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ORIGINAL STUDY

Assessing the Utilization of Glazing Types and Alternatives in Office Buildings to Reduce Energy Consumption and Carbon Emissions

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Abstract

According to Egypt's Vision 2030 and the recommendations of the Climate Conference, Cop 27, Egypt seeks to reduce energy consumption and emissions, especially carbon, by calculating the carbon footprint and moving towards issuing carbon certificates. The building envelope elements strongly impact energy consumption and carbon emissions. Glass is one of the most influential elements. Therefore, it is necessary to study the effect of glassing on energy consumption. The study aims to evaluate the use of glazing types and their alternatives to reduce energy and carbon consumption in administrative buildings by developing an estimation approach for assessing administrative buildings' energy performance and carbon dioxide (CO_2) emissions. This approach could help consumers and the government make decisions about converting to energy-efficient and zero-carbon products by selecting different types of glass. To achieve the goals, the study focuses on studying some types of glass and their alternatives, their properties, and the impact of using these alternatives on energy consumption and carbon emissions. Then determine the efficiency of glazing types and their alternatives and the percentage of their impact on reducing carbon emissions, carbon equivalents, and energy conservation by making simulations in the design builder program. The results concluded that using glass alternatives reduces energy consumption in different proportions. The research demonstrates that utilizing alternative glass is more energy-efficient than single, double, and nearly triple glazing by simulating the four cases. The best alternatives for glass are silica aerogels (2 mm glass, 12 mm aerogel, and 2 mm glass), which reduce the percentage of embodied carbon ($kgCO_2$) by 40%, the percentage of equivalent CO_2 ($kgCO_2$) by 43%, and the percentage of energy by 35% compared with the base case. Developers and building owners will find value in the results of the research because they can use them to reduce energy and minimize carbon emissions.

Keywords: Carbon emissions, Design builder, Energy conservation, Glazing types-glass alternatives

1. Introduction

The Egyptian code of energy efficacy used to calculate the energy consumption of buildings in Egypt includes the Building Thermal Insulation Code. They aim to reduce the energy requirements of buildings and enhance energy efficiency (Xue et al., 2023; Zhao et al., 2024).

The global energy and climate challenges must be resolved, and this requires increasing building energy efficiency (Badakhsh and Bhagavathy, 2024).

Buildings use almost 40% (Yadollahi and Rasouli, 2024) of the energy used worldwide (Xiao et al., 2023; Rashid et al., 2017) management skills, windows are one of the many energy-inefficient building components in modern buildings, accounting for over 60% of all energy loss (Balali et al., 2023). Due to their poor thermal properties.

Glass windows and doors, which provide most of the building envelope's heat and energy exchange with the outside environment, are important contributors to building energy conservation (Chao et al., 2023). 50% of the building envelope's energy consumption is primarily derived from windows and doors (Xu et al., 2023). So, it is important to use efficient materials to reduce energy consumption.

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A considerable amount of non-renewable energy is consumed by the construction sector, which also contributes to an important percentage of carbon dioxide (CO_2) emissions (Kolmas, 2023). Roughly 39% (Latré et al., 2020; Khamchiangta and Yamagata, 2024) of the yearly world CO_2 emissions come from buildings (Fig. 1). According to reports, the building construction sector in both developed and developing countries accounts for almost one-third of global energy consumption and CO_2 emissions (Ahmed et al., 2020; Khdary et al., 2022; Liao et al., 2024).

Energy conservation and emission reduction are necessary since the fast urbanization process will cause an important increase in CO_2 emissions (Xiao et al., 2023; Lin and Ullah, 2024; You et al., 2023).

COP28 highlighted the essential interplay importance of technological innovations to mitigate environmental pollution and achieve net-zero carbon emissions (Hu et al., 2024; Gao et al., 2024).

According to statistics from the Emissions Database for Global Atmospheric Research, the CO_2 emissions from buildings in Egypt are increasing. During the last 10 years, Emissions Database for Global Atmospheric Research n.d (Fig. 2).

Previous investigations about A new framework are established in this study to estimate changes in carbon emissions from urban residential buildings and the associated reduction potentials in three different scenarios in Jiangxi Province up to 2060. The framework consists of four building phases under a system dynamic model. The study's findings suggested that seven carbon abatement strategies were implemented during four building activities and that the overall carbon reduction did not equal the sum of the strategies' prospective reductions in carbon (You et al., 2023). Certain carbon abatement measures have shown synergistic effects; for example, low-carbon electrification reduces carbon emissions during building operation most significantly when combined with clean energy power generation. This was a comprehensive carbon reduction measure.

The current research focuses on two main areas of the building sector's carbon emissions in connection to the local climatic zone (LCZ) classification. First, it assessed the current daily energy consumption patterns for weekdays and weekends to determine the carbon emissions in the building sector (Latré et al., 2020). It focused on mapping urban carbon emissions related to LCZ. The case study utilized the Bangkok Metropolitan Administration (BMA), with 2016 serving as the foundational year for the analysis. The findings show that indirect emissions in Bangkok have the potential to exceed direct emissions by a factor of 10. According to the investigation, some LCZs had a comparatively higher carbon emission intensity than others, including large low-rise, warehouse zones, light industry, and compact high-rise.

Consequently, it is necessary to investigate glazing materials that offer improved energy efficiency, visual comfort, and sustainability to help achieve the goal of Egypt Vision 2030. Developing sustainable solutions is essential to reducing carbon emissions and improving energy efficiency. So this paper focuses on studying glazing types and the alteration of glass, then using a simulation program to evaluate the effect of on energy savings and carbon emissions by using the Design Builder program.

The methodology of this paper is an applied analytical study. At first, the literature and previous studies included studying glass, its properties and colors, and the impact of its use on energy and carbon. Then, for the applied analytical study, a building was chosen, the climate data for the climate region in which it was located was entered, an analysis of the environmental conditions was performed on the Climate Constant 6 program, and

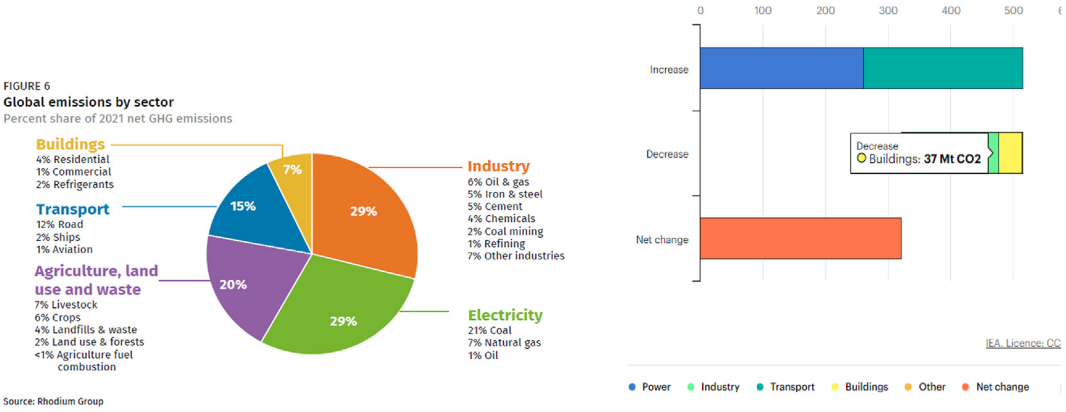


Fig. 1. Yearly world carbon dioxide emissions come from building, sources (Zhao et al., 2024).

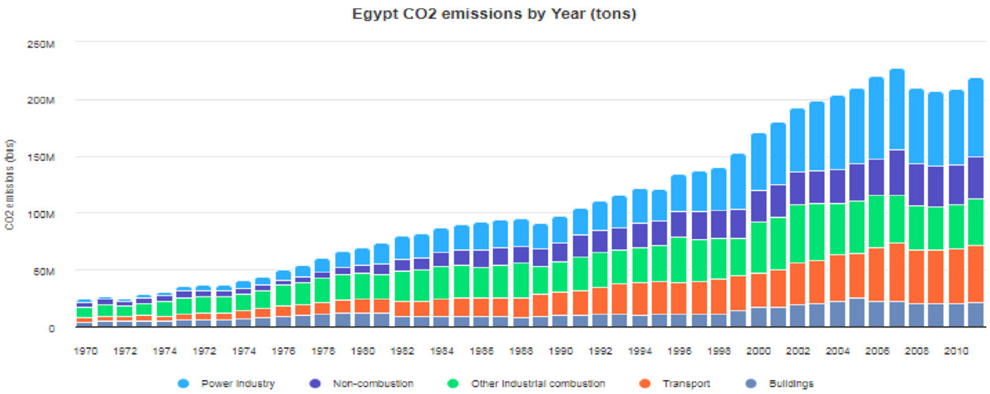


Fig. 2. Carbon Dioxide (CO_2) emissions of Egypt from building, source https://www.worldometers.info/co2-emissions/egypt-co2-emissions/.

then the building was simulated on the Design Builder program. 7 To evaluate the impact of glass and its alternatives on energy conservation and reducing carbon emissions (Fig. 3).

2. Glazing types in building

In this part, the paper focuses on an explanation of the difference between the materials in terms of architectural and engineering formation, their shape and color, and their properties.

The study focuses on the following types of glass Double Glass, Sage Glass Climaplus, and Triple Glass.

2.1. Double glass (2 panes of glass, each 6 mm separated by a cavity

A double-glazed unit with tinted glass that is either bronze or gray on the outside and clear on the inside features two layers of glass. There's an air gap between these two levels. Because there is insulating air space between the glass layers in double glazing, heat loss is reduced in comparison to single glazing. The energy performance of glass goods tinted gray and bronze is comparable. The bronze or gray tint's main objective is to lessen solar heat uptake (Fig. 4).

(a) Colour and types: it has many types with different colours and different thermal insulation such as blue 6 mm/13 mm air, Dbl Blue 6 mm/13 mm Arg, Dbl Clr Low Iron 3 mm/13 mm Arg, Dbl Elec Abs Bleached 6 mm/13 mm Air, Dbl Elec Abs Bleached 6 mm/13 mm Arg, Dbl Elec Abs Colored 6 mm/13 mm Air, Dbl Elec Abs Colored 6 mm/13 mm Arg, Dbl Green 6 mm/13 mm Air, Dbl Green 6 mm/13 mm Arg, Dbl Grey 6 mm/13 mm Air, and Dbl Grey 6 mm/13 mm Arg.

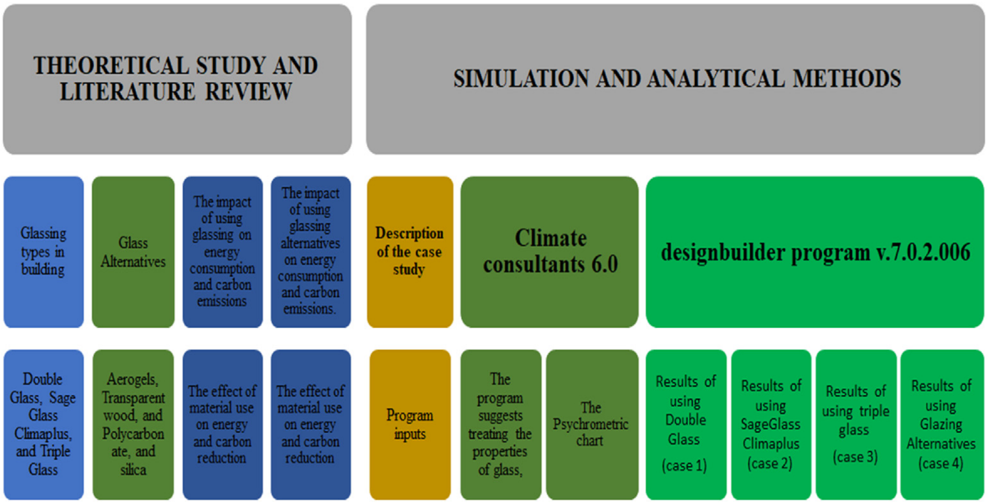


Fig. 3. The methodology of this paper.

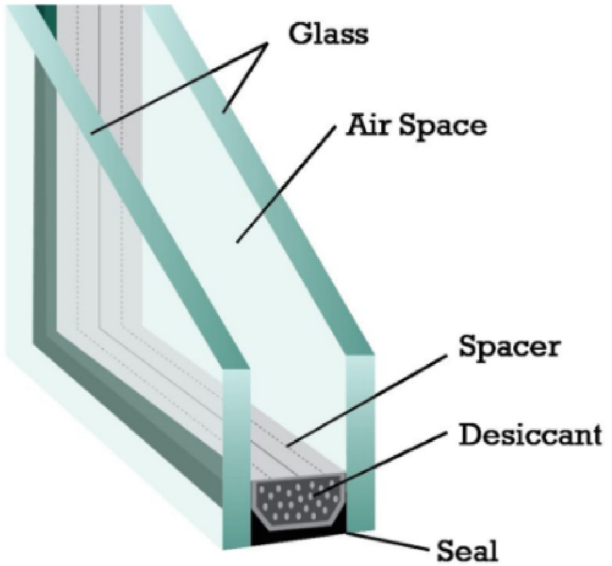


Fig. 4. Double Glass (two panes of glass, each 6 mm separated by a cavity).

(b) Properties: The properties of a double-glazed unit with bronze or gray-tinted glass are that the U-factors range between 7.21 and 0.80 (W/m^2K), solar heat transmitted SHGC is 0.63, and visible light transmitted is 0.61 in the case of the two layers of glass, with the outer layer of glass being bronze or gray tint and the inner layer being clear (Torres et al., 2024).

2.2. Sage glass climaplus

An inventive electrochromic is called SageGlass. It is dynamic glass that stays transparent while progressively changing from clear to colored (and back again) using a low-voltage current.

Thus, it is possible to regulate the amount of heat, light, and glare within a structure without ever obstructing the view of the exterior.

SageGlass is available in double- and triple-glazed insulated units. Affords maximum comfort and improves the building's energy efficiency (Fig. 5).

(a) Color and types: SageGlass Climaplus Blue, SageGlass Climaplus Green, SageGlass Climaplus Grey, and Thermochromic Glazing.

(b) Properties: The properties of Sage Glass Climaplus are Visible Light transmission is from 0.12 to 0.03, and SHGC is 0.287. The properties of electrochromic glass and conventional low-E glass are comparable. The distinction is that typical low-e coatings are fixed, but the electrochromic coating constantly modifies VLT and SHGC properties. Typical U-values of windows range from 0.6 to 1.2 W/(m^2·K) (Xin et al., 2023; SageGlass Europe & Middle East, 2024).

Fig. 5. Sage glass climaplus.

2.3. Triple glass (3 panes of glass, each 6 mm separated by a cavity)

It consists of three layers of glass, including two layers of air insulation, and is characterized by a high degree of insulation. It is considered the most expensive type (Fig. 6).

(a) Colour and types: Trp Clr 3 mm/13 mm Air, Trp Clr 3 mm/13 mm Arg, Trp LoE Film (66) Bronze 6 mm/6 mm Air, Trp LoE Film (66) Clr 6 mm/13 mm Air, Trp LoE Film (33) Bronze 6 mm/13 mm Air, Trp Clr 3 mm/25 mm Air for mid-pane blinds, Trp Clr 6 mm/25 mm Air for mid-pane blinds, Trp LoE (e2 = e5 = 0.1) Clr 3 mm/13 mm Air, and Trp LoE (e2 = e5 = 0.1) Clr 3 mm/13 mm Arg.

(b) Properites: Triple glass is the emittance of the low-E coated surface. e = 0.08, $^{3}/_{8}$–½″ air or argon spaces, SHGC is 0.39. Typical U-values of windows are from 0.6 to 1.31 W/(m^2·K) (Almasri, 2024).

3. Glazing alternatives and substitutes

The study focuses on the following types of Glazing Alternatives such as Aerogels, Transparent wood (TW), and Polycarbonate, and silica.

3.1. Aerogels

Aerogels is an alternative material for glass that is characterized by its light weight, high transparency,

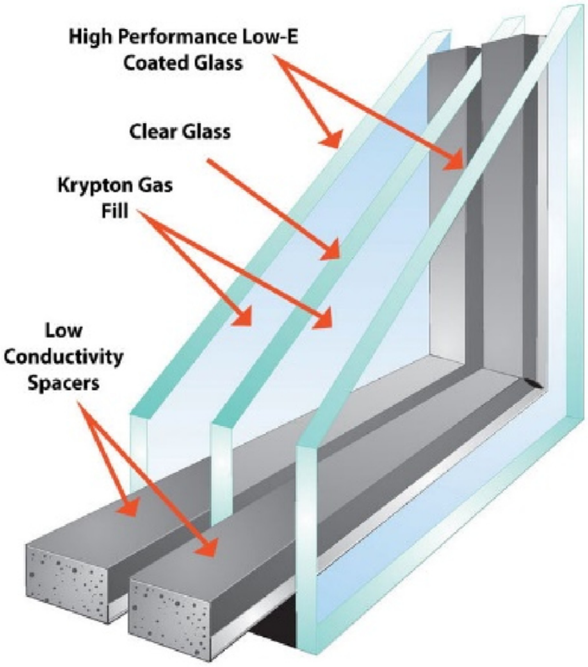


Fig. 6. Triple Glass (three panes of glass, each 6 mm separated by a cavity) https://www.royaltywindows.com/cost-triple-pane-windows/.

good thermal insulation, and high heat resistance. It is one of the Aerogels that represent highly porous solid materials with low density and do not resemble gel in their physical properties.

It consists of silica and air; the insulation property increases when carbon is added, which is characterized by its ability to absorb infrared rays. It also helps in providing natural lighting, saving energy, and achieving thermal efficiency (Abdul Latif et al., 2018; Huang et al., 2018) by installing glass panels filled with air gel, as was used in a university building and an exhibition. Yale Sculpture, which, by lowering the amount of heating and cooling necessary, lowers energy consumption and CO_2 emissions.

A thin-profile aerogel-insulated glazing unit that can replace glass panes to improve the energy efficiency of windows (Figs 7–9).

Silica aerogels is the lightest solid material, which has ultralow thermal conductivity, high porosity, and small particle diameters. Additionally, original silica-based materials that mix the capabilities of silica with other elements to form a new and reinforced architecture with highly valuable applications in various industries have been made possible

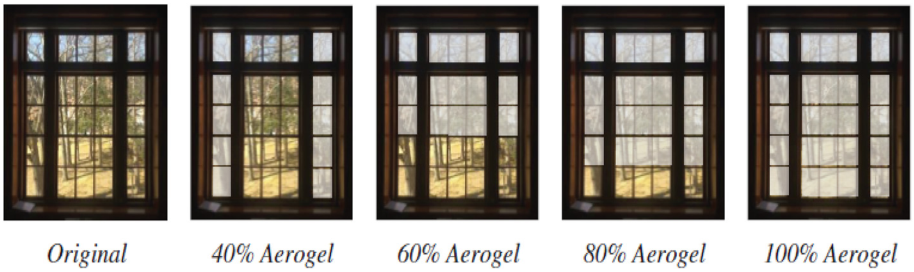
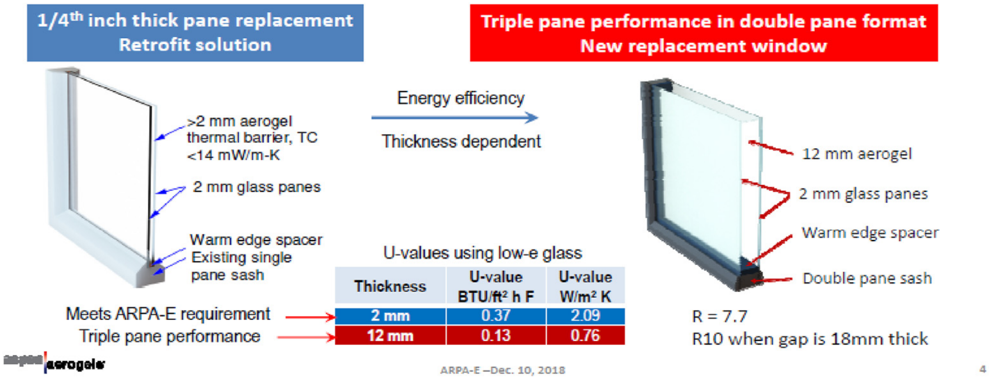

Original *40% Aerogel* *60% Aerogel* *80% Aerogel* *100% Aerogel*

Fig. 7. Glass with Aerogel, Berardi, U. (2015). Development of glazing systems with silica aerogel. Energy Procedia, 78, 394–399.


1/4th inch thick pane replacement
Retrofit solution

Triple pane performance in double pane format
New replacement window

>2 mm aerogel thermal barrier, TC <14 mW/m-K
2 mm glass panes
Warm edge spacer
Existing single pane sash

Energy efficiency
Thickness dependent

12 mm aerogel
2 mm glass panes
Warm edge spacer
Double pane sash

U-values using low-e glass

Thickness	U-value BTU/ft² h F	U-value W/m² K
2 mm	0.37	2.09
12 mm	0.13	0.76

Meets ARPA-E requirement → 2 mm
Triple pane performance → 12 mm

R = 7.7
R10 when gap is 18mm thick

aerogels

ARPA-E –Dec. 10, 2018

4

Fig. 8. Lawrence berkeley National Laboratory, National renewable energy Laboratory, research Triangle Institute, 2018, Aerogel insulated glazing unit (A-IGU) ARPA-.

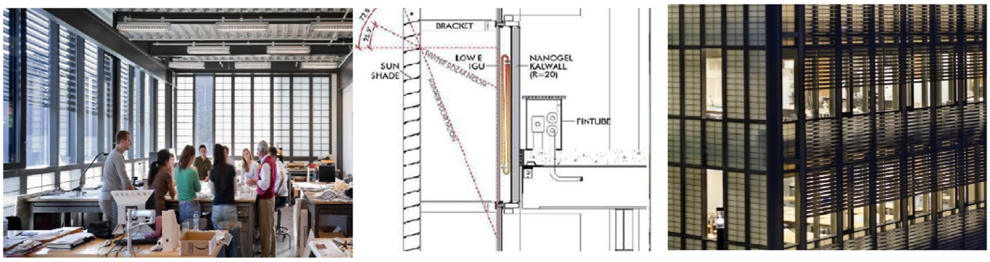


Fig. 9. The sculpture building, which uses aerogel in glass https://www.aiatopten.org/node/126.

by advances in synthesis techniques (Xue et al., 2023; Liao et al., 2024; Hu et al., 2024).

(a) Colour: Aerogels are transparent no color and little scattering effect.
(b) Properties: The bulk density varies between 3 and 300 kg/m^3, but the skeletal density is roughly 2200 kg/m^3, while the air density is roughly 1.2 kg/m^3 (Liu et al., 2021; Lamy-Mendes et al., 2018).

This substance is used as an isolating material because to its extremely low thermal conductivity, which is lower than that of still air. This lower value is at 0.02 W/mK in ambient pressure and 0.01 W/mK in evacuated settings (Mohammed et al., 2023; Song et al., 2023; Niculescu et al., 2024).

3.2. Translucent wood

The two main steps in making TW are coloring removal and polymer impregnation. The coloured lignin is modified or removed by soaking, brushing, or applying a bleaching solution to boards or veneer portions. After that, the wood can be made transparent by soaking it in a clear polymer like epoxy resin (Albalawi, 2024; Binyaseen et al., 2024).

Translucent wood using a few steps. The polymer lignin, which gives wood its strength and color, is first removed from the wood's cell walls during the production process (Samanta et al., 2022).

This process depends on Thicker samples. The choice of wood species also significantly impacts the delignification process (Fig. 10).

This is because various hardwood and softwood species differ in lignin content, Softwood species usually exhibit superior transparency due to their lower lignin content (Zhou et al., 2024).

Colour: TW is no color (Bisht et al., 2024).

(a) Properites: TWC has a good mix of mechanical (Bisht et al., 2022), thermal insulation qualities (thermal conductivity 0.36 W/mK) (Hegazy, 2020; Okonta, 2023; Fu et al., 2018), good optical transmittance (more than 80%) combined with high haze (more than 80%) (Bisht and Pandey, 2024). It is a viable option for use as an optically active transparent

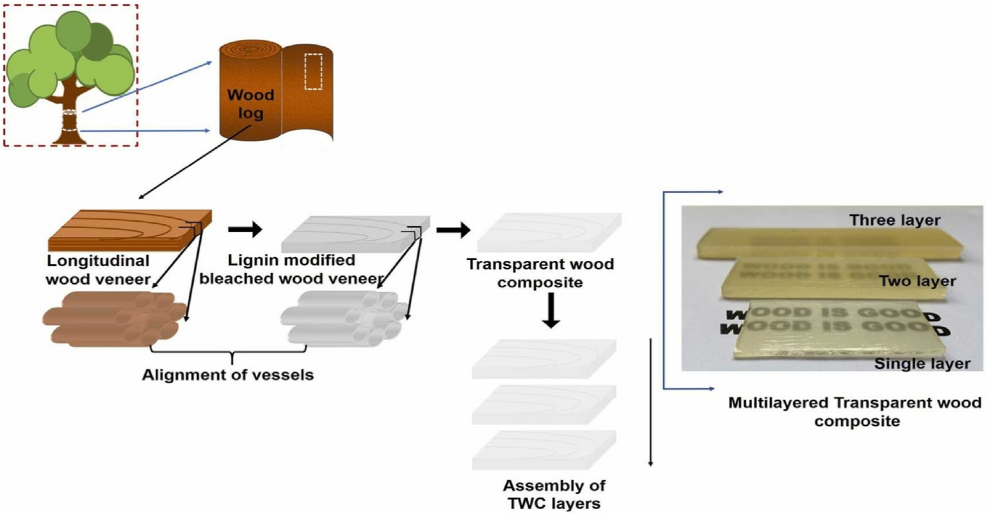


Fig. 10. Translucent wood, steps in making transparent wood https://knowablemagazine.org/content/article/technology/2023/why-scientists-are-making-transparent-wood.

material for energy-efficient smart windows, roofing, light-transmitting and harvesting (Xu et al., 2023), and other applications.

3.3. Polycarbonate

Due to its various degrees of translucency and ability to give the best possible light transmission and diffusion, polycarbonate has emerged as an enticing veneer substitute for glass. It can withstand temperatures ranging from −40 °C to 115 °C and is also lightweight, flexible, recyclable, strong, impact-resistant, and ultraviolet protected. However, in addition to its practical uses, this thermoplastic offers a plethora of artistic possibilities, enabling architects to design facades that are very dynamic and expressive.

Polycarbonate is used in the manufacture of lighting units with high light transmittance (Zheng et al., 2024). It is used in colored glass domes on ceilings and is widely used in the field of processing openings (Onatayo et al., 2024) (Fig. 11).

It is characterized by its strong resistance to shocks, in addition to being a good insulator of electricity, energy performance and having high transparency (Hu et al., 2023; Gupta et al., 2024), like glass in light transmittance. It is also resistant to fire (Satriopratomo et al., 2024; Moretti et al., 2018).

(a) Color and types: While these can be practically any color, common colors are grey and bronze.

(b) Properties: u-value is 1.90–5.7 (w/m^{2}K) if the thickness (mm) is from 10 to 32 mm and the R-Value is from 0.145 to 0.513 (m^{2}k/w) For 16 and 40 mm, the light transmittance is 0.61 and 0.42, correspondingly (Onatayo et al., 2024; Aguilar-Santana et al., 2020).

4. The impact of using glazing on energy consumption and carbon emissions

In comparison to double glazing, triple glazing lowered heat transfer by 50%, according to a study that performed a thorough parametric analysis on glazing types and air gap thickness. Furthermore, in a different study, the thickness of the insulating material significantly affected the U-value, or overall heat transfer coefficient, for vertical windows, outweighing the effect of glazing emissivity. After looking at how the number of glass layers and air gap thickness affected the U-value for sloped windows, we found that adding more air gap thickness increased the U-value by 10%.

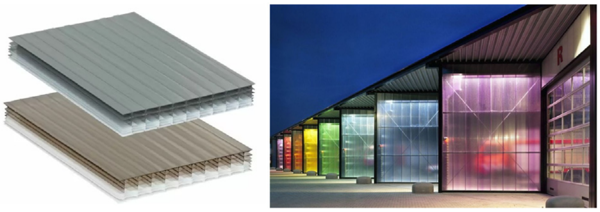


Fig. 11. Color of polycarbonate in window, https://www.archdaily.com/950927/expressive-polycarbonate-creating-colored-translucent-facades.

5. The impact of using glazing alternatives on energy consumption and carbon emissions

Overview of the literature that evaluates TIMs made of embedded polycarbonate. The experiment results, especially the long-term temperature response and passive solar gain data, are described in the distribution impact of different polycarbonate based TIMs on the effectiveness of the façades; The results show that the type of sunlight absorbing used has a considerable impact on the thermal performance of the solar facades that were tested; the difference might range from 35% to 54%. Additionally, the incorporation of prismatic glass when used with a basic two-wall polycarbonate panel can minimize solar penetration (‘EDGAR).

In study about TW was treated with a solar-blocking coating (Cs0.33WO3) as part of a study on the adoption of simple spin coating. Evaluations of the heat shield's ability to deflect solar radiation and potentially save energy were done through models and field testing. According to energy-saving calculations based on experimental results. With a 46.63% decrease in solar transmission over the original TW, the heat-shielding TW showed impressive solar-blocking capabilities.

When compared with typical glass, such heat-shielding TW provided energy savings of 9.6, 7.7, and 6.2%, providing increased energy efficiency (Zhou et al., 2024).

Overview of the literature that evaluates TIMs made of embedded polycarbonate. The experiment results, especially the long-term temperature response and passive solar gain data, are described in the distribution impact of different polycarbonate-based TIMs on the effectiveness of the façades; the results show that the type of sunlight absorbing used has a considerable impact on the thermal performance of the solar facades that were tested; the difference might range from 35% to 54%. Additionally, the incorporation of prismatic glass when used with a basic two-wall polycarbonate panel can minimize solar penetration (‘EDGAR).

A novel wood-based polymeric material known as transparent wood composite (TWC) is created by impregnating an appropriate polymer into a wood substrate that has been treated with lignin. TW is environmentally sustainability and multi-functionality (Zhao et al., 2024; Yadollahi and Rasouli, 2024). TWC is used in a variety applications, including as energy-efficient construction materials, solar cell substrates, light control systems, and TW smart windows (Bisht et al., 2022; Čekon and Struhala, 2018).

6. Simulation and analytical methods

The study applies an applied analytical study is done in three steps. At first, the case study is an existing building using real data and conditions. Consequently, the investigation is equivalent to a controlled experiment rather than a theoretical hypothesis (Fig. 12). The second step is the climate data for the climate region in which it was located. An analysis of the environmental conditions was performed on the Climate Constant 6 program. The third step is making a simulation in the Design-Builder program. 7 To evaluate the impact of glass and its alternatives on energy conservation and reducing carbon emissions.

The methodology applied in this research consists of developing a few variables for the glazing types of the test building, which serves as the basis for the simulations. To calculate and assess energy savings, carbon equivalents, and emissions. It falls into four categories:

First case: utilizing glass double glass (2 panes of glass, each 6 mm separated by a cavity).
Second case: SageGlass Climaplus.
Third case: triple glass, and triple glass (2 panes of glass, each 6 mm separated by a cavity).
Fourth case: glazing alternatives such as aerogels, TW, and polycarbonate, and silica.

6.1. Description of the case study

The building type is an office building (Administrative building at Nahda University), The building is in the new city of Beni Suef, which belongs to the North Upper Egypt region, which contains Beni Suef, Minya, and Fayoum. Which consists of administrative spaces, a theatre on the ground floor, and services. And administrative spaces on the recurring floors (Fig. 13). Curtin wall use in the facade in large areas, where the wall-to-windows ratio is 32% on the Energy Plus program, the climatic data for Minya was entered because it is in the same climatic region.

6.2. Simulation of the case study

The environmental simulation of the building was carried out in two stages, the first using the Climate Constant 6 program and the second using the Design Builder program, which measures the building's carbon emissions and energy consumption.

6.2.1. Climate consultants 6.0

The study used a climate consultant to assist in understanding the local environment's resources and how they impact the efficiency of the buildings. Version 6 of the Climate Consultant was used in this investigation. It offers climate data analysis and visualization to support energy analysis and building design. Climate Consultant 6.0 examines the distribution of this psychometric data in each

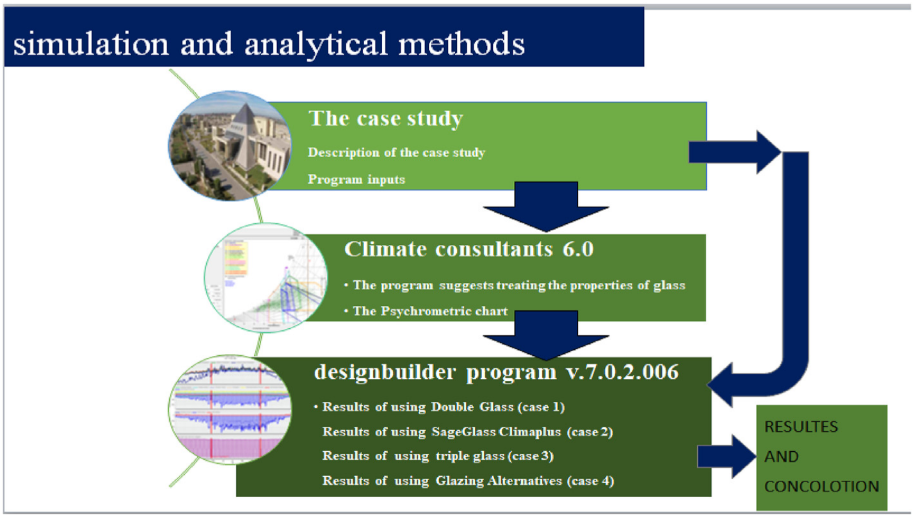


Fig. 12. Simulation and analytical methods.

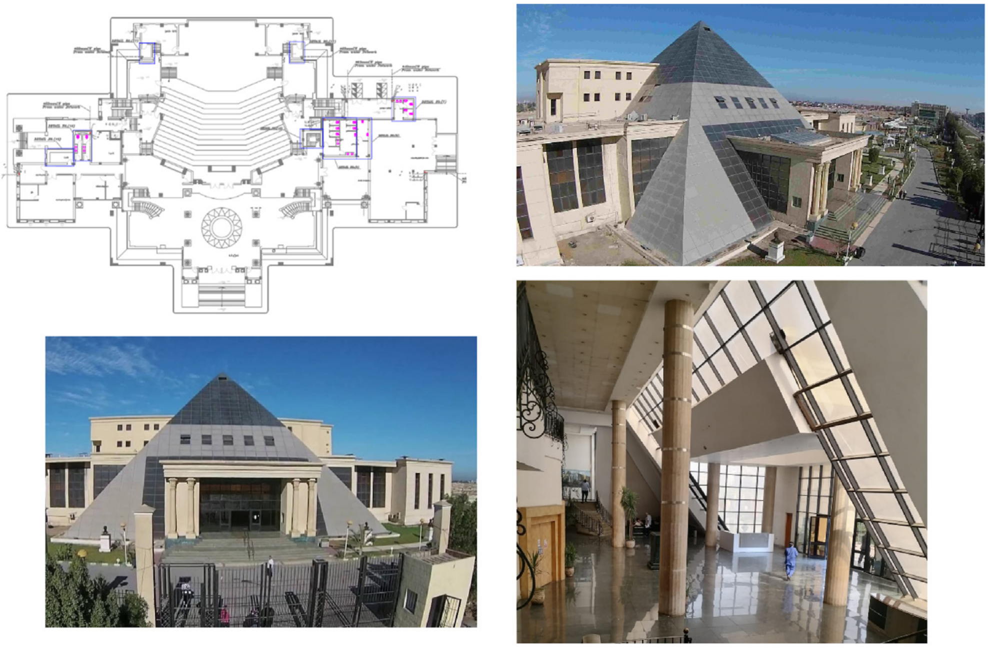


Fig. 13. Plan, exterior, and interior of case study (Administrative building at Nahda University).

Design Strategy zone to provide a unique set of Design Guidelines (Lin and Ullah, 2024; Alegbe, 2023; Tang et al., 2024) (Fig. 14). The study conducted an environmental analysis of the building using the Climate Constant 6 program in order to confirm the validity of the hypothesis that the building needs to treat glass, and single glass is not suitable for the climate region.

The Psychrometric chart provides concepts that, when utilized in application, will raise the level of comfort in buildings (Fig. 15). Using the Psychrometric chart, it shows that 23.3% of the simulations from January to December are inside thermal comfort for 2044 h, while 18.9% are exposed to direct solar radiation for 1659 h, and the internal heat gain reaches 25.9% for 2270 h.

The relative humidity present is from 20 to 60% as an in-timetable plot from the climate consultant program so the region does not need to treat humidity (Fig. 16).

From the sun shading chart of the case study region: 1025 h exposed and 407 h shaded.

As a result of using the Climate Consultant 6.0 program. In the months May to September, they are outside the range of thermal comfort (Fig. 17). The program suggests treating the properties of glass, and this is what will be done in the designbuilder program using different types of glass and its alternatives.

6.2.2. Design builder program v.7.0.2.006

The study uses designbuilder program v.7.0.2.006 to measure the building's carbon emissions and energy consumption.

The building inputs for a case study are listed in the table below (Table 1), which can be used to

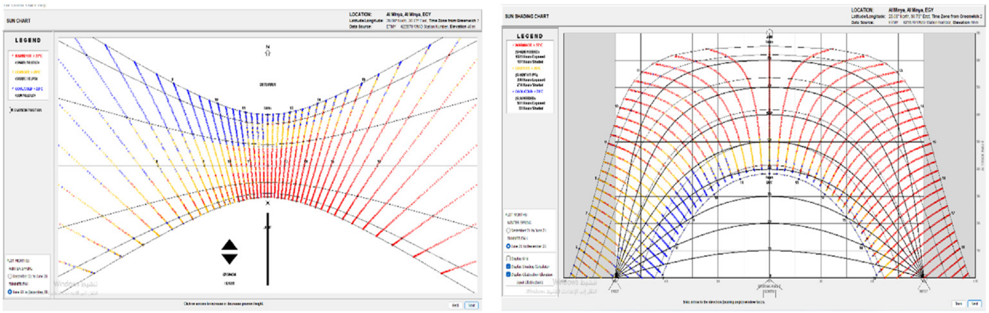
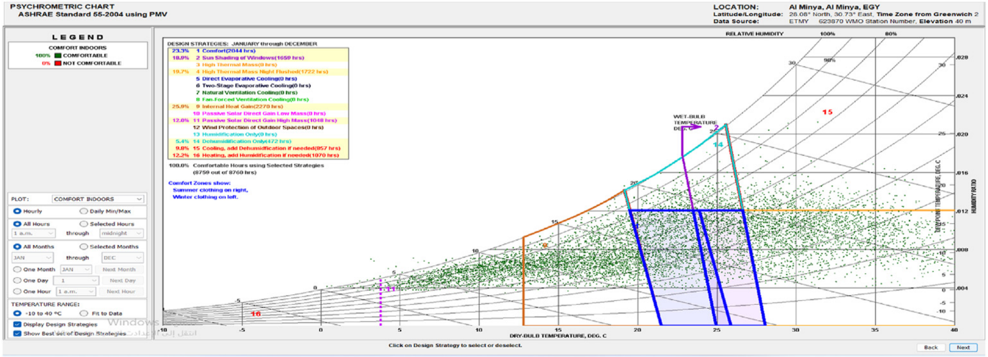


Fig. 14. The sun shading chart of the case study region, Climate Consultant 6.0 program (source researcher).



PSYCHROMETRIC CHART
ASHRAE Standard 55-2004 using PMV

LOCATION: Al Minya, Al Minya, EGY
Latitude/Longitude: 28.08° North, 30.73° East, Time Zone from Greenwich 2
Data Source: ETMY 623870 WMO Station Number, Elevation 40 m

LEGEND
COMFORT INDOORS
100% 🟩 COMFORTABLE
0% 🟥 NOT COMFORTABLE

DESIGN STRATEGIES: JANUARY through DECEMBER

23.3%	1	Comfort(2044 hrs)
18.9%	2	Sun Shading of Windows(1659 hrs)
	3	High Thermal Mass(0 hrs)
19.7%	4	High Thermal Mass Night Flushed(1722 hrs)
	5	Direct Evaporative Cooling(0 hrs)
	6	Two-Stage Evaporative Cooling(0 hrs)
	7	Natural Ventilation Cooling(0 hrs)
	8	Fan-Forced Ventilation Cooling(0 hrs)
25.9%	9	Internal Heat Gain(2270 hrs)
	10	Passive Solar Direct Gain Low Mass(0 hrs)
12.0%	11	Passive Solar Direct Gain High Mass(1048 hrs)
	12	Wind Protection of Outdoor Spaces(0 hrs)
	13	Humidification Only(0 hrs)
5.4%	14	Dehumidification Only(472 hrs)
9.8%	15	Cooling, add Dehumidification if needed(857 hrs)
12.2%	16	Heating, add Humidification if needed(1070 hrs)

100.0% Comfortable Hours using Selected Strategies
(8759 out of 8760 hrs)

Comfort Zones show:
Summer clothing on right,
Winter clothing on left.

PLOT: COMFORT INDOORS
● Hourly ○ Daily Min/Max
● All Hours ○ Selected Hours
1 a.m. through midnight
● All Months ○ Selected Months
JAN through DEC
○ One Month JAN Next Month
○ One Day 1 Next Day
○ One Hour 1 a.m. Next Hour
TEMPERATURE RANGE:
● -10 to 40 °C ○ Fit to Data
☑ Display Design Strategies
☑ Show Best Set of Design Strategies

Fig. 15. Psychrometric chart by the Climate Consultant 6.0 program for the case study region (source researcher).

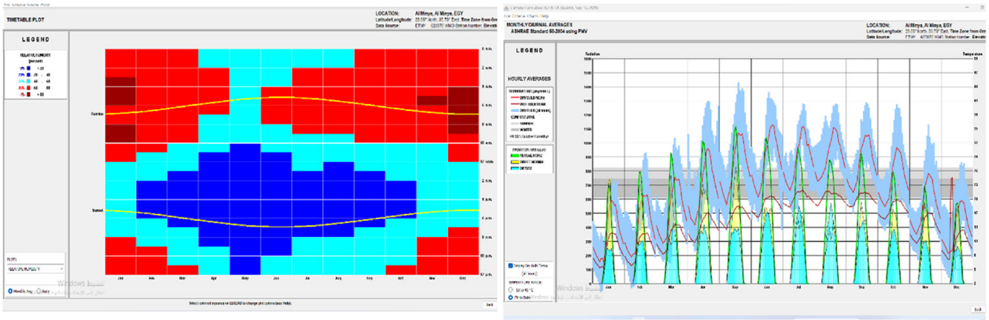


Fig. 16. The relative humidity present in the Climate Consultant 6.0 program for the case study region (source researcher).

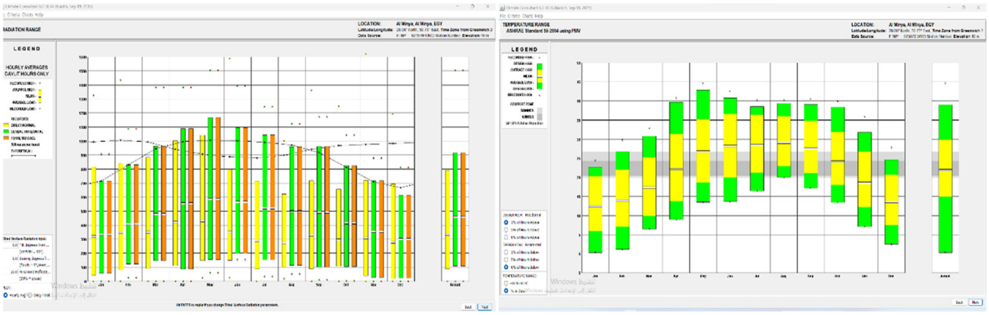


Fig. 17. Temperature range and radiation range measured by the Climate Consultant 6.0 program for the case study region. (Source researcher).

create a simulation in a design builder program after the building is drawn.

7. Results of simulation

The base case model is simulated by the Design Builder software, the model is examining the energy savings and Embodied Carbon ($kgCO_2$), and Equivalent CO_2 ($kgCO_2$).

7.1. Results of using double glass (case 1)

(Dbl Grey 6 mm/13 mm Arg) is more efficient than using (Dbl Green 6 mm/13 mm Arg) and (Dbl Blue 6 mm/13 mm Arg) by reducing carbon emissions by 24.8%, carbon equivalents by 29.1%, and energy consumption by 20.8% (Fig. 18).

Using (Dbl Elec Abs Colored 6 mm/13 mm Air) is better than using (Dbl Elec Abs Bleached 6 mm/

Table 1. Case study inputs for the design builder software.

Parameters	Inputs
Program Version and Build	Energy Plus, Version 9.4.0–217a24fc09, YMD = 2023.11.09 18:05 Design builder
Layout	
Location	Beni Suef
Building orientation	East south
Weather File	Al Minya Al Minya EGY ETMY WMO# = 623870
Latitude [deg]	28.08
Longitude [deg]	30.73
Activity	
Activity template	Offices
Working time	Sunday to Thursday day, from 8:00 am until 5:00 pm
Hours Simulated [h]	8760.00
Lighting type	
HVAC system	
holiday	Holidays 2 days/week
Equipment	computer, printer, and air conditions
Occupancy schedule	From 8:00 a.m. to 17:00 p.m.
Occupant Density	0.0215 People/m2
Metabolic rate	117 W/person
Clothing Insulation	0.5 clo for Summer and 1 clo for winter
Heating setpoint temperatures	Not active
Cooling setpoint temperatures	25 °C
Construction	
Finishing material for external walls	Savito in external walls curtain wall metal partitions
Glazing type	Curtain wall with metal partitions with the required width
Lighting	
Type of Lighting	Fluorescent, compact (CFL)
Opening	
Window to wall ration (WWR)	32%
Shading device	
Glazing type	Single glass gray in basic case
Simulation	
Time of simulation	8:00:17:00, 21 Mar/Sep
Tested façade	East
Type of glazing	Varies

13 mm Air) by reducing carbon emissions by 26%, carbon equivalents by 32.8%, and energy consumption by 22%. While equivalent (Dbl Elec Abs Colored 6 mm/13 mm Arg) and (Dbl Elec Abs Colored 6 mm/13 mm Air) in reducing carbon equivalents with 32.8% and energy consumption with 22%, carbon emissions are reduced to 26% if using (Dbl Elec Abs Colored 6 mm/13 mm Air) and to 27% if utilizing (Dbl Elec Abs Colored 6 mm/13 mm Arg).

Utilizing (Dbl Elec Abs Colored 6 mm/13 mm Arg) reduces carbon emissions by 27.2%, carbon equivalents by 32.1%, and energy consumption by 22% (Table 2).

7.2. Results of using SageGlass climaplus (case 2)

As a result of simulating carbon emissions, carbon equivalents, and energy consumption for the case study, it is clear that (SageGlass Climaplus Gray) reduces carbon emissions by 30% carbon equivalents 36%, and energy consumption by 18.6% while (Thermochromic Glazing) reducing carbon emissions by 31.1%, carbon equivalents 35.4%, and energy consumption by 21.5% (Fig. 19, Table 3).

As a result of the triple glass simulation, it is clear that clear glass is the least efficient type, and its thickness is better than 0000. The use of argon gas is more efficient, as it reduces carbon by a ratio of 2 : 3%, as well as carbon equivalents and energy emissions.

7.3. Results of using triple glass (case 3)

Using (Trp Clr 6 mm/25 mm Air for mid-pane blinds) reduces carbon emissions by 30% carbon equivalents 36%, and energy consumption 18.6% is more efficient than (Trp LoE Film (33) Bronze 6 mm/13 mm Air) after that (Trp Clr 3 mm/13 mm Air) and (Trp LoE Film (66) Bronze 6 mm/6 mm Air) (Fig. 20, Table 4).

7.4. Results of using glazing alternatives (case 4)

In case 4, using Silica Aerogels (2 mm glass, 12 mm aerogel, 2 mm) glass is more efficient than using 10 mm and 8 mm aerogel, which reduces the Percentage of Embodied Carbon (kgCO$_2$) from 32 to 40%, the Percentage of Equivalent CO$_2$ (kgCO$_2$) decreases from 40 to 43%, and Percentage of energy [kWh] reduces from 30 to 35%.

Utilizing Polycarbonate (12 mm bronze) is more efficient than using Polycarbonate (10 mm, 8 mm). That reduces the Percentage of Embodied Carbon (kgCO$_2$) from 28 to 35%, the Percentage of Equivalent CO$_2$ (kgCO$_2$ (from 25% to 40%, and the Percentage of energy [kWh] decreases from 25.8 to 30%.

Acrylic 12 mm reduces the Percentage of Embodied Carbon (kgCO$_2$) from 22 to 26%, Percentage of Equivalent CO$_2$ (kgCO$_2$) decreases from 19.5% to 22%, and the Percentage of energy [kWh] reduces from 17.6 to 21.4% with a change in the thinness of Acrylic from 8, 10, and 12 mm.

Using Aerogels decreases energy flow by 35% compared with TW, which decreases energy by 33%, and polycarbonate PC, which has low energy by 31% (Fig. 21, Table 5).

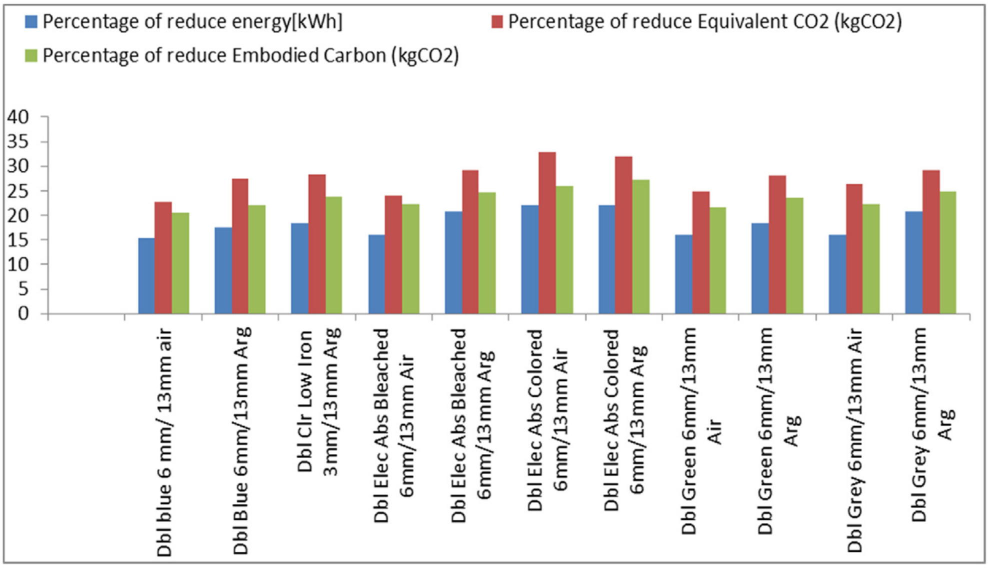


Fig. 18. Results of simulating carbon emissions, carbon equivalents, and energy consumption for case 1.

Table 2. Percentage of redaction emissions case 1.

	Percentage of reduce embodied carbon ($kgCO_2$)	Percentage of reduce equivalent CO_2 ($kgCO_2$)	Percentage of reduce energy [kWh]
Basic case	20401.9	13721.5	19210.9
Dbl blue 6 mm/13 mm air	20.6	22.7	15.3
Dbl Blue 6 mm/13 mm Arg	22.1	27.4	17.6
Dbl Clr Low Iron 3 mm/13 mm Arg	23.7	28.4	18.4
Dbl Elec Abs Bleached 6 mm/13 mm Air	22.3	24.0	16.0
Dbl Elec Abs Bleached 6 mm/13 mm Arg	24.7	29.1	20.8
Dbl Elec Abs Colored 6 mm/13 mm Air	26.0	32.8	22.0
Dbl Elec Abs Colored 6 mm/13 mm Arg	27.2	32.1	22.0
Dbl Green 6 mm/13 mm Air	21.6	24.9	16.1
Dbl Green 6 mm/13 mm Arg	23.6	28.1	18.5
Dbl Grey 6 mm/13 mm Air	22.3	26.4	16.1
Dbl Grey 6 mm/13 mm Arg	24.8	29.1	20.8

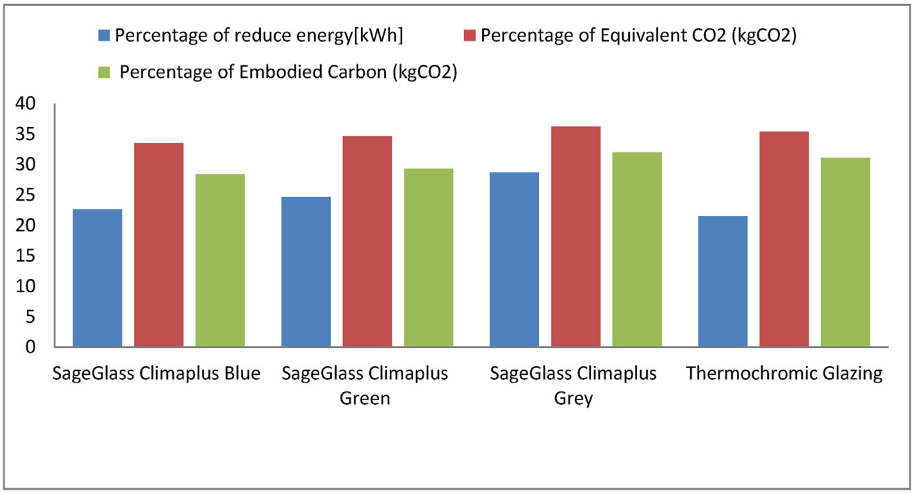


Fig. 19. Results of simulating carbon emissions, carbon equivalents, and energy consumption for case 2.

Table 3. Percentage of redaction emissions case 2.

	Percentage of embodied carbon ($kgCO_2$)	Percentage of equivalent CO_2 ($kgCO_2$)	Percentage of reduce energy [kWh]
Basic case	20401.9	13721.5	19210.9
SageGlass Climaplus Blue	28.4	33.5	22.6
SageGlass Climaplus Green	29.3	34.6	24.7
SageGlass Climaplus Grey	32.0	36.2	28.7
Thermochromic Glazing	31.1	35.4	21.5

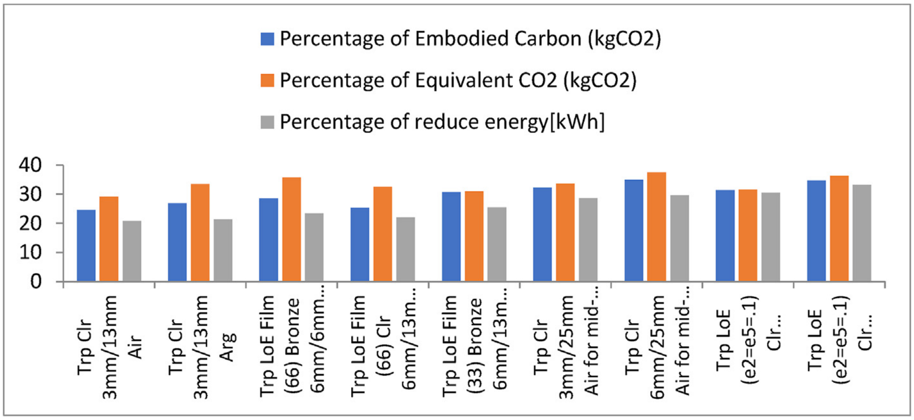


Fig. 20. Results of simulating carbon emissions, carbon equivalents, and energy consumption for case 3.

Table 4. Percentage of redaction emissions case 3.

	Percentage of embodied carbon ($kgCO_2$)	Percentage of equivalent CO_2 ($kgCO_2$)	Percentage of reduce energy [kWh]
Basic case	20401.9	13721.5	19210.9
Trp Clr 3 mm/13 mm Air	24.5	29.1	20.8
Trp Clr 3 mm/13 mm Arg	26.8	33.4	21.3
Trp LoE Film (66) Bronze 6 mm/6 mm Air	28.5	35.7	23.4
Trp LoE Film (66) Clr 6 mm/13 mm Air	25.4	32.5	22
Trp LoE Film (33) Bronze 6 mm/13 mm Air	30.7	30.9	25.5
Trp Clr 3 mm/25 mm Air for mid-pane blinds	32.2	335	28.6
Trp Clr 6 mm/25 mm Air for mid-pane blinds	34.9	37.4	29.5
Trp LoE (e2 = e5 = 0.1) Clr 3 mm/13 mm Air	31.3	31.5	30.5
Trp LoE (e2 = e5 = 0.1) Clr 3 mm/13 mm Arg	34.7	36.3	33.2

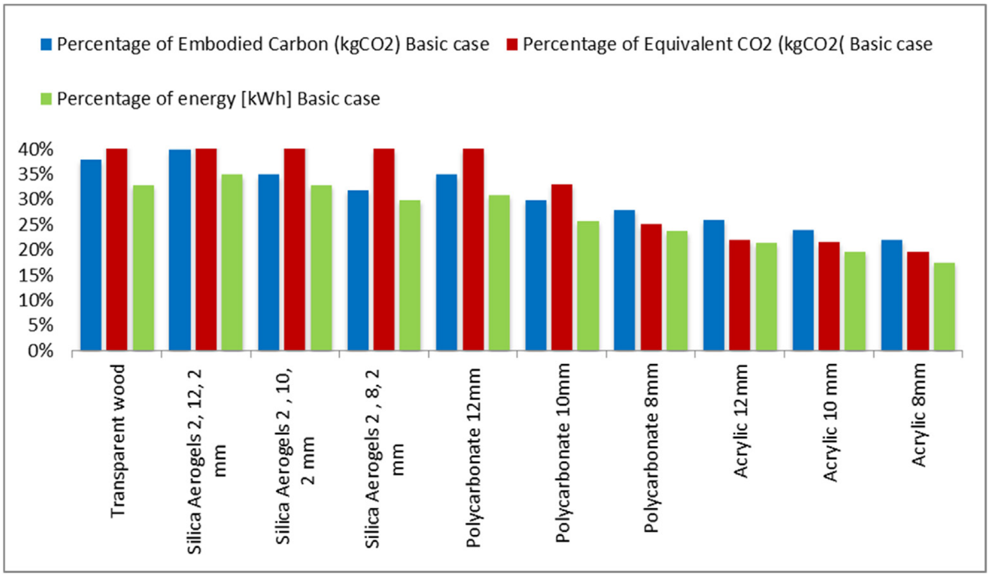


Fig. 21. Results of simulating carbon emissions, carbon equivalents, and energy consumption for case 3.

Table 5. Percentage of redaction emissions case 4.

	Embodied carbon ($kgCO_2$)	Percentage of embodied carbon ($kgCO_2$)	Equivalent CO_2 ($kgCO_2$)	Percentage of equivalent CO_2 ($kgCO_2$)	energy [kWh]	Percentage of energy [kWh]
Basic case	20401.9	Basic case	13721.5	Basic case	19210.9	Basic case
Transparent wood	12649.17	38%	8095.6	41%	12871.3	33%
Silica Aerogels 2 mm glass, 12 mm aerogel, 2 mm glass	12241.14	40%	7821.25	43%	12487	35%
Silica Aerogels 2 mm glass, 10 mm aerogel, 2 mm glass	13261.23	35%	7958.47	42%	12871.3	33%
Silica Aerogels 2 mm glass, 8 mm aerogel, 2 mm glass	13873.3	32%	8232.9	40%	13447.6	30%
Polycarbonate 12 mm bronze	13261.23	35%	8232.9	40%	13255.5	31%
Polycarbonate 10 mm	14281.33	30%	10565.5	33%	14408.17	25.8%
Polycarbonate 8 mm	14689.3	28%	10291.125	25%	16713.4	23.8%
Acrylic 12 mm	15097.4	26%	10702.77	22%	15176.6	21.4%
Acrylic 10 mm	15505.4	24%	10908.5	21.5%	15368.7	19.8%
Acrylic 8 mm	15913.4	22%	11045.80	19.5%	15945	17.6%

8. Results

Using tinted glazing, low-emissivity coatings, double or triple glazing, and glass alternatives improves energy efficiency and carbon emissions in buildings.

Buildings can optimize energy consumption and low carbon emissions by exploring various alternatives during the pre-construction stages, especially when focusing on glazing types and their alternatives.

Single-glazing windows provide high levels of light transmission but lack the thermal insulation required to effectively manage energy consumption in HVAC systems, especially in office buildings that use a wide area of Curtin walls.

Using double and triple glass is cost-effective because it reduced energy usage and the U-value when more glass layers were added.

It is best to use a suitable thickness of insulating material rather than adding more glass layers when utilizing thermal insulation material, such as argon, as this strikes a balance between energy savings and cost reduction for multi-glazed windows.

In addition to providing specific percentages and data regarding how these glazing types perform at different times of the year, including extreme weather scenarios, this paper evaluates the effects of three different glazing types and four types of alternative glass on energy efficiency and the reduction of CO_2 emissions. This research demonstrates how glazing choices can support sustainability goals in contemporary architecture.

Developers and building owners will find value in the results of the research because they can use them to reduce energy costs, minimize the emission of greenhouse gases, and create low-carbon, energy-flexible structures at the lowest possible cost.

In order to minimize energy loss and carbon emissions, it is crucial to use suitable glass. The building's facade, including its Curtain wall system, offers a variety of functions, including natural ventilation, daylight illumination, architectural appeal, and strategic solar gain.

A comprehensive knowledge of heat transfer processes is necessary to increase a building's energy efficiency and carbon emissions. Conduction, convection, radiation, and solar gain are the main physical processes at work here. These processes support critical energy performance metrics for fenestration systems, such as the U-factor and the Solar Heat Gain Coefficient (SHGC). Optimized visible transmittance of the window, to provide reduced thermal transmittance.

It is necessary to measure the energy performance of facade materials, especially the SHGC and U-factor. The rate of heat transmission through a window system as a result of temperature changes between indoor and exterior regions is measured by the U-factor. The percentage of solar energy that enters a window system from the outside and enters the interior is measured by the SHGC. It is therefore crucial to use the most energy-efficient varieties of glass and its substitutes.

The case study simulates and then replaces single glazing with different types of glass and alternatives.

As a result of the type of glass simulation, clear glass is the least efficient type. The use of argon gas is more efficient than air, as it reduces carbon by a ratio of 2:3%, as well as carbon equivalents and energy emissions.

In Case 1, double glazing involves changing the color and thickness of the glass, the insulating material between the two layers of glass, and the type of glass used.

Consequently, in case 1, utilizing (Dbl Elec Abs Colored 6 mm/13 mm Arg) is more efficient than using (Dbl Grey 6 mm/13 mm Arg) flows with (Dbl Green 6 mm/13 mm Arg) and (Dbl Blue 6 mm/13 mm Arg) to reduce carbon emissions by 27.2%, carbon equivalents by 32.1%, and energy consumption by 22%. This is the butter material used in double glass.

Case 2 simulation proves that utilizing SageGlass Climaplus Grey reduces carbon emissions by 32%, decreases the percentage of equivalent CO_2 ($kgCO_2$) by 36.2%, and reduces energy [kWh] by 28.7%.

The use of triple glazing (case 3) is more efficient than double glazing, and the TRP LoE is approximately equal to (e2 = e5). = 0.1 (Clr 3 mm/13 mm Air) with Glazing Thermochromic. Using (Trp LoE (e2 = e5 = 0.1) Clr 3 mm/13 mm Arg) is most efficient in case 3, which reduces energy by 33.2% compared with the basic case, which decreases carbon emission by 34.7% and decreases the percentage equivalent of C (kg CO_2) by 36.3%.

Case 4 involves utilizing Aerogels, TW, and Polycarbonate, and silica. The simulation proves that Aerogels, TW, and Polycarbonate reduce the percentage of Embodied Carbon ($kgCO_2$) by 40, 38, and 35%, respectively.

The Percentage of Equivalent CO_2 ($kgCO_2$) decreases by 43, 41, and 40% when utilizing Aerogels, TW, and Polycarbonate 12 mm bronze.

Consequently, by simulating the four cases, the paper proves that using alternative glass is more efficient than using single, double, or triple glazing.

The most effective alternatives for glass is Silica Aerogels (2 mm glass, 12 mm aerogel, 2 mm glass), as it reduces the Percentage of Embodied Carbon ($kgCO_2$) by 40%, The Percentage of Equivalent CO_2 ($kgCO_2$) by 43%, and energy by 35%.

8.1. Conclusion

In order to decrease carbon emissions and decrease energy consumption, the study's findings highlight the significance of choosing energy-efficient glass and using practical design techniques.

Implementing the recommendations will result in major energy savings, reduced consumption of energy, cost savings, more comfort, and the advancement of sustainable construction behaviors in Egypt.

According to simulation, using SageGlass Climaplus Grey results in 32% fewer carbon emissions, 36.2% fewer equivalent CO_2 ($kgCO_2$), and 28.7% fewer energy units (kWh). Triple glazing is more energy-efficient than double glazing, and with thermochromic glass, the TRP LoE is similar to (e2 = e5 = 0.1) Clr 3 mm/13 mm Air. Triple glass is the most efficient when using (Trp LoE (e2 = e5 = 0.1) Clr 3 mm/13 mm Arg), which saves energy by 33.2% in comparison to the basic case, which also reduces carbon emission by 34.7% and the percentage equivalent of C (kg CO_2) by 36.3%.

This study reveals the use of silica, polycarbonate, TW, and aerogels in construction. The simulation demonstrates that the proportion of embodied carbon ($kgCO_2$) that is reduced by aerogels, TW, and polycarbonate is 40, 38, and 35%, respectively.

This study shows how various varieties of glass affect a building's façade performance as well as how it affects energy use and carbon emissions. Typically, each type of glass utilized and investigated at throughout this study was triple-glazed, low-emission, and argon-filled energy-efficient glass. When compared with situations where there are double-glazed windows, the differences in consequences between the various scenarios are minimal.

Energy performance of facade materials must be measured; U-factor and SHGC measurements are especially important. Owing to temperature variations between indoor and outdoor areas, the U-factor calculates the rate of heat transfer through a window system. The solar energy penetration coefficient (SHGC) measures the amount of solar radiation that enters a window system from the outside to the inside. Therefore, it's critical to use the most effective glass varieties and substitutes.

This paper is the result of a thorough analysis of glazing performance in a particular climate context; the analysis is further detailed by the application of a climate-oriented approach, and the insights are especially useful for ongoing building projects and renovations because they make it easier to design structures that maximize energy efficiency and minimize energy consumption. This aids in the development of more ecologically friendly and sustainable buildings.

For developers and building owners, the results of the study will be helpful as it can be used to decrease energy use, CO_2 emissions, and construction costs while creating energy-flexible, low-carbon structures.

Using alternatives to glass will save energy consumption in buildings and reduce carbon emissions. Therefore, its use must be spread, especially in administrative buildings that have large area of Curtain walls in the facades.

Developers and building owners will find value in the results of the study because they may use them to create low-carbon, energy-flexible structures that use less energy and emit less CO_2.

This study assesses the effects of three different glazing types and four types of alternative glass on energy efficiency and the reduction of CO_2 emissions. It also offers precise percentages and data about the performance of these glazing types throughout the year, including during extreme weather conditions, demonstrating how these glazing options can support sustainability objectives in contemporary architecture.

To increase the sustainability and efficiency of buildings in hot climates such as which this study evaluated the results and recommendations of the study might be added to green building codes and standards.

Conflicts of interest

There are no conflicts of interest.

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