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Experimental and Theoretical Studies of Window Glazing Materials of Green Energy Building in Indian Climatic Zones

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Abstract

Buildings consume plenty of power for providing thermal and visual comfort inside the buildings. This paper aims at presenting the experimental results of spectral optical properties of the most widely used window glazing materials. The window glazing materials studied include clear glazing, bronze glazing, green glazing and grey coloured glazing materials. A Matlab code employing the British standard method was developed to compute transmittance and reflectance of window glasses at normal incidence angle. This code uses experimentally obtained spectral optical property data from Perkin Elmer lambda 950 spectrophotometer for the computation of transmission and reflection of window glasses. A computer program was developed for computing the total solar radiation passing through glass materials. The heat gain through different glass windows of eight coordinal orientations such as east, west, north, south, northeast, northwest, southeast and southwest in four climatic zones of India was investigated. The solar radiation through south oriented glass was found to be the least among all other orientations studied in four Indian climatic zones. The cooling load through south oriented bronze, glass, green glass and grey glass window were reduced by 23%, 31% and 37%, respectively, as compared to the south oriented clear glass window in four climatic zones of India. The grey glass window is observed to be the most energy efficient as it reduces maximum cooling loads within the building as compared to the other considered glazing materials. The results of this paper are helpful in designing energy efficient commercial buildings for reduced cooling loads.

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Keywords: Spectrophotometer; Spectral optical properties; Solar thermal properties; Window glass orientation; Energy efficient glass

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1. Introduction

Buildings consume lots of energy for artificial lighting and forced ventilation to provide visual and thermal comfort, respectively to the occupants inside the buildings. Glass is one of the most widely used building enclosures in commercial buildings. Extensive use of glass enclosures in commercial buildings causes more heat gain and uncomfortable conditions inside the building. Hence, attention has to be focused on the selection of alternative window glass materials for reducing cooling loads in buildings. With the appropriate selection of window glasses for windows, both visual and thermal comfort can be maintained inside the buildings. In the literature, TRANSYS was used to study heat transfer through the float and tinted glasses of single and double glazing with air gap filled by air, xenon, krypton gases in Indian climates [1]. The studies on the window glass inward tilt to reduce solar beam radiation through various glass materials in Baghdad city and various Indian climatic zones were carried out [2,3]. The studies have also been carried out for reducing cooling loads inside the building by providing air spaces with in the wall [4]. The studies on cooling load reduction by various insulation locations in the roof were reported [5]. The heat transfer through buildings with different glass and wall materials in warm and humid climates of India was presented in the literature [6]. The effect of moisture, relative humidity and temperature on heat transfer characteristics of laterite building walls was reported [7]. The objective of this work is to investigate heat gain through different window glass materials on peak summer day in a clear atmosphere for four climatic regions of India as per ASHRAE clear sky model.

Nomenclature	h_o Outside surface heat transfer coefficient
A_g Area of the glass	**Greek letters**
A Solar radiation in absence of atmosphere	λ Wavelength
B Atmospheric extinction coefficient	$\Delta\lambda$ Wavelength interval
C Dimensionless coefficient for sky radiation	β Solar altitude angle
d declination angle	θ Solar incidence angle
f Inward flowing fraction of energy	ϕ Solar azimuth angle
h hour angle	γ Surface solar azimuth angle
k angle of window glass from vertical	ρ_g Ground reflectance factor
l latitude	τ_s Solar transmittance
n number of days	ρ_s Solar reflectance
I_{DN} Solar radiation at normal incidence	α_s Solar absorbance
I_D Direct solar radiation from the sun	τ_λ Spectral transmittance
I_d Diffuse radiation from the sky	ρ_λ Spectral reflectance
I_r Ground reflected sun radiation	α_λ Spectral absorbance
I_T Total solar radiation	

2. Experimental methodology

Computation of solar radiation through window glasses requires the solar thermal properties of window glazing materials. The solar thermal properties of window glazing materials can be obtained from experimentally measured spectral optical properties in total solar spectrum region of 300nm to 2500nm as per ASTM Standards for normal angle of incidence (When the glass is placed vertically) [8]. The window glazing materials studied in this paper include clear glazing, bronze glazing, green glazing and grey glazing materials. The solar optical properties of glazing materials are transmission and reflection and they are obtained experimentally in spectrophotometer (Model: Perkin Elmer lambda 950). These solar spectral optical properties were utilized to compute solar thermal properties as per British standard method using Eqs (1)-(3) [9].

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

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

$$\alpha_s = 1 - \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \tau(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} - \frac{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \rho(\lambda) \Delta\lambda}{\sum_{\lambda=300}^{\lambda=2500} S_\lambda \Delta\lambda} \quad (3)$$

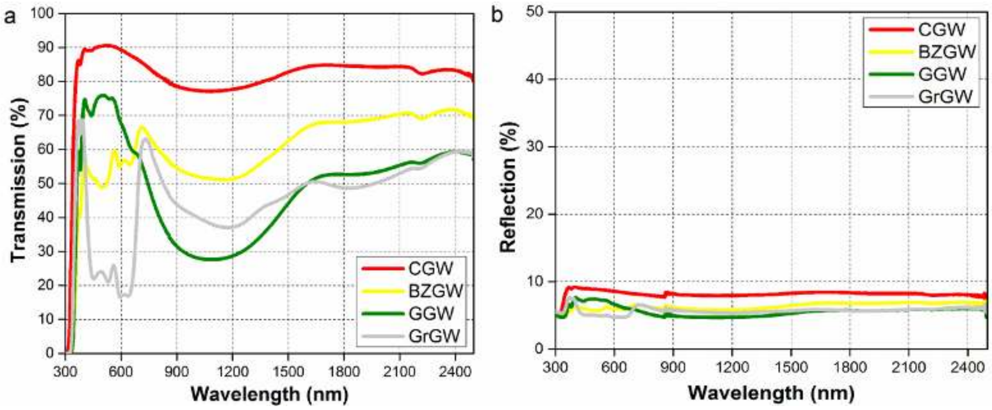

Fig. 1. (a) Spectral transmission of glass materials; (b) Spectral reflection of glass materials.

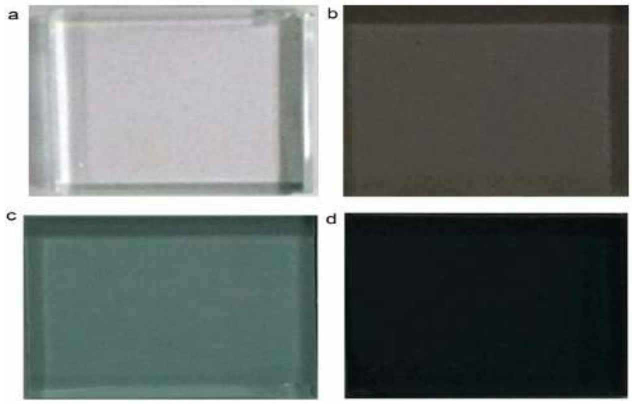

Fig. 2. Images of glass materials (a) Clear glass; (b) Bronze glass (c) Green glass; (d) Grey glass.

These properties are useful in computing solar heat gain coefficient of glass materials. The solar heat gain coefficient is used to compute total solar radiation passing through glass. The solar heat gain coefficient of the glass should be in between 0 and 1. The solar heat gain coefficient of the glass is directly proportional to the heat gain. Fig 1 (a) shows the spectral transmission of glass materials and Fig 1 (b) shows the spectral reflection of glass materials. From the figures, it is observed that the clear glazing has the highest transmission values and the grey glazing has the least transmission values among four studied window glazing materials. Fig 2 shows the images of clear, bronze, green and grey glass materials. Table 1 shows the solar thermal properties of window glazing materials.

Table 1. Solar thermal properties of window glazing materials.

Window glazing material	Code	Transmittance τ_s (%)	Reflectance ρ_s (%)	Absorbance α_s (%)
Clear glazing window	CGW	82	8	10
Bronze glazing window	BZGW	56	6	38
Green glazing window	GGW	47	6	47
Grey glazing window	GrGW	41	6	53

3. Computational method

Solar radiation from the Sun reaches the earth's surface in the form of direct and diffused radiation. The solar radiation enters into the building space through building enclosures such as walls, roofs and windows. The solar radiation passing into the building through window glazing is higher than that of any other enclosure of the building. Solar radiation through glazing enters into the building is in the form of direct radiation, diffused radiation and reflected radiation. A Matlab code has been developed to compute direct, diffused and reflected radiation through window glass. 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. The solar declination is the angle between the earth and sun vector and the equatorial plane. The various weather conditions across the globe are due to the tilt of the earth's equator by 23.45^o with respect to the earth's orbit plane around the sun. The declination angle can be computed using Eq (4). The vertical angle between the sun and the building wall is called the altitude angle which can be measured using Eq (5). The horizontal angle at which sun's radiation falls is called the solar azimuth angle and it can be computed by Eq (6). The directional characteristics of radiation can be computed by the angle of incidence using Eq (7). The solar irradiance on a clear day can be computed by Eq (8). The direct solar radiation received from the sun can be computed by Eq (9). The sun radiation scattered by the atmosphere is called sky, or diffused radiation and it is computed using Eq (10). The radiation reflected by the ground can be calculated using Eq (11). The total solar radiation can be computed using Eq (12). The internal and external surface resistances of the glass were taken as per CIBSE standards. In this work, the total solar radiation passing through four glass window materials placed in eight orientations of four climatic conditions of India was investigated. The total solar radiation passing through glass Sunrise (6:00am) to sunset (6:00pm) on peak summer day as per Indian standards was computed [10, 11]. The window to wall ratio considered to be 40%. The laterite building model of dimensions 3.5mX3.5mX3.5m was considered and a window glass of 2.45mX2m with thickness 5 mm was placed on the wall as per 40% WWR [12]. The total solar radiation passing through a window glass as per ASHRAE clear sky model in four climatic zones of India was computed [13].

Declination angle

$$d = 23.45 sin \frac{360(284+n)}{365} \quad (4)$$

Solar altitude angle

$$sin\beta = cosl cosd cosh + sinl sind \quad (5)$$

Solar azimuth angle

$$cos\phi = \frac{sin\beta sinl - sind}{cos\beta cosl} \quad (6)$$

Angle of incidence

$$scos\theta = cos\beta cos\gamma cosk - sin\beta sink \quad (7)$$

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

$$I_{DN} = \frac{A}{exp(B/sin\beta)} \quad (8)$$

Intensity of direct solar radiation

$$I_D = I_{DN} \cos\theta \quad (9)$$

Diffuse radiation from the sky

$$I_d = CI_{DN}\frac{1-\sin k}{2} \tag{10}$$

Ground reflected radiation is

$$I_r = CI_{DN}\rho_g\frac{1-\sin k}{2} \tag{11}$$

Total heat gain through windows

$$I_T = (I_D + I_d + I_r).\left(\tau_s + \frac{U}{h_o}\alpha_s\right).A_g \tag{12}$$

Where h_o outside heat transfer coefficient values are taken as per CIBSE standards [14].

4. Results and Discussions

4.1. Solar Heat gain through window glasses in Temperate climatic region

Bangalore city (12.97^{0}N 77.59^{0}E) has temperate climates. The temperatures in the Bangalore region are relatively moderate. The solar radiation in Bangalore is more or less the similar throughout the year. Fig 2 shows the solar heat gain through various window glasses in Bangalore climatic conditions on the hottest day. The hottest day for a Bangalore climatic zone is on 21st April as per Indian standards. The orientation order for placing window from the least heat gain to the highest heat gain point of view is S, N, S-W, S-E, N-W, N-E, W and E, respectively. From the results, it is noticed that the window glazing placed in South orientation gains the least solar radiation as compared to the other orientations. The heat gain through the window placed in the East orientation is the highest among eight studied orientations. The use of bronze, green and grey glasses for South oriented windows can reduce the cooling loads due to solar radiation by 18.88%, 31.13% and 36.56%, respectively as compared to the South oriented clear glass windows. The grey glazing is found to be the best from the least cooling loads point of view. Table 2 shows the solar heat gain through different window glazing placed in different orientation of the Bangalore climatic region.

Table 2. Solar heat gain through window glazing placed in different orientation of the Bangalore climatic region.

Window glazing material	Code	North	North East	East	South-East	South	South-West	West	North-West
Clear glazing window	CGW	6.72	13.17	15.77	12.17	5.3	12.17	15.77	13.17
Bronze glazing window	BZGW	5.17	10.14	12.14	9.37	4.08	9.37	12.14	10.14
Green glazing window	GGW	4.62	9.07	10.86	8.38	3.65	8.38	10.86	9.07
Grey glazing window	GrGW	4.26	8.35	10	7.72	3.36	7.72	10	8.35

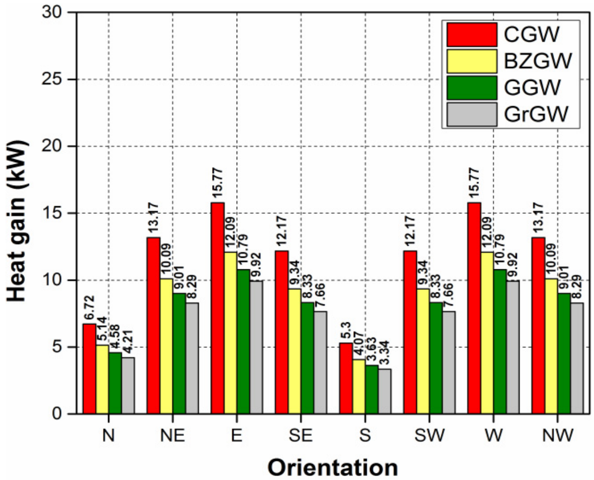

Fig. 3 Solar heat gain through various window glasses in Bangalore climatic conditions.

4.2 Solar heat gain through window glasses in Warm and Humid climatic region

Mumbai city (19.07^0N 72.87^0E) has Warm and Humid climates. The coastal parts of India have this climatic region. The relative humidity in this climatic region is very high as compared to the other climatic regions. Fig 3 shows the solar heat gain through various window glasses in Mumbai climatic conditions on the hottest day. The hottest day for a Mumbai climatic zone is on May 15^{th} as per Indian standards. The orientation order for placing window from the least heat gain to the highest heat gain point of view is S, N, S-W, S-E, N-W, N-E, W and E, respectively. From the results, it is clear that the window glazing placed in South orientation gains the least solar radiation as compared to the other orientations. The heat gain through the window placed in the East orientation is the highest among eight studied orientations. The use of bronze, green and grey glasses for South oriented windows can reduce the cooling loads due to solar radiation by 23.03%, 31.25% and 36.60%, respectively as compared to the South oriented clear glass windows. In Mumbai climatic conditions, the grey glass glazing is found to be the best from the least cooling loads point of view. Table 3 shows the solar heat gain through different window glazing placed in different orientation of the Mumbai climatic region.

Table 3. Solar heat gain through window glazing placed in different orientation of the Mumbai climatic region.

Window glazing material	Code	North	North East	East	South-East	South	South-West	West	North-West
Clear glazing window	CGW	9.00	14.28	16.18	11.88	5.60	11.88	16.18	14.28
Bronze glazing window	BZGW	6.91	10.96	12.41	9.11	4.29	9.11	12.41	10.96
Green glazing window	GGW	6.16	9.78	11.08	8.13	3.83	8.13	11.08	9.78
Grey glazing window	GrGW	5.66	8.99	10.19	7.48	3.52	7.48	10.19	8.99

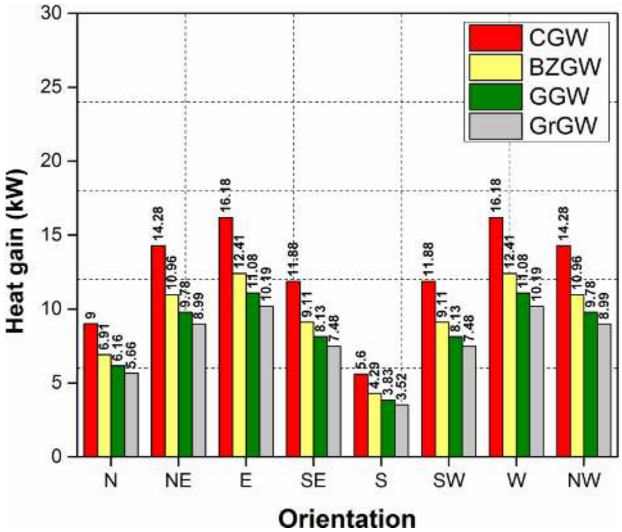

Fig. 4 Solar heat gain through various window glasses in Mumbai climatic conditions.

4.3 Solar heat gain through window glasses in Composite climatic region

Hyderabad city (17.38^0N 78.48^0E) has Composite climates. The moderate relative humidity levels during summer and winter differentiates composite climate from the hot and dry climates. Fig 4 shows the solar heat gain through various window glasses in Hyderabad climatic conditions on the hottest day. The hottest day for a Hyderabad climatic zone is on May 15^{th} as per Indian standards. The orientation order for placing window from the least heat gain to the highest heat gain point of view is S, N, S-W, S-E, N-W, N-E, W and E, respectively. From the results, it is noticed that the window glazing placed in South orientation gains the least solar radiation as compared to the other orientations. The heat gain through the window placed in the East orientation is the highest among eight studied orientations. The use of bronze, green and grey glasses for South oriented windows can reduce the cooling loads due to solar radiation by 23.03%, 31.16% and 36.64%, respectively as compared to the South oriented clear glass windows. The grey glass glazing is found to be the best from the least cooling loads point of view in the Hyderabad climatic zone. Table 4 shows the solar heat gain through different window glazing placed in different orientation of the Hyderabad climatic region.

Table 4. Solar heat gain through window glazing placed in different orientation of the Hyderabad climatic region.

Window glazing material	Code	North	North East	East	South-East	South	South-West	West	North-West
Clear glazing window	CGW	9.68	14.44	16.02	11.52	5.54	11.52	16.02	14.44
Bronze glazing window	BZGW	7.45	11.12	12.33	8.87	4.27	8.87	12.33	11.12
Green glazing window	GGW	6.86	9.94	11.02	7.93	3.81	7.93	11.02	9.94
Grey glazing window	GrGW	6.13	9.15	10.15	7.3	3.51	7.3	10.15	9.15

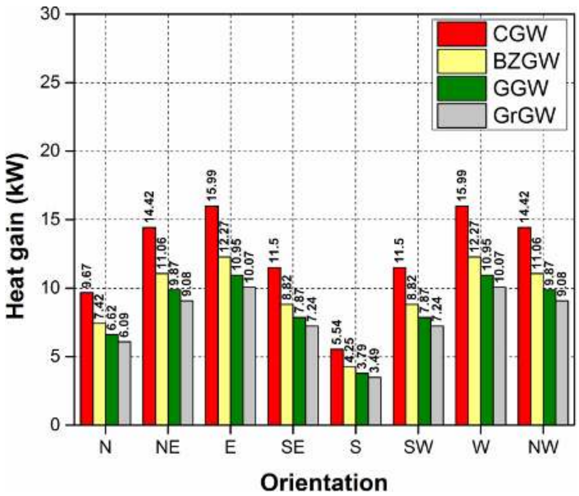

Fig. 5 Solar heat gain through various window glasses in Hyderabad climatic conditions.

4.4 Solar heat gain through window glasses in Hot and Dry climatic region

Jodhpur city (26.24^{0}N 73.02^{0}E) has Hot and Dry climates. The temperatures in the Jodhpur region are relatively high with low relative humidity levels. Fig 5 shows the solar heat gain through various window glasses in Jodhpur climatic conditions on the hottest day. The hottest day for the Jodhpur climatic zone is on June 21st as per Indian standards. The orientation order for placing window from the least heat gain to the highest heat gain point of view is S, N, S-W, S-E, N-W, N-E, W and E, respectively. From the results, it is obvious that the window glazing placed in South orientation gains the least solar radiation as compared to the other orientations. The heat gain through the window placed in the East orientation is the highest among eight studied orientations. The use of bronze, green and grey glasses for South oriented windows can reduce the cooling loads due to solar radiation by 23.03%, 31.11% and 36.61%, respectively as compared to the South oriented clear glass windows. The grey glass glazing is found to be the best from the least cooling loads point of view in The Jodhpur climatic zone. Table 5 shows the solar heat gain through different window glazing placed in different orientation of The Jodhpur climatic region.

Table 5 Solar heat gain through window glazing placed in different orientation of The Jodhpur climatic region

Window glazing material	Code	North	North East	East	South-East	South	South-West	West	North-West
Clear glazing window	CGW	9.84	14.98	16.91	12.59	6.46	12.59	16.91	14.98
Bronze glazing window	BZGW	7.58	11.53	13.02	9.69	4.98	9.69	13.02	11.53
Green glazing window	GGW	6.77	10.31	11.64	8.67	4.45	8.67	11.64	10.31
Grey glazing window	GrGW	6.24	9.5	10.72	7.98	4.1	7.98	10.72	9.5

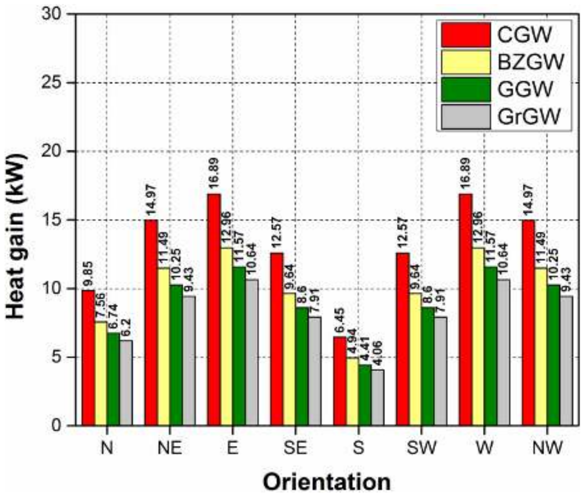

Fig. 6 Solar heat gain through various window glasses in Jodhpur climatic conditions.

5. Conclusions

The Present work presents the total solar heat gain through four different glass windows placed in eight orientations of four Indian climatic zones. The window placing orientation order for reduced cooling loads from the most energy efficient to the least energy efficient is South, North, South-West, South-East, North-West, North-East, West and East, respectively. The order of preference of glass materials from the most energy efficient to the least energy efficient point of view for reduced cooling loads is Grey, Green, Bronze and clear in eight orientations of four Indian climatic regions. The grey glazing window is observed to be the most energy efficient from the least heat gain point of view among studied glazing materials due to its lowest transmittance and highest absorbance values as compared to the other studied glasses. The results are helpful in selecting energy efficient window enclosure materials for reduced Air-conditioning loads in green energy buildings.

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