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ScienceDirect

Energy Procedia 138 (2017) 580–585

Energy Procedia

www.elsevier.com/locate/procedia

2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies
2017 AEDCEE, 25-26 May 2017, Bangkok, Thailand

Study of Various Glass Window and Building Wall Materials in Different Climatic Zones of India for Energy Efficient Building Construction

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Abstract

The commercial and residential buildings consume about 33% of energy for cooling and day lighting in India. This paper aims to present thermal performance of buildings constructed with various building and window glass materials in five different climatic zones of India. The climates considered include: hot and dry (Ahmedabad), moderate (Bangalore), cold (Guwahati), warm and humid (Madras), and composite (New Delhi). In this study, four building materials such as laterite stone, dense concrete, burnt brick, and mud brick were selected and four glasses such as clear, bronze, green, and bronze-reflective glasses were used for windows. Spectral characteristics of four glasses were measured experimentally by using Perkin-Elmer lambda 950spectrophotometer in the wavelength range of 300 -2500 nm as per ASTM standards. A mat lab code was developed to compute the solar optical properties such as transmittance and reflectance of glasses as per European standards in entire solar spectrum region. The building models were designed in Design builder 4.3.0.039 and thermal analysis was carried out in Energy plus 8.1.0.009. The solar heat gain in buildings was investigated. The results revealed that the mud brick wall building with south bronze-reflective glass window as energy saving from the least heat gain point of view among eighty building models studied. The results also showed that the mud brick wall building with bronze, green and bronze reflective window glasses reduces heat gain through wall by 2.52%, 3.83%, and 6.46% as compared to the mud brick wall building with clear glass window. The results helps in selecting energy saving combination of wall envelope and window glass materials for reducing air-conditioning loads in residential and commercial buildings of five different climatic zones of India.

Peer-review under responsibility of the scientific committee of the 2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies.

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Peer-review under responsibility of the scientific committee of the 2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies.
10.1016/j.egypro.2017.10.163

Keywords: Energy efficient glass; Passive cooling; Building simulation; Solar optical properties; Building materials.

1. Introduction

The commercial and residential buildings are responsible for 8% and 25% energy consumption in India, respectively [1]. The building enclosures such as walls, floors, roofs and windows are the most important elements of the buildings to control heat gain. Heat gain in buildings can be attenuated with the help of building enclosures. Glass is the main building element in the construction of residential and commercial buildings and it also accounts for a higher conductance coefficient than other building enclosures. Hence, it is mandatory to study the thermal behavior of the walls and window glasses to reduce heat gain in buildings.

The numerical computations of solar radiation in buildings using clear and brown glasses as window glazing were studied [2]. Solar optical properties of clear and bronze glasses were reported and thermal performance of glass combinations were studied [3]. The heat gain through window glasses of various window to wall ratios was reported [4] and the simulations were carried out on peak summer day of the cities [5-7]. The heat transfer modeling on clear glass window was carried out [8]. The insulation position inside the roof was optimized for reducing cooling loads [9]. The optical properties of low emissivity glasses were also studied and reported [10]. Thirteen various high performances glazing glasses of an office building with different window to wall ratios were studied and compared with conventional glasses in European continent (London, Helsinki, Rome) [11]. A novel methodology has been suggested to compute solar radiation through window glasses of various windows to wall ratios [12]. The present work presents the suitable combination of wall and window glasses for building enclosures to reduce heat gain in buildings of five different climatic zones of India.

2. Experimental procedure to measure the spectral data of window glasses

Solar radiation reaches the earth's surface in the form of electromagnetic waves. Solar radiation is divided in to three regions one is Ultra-violet wavelength region (300- 380 nm), second is visible wavelength region (380nm-780nm), and third is Infra-red wavelength region (780- 2500 nm). The ultra-violet rays are harmful to degradation of materials and skin of human beings and these ultra violet rays are responsible only for 5% of solar radiation. The visible rays produce about 45% of the solar radiation in the wavelength range (380- 780 nm). The infra-red region is responsible for 50% of solar radiation and this is lies in between (780- 2500 nm). For analytical computation of the solar radiation passing through window glasses, the spectral characteristics of glasses such as transmission and reflection are essential to measure in the entire solar spectrum wavelength region from 300 - 2500 nm wavelength region. The spectral data of four glasses (clear, bronze, green, and bronze-reflective glasses) were measured with Perkin Elmer Lambda 950 Spectrophotometer at INUP research center IIT Bombay, as per the standard procedure given in ASTM E:424 1971 standards [13]. The size of the glass used to explore spectral characteristics is 30 X 30 mm with 6mm thickness. Fig.1. (a) shows the spectral transmission characteristics of glass windows. Fig.1. (b) shows the spectral reflection of glass windows.

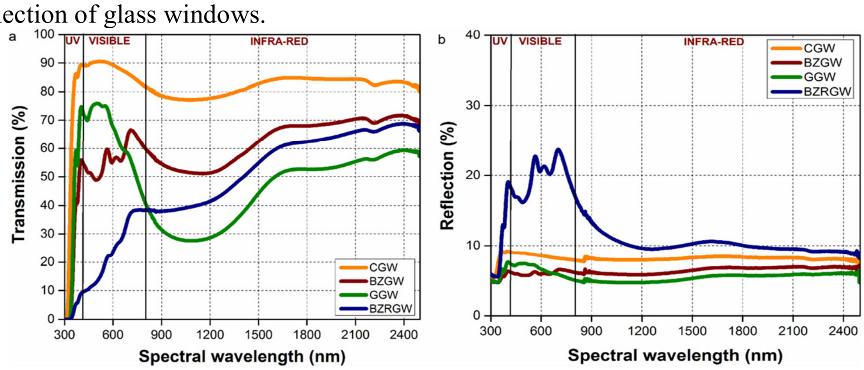

Fig. 1. (a) Spectral transmission of glass windows; (b) Spectral reflection of glass windows.

A Matlab code was developed to compute solar optical properties of glasses such as transmittance and reflectance in the entire solar spectrum wavelength region from 300 nm to 2500 nm. The weighted average of measured spectral data was used to compute solar optical properties of glasses as per BS EN: 410 1998 standards [14]. This method uses Eq. (1), (2) and (3) to evaluate total solar transmittance, total solar reflectance, and total solar absorbance, respectively.

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

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

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

Table 1. Solar optical properties of various glass windows.

Glass window	Code	Transmittance T_{sol} (%)	Reflectance R_{sol} (%)	Absorbance A_{sol} (%)
Clear glazing window	CGW	77	7	16
Bronze glazing window	BZGW	49	6	45
Green glazing window	GGW	42	6	52
Bronze-reflective glazing window	BZRGW	36	14	50

From Fig. 1, it is noticed that the bronze-reflective glass has the least spectral transmission and the highest spectral reflection values whereas, the clear glass has the highest spectral transmission and the lower spectral reflection values among four studied glasses. Table 1 depicts the solar optical properties of four glass windows.

Nomenclature

D_n	Density (kg/m^3)
C_p	Specific heat (J/kg K)
k_{th}	Thermal conductivity (W/m K)
U	Overall heat transfer coefficient
CGW	Clear glass window
BZGW	Bronze glass window
GGW	Green glass window
BZRGW	Bronze-reflective glass window
T_{sol}	Solar transmittance
R_{sol}	Solar reflectance
A_{sol}	Solar absorbance
S_λ	Relative spectral distribution of the solar radiation

Greek letters

λ	Wavelength
$\Delta\lambda$	Wavelength interval (nm)
τ_λ	Spectral transmittance
ρ_λ	Spectral reflectance
α_λ	Spectral absorbance

3. Thermal Analysis

The building models were designed with different building materials and window glasses in Design builder 4.3.0.039. The dimensions of building models are 4 X 4 X 3.5 m with 0.22 m wall thickness. The total sixteen building models were designed with different building materials (laterite, dense concrete, burnt brick, and mud brick) and different window glasses (clear, bronze, green, and bronze-reflective glasses) in each climatic zone, so total eighty building models were designed and analysed thermally with Energy plus 8.1.0.009. The floor was built with dense concrete of 0.15 m thickness. The cement plaster was added on top side of the floor with thickness 0.0125 m. The roof was modelled with reinforced cement concrete of 0.15 m thickness. The cement plaster of 0.0125 m thickness was added on top and bottom sides of the building roof. The walls of the building models were covered inside and outside by cement plaster of 0.0125 m thickness. Window to wall ratio is the ratio of the net glazing area to the gross exterior wall area [15]. The 40% window to wall ratio of window area 2.8 X 2 m has been provided to the building models as per ECBC standards. The South orientation has been taken as the reference to place the window due to its lowest heat gain in the south orientation in the summer seasons.

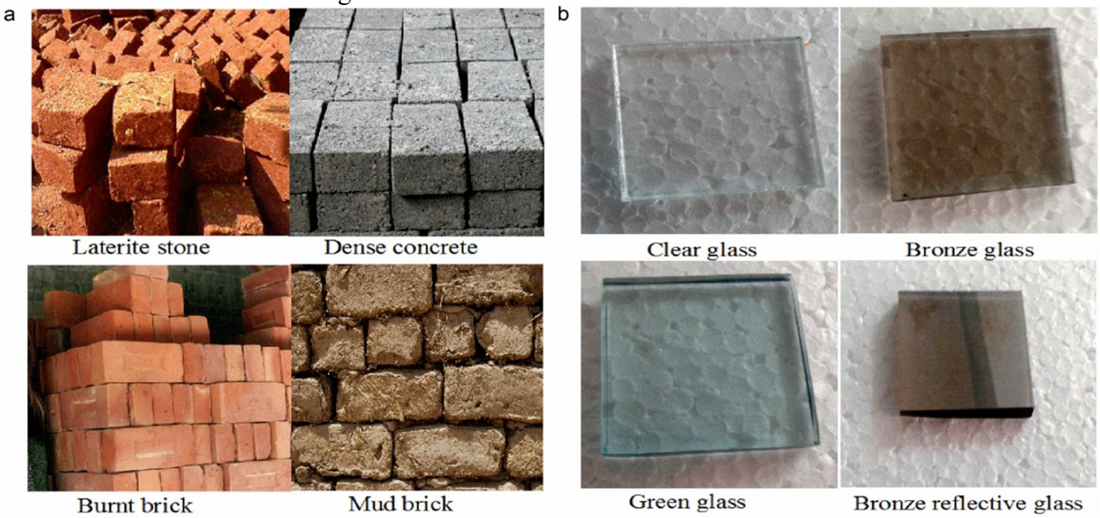

Fig. 2. (a) Building material images (Laterite, dense concrete, burnt brick and mud brick); (b) Glass windows images (Clear glass, bronze glass, green glass and bronze-reflective glass).

The heat gain in buildings through window glazing can be reduced by using suitable glasses for windows. Fig. 2. (a) shows building material images and Fig. 2. (b) shows glass window images. Table 2 presents thermo-physical properties of building materials. The heat gain in buildings of five different cities on the peak summer day was computed as per Indian standards. Thermo-physical properties of building materials are taken as per Indian standards [16]. Thermo-physical properties of laterite stone have been considered from the literature [17, 18].

Table 2. Thermo-physical properties of building materials.

Building wall material	Density D_n (kg/m^3)	Specific heat C_p (J/kg K)	Thermal conductivity k_{th} (W/mK)
Laterite stone wall	1000	1926.1	1.3698
Dense concrete wall	2410	880	1.74
Burnt brick wall	1820	880	0.811
Mud brick wall	1731	880	0.75
Reinforce cement concrete	2288	880	1.58
Cement plaster	1762	840	0.721

4. Results and Discussions

4.1 Heat gain in buildings of various building and glass materials at 40% WWR in five different Indian climatic zone cities

Fig.3. shows heat gain in buildings of various building wall and window glass materials at 40% WWR in five various Indian climatic zone cities. In hot and dry (Ahmedabad) climatic zone, mud brick wall building with bronze-reflective window glass gains 33.56 kWh of heat whereas, the dense concrete wall building with clear glass window gains 38.93 kWh of heat. In moderate (Bangalore) climatic zone, mud brick wall building with bronze-reflective window glass gains 20.29 kWh of heat whereas, the dense concrete wall building with clear glass window glass gains 23.96 kWh of heat. In cold (Guwahati) climatic zone, mud brick wall building with bronze-reflective window glass gains 21.20 kWh of heat whereas, the dense concrete wall building with clear glass window glass gains 26.23 kWh of heat. In warm and humid (Madras) climatic zone, mud brick wall building with bronze-reflective window glass gains 18.60 kWh of heat whereas, the dense concrete wall building with clear glass window gains 22.75 kWh

of heat. In composite (New Delhi) climatic zone, mud brick wall building with bronze-reflective window glass gains 37.82 kWh of heat whereas, the dense concrete wall building with clear glass window glass gains 45.08 kWh of heat. In all five climatic zones studied, the mud brick wall building with bronze reflective glass window combination was found to be energy saving combination for reduced cooling loads in summer.

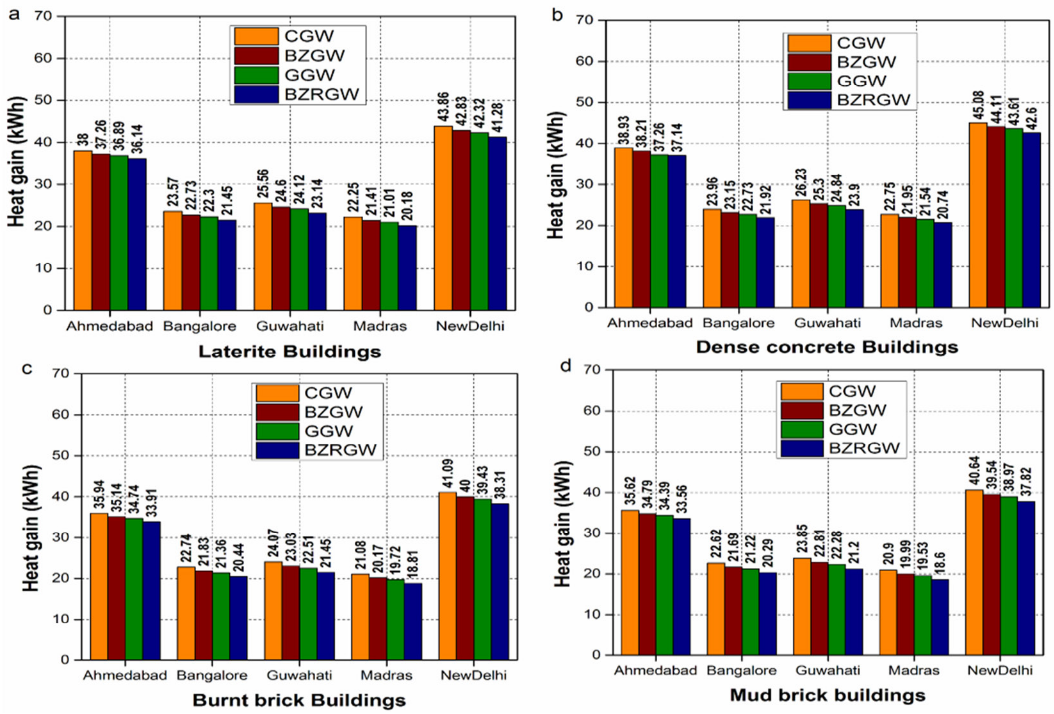

Fig. 3. Heat gain in buildings of various building and window glass materials at 40% WWR in five different Indian climatic zone cities.

5. Conclusions

This paper presents the thermal performance of buildings built with various building and window glass materials in five different climatic zones of India.

- The mud brick wall envelope with bronze reflective glass window was found to be energy efficient combination for reduced cooling loads in summer and the dense concrete wall envelope with clear glass window was found to be the least energy efficient combination for reduced cooling loads in summer among studied combinations of wall and glass materials.
- The mud brick wall buildings with bronze, green and bronze reflective window glasses reduce heat gain in buildings by 2.52%, 3.83%, and 6.46%, respectively as compared to the mud brick buildings with clear glass window.

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