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The Impact of Window to Wall Ratio (WWR) and Glazing Type on Energy Consumption in Air-Conditioned Office Buildings

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ABSTRACT

The quality of indoor environment is crucial in office buildings. In a direct way, it affects the occupants' health and performance. A large amount of energy is usually required to provide and maintain acceptable indoor thermal and lighting conditions. It is found that working spaces are mainly illuminated by artificial lighting systems, which are responsible for a major part of the total energy consumption. The lighting conditions of the interior space can be enhanced by the efficient utilization of natural lighting and the reduction of the amount of energy used. The window to wall ratio (WWR) and the type of glazing play a significant role in controlling the transmitted daylight into space, as well as the heat exchange between the interior space and the outside environment. This paper aims to investigate the impact of the WWR and the glazing type on the total energy consumption. The potential energy savings are also investigated. A parametric analysis was conducted to achieve the research objective using modeling and simulation methods. The main findings of this study showed that the large reduction in the energy consumption can be achieved when a certain glazing type with a high value of visible transmittance is used at small WWR. The type of glazing with a better thermal performance, on the other hand, provides the highest energy savings with larger WWR. The most suitable window area varies according to the zone orientation.

1. Introduction

Office buildings are characterized by very high rates of occupancy and much use of lighting and equipment. Therefore, they consume a large amount of energy for spaces' air-conditioning, lighting, equipment, and other applications. It is reported that a large amount of electric energy required for the working space illumination by artificial lighting. Therefore, the energy efficiency of the lighting systems should be improved to minimize the energy consumption as much as possible. Additionally, the energy efficiency can provide benefits in different economic and environmental

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aspects. It is reported that the artificial lighting systems are responsible for a significant part of the total energy use in office and educational buildings. For example, it was found that 20 to 30% of the total electricity load in office buildings in Hong Kong is consumed by electric lighting (Li & Lam, 2001). The use of the electric lights considerably varies from country to country owing to the country's cultural habits and climatic conditions. In the ASEAN countries (Indonesia, Philippines, Singapore, Malaysia, and Thailand), the electrical energy used for lighting is about 20% to 24% of the total energy consumption in office buildings and schools (Ghisi, 2002). A study on the energy consumption during 1999 and 2000 in commercial buildings in Egypt revealed that about 36% of the electricity was used for illumination by electric lighting systems (el Mohimen et al., 2005). In Saudi Arabia, it was reported that artificial lighting systems account for 20% of the total energy end-use in office and commercial buildings (Hasnain & Alabbadi, 2000).

Recently, there has been an increasing interest in reducing the energy consumption through daylighting and artificial lighting integration in the architectural design. The reduction in the energy consumption from daylighting will not only minimize electric lighting expenses, but also decrease the cooling load, and consequently smaller air-conditioning systems will be installed (Hassan & Al-Ashwal, 2015). Artificial lighting sources have widely been used as a replacement of natural light, because designers believe that they have full control over the illumination levels by using electric lighting sources. However, electric lighting is recommended to be used to supplement daylight in illuminating spaces with the proposed lighting conditions.

It was an essential task to properly design the buildings to utilize the available natural light before the existence of the artificial lighting. Large windows and high ceilings were used to provide sufficient natural lighting into the provided space due to the shortage of daylight. Different window designs were found in the southern countries due to the need to minimize heat gain during summer along with providing adequate natural lighting. It was found that incorporating a courtyard to the building design provided acceptable solutions to provide daylight into internal spaces (Phillips, 2004). In addition, the design of the building façade is an essential factor to allow the penetration of available daylight and avoid direct solar radiation (Hassan et al., 2015). Daylighting and artificial lighting are effectively integrated when electric lighting can be controlled according to the illumination level on the working surface. If daylight is properly integrated, the energy required for lighting and cooling the space can be significantly decreased due to reducing the reliance on artificial lighting (Yu & Su, 2015).

Many studies have addressed the implication of daylighting in the indoor lighting conditions and energy consumption. In Hong Kong, a method was proposed by Lam & Li (1998) to assess the possible decrease in energy consumed by the artificial lighting systems as a result of the daylight-natural light integration in the office buildings. As a result, quite substantial energy savings were estimated. About 59.7 kWh/m^2 per year saving in energy used by the electric lighting systems was reported in all zones (Lam & Li, 1998). A methodology to evaluate potential savings in lighting energy when daylight is utilized was proposed by (Ghisi & Tinker, 2005). The results indicated that a reduction of about 21% to 86% in lighting energy consumption was observed in Florianopolis. In Leeds, 11% to 44% lighting energy savings were recorded (Ghisi & Tinker, 2005). Krarti et al. (2005) estimated the impact of the window area, the glazing type, and the geometry of building on artificial lighting consumption when daylighting is utilized. Their results revealed that the visible transmittance value of the window and ratio of window to the floor area are the main factors, which significantly influence the predicted savings in energy. Energy savings of about 70% of the electricity used for lighting was accordingly obtained (Krarti et al., 2005). Concerning the use of dimming lighting control system with photoelectric sensors in an air-conditioned open plan office, Li et al. (2006) assessed the potential savings in energy. An annual reduction of about 33% in energy consumed by artificial lighting was estimated with the use of the proposed lighting control system (Li et al., 2006). Bodart & De Herde (2002) assessed the effect of daylighting on the building energy consumption using a combined approach, which integrates daylighting and thermal performance for a typical glazing type used in office buildings in Belgium. The approach implemented could reduce energy consumption by artificial lighting from 50% to 80%. Furthermore, up to 40% of the overall energy savings can be attained not only via minimizing lighting energy consumption, but also via reducing the internal loads generated from the artificial lighting (Bodart & De Herde, 2002). Abdul Fasi & Budaiwi (2015) investigated the potential decrease in energy consumption when both the daylight and the artificial light were properly integrated. The results indicated a significant reduction in the annual building energy consumption for all types of windows. For example, a reduction of about 14% in the total energy consumption was observed using double-glazed clear glass windows and 16% energy saving was obtained using double-glazed low-E windows (Abdul Fasi & Budaiwi, 2015). Al-Ashwal et al. (2014) proposed an approach to help designers select the proper window area in designing windows for energy efficiency. The authors stated that a decrease of about 39% in energy used by electric lighting could be obtained. The total energy used can be minimized by 11% provided that the available daylight is utilized through a proper lighting control system (Al-Ashwal et al., 2014).

In tropical regions, providing natural light for illuminating interior spaces is a key element in building designs. A minimum reduction of 10% in energy consumption could be managed by using simple daylighting strategies in Malaysia (Djamila et al., 2011). Zain-Ahmed et al. (2002) studied how daylight is properly utilized by using passive solar designs in buildings in tropical regions. The results revealed that 10% of the total energy consumption was reduced when daylighting strategies were properly implemented in the context of Malaysian buildings (Zain-Ahmed et al., 2002). Ossen et al. (2005) investigated the impact of using external horizontal shading devices on the penetration of natural light, solar heat gains, incident solar radiation, and energy consumption. It was found that energy savings of 6%, 8%, 14% and 11% can be attained using optimum overhang ratios of 1.0,1.0, 1.3, and 1.2 on the north, south, east, and west, orientations, respectively (Ossen et al., 2005).

To utilize natural lighting efficiently, windows need to be designed carefully. The design of

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windows needs to be considered at early design stages. This is because windows are the primary source of daylight and at the same time they are regarded as an additional source of excessive heat gain if not properly designed. The design of a window incorporates the selection of proper the glazing type, window to wall ratio (WWR), the height of the window and appropriate shading device. The type of glazing and window to wall ratio are considered as major elements in the design of windows. They both directly affect the amount and quality of the admitted natural light into space, as well as the extent of heat gain or loss. Therefore, the main objective of this research paper is to investigate the impact of the window to wall ratio (WWR) and the glazing type on the window design to achieve energy efficiency in office buildings in a hot-humid climate. The study mainly aims to find out the effect on the total energy used, the energy consumed by electric lighting systems, and the evaluation of the possible savings in energy consumption when artificial lighting is efficiently integrated with daylighting.

2. The Study Approach and the Characteristics of the Building Model

Building energy simulation is an essential tool to investigate the energy performance of buildings. Computer simulation programs are effective analytical tools for constructing the building models, which will be later used for building the energy research and evaluation of architectural design. It was reported that the computer simulation method is a very reliable tool to obtain data related to the illumination level of indoor spaces, because similar readings between the measured on-field and simulated data were found with a minor variation in values (Hassan & Arab, 2014). In this study, the VisualDOE software was selected to carry out the energy and daylight analysis of a typical office building. This software provides the ability for simulation and analysis of various design features and energy efficiency measures, comprising the daylight integration of with the electrical light. This software has been widely evaluated to validate its accuracy and consistency (Bahel et al., 1989; Zmeureanu et al., 1995).

An integrated base case model consisting of a thermal model and a lighting model is formulated according to a survey conducted to define the most common features of a typical office building located in the hot-humid climate of Dhahran, Saudi Arabia (Al-Ashwal & Budaiwi, 2011). Some values were assumed according to standards, literature review and logic. The values included occupancy density, lighting, and equipment power density, infiltration, and operation schedules. The base case model has four perimeter zones and a core zone for stairs and services. It has a gross floor area of 484 m^2 with the dimension of 22 m on each side of the building. The perimeter zones' depth was assumed to be 7.0 meter because the effectiveness of daylighting in space is within about twice the room height (Reinhart, 2005). Lighting control properties have to be defined for daylight integration. A dimming control strategy was selected due to the flexibility in response to illumination level changes. Each zone has two sensors for lighting control, and the illumination level was defined as 500 lux according to IESNA standard (Rea, 2000). The types of glazing selected for this study are illustrated in Table 1. They are four different types with different thermal characteristics; all using clear glass. The low transmittance value of the tinted glass is the main reason behind excluding this type of glazing in this investigation.

Table 1: Types of glazing selected for parametric analysis

Glazing Type	No: of Layers	Visible Transmittance	Shading Coefficient (SC)	Solar Heat Gain Coefficient (SHGC)	U-Value $W/m^2.K$
Single-Glazed Clear 6 mm **(Clr SG)**	1	0.88	0.95	0.81	6.17
Double-glazed Clear 6/12/6 mm **(Clr DG)**	2	0.78	0.81	0.70	2.74
Double-Glazed Clear Low-e 6/12/6 mm **(DG Low-E)**	2	0.74	0.65	0.56	1.78
Double-Glazed Clear Heat Mirror 6/12/6 mm **(DG HM)**	2	0.53	0.40	0.34	2.02

3. Results Analysis and Discussion

In this study, the simulations inspect a range of window to wall ratios (WWRs) starting from 0% to the maximum area possible in the exterior wall with a combination of different glazing types selected for this study. The influence of daylight is required at the work plane height (76 cm), so that the window sill is maintained at 80 cm with a window height of 220 cm. According to the simulation results, the building energy performance is recognizably influenced by the area of the window and glazing type used. The results are briefly outlined in the following paragraphs.

3.1 The Impact of Daylight Integration on the Energy Consumed by Artificial Lighting

The impact of various types of glazing with different WWRs on the energy used by the electric lighting systems was investigated when artificial lighting is integrated with the available daylight using dimming control system. The results of the simulation process revealed that there is a significant reduction in lighting energy consumption for all types of glazing and all possible WWRs when artificial lighting and daylight were integrated. In the north zone, the energy consumed for lighting was dramatically minimized when the area of the window was increased up to 5%, and it gradually declined with larger WWR up to 50% as illustrated in Figure 1(a).

About 40% to 54% reduction in energy consumed for the space illumination was found almost for all investigated WWRs and glazing types. The simulation findings showed that the type of glazing with a high visible transmittance value resulted in a low lighting energy consumption. This can be the result of the high amount of light admitted into space, which will, in turn, decrease the usage of electric lighting. It can be noticed that the energy consumed for lighting is reduced for all types of glazing when the area of the window is increased. This is due to the increase of the amount of daylight transmitted into space. There is a noticeable variation in lighting energy consumption among the investigated glazing types with the small area of windows. However, this variation is insignificant when larger windows were simulated. For other orientations, similar results of energy consumption were found as shown by the simulation results in Figure 1.

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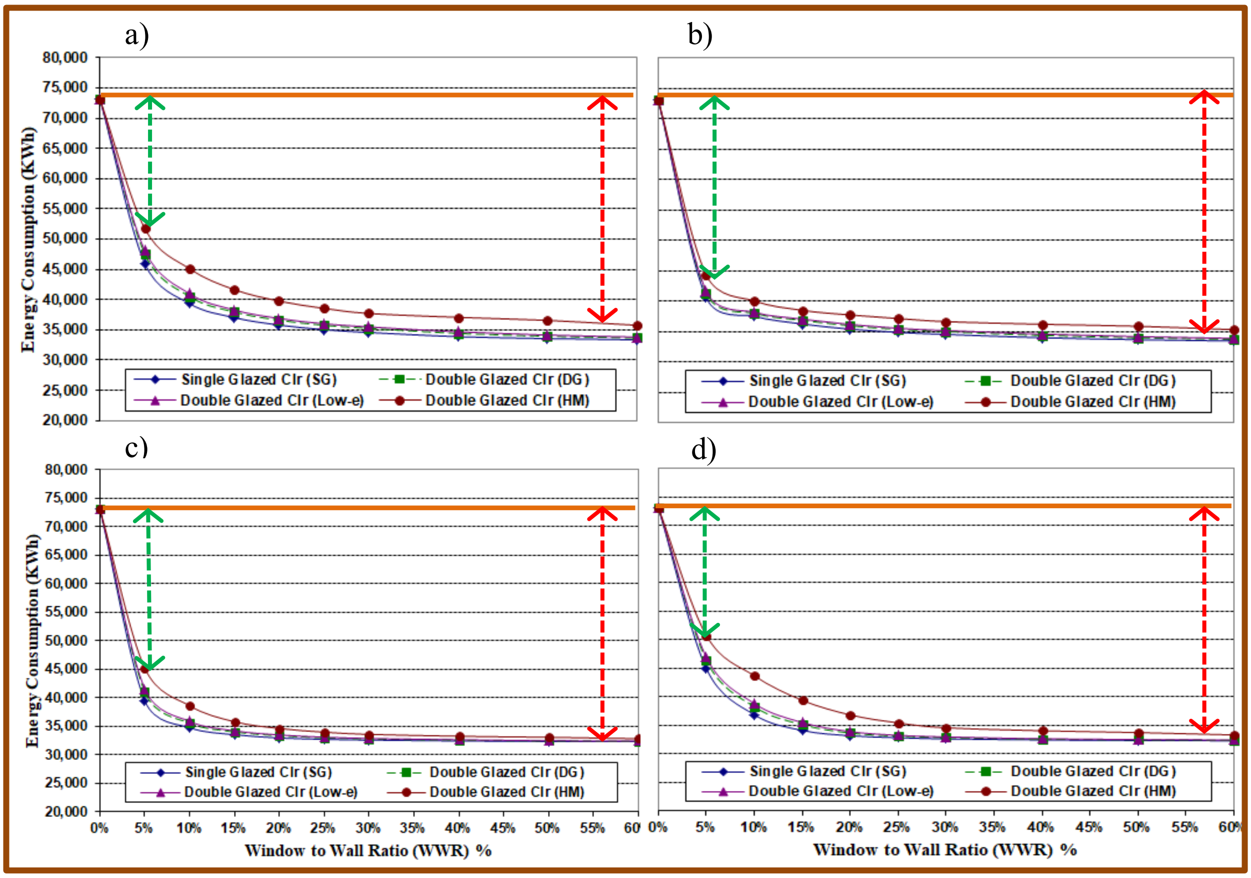

Figure 1: Lighting energy consumption for various glazing types – 2.2 m window height – [a) North zone, b) East zone, c) South zone, and d) West zone]

3.2 The Impact of Daylight Integration on the Total Energy Consumption

The selection of the glazing type and the size of the windows are crucial during the building design process as it directly influence the energy consumption of a building. The results of this paper demonstrated that the main factor determining the energy performance of a specific window is the value of shading coefficient associated with the glazing type. Figure 2 shows that the lower amount of total energy used can be obtained when a type of glazing with low shading coefficient value is used. The total energy consumption for all investigated types of glazing is minimized as a result of the efficient utilization of natural lighting as shown in Figure 2(a). A noticeable decrease in the energy consumption can be detected with a variation in amount depending on the selected WWR and the type of glazing. There is a very small difference in the amount of reduction in the total energy used with small WWRs and for all types of glazing when daylight and artificial lighting are integrated. The resulting energy consumption is slightly bigger than other types of in small WWR (5-15%) using the double-glazed heat-mirror glass. However, this type of glazing provides lower energy consumption than other types of glazing at large areas of window.

A similar trend in energy consumption was found in other orientations, but with variation in the amount of the total energy consumed in the building as illustrated in Figure 2. It can be noticed that the total energy consumption is lower in the north zone compared to the south, west, and east zones. It is found that the variation in the total energy consumption is insignificant with the change of glazing type in the north zone. However, this difference is clear in other orientations.

In the east and south zones, Figure 2(b) and Figure 2(c) show that a larger reduction in the total energy consumption can be obtained using heat-mirror glass with double-glazed. This can be due to the façade is exposed to the direct solar radiation for a long time during daytime. This kind of glass is good in preventing most of the direct solar heat gain. Furthermore, the maximum reduction in the total energy used is provided by the heat-mirror glass with two layers of glass for all zones, particularly when a large window area is used.

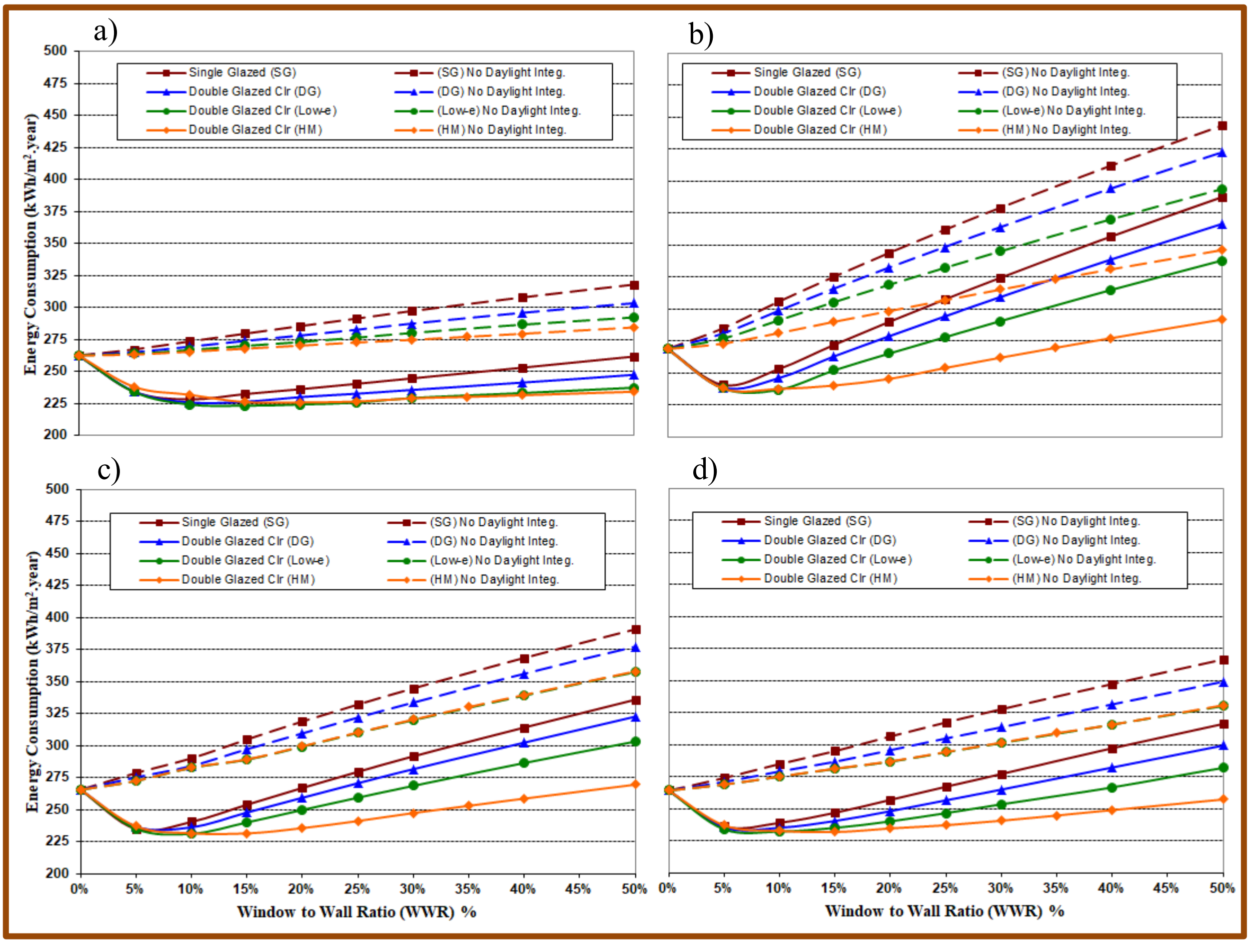

Figure 2: The impact of daylight integration on total energy consumption for various glazing types – 2.20m window height – [a) North zone, b) East zone, c) South zone, and d) West zone]

3.3 The Expected Energy Savings

The possible savings in energy as a result of the integration of electric lighting with daylighting were investigated for various types of glazing, and WWRs. The simulation findings showed that the window area and the type of glazing have a direct impact on the expected savings in the total energy consumption. This varies according to the zone orientation. The possible reduction in the energy consumption for the north zone can be seen in Figure 3(a). The results revealed that (9.7%-19%) saving in the total energy consumption could be obtained for all the investigated types of glazing with a direct relation with the selected WWR. When a small window area is used (5-10%), the highest reduction in energy is provided by a type of glazing with high visible transmittance (single clear glass). On the other hand, when larger windows (20-50%) are used, about 18% to 19%

reduction in energy could be achieved with double clear glass Low-E. This can be attributed to the properties of the clear glass, which allow more natural light than other types of glass at small WWRs. However, larger window areas allow for more heat gain along with the transmitted light. Using larger windows, a double glazed Low-E is a better choice due to its thermal characteristics.

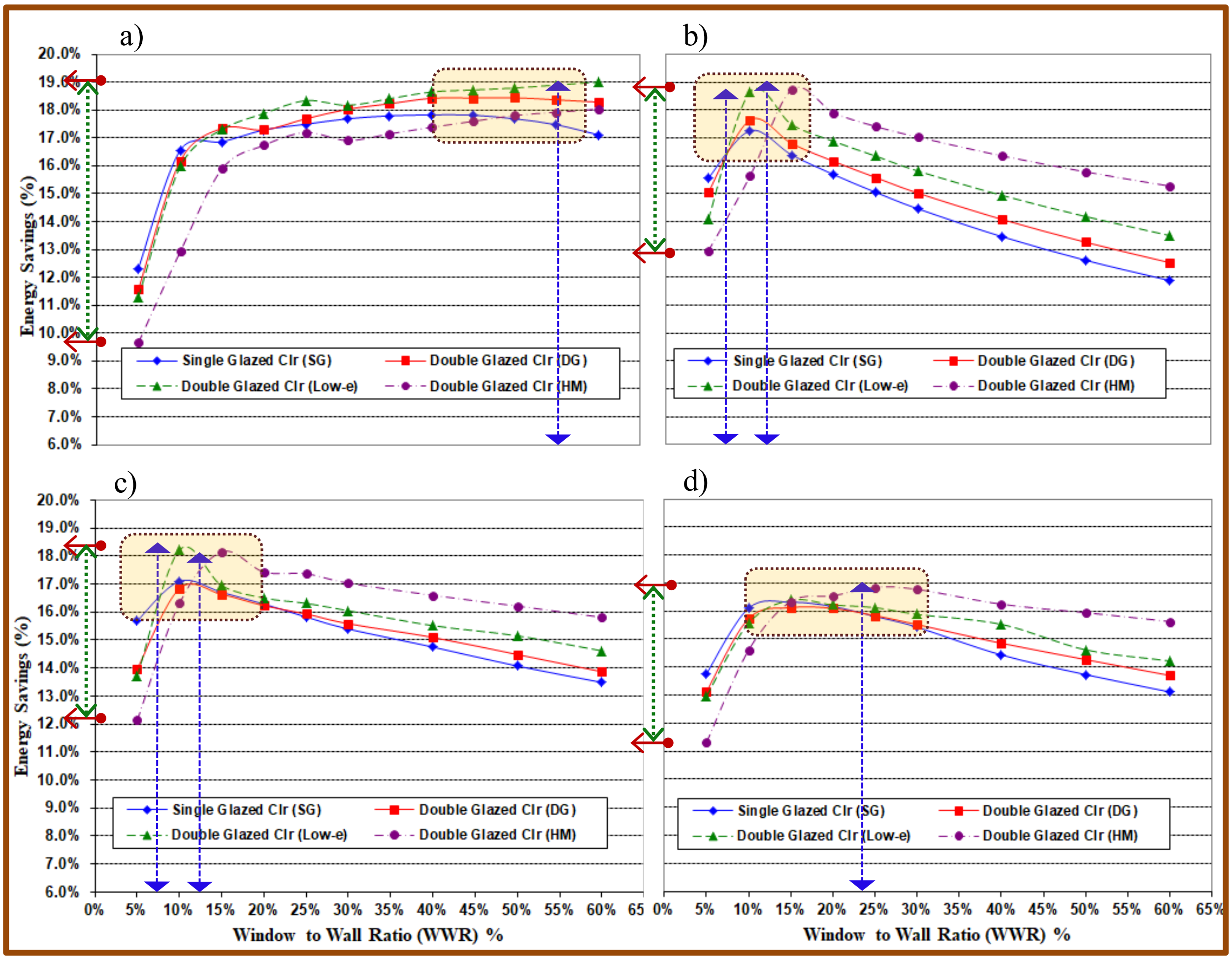

Figure 3: The expected energy savings for various glazing types – 2.20m window height – [a) North zone, b) East zone, c) South zone, and d) West zone]

Figure 3(b) shows that about 12.9% to 18.7% saving in energy is expected in the east zone for all the investigated types of glazing based on the WWR used. A Large reduction in energy is provided when a glass with low shading coefficient value is selected, because the east zone is exposed to direct solar radiation for a long time. Moreover, it is found that the double heat-mirror glass provides a lower reduction in energy compared with other types of glazing at small WWR. However, larger savings in the total energy used were obtained when larger windows were used. This is because of the ability of this type of glass to prevent the direct solar heat, which is better than other types and at the same time transmit sufficient daylight into space using window with large areas. Figure 3(c) illustrates the simulation results of the possible energy savings in the south zone. For all the investigated WWRs and types of glazing, about 12.1% to 18.2% reduction in the total energy consumption can be obtained. Using double glass Low-E at (5-15%) WWR can provide the maximum energy savings. However, the highest saving in energy was recorded when the double-glazed heat-mirror glass at larger areas of windows was used. Figure 3(d) shows a possible of 11.3% to 16.8% energy savings in the west zone.

4. Conclusion

In the office buildings, energy is mainly consumed by the air-conditioning system, lighting system, and equipment. This can be a consequence of the excessive usage of equipment and electric lighting for illumination. In addition, the occupancy rate in office buildings is higher than in other building types. One of the main measures that can be applied to reduce the energy consumption is the efficient integration of artificial lighting with daylight using proper lighting control system. Moreover, daylighting can enhance working space conditions and contribute to improving the occupants' performance in a healthier working place. The design of windows is key factor to achieve the efficient utilization of natural lighting. Architects and designers should properly select the glazing type, the window area (WWR), the window height, and wisely design shading devices. This study investigated the impact of the window to wall ratio (WWR) and the type of glazing used on the building energy performance. The main findings of this research demonstrated that a significant decrease in the energy consumed for space illumination could be achieved. The visible transmittance value of the glazing type influences the amount of light admitted into space so that larger energy savings can be attained. It is also found that the total energy consumption and the possible savings in energy, when a particular window is used, are highly affected by the shading coefficient value of the glazing type. The selection of the proper WWR is highly influenced by the type of glazing used. Last but not least, large window areas can be utilized when using a glazing type with a good thermal performance.

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