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Effect of Nanogel Windows on the Window-to-Wall Ratio (WWR) With Reference to Daylighting and Energy Consumption

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KEYWORDS:
Daylighting, Window to Wall Ratio, Aerogel glazing, Energy Consumption, Energy Simulation Tool.

***Abstract*— Electrical lighting accounts for a significant contributor to total electrical energy consumption. Lighting has an energy effect that is not limited to the energy consumption of light fixtures. It also contributes significantly to the building's heat burden. WWR and glazing systems are the most significant factors that affect the electrical lighting and cooling energy consumption of a building. Reduction in WWR means a reduction in solar heat gains and accordingly in cooling energy consumption, otherwise it means increasing in lighting energy consumption.**

Nanogel windows as highly energy-efficient windows have the greatest potential for improving the thermal performance, daylight, and solar properties in the windows sector due to their high thermal insulation coefficient.

The main objective of this paper is to discuss the effectiveness of implementing the recent innovations and technologies in glazing systems (Nanogel windows) in terms of daylighting and energy consumption with various Windows to Wall Ratio WWR. The final goal is to determine the appropriate WWR using this technology for office buildings in Egypt.

An Energy Plus based simulation was carried out for an office building and the Nanogel glazing was implemented with different Window to Wall Ratio (WWR), 20%, 40%, and 49% (the base case), compared to the existing glazing one. It is found that, concerning the lighting and cooling energy consumption, the WWR 49% (the base case) is the best ratio with using Nanogel windows. It results in a considerable reduction in the building energy consumption reaches 7.18% (90204 KWh), 1.71% (5226 KWh), and 5.23% reductions in cooling loads, electric lighting and the total energy consumption respectively.

I. INTRODUCTION

THE Concerns about energy conservation have recently focused on the power usage for lighting: as shown in Figure 1, electrical light sources consume a high percentage of the world's power generation; it is about 16–20 percent [1]. Lighting is one of the most significant power consumers and contributors to energy-related greenhouse gas emissions [2].

Electrical lighting accounts for a significant contributor to total electrical energy consumption. The energy effect of lighting is not confined to the energy consumption of light fittings. It is also a significant source of heat load for the

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building. In an air conditioned building this affects the initial plant size and the running cost of the system. Several studies indicated that daylighting could offer a cost-effective alternative to electrical lighting for commercial buildings [3].

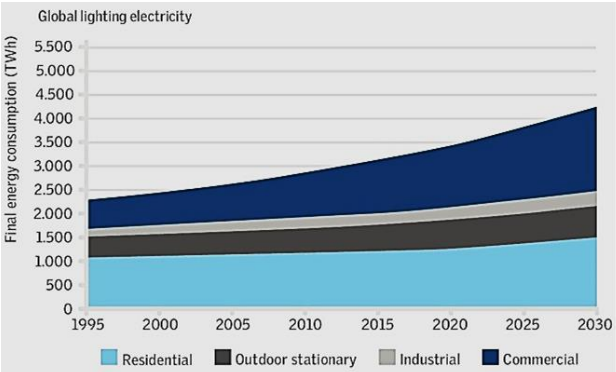

Fig. 1: Global electricity consumption for lighting (IEA, 2006) [2]

Daylighting strategies are comprehensive approaches that consider the characteristics of each window in the context – latitude, orientation, geometry, dimension, and glazing type – in a cohesive assembly that includes all other involved architectural elements: the geometry of the room, the geometry of the ceiling, the surface and color of the finishing materials [1].

Innovative nano based transparent materials for better heat resistance, have gotten a much attention due to their excellent thermal properties. Aerogel is a potential nanomaterial for application in high-efficiency buildings and windows. It is a porous low-density nanostructure material with high optical transparency and low heat conductivity (approximately 0.018 Wm/K for transparent granular aerogel).

There are two types of aerogels Figure 2: monolithic and granular aerogels. Monolithic silica aerogels have a greater solar transmittance than granular silica aerogels; for example, solar transmittance of 10 mm monolith transparent silica aerogel windows has been up to 0.8, whereas granular silica aerogel windows have a maximum solar transmittance of approximately 0.5 [4]


Fig 2 Aerogel insulation material for building applications: opaque blankets (b), and granular aerogels (c)

Aerogel windows have played an essential role in increasing both thermal performance and daylight in the fenestration sector due to their low conductivity, good acoustic insulation, light transmission, and low weight.

Among all the aspects affect cooling lighting and heating energy consumption in the building is the window system. Window systems are commonly regarded as a critical component that must be appropriately built for energy efficiency objectives. Glazing systems influence significantly on energy consumption since the quantity of heat gain, solar radiation, and illumination entering the area is determined by the glazing properties and window to wall ratio (WWR). The optimal WWR is the window area that helps to use the least amount of cooling, heating, and lighting energy for a year [5].

Investigating WWR to reach the optimal percentage has been studied in several researches concerning several aspects such as orientation [6], climate [7], [8], [9], building type [7] [10], [11] and others to achieve building energy efficiency. This paper tries to investigate the hypothesis that, by using the innovation technologies in glazing systems (Nanogel windows), large windows can be used to create desired lighting conditions. The greater size of the window generates a minor increase in thermal energy and has little influence on the cooling peak if the windows are used efficiently.

For this purpose, a simulation process carried out using Energy Plus software depending on a previous work of the researcher, an office building tested in Egypt climate to assist design of an energy efficient building. In this study, window to wall ratio alternatives were evaluated with Nanogel windows in terms of energy consumption and daylighting. The studied WWR percentages were 20%, 40% and the current ratio of case study building 49%. The performance of different alternatives is discussed in comparative form concerning the base case.

A. The problem

Electrical lighting accounts for a significant contributor to total electrical energy consumption, it consumes about 16-20% of world power generation [1]. The energy effect of lighting is not confined to the energy consumption of light fittings. It is also a significant source of heat load for the building.

B. Aim of Research

The main objective of this paper is to discuss the effectiveness of implementing the recent innovations and technologies in glazing systems (Nanogel windows) in terms of daylighting and energy consumption with various Windows to Wall Ratio WWR. The final goal is to determine the appropriate ratio using this technology for office buildings in Egypt.

II. METHODOLOGY

In order to investigate the impact of Nanogel windows on the Window to Wall Ratio WWR, a case study modeling is employed. Modeling was better suited for this study's goal since it allowed for a more flexible examination of numerous types of construction materials with diverse attributes. Furthermore, using modeling made it easier to relate to the authors' past research work [3], which served as the foundation for this study.

III. DAYLIGHTING

Several studies indicated that daylighting can offer a cost-effective alternative to electrical lighting for commercial buildings. Day lighting can reduce and eliminate the use of electrical lighting required to provide sufficient luminance levels inside office spaces through passive, active and hybrid ways. It is rule of thumb that increasing the Window to Wall Ratio and the glazing system are the most effective passive way to increase daylighting in the space.

A. Significance of Daylighting

1) *Performance and productivity*

According to Many researches, the quality of light may improve worker performance and productivity in the office, industrial, and retail environments. It is proved that employee's productivity increased by about 15% with better daylight conditions which resulted in considerable financial gains. Studies also demonstrate that learning is more successful in daylight conditions. It was found that classes with high WWR or with daylight help students to score 7% to 18% higher on the standardized tests than those with the least WWR or daylight. [2]

2) *Energy savings for electric lighting*

Daylighting saves energy by reducing the need for electric lighting. Several studies have found that utilizing daylight in office buildings saves electric lighting energy 20-60%. [2] A related benefit is the reduction in cooling loads and lowering a significant component of internal gains [3]

3) *Environmental Benefits*

Increased use of natural light in buildings, such as through windows in facades and roofs, can minimize the usage of electric lighting and, as a result, reduce reliance on fossil fuels and greenhouse gas emissions.

B. Factors Affecting Daylight

Among all the aspects that influence daylighting performance is the window system. Solar radiation and illumination entering the space is determined by the glazing properties and window to wall ratio (WWR).

1) *Window performance*

Windows significantly influence thermal comfort, daylighting and energy consumption in the buildings. A large portion of the total energy losses (up to 60 %) can be attributed to windows; this is due to transparent elements having lower thermal performance than the solid walls and is affected by radiation: in particular, highly glazed buildings [5].

Windows have a dual purpose in the thermal envelope of a structure.

- To decrease energy consumption for heating and air conditioning, thermal transmission qualities must be as low as feasible.
- For visual comfort and electric energy savings in illuminating plants, light transmission properties must be as good as feasible.

2) *Window to Wall Ratio WWR*

The percentage of a building's outside envelope that is made up of glazing, such as windows, is measured by the window to wall ratio. According to ASHRAE 90.1-2007, a Window to Wall Ratio (WWR) of 0.24 is excellent for maximizing internal sunshine and natural ventilation [12].

The ratio of transparent to opaque surfaces is a metric that has a significant impact on the building's energy balance as well as its architectural look.

WWR is one of the most significant factors affect the electrical lighting and cooling energy consumption of a building. Reduction in WWR a means reduction in solar heat gains and accordingly in cooling energy consumption, otherwise it means increasing in lighting energy consumption.

The optimal WWR varies depending on the environmental conditions. According to a study conducted by s.s.shebl, Housing and Building National Research Center, the study evaluates the effect of window to wall ratio (WWR), the results for the commercial sector in Egypt indicated that, WWR up to 20% is preferred to be energy efficient [3]. In addition, it was proven, through a researcher's prior study, that, the best WWR with respect to energy consumption is 20% which resulted in 4, 57% reduction in the building's total energy consumption

IV. NANOGEL WINDOWS

Because of its low heat conductivity and high daylight and solar energy transmittance, Aerogel is particularly appealing as a translucent or transparent insulating Aerogels show very interesting optical properties for building applications and their transmittance is high in the whole solar spectrum, including the visible range, where it is similar to that of a 6 mm thick clear float glass. For a 14 mm thick aerogel glass, values of light transmittance v equal to 0.78 and solar transmittance e equal to 0.80 were discovered [12]. Nanogel windows (with silica aerogel in the inter-space) is one of most energy efficient windows because of their high thermal insulation coefficient (thermal conductivity of silica aerogel is as low as 0.010 W/mK) and light transmittance [13].

There are two commercial products on the market, as shown in Table 1: [13]

TABLE 1
PROPERTIES OF GRANULAR SILICA AEROGEL MANUFACTURING CABOT CORPORATION [6]

Name	Thermal Conductivity	Density
Enova ®	0.012 W/mK (at 25 °C)	125-150
Lumira ®	0.018 W/mK (at 12.5 °C)	85
	0.023 W/mK (at 12.5 °C)	65

- LUMIRA TM aerogel, formerly Nanogel ®, is a translucent product developed by Cabot, to maximize light transmission in daylighting applications in buildings (Figure 3, 4). It gained wide acceptance across the USA and Europe for several kinds of highly insulated daylighting systems. The grain size of the Lumira TM aerogels ranges from 0.5 to 3.5 mm, and the thermal conductivity is around 0.018 W/m2 (mK) [12]
- ENOVA aerogel, (formerly Nanogel ® Aerogel, was designed as an additive in chemical applications (such as insulation coatings).

Fig 3 LUMIRA® VS Traditional Glazing [14]

Fig 4 A Classroom Setting Demonstrating Diffused Light LUMIRA® [14]

V. SIMULATION PROCESS

The Energy Plus software in its version (V.8.7.0) was used to simulate the building energy and Lighting performance for various Window to Wall Ratio with Nanogel windows. Energy Plus was developed from both the BLAST and DOE.2 programs.

The day lighting calculation in Energy Plus is taken from DOE-2.1E's day lighting calculation, but Energy Plus outweighs DOE-2.1 by two important variances [15]:

1. Energy plus uses four different sky kinds to calculate daylight factors: clear, clear turbid, intermediate, and overcast, whereas DOE-2 only uses two sky types: explicit and overcast.
2. Energy plus calculates clear-sky daylight factors multiple times a year based on hourly sun-path sun positions, whereas DOE-2 calculates daylight factors for 20 sun positions that span the yearly range of sun positions for a specific geographical region.

A. Scope of the Study

The paper conducted an empirical study aiming to indicating the effect of using Nanogel windows on the Window to Wall Ratio which affects the amount of daylighting and accordingly the energy consumption This is done by comparing the electric lighting, cooling and total energy consumption through the base case with WWR 49% and the improved models with WWR 40% & 20% using the Nanogel windows.

B. Study Area and Model Description

Alaraby Bank, Smart Village, Egypt, was chosen as the study's model building. This building was explored in a prior study undertaken by the researcher with different applications. The building was simulated with Sketch Up and Euclid as a plug in and Energy Plus program for a whole year. It consists of eight conditioned thermal zones [3]. Base Case was the name given to this sample. All data from the building's construction, including fenestration, glazing walls, and roof, as well as the HVAC system, activities, finishing materials, lighting fixtures, and appliances, is incorporated into the building's modeling.

Double-paned windows are used on the exterior. The external window panes (6mm panel thickness) as shown in Table 2 & 3, have a specific sun protection coating on their inside face (Stop sol silver dark blue), while the internal window panes (8mm thickness) are untreated (clear glass).

Non operable windows were simulated in the exterior walls of the case study building as a base case (WWR about 49% and reaches 78% in two of the ground floor zones). In the South West elevation WWR reaches about 48%, as shown in Figure 5, whereas according to the study, conducted by s.s.shebl, Housing and Building National Research Center, the study evaluates the effect of window to wall ratio (WWR), the results for the commercial sector in Egypt indicated that, WWR up to 20% is preferred to be energy efficient [3]. In addition, it was proven, through a researcher’s prior study, that, the best WWR with respect to energy consumption is 20% which resulted in 4, 57% reduction in the building’s total energy consumption [3].

TABLE 2
BASE CASE FENESTRATIONS CONSTRUCTION
(IN ORDER OF OUTSIDE TO INSIDE) [3]

Type	Blue (outside pane) & Clear (inside pane)
Number of Panes	2
Pane thickness	0.006m & 0.008 m
Air-gap thickness	0.132 m
Conductivity of glass	0.9 W/m-k

This part discusses the effect of reducing the Window to wall ratio to 20%, with its previous illustrated windows construction, on the building performance with concerning cooling and lighting energy consumption

TABLE 3
CHARACTERISTICS OF TYPICAL WINDOW PANELS STUDIED FOR THE BUILDING [16]

Structure		**Light Properties**		**Thermal properties**			**European U g**	**American Standards**		
Coating	Thickness	LT %	LR (EXT)%	EA%	SF%	SC%	W/m²-k	Summer U value W/m²-k	Winter U value	RHG W/m²
Sunergy Dark Blue	6mm	40	6	68	38	.44	4.1	4.59	4.59	327
	8mm	35	6	74	35	.39	4.1	4.54	4.60	300

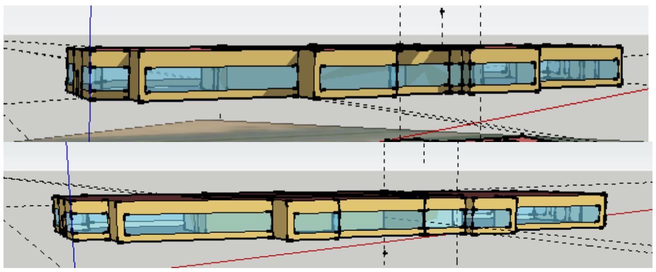
Fig 5: WWR on south west façade [3]

A number of assumptions were made for the study with regard to WWR:

1. The window was designed as a strip window. This gives a uniformity of the light distribution.
2. A working plane of 0.80 meters was used as this is common practice for office buildings.
3. The window wall ratio varies in width and in height.

C. Simulated Building Performance

The graphs shown in Figures 4 to 8 represent simulation results for the base case with the existing glazing system and WWR 49% in comparison to the investigated model with WWR 20%, it is found that:

- *Solar Heat Gains*

Figure 6 represents a comparison between Window Heat Gains through the base case, with WWR 49%, and the other simulated models with WWRs 40%, 20% with the existing glazing system. The figure illustrates that reduction in WWR resulted in reduction in window heat gains reaches 61.48% with WWR 20%.

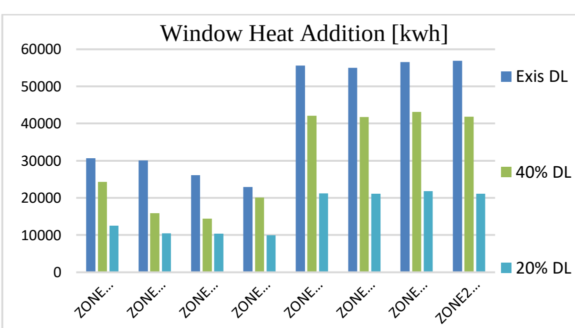

Fig 6 Comparison between window heat gains through different WWRs within the building thermal zones

- *Cooling and Lighting loads analysis*

1. Reduction in WWR (20%) results in a considerable reduction in cooling loads for the building associated to the reduction in widow to wall ratio, and reaches 7.11%
2. As shown in Figure 8, the highest values of reduction in cooling energy consumption are through the overheated period.
3. As shown in Figure 7, Reduction in WWR (20%) results in an increase in lighting energy consumption reaching 29.41%

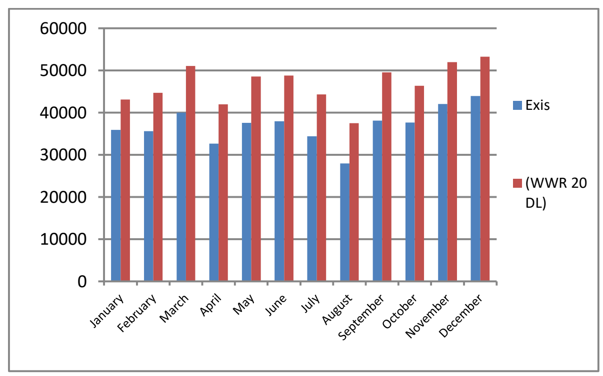

Fig 7 Monthly lighting energy consumption though the existing (49%) and 20% WWRs

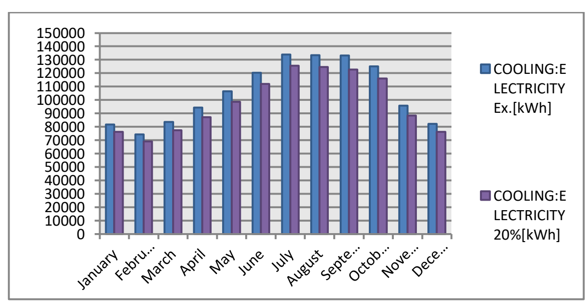

Fig 8 Monthly cooling energy consumption though the existing (49%) and 20% WWRs

- *Total load analysis*

The graphs in Figures 9, 10 represent a comparison between total energy consumption through the base case and the investigated model with WWR 20%, it is found that:
Reduction in WWR (20%) results in a slight reduction in the total energy consumption reaches 0.46% (12582 KWh)

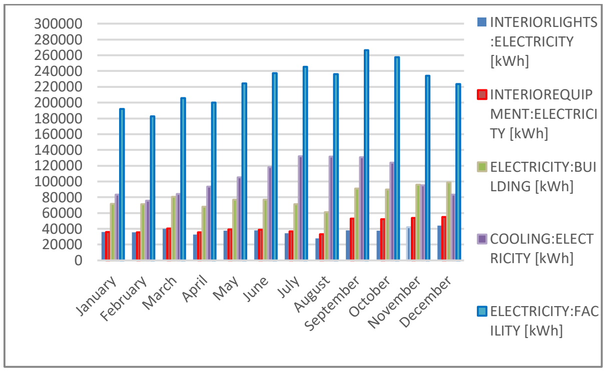

Fig 9 Monthly Total energy consumption though the existing WWRs(49%)

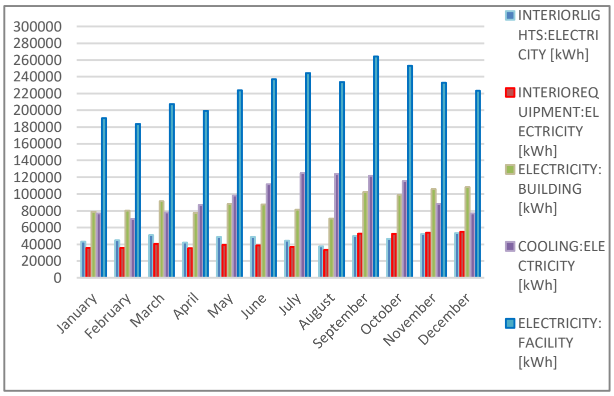

Fig 10 Monthly Total energy consumption though the 20% WWRs

VI. INVESTIGATED GLAZING SYSTEM

In this part, the research investigates the influence of using Nanogel windows (Lumira), with better thermal properties, U value 0.19, LT 38% with thickness 0.25 mm as shown in Table 4, with two window sizes which modeled with a fenestration window-to-wall ratio (WWR) 20% and 40%, where the wall area was defined as the floor to floor height. The thermal performance of window to wall ratio alternatives was evaluated in terms of cooling and lighting energy consumption. Figures (11 to 13) illustrate the difference in WWR between the base case and the other modified three models.

Fig 11 Existing building

Fig 12 Modified building with WWR

Fig 13 Modified building with WWR

TABLE 4
THE PERFORMANCE OF AEROGEL GLAZING SYSTEM [17]

Name	Lumira ® Aerogel Panel 16 mm (clear)	Lumira ® Aerogel Panel 25 mm (clear)
U Value	0.21	0.19
Light Transmission	50%	38%
Solar Heat Gain Coeff. (SHGC)	0.42	0.31
Condensation Resistance Factor (CRF)	G79	G79

A. Load Analysis

In this study; the thermal performance of window to wall ratio alternatives, with the presence of Nanogel windows, was evaluated in terms of cooling and lighting energy consumption. The performance of different alternatives is discussed in comparative form concerning the base case.

- *Solar Heat Gains*

Figure 14 represents a comparison between Solar Heat Gains through the base case, with and without Nanogel windows, and the other simulated models with different WWR with and without Nanogel windows. The figure illustrates that:

The highest portion of solar heat gain is through the base case with the existing glazing system. Although implementing Nanogel windows to the base case resulted in a high reduction in solar gains.

There are significant reductions in solar gains associated with the reduction in WWR with using Nanogel windows (Lumira), which reach about 78% through WWR 20%.

- *Cooling and Lighting Loads Analysis*

The reduction in widow heat gains resulted in reductions in cooling energy consumption. The graph shown in Figure 15 represents Simulation results for the three investigated cases: the base case (WWR 49%) and the other investigated two models with WWR 20% and 40% with and without the Nanogel windows as follows:

Concerning the base Case, implementing Nanogel window resulted in 7.97% (100160 KWh) and 9.14% (114830 KWh) reduction in cooling energy consumption with WWR 40% and 20% respectively.

Regarding electric lighting energy, as shown in Figure 16, there are considerable increase in the electric energy consumption for lighting reaches 8.5% (37608.4 KWh) and 25.8% (114521KWh) with WWR 40% and 20% respectively.

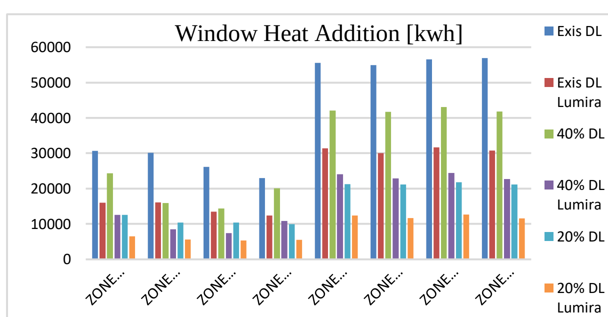

Fig 14 Comparison between window heat gains through different WWRs within the building thermal zones

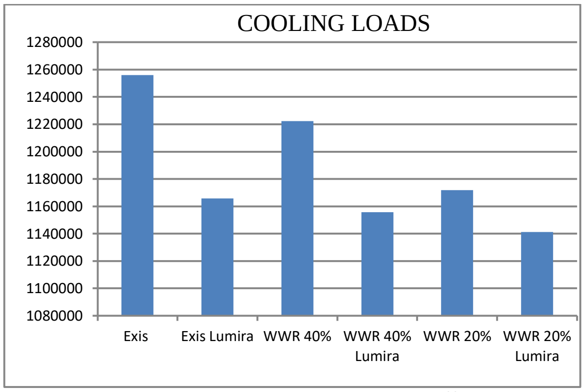

Fig 15 Comparison between cooling loads with different WWRs with and without Nanogel windows

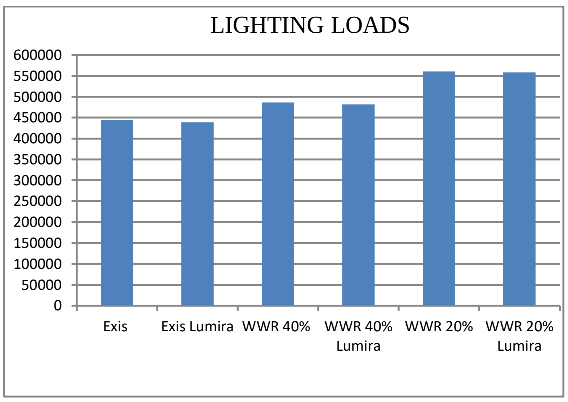

Fig 16 Comparison between Lighting loads with different WWRs with and without Nanogel windows

- Total Load Analysis

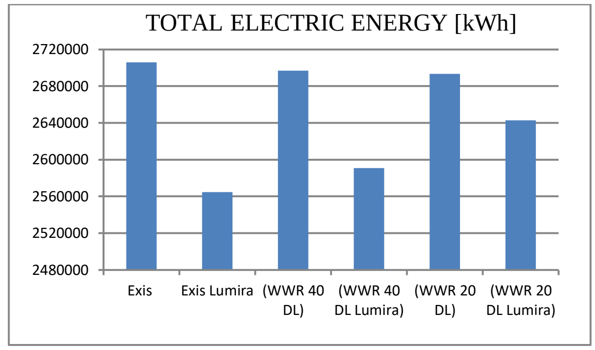

Fig 15 Comparison between total electric energy with different WWRs with and without Nanogel windows

- Reductions in the annual electric energy consumption, Figure 15, reach 4.26% (115193 KWh), and 3.7% (63194 KWh) with WWR 40% and 20% respectively.
- As shown in Table 5, comparing the investigated model with WWR 40% to the base case with WWR 49% on Nanogel windows it is found that:
- Cooling loads decreased by 0.85% (9956 KWh) whereas lighting loads increased by 8.9% (42834.4 KWh) whereas the annual electric energy consumption increased by 1.03% (26351 KWh)
- Implementing Nano-gel windows (Lumira) to the base case with WWR 49%: resulted in 5.23% (141454 KWh) reduction in annual electric energy consumption, 7.18% (90204 KWh) in cooling energy consumption, and 1.71% (5226KWh) reduction in the electric lighting energy.

TABLE 5
THE PERFORMANCE OF AEROGEL GLAZING SYSTEM [10]

Case	Cooling (KWh)	Cooling loads Energy Saving (%)	Interior Lights (KWH)	Lighting loads Energy Saving (%)	Annual Energy (KWH)	Energy Saving (%)
Base case WWR 49% with Nanogel window	1165780	7.18%	438593.8	1.71%	2564560	5.23%
Base case WWR 49% with existing glazing	1255984		443819.8		2706104	
WWR 40% with Nanogel window	1155824	7.97%	481428.2	-8.47%	2590911	4.26%
Base case WWR 49% with existing glazing	1255984		443819.8		2706104	
WWR 20% with Nanogel window	1141154	9.14%	558340	-25.8%	2642910	2.33%
Base case WWR 49% with existing glazing	1255984		443819.8		2706104	

VII. CONCLUSION

Depending on Innovative nano-based transparent materials for more excellent heat resistance have attracted much interest because of their remarkable thermal qualities. The research highlighted Aerogel as a nanomaterial with the potential to be used in high-efficiency windows. Nanogel window is one of the most energy efficient windows because of their high thermal insulation coefficient and light transmittance.

The paper investigated the potential contribution of Nanogel windows to increase the Window to Wall Ratio WWR as a significant factor affecting cooling and lighting energy consumption compared to the existing window glazing system through a simulation process as follow:

Two developed models were investigated in addition to the base case: 40% and 20% WWR

The comparison between the base case, 49% WWR, with and without Nanogel window to the other investigated models indicates that concerning the lighting and cooling energy consumption, the WWR 49% (the base case) is the best ratio with using Nanogel windows. It is found that, there is a considerable reduction in the building energy consumption reaches 7.18% (90204 KWh), 1.71% (5226 KWh) and 5.23% (141544 KWh) reductions in cooling loads, electric lighting and the total energy consumption respectively.

It is concluded that, Nanogel windows could be an effective alternative to conventional window solutions in terms of daylighting and energy consumption. Nanogel windows have a positive effect on the WWR, it has the potential to increase the percentage of the window, and the best ratio with using this technology is WWR 49%. The best WWR was chosen based on the least amount of energy consumed while maintaining a certain degree of lightning.

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Arabic Title

تأثير استخدام الزجاج القائم علي النانو علي نسبه الفتحات الي الحائط من منظور الاضاءه الطبيعيه واستهلاك الطاقه

Abstract in Arabic:

تسهم الإضاءة االصناعيه بنسبه كبيره في إجمالي استهلاك الطاقة الكهربائية. لا يقتصر تأثير طاقه الاضاءه على الاستهلاك لمصابيح الإضاءة فقط بل يساهم شكل كبير قي زياده الحمل الحراري للمبنى. تعد نسبه النافذه الي الحائطWWR وكذلك نظام التزجيج من أهم العوامل التي تؤثر على الإضاءة الكهربائية واستهلاك طاقة التبريد للمبنى. يؤدي الخفض في نسبه النافذه الي الحائط الي خفض الحرارة الشمسية المكتسبه ، وبالتالي خفض في استهلاك طاقة التبريد ، الا انه يؤدي الي زيادة في استهلاك طاقة الإضاءة.

تتمتع نوافذ Nanogel كنوافذ عالية الكفاءة في استخدام الطاقة بإمكانية أكبر لتحسين الأداء الحراري وضوء النهار في قطاع النوافذ نظرًا لمعامل العزل الحراري العالي.

الهدف الرئيسي من هذه الورقة هو مناقشة فعالية تطبيق الابتكارات والتقنيات الحديثة في أنظمة الزجاج (نوافذ Nanogel) من منظور الاضاءه الطبيعيه واستهلاك الطاقة مع نسب مختلفه للفتحات بالنسبه للحائط الهدف النهائي هو تحديد نسبه النافذه الي الحائط المناسبة مع استخدام هذه التكنولوجيا لمباني المكاتب في مصر.

تم إجراء محاكاة باستخدام Energy Plus لمبنى إداري مع استخدام زجاج Nanogel بنسب مختلفةٍ من النافذة إلى الحائط (WWR)، 20٪ ، 40٪ ، و 49٪ (الوضع القائم) ، بالمقارنةً بالزجاج الموجود. لقد وجد أنه فيما يتعلق بالإضاءة واستهلاك طاقة التبريد ، فإن 49 WWR٪ (الوضع القائم) هي أفضل نسبة مع استخدام نوافذ Nanogel.، حيث نتج عن ذلك انخفاض كبير في استهلاك الطاقة للمبنى يصل إلى 7.18٪ (90204 KWh) و 1.71٪ (5226 KWh) و 5.23٪ في أحمال التبريد والإضاءة الكهربائية وإجمالي استهلاك الطاقة على التوالي.