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# دراسة جدوى استخدام زجاج النانو وزجاج متغير الحالة (PCM) في المباني الإدارية

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الملخص

يستهلك قطاع المبانى حوالى ٤٠ % من اجمالى استهلاك الطاقة فى العالم و من المتوقع ان تصل هذة الزيادة الى اكثر من ٥٠٪ عام ٢٠٥٠. تنفذ المبانى الإدارية على المستوى المحلى فى مصر، خاصة المتعددة الطوابق بواجهات زجاجية مما يزيد الاكتساب الحرارى بداخل المبنى مع ارتفاع درجات الحرارة بمصر ، فبالتالى تسبب زيادة فى استهلاك التكييف المركزى بغرض التبريد مما يزيد الاستهلاك السنوى للمبنى .مؤخرا و مع تطور مواد النانو فى البناء يمكن استخدامها كبديل للنوافذ المزدوجة و الواجهات التقليدية المستخدمة فى مصر بهدف تقليل الاستهلاك السنوى للطاقة و تحسين اداء المبنى مع المحافظة على الناحية الجمالية و الوظيفية للمبنى.الدراسة تمت على مبنى إدارى متعدد الطوابق فى القرية الذكية فى مصر لدراسة مدى جدوى مواد النانو مثل زجاج النانو و زجاج متغير الحالة (PCM) قدرتهم على تقليل الاستهلاك السنوى للطاقة مع الاخذ فى الاعتبار دراسة الجدوى الاقتصادية على المدى البعيد .الدراسة و النتائج تمت عن طريق استخدام برنامج (DesignBuilder)لعمل مقارنة بين مواد النانو و الزجاج الثنائى التقليدى المستخدم و تاثيرهم على الاستهلاك السنوى للطاقة للمبنى الإدارى. اظهرت نتائج الدراسة ان زجاج النانو قلل الاستهلاك السنوى للطاقة بنسبة ١١,٧٪ بينما قلل . زجاج متغير الحالة ( PCM) الاستهلاك السنوى للطاقة بنسبة ١٠,٨٦٪.بناء على النتائج و الجدوى الاقتصادية يعتبر زجاج النانو البديل الاكثر كفاة من حيث استهلاك الطاقة و جدوى التكلفة.

*الكلمات الدالة: العزل الحرارى، الواجهات الزجاجية، استهلاك الطاقة للمبانى الادارية، زجاج النانو،*

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study findings will encourage the implementation of nano glazing in Egypt in any highly glazed buildings not just office buildings, to improve their energy performance & internal thermal comfort for occupants.

## 6. REFERENCES

[1] U.S Energy Information Adminstration. Annual Energy Outlook 2014 with projection to 2040.[Internet]2014.[Cited 2019 May 1];Available from:https://www.eia.gov/outlooks/aeo/pdf/0383(2014).pdf
[2] Egypt Electricity Consumption. [Internet] 2019. [Cited 2019 March 5] ;Available from: https://www.indexmundi.com/g/g.aspx?v=81&c=eg&l=en
[3] B.Hanna G.Energy Analysis for New Office Buildings in Egypt.International Journal of Science and Research (IJSR) 2015; 4(1):554-560.

[4] Casini M.Smart Buildings:Advanced Materials and Nanotechnology to Improve Energy-Efficiency and Environmental Performance .Cambridge:Woodhead Publishing;2016.

[5]Abdul Mujeebu M,Ashraf N and Alsuwayigh A.Energy performance and economic viability of nano aerogel glazing and nano vacuum insulation panel in multi-story office building.Energy journal 2016;113;949-956.

[6] Huang Y and Niu J. Energy and visual performance of the silica aerogel glazing system in commercial buildings of Hong Kong. Constr Build Mater 2015;94:57-72.

[7]Addington D.Michelle and L.Schodek D. Smart Materials and New Technologies For architecture and design professions. Oxford: Elsevier Architectural Press;2005.

[8] F. Goia M. Perino and V. Serra. Experimental analysis of the energy performance of a full-scale PCM glazing prototype, Sol. Energy 100 (2014) 217–233.

[9] Kalnæs, S and Jelle,B.2015.Phase change materials and products for building applications: A state-of-the-art review and future research opportunities.Energy and Buildings 2015.(94);50-176.

[10] DesignBuilder - Simulation Made Easy. [Internet] 2019Available from:https://designbuilder.co.uk//[Cited 2019 January 27].

[11] Westphal,F and Lamberts R.BUILDING SIMULATION CALIBRATION USING SENSITIVITY ANALYSIS. Ninth International IBPSA Conference .Montréal, Canada.2005.

[12] Saint-Gobain.PLANITHERM TOTAL+. [Internet] 2019. [Cited 2019 March 5];Available from:http://eg.saint-gobain-glass.com/product/1658/planitherm-total.

[13]Glass X Crystal North America.Glass X Crystal. [Internet] 2019. [Cited 2019 March 5];Available from: https://www.glassxpcm.com/products/glassx-crystal/

[14]Kalwall Corporation. K A L W A L L ® high performance translucent building systems. [Internet ]2016[Cited 2019 March 5];Available from:https://www.kalwall.com/wp-content/uploads/2016/09/kalwall_facade-brochure-1.pdf

Based on the simulation results, it is obvious that the most energy-efficient alternative for the existing double glazing is Case 1 Nano Aerogel window as it caused an annual total energy saving of 11.71 %.

### 4.4. Cost Analysis

Based on simulation results, smart glazing systems showed a significant thermal performance as alternatives for conventional double glazing systems in addition to their ability of annual energy consumption reduction. Despite smart glazing systems advantages still, their economic feasibility should be studied. Therefore, a cost analysis was performed which include the price of each material in United States Dollar per square meter (USD/m2), the annual energy saving of each glazing case ($USD/year), and the payback period. Considering the total area of glazing surfaces is 1707 m2.The prices were obtained from each material internal manufacturer website & brochure.

Cost analysis is illustrated in (Table 8).According to the cost analysis summary, Nano Aerogel window has the lowest payback period of 35 years, while Glass X has payback period 41-62 years. This indicates that the Nano Aerogel glazing is most economically feasible alternative for the current study of the office building.

Table 8.Cost Analysis Summary [11] [12] [13]

| Glazing system | Material Cost (USD/m2) | Annual Energy consumption (kWh/year) | Annual Energy saving (kWh/year) | Annual Energy saving (USD/year) ($0.064) | Life Span | Payback period (No. of years) |
|---|---|---|---|---|---|---|
| 1. Double glazing **(Base Case)** | $208/m2 | 2,408,148 | --- | --- | Only if damaged/ replaced | ---- |
| 2.Nano Aerogel window | $375/m2 | 2,126,154 | 281,994 | 18,047.62 | Only if damaged/ replaced | 35 |
| 3.PCM (Glass X Crystal) | $400-600/m2 | 2,146,624 | 261,524 | 16,737.53 | Only if damaged/ replaced | 41-61 |

*Note:*-The payback period is considered long due to the relatively cheap electricity cost (kWh) of Egypt compared to other countries.

- The Material cost (USD/m2) in addition to (USD value) listed is the average of 3 months (February-May) as the price of (USD) & material can vary slightly.

## 5. CONCLUSION

The study investigated and tested the impact of Nano aerogel window & (PCM) glass as smart alternatives to conventional double glazed panels of multi-storey office buildings located in Egypt which is a Hot-Arid zone. The study assessed the smart glazing impact on the annual energy consumption in addition to their economic viability on the long term period. The simulation results revealed that Nano aerogel window & (PCM) window reduced the annual energy consumption by 11.7% and 10.86% respectively, which are considered relatively close percentages. The cost analysis revealed that Nano aerogel window is the most economically viable alternative for conventional double glazed window while (PCM) window is not cost-effective.

It is highly recommended to integrate Nano aerogl window in multi-storey office buildings in Egypt for being energy-efficient and cost –effective alternative for conventional double glazed facades. The

(PCM) glass ,(Glass X Crystal ) reduced the annual energy consumption to 2,146,624 (kWh/year) ,approximately 10.86 % of the total energy consumption as illsutrated in (Fig. 7).

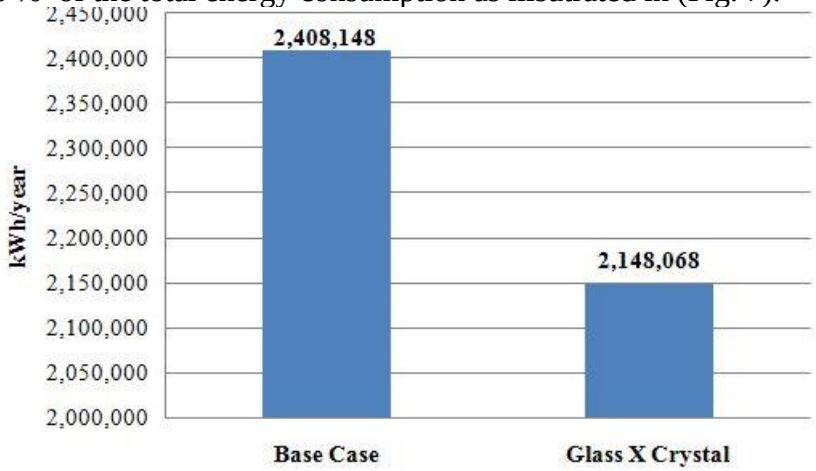



Fig.7. Comparison between the annual energy consumption of Base Case & (Glass X Crystal) glass panel

### 4.3. Comparative Analysis of the Annual Energy Consumption of Glazing panels Cases

Based on the simulation results, the annual energy consumption comparative analysis of glazing alternatives including Nano Aerogel window & Glass X compared to (Base Case) double glazing is illustrated in (Fig. 8).

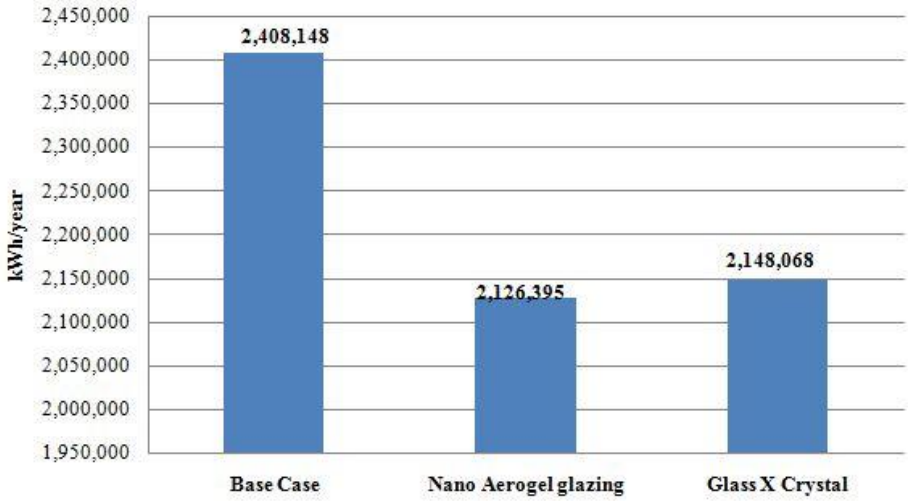



Fig. 8.Annual energy consumption comparison of smart glazing panels compared to existing double glazing

- In Case 1 Nano Aerogel glazing, reduced the Base case (U-value) from 1.464 (W/m2k) to 0.30 (W/m2k) ,with external glass panel total thickness of 50 mm, which reduced the total annual consumption from 2,408,148 to 2,126,154 (kWh/year), approximately 11.71 % reduction in annual energy consumption.
- In Case 2 PCM (Glass X Crystal) , reduced the Base case (U-value) from 1.464 (W/m2k) to 0.48 (W/m2k), with external glass panel total thickness of 70 mm, which reduced the total annual consumption from 2,408,148 to 2,146,624 (kWh/year) ,approximately 10.86 % reduction in annual energy consumption.

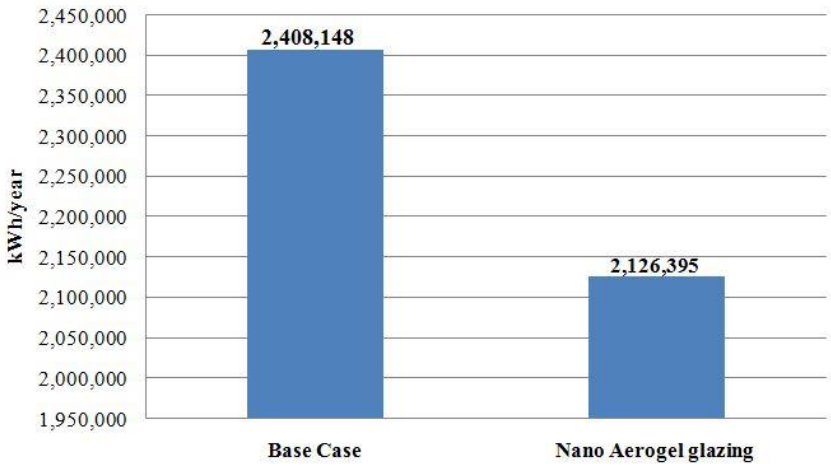



Fig. 6.Comparison between the annual energy consumption of Base Case & Nano Aerogel glazing panel

### 4.2. Glass X

The simulation specifications of (PCM) glazing ,(Glass X Crystal) is illustrated in (Tables 7 &8).

Table 7.Glass X Crystal glazing panel layers specifications calculated by DesignBuilder software**[14]**

| | Layer Name | Thickness (mm) | Thermal Conductivity (W/mk) | Solar Transmittance | Visible Transmittance |
|---|---|---|---|---|---|
| **1** | Tempered safety glass | 6 | - | - | - |
| **2** | Argon gas gap | 13 | - | - | - |
| **3** | Tempered safety glass with Low-E | 6 | - | - | - |
| **4** | Argon gas gap | 13 | - | - | - |
| **5** | Tempered safety glass | 6 | - | - | - |
| **6** | Air Gap between panes with (PCM) plate | 20 | - | - | - |
| **7** | Tempered safety glass | 6 | - | - | - |

Table 8.Glass X Crystal glazing Calculated values by DesignBuilder software

| Calculated Values (DesignBuilder software) | |
|---|---|
| **Total Thickness (mm)** | 70 |
| **Total solar transmission (SHGC)** | 0.339 |
| **Direct solar transmission** | 0.338 |
| **Light transmission** | 30% |
| **U-Value (W/m2k)** | 0.48 |

#### 4.2.1. Annual Energy Consumption

Table 3. Base Case Glazing layers specifications calculated by DesignBuilder software**[12]**

| | Layer Name | Thickness (mm) | Thermal Conductivity (W/mk) | Solar transmittance | Visible transmittance |
|---|---|---|---|---|---|
| **1** | Tinted glass | 6 | 1.00 | 0.44 | 0.58 |
| **2** | Air gap | 12 | --- | ---- | ---- |
| **3** | Clear Glass | 6 | 0.90 | 0.77 | 0.88 |

Table 4. Base Case Glazing values specifications calculated by DesignBuilder software

| Calculated Values (DesignBuilder software) | |
|---|---|
| Total Thickness (mm) | 24 |
| Total solar transmission (SHGC) | 0.48 |
| Direct solar transmission | 0.37 |
| Light transmission | 50% |
| U-Value (W/m2k) | 3.157 |

## 4. RESULTS

### 4.1. Nano Aerogel Window

The simulation specifications of Nano aerogel window is illustrated in (Tables 5 & 6).

Table 5. Nano Aerogel glazing panel layers specifications calculated by DesignBuilder software**[13]**

| | Layer Name | Thickness (mm) | Thermal Conductivity (W/mk) | Solar Transmittance | Visible Transmittance |
|---|---|---|---|---|---|
| **1** | Tinted glass | 5 | - | - | - |
| **2** | Argon gas | 12 | - | - | - |
| **3** | Nano silica Aerogel | 16 | - | - | - |
| **4** | Argon gas | 12 | - | - | - |
| **5** | Clear Glass | 5 | - | - | - |

Table 6 .Nano Aerogel values calculated by DesignBuilder software

| Calculated Values (DesignBuilder software) | |
|---|---|
| Total Thickness (mm) | 50 |
| Total solar transmission (SHGC) | 0.26 |
| Direct solar transmission | 0.48 |
| Light transmission | 21% |
| U-Value (W/m2k) | 0.30 |

#### 4.1.1. Annual Energy Consumption

Nano Aerogel glazing panel, reduced the annual energy consumption to 2,126,154 (kWh/year), approximately 11.71 % of the total energy consumption as illsutrated in (Fig. 6).

The model (Base Case) was performed using DesignBuilder Software version (6.0.1). The main advantage of DesignBuilder as a thermal simulation tool, is its ability to evaluate and compare between building materials or design criteria alternatives to apply the most efficient alternative for more energy consumption reduction for the given or existing building (Base case) [10]. The model was divided into several blocks, representing each floor to form the four elevations of the office building, representing the office building envelope (Glazing, roof & external wall) as illustrated in (Fig.4).

Energy simulation conducted by DesignBuilder has been compared to the actual monthly & annual energy bills of (ECG) to verify that the simulation is being conducted correctly and have a realistic output results with minimum errors. The results in (Fig.5) show the slight difference, approximately (2.2%) between the simulation results & actual energy consumption bills, which is considered an acceptable percentage [11].

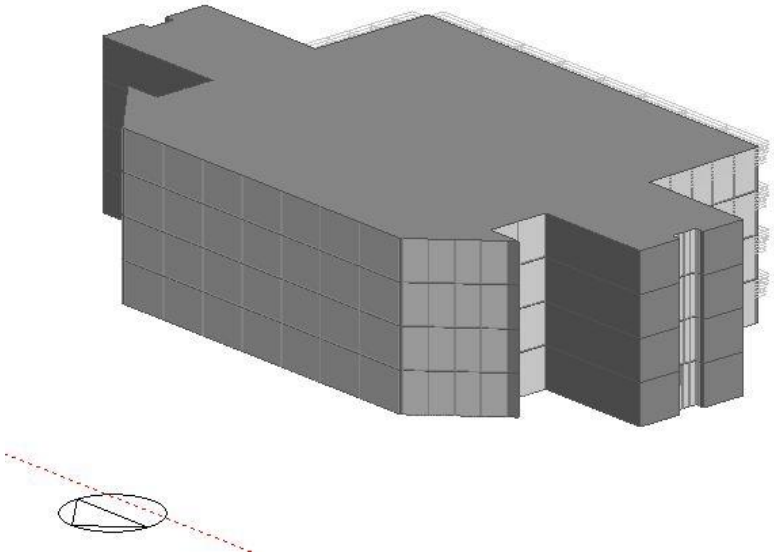


Fig. 4.Base Case shot for (ECG) office building.

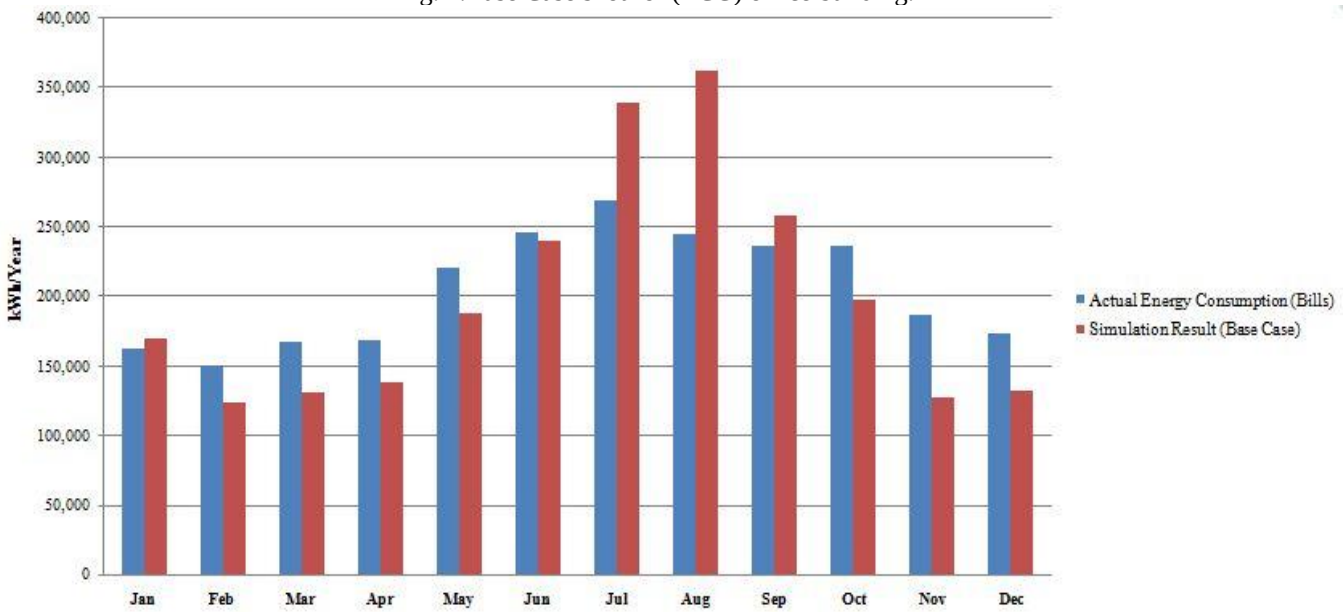



Fig. 5.Comparison between monthly simulation result and the actual energy consumption bills of (ECG)

The existing double glazing (Base Case) specifications are illustrated in (Tables 3 & 4)

Glass X allows natural daylight transmittance to provide natural daylight in internal spaces for better visual comfort especially in office buildings. Glass X panel is about 79 mm thickness and has thermal conductivity of 0.48 (W/m2k) .Glass X specifications are illustrated in (Table 1).

In 2014, a study was conducted to perform a test on a Glass X integrated in the south glazed façade of office building located in a sub-continental climate and compared the results to the conventional double glazing. The results showed that Glass X reduced the heat gain in summer moths by more than 50% [8]. "Sur Falveng" ,a zero-energy efficient office building in Switzerland was constructed by Glass X glazing system which resulted in total annual energy saving of 23.9% [9]. Despite the multiple advantages of (PCM) glazing regarding energy efficiency, the main disadvantage is its relatively high cost compared to other glazing systems.

Table 1 .Glass X specification [4]

| Thermal and luminous parameters | Values |
|---|---|
| *U* (max) | 0.48 W/m$^2$ K |
| Visible light transmission (VLT) (PCM in crystalline state) | 8–28% (±3%) |
| VLT (PCM in liquid state) | 12–44% (±4%) |
| Diffused VLT | 29% |
| Solar heat-gain coefficient (SHGC), winter months, crystalline PCM | 33% |
| SHGC winter months, liquid PCM | 35% |
| SHGC summer months, crystalline PCM | 6% |
| SHGC summer months, liquid PCM | 9% |
| Accumulation capacity | 1185 W h/m$^2$ |
| Accumulation temperature | 26–28°C |
| Maximum size | 3000 × 2000 mm |

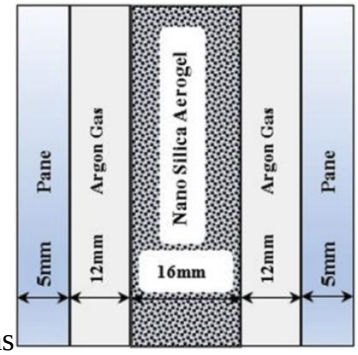
## 3. METHODOLOGY

The study was conducted on a multi-storey office building located in Smart village, Egypt. The aim of the case study was to assess ability of smart materials in terms of smart glazing including Nano Aerogel & (PCM) in reducing the annual office building energy consumption & cost. The office building specifications are illustrated in (Table 2).The energy simulation was conducted by DesignBuilder software. A whole year simulation was assessed to investigate Nano & (PCM) glazing impact on the annual energy consumption. A cost analysis was also conducted to investigate the feasibility of applying such glazing on the long term period in terms of cost effectiveness.

Table 2.Case study specification

| Aspect | Specification |
|---|---|
| Completion Date | March 2010 |
| Building Size | 15,538 m2 Gross Internal Area (GIA) ,(8,505 above ground & 7,033 m2 underground parking). |
| Total glazed facades area | 1707 m2 |
| Number of floors | Ground floor,3 floors above ground & 2 underground floors (basements). |
| Floor Height | 3.8 meters |
| Office hours | 7.30 a.m-5 p.m |
| Windows | Double glazed windows |
| Annual Energy consumption (EGP) | 2,462,489 (kWh), (Calculated in 2018) * |
| Annual Cost of energy consumption (EGP) | 2,418,125 EGP/Year* |

*Maintenance Department, Engineering Consultants Group (ECG),Smart Village, Egypt




as

Fig. 2. Nano Aerogel window panel section [5]

A lot of researches investigated their ability concerning their thermal performance when applied to building envelope glazed facades. In 2015; a study was conducted to study the thermal and optical properties of nano aerogel glazing system applied in a commercial building in humid subtropical climate. The results showed that nano aerogel glazing reduced the annual cooling load by 4% and reduced the building envelope heat gain by 60 % [6].In 2016; a study was conducted to study the application of nano aerogel glazing in multi-storey office buildings in Saudi Arabia. The results showed that nano aerogel glazing panels reduced the annual energy consumption by 14% [5].Despite the multiple advantages of aerogel glazing regarding energy efficiency ,the main disadvantage is its relatively high cost compared to other glazing systems.

**B. Phase Change Material Glazing**

Phase change material (PCM) is a smart material which undergoes phase changes as gas liquid or solid. These phase transformation is a result of change in pressure or temperatures which cause the material to transform form one phase to another. Phase change glass mainly absorb, store and release the trapped solar energy in form of latent heat . (PCM) glass usually undergoes phases change and vice versa at an average temperature of 23 °C [7]. (PCM) glass is known as Glass X. Glass X is a triple glass unit integrating a (PCM) thermal insulating layer, which can be applied in any glazed facades to provide the maximum thermal insulation compared to conventional double glass panel. Glass X has the potential of reducing the over-all annual energy consumption for heating & cooling needs by reflecting solar radiation in summer & storing it in winter in the (PCM) layer integrated in the glass panel as illustrated in (Fig.3) Glass X can undergo several phase transformation without degradation or being damaged and it is available in several sizes to fit any constructions [4].

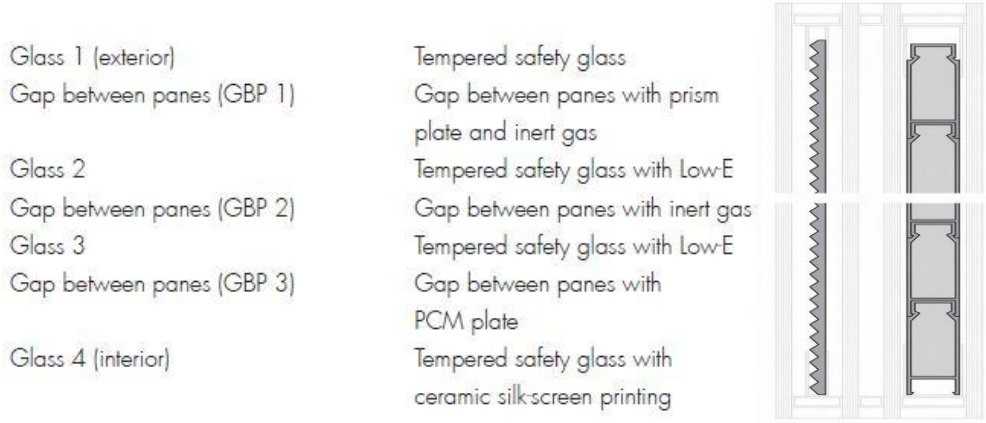



Fig.3. Glass X (PCM) glazing section [4]

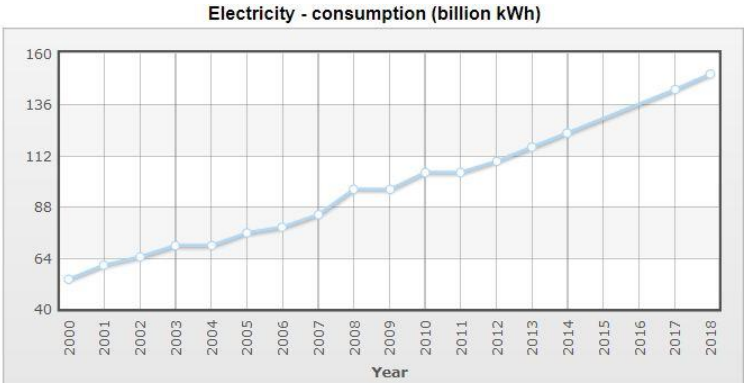



Fig 1. Egypt Electricity consumption from 2000-2018 [2]

Moreover, office buildings face the problem of low energy efficiency and wasted energy as the majority of multi-storey office buildings are built in curtain walls and glazed façades which result in increasing the heat gain especially in the summer (June-September) internally leading to increasing the HVAC energy consumption for cooling needs [3]. The increased energy consumption leads to depletion of non-renewable energy sources & economic resources' in addition to carbon emissions. Recently, new technologies as nanotechnology offered new potentials towards inventing new smart materials that can be applied in building envelope as alternatives to conventional building materials and glazed panels for their ability of energy efficiency, improving building energy performance and protecting the environment as they are environmentally friendly materials [4]. The nano aerogel window & phase change materials (PCM) glass has proved their ability of providing high thermal insulation as alternatives to conventional glazing panels & their ability of reducing the annual energy consumption.

## 2. LITERATURE REVIEW

### A. Nano Aerogel Glazing

Aerogel was discovered by Samuel Kistler in 1931.It is a material made from nanometer-scale particles, consisting mainly of air and gel, its porosity is more than 90% and usually described as "Frozen smoke" or "Blue smoke" as a result of its transparency [4]. Aerogel is applied in several fields but mainly used as thermal insulation material. Aerogel include Nano silica Aerogel is which is considered an energy-efficient alternative for conventional glazing panels regarding thermal insulation. Nano silica aerogel ,known as (Nano window) ,can be applied in skylights & glazed facades to conserve the aesthetic quality and provide the appropriate daylight transmittance at the same time ,which is required in office buildings, without causing any excessive heat gain in internal space. Nano aerogel windows can significantly reduce the annual energy consumption as it has high thermal conductivity of 0.3 (W/m2k) and total thickness of 50mm as illustrated in (Fig.2) [4].The leading manufacturing company for these types of windows is Kallwall Corporation located in United States of America [4] .

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# ECONOMIC FEASIBILITY OF NANO AEROGEL GLAZING & PHASE CHANGE MATERIAL GLAZING IN OFFICE BUILDINGS

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## ABSTRACT

The building Sector is currently responsible for approximately 40% of global world energy consumption and still expected to increase by 50% in year 2050.In Egypt, most multi-storey office buildings have curtain walls facades which result in increasing energy consumed by HVAC systems for cooling needs, especially as Egypt is located in Hot-Arid Zone. Recently, nano materials offered new potentials towards reduction of the annual energy consumption if applied as alternatives, in curtain wall or glazed facades. The study was addressed in multi-storey office building in smart village, Egypt to investigate nano materials (Nano aerogel window & Phase Change material glazing) application in the office building glazing to study their impact on annual energy consumption performance compared to the existing conventional double glazing panels. The office building energy simulation was simulated by DesignBuilder Software Version (6.0.1).A cost analysis was conducted to assess these nano materials alternatives economic feasibility on long term period. The simulation results showed that Nanogel Aerogel glazing reduced the annual energy consumption by 11.71 % while Phase change material (PCM) glazing reduced the annual energy consumption by 10.86 %.For the current office building, the most efficient alternative in terms of energy consumption and cost-effectiveness is Nano Aerogel glazing.

*KEYWORDS: Thermal insulation, Glazed facades, Office buildings energy consumption, Nano Aerogel glazing, Phase change material Glazing*

## 1. INTRODUCTION

The continuous increase of energy consumption became an international threat to economy, society and environment as it cause critical environmental consequences as global climate change. According to the U.S Energy information Administration (EIA), the building sector is responsible for approximately 40% of total energy consumption consumed in United States, commercial buildings including office building consume about 18% [1].

Locally, Egypt energy consumption is in continuous increase since the last decade. In 2018,the total energy consumption was 150.4 Billion Kilo-watt hour (kWh) compared to 96.2 Billion (kWh) in 2008,which is about 36% increase in the total energy consumption during the last 10 years [2] as illustrated in (Fig.1).

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