Advanced Glazing Technologies for Energy-Efficient Building Envelope

With Reference to the Nano Aerogel Windows

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ABSTRACT

The electric energy consumption for lighting, cooling, heating and ventilating the environment within buildings represents a significant fraction of the energy drain. Building envelope, particularly the transparent elements plays a strategic role in the environmental performance and energy consumption of the building, significantly affecting the levels of indoor comfort. In recent years there has been rapid development in the technology of the building envelope, especially the sphere of glass. This paper aims, through an analytical, comparative study, at providing a review of the scientific literature that deals with the use of advanced glazing technologies, in view of letting architects, engineers, and builders know the scope of these technologies existing in the market and employ them to achieve energy efficiency in buildings. Firstly, the paper reviews existing glazing systems showing their thermal and lighting performance. Then, it investigates the effect of nanotechnology as a revolution technology on these types and its effect on developing high energy efficient windows such as Aerogel windows. Finally, the paper concluded through a comparison between aerogel glazing and the other systems that, aerogel glazing can be a good alternative of glazing to reduce the building energy consumption.

Keywords: Building Energy Consumption, Building envelope, Advanced Glazing Technology, Nanotechnology, Aerogel Glazing window,

Problem

Between 2010 and 2050, global heating and cooling needs are expected to increase by 79 % in residential buildings and 84 % in commercial buildings [(1)]. Energy consumption for cooling is set to increase by almost 150% globally, and by 300-600% in developing countries, by 2050 [(2)].

Introduction

Today the energy consumption in buildings to maintain indoor temperature is being recognized as the main responsible for the energy demand world-wide [(3)]. According to IEA (2013), energy consumption for cooling expected to increase sharply b 2050- by almost 150% globally and by 300 to 600% in developing countries [(1)]. In hot climates with reference to Egypt, and as a consequence of climate change, building cooling needs expected to increase in coming years. The residential and commercial sectors are responsible for more than 50% of the final energy consumption in Egypt. The large environmental impact of the increase in energy consumption behaviors has raised concern about the urgency of promoting the drastic building energy efficiency.

It is well-established that building envelope (glazed and opaque elements) as a thermal and lighting, moderate and Building Materials represent the main contributor to the building energy consumption. Moreover researches have shown that building envelopes contribute more than 50% of the embodied energy distribution in major building elements in residential buildings; it also contributes approximately 50–60% of the total heat gain in buildings [(4)].

Minimizing the cooling needs of a building by appropriate architectural design mainly means minimizing the solar load, since the sun can irradiate surfaces with approximately 500 W-m^2 over a wide range of latitudes, and about 90% of this will pass through a normal pane glass. In addition, solid-state conduction of heat takes place from the hot air outside through the glass.

Consequently, transparent elements have an important role in buildings in terms of energy demand, thermal comfort, and daylighting. Most of the total energy losses (up to 60 %) can depend on the windows; especially in highly glazed buildings (1). Selecting the ideal level of visible light transmission is thus important for visual comfort. This measure may also considerably reduce electricity consumption for artificial lighting (3).

In the context of the building energy efficiency through the building envelope, many studies discussed separately the different types of advanced glazing technologies which have been developed to prevent sun radiation and heat conduction from hot air to reduce cooling loads such as low-E glazing, switchable glazing and recently the use of next-generation products, nano-based transparent materials. The advanced nano-based transparent materials and solutions for improved thermal resistance have been receiving attention due to their significance for reducing energy consumption. Aerogel is one of the most promising nanomaterials for use in highly energy-efficient buildings and windows.

The main objective of this paper is to present an analytical comparative study to point out the development in the transparent building envelope elements. Firstly discussing the various advanced glazing technologies. Then study the recent most promising type, aerogel window, and finally to conclude a comparison between these types.

2- Building Envelope and Energy Consumption

The building envelope is a critical component of any facility since it both protects the building occupants and plays a major role in regulating the indoor environment. The building envelope can be considered the selective pathway for a building to work with the climate—responding to heating, cooling, ventilating, and natural lighting needs. The design of the envelope and, in particular, the selection of insulation and materials can have a major impact on the energy needed to heat and cool buildings. The building envelope is composed of opaque (walls) and translucent (windows) parts. Windows have a double role in the building thermal envelope (5):

• Thermal transmission properties have to be as low as possible in order to reduce energy consumption for heating and air conditioning;
• Light transmission characteristics have to be as high as possible for visual comfort and electric energy saving in illuminating plants, thanks to natural lighting.

Glazed areas of building envelope considered “energy losers” as their use would result in increased energy consumption to substitute the additional cooling or heating loads they add. It can contribute to 22% of energy consumption in residential buildings (6).

According to the Department of Energy of the United States, from 25% to 35% of energy in buildings is wasted due to inefficient windows. The California Energy Commission estimates that about 40% of the cooling demand of a typical building is due to the solar heat gain through windows (7). Therefore, attempts to mitigate heat gain should focus more on window glazing than any other part of a building, especially in buildings with large window-to-wall ratios.

To reduce the flow of heat through the windows, it is found that, acting only on conduction by using multiple-glazing units is insufficient; it is also necessary to intervene in the phenomenon of irradiation. Glass has a high absorption coefficient for wavelengths emitted by bodies at room temperature, and as a consequence has a high emissivity for the same wavelengths (the normal emissivity for uncoated soda-lime glass and borosilicate glass is equal to 0.837) (8).

The traditional widows systems (single float glass, double glazing, or triple glazing) are providing insufficient requirements for energy efficiency for buildings, Fig. (1) Illustrates the thermal transmittance of a single-glazed, double-glazed, and triple-glazed window [8]: the first case, a 5 mm thick float glass, has an Ug transmittance equal to 5.88 W/m2K, while it reduced to be 1,9 for the third case, three 4 mm thick float glass panes and two cavities of 12 mm each (4-12-4e12-4).

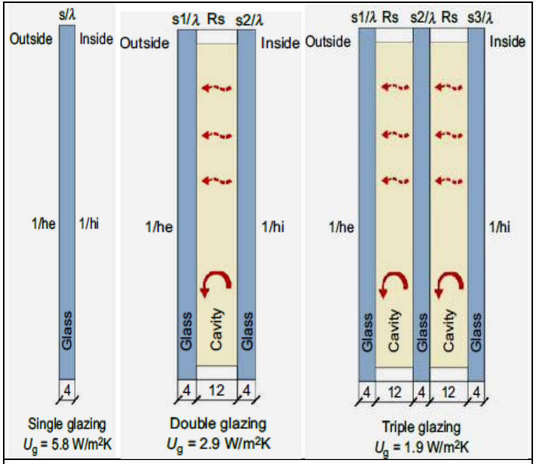

Fig. (1): Thermal transmittance of a single-glazed, double-glazed, and triple-glazed window [8].

The development of the glazed systems, with lower U values, for energy savings is among the compelling topics in the building sector worldwide. There are many advanced technologies in this area as will be discussed through the following part of the paper.

3- Advanced Glazing Technologies

The thermal insulation of transparent closures is a prerequisite in the pursuit of thermal comfort of the interiors and the reduction of energy consumption in buildings. Extensive researches and development have been reported on advanced glazing technologies. The state-of-the-art high-performance glazing technologies can be classified into three groups based on their working principle; solar control (radiation); heat exchange control (conduction); and ventilation control (convection) [9]. The spectrally selective technique aims at regulating VT and solar heat gain coefficient (SHGC) of the glazing unit by active or passive means, which include chromogenic materials or coatings [10]. The following part presents a brief review of the most popular advanced glazing techniques such as advanced low-emission glazing, solar control glass, switchable or chromogenic glazing and the effect of nanotechnology and nanomaterials on these types of glazing systems and finally the nano-silica aerogel as an application of nanomaterials represented in nano aerogel glazing.

3-1-Advanced low-emission glazing

Low-E coatings have been developed to minimize the amount of ultraviolet and infrared light that can pass through glass without compromising the amount of visible light that is transmitted. There are actually two different types of low-E coatings: **passive** low-E coatings and **solar control** low-E coatings. Passive low-E coatings are designed to maximize solar heat gain into a building to create the effect of "passive" heating and reducing reliance on artificial heating. Solar control low-E coatings are designed to limit the amount of solar heat that passes into a building for the purpose of keeping buildings cooler and reducing energy consumption related to air conditioning [13].

3-1-1 Passive Low-E Coatings

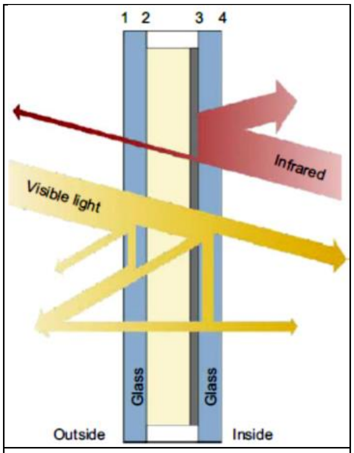

Fig. (2):Double glazing with Low-e coating [8].

Surface coatings with a thickness of 0.01-1 mm can improve the physical properties of glass regarding radiation; depending on the layer thickness and composition, energy transmission (ET) can be reflected or absorbed and emissivity reduced [8]. By coating at least one of the four glass surfaces of a double-glazing unit with a layer of material highly reflective to IR radiation (low-E), it is possible to obtain insulating glazing with high thermal performance. Instead of radiating part of the absorbed heat outward and dissipating it, the glass pane reflects it toward the interior, reducing overall transmittance, as shown in Fig. (2). Thanks to these coatings, low-E glazing reflects toward interiors up to 90% of the radiation produced with a wavelength greater than 2.5 mm, preventing it from escaping, while the transmission of sunlight remains largely unchanged. The coefficient of visible transmission is equal to 70-80% and the SHGC to 50-70% [(8)].

3-1-2 Solar Control Low-E Coatings

Solar control glazing represents the possibility of energy savings for cooling and air-conditioning in buildings since low-E glazing has thermal transmittance values between 1.7 and 1.0 W/m2K for double glazing and values lower than 0.7 W/m2K for triple glazing [(8)]. On the other hand, they could reduce luminance in interiors. Solar glasses offer a modified passage of light and heat energy compared to clear glass of the same thickness as shown in Tab. (1). They can reduce the transmittance of solar radiation into interiors. The reduction of the transmittance is achieved by [(11)]:

- Higher reflectance (reflective and mirror coatings on the surface of the glass pane, thin metal layers with thin dielectric coatings or multilayered dielectric thin films);
- Absorptance (tinted glass, glass with prints, glass with absorbent particles);
- Light scattering (glass with patterned, sandblasted or partly printed or an enameled surface or special glazing with the diffusive component inside of the glass pane).

Tab.1:.Main energy parameters in glazing [(8)]

VLT	SHGC	U_g	VLT	SHGC	U_g	VLT	SHGC	U_g
Double glazing			Double glazing with low-e coating			Triple glazing with low-e coating		
82%	0.78	2.7	80%	0.62	1.1-1.3	70%	0.55	0.6-0.7

Some solar control glass units contain elements made of special reflective louvers fixed in the inner cavity According to a study conducted -on three types of solar control glass- by a computer daylight simulation program WDLS; the internal luminance on a working plan 0.85 m over the floor level was determined by the depth of the room at a distance of 1m and 3m outside of the windows; see Fig. (3)[(11)]

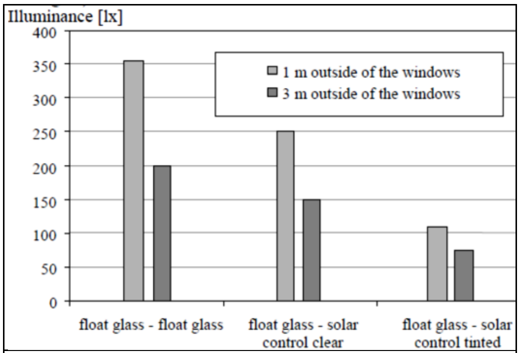

Fig. (3): Comparison of internal luminance on the working plane in the reference room with different window glazing [(11)]

3-2- Switchable or chromogenic glazing

Chromogenic materials belong to the category of smart materials. The use of transparent chromogenic materials in architecture allows transparent envelopes with variable performance, called smart windows, dynamic glazing, or switchable glazing, able to optimize the energy behavior of buildings and at the same time meet the comfort needs of users [(8)]. The idea of switchable or chromogenic glazing is to switch the glazing between transparent, translucent and opaque conditions. The switching is done by means of active or passive materials into the glazing unit, whose function is to reversibly change the light transmission level with resultant variations in VT and SHGC. There are four kinds of chromogenic materials of primary interest for glazing in buildings. They are referred to as ‘Photochromic’, ‘thermochromic’, ‘electrochromic’ and ‘gasochromics’[(8)]; two of them will be discussed as follows:

3-2-1- Thermochromic Glazing

Thermochromic glazing is capable of modifying its optical properties according to the external surface temperature. When a thermochromic glazing reaches the switching temperature, it becomes reflective and prevents UV-radiation to pass through the window, controlling the amount of heat caused by sunlight. For window applications, thermochromism has been made possible by the use of metallic oxide coatings such as vanadium dioxide (VO_2) or tungsten trioxide (WO_3). Another approach is to apply an intermediate gel layer between two layers of glass. A thermotropic gel that has been commercially available since 1995 is Cloud Get. Cloud Gel is an aqueous polymeric solution, which is sandwiched between two external clear plastic films. The gel remains transparent up to a critical temperature, above which it appears white and the polymer chains that make up the gel curl up into balls, reflecting 90 % of the incoming solar radiation [12].

Applied in buildings, thermochromic windows allow optimizing the energy consumption of the building thanks to the high percentage of light transmitted both in the transparent as well as the opaque state. Thermochromic windows automatically modify their transparency and thus their light absorption in relation to their external surface temperature. Initially transparent, above a critical temperature, which may vary from 10 to 90 °C, they become opaque. When the temperature decreases below the critical value, they return to being transparent [12].

Tab.2:.Main Thermochromic Glazing on the Market [8

Temp.	VLT	SHGC	U_g	VLT	SHGC	U_g	VLT	SHGC	U_g
	PLEOTINT SUNTUITIVE CLEAR			INNOVATIVE GLASS SOLARSMART			RAVENBRICK RAVENWINDOW		
Low	60%	0.37	1.36	55%	0.36	1.36	33%	0.28	1.36
High	13%	0.17	Argon	5%	0.12	Argon	5%	0.18	Argon

Advantages of Thermochromic Windows [12]

1- they reduce cooling and ventilation loads in an autonomous mode and eliminate problems of overheating by regulating the solar intake, contributing thus to energy savings;
2- They diffuse the light in a constant and uniform manner, both in the opaque as well as the transparent state;
3- They are simple to apply during building construction, and have low cost and long durability.

Disadvantages of Thermochromic Windows

1- The typical ranges of light transmission and solar heat gain in correspondence of transparent and opaque states when coupled with a clear glass, as shown in Tab. (2), are respectively VLT = 60-13% or 55-5% and SHGC 0,37 to 0.17 Or 0, 36 to 0.12 with switching times in the order of a few minutes;

2- They can only be regulated using electrical circuits printed on the layers which cover the thermochromic film or layer, and some polymeric films have the tendency to turn yellow with time due to UV radiation [12].

3-2-2- Electrochromic (EC) Glazing

Electrochromic (EC) Materials change their optical properties because of the action of an electric field and can be changed back to the original state by a field reversal, Fig.(4) illustrates the construction of an electrochromic foil device.

The major advantages of Electrochromic materials are that they only require power during switching, have a long-term memory (12-48 h), require small voltage to switch (1-5 V), and have the potential for large-area application [11].
Light transmission varies from 60% in the transparent state to 1% when opaque. SHGC is instead comprised between 0.46 and 0.06, as shown in Tab. (3) [13].

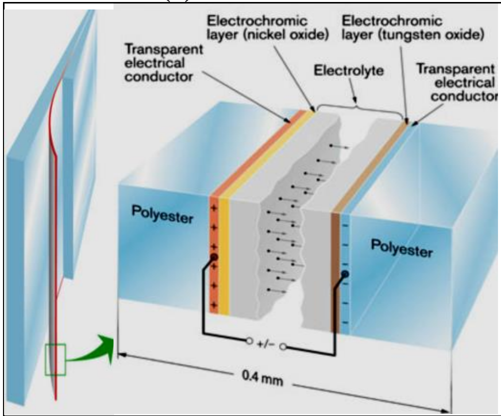

Fig. (4): Construction principle for an electrochromic foil device. The entire foil can be used as a laminate between two glass panes [1].

Electrochromic windows have shown a 54 % energy reduction in Electrochromic windows when compared to standard single-glazed windows for a 25 year life cycle [1]

Tab. 3:.Main Electrochromic Glazing on the Market[8]

Tinted state.	VLT	SHGC	U_g	VLT	SHGC	U_g	VLT	SHGC	U_g
	GUARDIAN SUNGUARD EC (Low-e)			VIEW DYNAMIC GLASS			SGG SAGEGLASS		
0	50%	0.34	1.10	58%	0.46	1.64	60%	0.41	1.64
1/3	35%	0.24	Argon fill	40%	0.29	Argon fill	18%	0.15	Argon fill
2/3	18%	0.13		20%	0.16		6%	0.10	

4- Nanotechnology in Glass Materials

Nanotechnology is an enabling technology that allows developing materials with improved or totally new properties. Nanotechnology is being used in several applications to improve the environment. Application of nanotechnology in materials which would store and release heat energy based on the thermal load demand in buildings is inexorable [1]. It can significantly enhance the performance of building materials, adding useful properties, such as smart windows, and super-insulation materials. Nanomaterials are a field which takes a materials science-based approach to nanotechnology.

Many glass materials, especially those developed in the second half of the 20th century, are essentially nanocomposites since they contain a nanosize component. Nanostructured materials as aerogels could be suitably employed in highly insulating windows and in the last 15 years windows based on translucent granular or monolithic aerogels were developed by companies in cooperation with researchers. Aerogel is a highly porous nanostructured and light material, with many particular properties that attracted the attention of researchers in various areas of science and technology, and also for building applications [5].

5- Applications of Nanotechnology for Windows Glass

The application of nanotechnology has major importance in providing solutions which contribute to the reduction in energy consumption, especially in construction materials such as glass systems which help in reducing heat transfer through the building envelope. Literature reviewing illustrates that nanotechnology has a significant impact on the advanced glazing technologies (efficient glazing systems, as will be discussed); and there are many alternatives nano-based glazing systems. Aerogel glazing technology has attracted a great deal of attention, which is the focus of this paper. Aerogel is one of the most promising nanomaterials for use in highly energy-efficient windows: it is a highly porous nanostructured material, with a very low thermal conductivity (down to 0.010 W/m K in vacuum conditions), and good optical transparency (light transmittance).

5-1 Low E Coatings

Today, low-E coatings may even take advantage of nanotechnology, employing coatings obtained by layered deposition of nanoparticles of metallic oxides and nitrides via magnetic-enhanced cathodic sputtering under vacuum conditions (Saint-Gobain SGG Nano). Furthermore, while gold-based reflective coating technology is very expensive for window glazing and is not color neutral, new nanomaterials offer gold nanoparticles coatings with optimized reflectance and color [8].
Metal or metallic nanoparticles with controlled properties (i.e. size, shape and surface) have been extensively studied for several decades, including those typical low-E materials such as silver (Ag), gold (Au), and transparent conductive metal oxides.

5-2- Switchable or chromogenic glazing

Electrochromic Glazing was previously available on the market, but has since largely disappeared due to two main disadvantages: a constant electric current was necessary to maintain a darkened state and larger glass surfaces often exhibited optical irregularities. The advent of nanotechnology has provided a new means of integrating electrochromic glass in buildings. The primary difference to the earlier product is that a constant electric current is no longer necessary. A single switch is all that is required to change the degree of light transmission from one state to another, i.e. one switch to change from transparent to darkened, and a second switch to change back. Different levels of light transmission with various darkening effects are also possible, either as a smooth gradient or clearly differentiated. The electrical energy required to color the ultra-thin nanocoating is minimal [12].

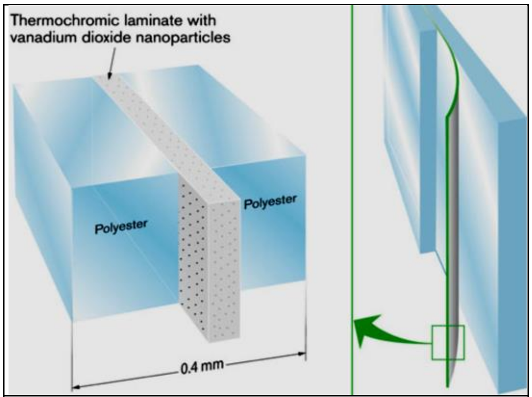

Fig.5: Conceptual sketch of a thermochromic foil incorporating a laminate with VO2-based nanoparticles between two foils of (polyester, PET) [1]

Thermochromic Glazing: The nanoparticles composites can be useful in several ways and may be incorporated in polymer foils or laminates for practical low-cost thermochromic glazing as indicated in (Fig. 5).

5-3 Silica Nanogel for Energy-Efficient Windows

Aerogel is a low-density nanostructure porous material, with a very low thermal conductivity (about 0.018 Wm/K for translucent granular aerogel), and good optical transparency (light transmittance). The research on silica aerogel for windows recently touched upon the possibility of achieving high-performance glass materials using silica aerogels. The thermal conductivity is about 0.17–0.18 W/m K compared to about 1 W/m K for a float glass, together with high transparency (the light transmittance is 91–96 % at 500 nm) [1]. Tab. (4) illustrates the optical and thermal properties of some Aerogel glazing systems.

Tab.(4): Some glazing systems with translucent aerogel [1]

	VLT	SHGC	U_g	VLT	SHGC	U_g
Insulated glass units	Glazing System + aerogel insulation, 25.4mm, 44.45 mm, 76.2mm			OKAGEL, 30mm, 60 mm		
	10-45%	0.10-0.42	1.14	<59	0.61	0.60
	9-40%	0.09-0.37	0.61	<45	<0.54	0.3
	7-32 %	0.70-0.30	0.31			

5-3-1 Forms of Silica Aerogel

In the building insulation material sector, silica aerogels were developed in two main forms (Fig. 7):

a- Translucent Granular

It is used in the interspace of advanced glazing windows or skylights; It is proved that the granular aerogel insulation on single-glazed window of an office building could be reduced 80% of heat loss without affecting the light transmission [1].

b- Transparent Monolithic panels

Monolithic aerogel panes appear as a very transparent and lightweight material, Fig. (6), but they have a tendency to scatter the transmitted light, resulting in a hazy picture when objects are viewed through them [5].

Fig.(6) View through a monolithic aerogel sample [5]

5-3-2 Performance of Aerogel Glazing Systems

Silica aerogels, monolithic and granular translucent ones, can be used in order to obtain high-insulated nanogel windows, thanks to excellent thermal insulation properties and good light transmission [1].

a- Thermal Performance

Transparent Silica aerogels have excellent thermal properties: the thermal conductivity is

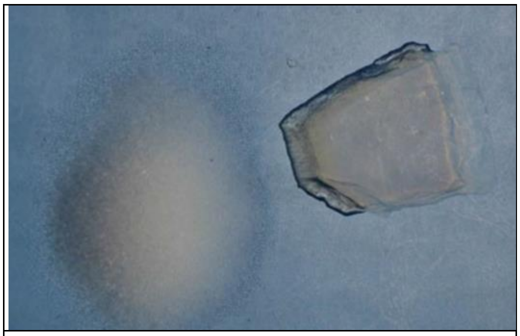

Fig. (7): Silica aerogels: granular (left) and monolithic pane (right) [1]

the lowest among solid materials, and it varies in the 0.004 W/m K (evacuated monolithic silica aerogel) 0.018 W/m K (granular silica aerogel) range, at room temperature. Thermal performance of monolithic aerogel windows was experimentally evaluated only on new prototypes developed in European research projects, showing excellent properties with moderate thickness. Aerogel glazing prototypes were made under vacuum conditions, including transparent insulating silica aerogel tiles (thickness about 15 ± 1 mm, 55 × 55 cm2); the centre U-value was below 0.7 Wm^2K. The measured value for the monolithic window prototype (15 mm aerogel) was higher than 75 %, and the U-value was equal to the best triple-layered gas-filled glazing units (U < 0.6 W/m2 K) [1]. International Energy Agency Solar Heating and Cooling Program, Task

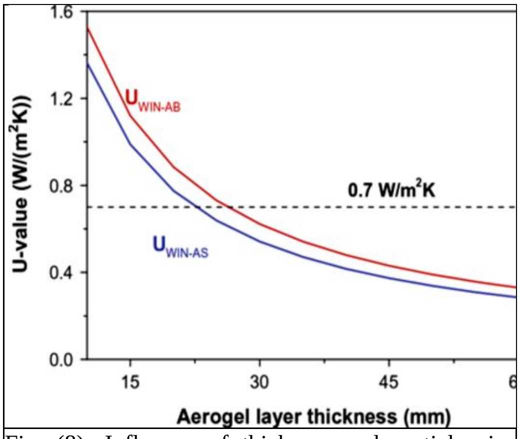

Fig. (8): Influence of thickness and particle size (Aerogel-AS: small granules, blue line; Aerogel-AB: Large granules, red line) of aerogel on thermal performance [1]

18Advanced Glazing's and Associated Materials for Solar and Building Applications were involved in a project to develop and set up super
-insulating glazing with monolithic aerogel. Five different samples were realized, characterized by different density, thickness and transparency: the light transmittance was in the 0.75–0.96 range. Depending on the density of the sample, the measured thermal conductivity was in the 0.015–0.017 W/(mK) range and the thermal transmittance reached a value less than 0.50 w/m^2K [5].

Granular Aerogel

Thermal properties of granular aerogel glazing systems are significantly affected by aerogel thickness and particle size, as. Moreover, a significant reduction in U-value was observed by incorporating the aerogel granules into the cavity of double glazing, shown in (Fig. 8), there were 58 and 63 % reduction, respectively, in heat losses when compared to a conventional double glazing unit with the same interspace thickness (14 mm), but with air instead of aerogel granules [1].

b- Visual Performance

The light transmittance of a 10 mm thickness of monolithic aerogel is high and similar to the one of a 6-mm-thickness clear float glass (considering an aerogel pane); its solar transmittance is also high and equal to 0.88. Nevertheless, the quality of the vision through the material is poor and optical images could be hazily deformed (Fig. 9).

Fig. (9): Aerogel effect on the vision by comparing the double glazed unit with and without the monolithic aerogel panel [1]

Granular Aerogels

Granular aerogels light transmission is about 80 % (10 mm thickness, Cabot), lower than the one of the monolithic samples with the same thickness. It decreases by 20 % for each 10 mm thickness increasing. A 38 % reduction in light transmittance was observed with large aerogel granules in the interspace (particle size 3–5 mm) when compared to conventional double glazing, while the reduction is 81 % with small aerogel granules (particle size < 0.5 mm) [1].

6- Building Applications of Nano-gel Windows

A wide number of applications of daylighting systems with granular aerogels could be found in schools, commercial and industrial buildings, airports, etc., especially in the USA and in Europe. An example of a recent application as a wall system in a multifunctional building (consisting of a home, an office, a workspace, and a retail environment) is shown in Fig. (10). The key results from the literature review about building application of nanogel windows and their benefits are discussed in the following paragraphs, highlighting the recent developments.

Fig. 11: Translucent aerogel daylighting panel at Buchwiesen School Sports Hall [10]

Fig. 12: Facades of the case study building at Worcester Polytechnic Institute [10]

6-1-Buchwiesen School Sports Hall, Zurich

This is the first installation of translucent aerogel daylighting panel in Europe (Beck, 2005). the panel was installed in 1000 m2 of roofing and 350 m2 of the north-facing facade of the sports hall (Fig. 11). The performance of this installation was evaluated by a research team from the Technical University (ETH) Zurich and found that light distribution had consistent brightness and ability to maintain comfortable climatic conditions in summer and winter [10].

Fig. 10: Example of the application of aerogel in polycarbonate sheets in a multifunctional building in Seattle, Washington’s Freemont District [1].

6-2-Educational building at Worcester Polytechnic Institute, USA

This study has focused on developing a monolithic aerogel window (Fig. 12) for an educational building at Worcester Polytechnic Institute, Massachusetts, and the USA. The developed window was and tested for its thermal and lighting performances. Study on various retrofitting options with aerogel application on windows has revealed a potential of up to 80% in energy consumption of the building [13]

6-3 Office building, London, UK

This study (Moretti et al., 2018) has focused on the feasibility of employing aerogel filled Multiwall PC panels (Fig. 13(a)) on the roof (Fig. 13(b)) and external walls (Fig. 13(c)) as a refurbishing option for an office building situated in London, UK. The samples were made of three walls with different geometry and thickness (16, 25, and 40 mm). By filling aerogel granules in the glazing unit, the U-value could be reduced by 46%-68%, depending on the aerogel layer thickness. Energy simulations of typical climatic conditions such as cold, moderate, and hot showed that the aerogel-filled PC glazing unit was efficient for reducing both heating and cooling loads in all the climates, compared with conventional double glazing units [10].

Figure 13: Application of aerogel-filled glazing panel on roof and walls of office building. (a) Aerogel-filled polycarbonate glazing unit; (b) Application on roof; (c) Application on wall [10].

7- Feasibility of employing aerogel

Feasibility of aerogel glazing in various climates of China was investigated by using e Quest energy simulation program. Compared with the conventional glazing, energy efficiency of 20%, 11%, and 9% could be obtained by aerogel glazing, in Harbin, Beijing and Shanghai, respectively. This study has shown that aerogel glazing is feasible in cold, hot summer, and cold winter climates [1]. It is found that filling silica aerogel between two clear glass panes in a commercial building in a humid subtropical climate and this application could reduce the annual cooling load and envelope heat gain by about 4% and 60%, respectively. Granular aerogel in the cavity of double glazing units could save 21% of the building's energy consumption, with a payback period of around 4 years [10]. As one of the introductory research studies on the application of aerogel glazing in Saudi Arabian buildings, the energy performance of nano aerogel glazing applied to simple and multistory office buildings assessed. It was shown that replacing the double-glazed (DG) windows with nano aerogel glazing could yield savings of 14%e16% in the annual energy consumption of the building [10].

Another study investigated monolithic aerogel-glazed windows for a retrofitting project of an educational building in Central Massachusetts. Four configurations with the different rates of aerogel replacements were considered (40, 60, 80, and 100 %, Fig. 14a), and the energy demand was evaluated: the heating energy consumption decreased linearly with increasing the aerogel proportion in the windows, whereas the cooling

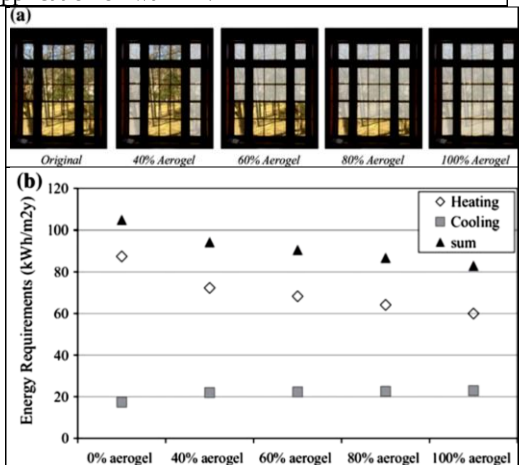

Fig. 14 The investigated window configurations with different percentages of aerogel inclusion (a); heating and cooling energy requirements for different window systems (b) [1]

energy consumption kept almost stable with percentages of aerogel above 60 % (Fig. 14b). Nevertheless, the daylight analysis indicated that the 60, 80, and 100 % aerogel windows could have a poorer effect over the daylight availability. Furthermore, the window with 40 % aerogel panels could improve the Useful Daylight Index (UDI, as a percentage of time in which the daylight luminance level is sufficient and useful for the occupant) when compared to conventional solutions [(1)].

Consequently, a 40 % aerogel window could be a good compromise, because it reduces the energy consumption simultaneously improving the daylight availability. However, since the cost of an aerogel window could be six times higher than a conventional window, this constitutes a challenge that needs to be overcome [(1)].

- Comparing the aerogel units for windows and the advanced glazing technologies (low-E glazing, Thermochromic and Electrochromic glazing) as shown in Tab. (5):
  - The comparison conducted between some systems commercially available on the market with the same light transmittance as illustrated previously.
  - The comparison focused on the lighting and thermal performance of the glazing system. It is concluded that; Aerogel glazing systems have the lowest potential u-Values in the windows market due to their thermal properties.
- Innovative aerogel glass materials are very attractive for future window glazing applications. It offers a potential to revolutionize windows allowing great thermal performance combined with high light transmittance.

Tab.5: A comparison between Aerogel window and the other advanced glazing technologies (lighting and thermal performance) (the researcher)**

	VLT	SCHG	U_g	VLT	SCHG	U_g	VLT	SCHG	U_g	VLT	SCHG	U_g
Type	glazing system with translucent aerogel (OKAGEL, 30mm)			Double glazing with low-e coating			Thermochromic Glazing (PLEOTINT SUNTUITIVE CLEAR)			Electrochromic Glazing (SGG SAGEGLASS)		
	<59%	0.61	0.60	80%	0.62	1.1-1.3	60%	0.36	1.36	60%	0.41	1.64

Conclusion

- Minimizing the cooling needs of a building mainly means minimizing the solar load and the conductive daytime heat gain through the building envelope. Transparent elements have an important role in buildings in terms of energy demand, thermal comfort, and daylighting: most of the total energy losses (up to 60 %) can depend on the windows, especially in highly glazed buildings, because the transparent systems have thermal performance lower than the opaque walls.
- Nowadays, alternative high-performance glazing solutions, such as Low-E coatings, Solar Control Low-E Coatings, and Switchable or chromogenic glazing, are significantly affected by nanotechnology.
- Aerogel is one of the most promising nanomaterials for use in highly energy-efficient windows.
- Economically, further studies are still necessary to improve the feasibility of using the aerogel glazing system in Egypt through a comparison between the initial and the running cost of the buildings.
- It is recommended to examine and assess, through a comparative study, the most economically and environmentally efficient type of the previous discussed glazing systems to implement in Egypt.

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تقنيات التزجيج المتقدمـه لغلاف مبنـي موفـر للطاقـه

Nano-Aerogel بالاشاره الي نوافـذ

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ملخص البحث

يمثل استهلاك الطاقة الكهربائية لإضاءة ، تبريد ، تدفئة وتهوية البيئة الداخليه للمباني جزءًا كبيرًا من استنزاف الطاقة. يلعب غلاف المبنى ، وخاصة الاجزاء الشفافة ، دورًا استراتيجيًا في الأداء البيئي واستهلاك الطاقة للمبنى ، مما يؤثر بشكل كبير على مستويات الراحة الداخلية. هناك تطور سريع في تكنولوجيا غلاف المبنى في السنوات الأخيرة ، وبخاصة في مجال الزجاج. تهدف هذه الورقة ، من خلال دراسة تحليلية مقارنة ، إلى تقديم مراجعة للأدبيات العلمية التي تتناول استخدام تقنيات الزجاج المتقدمة بهدف السماح للمعماريين والمهندسين والبنائين بمعرفة نطاق هذه التقنيات الموجودة في السوق وتوظيفها للوصول الي كفاءه في استخدام الطاقه في المباني. يستعرض البحث أولاً أنظمة التزجيج الحالية لإظهار أدائها الحراري واداء الإضاءة. ثم يبحث في تأثير تقنية النانو بما تمثله من ثوره تكنولوجيه على هذه الأنواع وتأثيرها على تطوير نوافذ عالية الكفاءة من حيث الطاقة مثل نوافذAerogel . و أخيرًا ، خلصت الورقة من خلال مقارنة بين استخدام Aerogel في الزجاج " المعروف باسم "Aerogel" glazing والأنظمة الأخرى إلى أن هذا النظام يمكن أن يكون بديلاً جيدًا للزجاج لتقليل استهلاك الطاقة في المبنى.