IMPACT OF NANO INSULATING MATERIALS ON ENERGY RETROFIT OF BUILDINGS

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ABSTRACT

Climate change is one of the most significant challenges currently. Reducing greenhouse gas emissions and global energy demand has become an important research topic. These challenges have increased interest in retrofitting the existing building stock. Energy retrofitting, i.e., energy savings and optimal energy use, is necessary to close the gap between limited resources and increasing energy demand. Applying an energy-efficient insulation system can significantly decrease the energy consumed via a building's air-conditioning system during the summer. Hence, building insulation has become a promising research topic, especially insulation based on nanomaterials due to their low U-values. This research paper examines the energy retrofitting effectiveness of an old educational building in Egypt using Nanogel®Aerogel insulating material by integrating it with the building envelope, while walls are insulated with vacuum insulation panels (VIPs). The energy simulation was performed by DesignBuilder software (version 6.1.0.006). The results indicate that integrating VIP and aerogel in the building envelope can increase the thermal performance of a building in a hot climate like Egypt, which especially needs cooling loads during the summer months. It also shows a significant reduction in annual energy consumption, saving up to 36.5% compared to the base case.

Keywords: nano insulating materials, retrofit building, energy efficiency, simulation, aerogel, VIPs.

1 INTRODUCTION

Today, due to the rapid economic growth and high levels of living, the energy of fossil fuel procurement is significantly depleted, which has led to environmental pollution and an energy crisis. Existing buildings account for 40% of the total world's primary energy consumption and one-third of global carbon dioxide emissions [1]. This high energy consumption in buildings is mainly associated with the lower performance of the envelope of the building.

Retrofitting existing buildings offers a significant possibility for conserving energy and lessening emissions, because large numbers of the existing building stock have poor energy efficiency. Most of the existing buildings in Egypt were designed and constructed without specific energy performance requirements for building envelopes. Therefore, retrofitting existing buildings is one of the possible ways to improve energy efficiency. A well-designed envelope should use novel insulation materials to control the heat transfer and minimize it within the building. Using traditional insulating materials usually requires an increasing insulation layer on the wall, the floor and the roof. In retrofit projects, this, in turn, limit the ability to adjust the function and design and affects the ability to apply sustainable solutions depending on the required renewal level.

Accordingly, advanced solutions capable of combining energy efficiency with the quality of building architecture are needed, ensuring a higher comfort for its users. In that case, super insulation materials (SIMs) can achieve many benefits in existing buildings by improving their energy and environmental performance and increasing the building's life [2].

One type of SIMs is vacuum insulation panels (VIPs) and advanced nano-porous materials such as aerogel. VIPs have extraordinarily high thermal resistance values up to 20 times higher than conventional insulating materials (see Fig. 1); their significant advantage is that

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they can be available in thinner layers (approximately 5 to 50 mm thick) with low thermal conductivity values (0.015–0.004 W/mK) [1]

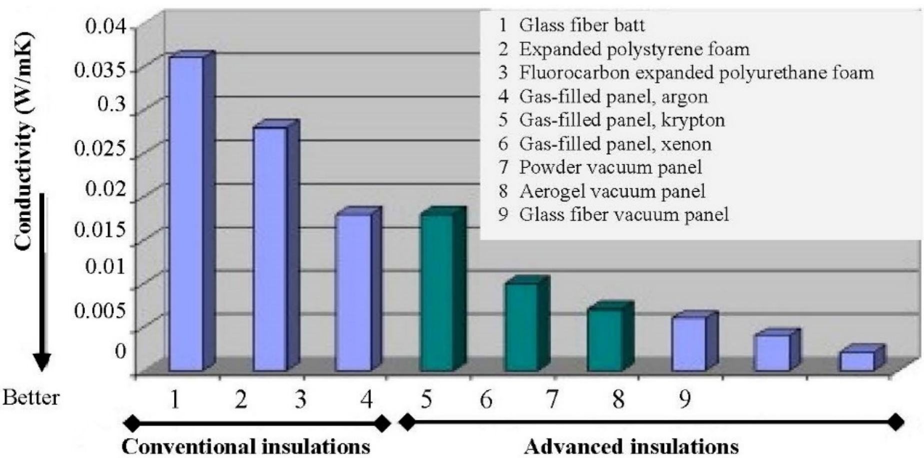


Figure 1: Thermal conductivities of conventional and advanced insulating materials [3].

VIP insulation consists of three main components: an inner porous core, a getter/desiccant, and an airtight envelope from plastic or aluminium, as shown in Fig. 2 [3].

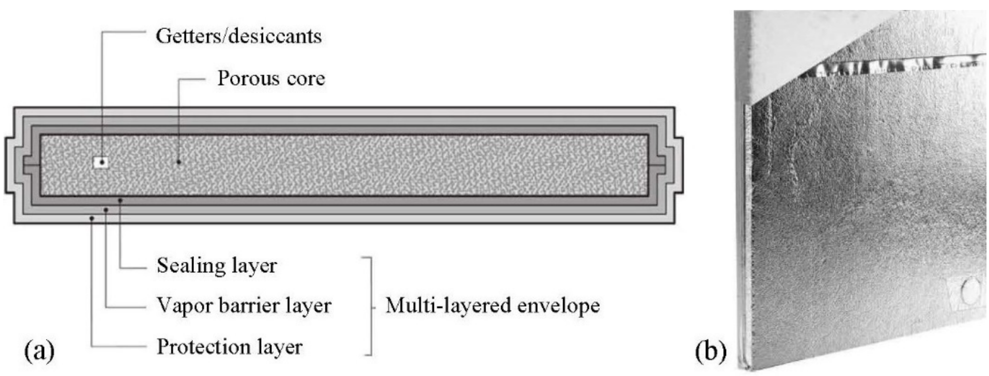


Figure 2: (a) Structure of a vacuum insulating panel; and (b) Vacuum insulating panel core and envelope [4].

The principle methodology that characterizes VIPs and allows for their exceptional performance is vacuum pressure, which can be used to decrease gaseous thermal conductivity that reduces heat transfer [4].

Aerogel is also applied in glazing as a granular aerogel encapsulated between panels; compared to the equivalent glass unit, it is 200 times higher in strength and 20% lighter in weight with low U-values (0.30 W/m^{2}K). Added to that, it has adequately optical transparency and increased acoustic insulation

Various research has been done recently to investigate the impact of nano insulation materials on building retrofits and evaluation of various energy retrofit strategies, including actual building studies, simulations, and laboratory experiments.

Ascione et al. [5] declared the dynamic testing of a concrete wall with VIPs in different weather conditions of the test building and furthermore conducted simulations of an office building model to assess the relative benefits of the very low conductivity of VIPs under multiple weather conditions. Challenges posed by using VIPs in external insulation systems were reviewed by Gonçalves et al. [3]. Another study in KSA by Mujeebu et al. [6] conducted a simulation study to determine the influence of applying aerogel (nanogel) glazing in windows and VIPs on external walls of a prototype office building on energy consumption; the study revealed that nanogel glazing alone could save 16% in building annual energy consumption.

Buratti and Moretti [7] studied silica granular nanogel in a glazing window with an aluminum frame prototype in an in-lab experiment. They discovered the extraordinary thermal performance of the material and its high acoustic properties.

In Egypt, sustainable design is still in its modest beginnings. A few numbers of architectural practitioners and building owners are interested in raising the energy efficiency of existing buildings stock and enhancing their internal comfort without consuming more harmful energy sources.

A current case study of retrofit of the building of the engineering faculty in Alexandria was selected to examine the impact of nano-insulating materials on the energy consumption of the building.

Firstly, a quick overview of the current reference case and location, followed by a methodology for the simulation stage and analysis of the different interventions used in the building compared to the base case by using DesignBuilder software for simulating the energy of each intervention, then the results and discussion, and finally, extract conclusions and recommendations to be a guideline for designers, researchers and buildings' owner.

2 THIS CASE STUDY: OVERVIEW

2.1 Faculty of Engineering, Alexandria University, Egypt

The case study building for this research is located in the Central district of Alexandria – El-Shatby – Egypt. The Engineering Faculty at Alexandria University (see Fig. 3) is operated as a typological representative for Alexandria's public institutions of architectural education.

The distinguished architect Dr. Mohamed Kamal Ismail designed the faculty's buildings and the studying initiated in the faculty in the 1942–1943 academic year. The building is old

Figure 3: The Engineering Faculty building at Alexandria University [8].

and deteriorated, while the preventative maintenance was inefficient. However, recently started, the restoration of the building's facades [8].

2.2 Alexandria climate

Egypt lies between latitudes 22° to 32° N and 25° to 35° E longitude. Egypt's climate is preponderantly hot. Egypt is divided by the Housing and Building Research Centre (HBRC) into eight various climatic design regions. According to Koeppen's climate classification, Alexandria is located in the north coast region and has a hot, humid climate. Alexandria's climate is hot in the summer, where the temperature can reach 32°C. or even 34°C, and the summer duration begins in May and ends in October. The winter period lasts from November to April [9].

3 METHODOLOGY

The current case study indicates how VIPs and Nanogel (Aerogel) can be used to retrofit old buildings and improve their energy efficiency performance. A simulation was applied using DesignBuilder software to determine the building's energy consumption and use intensity to achieve the most productive energy efficiency and investigate the effect of such nanomaterials on the building energy performance.

The presented study went through three primary simulation interventions. First, VIPs were added as exterior insulation to the building envelope; secondly, to achieve adequate energy performance, VIPs were used as interior insulation; and lastly, the old windows (3 mm single glass) were changed with double nano glazing windows. All the above-suggested interventions were simulated to compare results of the overall energy efficiency with the base case before retrofitting.

3.1 The base case

The southern side on the fourth floor of the building (see Fig. 4) was chosen for the current study for several considerations. It represents the primary floor of the architecture department which is diverse in functions (see Fig. 5); in addition, the zones range in cooling between air conditioning and natural ventilation; furthermore, part of this floor ceiling is an external roof. The southern facade was concerned with the study to demonstrate the results with more contrast and realism. Therefore, the current floor considers most factors affecting the energy performance of the building and represents a sample model of the rest of the buildings at the faculty.

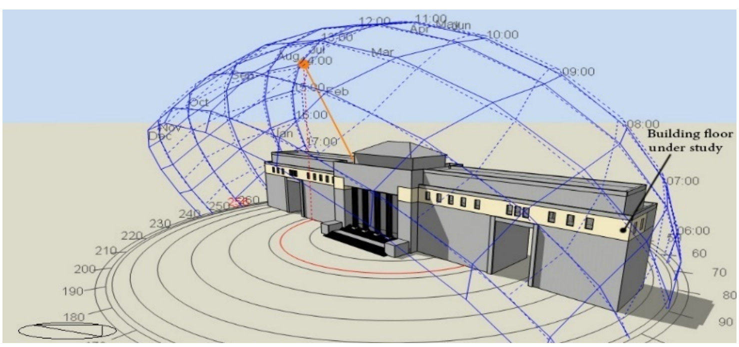


Figure 4: The base case simulation thermal model.

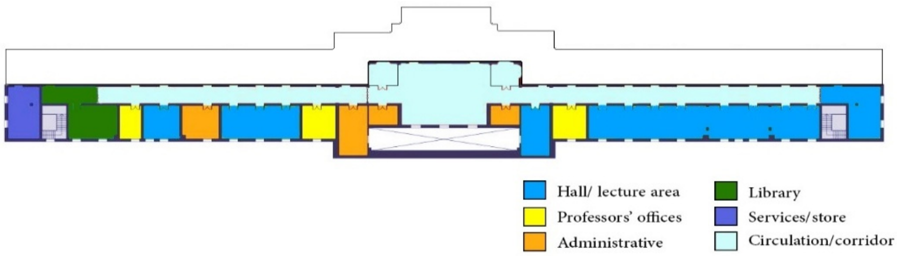
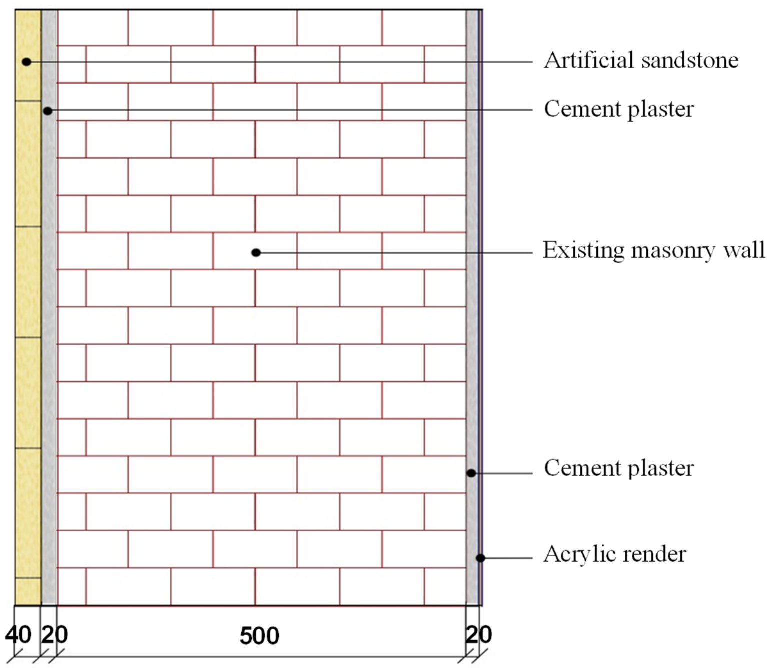


Figure 5: Southern side fourth level floor plan.

3.1.1 Constructions

The building has non-insulted brick masonry walls 500 mm thick covered with a 40 mm thick artificial sandstone on the exterior, providing a calculated U-value of 1.031 W/m^{2}K. The materials of the original building's envelope are described in Fig. 6.



Base case external wall (non-insulted brick masonry walls 500 mm thick).

U-Value: 1.031 Wm^{2}K

Figure 6: The base case materials of external walls.

3.1.2 Exterior openings

The exterior windows of the building are wooden frames with a single clear 3 mm glazing. The original window has a U-value of around 6.2 W/m^{2}K (see Table 1).

Table 1: Base case windows characteristics. *(Source: DesignBuilder.)*

Symbol	Window glazing	Solar transmission (SHGC)	Direct solar transmission	U-Value (W/m^2-K)
G0	Single Clear 3 mm	0.858	0.837	6.257

3.2 Weather data

DesignBuilder software (version 6.1.0.006) was used as a model utilizing the dynamic thermal simulation for various walls, roofs and windows. Building's 2D AutoCAD file plan was imported to draw the building and conduct the simulation analysis. The simulation evaluated the cooling load's annual energy consumption (AEC); the space cooling system implemented in the case study is a (split no fresh air) in all the conditioned zones. The schedules were set using settings of fixed activities based on the traditional Egyptian lifestyle (holidays, occupancy times, work hours).

The climate data was set to Alexandria climate data. DesignBuilder software contains EPW weather files for Alexandria city. The EPW's weather file is extracted from the weather database (Energyplus). The source of its data is the Egyptian Typical Meteorological Year (ETMY), developed from data provided by the U.S. National Climate Data Center.

3.3 The base case energy consumption

The base case results on the summer design date (see Table 2) were a cooling energy intensity (EUI) of 47.43 kWh/m^2 on 15 Aug, a cooling system design capacity of 62.41 kW and an annual energy cooling load of 60.758 kWh. The highest radiant temperature recorded was 33.97°C. The radiant temperature of the summer design date is shown in Fig. 7.

Table 2: Base case total cooling loads, design capacity and EUI.

	Annual energy cooling load (kWh)	Design capacity (kW)	Cooling energy use intensity (EUI) (kWh/m^2 yr)
Base case	60.758	62.41	47.43

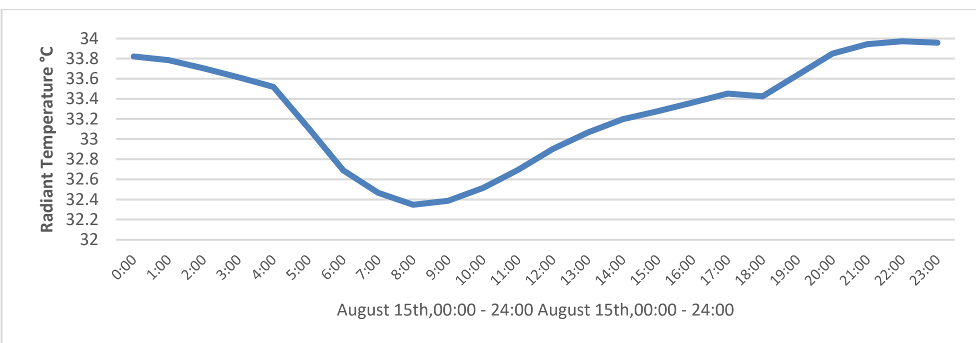


Figure 7: Radiant Temperature of the base case on the summer design day, 15 August.

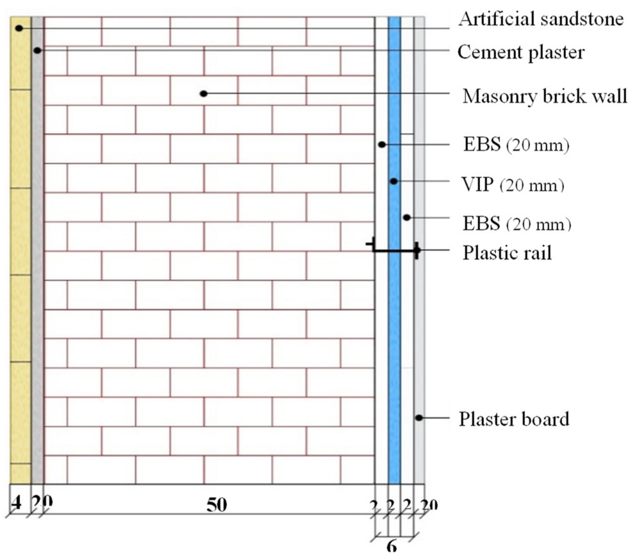
4 RESULTS AND DISCUSSION

Different interventions were studied to estimate the impact of nanomaterials on the building's energy-saving; each was examined individually to determine its effect on the building's energy consumption.

The results are presented by the energy-intensity (EUI) values of the cooling energy for each simulated intervention and then calculate the percentage of energy-saving achieved compared to the base case. EUI is calculated for the building by dividing the total annual energy consumption by the entire floor space with (kWh/m^2 yr) unit measurement. The lower EUI, the better the energy performance [10].

4.1 Nano insulating materials for external walls

The vacuum insulation panel (VIP) is one type of super insulation material (SIM). The VIPs with expanded polystyrene (EPS) cover layers (see Fig. 8) were selected for thermal insulation of the building's envelope, where the EPS cover layers were applied to decrease the thermal bridging produced by the VIP metal envelope. Therefore, the applied insulation layers consist of 20 mm EPS, 20 mm VIP, and 20 mm EPS. The VIPs' thermal conductivity is 0.002–0.008 W/(m.K), and the specific heat capacity is 850 J/(kg.K) [11].



External wall after insulated with Vacuum insulation panels.

U-value: 0.28 W/m^{2}K

Figure 8: External walls and roof after adding nano insulating material.

4.1.1 Results of the VIPs external wall insulation.

The energy use of the base case windows was 47.43 kWh/m^2/year for cooling. The results (see Fig. 9) of adding VIPs to the external wall insulation showed that total energy use was reduced by more than 4.9%. The difference in the percentage reduction in energy use is insignificant because the original building walls were made of 500 mm brick wall thickness with good thermal insulation (U-value = 1.031 W/m^{2}K). Besides, the reliance of many building areas on natural ventilation takes advantage of the mild climate of Alexandria during some periods of the summer day. Therefore, VIPs were applied to the interior walls to examine their effect on the thermal insulation walls of air-conditioned areas to achieve optimum energy efficiency.

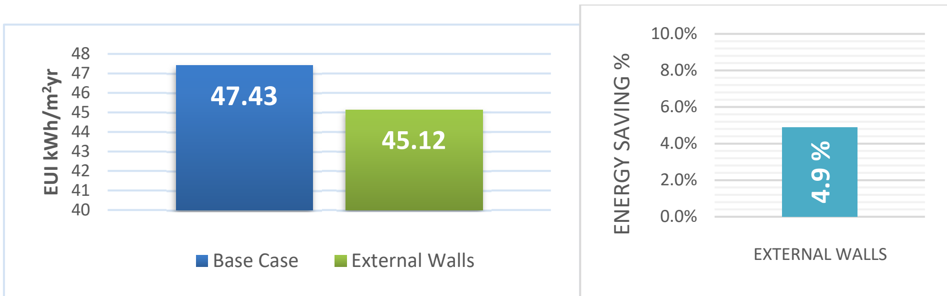


Figure 9: External walls cooling EUI, and energy saving compared to the base case.

4.2 Insulation of interior walls

Many of the building rooms are ventilated by natural ventilation, where a fan circulates the air in non-conditioned rooms to create homogenous temperature and thermal conditions. Therefore, interior insulation was assumed to be a feasible solution to achieve acceptable energy performance.

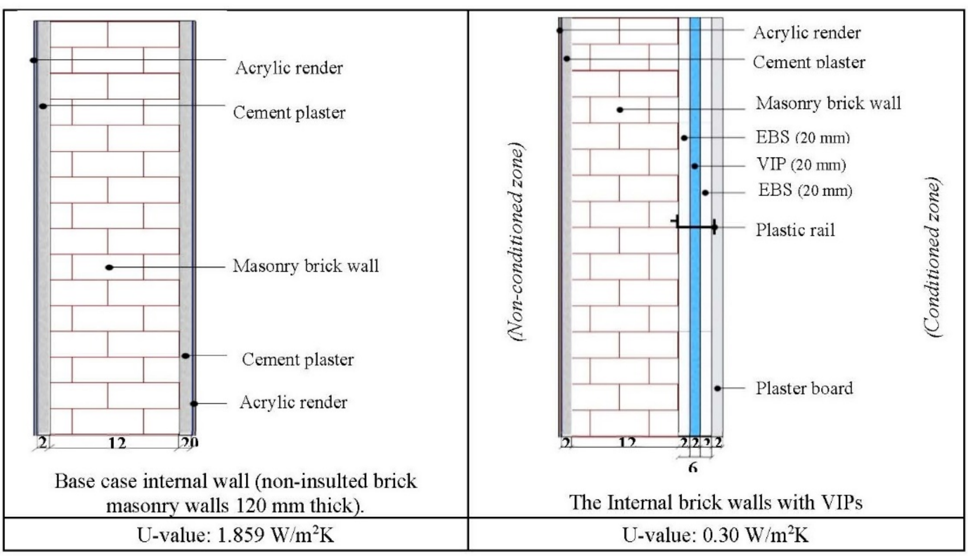


Figure 10: Internal thermal insulation for external and internal walls.

4.2.1 Results of the internal walls insulation:
The interior walls of the building are 120 mm non-insulated brick walls with a U-value of 1.859 W/m^{2}K; applying a 10 mm VIPs interior insulation granted a U-value of 0.30 W/m^{2}K. Fig. 11 shows the importance of adding thermal insulation to the interior and exterior walls; adding VIPs to internal walls alone saved about 8.9% of the energy use.

In a building with conditioned and non-conditioned areas, interior walls must be thermally insulated to keep the conditioned areas preserving their temperature during cooling and preventing heat from transferring through their walls, which decreases the use of conditioning systems and reduces energy consumption.

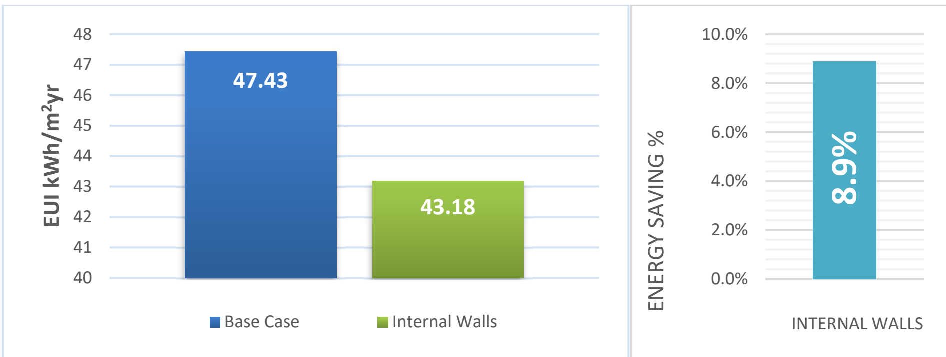


Figure 11: Internal walls cooling EUI, energy saving compared to the base case.

4.3 Thermal insulation glazing

This stage investigated the impact of nano-glazing materials on the studied building energy consumption. Table 3 shows the studied glazing characteristics.

4.3.1 Results of the glazing cases
Simulation results (see Fig. 12) revealed various improvements in the cooling EUI, with the highest improvement percentage of approximately 21% for the (G5) window, the double-glazed with a nanogel layer and two layers of argon. It is higher than the double-glazed with a 10 mm nanogel layer (G4), achieving about 9% saving. At the same time, the 6 mm single-glazed window (G1) scored a minimal impact on cooling energy intensity by 1.68%. The doubled glazing with the gab of air (G2) and void fill with argon (G3) achieved 3.12% and 4.02% savings in cooling energy intensity.

Compared to argon and air, the low thermal conductivity of aerogel allows for exceptional thermal insulation of nanogel glazing. In addition, the lower solar heat gain coefficient and U-value of aerogel increased its heat transfer [12].

4.4 All Nano insulating materials interventions in building's walls and windows

All the interventions were applied to the final simulation to determine the total energy saving. Accordingly, the double-glazed with a nanogel layer and two layers of argon was chosen as it achieved the most significant improvement. VIPs were used on the external walls and conditioned areas' internal walls.

Table 3: Specifications of the windows.

Symbol	Window glazing	Solar transmission (SHGC)	Visible light transmission	U-value (W/m^2K)
G0 (Base case)	Single clear 3 mm	0.858	0.837	6.257
G1	Single clear 6 mm	0.810	0.881	6.121
G2	6 mm clear glass, 13 mm air gap, 6 mm clear internal glass	0.697	0.781	2.708
G3	6 mm clear glass, 13 mm void filled with argon, 6 mm clear internal glass	0.698	0.781	2.549
G4	6 mm clear glass, 10 mm nanogel, 6 mm clear internal glass	0.52	0.379	2.061
G5	6 mm clear glass, 13 mm Argon, 10 mm nanogel, 13 mm Argon, 6 mm clear internal glass	0.35	0.31	0.45

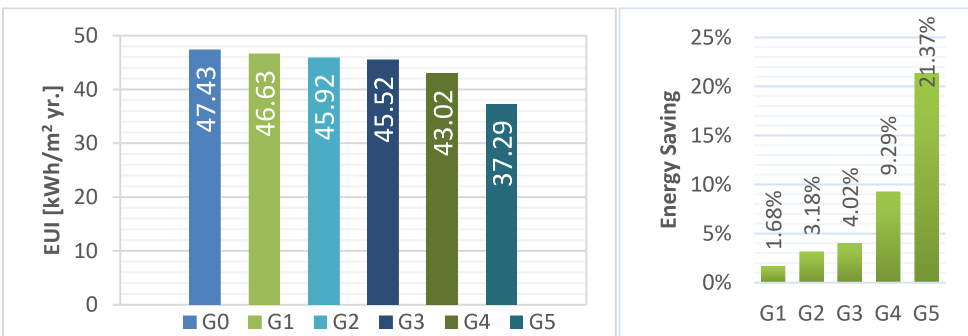


Figure 12: Windows glazing's cooling energy intensity (EUI) and energy saving percentage compared to the base case.

4.4.1 Results of nano insulating materials in walls (external and internal) and windows

The results (see Fig. 13) demonstrated an apparent reduction of 36.5% in cooling energy use intensity (EUI) for internal walls and windows thermal insulation relative to the base case.

In addition, the total cooling energy consumption decreased from 60.758 to 54.231 kWh, with a decrease in cooling loads by 6528 kWh annually, which is approximately 10.7% of the entire cooling loads. While the highest radiant temperature recorded was 31.02°C which, in turn, decreased by 2.95°C (see Fig. 14), as it recorded 33.97°C in the base case without any interference from HVAC systems.

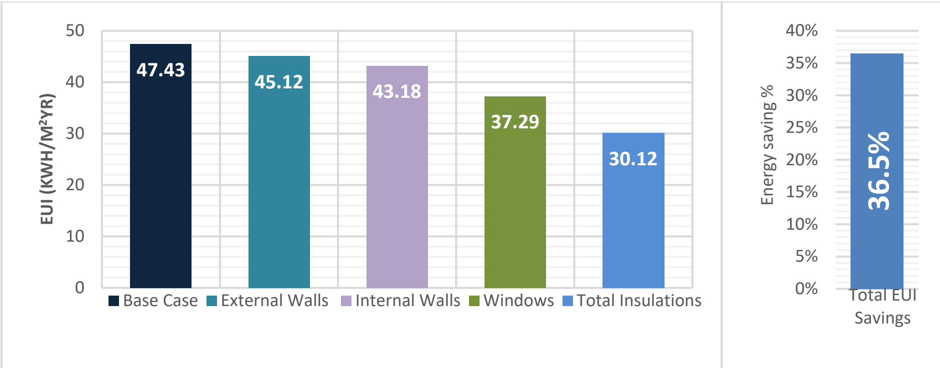


Figure 13: The cooling energy intensity (EUI), and energy-saving of all retrofitting interventions in building walls and windows.

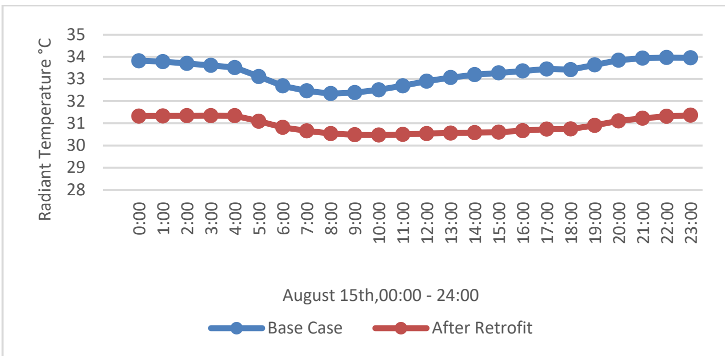


Figure 14: Comparison of the radiant temperature of the base case and after retrofitting on the summer design day, 15 August.

5 CONCLUSION

The present study investigates two nano-insulating materials – VIP and nanogel (aerogel) – to examine their potential for existing buildings, where the reduction of energy consumption and improved thermal comfort in buildings is essential. The energy use intensity (EUI), annual energy consumption, and energy savings of an educational building in Alexandria city, Egypt, were assessed.

The main outputs of the present study can be outlined as follows:

- Up to 21.37% improvement in total cooling energy use intensity (EUI) is achieved when nanogel glazing is used in the windows.
- Up to 4.9% and 8.9% improvement in total cooling, energy use intensity (EUI) is achieved when VIPs are internally used in the external and internal walls of an existing building.

These results can be used as a guideline for architects, designers and owners of buildings to examine advanced materials and to predict the energy performance for existing buildings. Furthermore, to utilize building energy simulation software as an aiding tool to indicate the building's performance and estimate different solutions to improve building energy efficiency.

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