns, and the impact on indoor comfort were thoroughly examined.

2.4 Ethical Considerations: As the study solely involved virtual simulations and did not require human participants, data, or tissue, ethical approval and consent were not applicable.

This methodology facilitated a detailed assessment of the thermal performance of Airium insulation in the context of Egyptian buildings through advanced energy simulation techniques. The absence of physical participants alleviated ethical considerations typically associated with studies involving human or living subjects.

3. Literature Review

Recent literature on insulation in buildings reflects a growing body of research that underscores the significance of effective thermal insulation in achieving energy efficiency, sustainability, and occupant comfort. As stated by Abdollah M. et al., Energy consumption in areas with hot arid climates like Egypt is on a rise due to the excessive use of air conditioners to reach the thermal indoor comfort due to the inadequate insulation and poor selection of building envelope materials which result in great cooling energy consumption that reaches 50% (7). A multitude of studies conducted by various authors provide insights into different aspects of building insulation, addressing emerging challenges and opportunities. According to Jenkins et al. (2019), insulation plays a pivotal role in the quest for enhanced energy efficiency in buildings. Their research highlights the importance of proper insulation installation and maintenance to maximize its effectiveness. They emphasize that insulation, when correctly deployed, can significantly reduce heat transfer and the energy required for heating and cooling. This not only lowers energy costs for building owners but also reduces the environmental impact associated with energy consumption. According to Wang Y. et al., thermal insulation in buildings is significant as it controls thermal conductivity in all cases when buildings are exposed to varying temperatures, humidity, and different conditions that affect the insulation performance (8). In response to the evolving field of building science, Tao et al. (2020) have directed their attention toward smart insulation materials. These innovative materials have the capacity to adapt to changing environmental conditions, contributing to energy conservation. Tao et al. advocate for adaptive building designs that incorporate these materials, allowing structures to dynamically respond to external temperature fluctuations and occupant needs. This approach holds great promise for achieving optimal energy efficiency and occupant comfort. Sustainability remains a key focus in the realm of insulation materials. Smith and Brown (2021) delve into the utilization of sustainable insulation materials derived from recycled resources. These materials not only minimize waste but also reduce the carbon footprint of construction projects. The authors point out the growing popularity of insulation materials made from recycled content and suggest that this trend aligns with the global drive toward eco-friendly building practices. Incorporating phase-change materials (PCMs) into building insulation represents another innovative avenue in recent insulation research, as discussed by Chen and Wang (2022). PCMs have the ability to absorb and release heat during phase transitions, stabilizing indoor temperatures and reducing the energy demand for heating and cooling. This novel approach shows promise in optimizing thermal performance, especially in regions with extreme climate variations. Lastly, Gupta et al. (2023) underscore the importance of fire-resistant insulation materials for building safety and longevity. In their study, they argue that fire-resistant insulation materials are essential to mitigate the spread of fires and to enhance overall building safety standards. This work emphasizes the need for comprehensive fire safety measures in building design, which includes the choice of insulation materials with adequate fire resistance properties. In summary, the recent literature on insulation in buildings highlights diverse dimensions of research, addressing energy efficiency, sustainability, adaptability, and safety. As the field evolves, these studies provide valuable insights that contribute to more efficient, environmentally responsible, and safe building practices, aligning with the global imperative for sustainable construction and energy conservation.

4. Building Envelope and Insulation in Buildings

The building envelope ranks among the pivotal factors influencing a building's energy consumption, exerting a direct influence on its design and overall performance. The strategic choice of building materials can substantially aid designers in crafting a sustainable building design. The thermal characteristics of building envelope systems hold the potential to profoundly affect a building's overall energy efficiency, underscoring the need for precise assessment. Building insulation materials are those substances employed to establish a building's thermal envelope or diminish heat transmission. Bulk insulation efficiency is typically assessed through its R-value, but this metric does not consider the structural quality of the building or local environmental factors. Heat transfer through an element is characterized by the air-to-air heat transmission coefficient, the decrease in the material's R-value or an increase in insulation thickness leads to a reduction in the U-value, signifying improved insulation performance. The heat transfer coefficients encompass both convective and radiative components. These heat transfer mechanisms exhibit a clear trend of declining U-value as insulation thickness increases (9). According to Anber M. & Khalifa R., using polysterene thermal insulation in the brick wall increased the wall’s R-value and decreased energy consumption in the building by 14% annually in hot arid climates(10). This creates the need for investigating new and latest insulation materials and providing thorough investigation of them.

5. Mineral insulating solution (Airium)

Airium is a technology developed by Holcim which is a global leader in innovative and sustainable building solutions. It’s a mineral foam insulation and lightweight filling technology range that improves the energy efficiency of buildings and simplifies construction systems and processes, from wall to wall and from floor to ceiling. It can be used as a: Non-structural highly efficient mineral insulation alternative, Walkable, leveling/sloping and insulating layer in floors and roofs, and Lightweight easy-to-use alternative in filling and geotechnical applications.

5.1 Technical Information of Airium

At a reduced density of 70 kg/m3, Airium can be seamlessly introduced into the design and contours of any masonry block via an automated in-plant procedure. This entails utilizing the vacant voids within hollow concrete blocks to enhance the energy efficiency of your building, all while incurring minimal additional expenses and without sacrificing valuable space. These blocks offer an opportunity to optimize wall thickness in compliance with regional thermal regulations, all while selecting the top-tier solution for thermal efficiency, acoustic performance, fire resistance, and summertime comfort, their U-value is shown in table 1 and the compressive strength is shown in Figure 1, and the different densities and specifications are shown in table 2. These blocks have already been successfully implemented in France, Poland, and Austria, demonstrating performance levels ranging from U = 0.16 to U = 0.9 W/m^2K. Notably, the adoption of Airium blocks does not necessitate alterations to the existing local construction processes for contractors and applicators. In regions like Poland and Austria, innovative customers have developed monolithic blocks that fulfill stringent wall thermal insulation standards without the need for additional layers. Moreover, from an environmental standpoint, used in low-density blocks (70 kg/m3) presents a reduced CO2 footprint, amounting to just 26 kg of CO2 eq/m3. As a mineral material, it lends itself to easy recycling in conjunction with the block at the end of a building's lifecycle, aligning with sustainability objectives. It offers a versatile solution for flat roofs, where it can serve as an insulating slope, typically with a density of 400 kg/m3. This unique application enables simultaneous construction and insulation, holding particular significance in emerging nations. Comprised of locally sourced components, it typically supersedes the need for separate insulation materials, such as Polystyrene or Cork, and the concrete slope. It does so by providing an insulation layer of 10 to 15 cm. In cases where stricter regulations apply, it can also serve as a lighter alternative to traditional screed for sloping purposes, while still allowing for compatibility with additional insulation materials (11).

Table 1: Comparison between U-Value of a block with and without Airium
Source: Holcim Ltd Company- HOLCIM MAQER VENTURES

Block thickness	U-value without foam	U-value with Airium™
20 cm	1.17 w/Km²	0.53 w/Km²
36 cm	0.35 w/Km²	0.23 w/Km²
50 cm	0.23 w/Km²	0.16 w/Km²

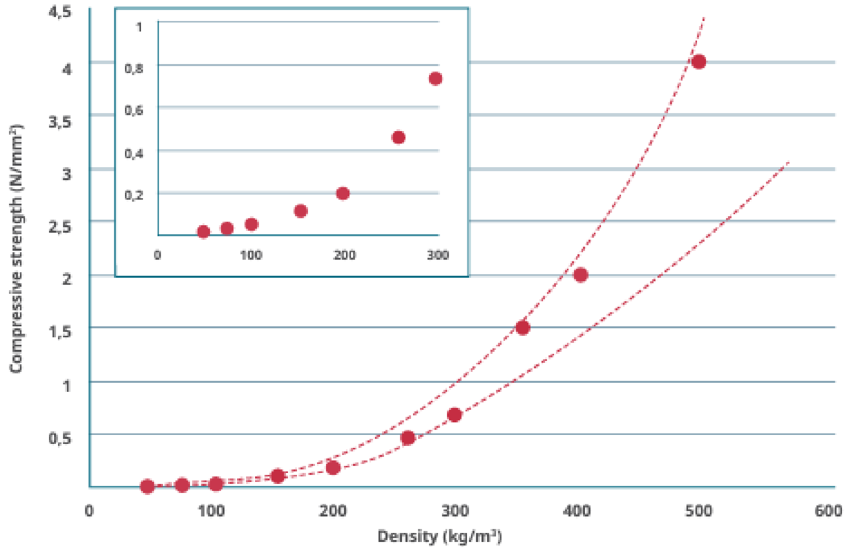

Figure 1: Compressive strength vs density curve of Airium
Source: Holcim Ltd Company- HOLCIM MAQER VENTURES

Table 2: Different densities and specifiactions of Airium
Source: Holcim Ltd Company- HOLCIM MAQER VENTURES

Airium® at different densities	Airium® 50	Airium® 70	Airium® 150
Applications			
Floors			Sub screed
Roofing	Non walkable attics		Walkable attics
Blocks and precast		Blocks	Sandwich walls
Lightweight filling			
Density (dry)	50 kg/m³	70 kg/m³	150 kg/m³
Minimum thickness	4 cm	4 cm	4 cm
Thermal conductivity (dry)	0,037 W/m.K	0,042 W/m.K	0,055 W/m.K
Compressive strength	10 kPa	20 kPa	150 kPa
Fire Resistance	A1	A1	A1
Water vapour permeability (μ-value)	3	3	5
VOC Emission (Eurofins)	A+	A+	A+

5.2 Different uses of Airium insulation

Airium insulation can be used in different ways, it can be used as a sub-screed as shown in Figure 2 to simplify work and logistics on site, provide a better levelling than fossil fuel-based alternatives and contribute to thermal and acoustic comfort as shown in figure.

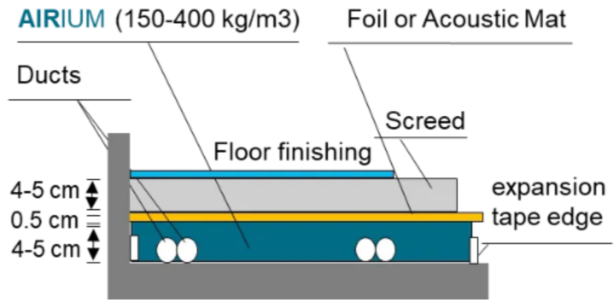

Figure 2 :Detail of Airium used as a sub-screed
Source: Holcim Ltd Company- HOLCIM MAQER VENTURES

It can also be used below the slab replacing both the insulation layer and any additional backfilling or levelling layers as shown in figure 3. It also eliminates the need for the time-consuming compaction step. The exact system must be adapted to local norms and needs of each country.

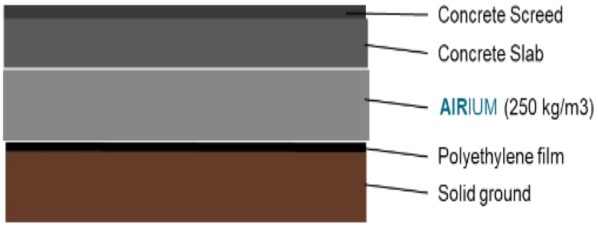

Figure 3 :Detail of Airium used below slab
Source: Holcim Ltd Company- HOLCIM MAQER VENTURES

Airium can be used as a screed to substantially lighten the load and the weight of a building (4 times lighter than a traditional screed) as shown in figure 4.

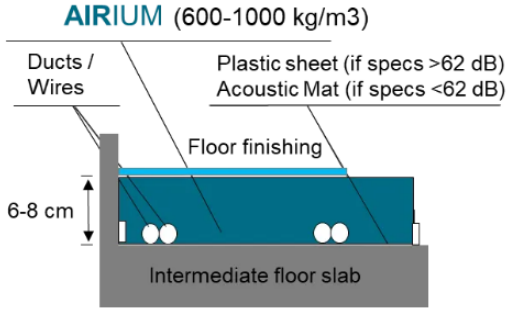

Figure 4 :Detail of Airium used as a screed
Source: Holcim Ltd Company- HOLCIM MAQER VENTURES

Airium insulation can also be used in walls to fill the concrete blocks to provide high insulation and it is VOC- free. It is also 100% recyclable feeaturing high production capacity.

It can be automatically introduced into the design and structure of various masonry blocks at a low density of 70 kg/m3, utilizing the voids within hollow concrete blocks as shown in figure 5. This process enhances a building's energy efficiency without substantial added expenses and without sacrificing available space.

Figure 5: Examples of blocks filled with Airium material
Source: Holcim Ltd Company- HOLCIM MAQER VENTURES

5.3 Different applications of Airium around the world

Airium insulation was used in a multifamily residential building in Poland. Its application was 8 cm of Airium 250 kg/m3 as sub-screed poured on top of the floor slab on surface 2000 m2, followed by an acoustic membrane and a dry screed on top. The application of Airium went four times faster than other alternative traditional systems, it also resulted in less waste on site and superior acoustic. Another application of Airium is in France, 20 cm Airium Blocks from Chausson, with Airium inside, were used for the external walls of a Grouped Housing project (R value of 1.12). Using Airium resulted in two hours more fire resistance performance and lower CO2 emissions compared to traditional masonry alternatives [**Error! Bookmark not defined.**]. Airium insulation technology hasn’t been yet applied in buildings in Egypt though theres a big need for insulation in buildings in Egypt given the climatic zone of it.

6. Building Information modeling (BIM)

Building Information modeling (BIM) analyzes building performance and has been applied in the design and construction industry from various aspects. BIM building envelope integrates a BIM building’s internal and external environments, improving energy efficiency and substantially lowering energy usage (12). BIM (Building Information Modeling) and BIM-related applications have the potential to facilitate sustainable design and environmentally friendly construction practices by offering tools and analyses for various aspects. These encompass acoustic assessment, carbon emissions tracking, management of construction and demolition waste, daylighting analysis, monitoring operational energy consumption, water utilization analysis, examination of building orientation, and evaluation of building form (13).

7. Case Study Description

The case study of this research paper is applied on a residential villa, a standalone unit in R7 plot G1, New Administrative Capital, Cairo, Egypt. The building is situated in hot desert climate (BWh) according to Köppen climate classification. The construction is normal concrete skeleton building with egyptian hollow clay bricks with 25 sm thickness, cement mortar and internal plastic paint. The glazing is 6mm single clear glass. The case study building was modeled on BIM and the main inputs were provided so as to simulate the building.

The case study plans and model are shown in figure 6, figure 7, figure 8, and figure 9. The building consists of groud, first and second floor. The total area is 440m2. The building's Window to Wall Ratio (WWR) is 15%. The glazing is 6mm clear glass and the infiltration rate is 0.7 ac/h. The building envelope specifiactions of the case study envelope are shown in table 3.

Figure 6: Ground floor plan of case study building
Source: Real estate developer at New Administrative Capital

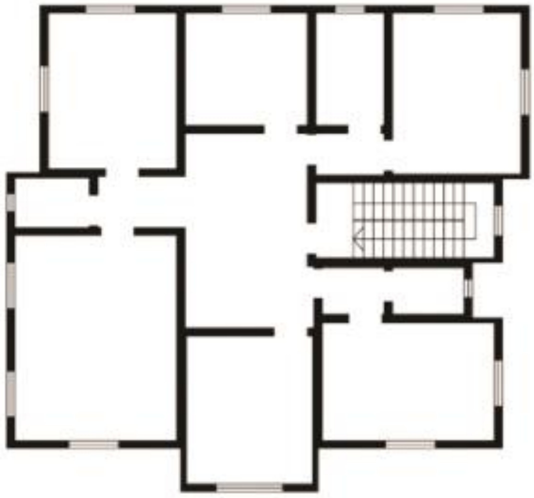

Figure 7: First floor plan of case study building
Source: Real estate developer at New Administrative Capital

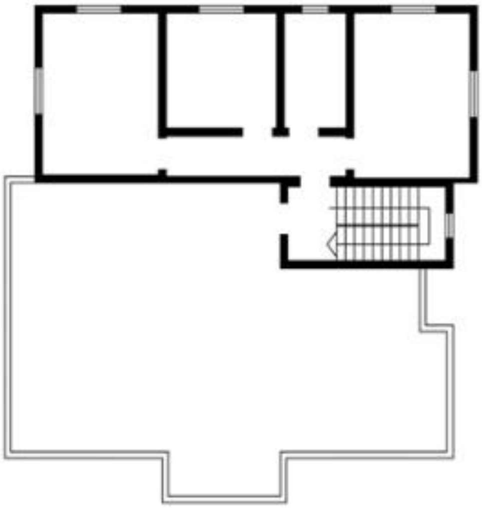

Figure 8: Second floor plan of case study building
Source: Real estate developer at New Administrative Capital

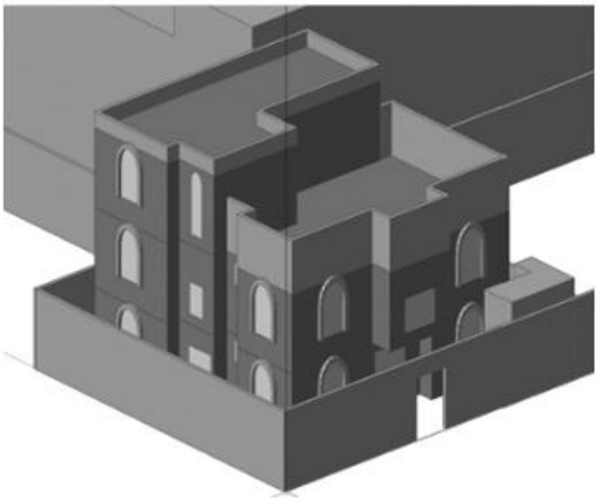

Figure 9: Stand alone villa (case study)
Source: Real estate developer at New Administrative Capital

Table 3: Base case building envelope specifications
Source: Real estate developer at New Administrative Capital

Building component	U-Value (W/m2 K)
Roof	3.4
Walls	1.82
Windows	5.71 SHGC -0.81

Table 4: Base case simulated energy consumtion on monthly basis
Source: By researcher using Energ simulation software

Month	January	February	March	April	May	June	July	August	September	October	November	December
Energy Consumption (Kwh)	2245	2389	3831	5704	7954	8390	10112	10347	9067	8007	5260	3478

Energy simulations were performed to test the base case energy consumption of the building without any solutions as shown in Table 4. It will work as the reference for the rest of the comparative study after testing and the impact of adding Airium insulation in both external walls and roof of the case study building. The case study base case annual energy consumption is 76784 Kw.h.

The case study will study the effect of applying Airium on different elements;

Case 1: Airium application: 8 cm of Airium 250 kg/m3 as sub-screed poured on top of the floor slab, followed by a dry screed on top.

Case 2: Airium application: 25 cm Blocks, with Airium inside, were used for the external walls.

8. Results and Discussion

The energy simulation results demonstrate the promising potential of implementing Airium mineral insulating solution in buildings across Egypt. Notably, applying Airium insulation to the roof resulted in a substantial decrease in annual energy consumption, reducing it from 76,784 KWh to 55,593 KWh, reflecting an impressive 27.5% reduction in annual energy consumption rates (refer to Table 5 and Figure 10). The impact of this insulation was particularly pronounced during the months of May, June, July, and August.

Extending the application of Airium insulation to external walls also yielded significant energy savings, lowering the annual energy consumption from 76,784 KWh to 68,489 KWh. This corresponds to a notable 10.8% decrease in annual energy consumption rates (see Table 6 and Figure 11). Similar to the roof insulation, the most substantial effects were observed during the warmer months of May, June, July, and August.

These findings align with and contribute to the existing body of research emphasizing the effectiveness of mineral insulation solutions, such as Airium, in enhancing the energy efficiency of buildings. The substantial reduction in energy consumption during peak summer months is particularly noteworthy, as it underscores the potential of such solutions in mitigating the impact of high temperatures on overall energy usage.

However, it is essential to acknowledge certain limitations in our study. Firstly, the results are based on simulations and assumptions, and real-world variations may exist. Additionally, the study primarily focuses on energy consumption, and broader considerations, such as cost-effectiveness, environmental impact, and long-term durability of Airium insulation, warrant further investigation. Future research should delve into these aspects to provide a more comprehensive understanding of the overall feasibility and sustainability of adopting Airium insulation in the context of Egyptian buildings. Despite these limitations, our study's outcomes suggest that Airium insulation holds promise for substantial energy savings, marking a positive step toward more sustainable and energy-efficient building practices in Egypt.

Table 5: Energy consumtion after applying Airium on roof
Source: By researcher using Energ simulation software

Month	January	February	March	April	May	June	July	August	September	October	November	December
Energy Consumption (Airium applied on roof)	1789	1793	2840	4210	5803	5789	6878	7067	6503	6037	4067	2817

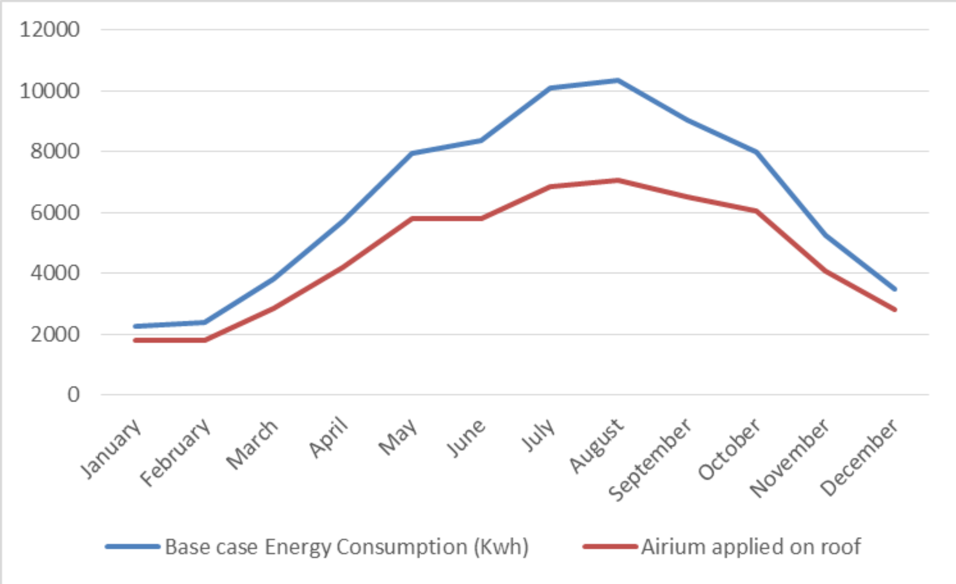

Figure 10: Energy consumption of base case and after applying insulation to roof
Source: By researcher using Energ simulation software

Table 6: Energy consumption after applying Airium on external walls
Source: By researcher using Energy simulation software

Month	January	February	March	April	May	June	July	August	September	October	November	December
Energy Consumption (Airium applied on roof)	2119	2237	3573	5232	7145	7463	8600	8854	8001	7098	4877	3290

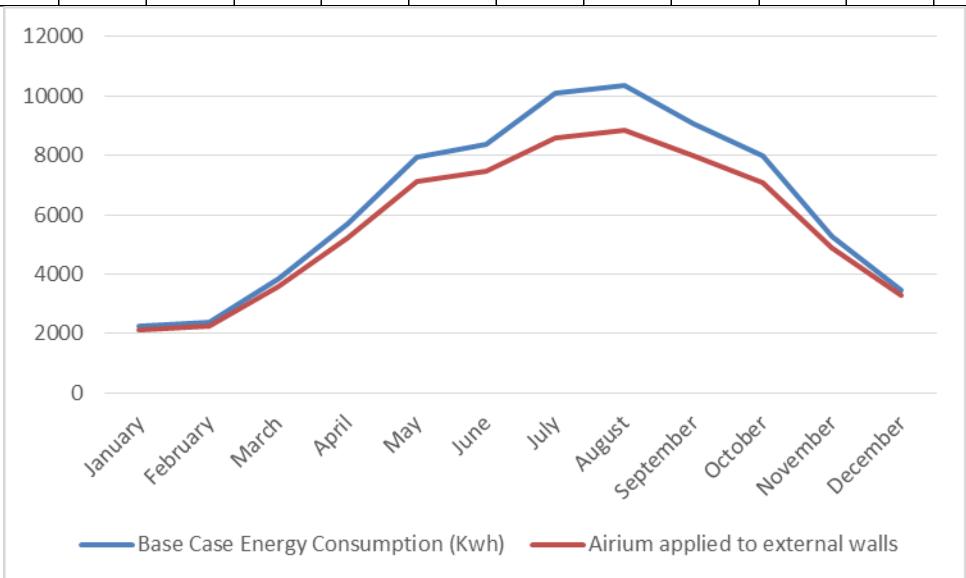

Figure 11: Energy consumption of base case and after applying insulation to external walls
Source: Real estate developer at New Administrative Capital

Conclusions

This paper evaluated the effect of using mineral thermal insulation on residential stand-alone villa in hot arid climate in the New Administrative Capital in Cairo, Egypt. The results of injecting Airium into masonry blocks and on flat roof with a layer of 10 cm gave boost to the energy efficiency of the building. the study indicated that applying the insulation on the roof is more effective than applying the material on external walls in terms of energy reduction. It is suggested that the insulation can only be applied to selected orientations of external walls to reduce the risk of overheating due to their solar exposure.

List of Abbreviations

MW	Mega Watt
Kw.h	Kilowatt hour
BIM	Building Information Modeling
BWH	Hot desert climate
PCM	Phase Change Material

Declaration

Availability of data and material: All relevant data are included within the manuscript

Funding: This research received no external funding

Competing of Interest: The author declares no conflict of interest.

Acknowledgment: Not applicable

Authors' contributions: Not applicable

References:

1- Santamaraa J, CampanoMA,andGiron S. "Method for the economic profitability of energy rehabilitation operations: Application to residential dwellings in Seville". Procedia Computer Science 2016.

2- William, Micheal & Elharidi, Aly & Hanafy, Ahmed & El-Sayed, Abdel-Hamid. (2019). Assessing the Energy Efficiency and Environmental impact of an Egyptian Hospital Building. IOP Conference Series Earth and Environmental Science. 397. 10.1088/1755-1315/397/1/012006.

3- 1 Miezis M, Zvaigznitis K, StancioffN,andSoeftestad L. "Climate Change and Buildings Energy Efficiency – the Key Role of Residents. Environmental and Climate Technologies" 2016.

4- 1 Ylmen P, Mjornell K, Berlin J,Arfvidsson J. The influence of secondary effects on global warming and cost optimization of insulation in the building envelope. Building and Environment 2017;118:174–183.

5- 1 Şahbaz, Mehmet & Kentli, Aykut & Eren, Ahmet & Bilik, Cangül. (2016). Material Selection for Insulation of Buildings by Multi-Criteria Decision Making Methods.

6- 1 Mohamed A., Building technology in achieving thermal comfort within buildings, International Journal of Advances Engineering and Civil Research, VOLUME 1, ISSUE 1, P 38-48 (2021) 2974-4393.

7- 1 Abdollah M., Scoccia R., Filippini G., Motta M. 2021.Cooling Energy use reduction in residential buildings in egypt accounting for global warming effects. Climate, 9(45):1-21.

8- 1 Wang Y., Zhang S., Wang D., Liu Y. Experimental study on the influence of temperature and humidity on the thermal conductivity of building insulation materials. Energy Built Environ. 2023;4:386–398.

9- 1 Ylmen P, Mjornell K, Berlin J,andArfvidssonJ.andIon I.V. "The influence of secondary effects on global warming and cost optimization of insulation in the building envelope". Building and Environment 2017.

10- 1 Anber, M. & Khalifa, R. (2022). Thermal Performance of Building Envelope in Residential Buildings in New Administrative Capital in Egypt, International Design Journal, Volume 12, Issue 6 - Serial Number 49, DOI: 10.21608/idj.2022.161750.1053

11- 1 Holcim Ltd Company- https://www.airium.com/

12- 1 Neda Sadeghi, Vahid Faghihi; BIM-BASED ENERGY PERFORMANCE EVALUATION OF A BUILDING ENVELOPE IN SEMI-ARID CLIMATE ZONE IN THE MIDDLE EAST. Journal of Green Building 1 June 2022; 17 (3): 227–258. doi: https://doi.org/10.3992/jgb.17.3.227

13- 1 Cavalliere, C., Habert, G., Dell'Osso, G., & Hollberg, A. (2019). Continuous BIM-based assessment of embodied environmental impacts throughout the design process. J. Clean. Prod., 941–952.