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Simulation determining passive cooling parameters for multi-storied residential buildings in Dhaka

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Abstract
The paper investigates the effect of passive cooling strategies of multi-storeyed residential buildings in achieving indoor thermal comfort in the context of Dhaka, Bangladesh. It examines two main passive cooling strategies for warm-humid climate - thermal mass and clear floor to ceiling height. The mentioned passive means are investigated by using the thermal simulation programme IES-VE to evaluate the isolated effect of each. Finally, an overview of conclusions with design guideline from the investigated data is cited. The main findings of this paper indicate best temperature results when thermal mass is 250mm brick wall and clear floor height is 3.35m.

Key words

Passive cooling, Simulation, Thermal mass, Clear floor to ceiling height

1.0 General introduction

This Paper is concerned with the environmental aspect of design. It particularly focuses on multi-storied residential buildings of the Dhaka city. It aims to identify design approaches that rely on natural systems in order to develop a comfortable indoor environment.
Dhaka, the capital of Bangladesh, lies between longitudes 90?20' E and 90?30' E and between latitudes 23?40' N and 23?55' N, with three sides bounded by rivers Buriganga in the south, the Tongi Khal (canal) in the north and the Turag river in the west. The climate of Bangladesh, based on the widely used classification by Atkinson (Koenigsberger et al, 1973), is categorised as warm-humid for much of the year.
The most practical problem of Dhaka is its population. Dhaka is the 11th largest city in the world with 12 million residents and has the highest growth rate of 3.2% (South Asia Population). To cope with this huge population mid-rise and high-rise apartments are growing up rapidly in the city. Most of these are developing without considering passive design methods for cooling. Residents have to use ceiling fans and air conditioner even in early winter, contributing to wastage of valuable energy. (Hafiz, 2002)

In the context of Bangladesh, where there is a burning energy crisis, it is wasteful to use energy for thermal comfort in buildings. So for the sustainable development of Dhaka the only way is the adoption of more effective and widely used methods for passively cooling buildings. Thus the paper tries to develop design guidelines in the context of Dhaka, for thermal mass and clear ceiling to floor height as passive design elements for multi-storied residential buildings.

Fig 1: Residential development of the city of Dhaka

1.2 Objectives:

The main objectives of the paper are:

To evaluate the physical properties of, thermal mass, and clear floor height as passive design means used in multi-storied residential buildings.
To investigate the primary factors that influences the design and performance of the mentioned design strategies and to provide design guideline for these.

1.3 Methodology

To achieve the above objectives the Paper first discusses passive design strategies for warm humid climates, especially thermal mass and clear floor height from literature review. Then thermal simulation, carried out to investigate thermal performance of these passive cooling systems, has been discussed, with analysis leading to design guidelines, as established upon synthesis of the findings.

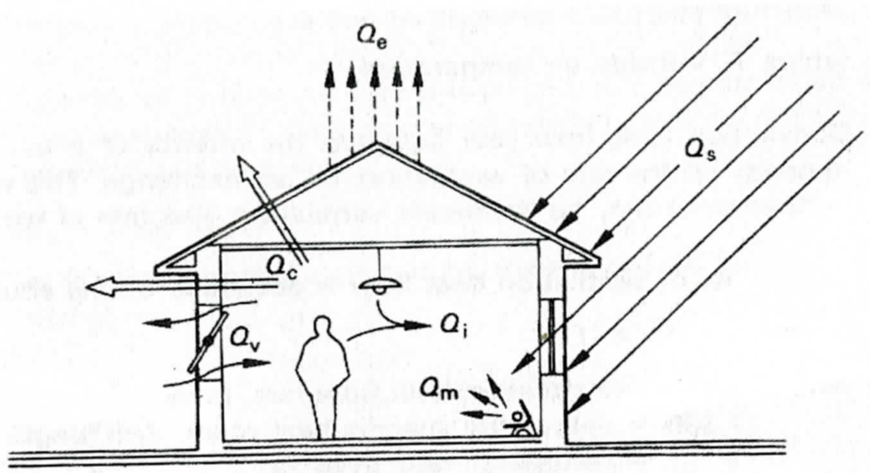
2. Passive cooling

Thermal comfort can be achieved by active or passive means. By active methods comfort it is achieved by energy-consuming mechanical devices, whereas passive strategies provide the same, naturally. However, in extreme climates it is sometimes impossible to rely only on passive means for indoor comfort. Hence the objective is to ensure the best possible indoor thermal conditions by passive means to reduce the use of active means.
Passive cooling strategies try to make the indoor cool, where the outdoor is hot. The principle objectives that outline the strategy for passive cooling are:

1. Prevention of heat gain
2. Protection from effects of heat gain
3. Promotion of cooling through heat loss

(Commission of the European Communities, 1992)

Fig 3: Influence of the height of the room on air change hour. (Ghiaus and Allard, 2005)



$$Q_i + Q_s \pm Q_c \pm Q_v \pm Q_m - Q_e = 0$$

Fig 2: Heat exchange of Buildings (Koenigsberger et al., 2004).
(Qi - internal heat gains, Qs - radiation, Qc - convection, Qv - ventilation Qm - mechanical equipment, Qe - evaporation)

2.1 Thermal mass

The effect of outdoor heat can be moderated by using the heat storage capacity of building materials to create comfortable and cooler indoor spaces. The thermal resistance and the heat capacity are the most important properties of the materials, which should be considered in design. (Givoni, 1981). The resistance moderates the heat flow external to internal surfaces, and the thermal capacity of a material stores heat and controls the fluctuation of indoor temperatures.

Heavy thermal mass is very effective in regions, where both external temperatures and diurnal temperature difference are high. In Bangladesh, the hot dry season between March and May are the most appropriate for the use of thermal mass. Passive cooling in such situation can be farther enhanced by removal of heat accumulated during the day by night ventilation (Givoni, 1981). The use of thermal mass has different effects in warm-humid season, where diurnal temperature range is low and the use of material having high thermal capacity may increase night time indoor temperature. In the winter the use of thermal mass may have advantages to make the indoors warm at night (Koenigshofer, 1981).

Using high thermal mass in buildings in warm humid areas should have insulation to increase resistance to heat gains. The proper location of the insulating layer is to the outside of the building envelop (Baker, 1987).

Brick and concrete are the most common materials of building construction in Bangladesh. The walls are built brick by brick manually and concrete is cast on site. This allows variation in thickness of the wall and roof elements easily and causes variation in thermal mass.

2.2 Clear floor height

The height between the floor and the ceiling affects the internal air flow as well as the feeling of comfort of the occupants. A sufficient value of clear floor height gives provision of enough space for warm air to rise above the occupant's level. On the other hand, too much height has a negative effect on the air change hours (ACH) of a room. Fig 3 shows the effect of floor height on the ACH (Ghiaus and Allard, 2005). These results are obtained from a simulation study carried out for a summer time outdoor temperature between 26-41?C and wind velocity between 0-10m/s. Hence, care should be taken while specifying floor height of a building.

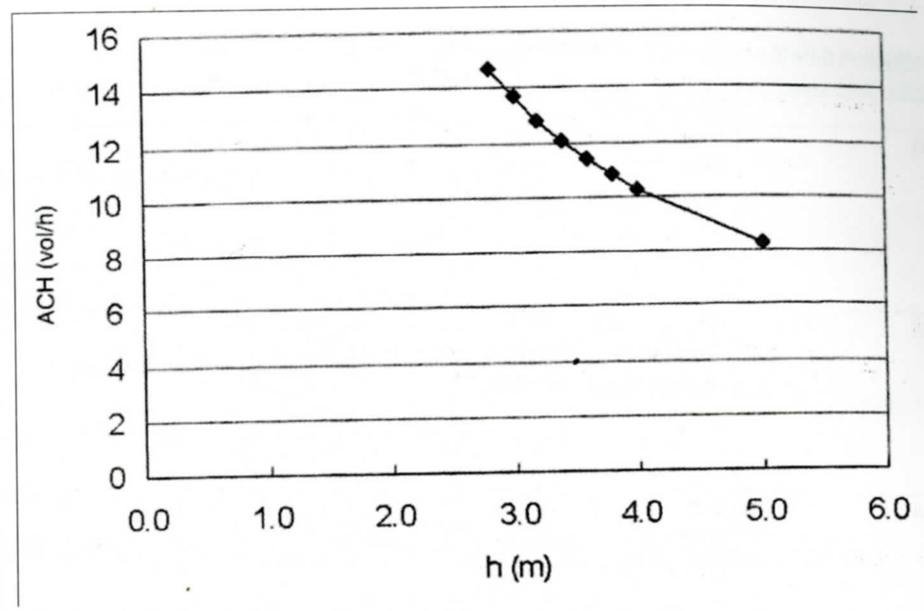


Fig 3: Influence of the height of the room on air change hour. (Ghiaus and Allard, 2005)

Table 1 presents the recommended values of ceiling height in Bangladesh by the Bangladesh National Building Code (1993). Surprisingly they do not have any recommendation for residential buildings.

Table 1: Minimum ceiling height for building

Occupancy	Minimum ceiling height (m)	
	Non-air conditioned buildings	Air conditioned buildings
Education, Institutional, Health care, Assembly	3.0m	2.6m
Industrial, Storage, Hazardus	3.5m	3.0m

(Source: Bangladesh National Building Code, 1993)

3. Simulation studies

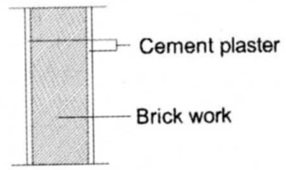
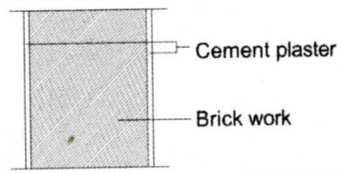
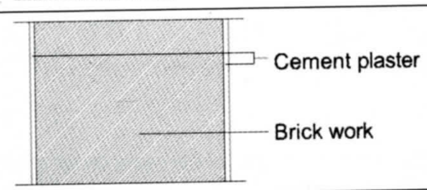
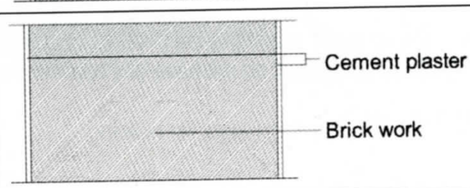
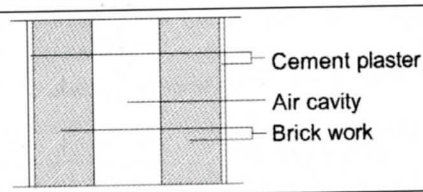
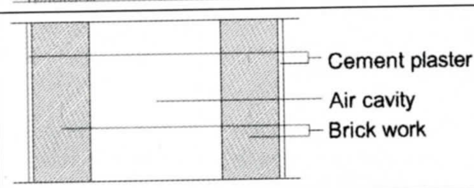
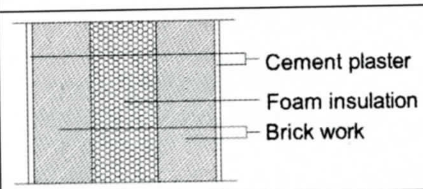
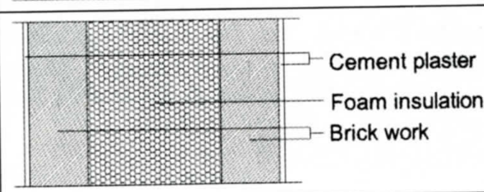
This section investigates the effect of the changes in thermal mass and clear floor height in indoor environment through simulation. For this simulation study a dynamic computer simulation program named 'Integrated Environmental Solutions - Virtual Environment' (IES-VE, version 5.8) has been used.

3.1 Parameters investigated

3.1.1 Thermal mass

The effect of thermal inertia was simulated as changes in wall thickness. Wall thickness varies as a multiple of 125mm, the width of a single brick. The effect of wall with air cavity and insulation was also simulated. Only external walls are subjected to changes as would happen in the commonly used column beam structural system. The constructional details of the investigated wall are shown in the Table 2.

Table 2: Construction details of different wall used in simulation

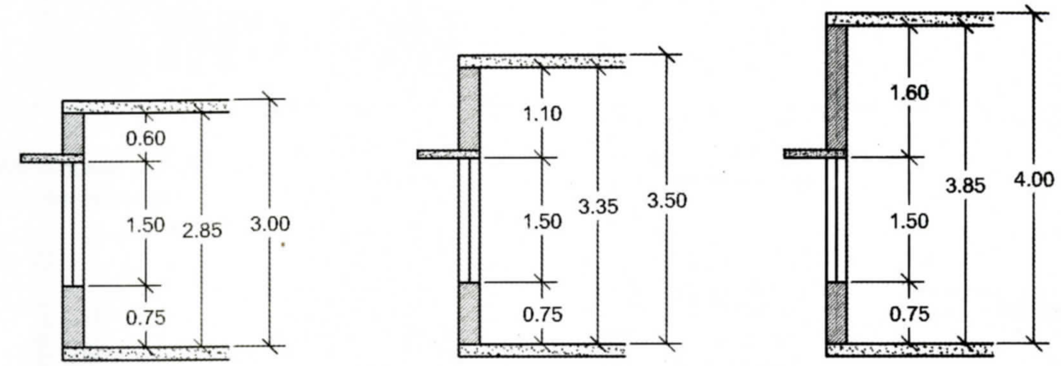
Name	Construction	
125mm wall	Cement plaster 10mm Brick work 110mm Cement plaster 10mm	
250mm wall	Cement plaster 10mm Brick work 230mm Cement plaster 10mm	
375mm wall	Cement plaster 10mm Brick work 355mm Cement plaster 10mm	
500mm wall	Cement plaster 10mm Brick work 480mm Cement plaster 10mm	
With 125mm air cavity	Cement plaster 10mm Brick work 110mm Air cavity 125mm Brick work 110mm Cement plaster 10mm	
With 250mm air cavity	Cement plaster 10mm Brick work 110mm Air cavity 250mm Brick work 110mm Cement plaster 10mm	
With 125mm foam insulation	Cement plaster 10mm Brick work 110mm Foam insulation 125mm Brick work 110mm Cement plaster 10mm	
With 250mm foam insulation	Cement plaster 10mm Brick work 110mm Foam insulation 250mm Brick work 110mm Cement plaster 10mm	

3.1.2 Clear floor height

The effect of clear floor height on indoor air temperature was investigated with three different clear floor heights. These are chosen from the commonly used floor to floor height (Table 3).

Table 3: Different floor height used in simulation

Name	Clear floor height	Floor to floor height
2.85m clear height	2.85m	3m
3.35m clear height	3.35m	3.5m
3.85m clear height	3.85m	4m



2.85m clear height 3.35m clear height 3.85m clear height

Fig 4. Detail of different floor height

3.2 The building model

A real apartment building; **Wari Tower,** 1 Hayer street road, Wari, Dhaka 1203; was chosen as the model for thermal simulation (Fig 5). This building was chosen to have simulations results as real as possible. The simulation was carried out for the corner rooms of the sixth floor. The reason behind choosing corners rooms, is that these are the practical situations of rooms with two exterior facades. For the simulations, the rooms were assumed to have no supplementary heating or cooling.

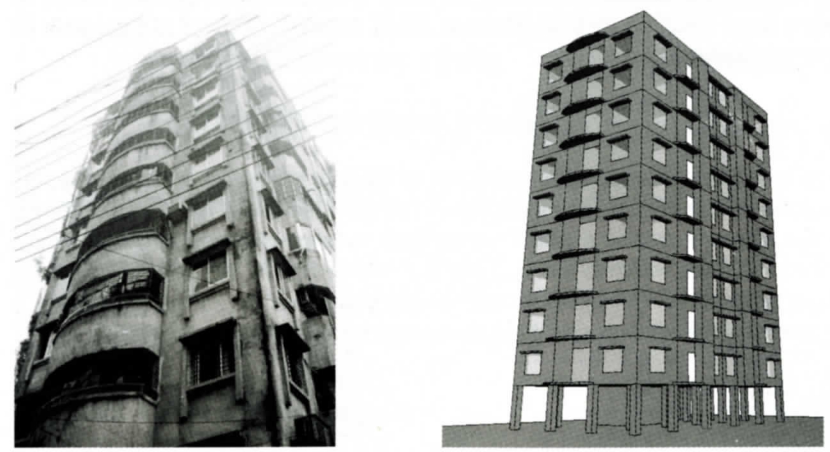


Fig 5: Wari tower and the Building model for simulation

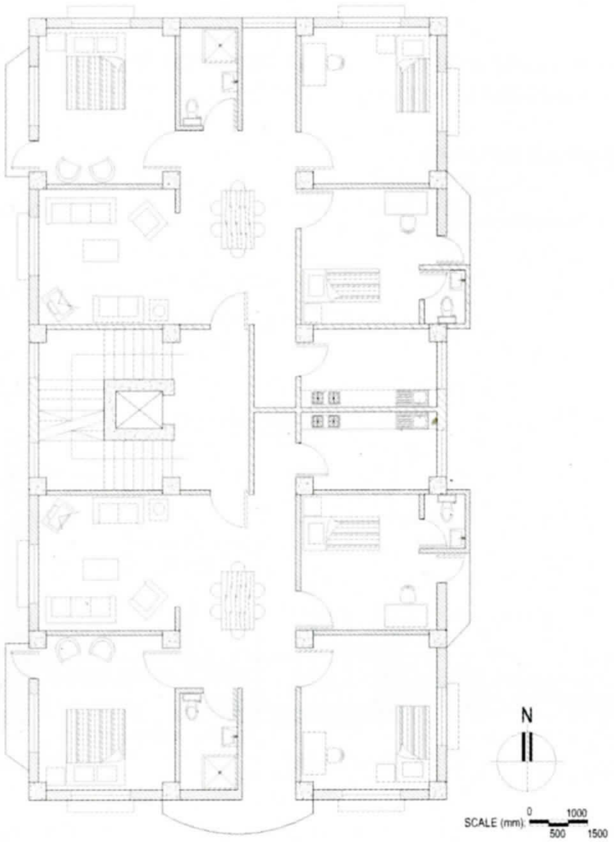


Fig 6.: Typical floor plan

3.3 Results and discussion

The indoor air temperatures generated for varying conditions of the parameters mentioned were analysed. The hourly indoor air temperatures for each condition were obtained from simulation for one year. The mean hourly temperatures are compared to each other for the four different seasons separately. Moreover, the total number of hours having air temperature in comfort air temperature range (26.3?C - 29.6?C) (Hossain, 2008). are also compared to each other for each different situation to find out the most suitable one.

3.3.1 Effect of thermal mass

The indoor air temperatures obtained for different external wall construction for 6th floor south-east corner room during the hot-dry season (March-May) are shown in the Fig 7. The Figure shows that the 125mm wall has a much different effect on indoor temperature than the others. It creates a diurnal temperature variation of almost 4?C with almost 34.8?C mean maximum temperature at 3:00 pm, which is 0.8?C higher than the others. All the other constructions have almost similar effect on indoor air temperature. The figures for other seasons show that the 250mm wall creates a bit lower day temperature compare to most of the other options, especially during the long warm-humid season.

South-east room

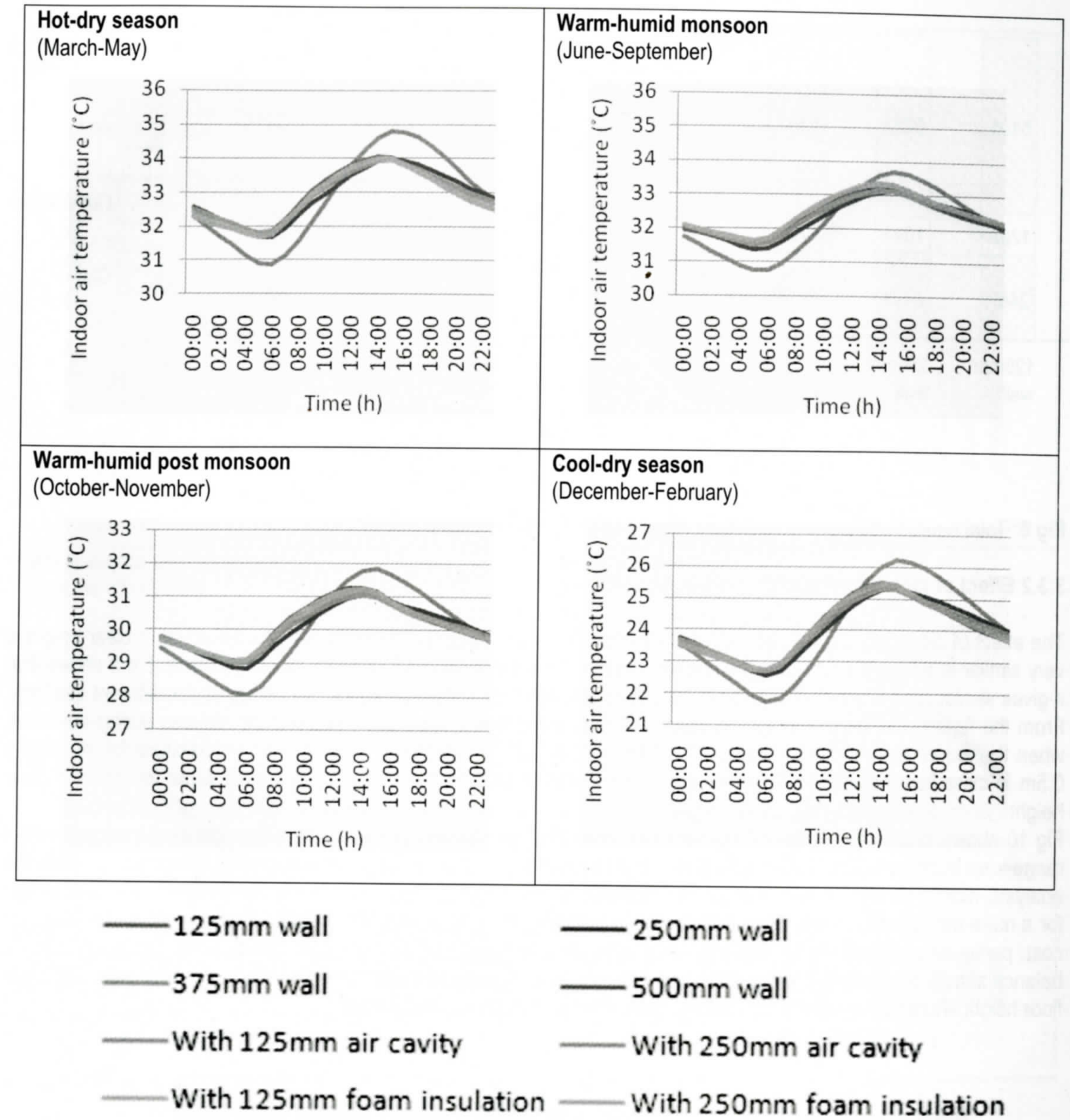


Fig 7.: Mean hourly indoor air temperature for different wall construction in south-east room.

The total hours with comfortable temperatures for each wall are shown in the Fig 8. The figure shows that the 125mm wall has the highest number of hours with temperatures in comfortable range and the 250mm wall has the second height. Though, the 125mm wall has the maximum number, but the hourly temperature results shows that it creates a much higher indoor air temperatures in the warm hours range compared to the others. The analysis of the simulation results suggests that the 250mm wall is the most suitable as external wall in creating comfortable indoor air temperature. It is also economical compared to the other six options, except for the 125 mm walls.

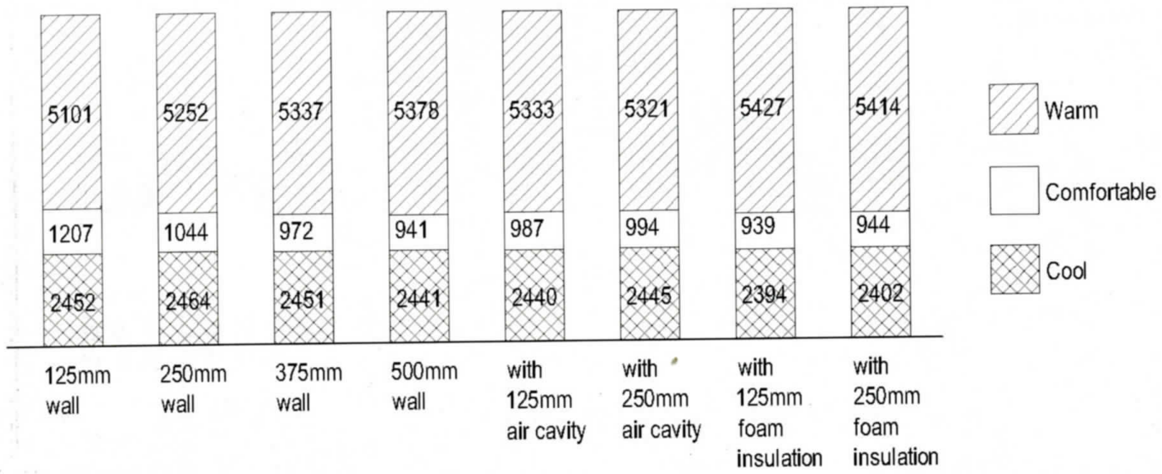


Fig 8: Total hours in different temperature range regarding comfort temperature.

3.3.2 Effect of clear floor height

The effect of clear floor height upon indoor temperature was analysed in the same way. As the effect of clear height is very similar in different room, only the results obtained from the south-east room are discussed here. Fig 9 shows that it gives similar results when compared to the others, though they have different air temperatures for different seasons. From the figure, it is clear that as the clear floor height increases, the indoor temperature reduces during day time, when the indoor environment is warm. It creates about 0.25?C less mean maximum air temperature for increasing 0.5m in clear floor height. On the other hand, during cool night hours the effects are almost same for different clear height.

Fig 10 shows that as the height of the floor increases the total number of hours with air temperatures within comfort range also increases. The 3.85m clear floor height room has the highest hours of comfortable temperature. Both the analysis, diurnal air temperature and total comfortable hours, suggests that it is better to have higher clear floor height for a more comfortable indoor environment. But in the real world increasing floor height adversely affects construction cost, particularly in multi-storied buildings, increasing the overall building height significantly. So in practical design a balance should be created, and the floor height should be as high as possible considering the economic side. The clear floor height should be at least 3.35m rather than the most commonly used 2.85m.

South-east room

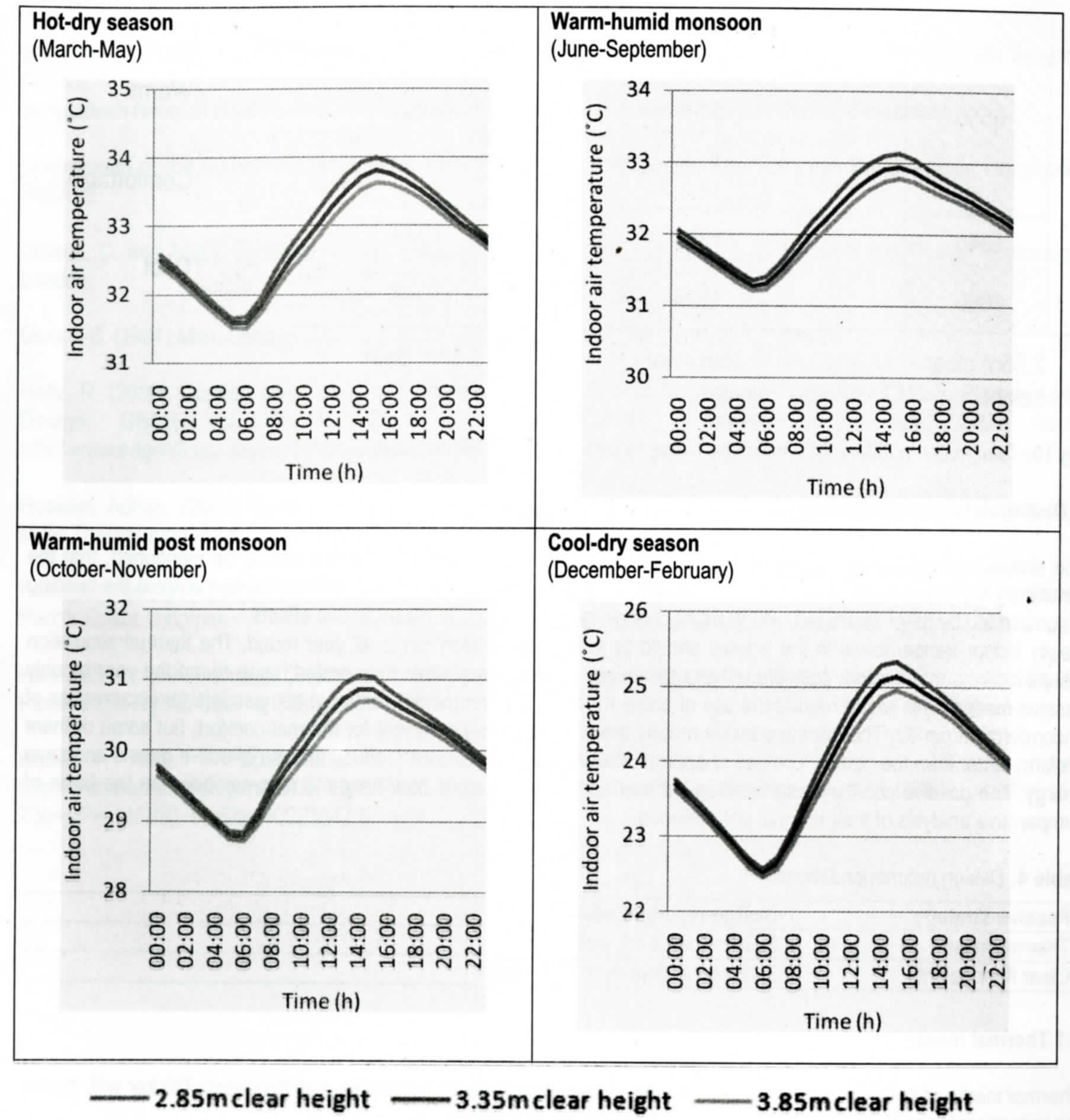


Fig 9: Mean hourly indoor air temperature for different clear floor height in south-east room.

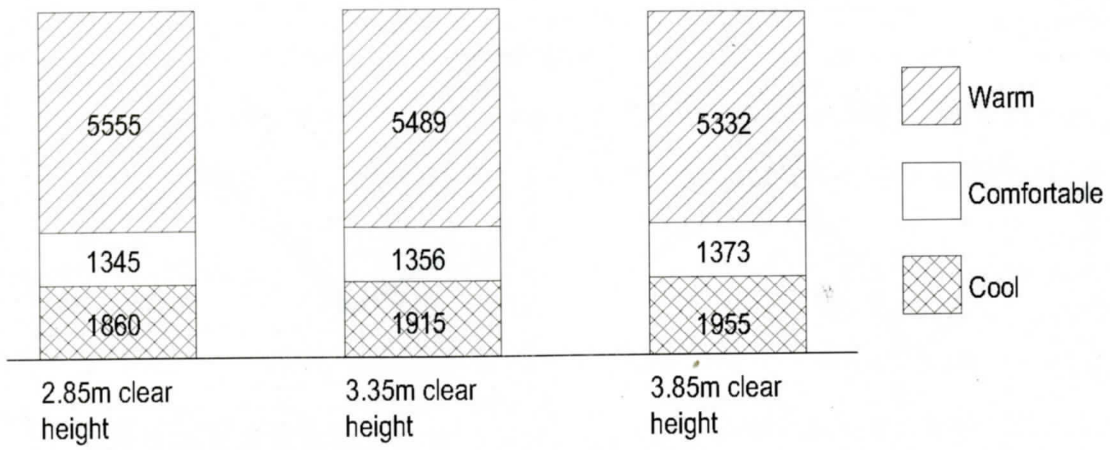


Fig 10: Total hours in different temperature range regarding comfort temperature.

4. Discussions and conclusions

The simulation results are discussed with a view to derive design guidelines. Here it should be mentioned, that the simulation was carried out with a condition, having open surroundings. But in the real world urban context the building is surrounded by other structures, which might change the results, due to microclimatic effects.

Ideally indoor temperatures in the houses should be within the comfort range all year round. The thermal simulation results indicate that it is not possible to keep the indoor temperatures within the comfort range round the year by only passive means. This would require the use of active means of environmental control to compensate for occurrences of uncomfortable period. Though the passive means are not completely sufficient for thermal comfort, but some of them perform better than the others. The use of appropriate passive strategies can reduce the use of active means and save energy. The passive cooling design strategy of thermal mass and clear floor height is recommended on the basis of comparative analysis of their thermal performance.

Table 4: Design recommendations

Passive strategy	Design recommendations
Thermal mass	250mm thick brick wall
Clear floor height	3.35m clear floor to ceiling height

4.1 Thermal mass

Thermal inertia of building fabric can be manipulated most conveniently by varying wall thickness. Thicker wall makes the indoor cooler and also reduces the diurnal temperature variation.

The simulation studies for multi-storeyed buildings show that a wall of 500mm thickness has a better performance than wall of 250mm thickness. But there is almost no better effect for increasing the wall thickness more than 250mm or introducing air cavity or thermal insulation to it for upper levels. Hence, the 250 mm thick wall construction is the best option for external walls of multi-storeyed residential buildings.

4.2 Clear floor height

The floor to ceiling height is an important issue regarding indoor thermal comfort. Particularly for high rise construction as it is a normal trend to keep floor height as low as possible in high-rises to reduce construction cost.

All the findings from thermal simulation present that it has a positive effect of increasing floor height to cool down indoor air temperature. So regarding indoor air temperature and construction cost, the clear floor height may be 3.35m.

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