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Simulation of Various Wall and Window Glass Material for Energy Efficient Building Design

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Abstract. Buildings consume huge amount of energy for forced ventilation and artificial day lighting. Use of appropriate material combinations for walls and window glass can help in reducing energy consumption for cooling and lighting. This paper presents the thermal properties of four building materials such as, laterite stone, dense concrete, burnt brick and mud brick. It also presents the experimentally measured optical properties of glass materials such as, clear glass, bronze glass, green glass and reflective. In this study building of size 5m X 5m X 3.2m with four wall materials and four glass materials were designed using design builder software. The thickness of the wall was considered as external wall with thickness 0.22m. All the walls covered with cement plaster on either side. Roof of the building is made of reinforced cement concrete and floor is dense concrete. Thermal analysis was carried out using by Energy plus software. Single sized glass windows were placed in south direction (Due to less heat gain in south direction) for Mangalore city (12.87^0N, 74.88^0E), Karnataka, India. Different window to wall ratios (20%, 40%, 60%, 80% and 100%) were maintained for buildings. Total eighty building models were investigated for heat gain into buildings. From the results, it is observed that irrespective of the window to wall ratio, mud brick walls with reflective window glass were observed to be energy efficient from the lower heat gain point of view, and laterite stone wall building with clear glass windows were observed to be the worst due to their higher heat gain values. At 60% window to wall ratio mud brick walls with reflective window glass have 24.93kWh heat gain and dense concrete walls with clear glass have 32.9 kWh heat gain. The results of the study help in establishing the best combination of wall and glass materials for minimum heat gain into buildings.

Introduction

The Building sector is responsible for 33% of energy consumption in India With commercial building sector and residential building sector responsible for 8% and 25%, respectively [1]. Buildings with Climatic responsive consume around 10 to 15% less energy as compared to conventional buildings. The building envelope is the most important and fundamental part of building. Building envelope consists of walls, roofs, floors and windows. These building envelopes help in blocking or attenuating the heat transfer, airflow and day lighting in the buildings. Earlier, researchers have also concentrated on numerical computations of design of windows to reduce solar radiation into the buildings with clear and brown glass materials [2] and the evaluation of thermal and optical properties of glazing [3]. The present study focuses on the appropriate wall and glass material combinations to the Mangalore latitude region during the Peak summer day (at April 15^{th}) [6, 7] to gain minimum heat gain in the buildings. This work helps in selecting appropriate building and glass material combinations for reduced cooling loads.

Nomenclature

$\Delta\lambda$ Wavelength interval (nm)
ρ_s Solar reflectance
τ_s Solar transmittance

ρ_λ Spectral reflection
τ_λ Spectral transmission

Experimental methodology for spectral optical properties of the glazing materials

The Perkin Elmer Lambda 950 Spectrophotometer experimental setup was used to find the spectral optical properties of different glass materials [8, 9]. To assess the quantity of direct solar radiation entering into the building through window glass, the spectral optical properties of glass materials are required. The experiments were conducted with four different glass materials of thickness 6 mm of the glasses at 0^0tilt angle of incidence and at various wavelengths ranging from 320-2500 nm. The spectral optical properties such as transmission and reflection of clear, bronze, green and reflective glass materials were measured at different wavelengths using UV-Win lab software in PC interfaced with the spectrophotometer as shown in Fig. 1.The measured spectral optical properties data of clear, bronze, green and reflective glass materials as shown in Fig. 2. From the results, it was observed that the reflective glass has the least spectral transmission values and highest spectral reflection values among four studied glass materials. The clear glass has the highest spectral transmission and the lowest spectral reflection among four studied glass materials.

Fig.1 Perkin Elmer Lambda 950 Spectrophotometer

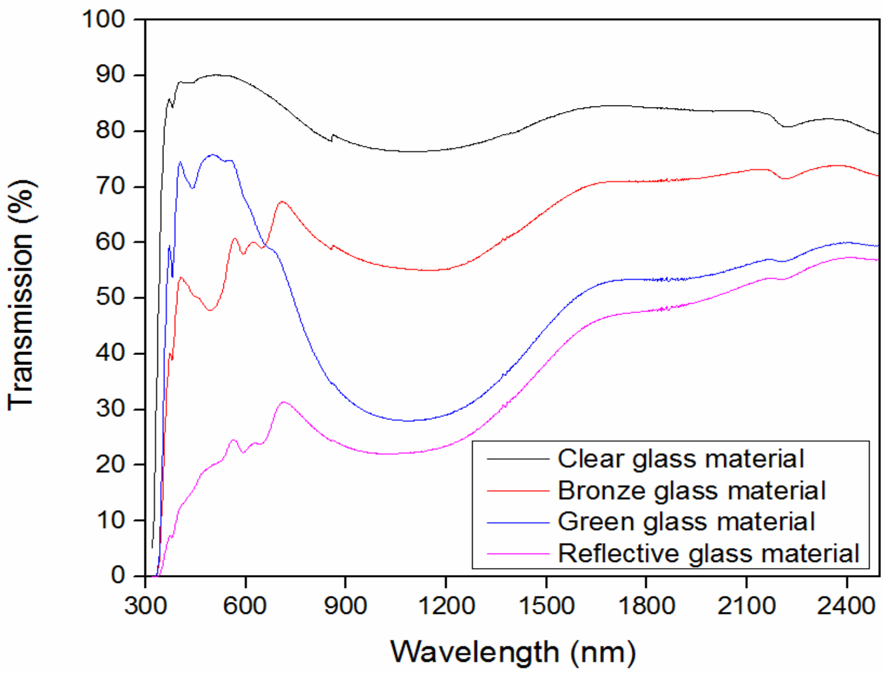


Fig.2 (a) Spectral transmission of all glass materials

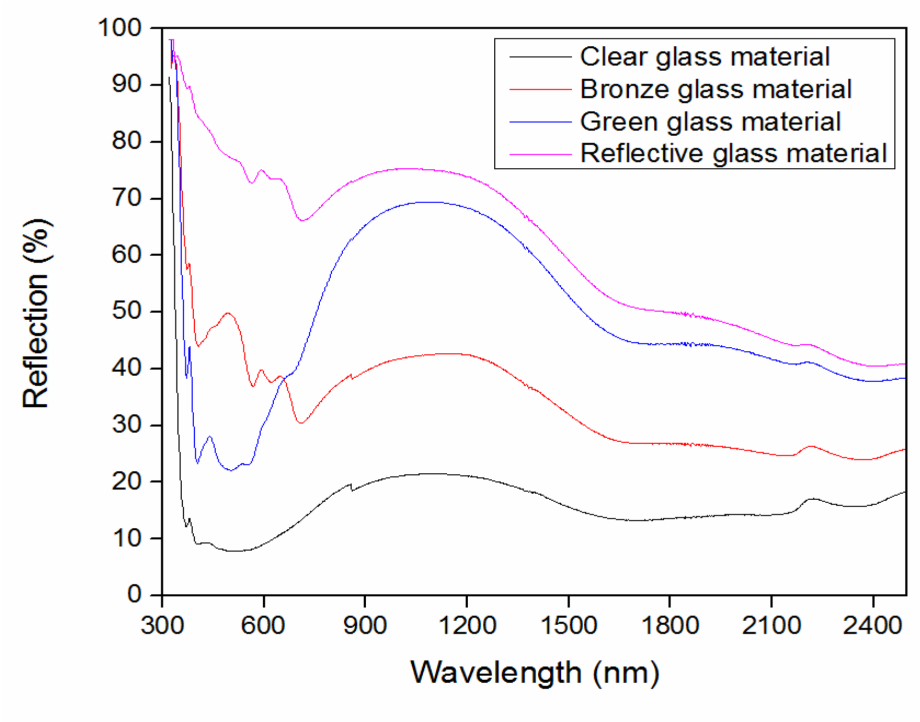


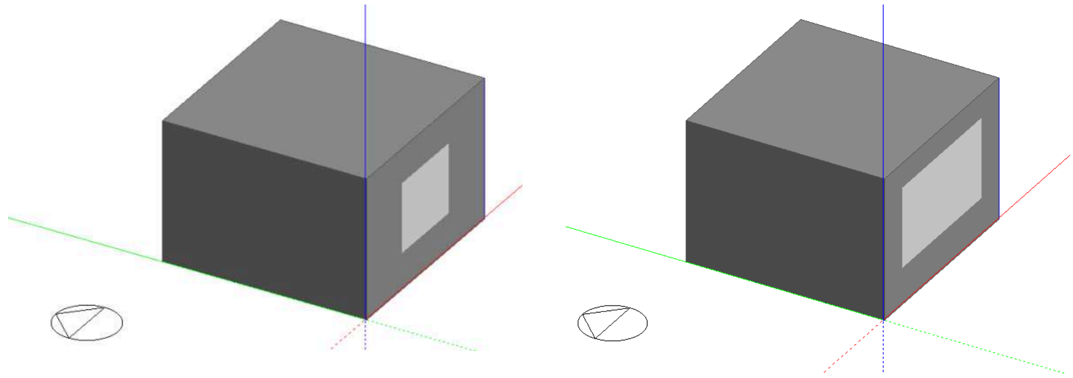
Fig.2 (b) pectral reflection of all glass materials

With these experimentally measured spectral properties, the solar thermal properties were determined by using the British Standard method [5]. The solar thermal properties, such as transmittance and reflectance factor for single glazing can be evaluated from the following Eqns. (1) and (2).

$$\tau_s = \frac{\int_{320}^{2500} s_\lambda \tau(\lambda)\Delta\lambda}{\int_{320}^{2500} s_\lambda \Delta\lambda} \tag{1}$$

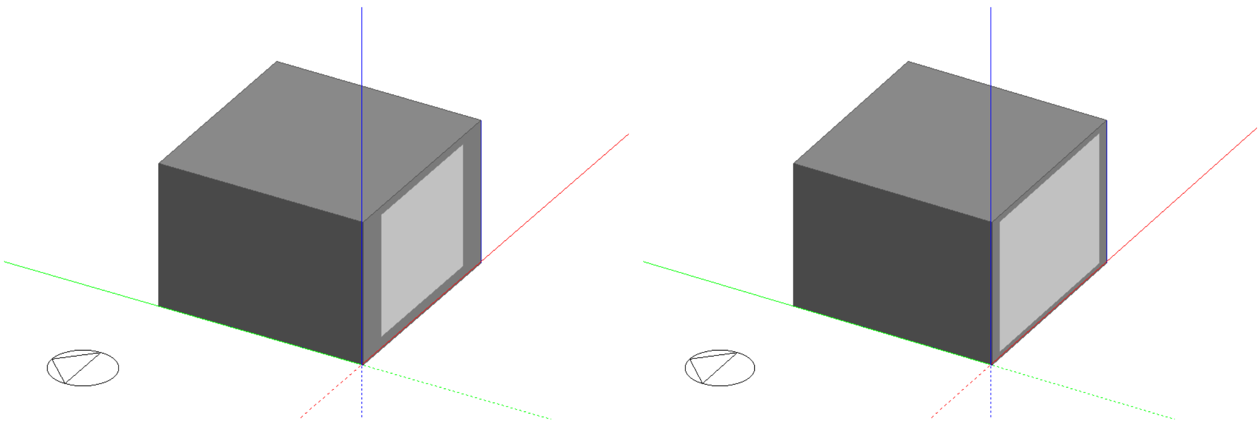
$$\rho_s = \frac{\Omega_{320}^{2500} s_\lambda \rho(\lambda)\Delta\lambda}{\int_{320}^{2500} s_\lambda \Delta\lambda} \tag{2}$$

The design builder software was used for the design of building models with different building and window glass materials. The building models of dimensions 5 m X 5 m X 3.2 m each were designed with different building and glass materials. The walls of the building models are considered as external walls. The thickness of the wall was taken as 0.22 m. The different building materials such as, laterite, dense concrete, burnt brick and mud brick were used for the study, floor was considered as dense concrete with thickness of 0.15m and the roof material taken is reinforced concrete with thickness of 0.15m. The walls of the building models were covered inside and outside, by 0.0125 m plaster. The building models with different building materials (laterite stone, dense concrete, burnt brick and mud brick) and different window glass materials (clear glass, bronze glass, green glass and reflective) were tried with different window to wall ratios. The window glass was assumed to be placed in the south direction with different window to wall ratios (20%, 40%, 60%, 80% and 100%) due to less heat gain in the buildings in the south direction. Total eighty buildings were studied for reduced cooling loads into the buildings. Fig. 3. (a) and (b) show building models designed with 20% and 40% window to wall ratios, respectively. . Fig. 4. (a) and (b) show building models designed with 60% and 80% window to wall ratios, respectively. Fig. 5 shows the building model designed with complete glass in South direction.



(a) (b)

Fig. 3 (a) Building model with 20% window to wall ratio; (b) Building model with 40% window to wall ratio



(a) (b)

Fig. 4 (a) Building model with 60% window to wall ratio; (b) Building model with 80% window to wall ratio

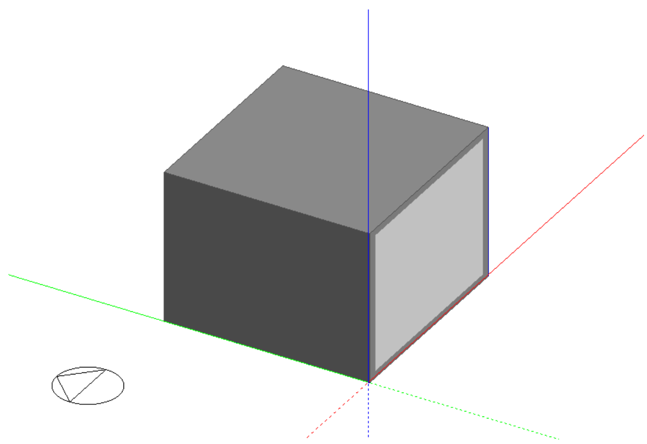


Fig. 5: Building model with 100% window to wall ratio

Table. 1. Thermo physical properties of different building materials

Building material	**k (W/mK)**	**C_p (J/kgK)**	**ρ (kg/m^3)**
Laterite stone	1.3698	1926.1	1000
Dense concrete	1.74	880	2410
Burnt brick	0.811	880	1820
Mud brick	0.75	880	1731
Cement plaster	0.721	840	1762

Table. 2. Solar thermal properties of different glass materials

Glass material	Transmittance (τ(%))	Reflectance (ρ(%))	Absorptance (α(%))
Clear glass	81.8455	16.0652	2.0891
Bronze glass	58.6682	39.0860	2.2452
Green glass	47.3208	50.3209	2.5382
Reflective glass	27.2272	70.1707	2.6021

Table 1 shows the thermo physical properties of building materials. The most widely used building materials in South-West India were considered for the study. Thermo physical properties of laterite stone were taken from the literature [4]. The thermo physical properties of building materials such as, dense concrete, burnt brick and mud brick were taken from the bureau of Indian standards [5]. Table 2 shows solar thermal properties of clear, bronze, green and reflective glass materials. These properties were used in Energy plus software and thermal analysis was carried out to Mangalore latitude, Karnataka, India (12.87^{0}N, 74.88^{0}E) on peak summer day (April 15th) to compute the heat gain into buildings from walls, floor, roof and window glass materials.

Results and discussions

Effect of heat gain into building with different window to wall ratio

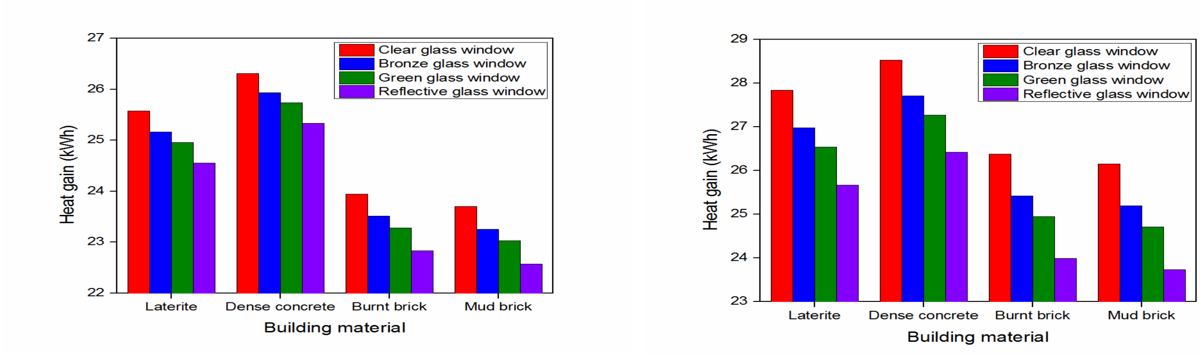
Fig 6 (a) shows the total heat gain into the buildings through walls, roof, floor and window glass of 20% WWR. From the results, it is observed that at 20% clear glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 25.57 kWh, 26.31 kWh, 23.94 kWh and 23.7 kWh of heat, respectively. From the results, it is observed that at 20% clear glass WWR mud brick buildings gain less heat. Similarly, at 20% bronze glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 25.16 kWh, 25.93 kWh, 23.51 kWh and 23.25 kWh of heat, respectively. 20% WWR of green glass for laterite stone, dense concrete, burnt brick and mud brick buildings, heat gain is 24.96 kWh, 25.74 kWh, 23.28 kWh and 23.08 kWh, respectively. When 20% WWR of reflective glass is used for the windows of laterite stone, dense concrete, burnt brick and mud brick buildings the total heat gain into the building is 24.55 kWh, 25.33 kWh, 22.83 kWh and 22.57 kWh, respectively. Referring to Fig 6, Fig 7 and Fig 8, it is observed that the heat gain into the buildings is more through dense concrete wall with clear glass material. It is because of thermo physical properties of dense concrete is more, and a solar thermal property of a clear glass material is more. And it is also observed that less heat gain through the mud brick wall with reflective glass material because due to less thermo physical properties of a mud brick wall material and solar thermal properties of reflective glass material is minimum.

Fig 6 (b) shows the total heat gain into the buildings through walls, roof, floor and window glass of 40% WWR. From the results, it is observed that at 40% clear glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 27.84 kWh, 28.53 kWh, 26.37 kWh and 26.15 kWh of heat, respectively. From the results, it is observed that at 40% clear glass WWR mud brick buildings gain less heat. Similarly, at 40% bronze glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 26.98 kWh, 27.71 kWh, 25.42 kWh and 25.19 kWh of heat, respectively. 40% WWR of green glass for laterite stone, dense concrete, burnt brick and mud brick buildings, heat gain is 26.54 kWh, 27.27 kWh, 24.94 kWh and 24.71 kWh, respectively. When 40% WWR of reflective glass is used for the windows of laterite stone, dense concrete, burnt brick and mud brick buildings the total heat gain into the building is 25.66 kWh, 26.42 kWh, 23.99 kWh and 23.73 kWh, respectively.

Fig 7 (a) shows the total heat gain into the buildings through walls, roof, floor and window glass of 60% WWR. From the results, it is observed that at 60% clear glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 30.28 kWh, 30.90 kWh, 28.95 kWh and 28.75 kWh of heat, respectively. Similarly, at 60% bronze glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 28.89 kWh, 29.57 kWh, 27.46 kWh and 27.23 kWh of heat, respectively. 60% WWR of green glass for laterite stone, dense concrete, burnt brick and mud brick buildings, heat gain is 28.19 kWh, 28.90 kWh, 26.68 kWh and 26.46 kWh, respectively. When 60% WWR of reflective glass is used for the windows of laterite stone, dense concrete, burnt brick and mud brick buildings the total heat gain into the building is 26.79 kWh, 27.53 kWh, 25.17 kWh and 24.93 kWh, respectively. From the results, it is observed that mud brick buildings with reflective glass window are found to be energy efficient from the least heat gain point of view.

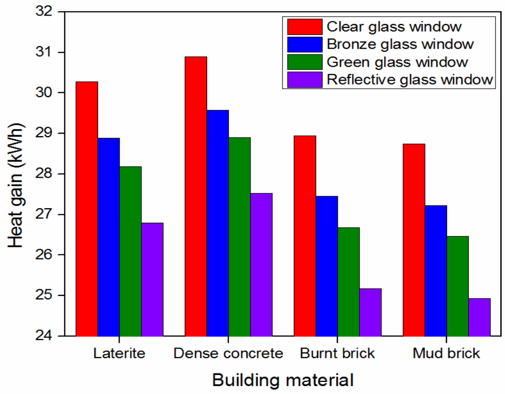
Fig 7 (b) shows the total heat gain into the buildings through external walls, external roof, floor and window glass of 80% WWR. From the results, it is noted that at 80% clear glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 32.83 kWh, 33.39 kWh, 31.65 kWh and 31.47 kWh of heat, respectively. Similarly at 80% bronze glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 30.89 kWh, 31.53 kWh, 29.56 kWh and 29.38 kWh of heat, respectively. 80% WWR of green glass for laterite stone, dense concrete, burnt brick and mud brick buildings heat gain is 29.92 kWh, 30.57 kWh, 28.51 kWh and 28.30 kWh, respectively. When 80% WWR of reflective glass is used for the windows of laterite stone, dense concrete, burnt brick and mud brick buildings the total heat gain into the building is 27.97 kWh, 28.68 kWh, 26.40 kWh and 26.18 kWh, respectively. From the results, it is observed that mud brick buildings with reflective glass window are found to be energy efficient from the least heat gain point of view and dense concrete buildings with clear glass found to be less energy efficient from heat gain point of view.

Fig 8 shows the total heat gain into the buildings through walls, roof, floor and window glass of 100% WWR. This configuration of 100% WWR is the most popular for commercial buildings. From the results, it is noted that at 100% clear glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 33.24 kWh, 33.79 kWh, 32.06 kWh and 31.91 kWh of heat, respectively. At 100% bronze glass WWR, laterite stone, dense concrete, burnt brick and mud brick buildings gain 31.22 kWh, 31.83 kWh, 29.90 kWh and 29.70 kWh of heat, respectively. 100% WWR of green glass for laterite stone, dense concrete, burnt brick and mud brick buildings, heat gain is 30.19 kWh, 30.83 kWh, 28.80 kWh and 28.60 kWh, respectively. When 100% WWR of reflective glass is used for the windows of laterite stone, dense concrete, burnt brick and mud brick buildings the total heat gain into the building is 28.15 kWh, 28.87 kWh, 26.60 kWh and 26.38 kWh, respectively.

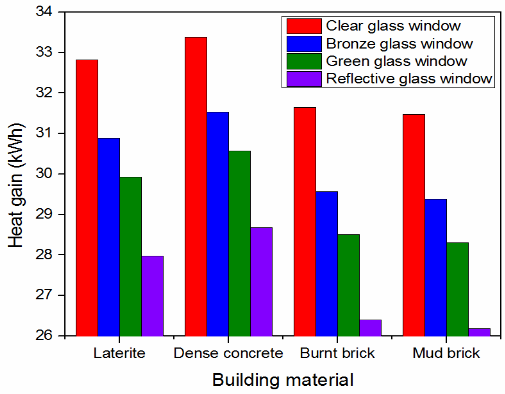


(a) (b)

Fig. 6 (a) Heat gain into buildings through different building materials of 9" wall with 20% window to wall ratio; (b) Heat gain into buildings through different building materials of 9" wall with 40% window to wall ratio



(a)



(b)

Fig. 7 (a) Heat gain into buildings through different building materials of 9" wall with 60% window to wall ratio; (b) Heat gain into buildings through different building materials of 9" wall with 80% window to wall ratio

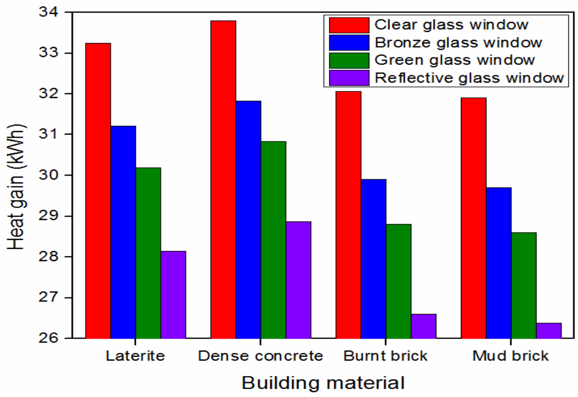


Fig. 8: Heat gain into buildings through different building materials of 9" wall with 100% window to wall ratio

Conclusion

The present work presents the significance of the selection of appropriate building materials with suitable window glasses for building openings for reduced cooling loads into the buildings. The most energy efficient building material among four studied building materials is found to be mud brick due to its lowest heat gain at all window to wall ratios. The commercial buildings with the highest window to wall ratios should prefer reflective glass to reduce air conditioning loads in the buildings. The reflective glass is recommended for the least heat gain into the buildings among four studied glasses. The results of the study helps in designing energy efficient residential and commercial buildings.

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