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# A Comprehensive Study on Various Window Glazing in Buildings for Composite Climatic Conditions

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**Abstract:** In a densely populated country like India, there is a lot of building construction happening daily and people due to a lack of awareness and information always tend to use simple, cheaper, and easily available window glazing which is less energy efficient, this happens due to the technology gap and lack of comparative analysis of different types window glazing. This study examines how different window glazing perform when it comes to changes in solar gains, embodied carbon content, heating and cooling loads as a result of the physical and optical characteristics of conventional windows and advanced window technologies with the help of computer simulations using building energy modeling in DesignBuilder software. The primary goal of this paper is to provide engineers with a comparative analysis of a wide range of window glazing and suggest the optimum case in which there is reduced decooling and heating loads for a given space along with the amount solar gain into the building's interior making the building’s energy efficient and reduce the carbon footprint that helps in earning carbon credits which will further reduce cost and payback period. The simulations and analysis are done for the composite climate of Roorkee, India.

**Keywords:** energy efficient, window glazing, solar gains, embodied carbon content

## 1. Introduction

The efficiency of a building is the key issue in a developing country like India, worldwide governments are passing laws in the construction industry to support and standardize energy-efficient buildings and reduce their carbon footprint. When it comes to addressing the issues of climate change, resource depletion, and environmental concerns in general, the built environment in urban areas plays a significant role. People will use more energy as a result of modern equipment like air conditioners and urban building spaces, as well as greater living standards and increased urbanization.

A building's exposure to solar radiation should be taken into account from the very beginning of the design process. This might affect decisions about the building's orientation, the quantity and kind of glass to be used in its various facades, whether it has to be shaded, and whether it needs air conditioning. For any wall-window combination the architect is considering for a certain project, he should ideally have available comparison data of solar heat gain [1].

As a barrier between interior and outside environments, windows play a key role in the energy consumption of buildings; nevertheless, due to their high heat transfer coefficient, they are the weakest part of buildings and are in charge of the majority of heat gain/loss [2]. Windows have a 60% greater heat gain/loss than other building materials, compared to 9% for flooring, 8% for walls, and 8% for the roof [3]. More than 80% of incoming solar radiation and more than 75% of visible light are transmitted through Clear glass. It might be advantageous for sun rays to enter indoor environments depending on the temperature, season, building purpose, and inhabitant activities, but it might also be exceedingly undesirable[4], [5]. To enhance the thermal efficiency of outside windows and lessen solar heat intake, various varieties of heat-blocking glass have been created. The impact of heat transfers and radiation on window glazing, as well as the decrease in energy consumption in buildings with the aid of various window glazing, have all been the subject of remarkable research by a number of researchers. K.A.R. Ismaila, & J.R. Henrıquez [6] did a brilliant study and analysis on the simple glass window. Windows with better insulating capabilities have been increasingly popular in recent years, helping buildings consume less energy. One such window has glazing panes, a gas fill, a frame, a spacer, and an edge seal in most cases as concluded by Van Den Bergh et al., [7]. Jelle et al., [8] mention in their study that a multilayer window can attain a low thermal transmittance of 0.28 W/m2-K if gas is enclosed in the space between the panes. Some of the recent research based on the energy simulations are done by Dac-Khuong Bui et al., [9] designed and evaluated the practicality of adaptable façade systems using the energy simulation software, and demonstrating the viability of the suggested methodology focused in reducing the overall energy consumption.

As per the above-discussed literature and keeping an eye on the research gaps, the primary goal of this study is to investigate the various window glazing that are offered on the market today for a window setup in a prototype building that has to withstand the climatic conditions of Roorkee City, India, and to evaluate their performance in some of the important conceivable directions, as discussed in the results and discussion section.

## 2. Description of the Building Envelope

The structure referenced in this study is an assumed prototype of a modern, one-story brick wall located at CSIR-CBRI, Roorkee. It functions as an entirely practical office setting. Figure 1a. depicts the building's sectional plan. Table 1, displays the building's current construction information. Due to the hot and humid climate in the tropical region where Roorkee is located, space cooling is necessary for 6–8 months out of the year. In the current study, DesignBuilder software, version v 6.1.8.021, is used to simulate the building.

### *2.1. Geographical and Metrological data*

The local weather conditions, which are determined by the temperature, humidity, and sun exposure, play a major role in determining the energy-loading demand of a building[2] The demo building investigated in the present analysis is located at CSIR-CBRI Roorkee. The details of the location and weather data are shown in Table 1 [10]

Table 1. Geographical and location data (design temperature based on 99.6%)

| Sr no. | Particulars | Details |
|---|---|---|
| 1 | Latitude (DD) | 29.85 |
| 2 | Longitude (DD) | 77.88 |
| 3 | Elevation above sea level (m) | 218 |
| 4 | WMO station identifier | 421400 |
| 5 | ASHRAE climate type | 2B |
| 6 | Cooling Max DBT (◦C) | 41.3 |
| 7 | Mean Coincidental WBT (◦C) | 23.8 |
| 8 | Heating DBT (◦C) | 1.7 |

### *2.2. Details of the building*

The construction specifics of the existing one-story building, are shown in Table 2 and Table 3. The window of the building has a southward orientation. The building has an occupancy density of 0.111 people per square meter, and it is assumed that the working schedule is from 9:00 a.m. to 5:00 p.m., Monday to Friday.

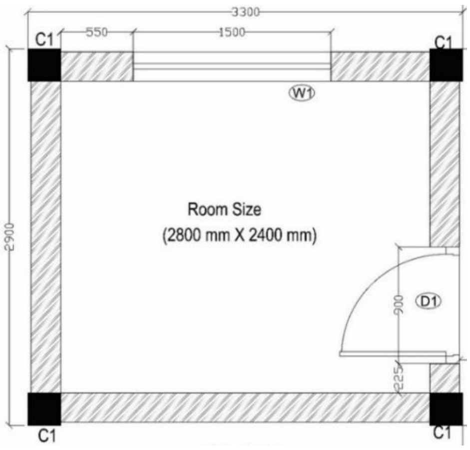



Figure 1a. Sectional plan of building

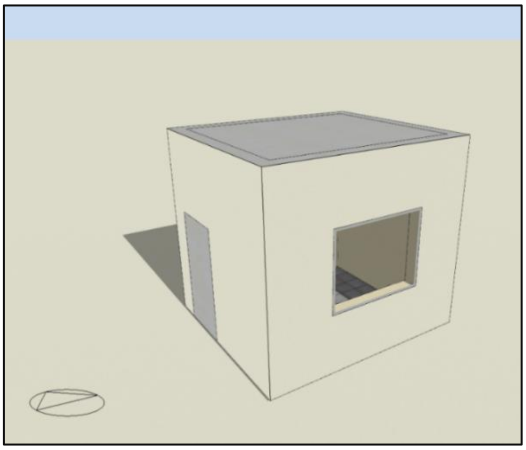


Figure 1b. Rendered view of the prototype building

Table 2. Details of the building materials

| Building element | Layer | Material details |
|---|---|---|
| Walls | Layer 1 (Outer surface) | 15mm cement Plaster |
| | Layer 2 | 200mm Autoclaved Aerated Concrete work |
| | Layer 3 (Inner surface) | 3mm Gypsum Plaster |
| Roof | Layer 1 (Outer surface) | 125mm Reinforced Concrete Construction |
| | Layer 2 (Inner Surface) | 15mm cement Plaster |
| Floor | Layer 1 (Outer surface) | 300mm Gravel Based Soil |
| | Layer 2 | 40mm Cast Concrete |

Table 3. Physical properties of materials

| Materials | $C_p$ (J/kg K) | ρ (kg/m^3) |
|---|---|---|
| RCC | 1000 | 2300 |
| Cement Plaster | 840 | 1760 |
| AAC | 1240 | 642 |
| Gypsum plaster | 1000 | 1000 |
| Cast concrete | 1000 | 2000 |
| Ceramic Floor Tiles | 850 | 1700 |

A packed direct expansion (DX) system with constant volume is used to model a single zone of air conditioning. The air temperature distribution mode is set to 1 - mixed (air is fully mixed and air temperature inside the zone is uniform), and the cooling and heating coefficients of performance are set to 2.5 and 2 accordingly. The chosen cooling and heating set points for the current analysis are 24°C DBT and 22°C DBT, respectively, with a relative humidity of 47.6%. The heat gain from people and lighting fixtures inside the prototype building is known as causal heat gain, and it takes the form of sensible heat gain. According to the degree of activity in the area, 0.9 of males are assumed to be the metabolic factor [11]. The results were obtained using the weather data of Saharanpur, the closest city to the location and the one with a climate similar to that of Roorkee. These weather data [10] include average data for the year 2002, which is regarded as a typical reference year (TRY), for dry bulb air temperature, dew point air temperature, solar radiation, wind speed, and direction, among other variables.

### *2.3. Details of the window glazing*

The most common and widely available glass is the single 3mm clear glass (S1) which is referenced as the base case for comparisons purpose. Analysis, provides basic insulation, while it might not provide the best thermal efficiency compared to thicker glass options, it is nevertheless a well-liked solution for residential and commercial applications where simplicity and cost-effectiveness are valued highly.

The various types of double-glazing [12] and triple- window glazing [13] with varying glass thickness, gap thickness, with varying gas fillings are taken into account. The double-glazing panes with the low emissivity coatings [14] were also considered for the comparison study.

| **Materials** | **$C_p$ (J/kg K)** | | **ρ (kg/m^3)** | |
|---|---|---|---|---|
| S1 (Base case) | Single, 3mm clear | 0.898 | 6.257 | 0.861 |
| S2 | Single, 6mm clear | 0.881 | 6.121 | 0.819 |
| D12 | Double, 3mm/13mm arg clear | 0.812 | 2.761 | 0.764 |
| D261 | Double, 6mm/6mm air clear | 0.781 | 3.157 | 0.700 |
| D22 | Double, 6mm/13mm arg clear | 0.781 | 2.549 | 0.704 |
| DL11 | Double LoE (e2=1), 3mm 13mm air clear | 0.769 | 1.798 | 0.598 |
| T11 | Triple, 3mm 13mm air clear | 0.738 | 1.778 | 0.684 |
| T12 | Triple, 3mm 13mm arg clear | 0.738 | 1.635 | 0.685 |

## 3. Mathematical Modelling

The presentation and discussion of mathematical models are covered in this subsection. That includes a few governing equations that are crucial for comprehending the ideas behind heat transfer that occurs through window glazing, along with all the underlying assumptions that were made.

### *3.1. The Glazing Heat Balance Equations*

By resolving the heat balance equations on each face at each time step, the temperatures of the window glass faces are calculated. There are 2N faces and, consequently, 2N equations to solve for a window with N layers of glass. The variables utilized for double glazing are shown in Figure 2, with N = 2. The heat balance equations are derived under the following presumptions [15]:

- There are no heat capacity terms in the equations because the glass layers are so thin (a few millimeters) to ignore heat storage in the glass.
- The heat flow is one-dimensional and perpendicular to the glass faces. For changes to the gap conduction in multi-pane glazing to take into account 2-D conduction effects across the pane separators at the glazing's edges, see "Edge of Glass Corrections," below.
- The glass layers block IR light. For the majority of glass goods, this is true. This is a bad assumption for thin plastic suspended films; hence the heat balance equations would need to be changed to account for this situation.

- The faces of the glass are isothermal. Given the great conductivity of glass, this is typically a sound assumption.
- The two faces of a glass layer can receive an equal share of the short-wave radiation that is absorbed in the layer.

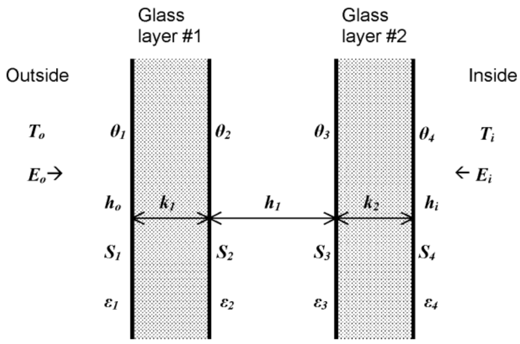



Figure 2. Glazing system with two glass layers showing variables used in heat balance equations [15]

The four equations for double-glazing are as follows. A single pane of glass (N = 1), as well as N = 3 and N = 4, have equivalent equations that are not illustrated [15].

$$E_o\varepsilon_1 - \varepsilon_1\sigma\theta_1^4 + k_1(\theta_2 - \theta_1) + h_o(T_o - \theta_1) + S_1 = 0 \quad (1)$$

$$k_1(\theta_1 - \theta_2) + h_1(\theta_3 - \theta_2) + \sigma\frac{\varepsilon_2\varepsilon_3}{1-(1-\varepsilon_2)(1-\varepsilon_3)}(\theta_3^4 - \theta_2^4) + S_2 = 0 \quad (2)$$

$$h_1(\theta_2 - \theta_3) + k_2(\theta_4 - \theta_3) + \sigma\frac{\varepsilon_2\varepsilon_3}{1-(1-\varepsilon_2)(1-\varepsilon_3)}(\theta_2^4 - \theta_3^4) + S_3 = 0 \quad (3)$$

$$E_i\varepsilon_4 - \varepsilon_4\sigma\theta_4^4 + k_2(\theta_3 - \theta_4) + h_i(T_i - \theta_4) + S_4 = 0 \quad (4)$$

*3.2. Absorbed Radiation*

In Equations 1 through 4, Si stands in for the radiation (including short-wave and long-wave from zone lights and equipment) that is absorbed on the ith face. Since it is assumed that short-wave radiation is absorbed uniformly along a glass layer, short-wave radiation (both solar and short-wave from lights) is distributed equally between the two faces of a layer for the purposes of the heat balancing calculation. Because glass layers are thought to be opaque to IR, the thermal radiation from lights and other equipment is only assigned to the inside (room-side) face of the interior glass layer. For N glass layers Si is given by [15]:

$$S_{2j-1} = S_{2j} = \frac{1}{2}\left(I_{bm}^{ext}\cos\,\phi A_j^f(\phi) + I_{dif}^{ext}A_j^{f,dif} + I_{sw}^{int}A_j^{b,dif}\right), j = 1 \text{ to } N \quad (5)$$

$$S_{2N} = S_{2N} + \varepsilon_{2N}I_{lw}^{int} \quad (6)$$

## 4. Results and Discussion

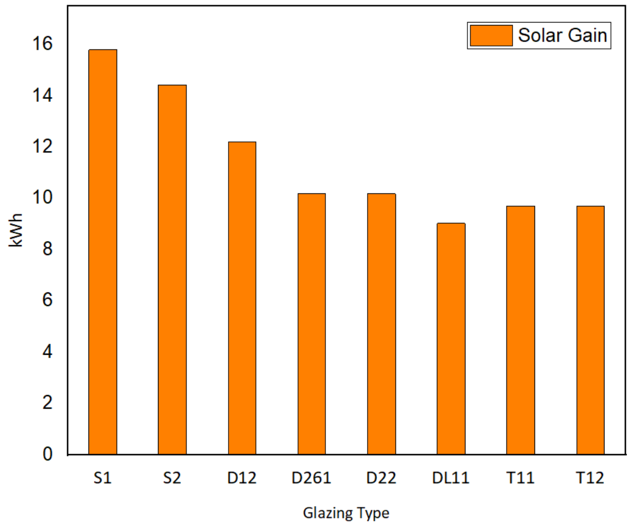
In order to compare each configuration, window glazing with various material properties were taken into consideration. An overall comparison between the solar gains, cooling and heating loads, daylighting and embodied carbon is done. The major goal is to suggest a glazing material that reduces cooling and heating loads while still letting the majority of daylight into the building's interior.

The analyses are basically done on the following parameters for the summer week (15th May to 21st May) and winter week (22nd December to 28th December) which include the references days for both seasons i.e., 16th May and 22nd December [16]:

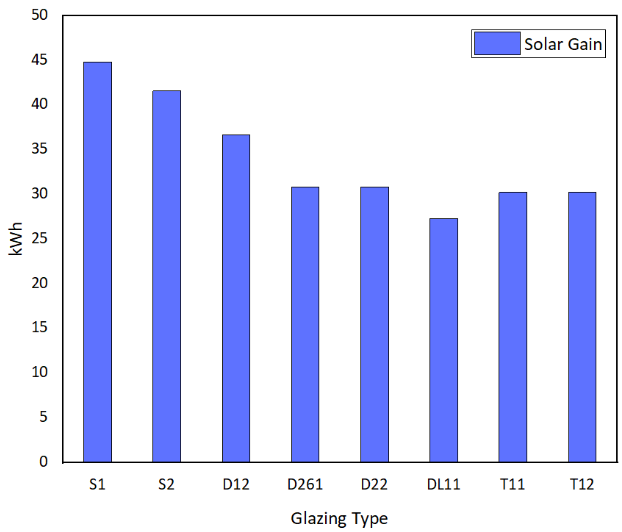
- Solar Gains through exterior windows (kWh)
- Cooling load and Cooling Electricity consumption (kWh)
- Heating load and Heating Electricity consumption (kWh)
- Embodied Carbon (kgCO2)

### *3.1. Solar Gains through exterior windows (kWh):*

In general, solar gain (or solar heat gain) (SHG) is the term used to describe the rise in temperature caused by absorbed solar radiation in a structure (or item) in a space. Sunlight-intercepting materials absorb the radiation, which raises their temperature. Naturally, some of the heat is then radiated again at far-IR wavelengths.




(a)



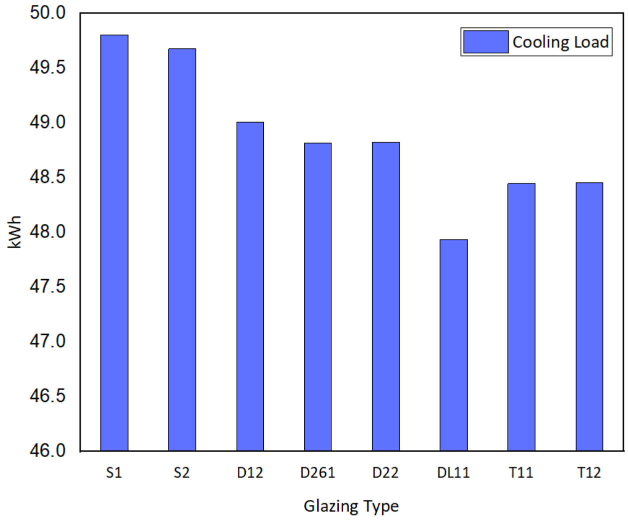

(b)

Figure 3. SHG profile (a) Summer week (b) Winter week

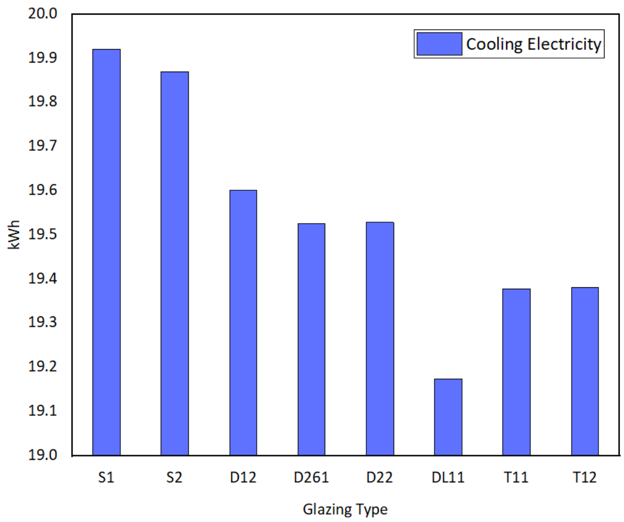
The effect of different glazing systems on the SHG through exterior window shown in Figure 3a & 3b indicates that maximum SHG occurs for S1 (base case) window in both the summer (15.801 kWh) and winter week (44.856 kWh). While the minimum occurs for DL11 window both summer (9.028 kWh) and winter (27.287 kWh) week. The SHG profiles for these different types of glazing follow nearly the same trend in both summer and winter, however the SHG range is greater in winter, which is due to the seasonal difference in sun angle from the window.

### *3.2. Cooling Loads (Qc) and Cooling Electricity consumption (Pc) (kWh):*

Among the different types of glazing, the high U-value glazing often yield higher Qc thus tending to higher Pc, while low U-value window conducts less heat from outside to inside during summer afternoon peak cooling hours tending to lower Qc and Pc.




(a)

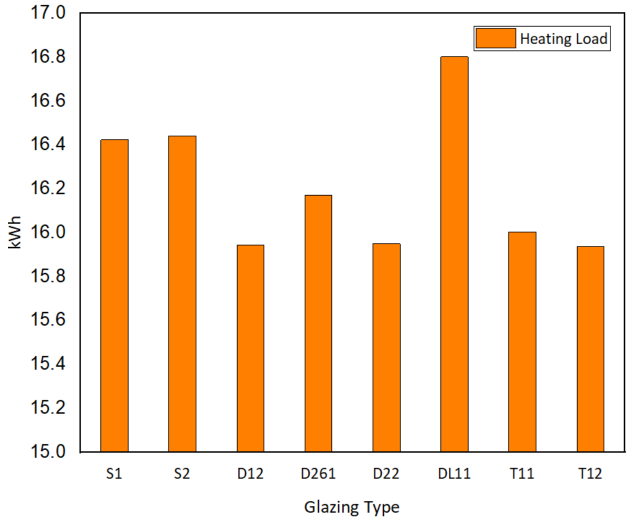



(b)

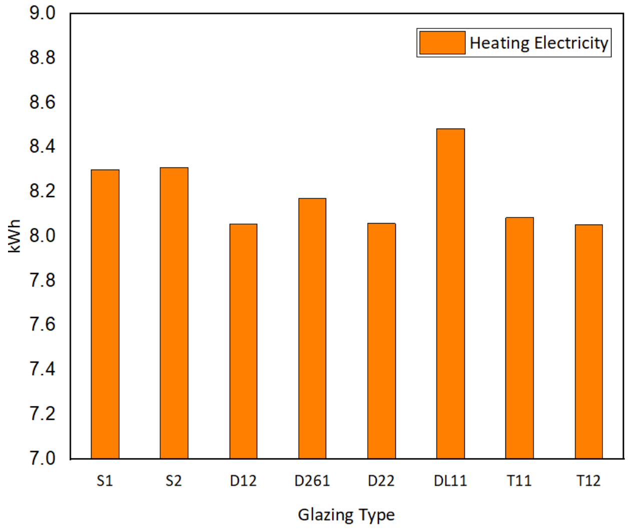
Figure 4. Summer week (a) Qc profile (b) Pc profile

The highest Qc (49.806 kWh) and Pc (19.922 kWh) for S1 and were essentially the same for S2. Comparing with the base case S1, the Qc has decreased by an average of 1.98% in D261 and D22. As opposed to the base case, T11 and T12 exhibit a reduction in Pc of 2.72% on average, with DL11 having the lowest Qc (47.936 kWh) and the Pc (19.174 kWh).

### *3.3. Heating Loads (Qh) and Heating Electricity Consumption (Ph):*




(a)




(b)

Figure 5. Winter week, (a) Qh (b) Ph, profile for the different types of window glazing

The governing parameters play a reverse role in the Qh's as higher the U value and SHGC the lower is requirement for heating room during the working hours and hence lower is Qh. The base case S1 has a Qh and Ph of 16.424 kWh and 8.299 kWh. The minimum Qh (15.93 kWh) and Ph (8.052 kWh) is for T12. Whereas DL11 has high Qh's because of its lower U- value and SHGC values.

*3.4. Embodied Carbon (EC) (kgCO2):*

Recently, many researchers have demonstrated that the embodied impacts of energy and carbon are increasing and occupy a significant proportion of the life cycle impacts of buildings [17]. The extraction, production, transportation, usage, and end-of-life factors of the window glazing have an impact on the EC content. The amount of carbon that is embodied in glazing goods might vary depending on their efficiency and design. The overall carbon footprint of a building can benefits from energy-efficient glazing systems that lower the need for heating, cooling, and lighting. Incorporating elements like low-emissivity coatings can help reduce the EC content of the glazing system to some extent.

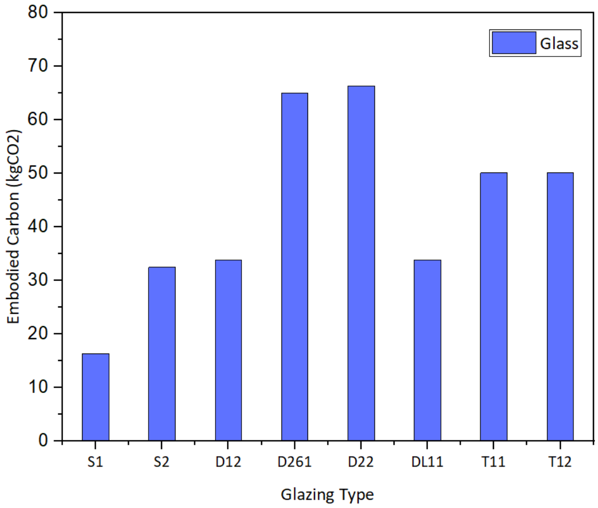



Figure 6. Embodied Carbon Content, profile for the different types of window glazing

The least EC is found in the base case S1 (16.3 kgCO2), followed by S2 and D12 since they are basic window glazing with few improvements. Whereas D22 (66.4 kgCO2) and D261 (65.1 kgCO2) have higher EC among the compared glazing types.

## 4. Conclusions

Numerous influencing factors in relation to energy-efficient buildings have been studied as a result of the investigation of the performance variability of various types of windows glazing. Examining the problems associated with this intricate process and creating an assessment approach that concurrently considers environmental and economic factors have both been made possible by analyses utilizing EnergyPlus code. The study's primary goal is to suggest a window glazing that reduces cooling and heating loads while still letting the majority of daylight into the building's interior. Following conclusions can be taken from the findings of the study's utilization of various window glazing of a prototype building which is scheduled for a working hour of 9AM to 5PM during the summer and winter weeks that include the prescribed reference days. Based on the results of various windows glazing, the following conclusions have been drawn.

- The maximum solar gain occurs for S1 (base case) in both the summer (15.801 kWh) and winter week (44.856 kWh). While the minimum occurs for DL11 window both summer (9.028 kWh) and winter (27.287 kWh) week.
- The maximum Cooling Electricity consumption is for S1 (base case) that is 19.922 kWh and the minimum is for DL11 of 19.174 kWh with reduction of 3.75%. The maximum Heating Electricity consumption is for DL11 that is 8.485 kWh and the minimum is for T12 that is 8.052 kWh.
  Note: All the cooling and heating load analysis were during the working hours.
- The least embodied carbon is found in the base case S1 (16.3 kgCO2), and the highest is found in D22 (66.4 kgCO2). Due to the developments and advancements in the window glazing, there will always be a rise in the percentage of embodied carbon, so the lesser the increase the more will be the carbon credits earning which will further reduce cost and payback period. In regard of this factor, Double LoE (e2=1), 3mm 13mm air clear (DL11) has a low amount of embodied carbon (33.8kgCO2) relatively.

**Nomenclature:**

| | |
|---|---|
| $A_j^{f\,diff}$ | Area of the External Surface of the $j^{th}$ segment that is exposed to the External Diffuse Solar Radiation. |
| $A_j^{b\,diff}$ | Area of the Internal Surface of the $j^{th}$ segment that is exposed to the Absorbed Solar Radiation. |
| DBT | Dry Bulb Temperature [$^0$C] |
| EC | Embodied Carbon |
| $h_i$ | Convective Heat Transfer Coefficient of $i^{th}$ face. |
| $h_{cv}$ | Convective Heat Transfer Coefficient from glass to gap air |

| | |
|---|---|
| $I_{bm}^{ext}$ | Exterior Beam Normal Solar Irradiance. |
| $I_{diff}$ | Surface Window Transmitted Diffuse Solar Radiation Rate. |
| $I_{diff}^{ext}$ | Exterior Diffuse Solar Incident on Glazing from Outside. |
| $I_{sw}^{int}$ | Interior Short-Wave Radiation Incident on Glazing from Inside. |
| $I_{bm}$ | Surface Window Transmitted Beam Solar Radiation Rate. |
| $I_{Iw}^{int}$ | Long-Wave Radiation from Lights and Equipment Incident on the Glazing from Outside |
| k | Thermal Conductivity of a Material [W/m K] |
| $P_c$ | Cooling Electricity Consumption [kWh] |
| $P_h$ | Heating Electricity Consumption [kWh] |
| $Q_c$ | Cooling Load [kWh] |
| $Q_h$ | Heating Load [kWh] |
| SHG | Solar Heat Gain |
| SHGC | Solar Heat Gain Coefficient |
| $S_i$ | Absorbed Radiation on $i^{th}$ face |
| $T_c$ | Crucial Transition Temperature. [K] |
| $T_0$ | Temperature of Surroundings. [K] |
| U | Thermal Transmittance. [W/m$^2$ K] |
| ꝥ | Density of Material. [Kg/m$^3$] |
| $T_v$ | Visible Transmittance. |
| Ø | The angle between the Incoming Solar Radiation and the Normal to the Surface. |
| ɣ | The Angle between the Normal Vector of Receiving Surface and the Direction of the Incoming Light. |
| Ω | Solid Angle of the Window Element. |
| $\varepsilon_i$ | Emissivity of $i^{th}$ face. |
| $\sigma$ | Stefan-Boltzmann Constant. [W/m$^2$ K$^4$] |

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**Conflicts of Interest:** The authors declare no conflict of interest.

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