IDENTIFYING OPTIMUM GLAZING PROPERTY FOR CONSERVING ENERGY IN HOT SEMI-ARID CLIMATE REGIONS

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ABSTRACT

Globally, the building sector is responsible for 40% of energy use and 30% of GHG emissions. The greatest portion of the energy is used during the operational phase (use stage) of buildings. The building envelope, especially the glazed components, plays an important role in determining the energy requirement of buildings. These glazed parts of the building envelope exposed to direct solar radiation are most vulnerable to heat loss and gain. Heat loss and gain through the glazing material depend on glazing properties (U-value, SHGC, VT) and building energy use changes according to the properties of the glazing system. A variety of glazing types has been developed over recent decades that use the properties of the glass as a means of responding to environmental conditions. This study is carried out to identify the optimum glazing property for conserving energy in cooling dominant regions using an early design energy modeling tool. It was found that a low SHGC is the most important glazing property for reducing cooling energy consumption. SHGC of less than 0.3 is found useful. This study would help building industry professionals evaluate the best glazing property while selecting the glazing type.

KEYWORDS

glazing properties, cooling dominant regions, energy conservation, energy modeling, SHGC

1. INTRODUCTION

Architectural design decisions have a significant impact on the energy performance of buildings and the best prospects for improving buildings' energy performance arise in initial stages of design (Haglund, 2010; Attia et al., 2012). Fenestration not only adds aesthetic to the building façade but plays an important role in providing thermal comfort and optimum illumination levels (Sadineni, Madala and Boehm, 2011) and has a significant impact on energy demand for heating and cooling, depending on climate. Glass manufacturing technology has undergone many innovations over time. The invention of modern float glass in the 1950s reduced the cost of glass and also created new applications such as glazed facades of high-rise buildings (Garg, 2007). The glazed facades impact significantly on heating and cooling requirements

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to create a comfortable indoor environment. This led to a great increase in the world's energy resources consumption. This extensive use of glass facades in the middle of the 20th century faced criticism with the evolution of the world's environmental agenda in the 1960s and due to the emergence of green architecture ideology. The glass was considered unnatural and environmentally harmful due to the large amount of energy being used for its processes and operation of the building. At the time of the oil crisis in 1973, sealed glazed facades were held responsible for energy wastage. The energy and environmental crisis called for engineers and architects to minimize the use of glass in buildings to reduce energy consumption (Elkadi, 2006). To avoid loss of market, the glass industry started working on energy-efficient types of glass and glazed building facades provided experimental grounds to develop technical solutions for integrating sustainability and energy efficiency measures (Garg, 2007, Elkadi, 2006).

Buildings consume a lot of energy to maintain a comfortable indoor environment. Despite efforts to reduce energy consumption, the building sector is still responsible for 40% of global energy use and 30% of global GHG emissions (Lee et al., 2013; UNEP SBCI, 2009). Life cycle analysis of buildings reveals that more than 80% of GHG emissions are associated with the operational phase to meet various energy needs such as heating, cooling, lighting, appliances, etc. The greatest reductions in GHG emissions can, therefore, be achieved by targeting the operational phase of buildings (UNEP SBCI, 2009). The building envelope, especially the glazed components, plays an important role in determining the operational energy requirement of the building (Raheem, Issa, and Olbina, 2016; Hee et al., 2015).

Glazed elements are the weakest links in the building envelope regarding energy performance. A large proportion of heat transfer occurs through windows due to the substantial difference between the heat transfer characteristics of windows and other components of the building envelope. For example, in a two-story house with a 30% window to wall ratio (WWR), up to 60% of energy transfer is through windows (Rezaei, Shannigrahi and Ramakrishna, 2017; Lee et al., 2013). When designing glazed buildings in cooling dominant regions, the key objective should be to avoid a high cooling demand to ensure low total energy consumption (Poirazis, Blomsterberg, and Wall, 2008). Studies on glazing and buildings' energy consumption find that improvement in façade glazing to control heat and daylight leads to considerable energy savings in heating, cooling, and lighting in buildings (Lee et al., 2013; Tian et al., 2010). Therefore, this is the logical place to look for improvement.

Buildings' energy performance is influenced significantly by the properties of glazing materials. Energy transfer through windows depends on many parameters such as the type of glazing, Window to Wall Ratio (WWR), window orientation, shading devices, and climatic conditions (Lee et al., 2013; Singh and Garg, 2009). While WWR, orientation, and shading are the focus of ongoing research relating to different climatic conditions, there is no significant information found in the literature about the optimum glazing property for hot semi-arid climatic conditions. The main objective of this work is therefore to identify the optimum glazing property for conserving energy for climates similar to Lahore (a hot semi-arid climate), Pakistan. Thermal transmittance (U-value), Solar Heat Gain Coefficient (SHGC), and Visible Transmittance (VT) are the three key parameters that are used to evaluate the performance and properties of glazing.

2. PROPERTIES OF GLAZING

U-value, SHGC, and VT are key parameters used in energy codes and standards to measure the energy performance of glazing (Elkadi, 2006). The U-value of a glazed element indicates the rate of heat flow through the glazing system by the combined effects of conduction, convection, and radiation due to the temperature difference between the inside and outside. It quantifies the insulating value of the material. SHGC represents the amount of solar heat that penetrates through the window system compared with the amount that strikes the outer surface of the window. It is therefore also the ability of the glazing material to resist heat gain from solar radiation. Visible Transmittance (VT) is an optical property that indicates the percentage of the visible light transmitted through a glazing material. VT is important for providing daylight and views and high VT is advisable for good daylighting utilization. Building energy use changes according to the properties of the glazing system (Lee et al., 2013). Heat loss and gain through thermal transmissions and the effects of solar radiations such as heat gains from the Sun, as well as transmitted visible light must all be considered when analyzing the performance of glazed building components, as they all influence the total heating, cooling and electric lighting demand of buildings (Rezaei, Shannigrahi and Ramakrishna, 2017; Grynning et al., 2013).

There is a broad range of glazing types developed over recent decades using glass with different properties. These may be used in a monolithic form (single glazing) or incorporated into an Insulating Glazing Unit (IGU) to improve energy performance. IGU is a fabricated unit made of two or more glass panes (such as double or triple glazed) separated by a sealed cavity. The cavity is generally filled with air but can also be filled with low thermal conductivity gases such as argon or krypton for improved U value (Garg, 2007; Elkadi, 2006).

Studies into the energy savings potential of different glazing types have employed a variety of software tools. Stegou-Sagia et al., (2007) investigated the impact of glazing type on energy consumption for office buildings in Greece using the computer program ENER-WIN and confirmed that the choice of glazing directly impacts the energy consumption. The energy consumption was highest with clear glazing compared to grey-tinted glazing. Sadrzadehrafiei et al., (2011) found annual cooling energy savings of up to 3.4%, 5.1%, and 6.4% by replacing the single clear glazing of the mid-rise office building in Malaysia with single low-E reverse, single low-E and double glazing (clear and low-E), respectively, using IES simulation software. Bojić and Yik (2007) evaluated energy savings by application of advanced glazing to high rise apartment buildings in Hong Kong using the simulation software EnergyPlus. Reduction in yearly cooling energy consumption by replacing single clear glazing with four different types of glazing was studied. The reduction in cooling electricity use with the application of clear plus low-E glazing was up to 6.6 %. The savings due to application of low-E reversible glazing, double-clear glazing, and low-E glazing was up to 1.9%, 3.7%, and 4.2% respectively. Singh and Garg (2009) selected five different climate zones of India and studied ten different types of glazing using the energy simulation software TRNSYS. They found that the same type of window will not work best for both heating and cooling climate. It was concluded that for locations where cooling is required for most of the year, reflective solar control windows are suitable (e.g. Delhi, Chennai, Bangalore, Jodhpur), but low-E glazing is beneficial for a location (Shillong) where the heating requirement is dominant during the year. However, Iqbal and Al-Homoud (2007) recommended using low-emittance double glazed windows in highly glazed facades in hot climates for energy efficiency.

Several studies have therefore recommended the application of advanced glazing for energy savings in buildings. However, there is little clarity regarding the optimum glazing properties for energy conservation in specific hot climatic conditions.

3. METHODOLOGY

The modeling focuses on the comparison of different glazing properties for building energy optimization in a hot semi-arid climate as experienced in Lahore, Pakistan. An early design energy modeling tool (COMFEN), a reference model of a $18m^2$ office room and local climatic data as used by Altaf and Hill (2019) for identifying optimum WWR for conserving energy in cooling dominant regions was further used in this work to find the optimum glazing property. The outdoor climatic data of Lahore was obtained using a TMY2 data file. Monthly average temperatures range between 12°C in January and 33°C in June. COMFEN, identified by Haglund (2010) as an accurate tool for comparative analysis of fenestration alternatives, was used for this study. It is based on EnergyPlus, Window, and Radiance. Schedules for occupancy, lighting, and equipment for an office building were set according to the default values of COMFEN. The loads for each schedule were set according to ASHRAE standards. Workplace density, miscellaneous equipment power, and artificial Lighting Power Density (LPD) for an office building were specified as 9 m^2/person, 8.07 W/m^2, and 10.76 W/m^2 respectively (assuming fluorescent lighting). As daylight sensitive lighting systems are rarely used, lighting demand was included whenever the office was occupied. The conditioning system is a single zone HVAC system automatically sized for the façade (including interior loads).

A smaller WWR of 20% was used for simulation. In order to explore the impacts of U-value, SGHC, and VT on energy performance, clear glass and range of products from tinted, solar control, and low-E were selected and included in double glazed units with air fill presented in Table-1. These double-glazed units were created in Window6 which works with COMFEN. The Energy Use Intensity (EUI) of the office with different glazing options was compared with a base case with air-filled double glazing with clear glass (DG1), which is the most generally used, being commercially available and a relatively economical glazing type. Simulations then examined the impact of U-value, SHGC, and VT on EUI when the reference room was modeled for each orientation (north, south, east, west) in turn. Two glazing types with the lowest EUI were further modeled with increasing WWR and low thermal conductivity gas to further study the impact of glazing properties on the energy demand.

4. RESULTS AND DISCUSSION

Simulation results of EUI for different WWR (Window to Wall ratio) with DG1 showed that cooling loads are dominant, making up 55–65% of the total energy demand, and when combined with the fan power required for this cooling, this rises to 70–80%.

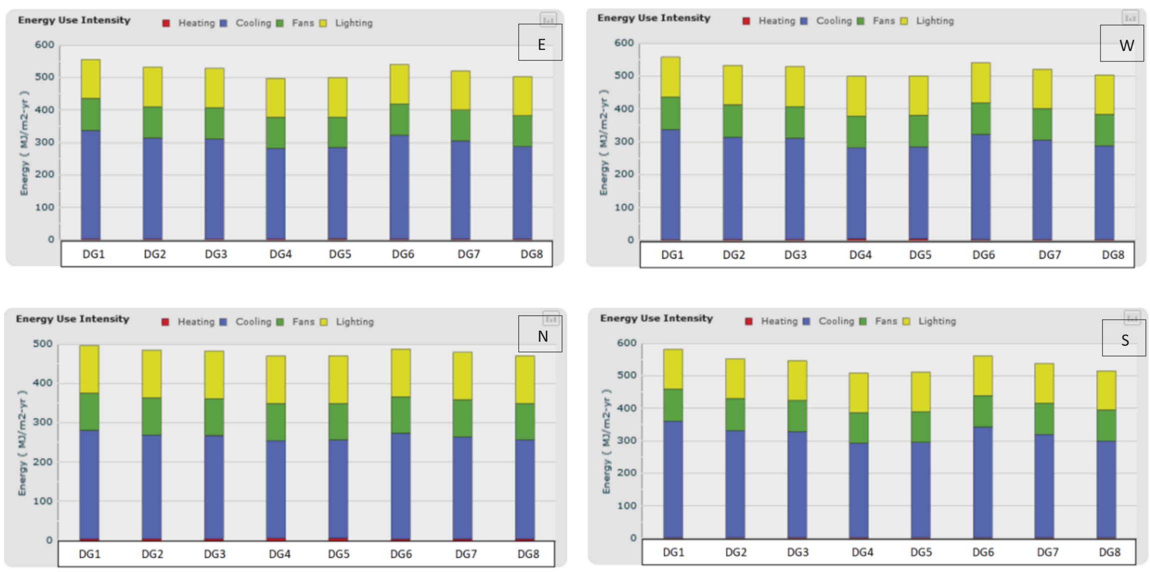
Most Appropriate Glazing Property

Energy demand from the use of the different glazing types on each orientation was found by simulation (Figure 1). The results show energy savings of 2.9% to 10.6% for east and west orientation and 3.5% to 12.5% for south orientation with different glazing types in comparison to DG1. The greatest energy savings (10.6% to 12.5%) are found from the use of glazing types with the lowest SHGC (G4, G5, G8) for east, west, and south orientation. Energy savings of 1.8% to 5.5% are observed for north orientation by using different glazing types in comparison to DG1. The impact of low SHGC is not so critical on the north orientation due to low solar radiation, and this is a beneficial orientation for fenestration for energy efficiency in cooling dominant regions. When applied to all facades, solar control glazing and spectrally selective glazing types, all of which have low SGHC, are found to deliver the lowest building energy demand in this climate (Figure 1).

TABLE-1. Double Glazed Unit (DGU).

No.	Glazing type	Description of DGU	Glazing properties		
			U-value W/m^2 K	SHGC	VT
DG1	Double glazed Clear	6mm clear, 12mm air gap, 6mm clear	2.69	0.716	0.789
DG2	Double glazed tinted	6mm green tinted, 12mm air gap,6mm clear	2.69	0.501	0.658
DG3	Double glazed tinted	6mm blue tinted, 12mm air gap, 6mm clear	2.69	0.464	0.511
DG4	Double glazedsolar control	6mm solar control coating, 12mm air gap, 6mm clear	2.69	0.252	0.232
DG5	Double glazed solar control	6mm solar control coating, 12mm air gap, 6mm clear	2.69	0.273	0.179
DG6	Double glazed Low-E	6mm thermally insulating low E, 12mm air gap, 6mm clear	1.65	0.533	0.777
DG7	Double glazed Low-E	6mm neutral soft coat low E, 12mm air gap, 6mm clear	1.65	0.385	0.693
DG8	Double glazed spectrally selective	6mm spectrally selective coating, 12mm air gap, 6mm clear	1.61	0.251	0.596

FIGURE 1. Comparison of energy consumption of glazing types DG1 to DG8 at 20% WWR for east, west, north and south orientation.



Examination of the relationship of EUI to each parameter demonstrated no identifiable relationship with U-value, and a significantly clearer relationship with SGHC than with VT, at R^2 values of 0.98 and 0.66 respectively (Figures 2–4).

It has also been found by Gasparella et al., (2011) and Poirazis, Blomsterberg, and Wall (2008) that the low solar transmittance has a great impact on cooling load reduction, whereas low thermal transmittance is a better choice for reducing heating load. However, they did not quantify the appropriate values for thermal and solar transmittance. This study confirms that a low SHGC is more significant than a low U-value for reducing the cooling load in cooling dominant regions, and finds that a SHGC of less than 0.3 is found useful for cooling load reduction.

FIGURE 2. Relationship of EUI to Solar Heat Gain Coefficient (SHGC) when each glazing type is used on all the facades.

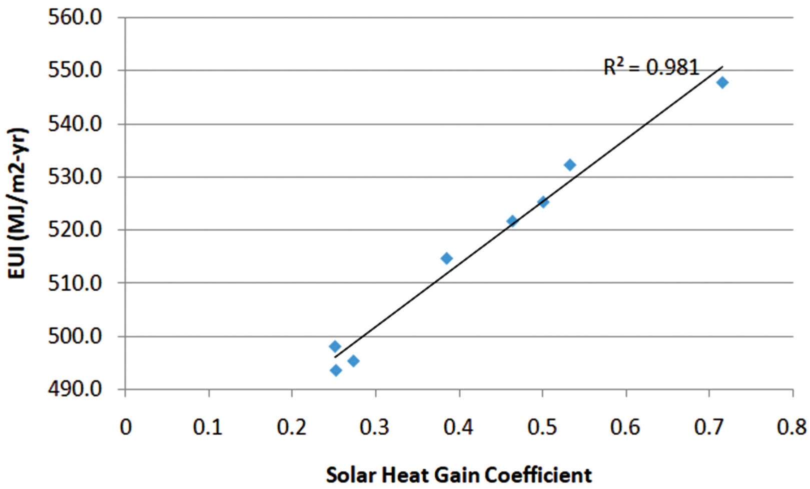


FIGURE 3. Relationship of EUI to visual transmittance (VT) when each glazing type is used on all the facades.

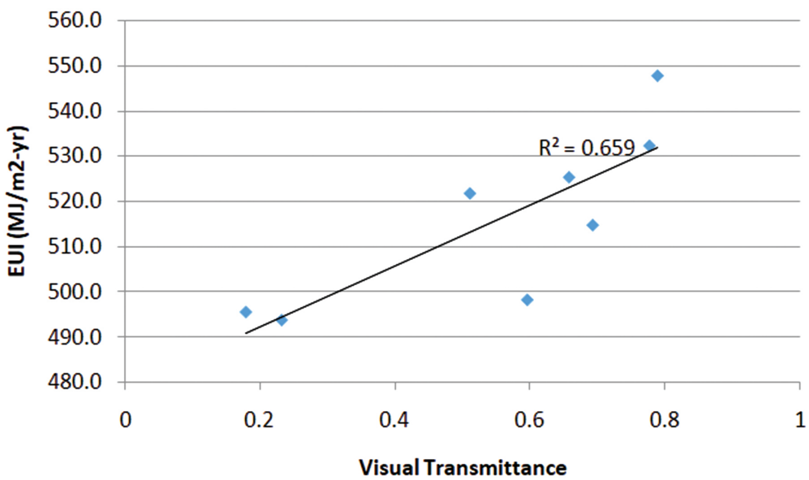
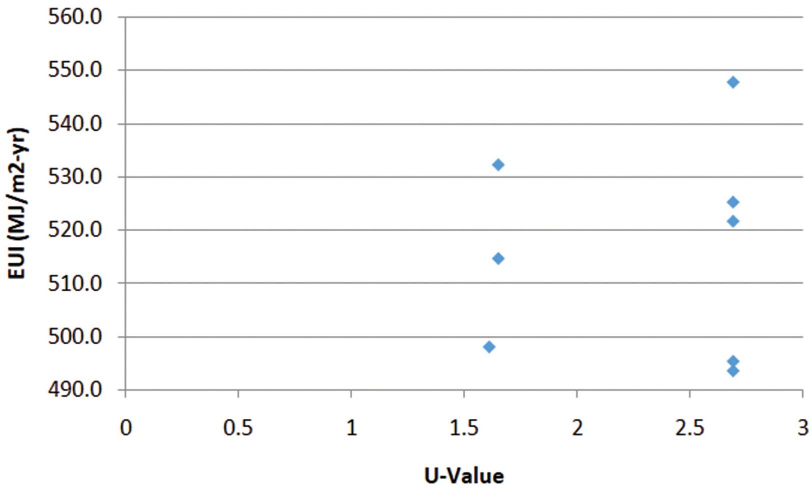


FIGURE 4. Relationship of EUI to U-value when each glazing type is used on all the facades.



Extended Freedom for the Selection of Glazing Area

As there is a strong preference among architects to increase the WWR for better visual comfort and aesthetics, the two glazing types (DG4, DG5) with the least energy consumption were further simulated with different WWRs to explore changes in energy consumption (Figures 5–8). As might be expected, the rate of increase in energy consumption is less with the glazing types with low SHGC leading to an alternative of planning higher WWRs with glazing types with low SHGC.

When using DG4 or DG5, even if the WWR is increased from 20% to 60% for east, west, and south orientation, the energy consumption does not exceed the EUI found when DG1 is used with 20% WWR (Figures 5,6,7). However, the north orientation is less effected by SHGC since solar radiations are not so critical for this orientation. On the north façade, a WWR of 40% can be planned with DG4 or DG5 in comparison to a 20% WWR with DG1 without any increase in energy consumption (Figure 8).

FIGURE 5. Comparison of energy consumption of different WWRs for DG4 and DG5 for east orientation.

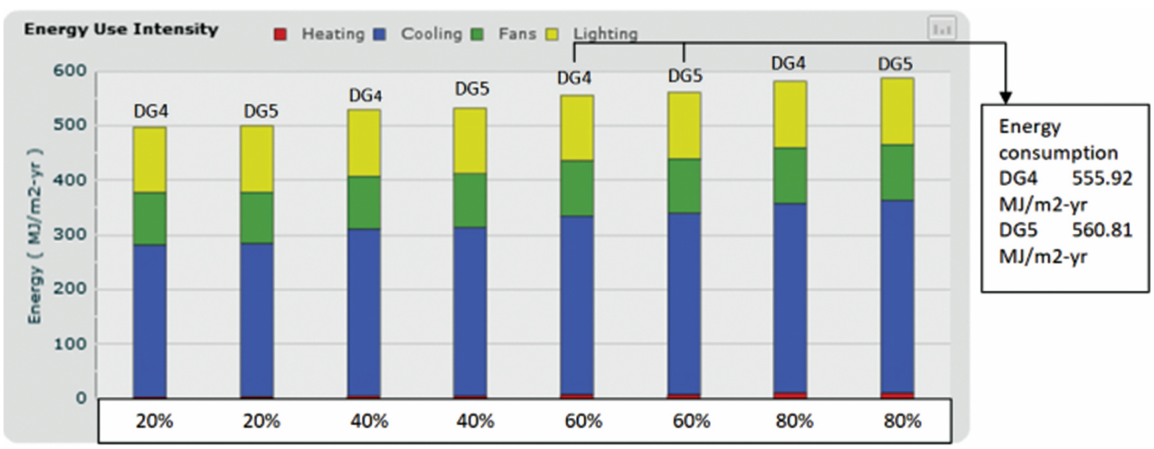


FIGURE 6. Comparison of energy consumption of different WWRs for DG4 and DG5 for west orientation.

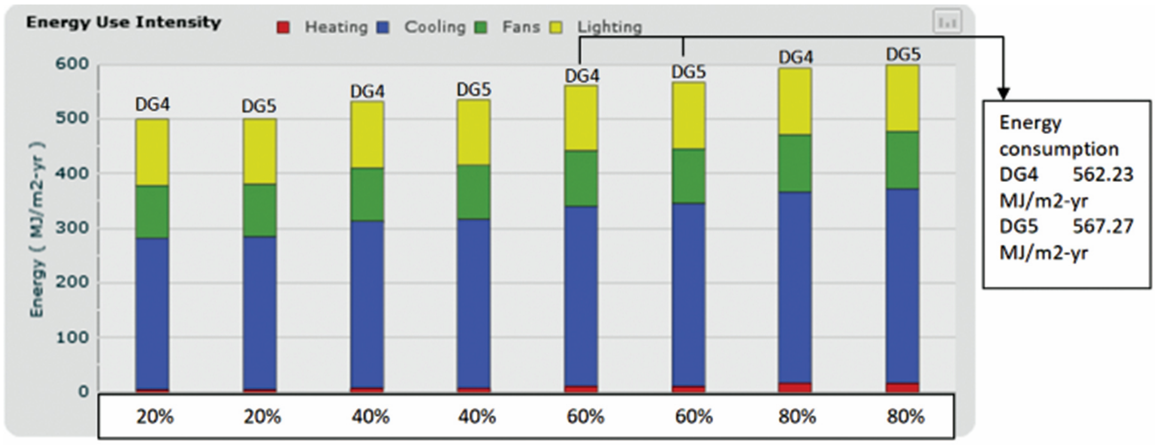


FIGURE 7. Comparison of energy consumption of different WWRs for DG4 and DG5 for south orientation.

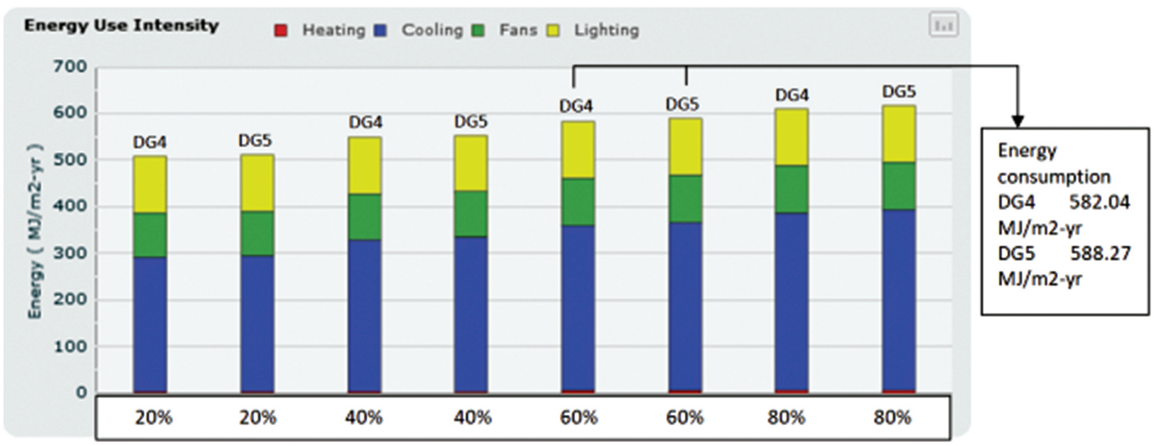
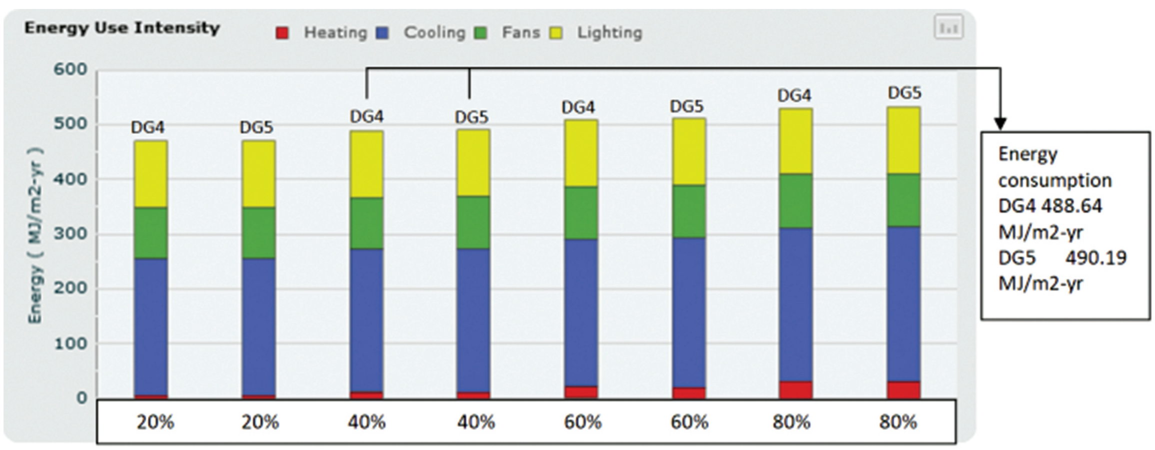


FIGURE 8. Comparison of energy consumption of different WWRs for DG4 and DG5 for north orientation.



DGU with Low Thermal Conductivity Gas Filling

It is generally believed that the double-glazed unit (DGU) with low thermal conductivity gas filling can increase the efficiency of windows. The thermal conductivity of argon and krypton gas is lower than air and it improves the U-value of glazing (Table 2). DGU with argon and krypton gas filling was created for the two best performing glazing types (G4, G5). Their glazing properties are presented in Table 2.

It is found from the simulation results that the increase in energy savings is not significant with argon and krypton gas filling. Low thermal transmittance of glazing material is found to be less significant than SHGC for conserving energy in hot semi-arid climatic conditions. In spite of improving the U-value by 6% and 9% depending on the gas, the thermal conductivity of argon and krypton gas filling is seen to offer less than 0.1% and 0.15% improvement in EUI. This further highlights that the emphasis should be more on reducing the SHGC of the glazing material than on increasing the insulating properties for saving energy.

TABLE 2. DGU with low thermal conductivity gas filling.

Glazing type	No.	Description of DGU	Glazing properties			Average EUI MJ/m^2-yr
			U value W/m^2 K	SHGC	VT	
Double glazed solar control	DG4	6mm solar control coated, 12mm air gap, 6mm clear	2.69	0.252	0.232	493.7
	DG4a	6mm solar control coated, 12mm argon gas, 6mm clear	2.52	0.249	0.232	493.4
	DG4b	6mm solar control coated, 12mm krypton gas, 6mm clear	2.46	0.247	0.232	493.1
Double glazed solar control	DG5	6mm solar control coated, 12mm air gap, 6mm clear	2.69	0.273	0.179	495.4
	DG5a	6mm solar control coated, 12mm argon gas, 6mm clear	2.52	0.271	0.179	495.2
	DG5b	6mm solar control coated, 12mm krypton gas, 6mm clear	2.46	0.268	0.179	494.9

5. CONCLUSION

COMFEN, an early design energy modeling tool was used in this study to identify the optimum glazing property. Through iterative simulations, the results indicate that the solar heat gain coefficient (SHGC) is the most important glazing property for conserving energy in cooling dominant climates. SHGC of less than 0.3 is found useful for cooling load reduction. A low SHGC is found to be significantly more important than a low U-value to reduce energy consumption, and for this reason, double glazed units with low thermal conductivity gas filling are not found to be beneficial when compared with DGU with air filling. Therefore, the emphasis should be more on reducing the SHGC of the glazing material than on increasing the insulating properties for saving energy in a hot semi-arid climate.

It is also found that if higher WWRs are required for certain building facades for better visual comfort and aesthetics, the energy demand impact is less with glazing types with a low SHGC (less than 0.3). For example, a WWR of 60% could be included with double glazed solar control glass compared to a 20% WWR with double glazed clear glass (base case) without any increase in energy consumption. However, if optimum energy demand reduction is required then both should be drawn down.

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