IJEMS The International Journal for Engineering and Modern Science
Year: 2024 Volume: 2 Article ID: 23004

Evaluating Advanced Glazing Technologies on Energy and Carbon Footprint of office buildings

Dr. Shaimaa H. Zaki [1], Dr. Ayah Mohamed [2*]

1,2Lecturer at Architecture Department, Modern Academy for Engineering & Technology, Cairo, Egypt

ARTICLE INFO.

Article history:
Received 3 September 2023
Revised 31 December 2023
Accepted 1 January 2024
Available online 2024

Keywords:
Energy Simulation
Thermal Comfort
Co_2 Emissions
Sustainability
Energy Efficiency

ABSTRACT

Recently, the strategy of adaptation of the local climate change and site conditions is always an important issue that faces the decision makers, especially reducing energy consumption. Governments have great efforts in reducing the amount of carbon dioxide as greenhouse gas emission that is released into the atmosphere.
In Egypt, temperatures in summer increase because of the intense solar radiation. Thermal environment of office buildings is deemed significant to enhance the quality of life. The research focuses on how smart glass affect energy consumption in office buildings while still getting the most natural light. Additionally, the study uses New- Cairo Egypt as it considers location. In this study, seven different types of glazing are compared and used in office building to see which one works best in this regard, in addition to study the effect of smart glass on increasing energy efficiency by using the simulation tool Energy Plus-Design Builder. Results show thermo-chromic and Sega glazing achieved the best results in reducing cooling energy consumption and enhancing CO2 Emissions. Moreover, the total energy consumption for cooling of the building decreased by 47.5% than the single clear glazing.

1. Introduction

In fact, environmental and energy problems are the most critical challenges in the world. Climate change is a cause of great concern due to rising temperatures around the world. Therefore, reducing energy consumption is the best solution. In hot and dry countries, the outer skin of the building conducts a significant amount of heat into the building [1]. The exterior skin plays an important role in the energy efficiency of buildings. Windows are a key factor in the heat transferring between indoor and outdoor, therefore, a suitable window system is one of the most important energy efficiencies. In many studies, the influence of exterior skin of the building such as walls, windows, and roofs on the cooling energy demand of the buildings has investigated. For adaptation of the buildings with climate change windows should have different properties. The ideal window is one that reflects all infrared (including solar and ambient) and Ultraviolet (UV), lets in all visible light, and is completely transparent to internal infrared [2].

Egypt is facing significant challenges in office buildings' energy consumption. It was found that these buildings consume 40% of total energy thereto in air and water treatment, lighting 37%, office equipment

*** Corresponding author**

E-mail address: Ayahezzat54@gmail.com

12%, while remaining 11% is used in construction and manufacture of building materials [3]. However, office buildings require expensive cooling systems, which leads to significant increase in energy consumption in summer. Rising energy prices led to the need for turning to performance assessment tools and green building (GB) rating systems to address energy challenges in Egypt and to evaluate and improve buildings energy performance.

2. Research Objective

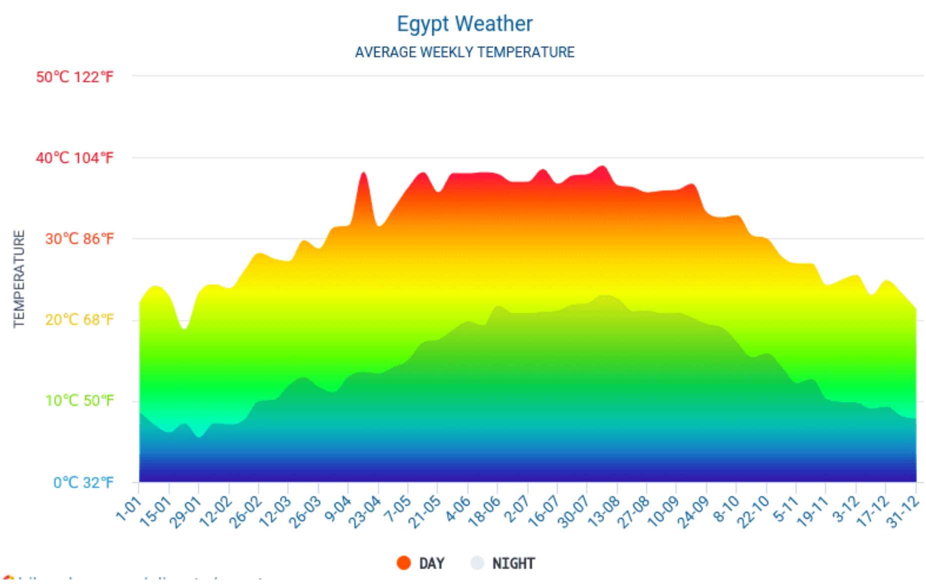
In this study, we tested an office building using Energy plus software to determine the most suitable and intelligent glazing option for office buildings with the primary aim of reducing CO_2 emissions and improving the building's energy efficiency. Energy analysis of an office building in Cairo was performed with advanced simulation using Design Builder software. In this case study, the performance of seven different types of glass as (Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glass , Single low-E coating 6mm, Thermochromic Glazing , Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glass, Glazing Integrated Photovoltaics, Sage-Glass Double Glazing and Single clear glazing 3mm) on the facade of an office building in all orientation was analyzed.

Additionally, these energy-saving techniques were suggested in this study using various type of glazing techniques, which significantly increased the studied office building's energy efficiency. This paper examines the impact of the functioning of advance smart glazing in the energy consumption for office buildings and compares it with clear glazing in Egypt by simulating the building with all orientation to record solar gain, cooling energy consumption and Co_2 Emissions.

3. Literature Review

3.1. Egypt's Climate Conditions

According to the world climate classification, Egypt is in a dry region [4]. Solar energy is abundant in Egypt. It enjoys solar radiation of 2000-3200 kWh/m2/year [5]. The duration of sunshine is approximately 9-11 hours per day, depending on Egypt's particular location in the Sun Belt region [5]. However, Egypt's desert conditions also lead to high summer temperatures and high dust levels, both of which have negative effects on solar technologies. They can lead to rapid deterioration of solar equipment. Despite these challenges, solar technology could be widely used throughout Egypt [6]. The three months with the most precipitation, January, December, and February, each had 47 mm. With an average of 18 mm, January is the month with the most precipitation. Cairo receives 74 mm of precipitation each year. Cairo's yearly mean temperature is 27 °C. The year's warmest month, July, has an average temperature of 33°C. The coldest month in Cairo is typically January when the average high is 19°C. The difference in temperature between July, the hottest month, and January, the coldest month, is 14°C. The highest amount of precipitation occurred in January, and the least amount occurred in September, a difference of 18mm as shown in Fig. 1.



	January	February	March	April	May	June	July	August	September	October	November	December
Day	19°C	20°C	23°C	27°C	30°C	32°C	33°C	33°C	31°C	29°C	25°C	21°C
Night	9°C	9°C	11°C	13°C	16°C	19°C	21°C	21°C	20°C	18°C	14°C	11°C

Fig 1. The Climate Graph of Cairo, Egypt (http://www.cairo.climatemps.com)

3.2. Thermal properties of Window glazing types

The Solar Heat Gain Coefficient (SHGC), which ranges from 0 to 1, [7] measures the amount of solar radiation that enters a space through fenestration and radiates heat into space. A lower SHGC value is preferable. [6]. The characteristics that are most heavily focused on when designing windows are the U-value, solar heat gain coefficient (SHGC), visual transmittance (VT), and air leakage. [8] These numbers vary widely and are entirely determined by the kind of window. However, installing a window with low SHGC and U-values is the most popular wish. Additionally, it must have apparent transmittance level (VT) [9]. Thermal properties of window glazing types like:

U-Value/ Thermal transmittance a measure of the efficiency of heat transmission through the fenestration; the lower the U-value, the better, the unit of measurement is W/m²K [10].

R-value- is the inverse of thermal conductivity or the ability of a material to resist heat flow, the unit of measurement is K m²/W.

Visible Light Transmission- The percentage of visible light that passes through the glass. The higher the VLT percentage, the more daylight. Also known as Tv, Tvis and LT. it is also measured perpendicular to the surface in the wavelength interval 380-780 nm [11].

Window to Wall Ratio (WWR)-The window-to-wall ratio (WWR) plays an important role in improving building design in terms of energy demand. It is observed that the higher the percentage, the higher the cooling load value [12].

3.3. Glazing Components

The thermal response of a window is governed by the physical characteristics of its parts. Any changes to the window's design alter one or more of these heat transfer modes, which in turn has an impact on the window's overall U-value., e.g., A decrease in the window's overall U-value is seen as a result of adding an additional glass layer, which lessens heat transfer through conduction [13]. According to Bitaab et al. [14], increasing the air gap from 12 to 21 mm reduces energy loss through the window by 5.1%. The thickness of the glass, the quantity of layers, and the type of insulation used in the space between the glass layers are all related to similar benefits. Common glazing types/variations include the following: [15]

- Glass thickness.
- Numbers of layers.
- Interspace gap.
- Filled gas/airspace insulation medium.

Fig. 2 illustrated how each of the three modes occurs through a window. Conduction occurs through the window frame and glass panes. While radiation happens through every component of the window, convection only occurs between the layers of glass or on top of glass panes [16].

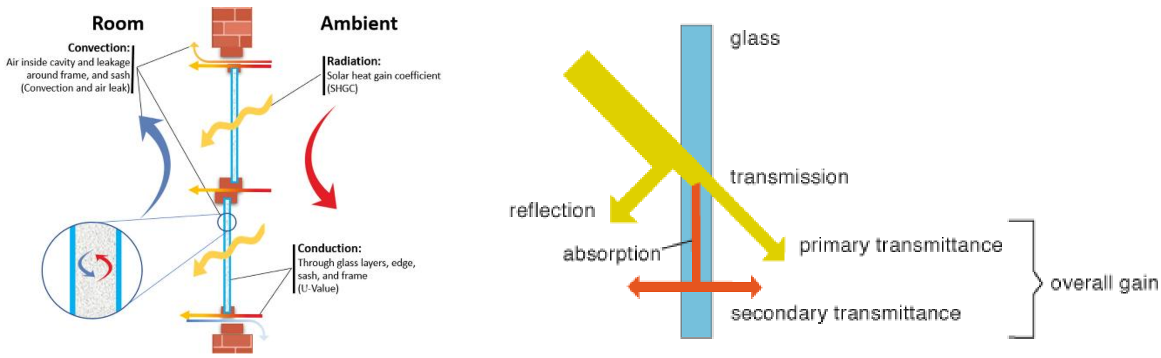


Fig 2. Heat loss mechanism demonstrated in a double-glazed window [16]

3.4.Smart Glazing

Smart glass technology is available in both passive and active forms. Either photochromic (light-sensitive) or thermochromic (heat-sensitive) materials serve as the functional layer in passive technologies [17]. They are referred to as passive because they respond automatically to changes in the sun's UV rays or radiant heat [18]. Users cannot change tint or opacity, but an electrical charge is not necessary [19], as shown in Fig.3.

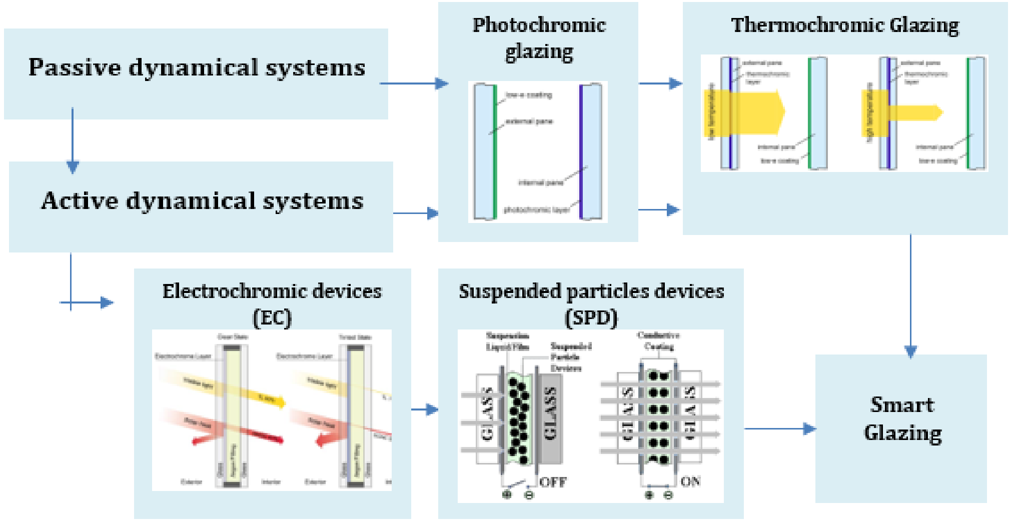


Fig 3. The smart glass category includes both passive and active technologies [18]

Smart windows, smart insulation, smart façades, smart systems, and smart technological equipment solutions like smart management systems are just a few examples of the technological innovations used in the construction of "smart envelopes," which are designed to provide the best conditions for users in terms of thermal comfort, indoor wellbeing, effective energy conservation, and effective use of the environment. A smart envelope's adaptive response could be passive, active, or a combination of the two. There is no interference from occupants during passive reactions [20].

The three types of chromic (thermochromic, photochromic, and electrochromic) devices that make up dynamic smart glazing units are suspended particle devices, liquid crystal devices, and chromic devices. They can also be separated into active and passive glazing, as shown in Fig. 3. Active glazing systems can be managed by a building management system (BMS) that responds to occupant demands and environmental changes. EC glazing provides better protection from solar and UV radiation than SPD and LCD glazing. Passive glazing systems do not need electrical stimuli; they change their properties themselves due to natural stimuli (e.g., heat and light). The prior art on the chromogenic and other technologies. Fig. 4 shows that photochromics, thermochromics, thermotropics, gasochromics and electrochromic which are the most promising for using in smart windows classification [21].

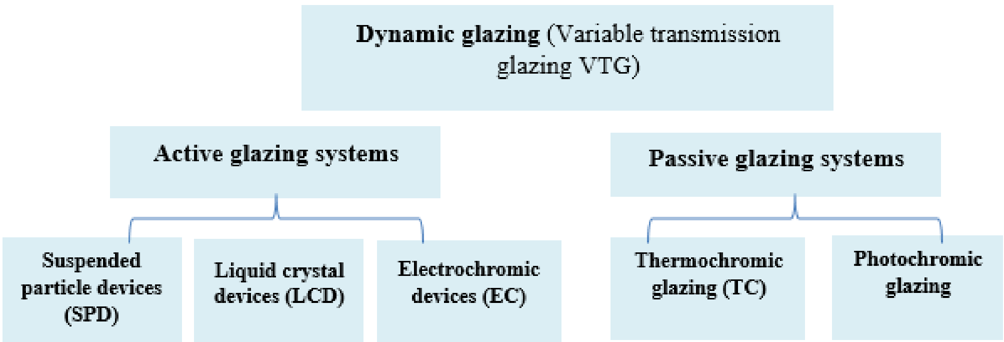


Fig 4. Dynamic glazing classification [21]

3.5.Sage Glass Description

Saint-Gobain Group's Sage Glass is an inventive electrochromic glass product. By adding adaptive, clever, and more efficient glazing to buildings, it transforms them much more than just using conventional glass options. This dynamic glass gradually changes from clear to tinted (and back again) while staying transparent by using a low voltage current. This guarantees the greatest level of comfort for those using the building and allows for the control of light, heat, and glare without ever obstructing the view of the outside. With Sage Glass, you can manually or automatically change the tint thanks to a control system. Automatic mode is the most efficient for controlling energy use. After a set period, such as 30 minutes, the system switches to automatic mode [22]. Fig. 5 shows Smart Glazing types.

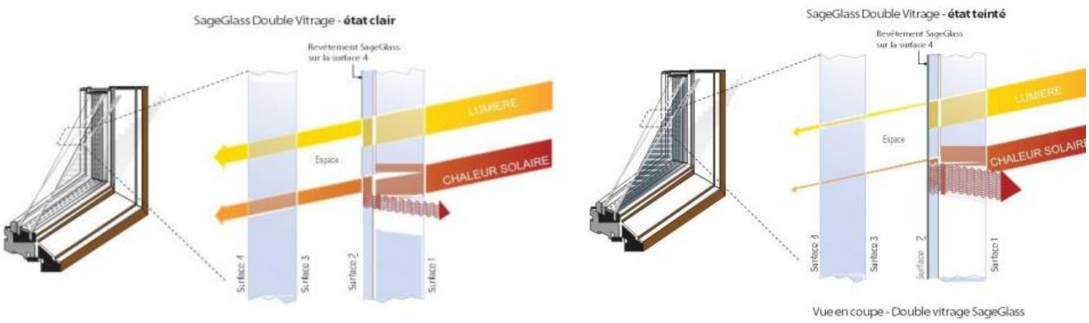


Fig 5. Smart Glazing types [22]

3.6.Advanced glazing technology

Presently available glazing technologies typically fall into three categories: highly insulating glazing, electricity-generating glazing and optically switchable (or smart) glazing as shown in Fig. 6 [23].

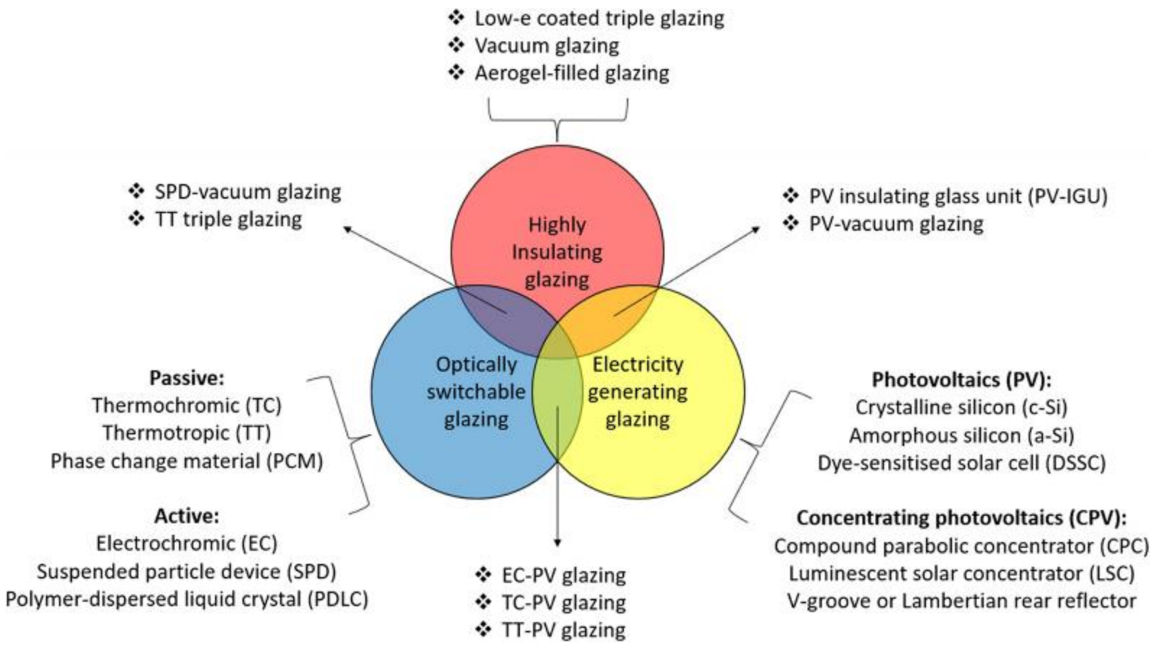
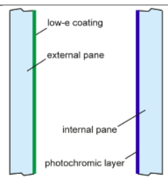
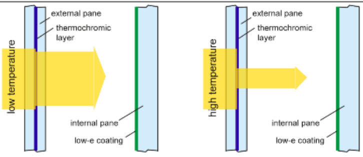
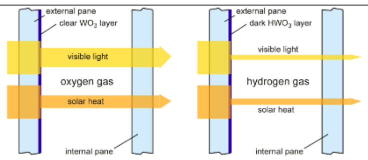
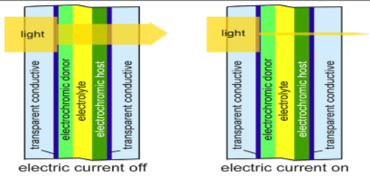
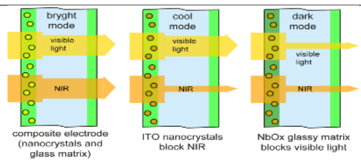
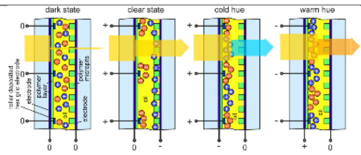


Fig 6. Categories of advanced glazing technologies [23]

The common glass-related materials are covered in this section. In the sections that follow, we'll talk about photochromic materials, thermochromic and thermotropic materials, electrochromic materials, nanocrystal in-glass, and electrokinetic pixel window technology [24], As illustrated in table 1.

Table 1. Conventional glazing materials

Materials		
Photochromic materials **[25]**	When exposed to ultraviolet and shortwave visible radiation, organic and inorganic compounds undergo a reversible color change known as the photochromism phenomenon. This phenomenon was first observed at the end of the 19th century.	

Thermochromic and thermotropic materials **[26]**	Smart windows based on thermochromic materials can regulate the amount of solar radiation that enters a building by changing color in response to changes in the ambient temperature.	
Gaso-chromic materials **[27]**	With gas chromic windows, it may be possible to combine the use of renewable energy with user comfort.	
Electrochromic materials **(Sage Glass Description)** **[28]**	An electrochromic window unit is made up of two glass substrates and a few microns thick five-layer coating (transparent conductive, electrochromic donor, ion conductive electrolyte, electrochromic host, and transparent conductive).	
Nanocrystal in-glass **[29]**	The most promising electrochromic new technology now is the nanocrystal in-glass composite window.	
Electrokinetic pixel window technology **[30,31]**	The system employs two planar electrodes, controlling an electrophoretic dispersion of particles of 2 biprimary, complementary colors characterized by opposite electrical charges.	

4. Methodology:

This study is divided into two parts:

4.1. Theoretical approach: Analysis of the different types of smart glazing including examination of the building envelope components' specifications used in office building, as well as the results of several earlier studies that found ways to utilize less energy and decrease Co2 emissions.

4.2. Practical Methodology: The practical approach was adapted by using the user-friendly environmental modelling program "Design Builder," which specializes in simulating energy usage, Energy Plus calculations use various data handling techniques and are based on ASHRAE definitions. Analysis of comparison and evaluation of their efficiency in achieving thermal comfort standards and energy consumption when adapting the cooling loads of the base case and the suggested smart glazing cases. The research methodology is outlined in the following chart. First, the office building was selected as the activity building. Next, the main goals of the study were established, including reducing solar heat gain through various types of glazing, increasing energy efficiency, and lowering carbon footprint. The most recent data on the climate region was obtained using Climate Consult, and Energy Plus (Design Builder V.7) was used to simulate the use of electricity and determine the range of CO2, as shown in Figure7.

The evaluation and simulation performed on a model of an office building in New Cairo. The researchers simulated various glass types "according to previous results" that can increase energy consumption for the envelope of the building. The adaptation of the various glazing types (Single low-E coating 6mm, Double clear glazing: 6mm clear glass-12 mm air -6mm clear glass, Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glass, Thermochromic Glazing, Sage-Glass Double Glazing, Glazing Integrated

Photovoltaics), recording the results of each element separately, and comparing them in terms of energy efficiency.

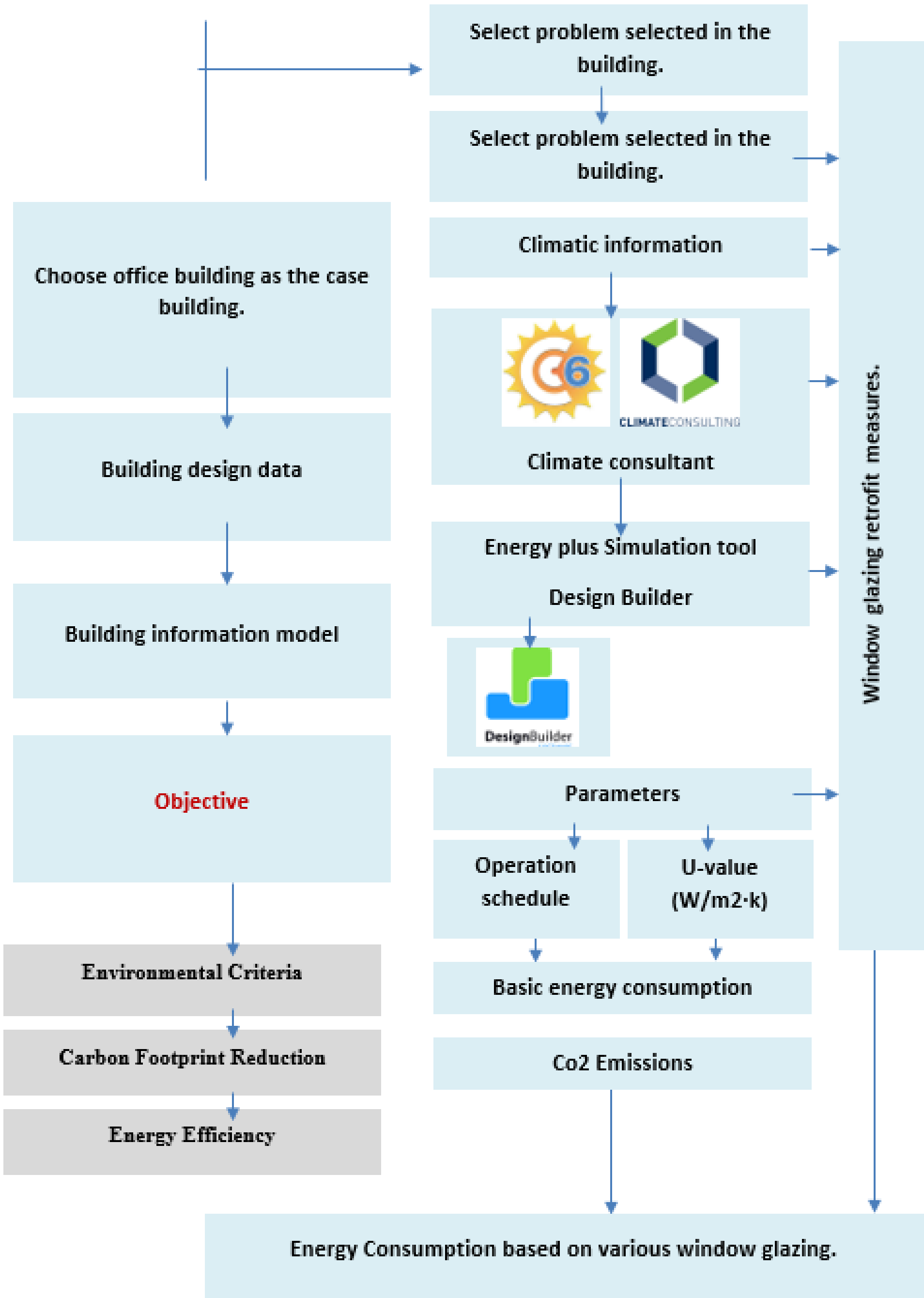


Fig 7. Methodology of the research

4.3.Case Study Description

The case study is situated near the Cairo Airport and has a semi-square layout, Fig. 8 shows its location. The structure consists of five regular floors and a basement; the first floor is for commercial use, and the top four floors are used as offices. The office building was constructed in 2018 and is situated in the 5th settlement of North 90th Street in New Cairo. The first four floors' glazing is clear, transparent single glazing with no thermal break.

The lack of natural ventilation and the large external glass surfaces used in current office buildings influence the air quality and thermal comfort of employees, which has an effect on their health, productivity, and adaptability. Based on this, a proposed office building with about 85% single-glazed surface area was chosen as the case study. Figs. 9,10, 11,12 depict the building model made by the simulation program tools. [32,33]. As a result, the occupants of this building experience a thermal burden, necessitating the extensive use of mechanical technologies to provide thermal comfort.

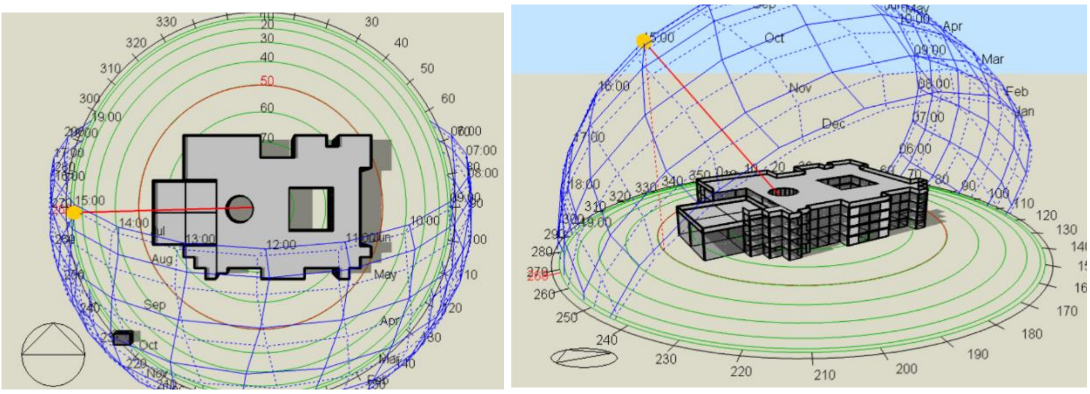


Fig 8. Lay-out and 3D view for the case study (Design Builder Software)

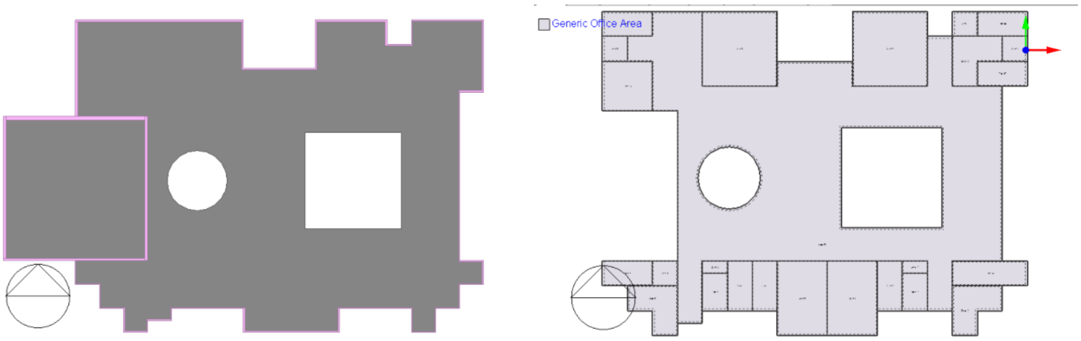


Fig 9. Internal plan for the case study (Design Builder Software)

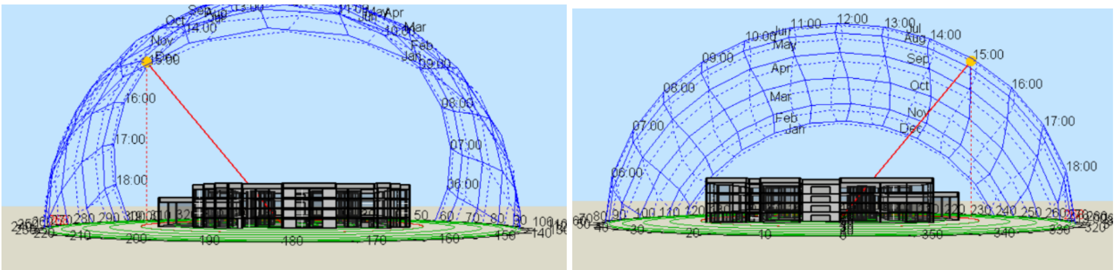


Fig 10. View of South façade, North facade (Design Builder Software)

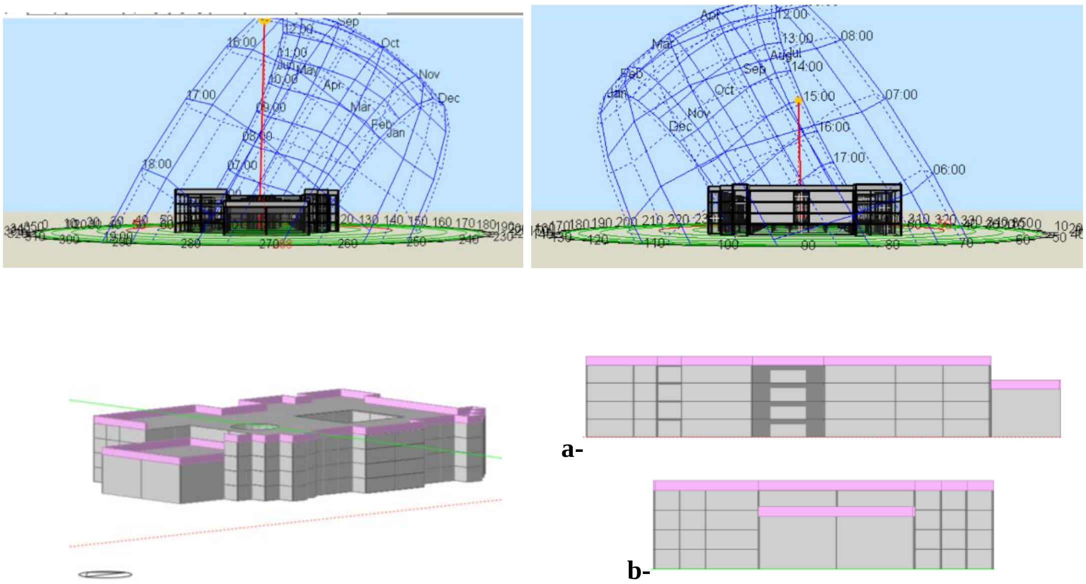


Fig 11. View of Axonometric of the building, a-South, b-East facade (Design Builder Software)

4.4.Input Data

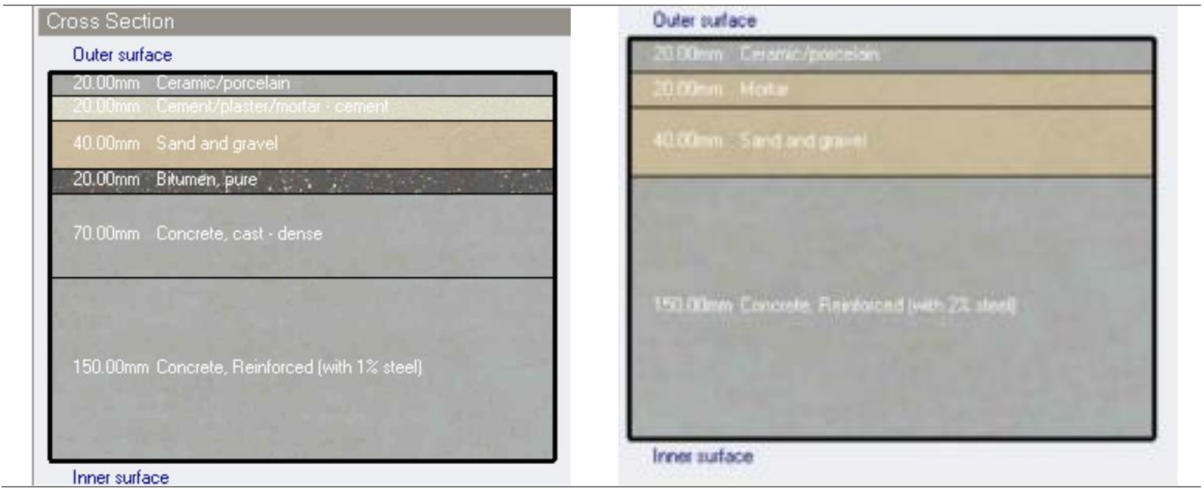
Design-Builder dialogues allow loading data into the model spaces (Activity, Construction, Openings, Lighting, HVAC, Outputs, and CFD dialogues). Activity dialogues define building usage data, including data on occupancy, internal temperature set points, equipment loads and schedules, ventilation rates, and illuminance levels. Lighting dialogues identify lighting power densities for general and task lighting. Construction dialogues identify generic construction data; opening dialogues identify fenestration data and glazing type [34]. Tables 2,3 summarize this data.

Table 2. Design Value for simulation input parameters in Design Builder.

Project Name	**781 office building**
Building type	Office
Owner	UPM Group and others are renting out offices.
Total Simulated area	50X120 M2
Window to wall ratio	80-95%
Transmittance degree	10-40%
Illuminance set point	500 LUX
Lighting density	6.4 W/m2 (by consuming 5 Lamps each one using 40 watt/hour)
HVAC Temperature	24 0C
Occupancy	4 persons:3 men and 1 woman (0.16 person /m2)
Lighting density	6.4 W/m2 (by using 4 Lamps each lamp consumes 40 watt/hr)
Equipment	The office room contain 4 lab tops and 1 printer consume 550 watt/hr.

Table 3. The proposed wall types of alternatives

<table>
<tr><th>Walls</th><th>Ground Floor Slab</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Roof Slab</th><th>Typical Floor Slab</th></tr>
</table>



5. Case Study Simulation

For one of the office buildings in New Cairo, simulation was done because office buildings typically require natural light and cooling. The simulation's output was broken down for solar gain, efficient cooling energy consumption, daylight saving, and light cargo to estimate how stylishly different types of glazing perform in comparison to transparent glazing. Fig. 13 shows the adaptation of Saga Double Glazing and their relationship with their annual saving energy. Where it is quite clear that the most effective optimization was the Saga Double Glazing by the 25% energy consumption, and table 4 shows Glazing types and Values.

Table 4. Glazing types and Values

	Glass type and description	U-value	SHGC	VLT
1	**Single clear 6mm**	5.778	0.819	0.811
	Single low-E coating 6mm	3.447	0.65	0.84
2	**Double clear glazing: 6mm clear glass-12 mm air -6mm clear glass**	2.685	0.703	0.781
3	**Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glass**	1.548	0.587	0.761
4	**Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glass**	0.21	0.42	0.520
5	**Thermochromic Glazing**	2.130	0.569	0.578
6	**Sage-Glass Double Glazing**	1.267	0.287	0.393
7	**Glazing Integrated Photovoltaics**	5.894	0.861	0.898

6. Results and Discussion

6.1.Types of glazing's impact on cooling energy efficiency at all orientations

Each type of glass' annual total energy consumption for cooling was calculated and expressed in kWh/m2. The peak of the cooling energy consumption curve occurs in July and August as a result of the increased solar radiation entering the office building through its walls.

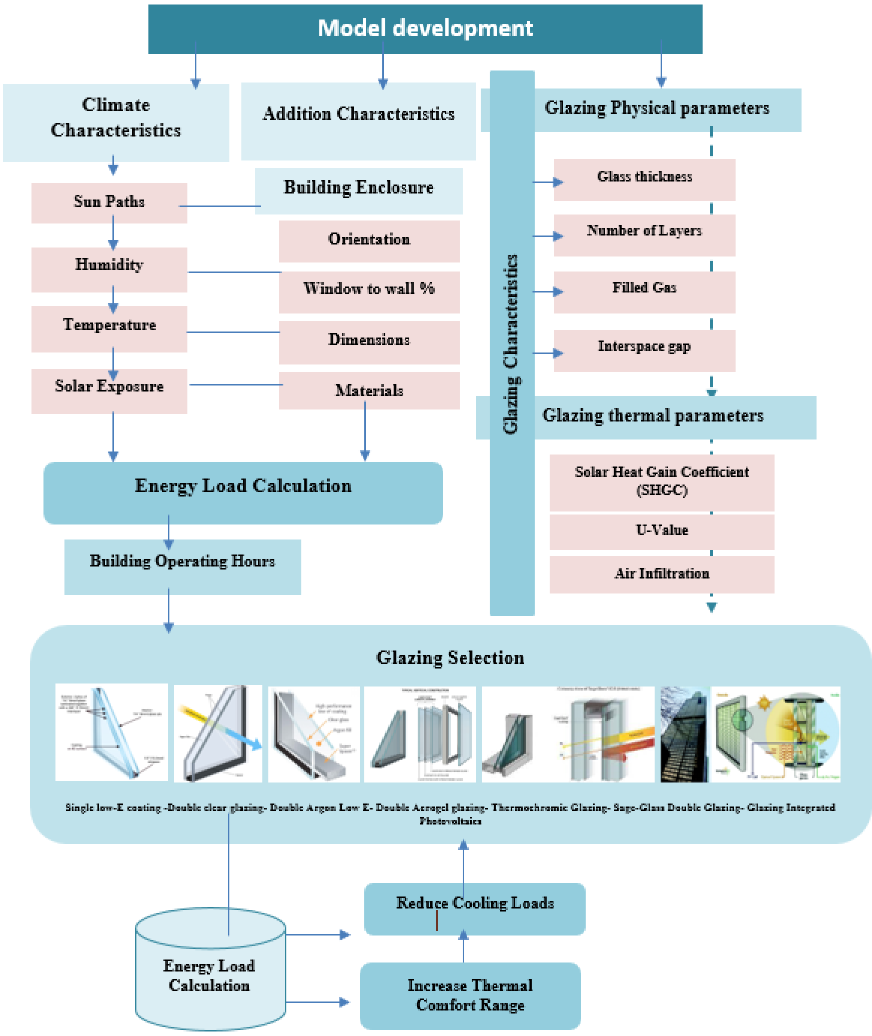


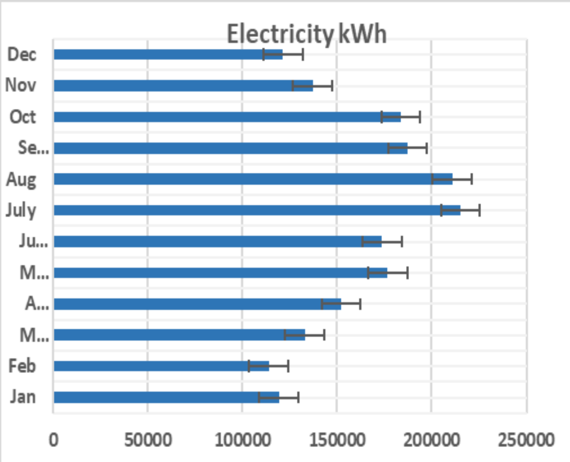
Fig 12. parameters of the adaptation for the case study

For cooling, energy is currently in high demand in Upper Egypt. The results of the monthly cooling energy usage for all types of smart glass in comparison to clear glass 3 mm are shown in table 5. Energy use increases in the summer because cooling load requirements grow. The Thermochromic, Sage-Glass Double Glazing and Glazing Integrated Photovoltaics significantly reduces the heat from the sun, reducing the need for the air conditioner. In all viewpoints, it can be shown that Thermochromic and Sage-Glass Double Glazing uses less cooling energy than clear glass. When compared to single glazing, cooling demand is reduced by adapting double aerogel and double argon low E windows, however there are some differences between the double-glazing types. Additionally, Single low-E coating glass required more cooling energy in the summer than other varieties of glass because of an increase in the transmission of solar radiation.

The design-builder's internal gain analyses determined the energy consumption rates for things like office electricity, lighting, cooling, domestic hot water, and heating. DHW stands for energy needed to heat the water, which is determined by the number of office rooms and dwelling units, the type of water heater, the distribution system, the fuel type, and the amount of heated floor space. In order to compare the various glazing types, as shown in Table 5, the monthly fuel breakdown charts in the design-builder were used. In the context of the internal gain, some numbers were incomprehensible, but they were viewed as inconsequential in the scheme of the overall results. By simulating all the types of smart glazing as shown in Fig. 14, the tests conducted illustrated that the Sage-Glass Double Glazing consumed the least energy (152615 kWh), followed by the Thermochromic Glazing (154674kWh) with minor differences. On the other hand, the Single clear glazing 6mm had the highest consumption rate (250674 kWh) with an obvious difference, as illustrated in Fig. 15.

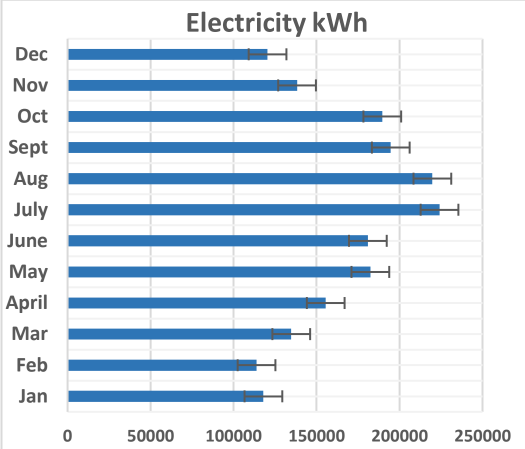
Table 5. Fuel total of Type of glazing in Design Builder Simulation tool

Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glass



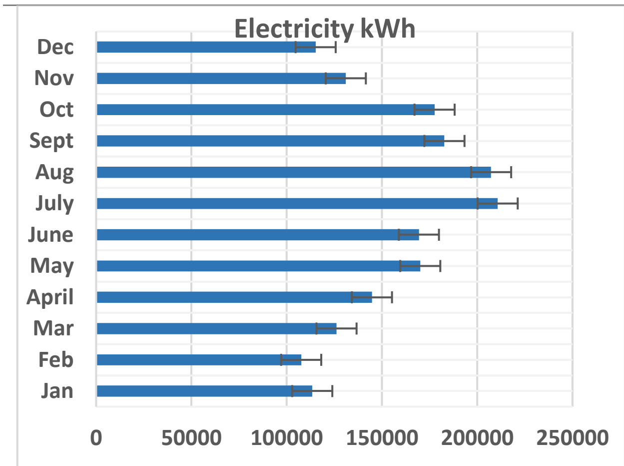
The annual average amount of Electricity 160298 kWh

Single low-E coating 6mm



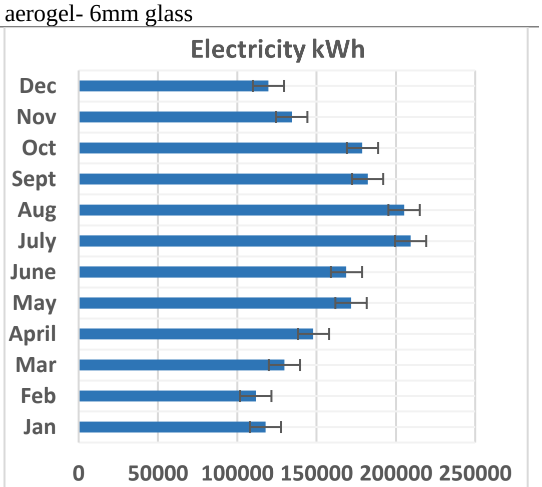
The annual average amount of Electricity 164377 kWh

Thermochromic Glazing



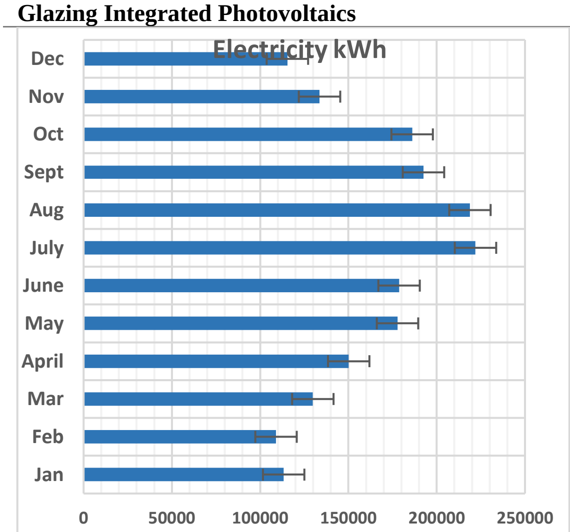
The annual averag amount of Electricity 154674 kWh

Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glass



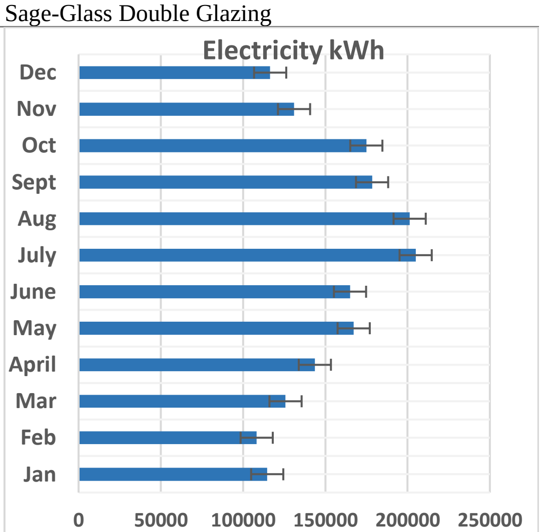
The annual averag amount of Electricity 160298 kWh

Glazing Integrated Photovoltaics



The annual averag amount of Electricity 156469 kWh

Sage-Glass Double Glazing



The annual averag amount of Electricity 152615 kWh

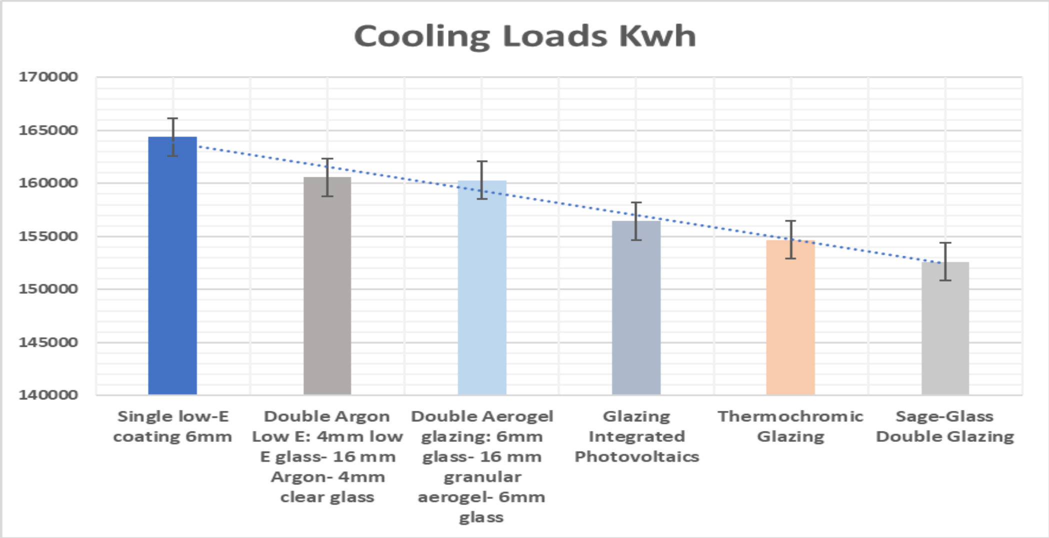


Fig 13. Cooling loads for the different type of glazing (Design Builder Software)

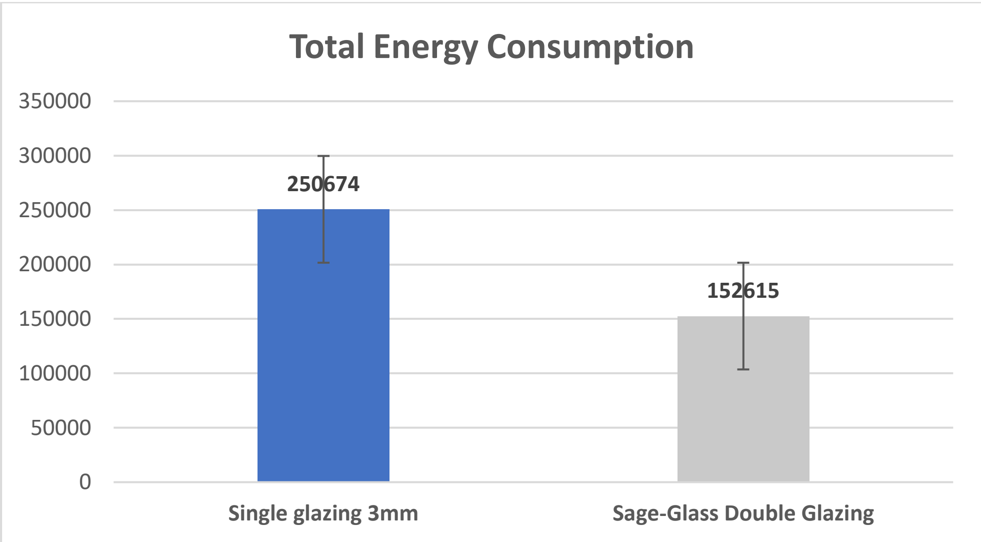


Fig 14. Total Energy consumption Comparison of single clear glazing and saga double glazing (Design Builder Software)

6.2.Effect of Glazing types on Solar Gain at all orientations

Effect of glazing types on solar gain for windows of different types of advanced glazing, the results show that Thermochromic glazing, double aerogel glazing, and saga Glass double glazing achieve better results with a little difference comparing to other types, up to 75% reduction in solar gain exterior window. Using double argon low E almost gives results less than single low E coating, up to 35% reduction in solar gain.

From Fig. 16 that shows the results of solar gain exterior window for single glazing compared to selected types of advanced glazing, critical results for these cases are obtained. The results are less efficient when using Glazing Integrated Photovoltaics and thermochromic glazing SHG=85% and 50% respectively findings compared to the base case with single clear glazing. The amount of heat gained has dramatically increased with single clear glazing 3mm with (186973.5 kWh) due to higher thermal transfer by window glazing's while the Sage-Glass Double Glazing , Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glass, Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glass and Single low-E coating 6mm with 69807 kWh, 65464 kWh, 105728 kWh1520100kWh respectively, as shown in Figs. 17, 18, and Fig. 19 shows solar Gain Exterior Window for all glazing types.

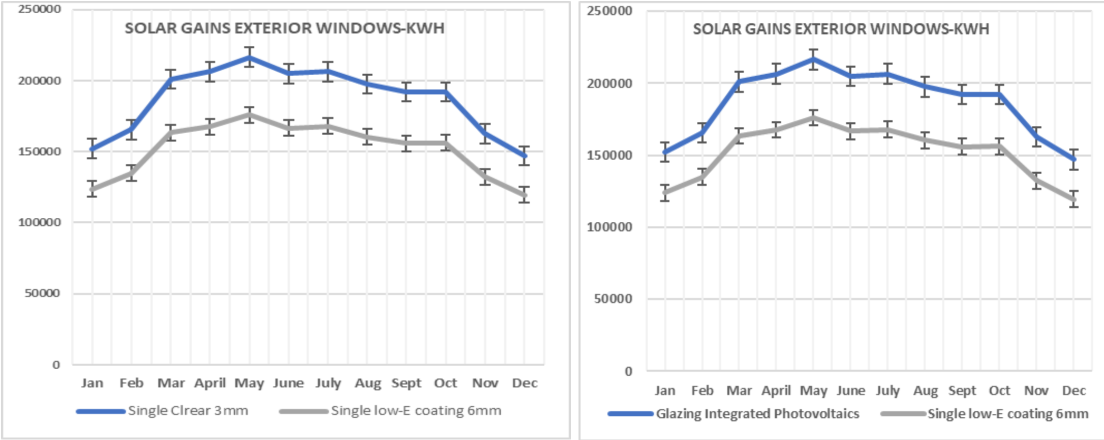


Fig 15. Solar Gains Exterior Window for the Glazing integrated photovoltaics and Single Low E

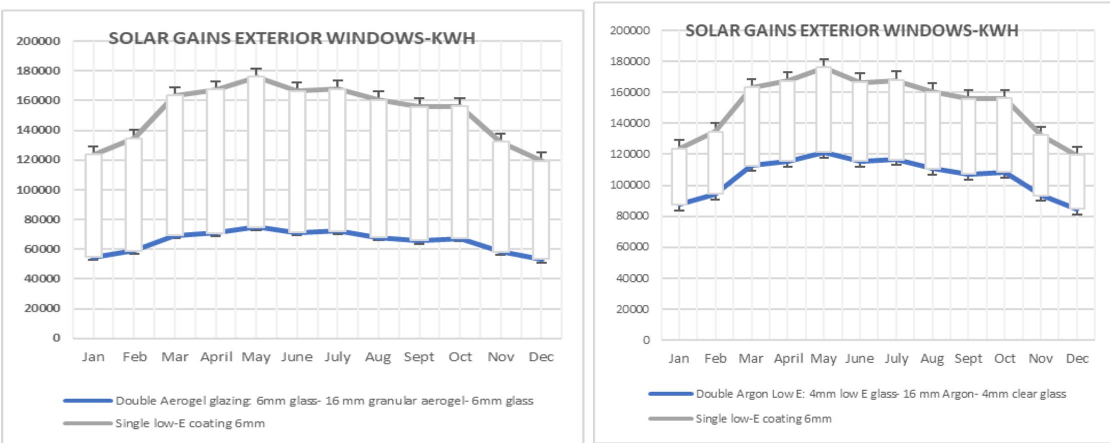


Fig 16. Solar Gains Exterior Window for Double Aerogel glazing and Double Argon LOW E glazing (Design Builder Software)

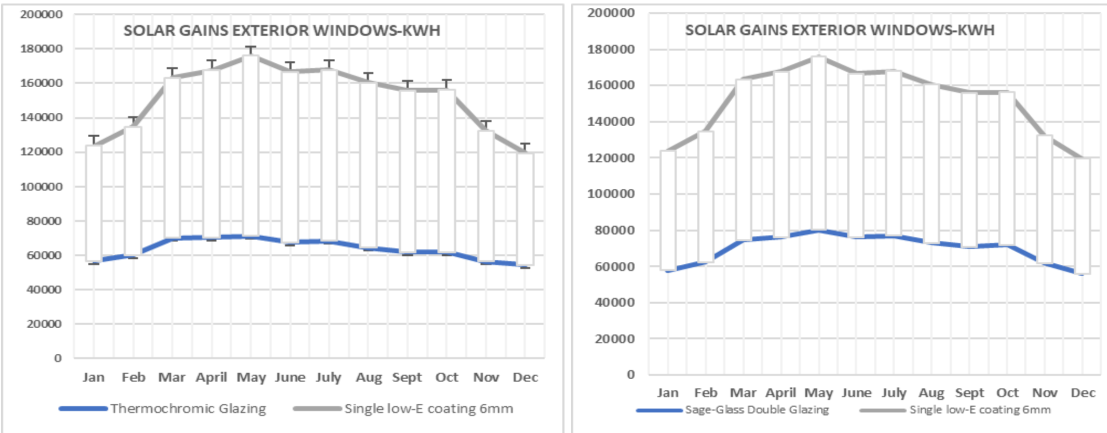


Fig 17. Solar Gains Exterior Window for the Thermochromic glazing and SaGA Glass Double Glazing (Design Builder Software)

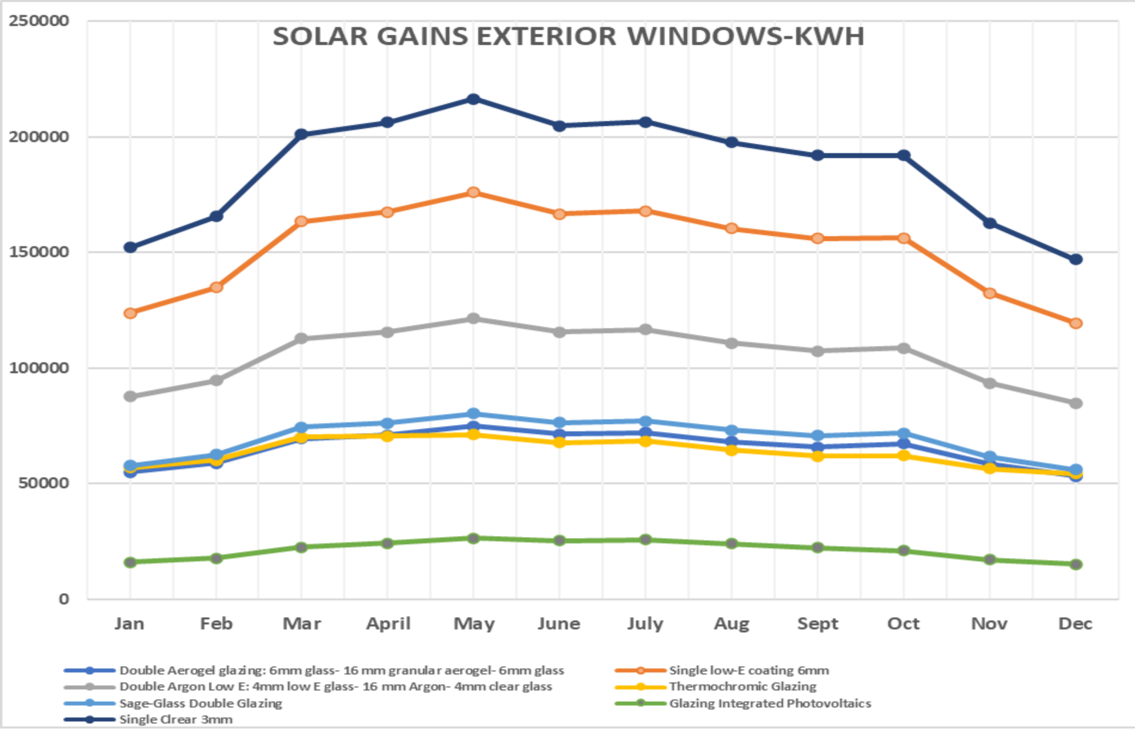


Fig 18. Solar Gain Exterior Window for the optimization of glazing types.

6.3.Effect of Glazing types on Co2 Emissions at all orientations

Glass production CO2 emissions are now a significant source of building CO2 emissions, which has garnered much more attention [35]. Based on the building's fuel consumption for the HVAC system and the operation of other activities like running lights and computer equipment, a carbon dioxide analysis has been done for the seven types of glazing used in the research. The analysis of both the highest emitting month and the annual average revealed that the Sage-Glass Double Glazing and the Thermochromic Glazing have the lowest emissions. On the other hand, the Single clear glazing 6mm, as shown in table 6, had the highest emission.

Even though the widespread use of Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glass achieve 90757kg and Sage-Glass Double Glazing 8840.55 insulating glass units in earlier generations of buildings significantly reduced CO2 Emissions while the single clear glazing achieve the highest value of CO2 emissions with 127319 kg as shown in Fig. 20.

Additionally, the CO2 emissions levels were reduced by an annual average of 78% after using Sage-Glass Double Glazing. This shows that Sage-Glass Double Glazing could be considered a very effective strategy in CO2 emissions reduction.

By deducting the performance of a baseline building with single-glazed windows, glazing-dependent building energy consumption and CO2 emission were examined. CO2 savings because of advanced glazing is more than a factor of two higher in summer months than in winter months in Egypt.

A Significant impact of reducing the Cooling loads (kWh) was achieved due to developing the Glazing system that stemmed in reducing glass (SHGC), U-value, and increasing Light Transmission Values (LT). Fig. 21 shows the outcomes of the skilled adaptation for each criterion:

- **Energy Conservation and Reduction of the Environmental Factors:** Owing to mixed mode ventilation in the advanced glazing systems, energy conservation is provided because of reducing the usage of mechanical air conditioning systems. And the advanced glazing type protects the building against external factors.

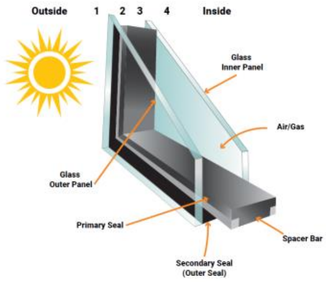
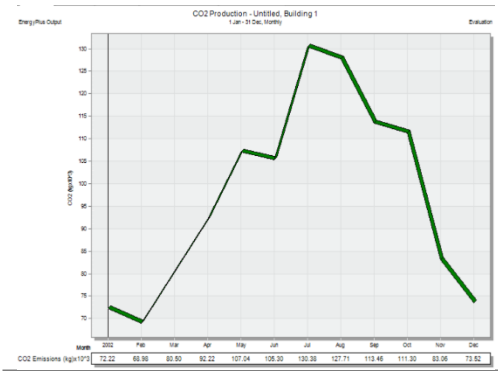
- **Carbon footprint Reduction**: Efficient advanced Glazing can reduce Carbon Footprint for the building, now that they have an additional tool, engineers and specifiers can lessen the environmental footprint impact of the building they are designing.

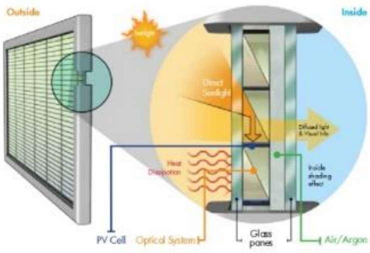
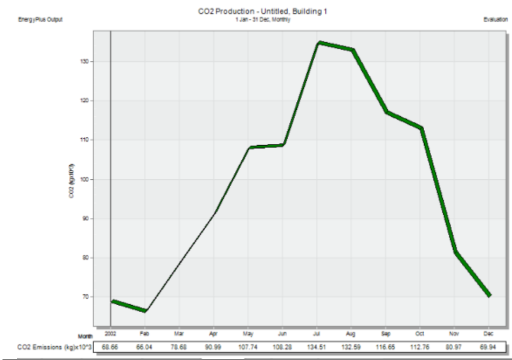
- **Increase Building Value**: By requiring less heating, cooling, and ventilation, smart glass lowers energy expenses. By choosing the Blackout state, which prevents structures from overheating, it lessens the need for these by blocking 99% of light.

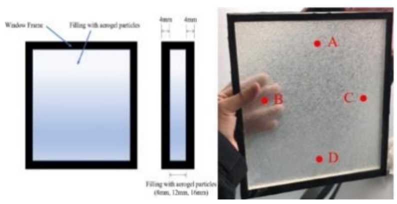
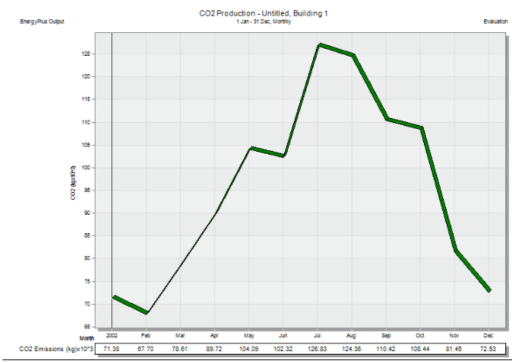
- **Thermal Comfort aims**: Using smart applications and cutting-edge technologies that integrate with communication technology within building components, smart architecture helps to achieve the thermal comfort Development Goals.

The selection of the best glazing is a difficult process that is influenced by several factors, not just thermal and optical characteristics. Table 7 shows some of the key performance criteria for smart control glass.

Table 6. Type of glazing in Design Builder Simulation tool

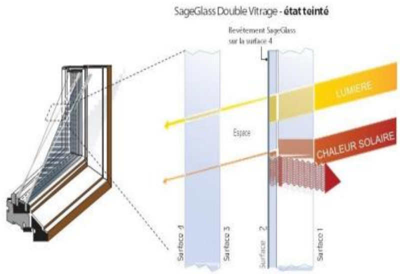
<table>
<tr><td></td><td>Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glass</td></tr>
<tr><td>
</td><td>

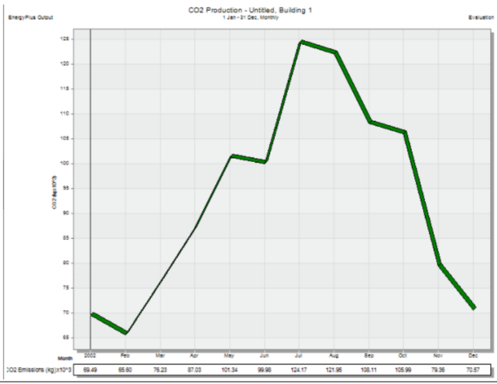
The annual average Co2 emissions is 97140 kg.</td></tr>
<tr><td></td><td>Glazing Integrated Photovoltaics</td></tr>
<tr><td>
</td><td>

The annual average Co2 emissions is 98284 kg.</td></tr>
<tr><td></td><td>Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glass</td></tr>
<tr><td>
</td><td>

The annual average Co2 emissions is 90757 kg.</td></tr>
</table>

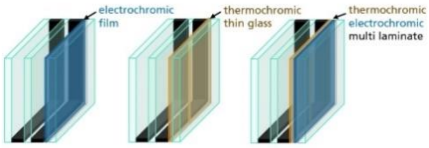
Sage-Glass Double Glazing

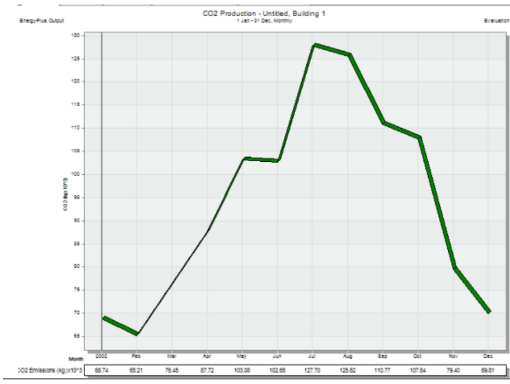




The annual average Co2 emissions is 8840.55 kg.

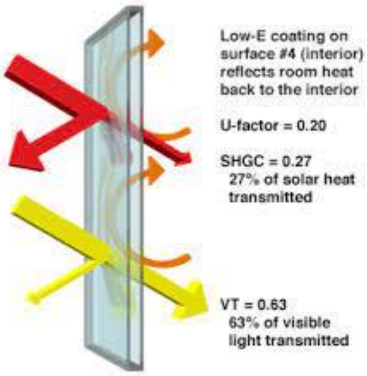
Thermochromic Glazing

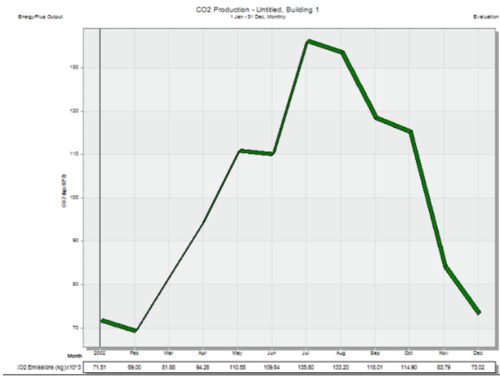




The annual average Co2 emissions is 93732 kg.

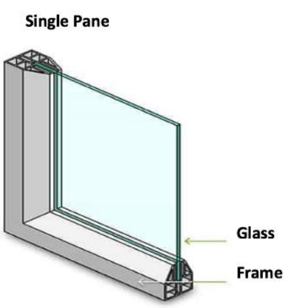
Single low-E coating 6mm

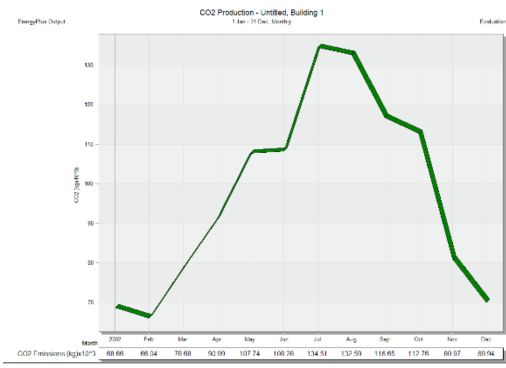




The annual average Co2 emissions is 99612 kg.

Single Glazing clear 3mm





The annual average Co2 emissions is 97319 kg.

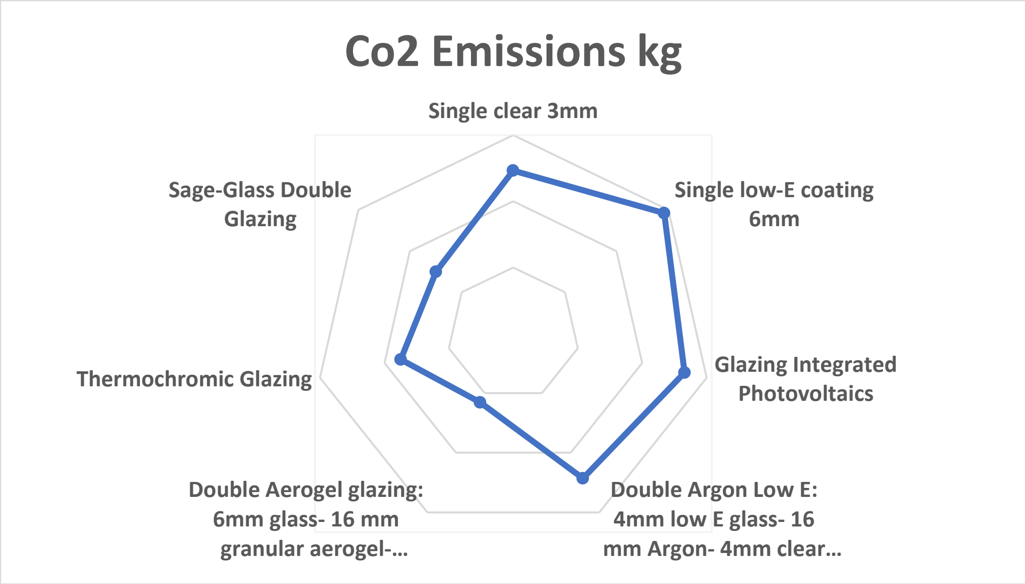


Fig 19. Comparison for Carbon dioxide produced in the building due to operation during one year for the different types of glazing.

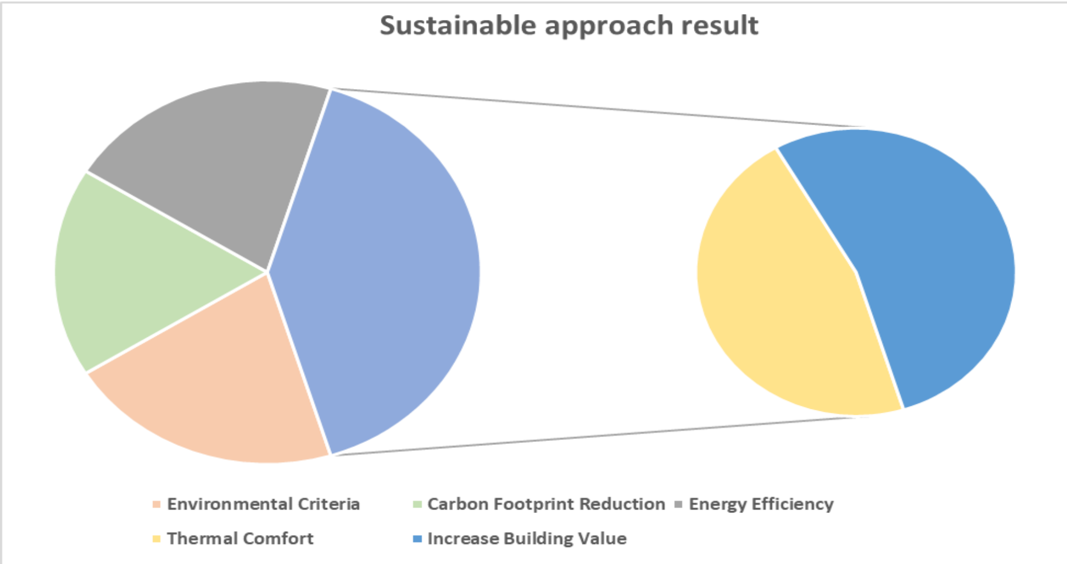


Fig 20. Result of adaptation of different glazing type on sustainable approach.

7. Conclusion

The development of glass façades and the rise in office buildings over the past ten years have had an effect on both the indoor and outdoor climate. This analysis highlights some of the most crucial ideas regarding how much energy is used by buildings. Building performance can be improved by choosing and using the proper type of building glazing at an early stage of the design process.

According to the findings, a building can use up to 25% of its total energy load for cooling load through type of advanced glazing in office building, so the influence of the building envelope on energy consumption should not be disregarded. By using Sage-Glass Double Glazing and Thermochromic Glazing can successfully reduce solar transmission through windows and its detrimental impact on building energy consumption and CO2 Emissions.

Table 7. key performance criteria for smart control glass.

Benefits	**Environmental Criteria**			**Carbon Footprint**			**Energy Efficiency**					**Durability**			
Glazing Types	**Impact of Glazing Geometry on Comfort**	**Environmental Conditions**	**Maximise natural light**	**Internal Comfort Range**	**Climatic Conditions**	**High future value benefit**	**Offers comfort and ongoing energy savings consumer.**	**Easy installing and**	**Maintenance cost**	**Retrofitted cost**	**Best U-value rating**	**Sustainable product 100% recyclable**	**Full range of sizes available**	**Contemporary colours**	**Flexibility of design**
Single Glazing clear 3mm								✓					✓		
Single low-E coating 6mm	✓			✓				✓	✓	✓					
Glazing Integrated Photovoltaics	✓	✓			✓		✓								
Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glass	✓			✓				✓					✓	✓	✓
Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glass	✓	✓			✓		✓	✓	✓			✓	✓	✓	✓
Thermochromic Glazing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sage-Glass Double Glazing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

On another hand using Double Argon Low E: 4mm low E glass- 16 mm Argon- 4mm clear glazing and Double Aerogel glazing: 6mm glass- 16 mm granular aerogel- 6mm glazing almost give very close results in reduction of cooling loads compared to the base case. Additionally, Single clear 3mm glazing represents the worst choice for cooling loads demand, which is not give much effect on cooling loads.

References

[1] Bohl, D. K., Hanna, T. L., Scott, A. C., Moyer, J. D., & Hedden, S. G. (2018). Sustainable Development Goals Report: Egypt 2030; Frederik S. Pardee Center for International Futures, University of Denver: Denver, CO, USA.

[2] IRENA, I. (2018). Renewable energy outlook: Egypt. International Renewable Energy Agency Abu Dhabi.

[3] Hanna, G. B. (2015, September). Energy efficiency building codes and green pyramid rating system. In Renewable Energy in the Service of Mankind Vol I: Selected Topics from the World Renewable Energy Congress WREC 2014 (pp. 597-608). Cham: Springer International Publishing.

[4] Abdelrady, A., Abdelhafez, M. H. H., & Ragab, A. (2021). Use of insulation based on nanomaterials to improve energy efficiency of residential buildings in a hot desert climate. Sustainability, 13(9), 5266.

[5] El-Shamy, H. M. (2019). Economic effects of renewable energy in Egypt. International Journal of Social Science and Economic Research, 4(5), 3726-3741.

[6] Aly, A. M., Hassn, M. H., Abdel Rady, Y. R., & Mohammed, A. T. (2020). The effect of using nano-materials in external openings on energy consumption in hot desert climate. JES. Journal of Engineering Sciences, 48(3), 468-477.

[5] Faggal, A. A., Moustafa, A. M., & Arafat, M. Y. (2019). EFFECT OF DIFFERENT WINDOWS'GLAZING TYPES ON ENERGY CONSUMPTION OF A RESIDENTIAL BUILDING IN A HOT-ARID CLIMATE. *Journal of Engineering Sciences Assiut University*.

[6] Chen, Z., Hammad, A. W., Kamardeen, I., & Akbarnezhad, A. (2020). Optimising embodied energy and thermal performance of thermal insulation in building envelopes via an automated building information modelling (BIM) tool. Buildings, 10(12), 218.

[7] Alghamedi, R., Vasiliev, M., Nur-E-Alam, M., & Alameh, K. (2014). Spectrally-selective all-inorganic scattering luminophores for solar energy-harvesting clear glass windows. Scientific reports, 4(1), 6632.

[8] Liao, W., & Xu, S. (2015). Energy performance comparison among see-through amorphous-silicon PV (photovoltaic) glazings and traditional glazings under different architectural conditions in China. Energy, 83, 267-275.

[9] Mohelnikova, J. I. T. K. A., & Altan, H. A. Ş. I. M. (2009). Evaluation of optical and thermal properties of window glazing. Wseas Transactions on Environment and Development, 86-93.

[10] Alwetaishi, M., & Taki, A. (2020). Investigation into energy performance of a school building in a hot climate: Optimum of window-to-wall ratio. Indoor and Built Environment, 29(1), 24-39.

[11] Valachova, D., Zdrazilova, N., Panovec, V., & Skotnicova, I. (2018). Using of aerogel to improve thermal insulating properties of windows. Civil and environmental engineering, 14(1), 2-11.

[12] Kontoleon, K. J., & Zenginis, D. G. (2017). Analysing heat flows through building zones in aspect of their orientation and glazing proportion, under varying conditions. Procedia environmental sciences, 38, 348-355.

[13] Cots, A., Dicorato, S., Giovannini, L., Favoino, F., & Manca, M. (2021). Energy efficient smart plasmochromic windows: properties, manufacturing and integration in insulating glazing. Nano Energy, 84, 105894.

[14] Bitaab, M., Hosseini Abardeh, R., & Movahhed, S. (2020). Experimental and numerical study of energy loss through double-glazed windows. Heat and Mass Transfer, 56, 727-747.

[15] Oleskowicz-Popiel, C., & Sobczak, M. (2014). Effect of the roller blinds on heat losses through a double-glazing window during heating season in Central Europe. Energy and Buildings, 73, 48-58.

[16] Casini, M. (2014, October). Smart windows for energy efficiency of buildings. In Proceedings of the Second International Conference on Advances in Civil, Structural, and Enviro nmental Engineering (Vol. 273).

[17] Xie, Z., Jin, X., Chen, G., Xu, J., Chen, D., & Shen, G. (2014). Integrated smart electrochromic windows for energy saving and storage applications. Chemical communications, 50(5), 608-610.

[18] Kraja, B. RESPONSIVE SKINS–EVOLVING PARADIGM IN CITIES.

[19] Malmquist, D., Sbar, N., & Electrochromics, S. A. G. E. (2013). The benefits of dynamic glazing.

[20] Ghosh, A., & Norton, B. (2018). Advances in switchable and highly insulating autonomous (self-powered) glazing systems for adaptive low energy buildings. Renewable Energy, 126, 1003-1031.

[21] Silva, T., Vicente, R., Rodrigues, F., Samagaio, A., & Cardoso, C. (2015). Development of a window shutter with phase change materials: Full scale outdoor experimental approach. Energy and Buildings, 88, 110-121.

[22] Xie, Z., Jin, X., Chen, G., Xu, J., Chen, D., & Shen, G. (2014). Integrated smart electrochromic windows for energy saving and storage applications. Chemical communications, 50(5), 608-610.

[23] Hur, M. G., Masaki, T., & Yoon, D. H. (2014). Thermochromic properties of Sn, W co-doped VO2 nanostructured thin film deposited by pulsed laser deposition. Journal of Nanoscience and Nanotechnology, 14(12), 8941-8945.

[24] Diop, D. K., Simonot, L., Martínez-García, J., Hébert, M., Lefkir, Y., Abadias, G., ... & Destouches, N. (2017). Spectral and color changes of Ag/TiO 2 photochromic films deposited on diffusing paper and transparent flexible plastic substrates. Applied Spectroscopy, 71(6), 1271-1279.

[25] Wu, L. Y., Zhao, Q., Huang, H., & Lim, R. J. (2017). Sol-gel based photochromic coating for solar responsive smart window. Surface and Coatings Technology, 320, 601-607.

[26] Jostmeier, T., Mangold, M., Zimmer, J., Karl, H., Krenner, H. J., Ruppert, C., & Betz, M. (2016). Thermochromic modulation of surface plasmon polaritons in vanadium dioxide nanocomposites. Optics Express, 24(15), 17321-17331.

[27] Krašovec, U. O., Orel, B., Georg, A., & Wittwer, V. (2000). The gasochromic properties of sol–gel WO3 films with sputtered Pt catalyst. Solar Energy, 68(6), 541-551.

[28] Granqvist, C. G. (Ed.). (1995). Handbook of inorganic electrochromic materials. Elsevier.

[29] Niklasson, G. A., & Granqvist, C. G. (2007). Electrochromics for smart windows: thin films of tungsten oxide and nickel oxide, and devices based on these. Journal of Materials Chemistry, 17(2), 127-156.

[30] Li, H., McRae, L., Firby, C. J., Al-Hussein, M., & Elezzabi, A. Y. (2018). Nanohybridization of molybdenum oxide with tungsten molybdenum oxide nanowires for solution-processed fully reversible switching of energy storing smart windows. Nano Energy, 47, 130-139.

[31] Gao, T., Ihara, T., Grynning, S., Jelle, B. P., & Lien, A. G. (2016). Perspective of aerogel glazings in energy efficient buildings. Building and Environment, 95, 405-413.

[32] DesignBuilder. User Manual; v6.1.0.6; Design Builder Software Ltd.: Stroud, UK, 2021. Available online: https://designbuilder.co. uk/download/documents (accessed on 11 December 2022).

[33] Briones-Llorente, R., Muñoz-Rujas, N., Martín, A., Millán, J. A., Rodríguez, Á., Aguilar, F., & Rubio-Pérez, G. (2023). Comparative Study of Building Energy Simulation Software Applied to Research Projects. Cases of Study in Spain and Portugal. In Building Engineering Facing the Challenges of the 21st Century: Holistic Study from the Perspectives of Materials, Construction, Energy and Sustainability (pp. 485-507). Singapore: Springer Nature Singapore.

[34] Al-Tamimi, N. (2022). Building envelope retrofitting strategies for energy-efficient office buildings in Saudi Arabia. Buildings, 12(11), 1900.

[35] Radhi, H. (2010). On the optimal selection of wall cladding system to reduce direct and indirect CO2 emissions. Energy, 35(3), 1412-1424.

Appendix

List of Abbreviations

- Green building (GB)
- Solar Heat Gain Coefficient (SHGC),
- visual transmittance (VT)
- Ultraviolet (UV)
- **Thermal transmittance (U-Value)**
- **Temperature difference per unit of heat flux (R-value)**
- **Visible Light Transmission**(VLT)
- **Window to Wall Ratio (WWR)**
- Building management system (BMS)
- **Suspended particle devices (SPD)**
- **Liquid crystal devices (LCD)**
- **Electrochromic devices (EC)**
- **Thermochromic glazing**