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Investigation of Different Window and Wall Materials for Solar Passive Building Design

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Abstract

The energy consumption associated with the cooling of the buildings is huge. In India buildings consume about 33% of country's power production for cooling and day lighting. The building enclosures such as walls, roofs and glasses play very vital role in reducing cooling loads in the buildings. The proper combination of window glass materials and wall materials can cut down the cooling costs extensively. In the present work, five different glass materials such as clear, bronze, grey, green and blue-green glass materials were selected and four different building materials such as burnt brick, cinder concrete, dense concrete and fly ash brick either side plastered with cement plaster were selected. Total twenty building models with various combinations of window glass and wall materials were designed in licensed Design builder 4.3.0.039 version and thermal analysis was carried out in Energy plus 8.1 software package. Thermal performance of various building models in four different climatic zones such as hot and dry, temperate, warm and humid and composite were investigated. From the results of the study, it is observed that fly ash brick wall building model with grey window glass is found to be energy efficient in all Indian climatic zones from the reduced cooling load point of view among all studied combinations in East, West, North and South orientations. From the results it is observed that the fly ash brick buildings with grey glass window is observed to be the most energy efficient combination for reducing cooling loads as they gain the least heat gain in south orientation (21.51 kWh) for Ahmedabad region. The results of the study help in designing energy efficient passive buildings.

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Keywords: Passive buildings; Green buildings; Building heat transfer; Energy efficient materials.

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1. Introduction:

Buildings are responsible for about 40% of total energy use in the world and they also account for more than 40% of the global carbon dioxide emissions. With the recent boom in the construction sector, there has been a sudden increase in energy consumption, especially in countries like India. Buildings are consuming 33% energy in India. In that 8% of energy is consumed by commercial buildings and 25% of energy is consumed by the residential sector [1]. India has substantial climatic variations from region to region. Passive building design is the most important factor in ensuring energy efficiency in buildings. Buildings with passive design can consume around 10% - 15% less energy as compared to conventional buildings without incurring any incremental cost [2]. Thus, it is necessary to focus on the vital aspect of energy efficiency at the design stage of the building itself. Previously, a study has been carried out on numerical computation of window design to reduce radiation in buildings using clear and brown glass window materials [3]. Thermal requirement of maximum window to wall ratio was studied earlier [4]. Optimization studies of the insulation location inside the flat roof were reported in the literature [5]. The evaluation of thermal and optical properties was studied earlier [6]. Impact of window to wall ratio on life cycle environment was presented in the literature [7]. Thermal response of laterite buildings was reported in literature [8].

The present work presents the thermal performance of buildings built with different combinations of window glass and building wall materials to recognize the energy efficient combination of window and wall materials in different climatic regions of India.

2. Methodology

The building models with dimensions 3.5 m X 3.5 m X 3.5 m were designed in Design builder. The thickness of the wall is 0.2 m plastered either side with 0.015 m cement plaster each side. Fig. 1. (a) shows the dimensions of a building model and Fig. 1. (b) shows the building model with 30% window to wall ratio. The window to wall ratio is the ratio of vertical fenestration area to the gross external wall area. The window to wall ratio for the building models taken is 30% as per the ECBC. The dimensions of the window are 2 m X 1.8375 m for 30% window to wall ratio. The roof material used is reinforced cement concrete of 0.15 m plastered either side by 0.015 m cement plaster each side. For floor, dense concrete was used. The roof and floor materials are same for the all building models studied. Fig. 2. shows the images of the wall materials used in the study. The wall materials used for the study are burnt brick, cinder concrete, dense concrete and fly ash bricks. Reinforced cement concrete is used as the roofing material. Thermo-physical properties of the wall materials are considered as per the Indian standards [9]. Table 1. shows thermo-physical properties of wall materials. Thermal properties of fly ash brick are taken from the literature [10]. The window glass materials used for the study are clear, bronze, grey, green and blue-green glasses. The solar thermal properties of five glass materials are taken as per the ASHRAE standards [11]. Table 2. Shows the solar thermal properties of the window glass materials used in the study. After designing, building models with all the combinations of wall and window glass materials, thermal analysis was carried out in Energy plus software package at four different climatic conditions of India. The major city is considered in each climatic zone of India for the analysis purpose. The four climatic zones of India are hot and dry (Ahmedabad 23.07^{o} N, 72.63^{o}E), temperate (Bangalore 12.97^{o}N, 77.58^{o}E) warm and humid (Bombay 19.12^{o}N, 72.85^{o}E) and composite (New Delhi 28.57^{o}N, 77.12^{o}E). The window is located in different orientations each time such as East, West, North and South. The heat gain through the roof, walls and windows were noted in different climatic zones with different combinations of wall and window materials to recognize the best location of the window (East, West, North and South) and the best combination of wall and window materials. Thermal analysis was carried out on the peak summer day of the cities considered for the study. In Ahmedabad the peak summer day is May 15th, in Bangalore the peak summer day is April 15th, in Bombay the peak summer day is May 15th and in New Delhi the peak summer day is June 21st as per the Indian standards [12].

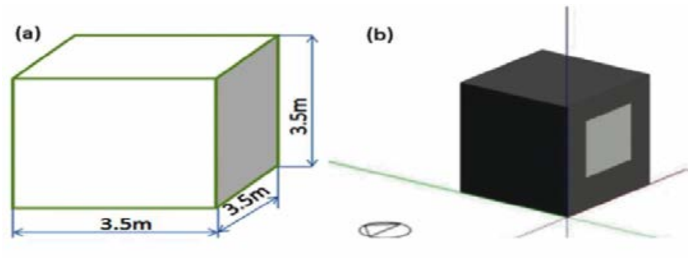

Fig. 1. (a) Dimensions of a building model; (b) Building model with window

Fig. 2. Images of different building wall materials

Table 1.Thermo physical properties of different building materials.

Building material	Thermal conductivity k (W/mK)	Specific heat C_p (J/kgK)	Density D (kg/m^3)
Burnt brick	0.811	880	1820
Cinder concrete	0.686	840	1406
Dense concrete	1.74	880	2410
Fly ash brick	0.360	857	1700
Reinforce cement concrete	1.58	880	2288
Cement plaster	0.721	840	1762

Table 2. The solar thermal properties of five different glass materials.

Glass material	Transmittance (τ) (%)	Reflectance (ρ) (%)	Absorptance (α) (%)
Clear glass	76	8	16
Bronze glass	49	5	46
Grey glass	46	5	49
Green glass	47	5	48
Blue-green glass	49	6	45

3. Results and Discussions

3.1. Heat gain in buildings of Ahmadabad (Hot & dry) region:

The summer solstice is the day with the most sunlight hours during the whole year due to noon sun's highest altitude. The hours of sun light varies from one latitude of the place to another latitude of the place. June 21st is the most sun light hours day during the whole year for latitudes 25°N and 29°N. For latitudes upto 21°N, the most sun light hours during the whole year can be obtained when the noon sun is at the zenith. The most sun light hours during the whole year for Ahmedabad, Bangalore, Bombay and New Delhi are different due to their different latitudes. Fig. 3. (a) shows the solar chart of Ahmadabad on peak summer of May 15th. Fig. 3. (b) Shows the heat gain in different building models of various walls and window material combinations in four orientations of the window location (East, West, North and South) in the Ahmedabad climatic region. The solar chart or sun path diagram is a graphical representation of the sun paths in the sky for various days in the year. The radial lines show the solar azimuth and concentric circles show the solar altitudes. The center of the chart indicates the zenith and outermost circles indicate the horizon. The series of curved lines passing from east to west represents the sun's path for selected days of each month. These curved lines are crossed by another series of curved lines which show the hour lines. The intersection point of sun's path line and the hour line is the position of the sun in that hour of that particular day. Fig. 3. (a) Shows the position of the sun at 3 PM on peak summer day of May 15th in Ahmedabad climatic region (23.07° N, 72.63°E) when the window is placed in the South orientation. From Fig. 3. (b), it is clear that the solar heat gain in building through south wall is the least for all the wall and window glass material combinations among four locations of window glasses studied. Table 3. shows solar heat gain in burnt brick buildings with different glass materials in four orientations of window glass in Ahmedabad region. From Table 3, it is noted that heat gain in buildings is less in south orientation as compared to the other orientations. it is also observed that burnt brick buildings with grey glass window in south direction is observed to be the best due to less heat gain of 23.42 kWh and burnt brick buildings with a clear glass window in south direction is observed to be the worst due to the high heat gain of 24.9 kWh. Table 4. shows solar heat gain in cinder concrete brick buildings with different glass materials in four orientations of window glass in Ahmedabad region. From Table 4, it is observed that heat gain in buildings is less in south orientation as compared to the other orientations. It is also observed that cinder concrete buildings with grey glass window in south direction is observed to be the best due to less heat gain of 22.85 kWh and cinder concrete buildings with a clear glass window in south direction is observed to be the worst due to the high heat gain of 24.33 kWh. Table 5. shows solar heat gain in dense concrete buildings with different glass materials in four orientation of window glass for Ahmedabad region. From Table 5, it is observed that heat gain in buildings is less in south orientation as compared to the other orientations. it is also observed that dense concrete buildings with grey glass window in south direction is observed to be the best due to less heat gain of 25.44 kWh and dense concrete buildings with a clear glass window in south direction is observed to be the worst due to the high heat gain of 26.82 kWh. Table 6. shows solar heat gain in fly ash brick buildings with different glass materials in four orientations of window glass in Ahmedabad region. From Table 6, it is observed that heat gain in buildings is less in south orientation as compared to the other orientations. It is also observed that fly ash brick buildings with grey glass window in south direction is observed to be the best due to less heat gain of 21.51 kWh and fly ash brick buildings with a clear glass window in south direction is observed to be the worst due to the high heat gain of 23.1 kWh. Among all wall and glass material combinations studied, fly ash brick buildings with grey glass window is observed to be the most energy efficient combination for reducing cooling loads as they gain the least heat gain in south orientation (21.51 kWh) for Ahmedabad region.

Table 3. Solar heat gain in burnt brick buildings with different glass materials in four orientations of window glass for Ahmadabad region

Direction	Clear glass (kWh)	Bronze glass (kWh)	Grey glass (kWh)	Green glass (kWh)	Blue green (kWh)
East	27.33	23.98	23.72	23.81	24.00
West	27.13	23.84	23.61	23.69	23.89
North	25.05	23.51	23.41	23.45	23.55
South	24.9	23.52	23.42	23.45	23.54

Table 4. Solar heat gain in cinder concrete buildings with different glass materials in four orientations of window glass for Ahmadabad region

Direction	Clear glass (kWh)	Bronze glass (kWh)	Grey glass (kWh)	Green glass (kWh)	Blue green (kWh)

East	26.86	23.45	23.22	23.29	23.5
West	26.66	23.33	23.12	23.19	23.4
North	24.49	22.93	22.84	22.87	22.96
South	24.33	22.93	22.83	22.85	22.95

Table 5. Solar heat gain in dense concrete buildings with different glass materials in four orientations of window glass for Ahmadabad region

Direction	Clear glass (kWh)	Bronze glass (kWh)	Grey glass (kWh)	Green glass (kWh)	Blue green (kWh)
East	28.81	25.6	25.37	25.44	25.64
West	28.65	25.53	25.31	25.38	25.58
North	26.94	25.5	25.4	25.44	25.53
South	26.82	25.53	25.44	25.47	25.55

Table 6. Solar heat gain in fly ash brick buildings with different glass materials in four orientations of window glass for Ahmadabad region

Direction (kWh)	Clear glass (kWh)	Bronze glass (kWh)	Grey glass (kWh)	Green glass (kWh)	Blue green (kWh)
East	26.05	22.5	22.26	22.34	22.55
West	25.77	22.31	22.07	22.14	22.36
North	23.32	21.65	21.55	21.58	21.68
South	23.1	21.62	21.51	21.56	21.64

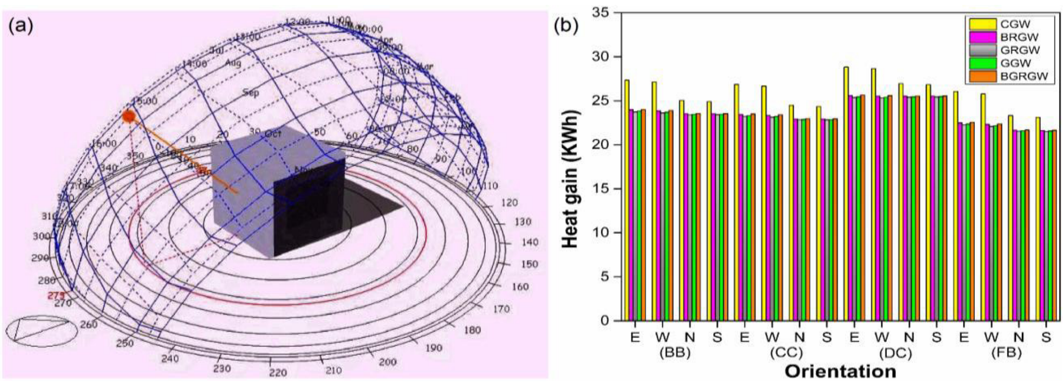

Fig. 3. (a) Solar chart of Ahmadabad on peak summer day; (b) Heat gain through building models in Ahmadabad climatic conditions.

3.2 Heat gain in buildings of Bangalore (Temperate) region:

Fig. 4. (a) shows the position of sun at 3 PM on peak summer day of April 15th in the Bangalore climatic region (12.97^{o} N, 77.58^{o}E) when the window is placed in the South orientation. Fig. 4. (b) Shows the heat gain in different building models of various walls and window material combinations in four orientations of the window location (East, West, North and South) in the Bangalore climatic region. From Fig. 4. (b), it is observed that burnt brick buildings with a clear glass window placed in south gain 14.91 kWh of heat. Burnt brick buildings with bronze glass window placed in south gain 13.45 kWh of heat. Burnt brick buildings with grey glass window placed in south gain

13.34 kWh of heat. Burnt brick buildings with green glass window placed in south gain 13.39 kWh of heat. Burnt brick buildings with blue-green glass window placed in south gain 13.47 kWh of heat. From Fig. 4. (b), it is also observed that cinder concrete buildings with a clear glass window placed in south gain 14.73 kWh of heat. Cinder concrete buildings with bronze glass window placed in south gain 13.23 kWh of heat. Cinder concrete buildings with grey glass window placed in south gain 13.13 kWh of heat. Cinder concrete buildings with green glass window placed in south gain 13.17 kWh of heat. Cinder concrete buildings with blue-green glass window placed in south gain 13.25 kWh of heat. From Fig. 4. (b), it is noted that dense concrete buildings with a clear glass window placed in south gain 15.82 kWh of heat. Dense concrete buildings with bronze glass window placed in south gain 14.41 kWh of heat. Dense concrete buildings with grey glass window placed in south gain 14.32 kWh of heat. Dense concrete buildings with green glass window placed in south gain 14.36 kWh of heat. Dense concrete buildings with blue-green glass window placed in south gain 14.43 kWh of heat. From Fig. 4. (b), it is noted that fly ash brick buildings with a clear glass window placed in south gain 14.24 kWh of heat. Fly ash brick buildings with bronze glass window placed in south gain 12.66 kWh of heat. Fly ash brick buildings with grey glass window placed in south gain 12.55 kWh of heat. Fly ash brick buildings with green glass window placed in south gain 12.60 kWh of heat. Fly ash brick buildings with blue-green glass window placed in south gain 12.69 kWh of heat.

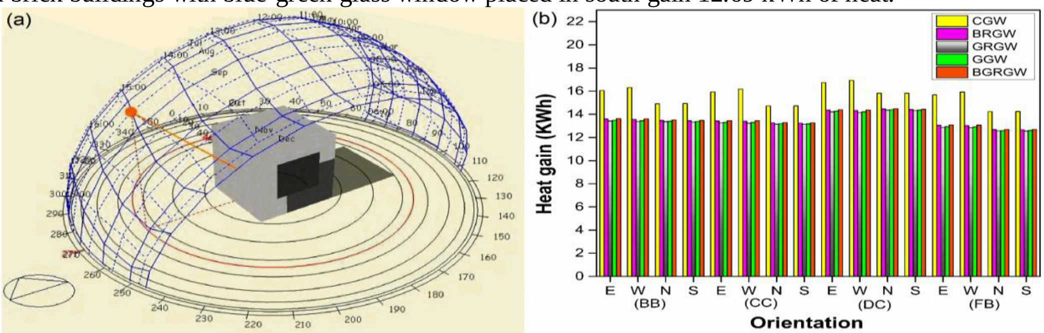

Fig. 4. (a) Solar chart of Bangalore on peak summer day; (b) Heat gain through building models in Bangalore climatic conditions.

From the results, it is observed that fly ash brick buildings with grey glass window placed in south orientation is the best from lowest heat (12.55 kWh) gain point of view in the Bangalore climatic region. The worst combination of wall and glass materials among studied models was found to be dense concrete with a clear glass window due to highest heat gain (15.82 kWh) in south direction of the Bangalore climatic region.

3.3 Heat gain in buildings of Bombay (Warm & Humid) region:

Fig. 5. (a) shows the position of sun at 3 PM on peak summer day of May 15th in Bombay climatic region (19.12^{o} N, 72.85^{o}E) when the window is placed in the South orientation. Fig. 4. (b) shows the heat gain in different building models of various walls and window material combinations in four orientations of the window location (East, West, North and South) in the Bombay climatic region. From Fig. 5. (b), it is observed that burnt brick buildings with a clear glass window placed in south gain 18.18 kWh of heat. Burnt brick buildings with bronze glass window placed in south gain 16.66 kWh of heat. Burnt brick buildings with grey glass window placed in south gain 16.55 kWh of heat. Burnt brick buildings with green glass window placed in south gain 16.59 kWh of heat. Burnt brick buildings with blue-green glass window placed in south gain 16.68 kWh of heat. From Fig. 5. (b), it is also observed that cinder concrete buildings with a clear glass window placed in south gain 17.85 kWh of heat. Cinder concrete buildings with bronze glass window placed in south gain 16.30 kWh of heat. Cinder concrete buildings with grey glass window placed in south gain 16.20 kWh of heat. Cinder concrete buildings with green glass window placed in south gain 16.23 kWh of heat. Cinder concrete buildings with blue-green glass window placed in south gain 16.32 kWh of heat. From Fig. 5. (b), it is noted that dense concrete buildings with a clear glass window placed in south gain 19.76 kWh of heat. Dense concrete buildings with bronze glass window placed in south gain 18.32 kWh of heat. Dense concrete buildings with grey glass window placed in south gain 18.23 kWh of heat. Dense concrete

buildings with green glass window placed in south gain 18.26 kWh of heat. Dense concrete buildings with blue-green glass window placed in south gain 18.35 kWh of heat. From Fig. 5. (b), it is noted that fly ash brick buildings with a clear glass window placed in south gain 16.69 kWh of heat. Fly ash brick buildings with bronze glass window placed in south gain 15.04 kWh of heat. Fly ash brick buildings with grey glass window placed in south gain 14.91 kWh of heat. Fly ash brick buildings with green glass window placed in south gain 14.96 kWh of heat. Fly ash brick buildings with blue-green glass window placed in south gain 15.06 kWh of heat. From the results, it is noticed that fly ash brick buildings with grey glass window placed in south orientation is the best from lowest heat (14.91 kWh) gain point of view in the Bombay climatic region. The worst combination of wall and glass materials among studied models was found to be dense concrete with a clear glass window due to high heat gain (19.76 kWh) in south direction of the Bombay climatic region.

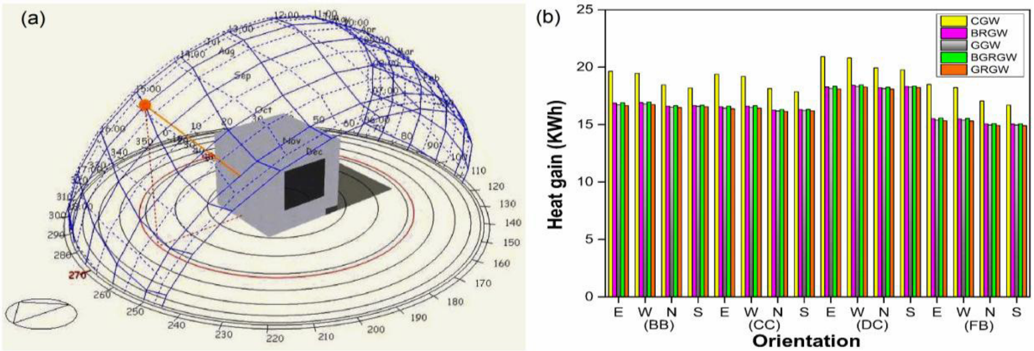

Fig. 5. (a) Solar chart of Bombay on peak summer day; (b) Heat gain through building models in Bombay climatic conditions.

3.4 Heat gain in buildings of New Delhi (Composite) region:

Fig. 6. (a) shows the position of sun at 3 PM on peak summer day of June 21st in New Delhi climatic region (28.57° N, 77.12°E) when window is placed in the South orientation. Fig. 4. (b) shows the heat gain in different building models of various walls and window material combinations in four orientations of the window location (East, West, North and South) in the New Delhi climatic region. From Fig. 6. (b), it is observed that burnt brick buildings with a clear glass window placed in south gain 28.66 kWh of heat. Burnt brick buildings with bronze glass window placed in south gain 26.93 kWh of heat. Burnt brick buildings with grey glass window placed in south gain 26.82 kWh of heat. Burnt brick buildings with green glass window placed in south gain 26.85 kWh of heat. Burnt brick buildings with blue-green glass window placed in south gain 26.96 kWh of heat. From Fig. 6. (b), it is also observed that cinder concrete buildings with a clear glass window placed in south gain 27.90 kWh of heat.

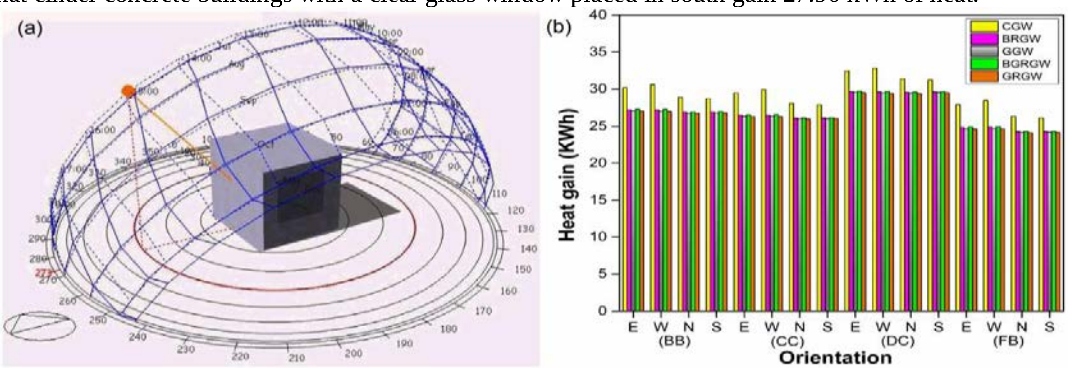

Fig. 6. (a) Solar chart of New Delhi on peak summer day; (b) Heat gain through building models in New Delhi climatic conditions.

Cinder concrete buildings with bronze glass window placed in south gain 26.14 kWh of heat. Cinder concrete buildings with grey glass window placed in south gain 26.02 kWh of heat. Cinder concrete buildings with green glass window placed in south gain 26.06 kWh of heat. Cinder concrete buildings with blue-green glass window placed in south gain 26.16 kWh of heat.

From Fig. 6. (b), it is noted that dense concrete buildings with a clear glass window placed in south gain 31.20 kWh of heat. Dense concrete buildings with bronze glass window placed in south gain 29.58 kWh of heat. Dense concrete buildings with grey glass window placed in south gain 29.47 kWh of heat. Dense concrete buildings with green glass window placed in south gain 29.50 kWh of heat. Dense concrete buildings with blue-green glass window placed in south gain 29.60 kWh of heat. From Fig. 6. (b), it is noted that fly ash brick buildings with a clear glass window placed in south gain 26.11 kWh of heat. Fly ash brick buildings with bronze glass window placed in south gain 24.26 kWh of heat. Fly ash brick buildings with grey glass window placed in south gain 24.13 kWh of heat. Fly ash brick buildings with green glass window placed in south gain 24.17 kWh of heat. Fly ash brick buildings with blue-green glass window placed in south gain 24.28 kWh of heat.

From the results, it is noticed that fly ash brick buildings with grey glass window placed in south orientation is the best from lowest heat (24.13 kWh) gain point of view in the New Delhi climatic region. The worst combination of wall and glass materials among studied models was found to be dense concrete with a clear glass window due to high heat gain (31.20 kWh) in south direction of the New Delhi climatic region.

From the lower heat gain point of view, the best combination of wall and window glass materials is fly ash brick with grey glass and the worst combination of wall and window glass materials is dense concrete with clear glass in all four orientations of the windows and among all the studied wall and glass material combinations.

4. Conclusions:

This work helps in selecting an appropriate wall and the window glass material combination for reducing cooling loads in buildings. From the results, it is observed that the best combination of wall and window glass materials is found to be fly ash brick with grey glass window and the worst combination of wall and window glass materials is found to be dense concrete with a clear glass window in all four orientations of window placing and among all the wall and glass material combinations studied. The fly ash brick buildings with grey glass window placed in south orientation is the best from the lowest heat gain point of view as they gain the least amount of heat of 21.51 kWh, 12.55 kWh, 14.91 kWh and 24.13 kWh in Ahmedabad, Bangalore, Bombay and New Delhi climatic regions, respectively among studied wall and window material combinations. The results of the study help in designing energy efficient passive buildings.

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