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Energy Cost Saving Prospects in Buildings Using Various Window Glazing in Dhaka

Kiran Kumar Gorantla[#], Shaik Saboor*[,1], Habibur Rahman Sobuz[+], Sai Siva Subramanyam Vankadaru[#,] and Chelliah Arumugam*

Abstract – *Energy saving is one of the opportunities in residential and commercial building sectors. Proper selection of window glasses reduces the energy consumption in the built environment. The objective of this work is to ascertain the best glazing and it's orientation to save the high air-conditioning costs in buildings of the Dhaka in Bangladesh. This article presents the experimental results of solar optical characteristics of four different glasses such as clear, tinted bronze, tinted green, and bronze reflective glasses. Burnt brick buildings were modeled with four different glasses and analyzed for air-conditioning cost-saving prospects. The results reveal that among the four window glazing processes; the bronze reflective glazing has 45.66% and 26.42% higher energy cost-saving potential compared to the tinted bronze and tinted green glazing, respectively. The bronze reflective glazing gives the highest air-conditioning demand and hence cost savings with the lowest payback periods (0.95 in SE) and adequate daylight factors. The four window glazing materials have also shown better daylight factors than the recommended values. The southeast orientation was observed to be the optimal orientation for the placing of glazing for maximum air-conditioning cost savings followed by the southwest and south. The results of this article can be used for the design of energy-efficient buildings.*

Keywords – *Air-conditioning, cost-saving, building physics, window glazing, energy-efficient glasses, payback period.*

1. INTRODUCTION

Globally building sector is responsible for a minimum of 40% energy consumption and there is a continuously increasing demand for energy in forthcoming years for its operations and maintenance. Heating and cooling of the space consume around 60% of the total energy consumption in buildings, which is the largest portion of energy usage [1]. In Bangladesh too buildings are responsible for major power consumption which is about 50%, with a near consistent rise of 8% over the coming years as per SREDA [2]. In hot climatic regions, cooling demand in residential and commercial buildings is an important concern for its functional requirements and to maintain thermal comfort. Energy demand in buildings would continue to rise unless appropriate actions to improve the energy efficiency are taken up immediately because of urbanization, increasing gross built-up area, and standard of living. Solar passive buildings with energy-efficient designs of systems consume around 30% less energy as compared to conventional buildings [3]. Building components such as walls, roofs, floors, and glazings are responsible for the heat gain. In passive building design, the building envelope is the most significant and basic element to save energy. Suitable design and materials selection of the components is an efficient measure to reduce the energy consumption in the buildings. Optimization of building materials and components specifications is an important aspect to achieve energy conservation. Such building enclosures help in resisting or reducing the heat gain. Glazing placed in an optimum tilt angle to the vertical external wall curtailed the intensity of solar radiation in the buildings [4], [5] Investigations concluded that installing windows at an inward tilt position is an effective and inexpensive technique in reducing the solar heat gain in the buildings for hot climatic conditions. The effect of external wall thickness on the thermal comfort of the building is studied and reported that houses that have thick walls will be comfortable all year round as opposed to houses with thin walls [6]. Radiation control coatings applied on the opaque outer surfaces of the building had shown a reduction in solar heat gain. DOE Simulations for the warm climatic zones reported a 60% reduction in the heating and cooling loads. The reduced loads, economize the size of the air-conditioning system to be installed by 50% or more [7]. Dynamic thermal modeling of industrial buildings (Retail shed) in China, and Australia with reflective coatings over the external surfaces such as walls, roofs, and glazing's had shown a minimum of 30% reduction in the cooling load. The study concluded that the use of reflective coatings as a passive measure to control heat gain in the buildings can potentially save operational energy as high as 25% [8].

Numerous experiments and simulations have been conducted to mitigate solar radiation through building

[#]Department of Mechanical Engineering, Sasi Institute of Technology and Engineering, Tadepalligudem, India.

*Department of Thermal and Energy Engineering, School of Mechanical Engineering, Vellore Institute of Technology, Tamil Nadu, India.

[+]Khulna University of Engineering and Technology (KUET), Bangladesh.

[1]Corresponding author:
Email: saboor.s@vit.ac.in

components, Taleb and Al-Watter designed the windows to reduce solar radiation transmission in the building enclosures and reported analytical models to compute the solar radiation [9]. Detailed mathematical calculations were reported to compute the glazing properties such as overall heat transfer coefficient, solar heat gain coefficient, and solar optical properties for different window systems in various climatic conditions [10]. Thermal insulation of external walls improves the thermal resistance to heat gain and significantly reduce the energy consumption of cooling and heating. Thicker thermal insulation diminishes cooling and heating load and improves the energy-saving effects [11], [12]. Optimum economic insulation thickness of various building components was computed considering comprehensive interaction among the external walls, roof, and windows for various window-to-wall ratios. A suggested combination of the insulation thickness with optimum WWR had shown significant energy savings [13]. Thermal insulation provided to the external walls, roofs, and floors mitigates heat gain through them and improve the thermal performance of the built environment [14], [15]. Thermo economic analysis is carried out to optimize the insulation thickness of external walls in different climatic regions of Turkey [16]. Aerogel based super insulation materials were investigated for the optimum thickness of the insulation and its environmental impacts to abate the greenhouse gases. These insulating materials had shown a reduction in the cooling loads along with a reduction in the CO_2 and SO_2 emissions [17].

The window-to-wall ratio (WWR) is defined as the ratio of the glazed area to the gross exterior wall area. WWR is an important parameter that affects the energy performance in the building. Window area has an impact on building the heating load, cooling load, and natural daylighting. The impact of Window to wall ratio on thermal and visual comfort for various interiors of the residential building studied, it had shown a substantial reduction on the cooling and heating energy consumption in hot summer and cold winter zones of China [18]. In a solar passive building, the area of the window to the external wall area in the south orientation was optimized to achieve the highest energy efficiency in Turkey for five different cities [19]. Thermal analysis of various buildings and glass materials with different WWR has been carried out to obtain a feasible combination to minimize the external cooling load in the building [20]. The efficient utilization of natural daylight for illumination will show the reduction in artificial daylight energy consumption. The natural daylight availability of global solar radiation was estimated with the help of different models for different climatic zones [21]. Single pane glazing can be retrofitted with reflective glasses [22] and double pane windows to reduce the heat gain and cooling load. Thermal and cost analysis of the air-filled reflective double glazing had shown a substantial reduction in heat gain. Double glazing showed significant net annual energy savings at a low payback period of 1.42 years [23]. The heat gain through the various float and tinted glasses was determined for buildings of different Indian climatic zones [24]. Energy-efficient window and wall building materials were proposed based on the heat gain using Energy plus simulation tool for Indian climatic regions [25], [26]. Heat transfer characteristics of five homogeneous and composite building materials were reported using the admittance method [27].

The above-discussed literature reveals the importance of the control of heat gain in the building through its components. The literature reveals a significant gap in the research on thermal and visual comfort potential of glazing for buildings in Dhaka (23.81^0N 90.41^0E). Heat gain in the building is the most critical parameter to determine the air-conditioning energy and cost-saving prospects of the building. In the present study, four different window glazing are studied for solar heat gain/loss and energy-saving prospective. The spectral properties of the glasses are measured experimentally and these results are used in the mathematical model to compute the solar heat gain/loss and air-conditioning cost savings. This work aims at proposing the best energy-efficient window glazing for buildings in the Dhaka taking peak climatic conditions. This work proposes thermal and visual comfort potential of four different window glazing types (clear glass, tinted bronze glass, tinted green glass, and bronze reflective glass) for the buildings of Dhaka climatic conditions. The results of this work are significant in selecting a suitable glass for reducing cooling loads in the built environment.

2. METHODOLOGY

Figure 1 shows the flow chart of the procedure followed to obtain optimum air-conditioning cost-saving potential of glazing with adequate daylight factors. Solar gain through the glazing can be computed with the help of solar optical properties of the glasses. The solar spectral characteristics of different glasses were obtained by striking light at zero angle of incidence onto the glass surface in the Perkin Elmer Spectrophotometer with the spectrophotometric method [28]. Figure 2 shows an integrating sphere spectrophotometer interfaced with UV Win Lab software used in the experimentation.

The solar spectral characteristics of four 5 mm thick glasses like clear glass, tinted bronze, tinted green, and bronze reflective were measured for the light spectrum range of 300-2500 nm. These spectral characteristics of the glasses were further deduced to obtain solar energy transmittance and reflectance in British Standard [29], [30]. Spectral transmission and spectral reflectance were measured in specular mode and diffusive reflectance mode respectively. Spectral absorption of glasses obtained from the summation rule. The spectral transmission and reflection properties of the glasses have been depicted in Figure 3 and Figure 4 respectively. The solar optical properties of window glazing have been presented in Table 1. The U-value of the glazing is 5.70 W/m^{2}K.

The solar energy transmittance and reflectance for single-pane glazing can be computed using Equations (1) and (2). In Figure 4, the graph shows the least spectral transmission for bronze reflective glass and the highest spectral transmission for clear glass among four glasses.

Solar transmission is the fraction of the solar radiation transmitted through the glazing that is incident on the glazing and is calculated using the following formula.

$$T_{SOL} = \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \tau(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \quad (1)$$

Solar reflectance is a fraction of the solar radiation reflected from the glazing that incident on glazing and is calculated as follows.

$$R_{SOL} = \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \rho(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \quad (2)$$

The percentage of solar transmission and solar reflectance can be calculated by multiplying with 100 using Equations (1) and (2).

Solar absorption can be calculated using the following formula.

$$A_{SOL} = \left(100 - T_{SOL} - R_{SOL}\right) \quad (3)$$

Burnt clay facing brick is a construction material, which is used to make the building walls in Dhaka (23.81^{0}N 90.41^{0}E), a city in Bangladesh. Thermo-physical properties of burnt clay facing brick are as per the Bangladesh standards (BDS 1250:1990) [31].

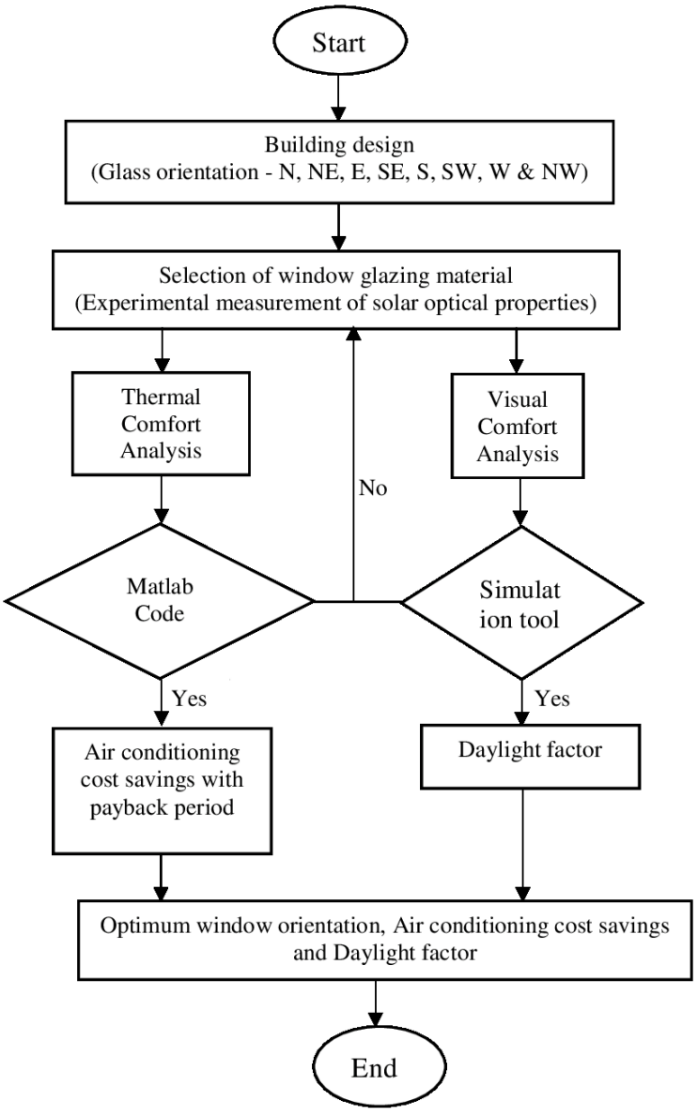

Fig. 1. Flowchart of methodology.

Fig. 2. UV-Vis-NIR Perkin Elmer (Lambda 950) spectrophotometer.

Table 1. Solar optical properties of glasses of 5mm thickness.

Window glass	Transmittance T_{SOL} (%)	Reflectance R_{SOL} (%)	Absorbance, A_S (%)	SHGC (%)
Clear glass	82	8	10	84
Tinted Bronze glass	56	6	38	65
Tinted Green glass	47	6	47	58
Bronze Reflective glass	41	6	53	48

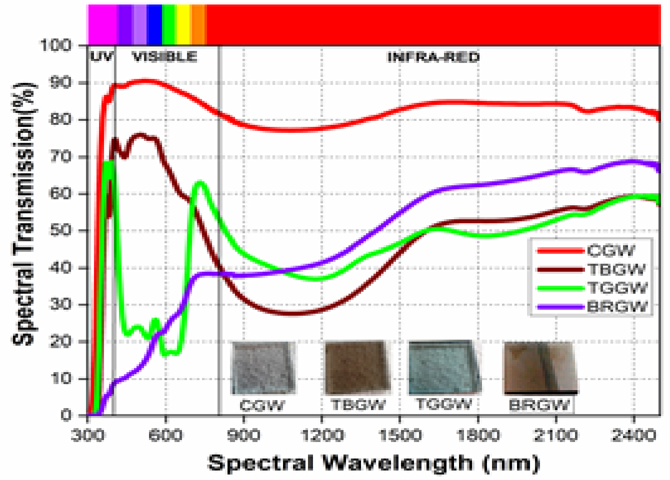

Fig. 3. Spectral transmission of glass materials.

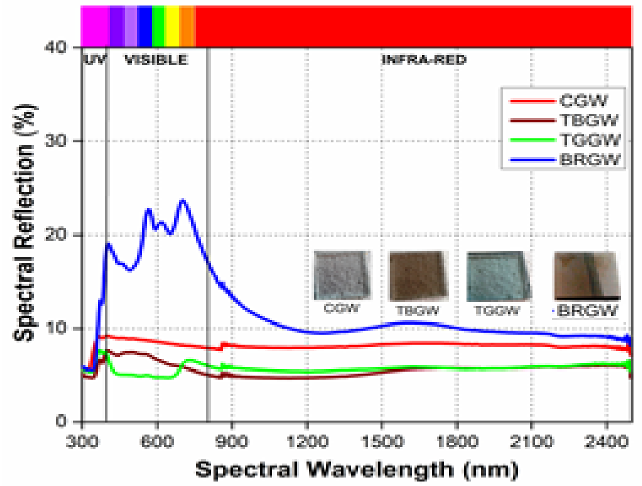

Fig. 4. Spectral reflection of glass materials.

3. ANALYTICAL METHOD TO FIND THE SOLAR HEAT PASSING THROUGH GLASS WINDOWS

To determine the solar heat gain through the glass, it is required to find the three radiation components such as direct, diffuse, and ground reflected radiations falling on building surfaces. The solar radiation reaches the earth in the form of electromagnetic waves (300 nm - 3000 nm). The 2-3 % quantum of radiation exists in the ultraviolet zone (0.30 mm–0.38 mm), 47% in the visible zone (0.38 mm–0.78 mm), and nearly 51% of the radiation in the near-infrared region. To find the solar heat gain passing through the glass window it is necessary to account for these radiation factors in each zone. The total solar radiation that enters the building through the glazing is the sum of direct normal radiation (I_{dir}), sky-diffuse radiation (I_{dif}), and ground reflected radiation (I_{grr}). Solar radiation in the wavelength range of 300 nm to 2500 nm was considered to compute the heat gain through the glazing. The total solar irradiance (W/m^2) that reaches the earth is related to solar geometry, which includes several angles. Solar azimuth and altitude angles depend on the fundamental angles such as solar declination, latitude, and hour angle. In this work, the warm and humid climatic condition was considered, i.e. Dhaka (23.81^{0}N 90.41^{0}E), a city in Bangladesh and analyzed for heating and cooling costs. The analysis was carried out, between 6:00 am to 6:00 pm (LAT), and 7:00 am to 5:00 pm (LAT) for peak summer and winter days, respectively. The room setpoint temperatures are 24^{0}C and 21^{0}C, respectively for summer and winter as per ASHRAE (2001). Building model of dimensions 5 m X 5 m X 3.2 m was considered and four glass windows were placed at a 40% window to wall ratio (3.2 m X 2 m). The building models are considered as commercial/office buildings that use the air-conditioning system (cooling and heating systems) during diurnal hours. Thermal and cost assessment was carried out for this climatic region, in eight cardinal directions to compute the solar heat gain/loss and energy savings. Total solar radiation admitted in building through the glazing is calculated as per the following procedure at given latitude as per ASHRAE clear-Sky and intermediate sky models [32].

Declination angle is the inclination of the earth's axis measured from the perpendicular to the sun's rays. It can be computed by Equation (4).

Declination angle

$$d_{an} = 23.45 \sin \frac{360\left(248 + n_{da}\right)}{365} \tag{4}$$

Solar altitude angle

$$\sin \beta_a = \cos l \cos d_{an} \cosh_{an} + \sin l \sin d_{an} \tag{5}$$

Solar azimuth angle

$$\cos \phi_a = \frac{\sin \beta_a \sin l - \sin d_{an}}{\cos \beta_a \cos l} \tag{6}$$

Surface solar Azimuth angle

$$\gamma_a = \phi_a - \psi \tag{7}$$

The surface azimuth measured from the south for the orientations N, NE, E, SE, S, SW, W, and NW is 180^0, -135^0, -90^0, -45^0, 0^0, 45^0, 90^0, and 135^0, respectively.

Angle of incidence

$$\cos\theta = \cos\beta_a \cos\gamma_a \cos k - \sin\beta_a \sin k \tag{8}$$

Terrestrial solar radiation on a clear atmosphere day is given by

$$I_{DN} = \frac{A}{\exp\left(B/\sin\beta_a\right)} \tag{9}$$

Where, the constants A, B, and C are used for calculating solar radiation per hour in Dhaka climates as per ASHRAE (2001).

Total solar radiation passing through a single glazing window can be obtained from Equation (10).

$$I_{SRSGW} = \left((I_{DN} \cos\theta) + (C I_{DN} \frac{1-\sin k}{2}) + ((C + \sin\beta_a) I_{DN} \rho_g \frac{1-\sin k}{2}) \right) . \left(T_{SOL} + \frac{U}{h_o} A_{SOL} \right) . A_G \tag{10}$$

Where

$$U = 1/\left(1/h_o + L/K + 1/h_i\right)$$

Where (h_i, h_o are considered as per standards (CIBSE, 2006 [33])).

The results obtained were compared with results found in the literature Ishwar *et.al.* (2011) on this subject for validation purposes. The validation of the MATLAB program was carried out for a 3 mm clear glass window in New Delhi climatic conditions. The deviation of the validation results was within ±1%. Hence, the program was considered to be reliable for studying other glasses [34].

3.1 Cost Analysis Methodology

The procedure is followed to find the total cost savings per year through all window glasses.

The savings in yearly net cooling and heating cost of glass windows in eight directions were determined for the warm and humid climatic region of Dhaka. For computing net cost savings annually, the following procedure has been followed [35].

The mean diurnal incident total solar radiation onto the glazing during any season can be computed by Equation (13). For computing incident solar radiation on glazing in both summer and winter seasons, the following months are considered in the study: i.) Summer season is from April to August ii.) Winter season is from September to March. The number of days in each month are also considered for computing average daily incident total solar radiation onto the glazing.

Total solar radiation in the summer months:

$$Q_{sol,\text{summer}} = (q_{ds_{April}} X30) + (q_{ds_{May}} X31) + (q_{ds_{June}} X30) + (q_{ds_{July}} X31) + (q_{ds_{August}} X31) \quad (11)$$

Total solar radiation in the winter months

$$Q_{sol,\text{winter}} = (q_{dw_{Sep}} X30) + (q_{dw_{Oct}} X31) + (q_{dw_{Nov}} X30) + (q_{dw_{Dec}} X31) + (q_{dw_{Jan}} X31) + (q_{dw_{Feb}} X29) + (q_{dw_{Mar}} X31) \quad (12)$$

Then the decrease in annual cooling load and the increase in annual heating load due to the different glasses becomes:

$$\textit{Cooling load decrease} = Q_{sol,\text{summer}} X\ A_G\ X\left(SHGC_{CGW} - SHGC_{SGW}\right) \quad (13)$$

$$\textit{Heating load Increase} = Q_{sol,\text{winter}}\ X\ A_G\ X\left(SHGC_{CGW} - SHGC_{SGW}\right) \quad (14)$$

The unit cost of the electricity and natural gas considered is \$0.075 kWh and \$0.45/therm, respectively. The coefficient of performance of the cooling system and efficiency of the furnace is taken as 2.5 and 0.8, respectively.

1Therm=29.31 kWh, the corresponding decrease in cooling costs and the increase in heating costs are

Decrease in cooling costs = (cooling load decrease) (unit cost of electricity) / (COP) (15)

Increase in heating costs = (heating load increase) (unit cost of fuel) / (Efficiency) (16)

The net annual cost savings = Decrease in cooling costs – increase in heating costs (17)

Simple payback period = (Implementation cost) / (Annual cost savings) (18)

Implementation cost = (Unit price of glazing (\$/m^2) X (Glass area (m^2)) (19)

4. RESULTS AND DISCUSSION

4.1 Incident Solar Radiation and Radiation Passing through a Glazing

Figure 5 presents the solar radiation falling and passing through four glazings on a peak summer day (May 15th) of the Dhaka region as per standards [36]. The results have shown the least incident radiation in the south orientation among eight orientations studied. It is also observed that heat gain through the south-oriented glazing is the least compared to the other orientations.

Figure 6 presents the solar radiation falling and passing through four glazings on a peak winter day (Dec 21st) of the Dhaka region. The results have shown the highest incident radiation in the south orientation among eight orientations studied. It is also observed that heat gain through the south-oriented glazing is the highest compared to the other orientations. The heat gain/loss through CGW is significantly high and contributes to the higher cooling and heating costs. Though the incident radiation is the same for all the glazing, their heat gain/loss is different for different window glazing. The glazing which is the best in the summer season observed to be the worst in the winter season. Therefore, it is necessary to identify the best window glazing to save cooling and heating cost collectively. For this purpose, air-conditioning cost-saving prospective of various window glazing has been carried out.

4.2 Annual Air conditioning cost-saving prospects of window glazing in buildings within the Dhaka climatic zone

Figure 7 presents the air conditioning cost-saving prospective of various window glazing of the Dhaka climatic zone. The energy-saving prospective of tinted and reflective window glazing compared to clear glazing has been reported in this work. The results have shown the highest air-conditioning cost savings in southeast orientation compared to other orientations for all window glazing. Bronze reflective glass window reported the highest energy cost savings compared to other window glasses studied. Bronze reflective window glazing saves 45.66% and 26.42% more air-conditioning cost savings compared with tinted bronze and green glass windows, respectively. The SE orientation is followed by SW, S orientations are recommended for the highest cooling and heat cost savings in buildings. The North and NE orientations are not recommended to place glazing due to their lowest air-conditioning cost-saving prospective.

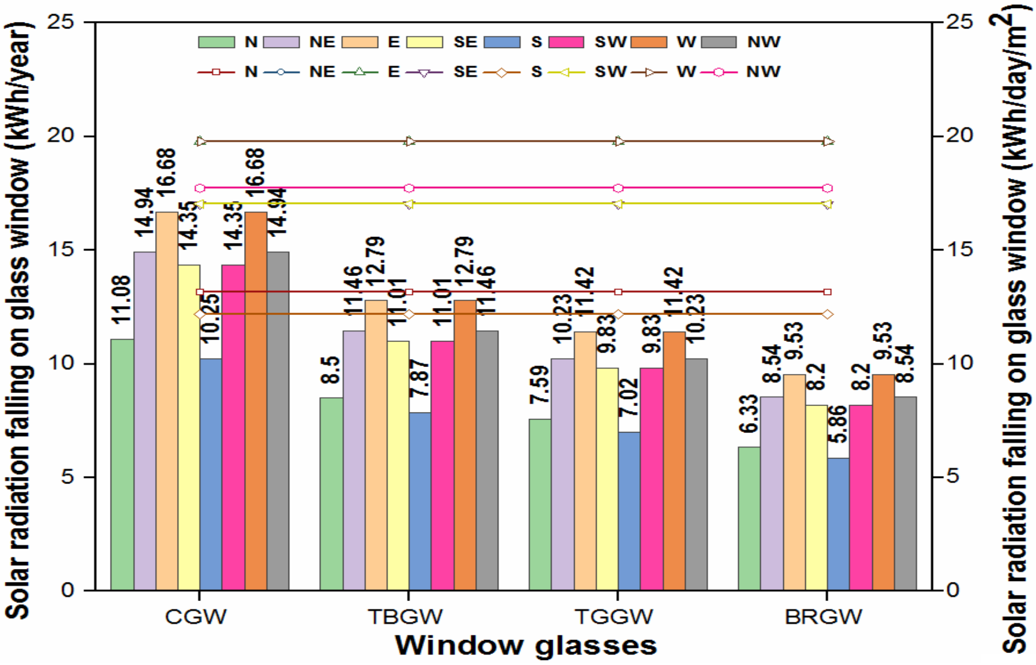

Fig. 5. Solar radiation falling and passing through window glazing of the Dhaka region on a peak summer day.

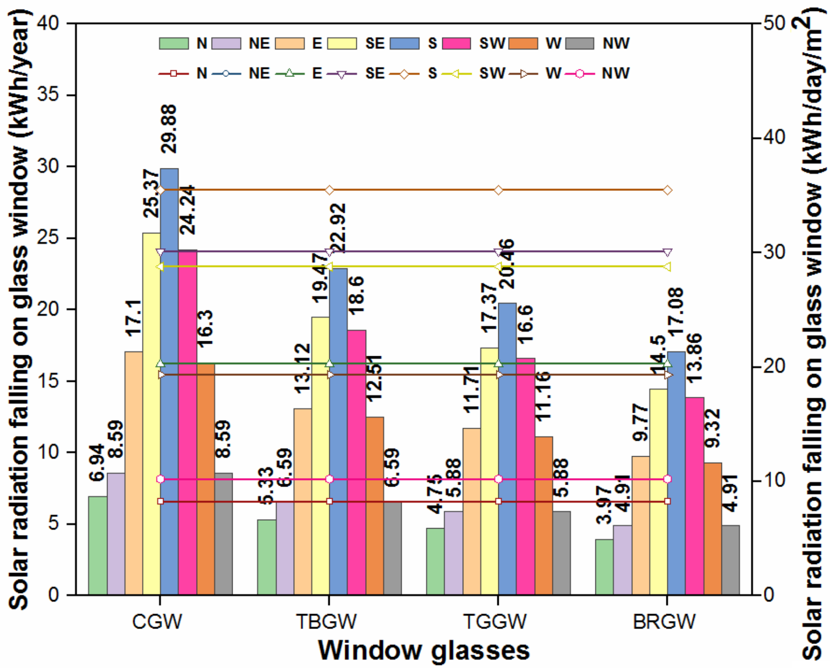

Fig. 6. Solar radiation falling and passing through window glazing of the Dhaka region on a peak winter day.

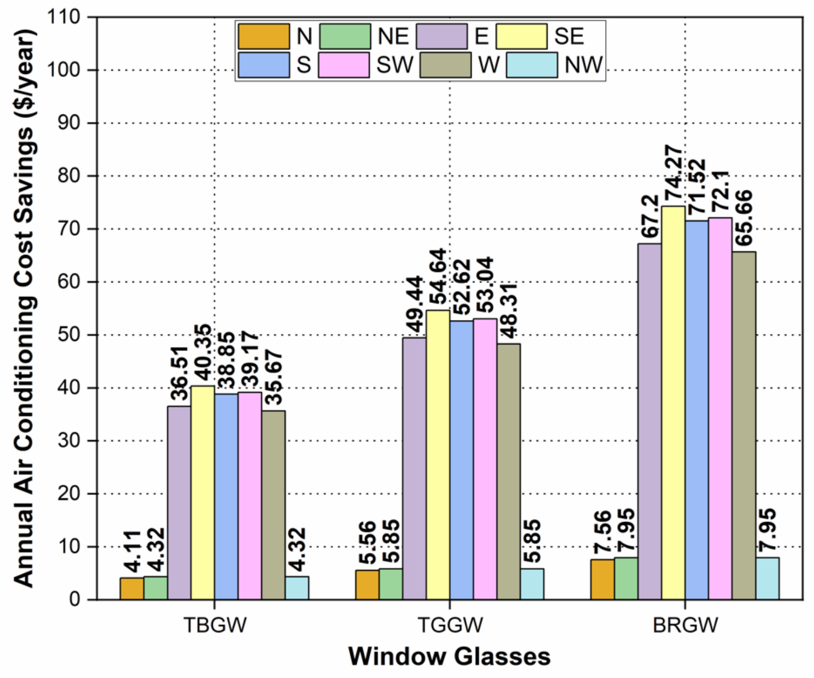

Fig. 7. Annual air conditioning cost savings of buildings using various glass windows compare with a clear glass window.

4.3 Payback Period of Various Window Glazing in Dhaka Climatic Region

Figure 8 shows the payback period of various window glazing compared to the clear glazing in Dhaka Region. From the results, it is observed that the payback period of bronze reflective window glazing is the shortest compared to the other studied glass windows. The SE orientation has been observed to be the best for the shortest payback periods of 0.95 years compared to the other studied orientations. The SE orientation followed by South and Southwest orientations is preferable for the shortest payback periods. The North and NE orientations are not recommended to place glazing due to longer payback periods.

4.4 Daylight Factor of Various Window Glazing in Dhaka Climatic Region

Figure 9 shows the average daylight factors of various glazing materials. The average daylight factor (ADF) is the measure of the level of illuminance in the indoor room following the external daylighting. The average daylight factor was evaluated for Dhaka climatic condition in Design builder and Energy Plus simulation tools from 7 am to 5 pm on peak winter day and 6 am to 6 pm on peak summer day for four best directions of air-conditioning cost savings (SE, E, W, and SW). For office inquiry rooms, living rooms, bedrooms, library stack rooms, and in most of the rooms, the minimum recommended average daylight factor is 0.625 as per the standards [29]. All four glass materials in all four directions (SE, E, W, and SW) have shown better daylight factors than the recommended levels on both peak summer and winter days. The south gives the best daylighting in winter whereas, the East gives the best daylighting in summer. The daylight factor of the bronze reflective glass window (BRGW) ranges from 92% (On peak summer day) to 204% (On peak winter day) higher than the recommended daylight factor values in the southeast orientation. From the results, it is observed that all four window glazing studied give adequate daylight factors.

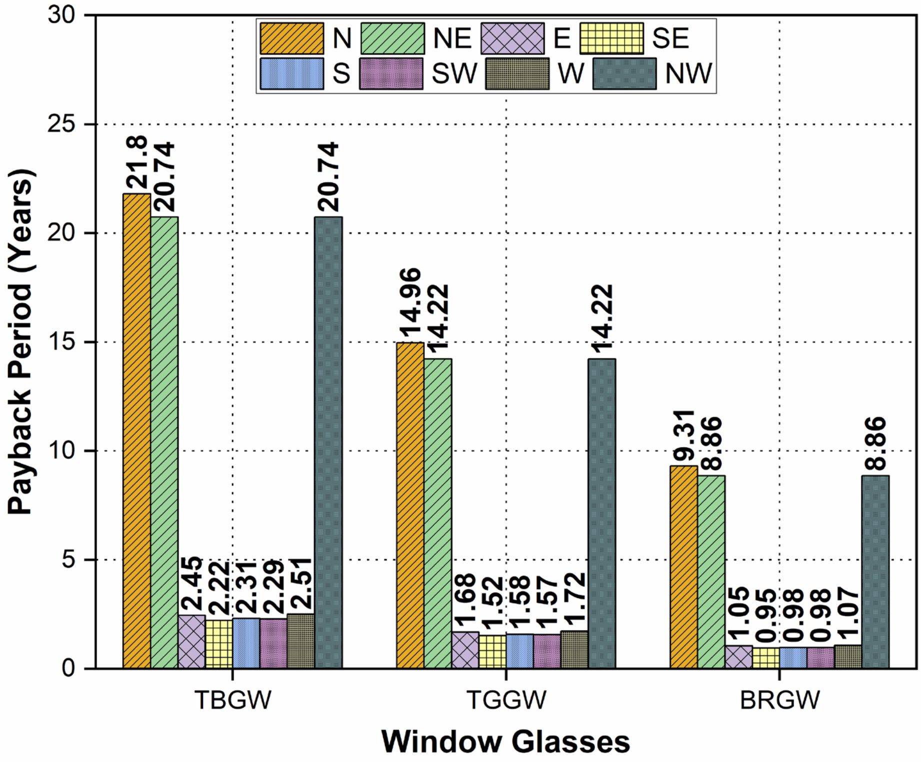

Fig. 8. Payback period of various window glazing.

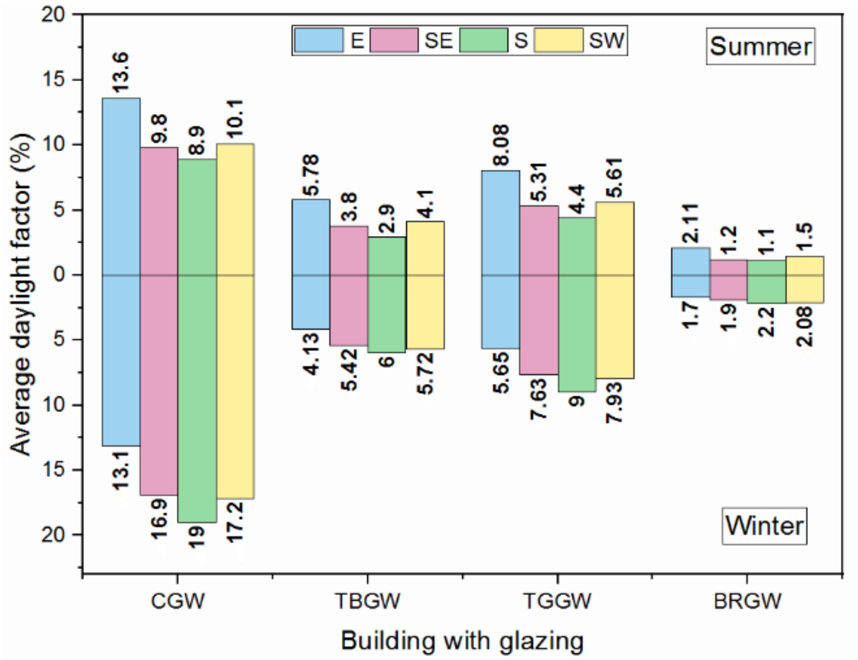

Fig. 9. Average daylight factors of various window glazing.

5. CONCLUSION

The objective of this work is to ascertain the best glazing and it's orientation to save the highest air-conditioning costs in buildings of the Dhaka climatic region, Bangladesh. From the results, it is concluded that

- The use of bronze reflective glazing for buildings contributes to the higher air-conditioning cost savings of about 45.66% and 26.42% compared to the tinted bronze and tinted green glazing, respectively. The bronze reflective glazing gives the highest air-conditioning cost savings with the lowest payback periods (0.95 in South East) and adequate daylight factors.
- The southeast orientation for glazing is observed to be optimal for increased energy

cost savings followed by southwest and south. The north and northeast orientations for glazing lead to higher energy costs and therefore they are not recommended for energy saving.

- The four window glazing materials of the building have shown better daylight factors than the recommended values. The bronze reflective glazing is responsible for the highest air-conditioning cost savings with adequate daylight factors inside the building.

The results of the paper can be extremely useful in designing the most energy-efficient buildings.

NOMENCLATURE

A_G	Area of the glass (m^2)
A	Solar radiation in absence of atmosphere (W/m^2)
B	Atmospheric extinction coefficient (W/m^2)
C	Dimensionless coefficient for sky radiation
d_{an}	Declination angle (^{0}Deg)
h_{an}	Hour angle (^{0}Deg)
k	Angle of window glass from vertical (^{0}Deg)
l	Latitude (^{0}Deg)
n_{da}	Number of days
I_{DN}	Solar radiation at normal incidence (W/m^2)
h_o	Outside surface heat transfer coefficient (W/m^2K)
h_i	Inside surface heat transfer coefficient (W/m^2K)
I_{TSRSGW}	Total solar radiation through single glass window (kW)
$Q_{Sol,summer}$	Solar radiation in summer months (kW)
$Q_{Sol,winter}$	Solar radiation in winter months (kW)
q_{ds}	Daily average solar radiation in summer month (kW)
q_{dw}	Daily average solar radiation in winter month (kW)
T_{SOL}	Solar transmittance (%)
R_{SOL}	Solar reflectance (%)
A_{SOL}	Solar absorbance (%)
$S\lambda$	Relative spectral distribution of the solar radiation (W/m^2)
U	Thermal transmittance (W/m^2K)

Greek letters

λ	Wavelength (nm)
$\Delta\lambda$	Wavelength interval (nm)
β_a	Solar altitude angle (Deg)
θ	Solar incidence angle (Deg)
Φ	Solar azimuth angle (Deg)
γ_a	Surface solar azimuth angle (Deg)
Ψ	Surface azimuth angle (Deg)
ρ_g	Ground reflectance factor
(λ)	Spectral transmission (%)
(λ)	Spectral reflection (%)
$\alpha(\lambda)$	Spectral absorption (%)

Abbrevations

BRGW	Bronze reflective glass window
CGW	Clear glass window
NIR	Near infrared
SG	Single glass
SGW	Selected glass window
TBGW	Tinted bronze glass window
TGGW	Tinted green glass window
UV	Ultra-Violet Region

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