Influence of Building Envelope on Energy Conservation Towards Sustainable Building in the New Egyptian Administrative Capital

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1 Introduction

Building envelopes are the main barrier between the indoor and outdoor zones. Building envelopes consist mainly of walls, structure and fenestrations. Fenestrations are significant for the thermal comfort of the occupants in any building [10]. Moreover, Buildings in Egypt are divided into categories of energy consumption and according to this category the electricity bill is calculated. There are some factors that affect the energy consumption for buildings. Air leakage, windows, and walls are three of these factors. There are different sources of leakages in buildings, windows take around 31% of air leakages which causes the buildings in thermal discomfort [5]. This increases the demand on air condition (AC). In Egypt, 12% of the capacity of power stations are consumed by AC [19]. In addition, according to the Central Agency for Public Mobilization and Statistics (CAPMAS) in Egypt, the energy consumption of residential buildings is around 42% of the total energy consumption of buildings in Egypt [2]. Choosing an intelligent combination of building system can help in minimizing these energy needs. Furthermore, knowing that the concept of go-green is one of the main topics that of great concern to the researchers worldwide, it shows its significance. In the past few decades, a lot of changes have happened to the construction industry which changed the way we see the environment. Some of these changes affect how we target to solve environmental problems or should solve it. Building envelop is one of the major and significant factors that contributes in these environmental issues [1]. Additionally, the choice of fenestrations is becoming a crucial aspect of the shift to green buildings and design. Since these issues are diverse and have many different dimensions regarding the impact on the environment, the need for deeper analysis on the effect of building envelops and fenestrations on the

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energy consumption and total construction initial cost is significant. Consequently, the current era of the use of materials in the construction industry has expanded. The use of other types of wall systems and the use of other sustainable materials are taking over the traditional ones. Introducing uncommon glazing types is becoming available. Also, sustainable products are contributing to solve part of the problem of using other materials that affect the environment and the indoor air quality. By 2020, the global market for the sustainable products is estimated to be with a large value that could reach €200 billion per year [6].

The use of uncommon fenestration types faces some challenges especially in Egypt where the initial cost of the material determines the choice of the materials to be used. In spite of the fact that the initial cost is higher, there are some benefits for using more sustainable glazing on the long-term that constitutes for this. However, Egypt, like other countries, is suffering from the increase in electricity tariffs due to high energy consumption and thermal discomfort. Using new building envelops is promising because there is a strong demand to reduce energy consumption, hence cost [10]. There are some attempts to use advanced wall systems in some projects in Egypt such as 57357 Hospital, the New Egyptian Administrative Capital and few others, however, still the gains from whether financially from the energy consumption and the initial construction cost savings or environmentally from the reduction of CO_2 emissions are not clear to the investors to make a move towards new sustainable building wall systems [15].

1.1 The New Egyptian Administrative Capital

Egypt is moving towards constructing one of the major mega projects which is the New Egyptian Administrative Capital. The proposed master plan has more than 40,000 residential units, commercial, governmental, industrial areas and others. Two of the main concepts that are promising in the initial design state are being a green and sustainable city [13]. There are some initial considerations towards energy conservation by using more uncommon building envelops. In the residential areas, a double wall red brick with air gap is used which will decrease the energy consumption more than the traditional single wall system, but it still is not sufficient to make a huge difference. However, the traditional building materials are yet being used.

1.2 Study Significance

The aim of this study is to evaluate the use of four fenestration types that are commonly used in Egypt and study the effect of them on energy consumption, thermal comfort, CO_2 emissions and long-term cost (running cost). Through connecting the various characteristics of fenestrations and shading parameters specified in the Egyptian Code for Improving the Efficiency of Energy Use in Buildings Part 1 for Residential Buildings (EREC) [7] that affect the performance of the buildings as a whole, the best combination of long term running cost, initial investment cost, and thermal comfort will be achieved. This will be done by conducting a simulation study on a residential building from the New Administrative Capital through assessing building components such as external wall system, fenestrations and interior finishing materials the research aims to define the initial construction cost, environmental impacts and the thermal performance of four fenestration types—wall systems. The main objectives of this study are to:

- Examine the different parameters that affect the performance of the fenestrations using the recommendations of the EREC, Housing and Building National Research Center (HBRC) (HBRC 2016), and Center for Planning and Architectural Studies (CPAS) [3].
- Simulate the building on a thermal performance tool—Design Builder.
- Compute the monthly and annually energy consumption and calculate the percentages of savings in energy consumption.

2 Methodolgy

This study was done on a residential building in the New Administrative Capital in the second residential area “R2”. This analysis was done using a computer software that is adjusted to simulate different thermal conditions. It was done by simulating the weather conditions of Egypt over a range of a year from 1st of January to 31st of December. Nine simulations took place and for each fenestration type two simulations were running. The outputs of these simulations record two main parameters which are the monthly energy consumption (kWh) and the indoor air temperature (^{o}C). Moreover, the excessive environmental analysis on each building regarding carbon emissions, thermal comfort, humidity, cooling and heating designs, were studies as well. In addition, a comparative cost analysis was conducted to demonstrate the difference in initial construction cost of each wall system.

2.1 Model Framework

The model framework that was used to work on the simulations till the analysis stage is presented in Fig. 1. The framework consists of four main stages which are modeling, specifications, simulation, and analysis. The verification process was according to the recommendations of the EREC, HBRC, and CPAS.

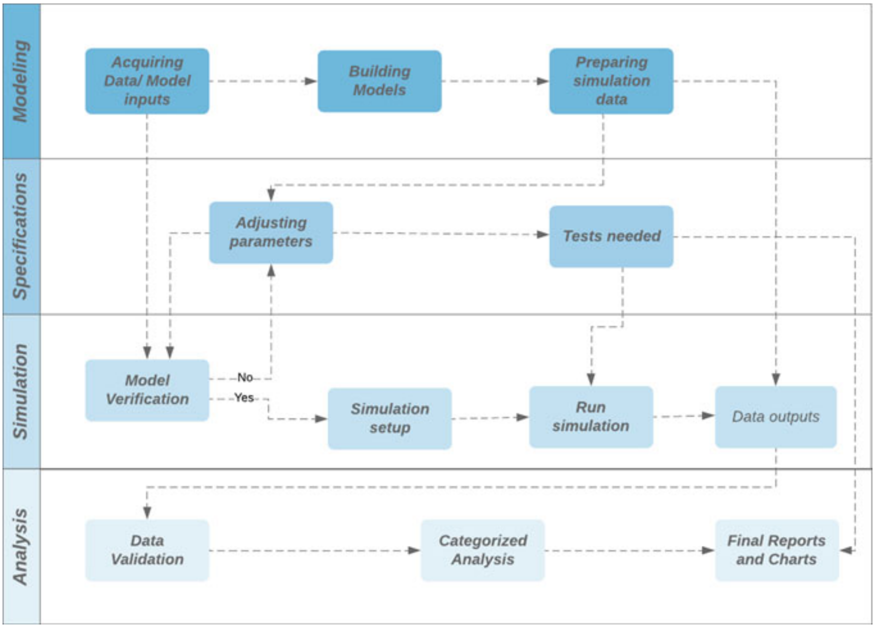

Fig. 1 Block diagram of the simulation framework

2.2 Models Definition

Two models were used in the simulation. The first one is the original model with the original WWR and shading conditions as seen in Fig. 2. The second one is the modified model with the calculated WWR, SHGC, and shading parameters as seen in Fig. 3. In addition, all the data for the building were collected from site working

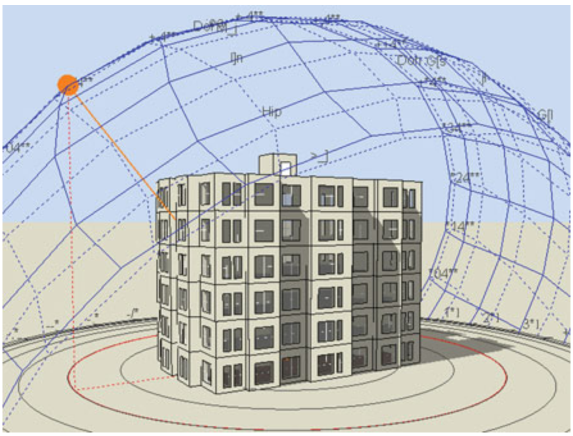

Fig. 2 Original simulated model

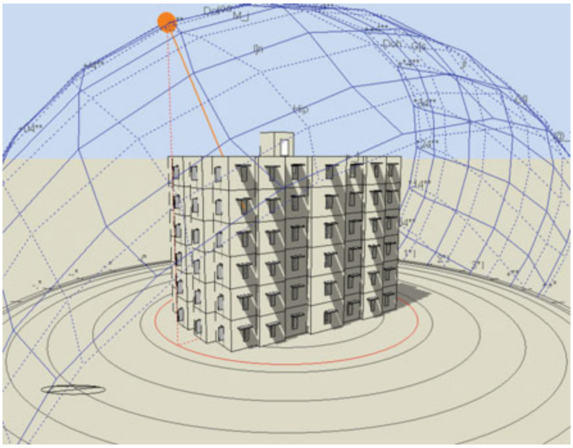

Fig. 3 3D Alternative simulated model

drawings which includes sections, elevations, and floor plans that were used in the simulation. The simulated building is around 460 m^2 and it consists of six floors and each floor consists of four typical apartments. The approximate area of each flat is 80 m^2. This building is a residential complex. Figure 4 shows the floor plan for the building and Fig. 5 represents the external wall section.

Fig. 4 Typical floor plan for the simulated model

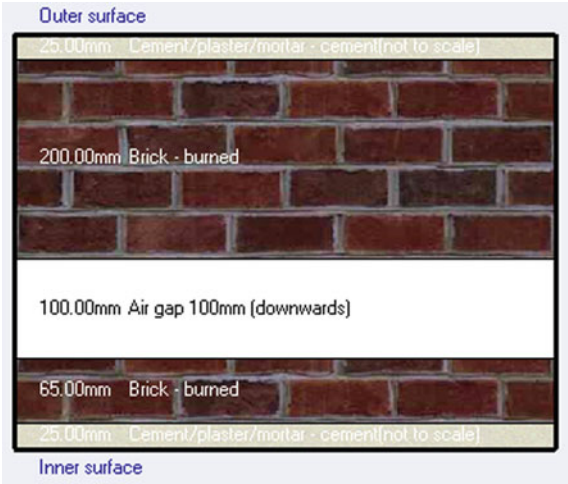

Fig. 5 External wall cross section

2.3 Simulation and Materials Specifications

2.3.1 Weather Data Files

The modeling was done on a user-friendly interface-Design Builder and its tool for thermal performance Energy Plus [14]. The needed weather data files were downloaded from the website of the US Department of Energy (USDOE) [4]. The weather data file that covers the period till 2025 and the current climatic conditions of Egypt from the 2002 data file which covers a period of 14 years were used.

2.3.2 Thermal Comfort

The thermal comfort of each person differences from the other according to the HBRC and that supports the adaptive comfort theory [8]. Consequently, in the simulation an adjustment was done to the thermal zones. The modified zones that were used in both simulations are 20–28 °C.

2.3.3 External Wall Specification

The used wall systems and their thermal specifications are mentioned in Table 1. All building components were adjusted in the simulated models to fit Cairo's climatic zone [18]. The adjustments were based on the recommendations of the EREC [7] and CPAS [3]. Appropriate wall systems were used according to the area of the new capital. From the construction site, they used a double red brick with air cavity wall system. Figure 5 shows the cross section of the used wall system.

Table 1 External wall system specifications

Type	Category	External system	ISR* (m^2K/W)	ESR* (m^2K/W)	Thickness (mm)	U-Value (W/m^2K)
Residential	Original-Type A	Double wall of red brick with air cavity	0.13	0.04	365	0.81

**ISR* Internal surface resistance
**ESR* External surface resistance

2.3.4 Glass Specifications

In Egypt, commonly four glass types are used, and they are specified by the EREC which are: Single glass, Single reflective glass, Double glass, and Double Reflective glass [11] and were used in the simulation. Table 2 represents the types of glass used in both models and the parameters of each glass type such as the Light Transmission (LT) values, the Solar Heat Gain Coefficient (SHGC), and the U-values according to the recommendations of the HBRC and the EREC [9].

2.3.5 Activities, Occupancy, and HVAC

For the simulation, the schedules of the buildings for the activities, the working profile and the occupancy were adjusted to fit with the Egyptians occupant's lifestyle according to the recommendations of the HBRC and the EREC. Also, they were fixed in all the simulations taking in consideration the holidays, working profiles and the usage of different residential spaces per day [8]. For the HVAC systems, mixed moods were used where natural and mechanical ventilation were allowed. The common air condition systems that are used in Egypt in the residential buildings are the split AC units. In the summer session, the AC systems are used almost all day due to the increase in temperatures, thus humidity levels and thermal discomfort. In addition, the set points for heating and cooling were adjusted to 22 and 20 °C. Also, the setback was adjusted at 12 and 28 °C [9].

Table 2 Glass specifications

Type	Name	Category	LT	SHGC	U-Value (W/m^2K)
Single/original glass	SG/OG	Clear 6 mm	0.66	0.49	5.76
Single reflective	SR	Clear Reflective 6 mm	0.06	0.18	5.36
Double glass	DG	Clear 3 mm/6 mm air	0.81	0.705	3.226
Double reflective	DR	Clear Reflective 6.4 mm/6 mm air	0.05	0.13	2.66

2.4 Thermal Performance Parameters

2.4.1 Shading Parameters

The original shading devices for the model were kept in the original model simulation. For the proposed model, the depth, protrusion, and length of the shading devices were calculated. The shading systems that were used for the needed facades were based on the recommendations of the EREC in the Annex A-3 [7]. Vertical and Horizontal shading devices were used in each model according to the orientation of each façade. No shading devices were used in the North façade. Moreover, some equations were used to calculate the shading device dimensions for the building. By using the design chart for shading devices and given the latitude of Cairo, Egypt 30° N, the cut off times and the needed height, the depth (d), and protrusion (p) were extracted in the form of (d/h) and (p/h) ratios of 58% and 67% respectively. Then they were inserted in the equations to calculate the designed d, p, and length (l) of the shading for the simulated model as shown in Eqs. 1–3 [16].

$$d = (d/h) \times h \tag{1}$$

$$p = (p/h) \times h \tag{2}$$

$$l = w + 2p \tag{3}$$

2.4.2 Window to Wall Ratio (WWR) and SHGC

The Window to Wall Ratio (WWR) is the ratio between the areas of the total façade to the areas of the openings in each façade [17]. WWR of each façade of the original model was identified based on the shop drawings. The original Elevations and plans were used to identify the area of each façade and the area of the openings as well. In addition, no modifications were done to the facades and the WWR was adjusted in the simulations. According to the EREC, there are four percentages to the WWR which are less than 10%, from 10 to 20%, from 20 to 30%, and more than 30% which were used in the simulation. Moreover, according to the same recommendation, the SHGC for $\leq$20% WWR should be 0.4 max and the SHGC for $\geq$20% WWR should be 0.25 max [18]. Table 3 shows the calculations for the WWR and SHGC for the original model.

Table 3 WWR and SHGC specifications for original model

Elevation	Total area (m^2)	Openings (m^2)	WWR%	SHGC
North	468	182	38.9	0.25
South	468	182	38.9	0.25
East	324	115	35.5	0.25
West	324	115	35.5	0.25

2.5 Financial Analysis

For the analysis of the initial cost difference, the long-term investment, and the comparison between the four used glass types consumption, the prices of glass, bricks, concrete, shading devices, and frames were based on the price list of the ministry of housing [13]. On the other hand, for the energy consumption, the electricity tariffs were used according to the ministry of electricity and renewable energy latest report [12]. The energy consumption of each apartment in the model per floor was obtained from the simulation to calculate the energy consumption per month and annually.

3 Results and Discussions

3.1 Thermal Performance Simulation Results

The simulation results were obtained, and the four glass types were compared. The data outputs are shown in tables and graphs format. In addition, according to the code it is not recommended to use WWR of 30% in Cairo. From the results, it is shown that the SR and DR don't need shading as they reflect sun, hence decrease the energy consumption and increase thermal comfort. Table 4 represents the outputs from the models including external infiltration, CO_2 production, and solar gain and it has the highest record of the four glass types with the different WWR%'s. The solar gains of each WWR % and glass type were obtained, and DG 20% and SG 20% have the highest solar gains, hence, the highest energy consumption. The lowest record is the DR 10%.

Comparing the WWRs of 10% and the WWRs of 20%, it shows that the 10% performance is better and gives the best results. The 10% WWR has the best thermal performance, hence, the best thermal comfort for occupants. However, glass types SR and DR don't show a noticeable performance in energy consumption and running cost. The monthly energy consumption of the glass types reflects that the peak months are from May to October. The highest energy consumption is by the OG in the original simulated model. The calculations are done assuming that there are no other sources of energy such as boiler, fans, and others.

Table 4 Simulation results for the glass types

Glass type	External infiltration (kWh)	CO_2 production ($\times 10^3$)	Solar gains ext. windows (MWh)
OG	−18,422.9	379.96	51.58
SG 10%	−15,720.23	350.11	11.34
DR 10%	−15,026.26	344.72	1.3
SR 10%	−15,247.44	347.67	4.15
DG 10%	−16,108.31	350.64	17.31
SG 20%	−16,541.66	359.41	24.48
DR 20%	−15,181.47	347.83	2.84
SR 20%	−15,590.29	354.12	8.98
DG 20%	−17,429.05	361.01	37.49

Figure 6 represents a comparison between the alternative glass types, OG and the outdoor temperatures. The shaded part is the comfort zone from 20 to 28 °C, according to the recommendations of the EN 15,251, ASHRAE 55, and the ISO 7730. The results show that the OG, SG, and DG are not in the comfort zone between the months of January till March. In addition, Table 5 shows the percentages of savings in energy consumption regarding each glass type. As expected, the performance of the double glass is better than the single glass. Moreover, DR 10% has the highest energy saving percentage; however, it has a high initial cost (see Table 6) followed by SR 10% and DR 20%.

Figure 7 demonstrates a comparison between the glass types energy consumptions monthly where the shaded area is the peak hot period yearly. Performing this comparison between the glass types with respect to the simulation output indoor/outdoor temperatures, hence indoor thermal comfort, it shows that the SG with different WWR % and the OG are the least comfort where they are out of the comfort zone.

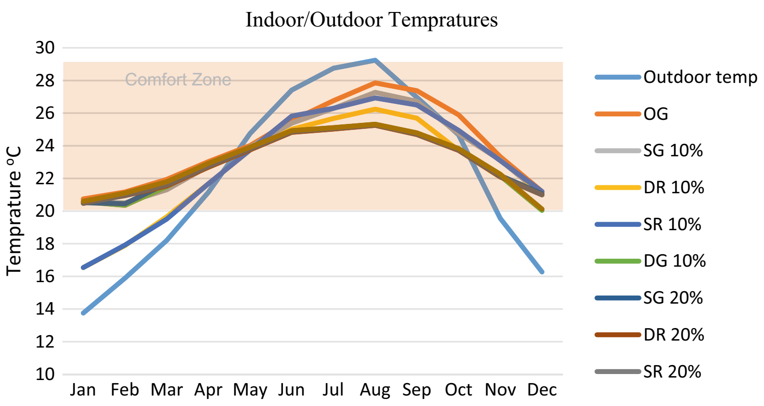

Fig. 6 Temperatures comparison between the glass types

Table 5 Annual energy savings percentages comparison

	Original consumption (kWh)	Alternative consumptions (kWh)	Savings (%)
OG	466,673	–	–
SG 10%		378,114	19.0
DR 10%		362,138	22.4
SR 10%		370,909	20.5
DG 10%		378,718	18.8
SG 20%		405,718	13.1
DR 20%		371,401	20.4
SR 20%		390,099	16.4
DG 20%		410,357	12.1

Table 6 Total cost and system savings calculations

Type	Energy consumption (LE)	Initial brick cost (LE)	Fenestration cost (LE)	Shading cost (LE)	Total cost (LE)	Savings of system (%)
OG	676,715	428,794	118,272	49,270	1,273,051	–
SG 10%	548,306	526,331	41,976	12,317	1,128,930	11
DR 10%	525,140		89,676		1,153,464	9
SR 10%	537,858		47,700		1,124,206	12
DG 10%	549,181		83,952		1,171,781	8
SG 20%	588,331	500,513	62,172	24,635	1,175,651	8
DR 20%	556,601		132,822		1,214,571	5
SR 20%	565,683		70,650		1,161,481	8
DG 20%	595,057		124,344		1,244,549	2

However, DR and SR with different WWR % achieve higher thermal comfort and less energy consumption with noticeable differences than the SG and DG with different WWR%.

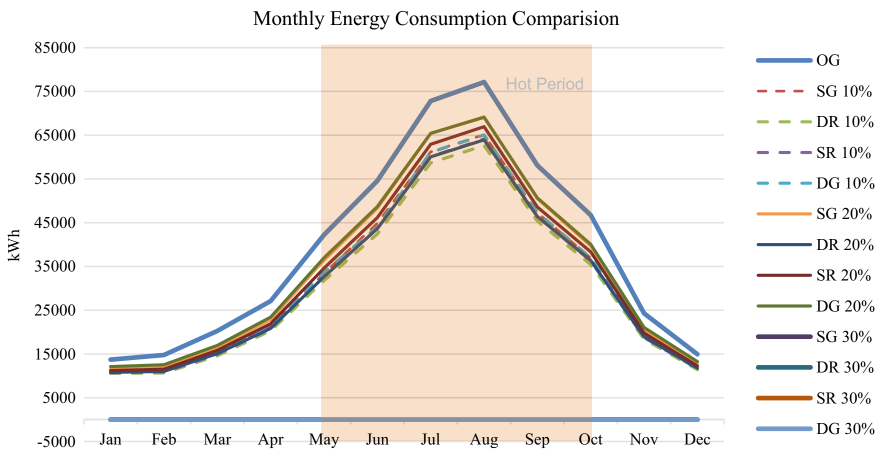

Fig. 7 Monthly energy consumption of each glass type

3.2 Financial Analysis Results

The analysis was done on the four glass types that were used in the simulated model. In addition to the initial cost of the materials, the shading device cost and the long-term running cost were taken in consideration. The analysis provides the best glass type with respect to the best cost effective regarding these parameters. The WWR 10% achieves better results as seen in Table 6. Moreover, SR and DR in this % achieve the best savings. Additionally, the differences are not noticeable to the SG total system savings.

Tables 7 and 8 represents the initial costs, running costs and overall savings after 14 years. Note that the negative running or initial costs means savings to the corresponding glass type when compared to the OG. The analysis shows the cost of the OG and SG are the best when it comes to initial cost; however, it is the least in the running/annual cost. The annual energy cost of the OG is the highest. The WWR

Table 7 Financial analysis WWR 10% over 14 years

Type	Initial wall cost	Annual running cost	Initial cost difference	Accumulated initial cost	Running cost difference	Accumulation of running cost	Savings in total cost
OG	596,336	676,715	0	0	0	0	0
SG	580,624	548,306	(15,712)	(48,170)	(128,409)	(393,677)	(441,847)
SR	586,348	537,858	(9,988)	(30,621)	(138,857)	(425,708)	(456,330)
DG	622,600	549,181	26,264	80,520	(127,534)	(390,994)	(310,474)
DR	628,324	525,140	31,988	98,069	(151,575)	(464,699)	(366,630)

Table 8 Financial analysis WWR 20% over 14 years

Type	Initial wall cost	Annual running cost	Initial cost difference	Accumulated initial cost	Running cost difference	Accumulation of running cost	Savings in total cost
OG	596,336	676,715	0	0	0	0	0
SG	587,320	588,331	(9,016)	(27,641)	(88,384)	(270,968)	(298,609)
SR	595,798	565,683	(538)	(1,649)	(111,032)	(340,402)	(342,052)
DG	649,492	595,057	53,156	162,966	(81,658)	(250,347)	(87,382)
DR	657,970	556,601	61,634	188,958	(120,114)	(368,246)	(179,288)

10% achieved better results than the WWR 20%. In addition, the SR and DR with 10% WWR have the maximum financial gains over the 14 years period.

4 Conclusion

To sum up, this paper formulated a study on the fenestrations in Egypt using a residential model from the New Administrative Capital. Through evaluating the shading devices, WWR%, and other factors according the recommendations of the EREC, HBRC, and CPAS, the savings in the initial cost and running cost are justified. Additionally, a financial analysis was done on the building to see the effect of using uncommon glazing on the initial cost and running cost after a period of investment of 14 years which is the simulation period. The results of the simulations showed that the single glazing (SG) is the best in the initial cost; however, it is not the best in the energy consumption. The DR glass is the best in achieving energy savings on annual basis; however, it has higher initial cost. In general, in terms of energy consumption, hence thermal comfort and cost, the SR is the most cost-effective glass type that has the highest return back over the period of 14 years.

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