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Thermal and Energy Saving Analysis by Using Tinted Double Window Glass Combinations for Heat Gain in Buildings

Kirankumar Gorantla*,[1], Saboor Shaik[+], and Ashok Babu Putta Ranga Talanki Setty*

Abstract – *Buildings consume large amount of energy to accommodate thermal and visual comforts, in which glass windows play an important role as we used as building envelope. Universally clear glass is used as chief building envelope for buildings. As clear glass is having more transmission property it permits more radiation and day light into the buildings which creates uneasy feeling to the occupants. This paper presents the experimental measurement of spectral characteristics of three tinted glasses which include transmission and reflection in entire solar spectrum wavelength region from 300nm to 2500nm as per ASTM standards by using UV 3600 Shimadzu spectrophotometer. These measured spectral characteristics were used to compute solar optical properties as per British standard by using MATLAB code. To find the total solar radiation through double tinted window glass combinations GC1 to GC6 place as building envelopes of New Delhi climatic zone by using MATLAB code and to find the monthly solar radiation passing into the building which is helpful to calculate the cost energy saving annually for cooling and heating loads. From the results GC6 combination windows are saving cost i.e. 61.16 (US Dollars/year) in south, 60.54 (US Dollars/year) in south east and 59.23 (US Dollars/year) in south west orientations annually than other combination windows.*

Keywords – double tinted window glass combinations, solar optical properties, spectral characteristics, spectrophotometer.

1. INTRODUCTION

Glass has been a fascinating material since it was first manufactured about 500 BC. It is one of the most versatile and oldest materials in the building enterprises. Glasses play a major role in captivating day light into the buildings when used as building envelopes. Most of the commercial and residential buildings today are employing glasses to cover major portion of their buildings. Generally, clear glass allows more amount of direct solar radiation and also high percentage of day lighting into building. This is because this glass has high transmission property in comparison with other building enclosures which allows more radiation leading to uncomfortable condition to the building occupants. Tinted glasses are which are colored with specific ingredients formulated to produce light reducing and heat absorbing glass products without compromising its strength. These can be used instead of clear glasses to reduce direct sun radiation into the buildings and avoid more day light passing through them. As such, in this work we have reported double glazing unit with an unventilated air gap between tinted glass combinations from GC1 to GC6 for composite (New Delhi) climatic zones in India.

Singh and Bansal, 2011 computed the solar radiation transmission into the buildings of clear and bronze glass by TRANSYS simulation software. The glasses were positioned as single glass and double glasses with an air gap of 12.7 mm filled by air, xenon, krypton gases [1]. Different window to wall ratios to project a least heat gain into the building in warm and humid climatic zone of Mangalore city in India was investigated. [2]. Sujoy *et al.*, 2009 reported decrease in the solar beam energy into the buildings by slanting the position of the clear and brown window glass material in inward direction in Baghdad, Iraq in both summer and winter periods [3]. Studies on solar energy transmission into the building with the help of 4mm clear glass was experimented and this was compared and validated with the mathematical model [4]. Best energy efficient building model to consume least heat gain by maintaining 30% window to wall ratio for several walls and window glass materials in different directions of all Indian climates was determined [5]. Optimum tilt of south facing solar plate collectors to increase heating and decrease cooling loads for saving energy in Karachi latitude region, Pakistan was investigated. It was reported that ϕ+200 tilt is better in heating season and ϕ-200 tilt better in cooling season [6].

Effective energy glass model for solar radiation into the building by measuring the spectral characteristics of clear, double low-E and triple low-E glasses and evaluation of these results was reported [7]. Reduction in the energy consumption in buildings by using various single, double Low-E glasses, thermo tropic and photovoltaic windows as building envelope from all orientations of different climatic regions in Malaysia was reported [8]. In an adiabatic room, changing the position of window locations of single and double low-E glasses by maintaining them as building envelopes to decrease the solar radiation in summer and increase of solar radiation in winter seasons was studied in detail [9]. Studies on solar radiation for six latitudes

*Department of Mechanical Engineering, National Institute of Technology Karntaka, P.O. Srinivasnagar, Mangalore 575025, Karnataka, India.

[+]Department of Thermal and Energy Engineering, VIT University, Vellore 632014, Tamilnadu, India.

[1]Corresponding author;
Tel: + 91 9740251522 ext. 345, Fax: + 12 345 678 980 10.
E-mail: gorantla.kirankumar@gmail.com.

of India by placing different inward window glass slopes in all orientations of a building was done and it was found that in south orientation it attained zero radiation for all four various window glasses like clear, bronze, green, bronze, and reflective [10]. Thermal transmittance was determined by analyzing the heat transfer with internal louvered blind as high and low thermal conductivity in double-glazed unit by comparing a biquadratic equation and also with computational fluid dynamics at various places [11]. A study has been done on influencing factors which improve the green performance on buildings implemented generalized additive model and it was found that construction scales greater than 20,000 m^2 gave lesser green building enactment and also government policies plays a leading role in China country [12].

Karmele and Jose, 2012 proposed a method to evaluate the monthly mean global solar radiation by considering three global solar radiation correlations which were proposed by previous researchers. They found that proposed method gives 5% error and gave better accuracy in comparison with other models [13]. The effect of various building envelopes such as sun shields, various roof construction and window glasses like Low-E glass to reduce the solar energy transmission and also to save the electricity monthly and annually for residential building with help of EQUEST software in Taiwan was reported [14]. The solar optical properties of non-coated and coated single pane glazing's values are taken into account and validated with analytical Fresnel equations to find the dynamic solar radiation passing into the building was studied in detail [15]. Studies on thermal performance of residential building integrated with adaptive kinetic shading system with window and without window were examined. The results showed that kinetic shading system decrease energy consumption nearly 18-20% and decrease the inter temperature when compared to without kinetic shading system [16].

Parishwad *et al.*, 1999 developed software prescribed by ASHRAE to find the cooling loads of buildings which is in eight different locations of India. The parameters considered were monthly-mean hourly wind velocities, humidity ratios, building materials and occupants, these results were compared with solar heat gain factor method and reported a deviation of 6.5% to 15.7% [17]**.** Minimum heat gain into buildings through float and tinted window glasses in summer season for all eight coordinal directions of Indian climatic regions was reported [18]. In the literature, seven empirical models developed to estimate the diffuse solar radiation on horizontal surface where diffuse solar radiation not measure directly in Northern Sudan region, and it has used the parameters sunshine hours and global solar radiation and found the diffuse solar radiation in two stations Hudeiba and Dongola, models developed based on clearness index showed enhanced than the models based on sunshine fraction. Though, hybrid model (M 24) developed on the basis of both clearness index and sunshine fraction, expressed the highest performance [19]. From the above literature, it is clearly observed that there is no significant work has been reported on thermal performance of double tinted window glasses. There are no significant studies on cost savings, net cooling, and heating loads in buildings through double tinted glasses. The objective of this research paper is to study the various double tinted glass window combinations keep them as an envelopes for buildings and try to reduce total solar radiation into the buildings and evaluate the thermal performance, energy cost savings, net cooling, and heating loads. Thermal performance of various tinted glasses has been compared with double clear glass window combination of composite climatic zone in India (New Delhi) from all eight orientations. This paper also presents the experimentally measured spectral characteristics of three tinted glasses in the total solar spectrum region. The results of this paper are useful in designing energy efficient solar passive buildings.

2. EXPERIMENTAL TECHNIQUE TO MEASURE THE SPECTRAL CHARACTERISTICS OF TINTED GLASSES

UV-3600 Shimadzu Spectrophotometer is an UV-VIS-NIR instrument which is used in this study to measure the spectral characteristics of any window glasses. This work measures the spectral characteristics of tinted glasses like bronze, green and grey glasses of size 30mmX30mm and thickness of 5 mm. The measurements were made at normal angle of incidence in entire solar spectrum wavelength region from300 nm to2500 nm based on ASTM E424 1971standards [20]. A MATLAB code was developed to compute the solar optical properties like transmittance, reflectance in the solar spectrum region by using Equations (1), (2) based on British standards BS EN 410 1998 [21]-[23]

$$T_S = \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \tau(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \tag{1}$$

$$R_S = \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \rho(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \tag{2}$$

Solar absorbance of the glass can be found by knowing the solar transmittance and reflectance.

$$A_S = 100 - \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \tau(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} - \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \rho(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \tag{3}$$

Solar heat gain coefficient is defined as sum of solar transmittance and product of solar absorbance of window glass. It is determine how much solar radiation passing through window glass. Solar heat gain coefficient of single and double window glass correlation with Equations (4) and (5).

$$SHGC_{SG} = \left(T_S + \frac{U}{h_o} A_{SL} \right) \tag{4}$$

$$SHGC_{DG} = \left(T_{SL} + U \left(\frac{\alpha_i + \alpha_o}{h_o} + \alpha_i X C_{AG} \right) \right) \tag{5}$$

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

Window glass	Transmittance T_S (%)	Reflectance R_S (%)	Absorbance A_S (%)
Bronze glass	56	6	38
Green glass	47	6	47
Grey glass	41	6	53

Figure 1 shows the UV-3600 Shimadzu spectrophotometer is interfaced with UV-Win lab software and Figure 2 shows the images of tinted glass windows. The spectral transmission of glass windows can be seen from Figure 3, it can be observed that bronze glass is has maximum transmission and grey glass is has least transmission in comparison with other glasses. The spectral reflection of glass windows in entire total solar spectrum wavelength region from 300nm to 2500nm can be seen from Figure 4.

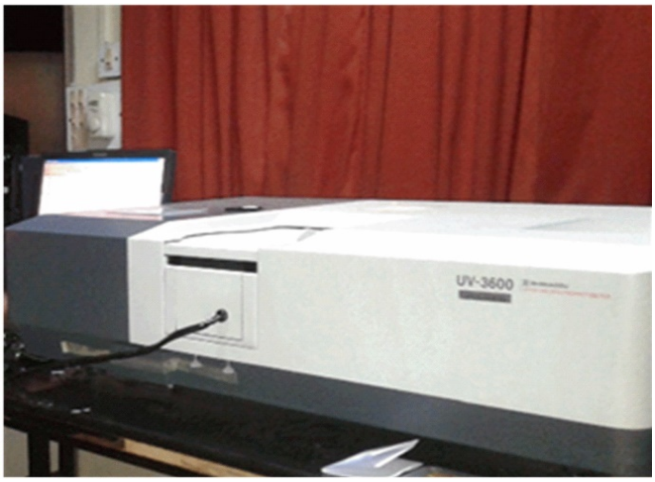

Fig. 1. Spectral transmission of tinted glass windows.

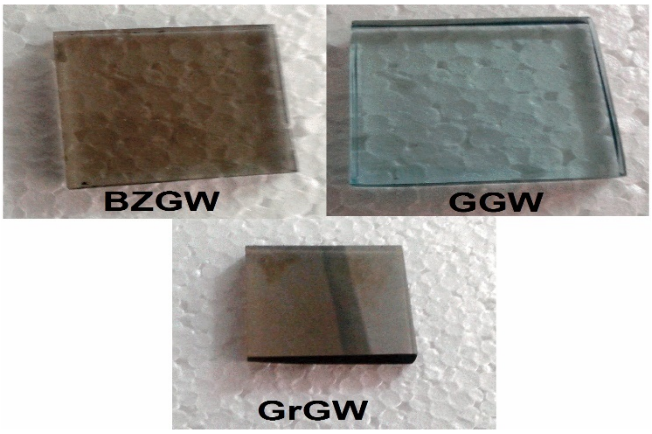

Fig. 2. Images of glass windows.

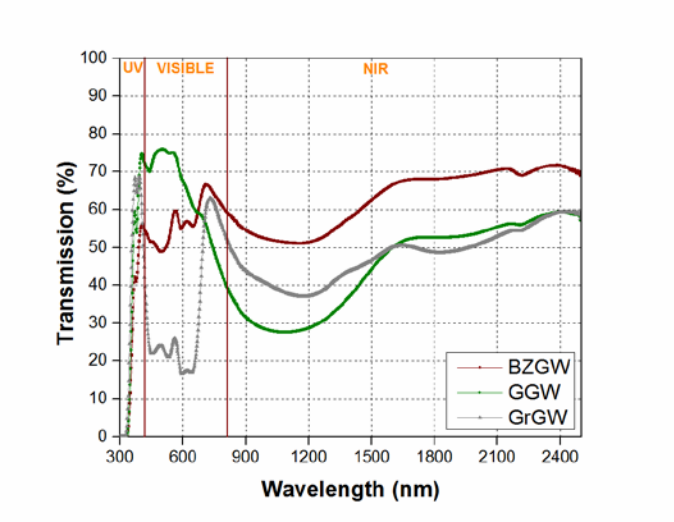

Fig. 3. Spectral transmission of tinted glass windows.

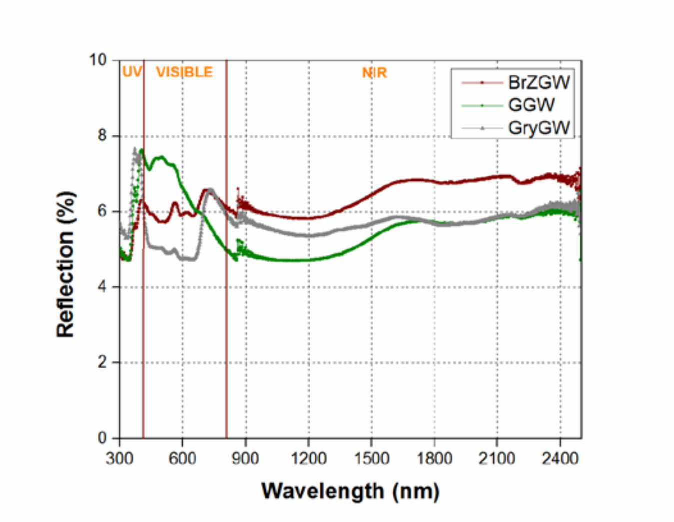

Fig. 4. Spectral reflection of tinted glass windows.

3. ANALYTICAL PROCEDURE TO FIND THE SOLAR RADIATION PASSING THROUGH GLASS WINDOWS

Solar radiation from sun reaches the surface of earth in the form of direct and diffused radiation. Solar radiation enters into the building space through building enclosures such as walls, roofs and windows. This radiation passing into the building through window glass is higher than any other enclosure of the building. Solar radiation through glass enters into the building is in the form of direct, diffused and reflected radiation. A MATLAB code was developed to compute direct, diffused and reflected radiation. The computer program utilizes the mathematical correlations of declination angle, solar altitude, solar azimuth angle, surface solar azimuth angle and angle of incidence to compute the intensity of direct, diffuse and ground reflected radiation. In this work, total solar radiation passing through three glass windows such as bronze, green and grey glasses are considered. They are placed as double window glass combinations, in which one glass is exposed to the environment and other glasses are placed inside the buildings. They are abbreviated as GC1, GC2, GC3, GC4, GC5 and GC6 and filled with an unventilated air gap of 10mm as shown in Figure 2. All eight orientations of composite climatic zone (New Delhi) in India are studied. The total solar radiation passing through these glasses from sunrise (6:00) to sunset (18:00) at peak summer day and at peak winter day sunrise (7:00) to sunset (5:00) as per Indian standards [24]-[26] is computed with MATLAB code. The laterite building model of dimensions 4mx4mx3.5m is considered and the window to wall ratio of 40% is maintained, and the area of glass becomes 2.8mx2m with thickness 5 mm as per Indian standards [27].

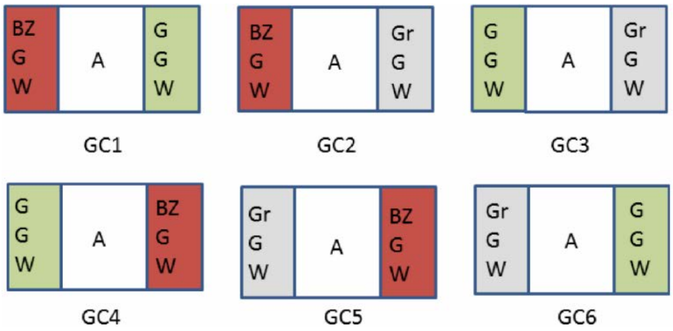

Fig. 5. Double tinted window glass combinations with an air gap of 10mm.

The total solar radiation passing through these window glasses as per ISHRAE clears sky and intermediate sky model in both summer and winter seasons of New Delhi climatic zone in India is computed with correlations are given below [28].

Declination angle:

$$d_{ia} = 23.45\sin\frac{360(284+n)}{365} \tag{4}$$

Solar altitude angle:

$$\sin\beta_a = \cos l\cos d_i\cos h + \sin l\sin d_i \tag{5}$$

Solar azimuth angle:

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

Surface solar azimuth angle:

$$\gamma = \phi - \Psi \tag{7}$$

Angle of incidence:

$$\cos\theta_i = \cos\beta\cos\gamma\cos k - \sin\beta\sin k \tag{8}$$

At the earth's surface on a clear day solar irradiance is given by:

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

Table 2. Surface orientations and azimuths, measured from south *(ASHRAE 2001)*.

Orientation	Surface azimuth Ψ
North	180
North-East	-135^0
East	-90^0
South-East	-45^0
South	0
South-West	45^0
West	90^0
North-West	135^0

Table 3.Values of constants A, B and C obtained for predicting hourly solar radiation in India *(Source: [29], [30])*.

Day	A (W/m^2)	B	C
Jan. 21	610.00	0.000	0.242
Feb. 21	652.20	0.010	0.249
Mar. 21	667.86	0.036	0.299
Apr. 21	613.35	0.121	0.395
May. 21	558.39	0.200	0.495
Jun. 21	340.71	0.428	1.058
Jul. 21	232.87	0.171	1.611
Aug. 21	240.80	0.148	1.624
Sep. 21	426.21	0.074	0.688
Oct. 21	584.73	0.020	0.366
Nov. 21	616.60	0.008	0.253
Dec. 21	622.52	0.000	0.243

Intensity of direct solar radiation:

$$I_{DISR} = I_{DN}\cos\theta_i \tag{10}$$

Diffuse radiation from the sky:

$$I_{dISR} = CI_{DN}\frac{1-\sin k}{2} \tag{11}$$

Ground reflected radiation is:

$$I_{REGR} = CI_{DN}\rho_g\frac{1-\sin k}{2} \tag{12}$$

Total solar radiation falling on glass windows:

$$I_{TSR} = \left(I_{DISR} + I_{dISR} + I_{REGR}\right) \tag{13}$$

Total solar radiation passing through single glass windows:

$$I_{TSRSGW} = \left(I_{DSR} + I_{dSR} + I_{GRD}\right).\left(T_S + \frac{U}{h_o}A_S\right).A_G \tag{14}$$

Total solar radiation passing through double glass window:

$$I_{TSRDGW} = (I_{DSR} + I_{dSR} + I_{GRD}).\left(T_S + U\left(\frac{\alpha_i + \alpha_o}{h_o} + \alpha_i XC_g\right)\right).A_G \tag{15}$$

In this paper temperature, convective and Radiative heat transfer coefficient considered in external and internal surface resistance of the glazing as per CIBSE (Chartered Institute of Building Service Engineers UK) standards the correlations are as give below.

$$R_{se} = \frac{1}{h_c + Eh_r}$$

$$R_{si} = \frac{1}{1.2Eh_r + h_c}$$

Where R_{se} = External surface resistance = 0.040 m^2K/W

R_{si} = Internal surface resistance = 0.130 m^2K/W

as per CIBSE standards:

h_c = Convective heat transfer coefficient

= $16.7C_s^{0.5} W/m^2K$ (for air velocity C_s < 3.5 m/s)

E = Emissivity factor
E = kε
k = geometry constant = 1
ε = Emissivity of surface = 0.9
hr = Radiative heat transfer coefficient
= $4\sigma T_s^5$
σ = Stefan Boltzmann constant = 5.67×10^{-8} W/m^2K
Ts = Surface absolute temperature (in Kelvin)

Where;

$$U = 1/\left(1/h_o + dx1/K1 + C_{AG} + dx2/K2 + 1/h_i\right)$$

where, C_{AG} is the thermal resistance of the air gap between two glasses

$$C_{AG} = \left[1/\left(1.25 + \left(2.32X\left(\sqrt{\left(1+\left(\frac{t_{ag}^2}{w_{ag}^2}\right)\right)} - \frac{t_{ag}}{w_{ag}}\right)\right)\right)\right] \tag{16}$$

Where t_{ag} = Thickness of the air gap
w_{ag}= Thickness of the air gap width

The Rsi, Rso values are taken from CIBSE standards [31].

For the validation of present MATLAB code, 3mm clear glass window was used as that of the previous researcher. The direct solar radiation results of New Delhi climatic region obtained from the MATLAB code are compared with Ishwar *et al.* (2011) results and they are listed in Table 3. The deviation of MATLAB code results with Ishwar *et al.* (2011) is less than 1%. Therefore the developed MATLAB code is reliable and hence it can be used for the computation of solar radiation for different glasses.

Table 4. Theoretical validation of direct solar radiation passing through 3mm clear glass of Ishwar *et. al.* (2011) and present program results to New Delhi climatic region at peak summer day June 21st [32].

S.No.	Orientation	Ishwar *et al*. (2011)	MATALAB program results	Deviation (%)
1	North	178.36	178	-0.20
2	North East	1289.98	1292	-0.15
3	East	1953.83	1952	-0.09
4	South East	1273.55	1272	-0.12
5	South	184.27	184	-0.14
6	South West	1273.55	1272	-0.12
7	West	1953.83	1952	-0.09
8	North West	1289.98	1292	-0.15

4. RESULTS AND DISCUSSIONS

4.1 Solar Radiation Gain into Buildings through Double Tinted Glass Windows of New Delhi (Composite) Climatic Region in Both Summer and Winter Seasons

Figure 6 shows the solar radiation through different double tinted window glass combinations of New Delhi (28.58^0N, 77.20^0E) climatic condition at peak summer day *i.e.*, on June 21^{st} from morning 6:00hrs to evening 18:00hrs, from all eight coordinal directions. Form the graph it is clearly observed that in south orientation of all double tinted glass window combinations are gaining less heat in summer season. In south orientation GC3 combination window is permitting less heat in summer season when compared with all other combination windows, because it depends on solar optical properties and solar heat gain coefficient values of window glasses.

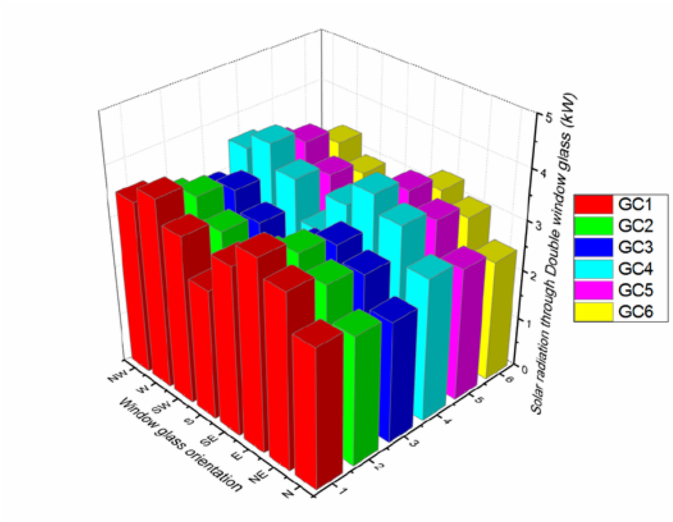

Fig. 6. Total solar radiation passing through tinted double window glass combinations from all eight orientations of New Delhi climatic region at peak summer day.

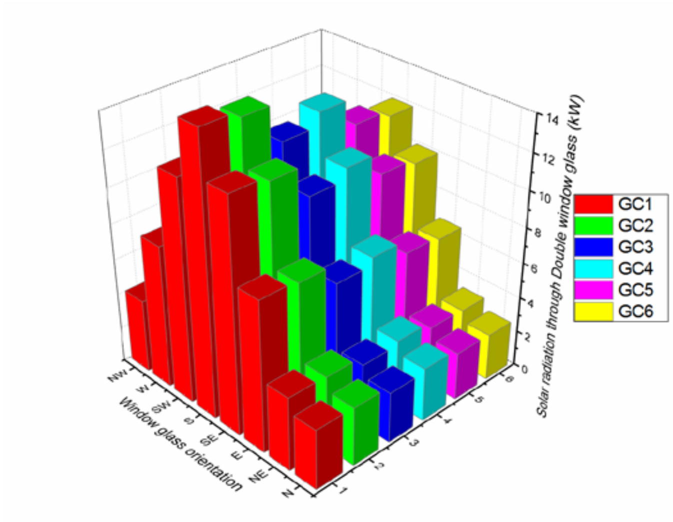

Fig. 7. Total solar radiation passing through tinted double window glass combinations from all eight orientations of New Delhi climatic region at peak winter day.

Figure 7 shows solar radiation through different double tinted window glass combinations of New Delhi climatic condition at peak winter day December 21st from all eight coordinal directions from morning 7:00hrs to evening 17:00hrs. In south orientation GC1 combination windows is permitting more heat in winter season compared to all other combination windows, because it depends on solar optical properties and solar heat gain coefficient values of window glasses.

4.2 Effect of Various Tinted Double Window Glass Combinations on Cooling and Heating Loads per year of New Delhi (Composite) Climatic Region in all Orientations

The given below procedure is to find the total solar radiation in summer months considered (April, May, June, July and August) and winter months considered (September, October, November, December, January, February and March) and also observed that cooling load decrease in summer months and heating load increases in winter months, and finally the power saving per year for both cooling and heating loads are determined through all double tinted window glass combinations when compared with double clear glass window combination [33].

Total solar radiation in summer months:

$$Q_{sol,summer} = (q_{ds_{April}} X30) + (q_{ds_{May}} X31) + (q_{ds_{June}} X30) + (q_{ds_{July}} X31) + (q_{ds_{August}} X31) \tag{17}$$

Total solar radiation in winter months:

$$Q_{sol,winter} = (q_{dw_{Sep}} X30) + (q_{dw_{Oct}} X31) + (q_{dw_{Nov}} X30) + (q_{dw_{Dec}} X31) + (q_{dw_{Jan}} X31) + (q_{dw_{Feb}} X29) + (q_{dw_{Mar}} X31) \tag{18}$$

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

$$\text{Cooling load decrease} = Q_{sol,summer} X\ A_G\ X\left(SHGC_{DCGW} - SHGC_{SDGW}\right) \tag{19}$$

$$\text{Heating load Increase} = Q_{sol,winter}\ X\ A_G\ X\left(SHGC_{DCGW} - SHGC_{SDGW}\right) \tag{20}$$

Figure 8 shows that graph between annual cooling and heating load of tinted double window glass combination (GC1) compared with double clear glass window combination of New Delhi climatic region in all orientations of the building. From the Figure 8 it is clearly shown that double tinted window glass combination, in south orientation is reducing heat in terms of cooling load *i.e.* 369.8 kW in summer season and increasing heat in terms of heating load *i.e.* 1483.74 kW in winter season when compared with all other orientations, respectively.

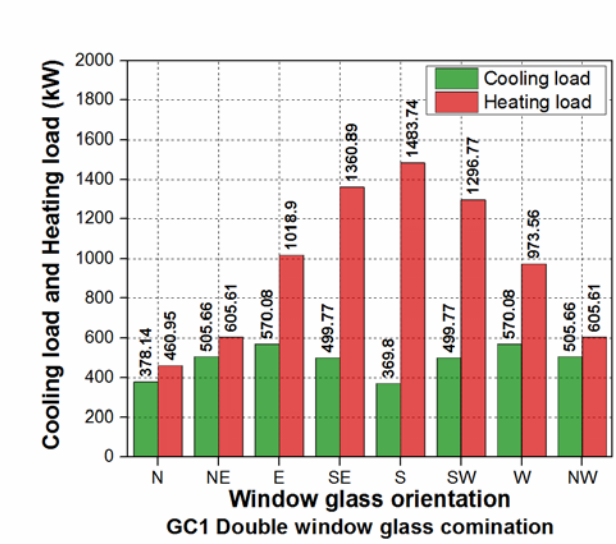

Fig. 8. Annual cooling and heating load of tinted double window glass combination (GC1) compared with double clear window glass combination of New Delhi climatic region.

Figure 9 shows that graph between annual cooling and heating load of tinted double window glass combination (GC2) compared with double clear glass window combination of New Delhi climatic region in all orientations of the building. From the Figure 9 it is clearly shown that double tinted window glass combination, in south orientation is reducing heat in terms of cooling load *i.e.* 411.86 kW in summer season and increasing heat in terms of heating load *i.e.* 1551.88 kW in winter season when compared with all other orientations, respectively.

Figure 10 shows that graph between annual cooling and heating load of tinted double window glass combination (GC3) compared with double clear glass window combination of New Delhi climatic region in all orientations of the building. From the Figure 10 it is clearly shown that double tinted window glass combination, in south orientation is reducing heat in terms of cooling load *i.e.* 441.23 kW in summer season and increasing heat in terms of heating load *i.e.* 1896.68 kW in winter season when compared with all other orientations, respectively.

Figure 11 shows that graph between annual cooling and heating load of tinted double window glass combination (GC4) compared with double clear glass window combination of New Delhi climatic region in all orientations of the building. From the Figure 11 it is clearly shown that double tinted window glass combination, in south orientation is reducing heat in terms of cooling load *i.e.* 352.99 kW in summer season and increasing heat in terms of heating load *i.e.* 1773.98 kW in winter season when compared with all other orientations, respectively.

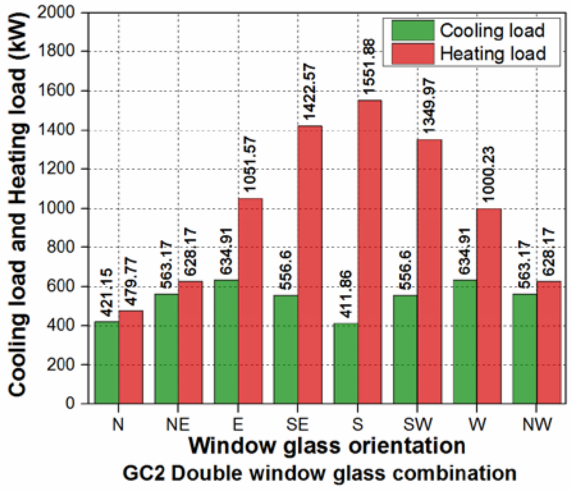

Fig. 9. Annual cooling and heating load of tinted double window glass combination (GC2) compared with double window clear glass combination of New Delhi climatic region.

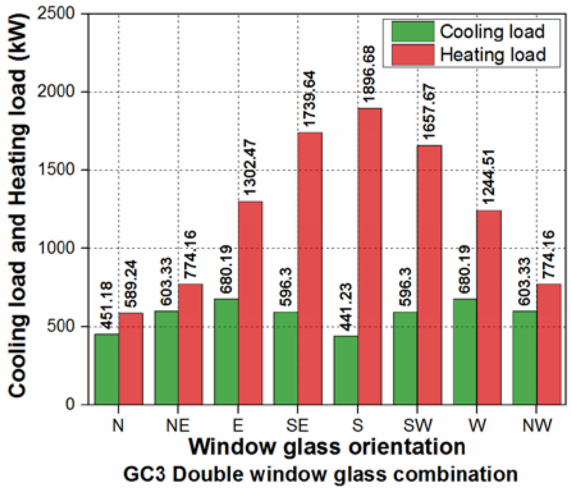

Fig. 10. Annual cooling and heating load of tinted double window glass combination (GC3) compared with double clear window glass combination of New Delhi climatic region.

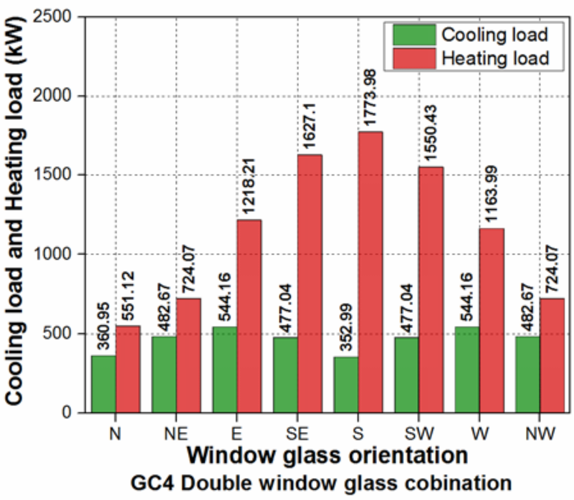

Fig. 11. Annual cooling and heating load of tinted double window glass combination (GC4) compared with double clear window glass combination of New Delhi climatic region.

Figure 12 shows that graph between annual cooling and heating load of tinted double window glass combination (GC1) compared with double clear glass window combination of New Delhi climatic region in all orientations of the building. From the Figure 12 it is clearly shown that double tinted window glass combination, in south orientation is reducing heat in terms of cooling load *i.e.* 391.72 kW in summer season and increasing heat in terms of heating load *i.e.* 2026.21 kW in winter season when compared with all other orientations, respectively.

Figure 13 shows that graph between annual cooling and heating load of tinted double window glass combination (GC6) compared with double clear glass window combination of New Delhi climatic region in all orientations of the building. From the Figure 13 it is clearly shown that double tinted window glass combination, in south orientation is reducing heat in terms of cooling load *i.e.* 437.91 kW in summer season and increasing heat in terms of heating load *i.e.* 2090.44 kW in winter season when compared with all other orientations, respectively.

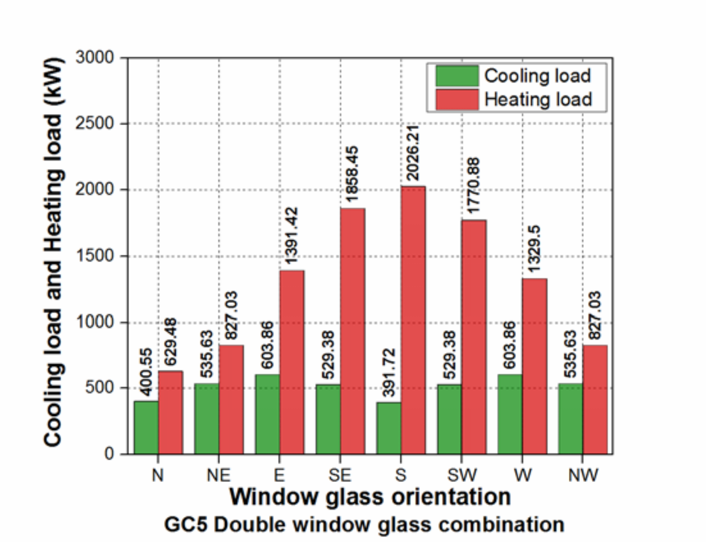

Fig. 12. Annual cooling and heating load of tinted double window glass combination (GC5) compared with double clear window glass combination of New Delhi climatic region.

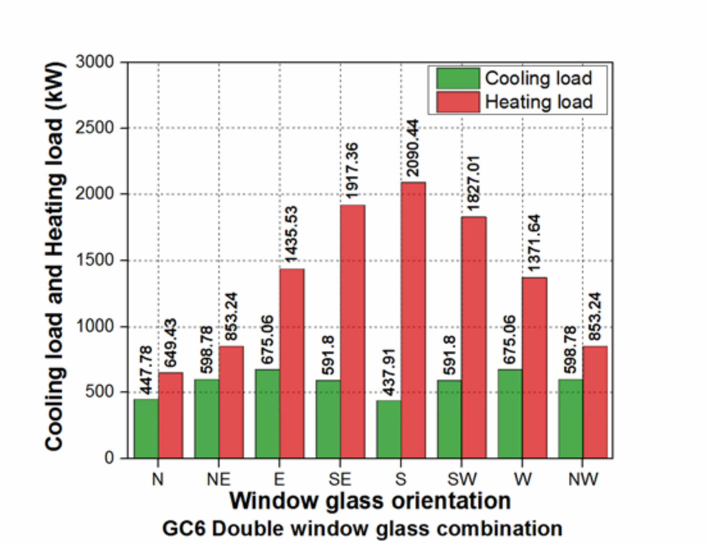

Fig. 13. Annual cooling and heating load of tinted double window glass combination (GC6) compared with double clear window glass combination of New Delhi climatic region.

4.3 Annual Cost Savings of Tinted Double Window Glass Combinations Compared with Double Clear Glass Window Combination for New Delhi (Composite) Climatic Region

The given below procedure is to find the total cost savings per year through all double tinted window glass combinations.

The properties of clear glass such as transmittance, reflectance and absorbance are 82%, 8% and 10%, respectively taken from literature. In the present study, the unit cost of the electricity and natural gas considered are □5.12 kWh and □32/therm, respectively. The coefficient of performance of the cooling system and efficiency of the furnace are 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) (21)

Increase in heating costs = (heating load increase) (unit cost of fuel) / (Efficiency) (22)

The net annual cost savings = Decrease in cooling costs – increase in heating costs (23)

Figure 14 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in north orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 27.89 (US Dollars/year) when compared with all other window glass combinations.

Figure 15 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in northeast orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 37.11 (US Dollars/year) when compared with all other window glass combinations.

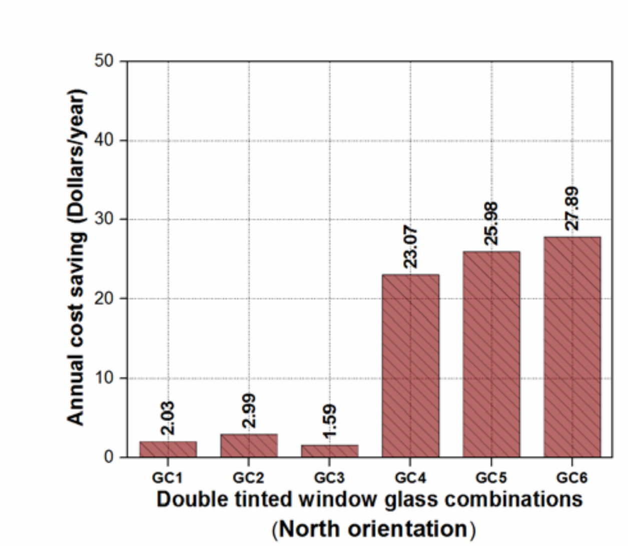

Fig. 14. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in north orientation.

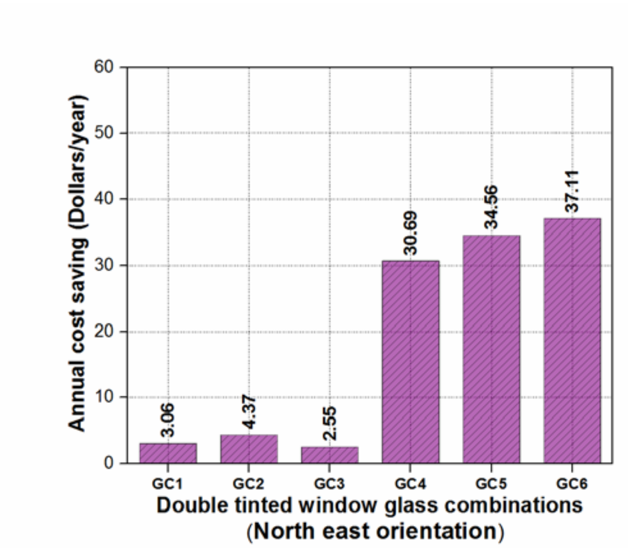

Fig. 15. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in northeast orientation.

Figure 16 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in east orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 52.72 (US Dollars/year) when compared with all other window glass combinations.

Figure 17 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in southeast orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 60.54 (US Dollars/year) when compared with all other window glass combinations.

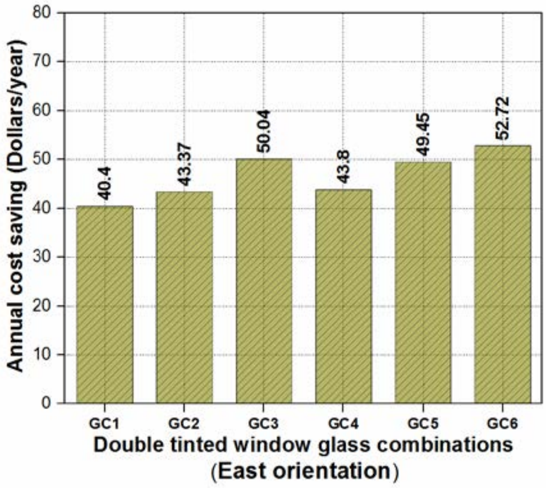

Fig. 16. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in east orientation.

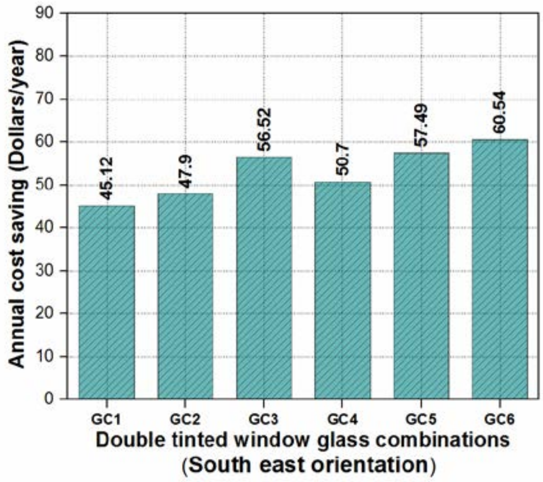

Fig. 17. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in southeast orientation.

Figure 18 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in south orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 61.16 (US Dollars/year) when compared with all other window glass combinations.

Figure 19 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in southwest orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 59.23 (US Dollars/year) when compared with all other window glass combinations.

Figure 20 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in west orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 51.36 (US Dollars/year) when compared with all other window glass combinations.

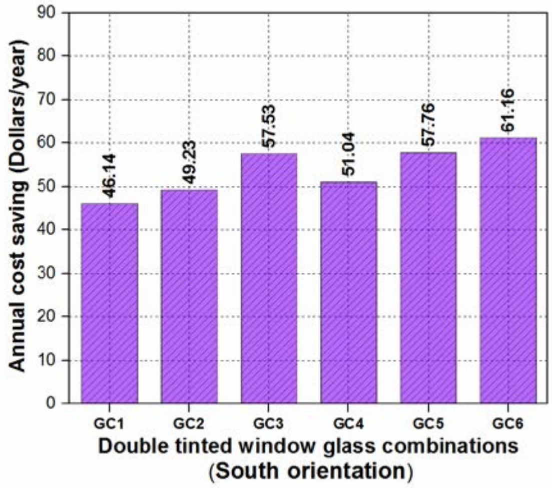

Fig. 18. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in south orientation.

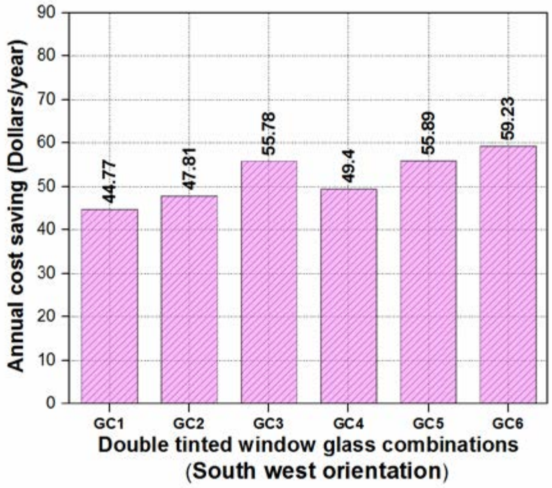

Fig. 19. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in southwest orientation.

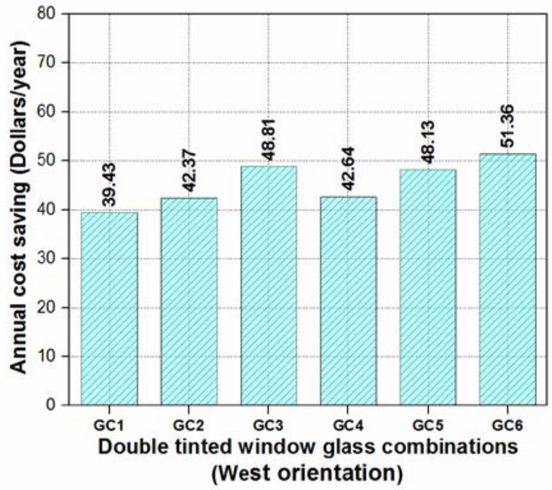

Fig. 20. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in west orientation.

Figure 21 shows the graph between six double tinted window glass combinations saving annual cost in rupees per year compared with the double clear glass window combination in northwest orientation of New Delhi climatic region. From the graphs it is clearly shown that GC6 combination window glass is the most energy efficient window glass and it is saving more cost 37.11 (US Dollars/year) when compared with all other window glass combinations.

In summer season, double tinted glass GC3 was found to be the best from reduced cooling loads point of view among all six studied double tinted window glass combinations in eight orientations. In winter season, double tinted glass GC1 was found to be the best from reduced heating loads point of view among all six studied double tinted window glass combinations in eight orientations. In year-round, GC6 was found to be the best from both reduced heating and cooling loads point of view among all six studied double tinted window glass combinations in eight orientations.

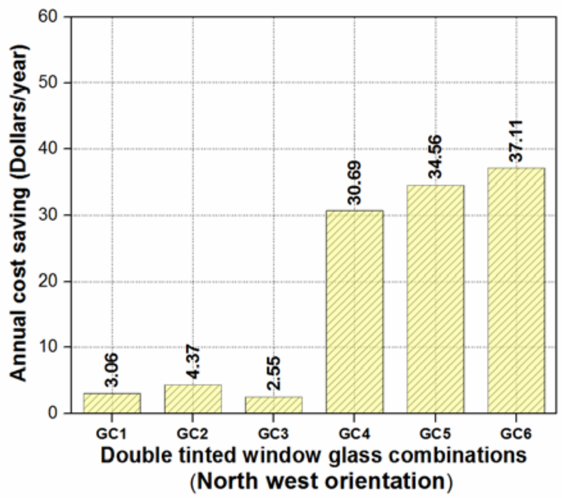

Fig. 21. Annual cost savings of different tinted double window glass combinations compared with double clear glass window combination of New Delhi climatic region in northwest orientation.

5. CONCLUSION

The main objective of this work is to establish best combination double tinted glass for summer, winter and year-round climates. The six double tinted glass window combinations GC1 to GC6 have been studied for the net cooling and heating loads inside the buildings. The annual energy savings of the six double tinted glasses have been compared with double clear glass window in buildings of composite (New Delhi) climatic zone in India. Form the results it can be conclude that:

- In summer season, double tinted glass GC3 *i.e.*, combination of green glass (outside) and grey glass (inside) separated by an air gap was found to be the best from reduced cooling loads point of view among all six studied double tinted window glass combinations in eight orientations.
- In winter season, double tinted glass GC1 *i.e.*, combination of bronze glass (outside) and green glass (inside) separated by an air gap was found to be the best from reduced heating loads point of view among all six studied double tinted window glass combinations in eight orientations.
- In year-round, GC6 *i.e.*, combination of grey glass (outside) and green glass (inside) separated by an air gap was found to be the best from both reduced heating and cooling loads point of view among all six studied double tinted window glass combinations in eight orientations. The results of the paper are extremely useful in designing the most energy efficient solar passive buildings.
- In summer, south oriented GC3 combination window is found to be the more energy efficient glass due to its least heat gain of 441.23(kW) in buildings as compared to the double clear glass window. Hence, GC3 saves 19.99% of energy as compared to the double clear glass window. In winter season, GC1 combination window is the more energy efficient glass due to its highest heat gain of 1483.74 (kW) in buildings as compared to double clear glass window. Hence, GC1 saves 29.02% of energy than double clear glass window in winter season.
- In year-round conditions, GC6 combination window saves the most annual net cost as compared to the double clear glass window combination in all eight orientations. It saves 61.16, 60.54 and 59.23 US Dollars/year in South, South-East and South-West orientations, respectively as compared to double clear glass window combinations of New Delhi climatic region in India. The results of the paper are extremely useful in designing the most energy efficient solar passive 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
C_{AG}	Conductance of the air gap in (mm)
d_{ia}	Declination angle (^{0}Deg)
f	Inward flowing fraction of energy
h	Hour angle (^{0}Deg)
k	Angle of window glass from vertical (^{0}Deg)
l	Latitude (^{0}Deg)
n	Number of days
I_{DN}	Solar radiation at normal incidence (W/m^2)
I_{DISR}	Direct solar radiation from the sun (W/m^2)
I_{dISR}	Diffuse radiation from the sky (W/m^2)
IREGR	Ground reflected sun radiation (W/m2)
ITSR	Total solar radiation (W/m2)
ho	Outside surface heat transfer coefficient (W/m2K)
hi	Inside surface heat transfer coefficient (W/m2K)
ITSRSGW	Total solar radiation through single glass window (kW)
ITSRDGW	Total solar radiation through double glass window (kW)
QSol, summer	Solar radiation in summer months (kW)
QSol, winter	Solar radiation in winter months (kW)
qds	Daily average solar radiation in summer month (kW)
qdw	Daily average solar radiation in winter month (kW)
TS	Solar transmittance (%)
RS	Solar reflectance (%)
Rsi	Internal surface resistance of the glass
Rso	external surface resistance of the glass
AS	Solar absorbance (%)
$S\lambda$	Relative spectral distribution of the solar radiation (W/m2)

Greek letters

λ	Wavelength (nm)
$\Delta\lambda$	Wavelength interval (nm)
βa	Solar altitude angle (Deg)
θi	Solar incidence angle (Deg)
Φ	Solar azimuth angle (Deg)
γ	Surface solar azimuth angle (Deg)
Ψ	Surface azimuth angle (Deg)
ρg	Ground reflectance factor
$\tau(\lambda)$	Spectral transmission (%)
$\rho(\lambda)$	Spectral reflection (%)
$\alpha(\lambda)$	Spectral absorption (%)

Abbrevations

DG	Double glass
DISR	Direct solar radiation
dISR	Diffuse solar radiation
NIR	Near infrared
REGR	Reflected ground radiation
SG	Single glass
SHGC	Solar heat gain coefficient
DCGW	Double clear glass window
SDGW	Selected double glass window
UV	Ultra-Violet Region
GC1	Bronze glass window-air gap 10mm-Green glass window
GC2	Bronze glass window-air gap 10mm-Grey glass window
GC3	Green glass window-air gap 10mm-Grey glass window
GC4	Green glass window-air gap 10mm-Bronze glass window
GC5	Grey glass window-air gap 10mm-Bronze glass window
GC5	Grey glass window-air gap 10mm-Green glass window

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