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Energy-Efficient Passive Cooling Design for Residential Buildings in Hot and Arid Climates: A Parametric Study

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Abstract

This study addresses the pressing issue of rising energy consumption for cooling residential buildings, with a specific focus on hot and arid desert regions. The main objective of this research is to explore the energy demand associated with cooling by employing passive strategies, namely the window-to-wall ratio (WWR), window glazing properties, and roof surface albedo. To achieve this goal, the building model underwent validation by comparing actual energy consumption data with simulation results obtained using Design Builder software. Subsequently, twelve distinct parametric options were simulated and analyzed to assess their effectiveness in reducing cooling energy requirements. These options were grouped into four categories, each encompassing different combinations of WWR, glazing types, and roof surface albedo. The study findings reveal that the most energy-efficient configuration among the investigated options entails buildings with a WWR of 10%, 6mm triple glazing panes with a 6mm air cavity, and a roof surface albedo of 0.9. This configuration demonstrates a significant improvement of 36-37% in cooling energy demands compared to the base-case building option. Furthermore, this option achieved a remarkable improvement rate of 40–41% in terms of energy cost. The research outcomes make notable contributions to enhancing internal thermal performance, decreasing energy consumption, and achieving cost savings in cooling applications.

Keywords. Passive cooling, Window-to-wall ratio (WWR), Glazing types, Roof surface albedo, Cost benefits.

1. Introduction

Egypt has been facing significant challenges with energy in recent years, with rising demand for energy driven by population growth, economic development, and urbanization [1]. The country has been struggling to keep up with the increasing demand for energy. Along with this, the country's energy mix has been dominated by fossil fuels, with a high dependency on natural gas, which is a finite resource. This has led to concerns about the sustainability of the energy sector in Egypt and the need to transition towards renewable energy sources [2]. Several studies have been conducted to address these challenges and explore potential solutions, including using renewable energy sources such as solar and wind power and the implementation of energy efficiency measures in buildings and industries [2-4].

Improving energy efficiency in buildings is a key priority in Egypt due to the challenges posed by the rising demand for energy, population growth, and urbanization [5]. Passive design strategies have been identified as effective means to reduce energy consumption and improve the comfort of indoor environments [6, 7]. In hot arid regions like Egypt, where cooling demand is high, several strategies could affect the amount of energy needed for cooling, including building proportions [8], building orientation [9, 10], shading [11], insulation [12-14], cool roofs [15], natural ventilation [16], and thermal mass [17]. By integrating these strategies into building design, energy consumption for cooling can be reduced, leading to lower energy bills, improved comfort, and reduced greenhouse gas emissions. Furthermore, the use of passive design strategies can contribute to the sustainable development of Egypt's building sector and help the country transition towards a more sustainable energy future [18, 19].

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Alghoul et al. [20] investigated the impact of window-to-wall ratio (WWR) and window orientation (WO) on cooling, heating, and total energy consumption in buildings. The study aims to provide architects with a simple correlation for the proper design of facades for office buildings from an energy consumption point of view. According to their findings, the annual average energy consumption rises by 6- 181 % when windows are added to a façade. Chiesa et. al. [21] propose a coding approach to dynamic energy simulation for building design optimization, with a focus on reducing energy needs and pollution. The main design parameter considered is the window-to-wall ratio, and the approach is adapted to passive design optimization. Their findings show that optimizing anticipated energy consumption based on diverse factors (cooling, heating, lighting, and design choices) necessitates including a greater number of variables from the earliest design configurations. Python scripting is used for the coding, while energy simulations based on EnergyPlus are used for the dynamic aspects.

Zhen Chen and Jiapeng He [22] analyze the impact of window-wall ratio on energy consumption for office buildings in a hot summer and cold winter area using hourly typical meteorological year data in Nanjing. The study shows that the increase in the north-facing window-wall ratio leads to an increase in total heating and air-conditioning energy consumption, while for PVC plastic hollow windows, the increase in the south-facing window-wall ratio is followed by a decrease in annual electricity consumption. The results of the paper show that the increase in the north-facing window-wall ratio leads to an increase in total heating and air-conditioning energy consumption, while for PVC plastic hollow windows, the increase in the south-facing window-wall ratio is followed by a decrease in annual electricity consumption. The study suggests that PVC plastic hollow windows should be used in Nanjing during hot summers and cold winters.

Zhen Yu et al. [23] investigate the impact of building orientation and window-wall ratio on the energy consumption of an office building using energy consumption simulation software. The study found that heating energy consumption, air-conditioning energy consumption, and total energy consumption increase with an increase in the window-wall ratio under the same orientation. The study found that heating energy consumption, air-conditioning energy consumption, and total energy consumption gradually increased with the increase of the window-wall ratio under the same orientation.

Muhaisen and Abed [24] examine the impact of building proportions and orientations on the thermal performance of housing units in the Mediterranean climate of the Gaza Strip. The study concludes that choosing the optimum building width-to-length (W/L) of 0.8 can reduce energy consumption by 39%. Ragab [8] analyzed the impact of building proportions, surface-to-volume ratios, building width-to-length ratios, and orientation on the energy demand for cooling in Aswan City, a hot arid region. Using the Design-Builder tool, the study found that these factors have a significant impact on energy consumption for cooling. Buildings with a surface-to-volume ratio of less than 0.38 can achieve over 36% energy savings for cooling. A significant correlation was also observed between building surface-to-volume ratios and energy demand for cooling.

Existing research has primarily concentrated on investigating the influence of window-to-wall ratio (WWR) and building orientations in hot and arid regions, while neglecting the potential impacts of other crucial building envelope variables, such as window glazing type and roof surface albedo. Consequently, this study seeks to fill this research gap by examining the effects of these additional variables on energy efficiency in buildings situated in hot and arid regions. The primary objective of this research is to determine the impact of window-to-wall ratio, glazing composition, and roof surface albedo that would result in the least amount of energy consumption, thus contributing to the overall promotion of energy efficiency. Expanding the scope of the investigation to include window glazing and roof surface albedo could provide valuable insights and practical recommendations for architects, urban planners, and building designers in the pursuit of energy-efficient building designs in these specific climatic contexts.

2. Study area

Aswan is in the southern part of Egypt, on the Nile River's eastern bank. It is located at a latitude of 24.0934° N and a longitude of 32.9070° E. Aswan has a desert climate, with hot summers and mild winters. The average temperature during the hot months ranges from 35 to 38°C (95 to 100 °F), with occasional heat waves that can push temperatures well above 40°C (104°F). The cold months are characterized by cooler temperatures, with average highs ranging from 22–26 °C (72–79 °F). The city receives very little yearly rainfall, with an average annual precipitation of only 2 mm [25]. Figure 1 highlights the location of Aswan City in Egypt.

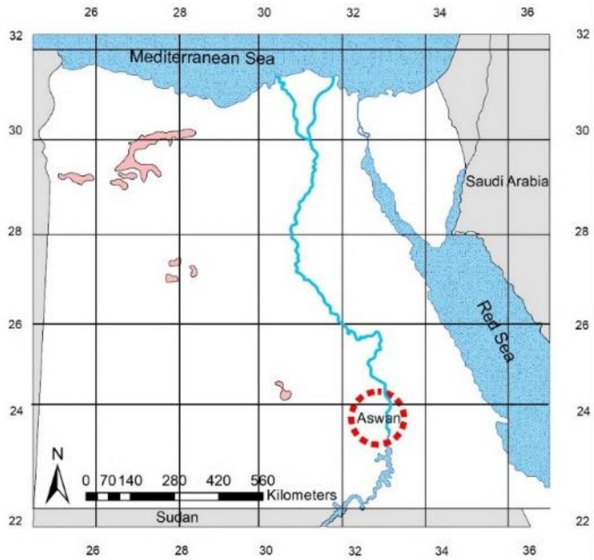


Figure 1: The location of Aswan city in Egypt [26].

3. Methodology and materials

3.1. Simulation process and input data

The objective of the study was to determine the effect of different window-to-wall ratio (WWR), glazing type, and roof surface albedo to achieve energy-efficient cooling in residential buildings located in hot arid regions. To achieve this, the study involved various steps such as conducting simulations throughout the year using weather data obtained from the Meteorological Station of Aswan University. The data were converted from CSV to epw format using Energy-Plus weather statistics and conversion tool and were used as input data in Design Builder [14]. The study also provided other input data such as constructions, openings, and HVAC from common residential building configurations [8]. The interior spaces were assumed to be fully air-conditioned with fixed hours of occupancy based on the traditional Egyptian lifestyle [27]. The conventional daily routine of Egyptian families, as established by prior studies[27, 28], was acquired and subsequently inputted into the selected simulation software for analysis. Indoor heat gains from occupancy and appliances, as well as energy demands for heating and lighting, were not considered due to their minor contribution to total energy consumption in hot arid regions [29].

3.2. Proposed study variables

The primary objective of this study is to investigate the impact of WWR, glazing types, and roof surface albedo on reducing the cooling energy demand in two specific building configurations, which have been identified as the most effective strategies based on existing literature [8, 30]. Consequently, multiple variables have been proposed for each strategy under investigation.

3.2.1. Building proportions

The impact of various building width-to-length ratios (W/L) on cooling energy demand and potential energy savings in four directions was investigated by Ragab [8], while also considering surface-to-volume ratios (S/V). The investigation examined a range of ratios spanning from (W/L = 0.1) to (W/L = 1) in relation to a building area of 200 m^2. This dimension is frequently observed in multi-story residential constructions located in Aswan City. It was proposed that the highest point of the building was 15 m, equivalent to a five-times story building, a customary feature of domiciliary constructions in Aswan. The study's results suggest that the most favorable building proportions are 0.5 and 0.6. Consequently, the present investigation has chosen these specific building proportions in conjunction with the optimal building orientation (90°) corresponding with those proportions. Furthermore, the study evaluated the influence of three variables, namely window-to-wall ratios, glazing types, and roof surface albedo values, on the cooling energy demand.

3.2.2. Window to wall ratio

The WWR is an important factor to consider in building design, as it can have a significant impact on the energy performance of a building [29]. In Egypt, the WWR is typically regulated by the country's energy code for buildings. The energy code for residential buildings in Egypt sets minimum requirements for the WWR based on the orientation of the building and the climate zone in which it is located. For example, in hot and dry climates like the one found in much of Egypt, the code recommends a WWR of no more than 40% for south-facing facades, and no more than 25% for east- and west-facing facades. This is because a higher WWR can lead to increased solar heat gain, which can cause the building to overheat and increase the need for cooling.

However, it has been found that the WWR requirements in the Egyptian energy code may not be optimal for all building types and orientations. A study by Karimi et al [31]. employs BEopt™ energy simulation software to analyze simulation models. The findings highlight the energy-saving potential of windows located on the southeast, south-southeast, south, and south-southwest facades, while windows on other facades lead to higher energy demands when compared to windowless facades. The total energy demand of the room, varying with different window-to-wall ratios (WWR) on specific facades, exhibits a U-shaped curve, with the minimum value achieved at specific WWR values for each facade. The optimization of WWR yields a maximum energy saving of 6.5%, while the addition of windows with a WWR of 0.7 to other facades increases energy consumption by up to 29%. Consequently, the study concludes that the optimization of WWR in different orientations during the design phase contributes significantly to the reduction of heating and cooling energy consumption.

3.2.3. Glazing types and specifications

The selection of glazing plays a crucial role in optimizing energy efficiency and reducing cooling energy consumption in buildings, particularly in warmer climates. Window glass can be classified into several types, including single, double, and triple-pane glass. The efficiency of window glass used in windows varies depending on several factors such as glass thickness, the type of gas filling the space between the layers, and their thermal properties. The study selected different types of clear glass, which are described below along with their respective U-value (w/m^{2}K), Solar Heat Gain Coefficient (SHGC), and Visible Light Transmittance. Table 1 presents the glass specifications.

Table 1: Characteristics of glazing types.

Types	Specifications	U-value (w/m^2 K)	Solar Heat Gain Coefficient (SHGC)	Visible Light Transmittance
G1	Single clear glass with thickness 0.3	5.894	0.861	0.898
G2	Single clear glass with thickness 0.6	5.778	0.819	0.881
G3	Double clear glass each one is 3mm and 6mm argon	2.884	0.763	0.812
G4	Double clear glass each one is 3mm and 6mm Air	3.159	0.762	0.812
G5	Double clear glass each one is 6mm and 6mm argon	2.829	0.702	0.781
G6	Double clear glass each one is 6mm and 6mm Air	3.094	0.700	0.781
G7	Triple clear glass each one is 3mm and two layers of argon with 6mm thickness	1.930	0.683	0.738

G8	Triple clear glass each one is 3mm and two layers of Argon air with 6mm thickness	2.178	0.682	0.738
G9	Triple clear glass each one is 6mm and two layers of argon with 6mm thickness	1.893	0.611	0.696
G10	Triple clear glass each one is 3mm and two layers of air with 6mm thickness	2.132	0.609	0.696

3.2.4. Roof surface albedo

Surface albedo is an important strategy that refers to the reflectivity of a surface and is measured as the ratio of the reflected solar radiation to the total amount of incoming solar radiation. The albedo value of a surface plays a significant role in determining the amount of solar radiation that is absorbed by the surface and the amount of heat that is emitted. Surfaces with high albedo values reflect more sunlight and absorb less heat, while surfaces with low albedo values absorb more sunlight and emit more heat [32].

To evaluate the impact of different roof surface albedo values on the consumption of cooling energy, a set of multiple roof surface albedo values was chosen for the study. The selected roof surface albedo values were 0.9, 0.7, 0.5, 0.3, and 0.1, representing a range of surface reflectance levels from very high to very low. These values were chosen to reflect a variety of surface types, including light-colored and dark-colored surfaces, as well as natural and artificial surfaces. The reason for choosing these values was to assess the impact of surface reflectance on the amount of cooling energy required to maintain comfortable indoor conditions in a building. By comparing the cooling energy consumption for different albedo values, it is possible to identify the optimal surface reflectance level that can help to reduce the need for cooling energy and improve building energy efficiency.

3.3. Egyptian Electricity Consumption Tiers and Costs

The cost of electricity consumption is determined by the amount of electricity consumed. To calculate the cost of electricity in Egypt, we need to know the electricity consumption tiers, which are categorized by the amount of electricity used[33]. Electricity consumption is divided into seven categories based on the amount of electricity used per month. These categories have been presented in Table 2.

Table 2. The electricity price for each category.

Bracket	First	second	third	fourth	fifth	sixth	seventh
Category (kWh)	1-50	51-100	101-200	201-350	351-650	651-1000	more than 1000
Price (EGP)	0.48	0.58	0.77	1.06	1.28	1.4	1.45

3.4. Study model validation

The most prevalent building model was subjected to validation through the comparison of monthly simulated results of energy consumption with actual collected monthly electricity bills from a family building located in Aswan. The validated building has a total area of 200m² and stands at a height of 15m. To accurately simulate the current state of the building model, various data inputs were provided to the simulation software. For instance, the external walls consist of three layers: a 20mm cement plaster layer, a 250mm brick layer, and a 20mm innermost layer. In this specific case, the window-to-wall ratio is approximately 10%. The roof surface has a surface albedo value of 0.5. The windows are constructed of metal and feature a single layer of glazing that is 3mm thick. The glazing possesses the following characteristics: A Solar Heat Gain Coefficient (SHGC) of 0.861 and a U-value of 5.894 W/m²K. By employing this comprehensive set of data inputs, the simulation endeavors to accurately replicate the real-world conditions and characteristics of the building model. The validation process, which compares the simulated energy consumption with actual electricity bills, demonstrates a reasonably close agreement between the two, with an average error of 9.76% as depicted in Figure 2. These details regarding the building's dimensions, wall composition, window-to-wall ratio, roof surface albedo, and window glazing properties contribute to the robustness and reliability of the simulation results, enabling a more accurate assessment of the building's energy performance.

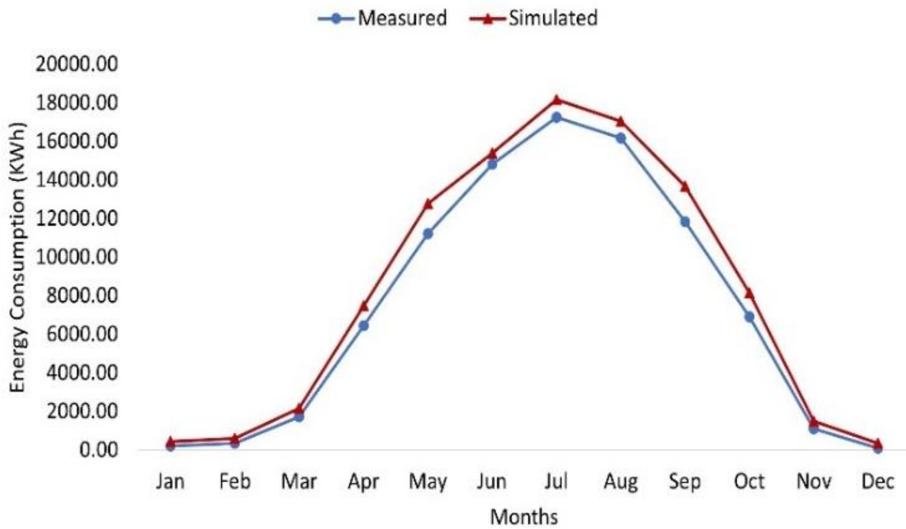


Figure 2: The indirect validation of the common building model.

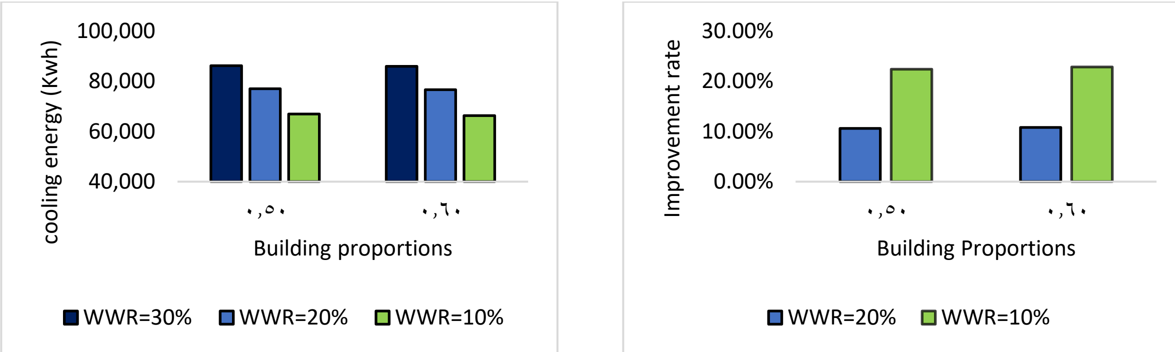
4. Result & Discussion

These results obtained from this study provide detailed insights into the impact of each proposed variable on energy consumption for cooling purposes, considering the specific context of Egyptian electricity prices. By analyzing the data, the study examines the relationship between the studied variables, such as window-to-wall ratio, glazing type, and roof surface albedo, and their influence on the cooling energy requirements of buildings. The associated costs of energy consumption are also considered, aligning with the prevailing electricity pricing structure in Egypt. These findings contribute to a comprehensive understanding of the factors that affect cooling energy demand and costs in the specific context of Egypt's electricity pricing system.

4.1. The impact of the window-to-wall ratio on the cooling energy demand.

The window-to-wall ratio (WWR) and building proportions have a significant impact on the amount of cooling energy required for a building. This study investigated two building proportions (0.5- 0.6). The study found that increasing WWR contributes to a significant amount of heat gain through the building envelope. Therefore, in this study, WWR with 30% requires the highest amount of cooling energy and was therefore used as a benchmark for evaluating other WWR ratios. For building proportion = 0.5, the cooling energy required has been found 66891.43 kWh, 77074.81 kWh, and 86206.77 kWh for WWR= 10%, 20%, and 30% respectively. Generally, the study found that a WWR of 10% resulted in the most substantial improvement, with a rate of 22.41%. A WWR of 20% had a lower improvement rate of 10.59%. Generally, Figure 3 illustrates the cooling energy and annual energy savings for the 0.5 building ratio options in terms of investigating several WWR values.

Building proportion= 0.6 has almost the same performance as building proportion= 0.5 with a slight improvement. In more detail, building proportion= 0.6 could improve the energy efficiency with 22.87%, and 10.83% for WWR= 10%, and 20% respectively. Generally, building proportion 0.6 consumes 66335.23 kWh, 76696.75 kWh, and 86008.77 kWh for WWR= 10%, 20%, and 30% respectively. Considering the energy consumption for building proportion= 0.6, and 0.5, it was found that decreasing S/V from 0.367 in the case of building proportion= 0.5 to S/V= 0.359 in the case of building proportion= 0.6 could enhance the effectiveness of energy efficiency in these buildings.



(a) (b)

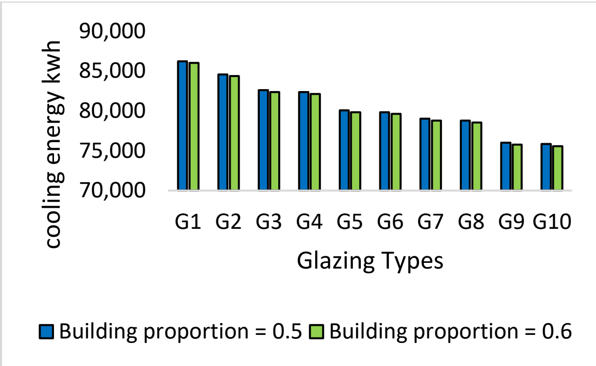
Figure 3: Simulation results for building proportion 0.5 & 0.6 considering different WWRs; (a) annual energy saving, (b) improvement rate (%) in terms of energy savings.

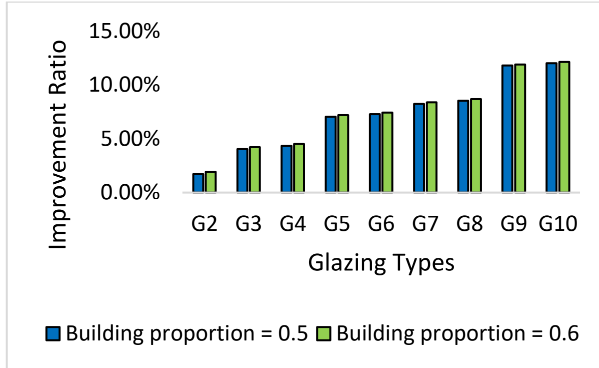
4.2. The impact of glazing types on the cooling energy demand.

According to the study findings, G1, which exhibited the single-glass model with a thickness of 0.3 mm uses the most energy for cooling, making them the least efficient option. As a result, it was taken as a guideline for selecting the optimum glass types to lower annual cooling energy consumption. For the building proportion = 0.5, the study found that the energy consumption for cooling is within a certain range, and the best type of glass to improve the energy demand for cooling is G6 and thicker air-to-air thermal insulation. 0.6 mm, showing an improvement rate of 11.86%. Other types of glass that showed improvement rates in decreasing order are 0.6mm thick triple-layered glass with argon heat insulation, 0.3mm thick triple-layered glass with air heat insulation, and 0.3mm thick triple layered glass with argon heat.

The study findings of building proportion= 0.5 show that G10 (two glazing panes with 6mm thickness filled by 6mm air) exhibited the most efficient glazing type among the studied glazing types showing an improvement rate of 12.03% compared to G1. Other types of glazing showed improvement rates ranging between 1.91% and 11.81%. Figure 4 (a) shows the annual energy required for cooling reasons. The investigation of building 0.6 demonstrated that energy consumption for cooling has the same trend of performance with a significant improvement rate for G10 exhibiting an improvement rate of 12.13%. The study also found that G9, G8, G7 are the next most efficient glazing options among the studied options. For G2, G3, G4, G5, G6, G7, G8, and G9 the energy savings percentages are 1.92%, 4.23%, 4.52%, 7.19%, 7.44%, 8.39%, 8.68%, and 11.91% respectively. The annual improvement rate in terms of cooling energy for different building proportions are presented in Figure 4 (b).

After conducting a thorough study and analysis, the study has determined that glass type G10 is the optimal choice for reducing energy consumption for cooling by a percentage ranging from 12.03% to 12.13%, surpassing the results of glass G9 which only contributed to a temperature reduction by a rate ranging from 11.81% to 11.91%, despite the use of argon as a thermal insulator. These findings align with previous research indicating that utilizing air as a thermal insulator between glazing panels can be more effective than using argon between the panels themselves. Although argon is typically considered a superior insulator compared to air, its use in glass can lead to a phenomenon called convection rings. This occurs when gas circulates inside the gap between the panels, ultimately decreasing the insulation performance of the glass. As a result, the effectiveness of argon filling gas as an insulator may be reduced.





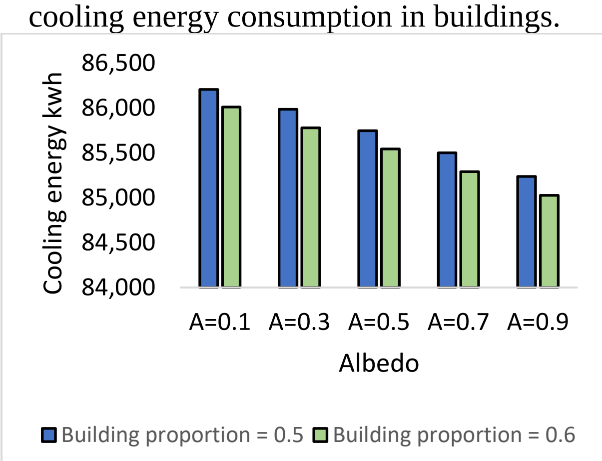
(a) (b)

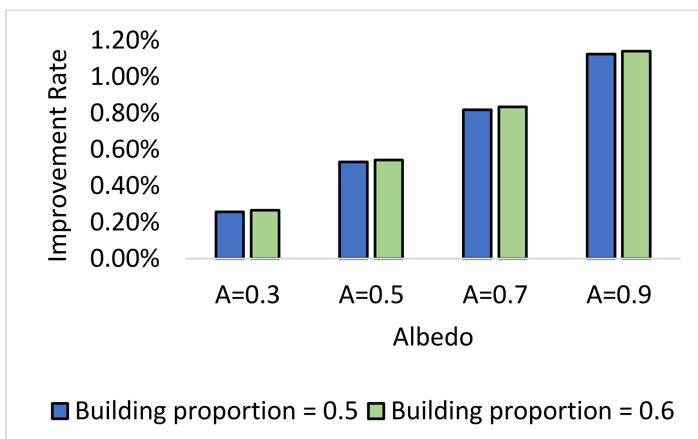
Figure 4: Simulation results for building proportion 0.5 & 0.6 considering different glazing types; (a) annual energy saving, (b) improvement rate (%) in terms of energy savings.

4.3. The impact of Albedo on the cooling energy demand

The findings of the study indicate that roof surface albedo has a minimal impact on cooling energy consumption in buildings with a proportion of 0.5 and 0.6. The improvement rate in cooling energy consumption ranged from 0.26% to 1.12% for buildings with a proportion of 0.5, and from 0.27% to 1.14% for buildings with a proportion of 0.6. These results suggest that changes in roof surface albedo have a slight effect on the amount of cooling energy required to maintain comfortable indoor conditions in buildings.

Figure 5 in the study illustrates the cooling energy usage and annual energy savings for a variety of building proportions. The figure provides a visual representation of the impact of different roof surface albedo values on the cooling energy consumption of buildings, highlighting the relatively minor effect of roof surface albedo on cooling energy usage in buildings. The study's findings contribute to a better understanding of the role of roof surface albedo in building energy efficiency and can inform the development of strategies aimed at reducing cooling energy consumption in buildings.





(a) (b)

Figure 5: Simulation results for building proportion 0.5 & 0.6 considering roof surface albedo; (a) annual energy saving, (b) improvement rate (%) in terms of energy savings.

4.4. The energy results for the proposed integration building options.

The study first examined each strategy that impacts energy consumption for cooling individually. Then, the building models were analyzed considering the combined effects of the three strategies: WWR, type of glazing, and roof surface albedo. Based on this analysis, the study developed multiple proposals and identified optimal solutions aimed at reducing energy consumption for cooling. The developed proposed options have been divided into twelve parametric options. Furthermore, these options were divided into four categories. In the first category (a), WWR values were combined with the worst glazing types and worst surface albedo values as detected in O1, O5, and O9. The second category (b) depends on examining all WWR values integrated with the best glazing type and worst surface albedo value as depicted in O2, O6, and O10. The third category (c) included O3, O7, and O11. Where the WWR values were examined along with the worst glazing type and the best surface albedo value. The fourth category (d) examines all WWR values with the best glazing type and the best surface albedo value as depicted in O4, O8, and O12. Table 3. Presents the parametric investigated building options. The research methodology and procedures have been outlined in the study framework, as illustrated in Figure 6.

Table 3: Characteristics of Building options

	O1	**O2**	**O3**	**O4**	**O5**	**O6**	**O7**	**O8**	**O9**	**O10**	**O11**	**O12**
WWR	30%	30%	30%	30%	20%	20%	20%	20%	10%	10%	10%	10%
Glazing types	G1	G10	G1	G10	G1	G10	G1	G10	G1	G10	G1	G10
Surface albedo	0.1	0.1	0.9	0.9	0.1	0.1	0.9	0.9	0.1	0.1	0.9	0.9
Category	a	b	c	d	a	b	c	d	a	b	c	d

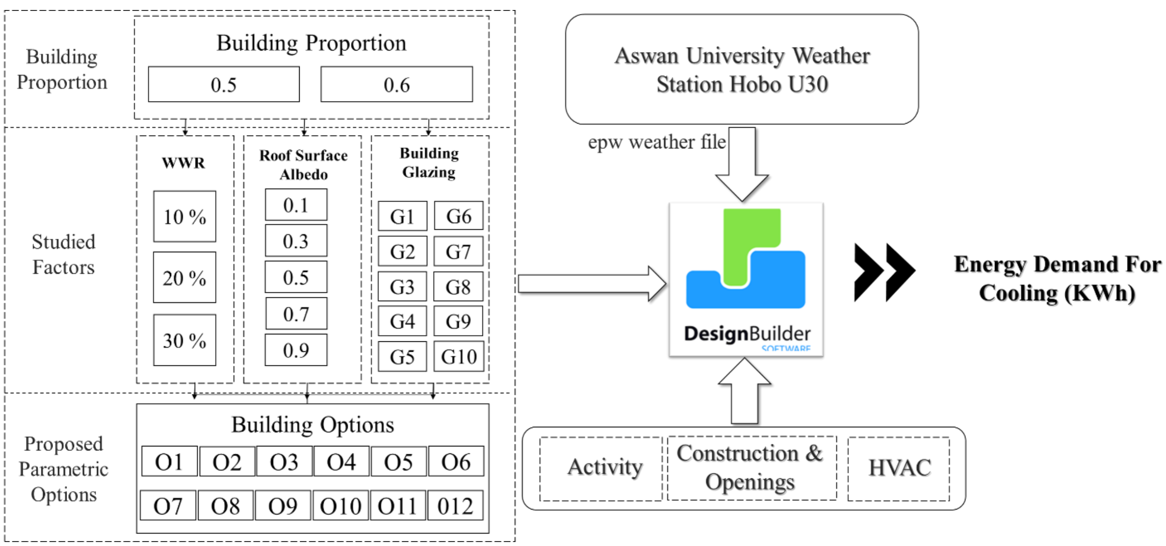


Figure 6: The methodological framework.

Initially, the study conducted a detailed analysis of each studied variable that influences cooling energy consumption. Subsequently, this investigation assessed how these factors together affected buildings with proportions of 0.5 and 0.6. The cases were classified into four categories (a, b, c, and d). In the first category (a), the study revealed that option O1 had a minimal impact on reducing cooling energy consumption, resulting in 2844.82 kWh of energy consumption for a building proportion of 0.5 and 2838.29 kWh for a building proportion of 0.6. Comparatively, option O5 had a significant impact, with energy consumption of 2543.47 kWh for a building proportion of 0.5 and 2530.99 kWh for a building proportion of 0.6. Option O9 had the most significant impact, leading to energy consumption of 2207.42 kWh for a building proportion of 0.5 and 2189.06 kWh for a building proportion of 0.6, making it the most effective option in this category.

In the second category (b), it was observed that a significant impact was made by G10 on the reduction of energy consumption in buildings with proportions of 0.5 and 0.6. Energy consumption for cooling in O2 was recorded as 2502.55 kWh for a building proportion of 0.5 and 2494.09 kWh for a building proportion of 0.6. The second-best option, O6 showed energy consumption of 2282.52 kWh for a building proportion of 0.5 and 2272.39 kWh for a building proportion of 0.6. The most efficient option in this category was found to be O10, with energy consumption of 2063.49 kWh for a building proportion of 0.5 and 2047.13 kWh for a building proportion of 0.6. The study found that in the third category (d), roof surface albedo =0.9 plays a secondary role. The worst option in this building category is O3, which consumes a cooling energy of 2812.83 kWh in building proportion = 0.5

and 2805.89 kWh in building proportion = 0.6. However, in O7, the consumption was observed to be 2173.05 kWh in building proportion = 0.5 and 2154.49 kWh in building proportion = 0.6. For O11, the consumption was found to be 2173.05 kWh and 2154.49 kWh in building proportion = 0.5 and 0.6 respectively.

Regarding the fourth category, which represents the best option for reducing energy consumption for cooling due to its effective integrated solutions of G10 and A0.9, the study found that O4 had energy consumption of 2465.36 kWh in building proportion = 0.5 and 2456.49 kWh in building proportion = 0.6. In O8, energy consumption was observed to be 2245.99 kWh in building proportion = 0.5, and 2233.37 kWh in building proportion = 0.6. Finally, option O12 was found to be the most efficient solution in reducing energy consumption for this category and all the aforementioned categories, due to its distinguished features of WWR=10%, G10, and A0.9. The energy consumption was observed to be 2028.06 kWh in building proportion = 0.5 and 2011.42 kWh in building proportion = 0.6. Figure 7 presents the simulation results for the proposed integration building options.

After analyzing the options, it was found that O1 was the least efficient for building proportions of 0.5 and 0.6 due to its WWR of 30%, G1 glazing type that exhibited single glazing of 3mm, and surface albedo of 0.1, which resulted in the highest energy consumption for cooling among all the options (2844.82 kWh and 2838.29 kWh for building proportions of 0.5 and 0.6 respectively). Therefore, O1 was used as a reference point to evaluate the efficiency of the other options. The data revealed that O3 experienced about 1% improvement in building proportions of 0.5 and 0.6 due to its similarity to the reference point, with the only difference being the surface albedo ratio of 0.9. O5 also showed an improvement of about a 12% increase in the case of building proportions of 0.5 and 0.6, followed by O7, which improved between 13% and 14% in building proportions of 0.5 and 0.6, respectively. O2 improved by 14%, while O4 showed an improvement between 15% and 16% in building proportions of 0.5 and 0.6, respectively. O6 showed a significant improvement of 25%, followed by O8, which improved by 27% in building proportions of 0.5 and 0.6. O10 could save energy between 38% and 39% in building proportions of 0.5 and 0.6. O9 showed an improvement between 29% and 30% in building proportions of 0.5 and 0.6, respectively. Lastly, O11 had an improvement of 31% and 32% in building proportions of 0.5 and 0.6, respectively. After comparing all options, the most efficient choice for improving energy consumption for cooling was found to be O12, with a WWR of 30%, glazing type of G10, and albedo of 0.9. This option had the highest improvement, with a 40% increase in building proportion of 0.5 and a 41% increase in building proportion of 0.6. Figure 8 presents the improvement rate (%) in terms of energy savings for the proposed integration building options.

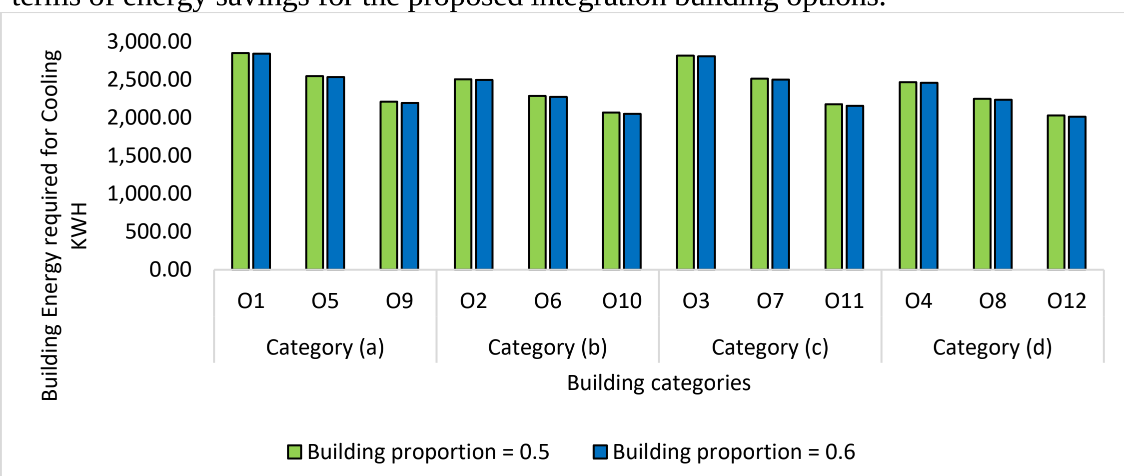


Figure 7: Simulation results for the proposed integration building options.

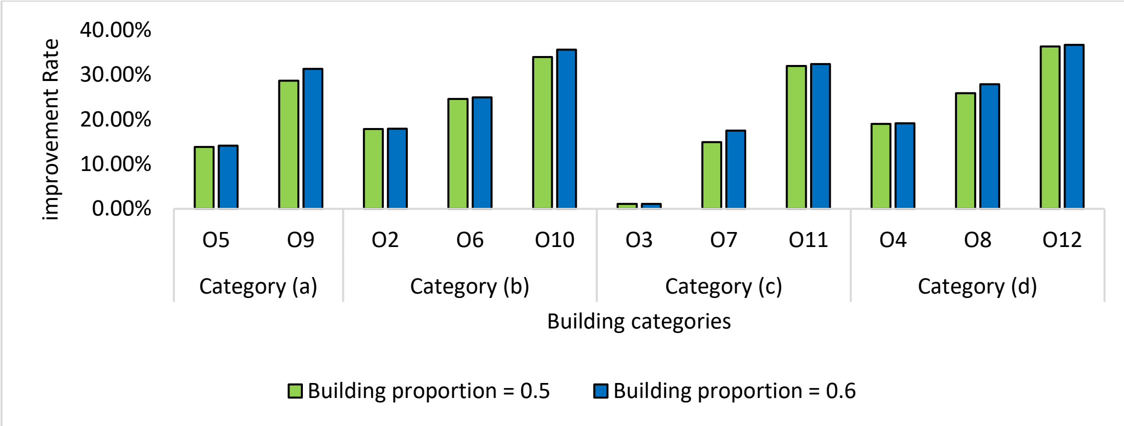


Figure 8: Improvement rate (%) in terms of energy savings.

4.5. Analyzing the Cost of Electricity Consumption for Window-to-wall ratio

Cooling energy cost is a crucial consideration in building design, influenced by various design parameters, such as window-to-wall ratio (WWR). This study investigated the effect of different WWR percentages on cooling energy cost in a building proportion =0.5. The results showed that a WWR of 10% resulted in an annual cooling energy cost of 18,996 EPG, while a WWR of 20% and 30% increased the annual cooling energy costs to 22,182 EPG and 24,761 EPG, respectively.

Additionally, the study found that using a WWR of 10% reduced cooling energy cost by 5,764 EPG per year, while a WWR of 20% reduced it by 2,578 EPG per year. In a building with a proportion of 0.6, using a WWR 10% reduced cooling energy cost by 5,868 EGP per year, while using a WWR 20% reduced it by 2,707 EGP per year.

These findings emphasize the importance of selecting the appropriate WWR percentage in building design to minimize cooling energy cost. Further research is necessary to determine the optimal WWR percentage that achieves a balance between energy efficiency and cost-effectiveness, leading to the creation of more sustainable and cost-effective building designs.

4.6. Analyzing the Cost of Electricity Consumption for glazing

The type of glazing used in building design can affect cooling energy costs. In a building proportion = 0.5, the study found that cooling energy costs ranged from 21,801 EPG to 24,761 EPG per year, depending on the glazing type. Among the case studies (G1, G2, G3, etc.), G10 reduced cooling energy costs by 2,959 EPG per year, while G2 reduced depreciation costs by 462 EPG per year. The study also found that lower-efficiency glazing led to lower cooling energy costs. In a building proportion = 0.6, the study found that cooling energy costs ranged from 21,732 EGP to 24,709 EGP annually, depending on the glazing type. G10 had the lowest cooling energy cost at 21,732 EGP annually, while G9, G8, G7, G6, G5, G4, G3, and G2 had cooling energy costs of 21,781 EPG, 22,566 EPG, 22,632 EPG, 22,880 EPG, 22,938 EPG, 23,585 EPG, 23,653 EPG, and 24,243 EPG annually, respectively. G1 had the highest cooling energy cost at 24,709 EPG per year.

The improvement in cooling energy cost ranged from 466 EPG to 2,977 EPG annually, depending on the glazing type. These findings suggest that selecting the appropriate glazing type can help reduce cooling energy costs and improve energy efficiency in building design. Further research is necessary to determine the optimal glazing type that balances energy efficiency and cost-effectiveness, leading to the creation of more sustainable and cost-effective building designs.

4.7. Analyzing the Cost of Electricity Consumption for Roof Surface Albedo

Roof surface albedo is a crucial strategy that can impact the cost of cooling energy consumption in buildings. This study investigated the effect of different albedo ratios on cooling energy cost in building proportions of 0.5 and 0.6.

The results indicate that in a building proportion of 0.5, the cost of consuming cooling energy ranged from 24,486

EPG to 24,761 EPG annually, depending on the albedo ratio used. Specifically, using an albedo of 0.9 reduced the cost by 274 EPG annually, while an albedo of 0.7 reduced the cost by 200 EPG annually. An albedo of 0.5 and 0.3 reduced the cost by 130 EPG and 62 EPG annually, respectively.
In a building proportion of 0.6, the study found that the cost of consuming cooling energy ranged from 24,431 EPG to 24,709 EPG annually. The improvement difference between the best and worst-performing albedo ratios was between 278 EPG to 65 EPG annually.

4.8. Analyzing the Cost of proposed integration building options

Upon examining the results, it was found that there is a direct relationship between the effectiveness of the options in reducing energy consumption for cooling and the cost of energy consumption. The more effective an option is in reducing electricity consumption, the more effective it will be in reducing the cost of annual cooling. The worst option for reducing energy consumption is also the worst for reducing cost. The cost of annual energy consumption for O1 ranges between 3412.29 and 3406.35 EGP per year in building proportions of 0.5 and 0.6, respectively.
The remaining options are graded in descending order based on their effectiveness in reducing the cost of energy consumption for annual cooling. O3 is next, with costs ranging between 3375.45 and 3369.03 EGP per year in building proportions of 0.5 and 0.6, respectively. The cost then decreases for options O5, O7, O2, O4, O6, O8, O9, O11, and O10, respectively, with costs ranging from 2938.77 to 2252.78 EGP per year in building proportion = 0.5. In building proportion = 0.6, the costs range from 3406.35 to 2192.18 EGP per year, represented by the same options.
Finally, the most efficient among the studied options in terms of reducing the cost of energy consumption is O12, with costs of 2172.56 EGP per year in building proportion = 0.5 and 2155.54 EGP per year in building proportion = 0.6. Figure 9 shows the energy cost for building options 0.5 & 0.6.
The study has revealed a range of improvement rates in terms of energy cost, spanning from 1% to 37%. Notably, the most substantial improvement rate was observed in option O12 for the building proportion of 0.6, resulting in a decrease in energy consumption of 37%. Conversely, for the same option in the building proportion of 0.5, the energy efficiency declined to 36%. Option O10 demonstrated the second highest improvement rate, exhibiting a reduction of 34% and 36% in energy consumption for the building proportions of 0.5 and 0.6, respectively. Following closely, option O11 achieved an improvement rate of 32% for both building proportions. On the other hand, option O3 displayed the lowest efficiency, with a mere 1% improvement. The improvement rates in terms of energy costs for the proposed integration building options are visualized in Figure 10.

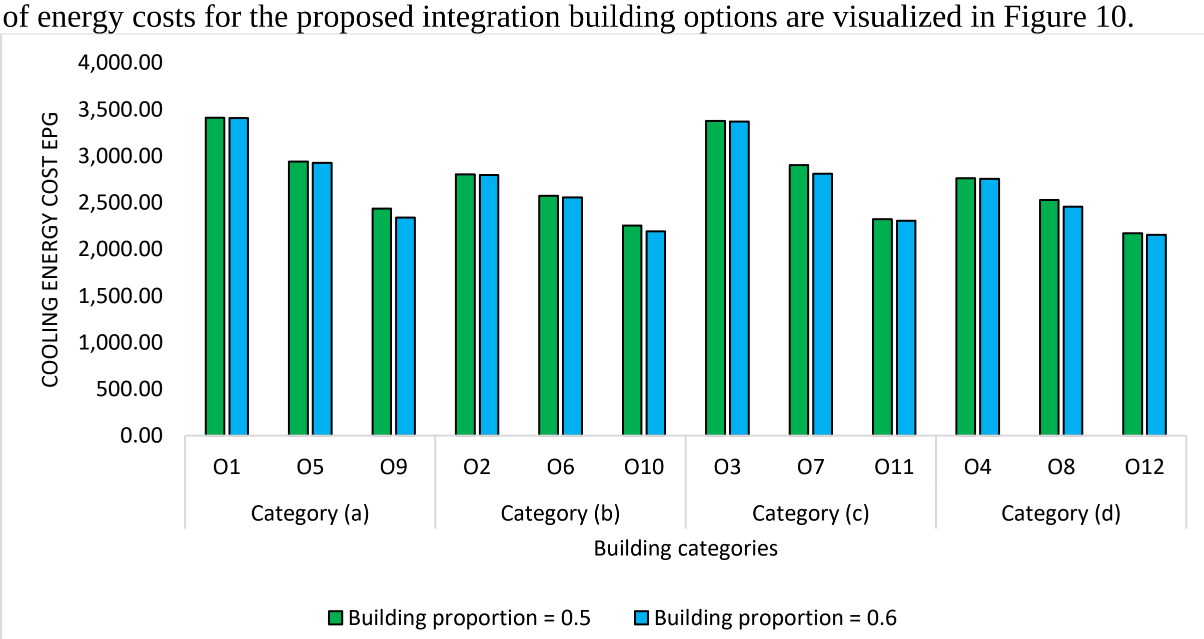


Figure 9: Results of energy cost for building options 0.5 & 0.6.

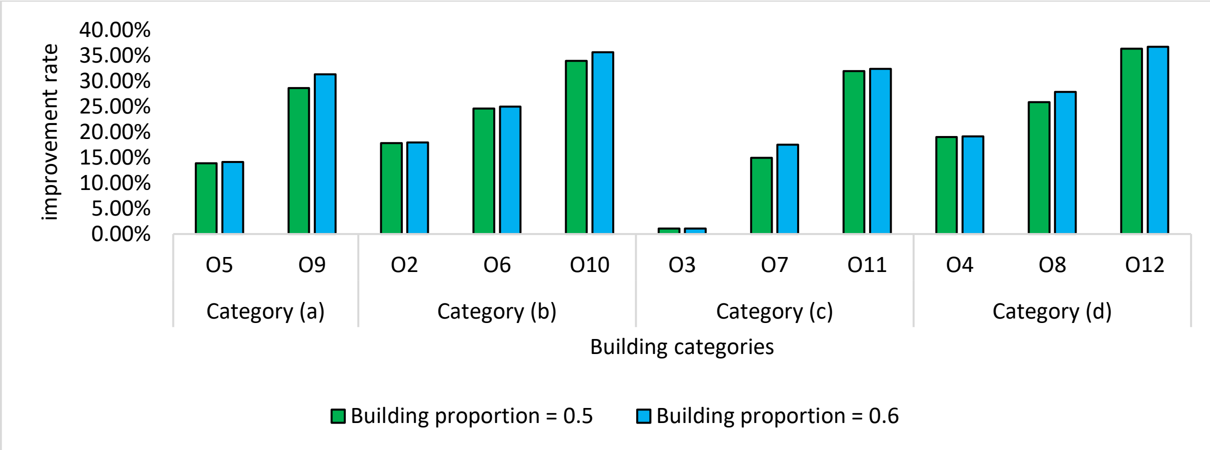


Figure 10: Improvement rate (%) in building options cost 0.5 & 0.6.

5. Conclusion

The objective of this study is to enhance energy consumption for cooling purposes in buildings located in hot and arid regions during the early stages of architectural design. The main parameters to achieve this goal are window-to-wall ratio, glazing type, and roof surface albedo considering two building proportions (0.5 and 0.6).The main outcomes are:

- A building proportion of 0.6 exhibited slightly better performance. For example, a building proportion of 0.5, and WWR= 10% could enhance energy consumption by 22.41%, while a WWR of 20% could lead to a 10.59% improvement.
- For a building proportion of 0.5, G6 which is 6mm air embedded between two panes of glass is the most efficient glazing type among the studied glazing types with a 11.86% improvement.
- Similarly, for a building proportion of 0.6, G10 (three glazing panes with two layers of 6mm air) is the highest efficiency, with an improvement rate of 12.13%.
- The study finds; that embedding the air as a thermal insulator between the glazing panes is more efficient than argon due to convection rings that diminish argon's insulation performance.
- The surface albedo parameter has a minimal impact on cooling energy consumption in buildings for both building proportions (0.5 and 0.6). with 0.26% to 1.14% improvement, respectively.
- The outcomes highlighted that option O12, featuring a WWR of 10%, glazing type G10, and an albedo of 0.9, exhibited the most substantial improvement, reducing cooling energy consumption by 37%, in a building proportion of 0.5 and 36% in a building proportion of 0.6.
- Conversely, O3, characterized by a WWR of 30%, single glazing type G1, and an albedo of 0.9, was the least efficient by 1%, consuming the highest amount of energy.

The results and conclusions of this study are limited to hot and arid regions, and their applicability to other climatic contexts should be approached with caution. Further research is needed to assess the generalizability and effectiveness of the identified parameters, such as window-to-wall ratio, glazing type, and roof surface albedo, in diverse climate conditions. Considering the specific characteristics of each region, including temperature, humidity, and solar radiation patterns, will contribute to a more comprehensive understanding of energy-saving strategies for buildings across different climates.

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