COMPUTATIONAL MODELLING IN A HIGH-RISE BUILDING WITH DIFFERENT BUILDING ENVELOPE MATERIALS FOR SUSTAINABLE LIVING

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ABSTRACT

This research focuses on identifying a sustainable material for building envelope for energy efficacy in naturally ventilated high-rise residential buildings through computational fluid dynamics. Convective heat transfer is observed in 3levels of the 14 storied highrise naturally ventilated building using three different building envelope materials- burnt clay bricks, solid concrete block and hollow concrete block. To artificially create the environment with computational Fluid dynamics the different temperatures and velocities are used. The boundary conditions - initial outdoor temperatures 30°C and 23°C respectively were kept constant and the initial outdoor velocities 1m/s to 10m/s, were varied and simulated at 12 noon condition. Simulation results reveal, higher indoor temperatures in the roof exposed floor. At 30 ºC it is observed that there is a 0.2 ºC to 0.3 ºC difference between the burnt clay brick wall and the hollow concrete block wall through the varied velocities. In all cases of air velocities, the air temperature in the indoor spaces of the solid concrete block wall was found to be highest. This proves that solid concrete block wall has the highest conductivity and least resistivity over the other two materials. In the hollow concrete block, the process of conduction slow and apparently the temperature in the indoor spaces is reduced. Thus, the results clearly indicate that the indoor spaces with the hollow block building envelope is comparatively low when compared to the other two building materials.

Keywords**:** Heat Transfer, Natural Convection, Computational Fluid Dynamics, building envelope material, Building Height

1. Introduction

Environmental sustainability with energy efficient concepts and technologies in the early stage of design and construction is a paramount need to minimize global warming. In India, according to the

World Resource Institute and the Energy Statistics from the Ministry of Statistics, Planning and implementation; 32% of the country's total electricity in 2016 was utilized by the commercial and the residential sectors [1]. Building envelopes, which include the walling materials, construction techniques, window openings and the roofs, acts as a catalyst for the heat transmission [2]. The thermal mass of the envelope should be alone with the occupancy time to determine the efficacy of the building envelope [3]. The thermal conductivity of the building materials used in the building envelope plays a significant role in the heat transfer process [4].

Energy efficient sustainable approaches to building envelope requires a wide knowledge of the climatic factors and the meteorological data, hence a simulation model can assist to provide an energy efficient solution for any location for a building designer [5]. The study found variations in building envelope performance in residential buildings in Cambridge, Hong Kong, and Shanghai. The thermal transmittance of the building envelope is regulated by policies in countries like the UK, where net-zero building envelope is strictly implemented. To reduce cooling load, high thermal admittance values and low thermal transmittance values are recommended [6-8]. The use of computational fluid dynamics (CFD) models has many benefits over other approaches, including the ability to produce full-scale simulations, offer precise statistics at any location on the computational domain, and produce accurate results when utilised in parametric investigations. Inlet and outlet positions of façade openings are crucial for determining the airflow in a naturally ventilated building, together with wall porosity [9-16].

Natural ventilation can provide effective thermal comfort to indoor environment by supplying fresh air and removing aged air present. Natural forces such as wind, buoyancy or a combination of both and the ventilation rates can be calculated by using computational fluid dynamics (CFD) stimulations, building energy stimulation (BES) and multi-zone air flow modelling [17]. Energy consumption under various wind angle conditions were studied in Shenyang using CFD and energy modelling software by sequentially adjusting the angle between the direction of the building and the outdoor wind. When wind direction angles of buildings range from 0° to 45°, energy consumption was found to be steady, and it was lowest at 15° [18].

Effect of PCMs on indoor environment of buildings in hot-humid climate of Malaysia was examined with different temperature transitions and quantities. Reduction in Peak indoor air temperature (T_i) was found with lower melting temperatures and higher quantities, and optimum performance when combining lower melting temperature and night ventilation (NV) due to night coolness storing. Lowest transition temperature led to PCMs complete freezing and hence PCMs freezing temperature should be considered [19].

The thermal comfort of the internal spaces is influenced by the thermal interactions between the building envelope and its surroundings. The architect, builder, and client can be guided by building simulation with the necessary building envelope materials in the early stages of the design to select a smart green building envelope material to deliver an effective thermal solution with low energy usage. Parametric studies and full scale simulations provides specific data at every point on the computational fluid dynamics (CFD) models, it provides accurate results. Thus these models have numerous advantages when compared with other methods [20-25].

This paper gives a complete examination on computational analysis for natural convection in a high-rise naturally ventilated building employing three various building materials—solid concrete block, burnt clay brick, and hollow concrete block. In the problem, Dirichlet Boundary Conditions were used, and the inlet air velocities of 2 m/s and 5 m/s were employed while the maximum temperature and minimum temperature were constant at 30 °C and 23 °C, respectively.

2. Methodology

A computational analysis for natural convection was performed in block-A of a 14 story residential naturally ventilated building in Chennai, a major metropolis in Tamil Nadu, India. Building materials, burnt clay bricks, solid concrete blocks, and hollow concrete blocks were varied in the computational analysis for the exterior façade in the three floors, the lower floor (first floor), mid-floor (seventh floor), and the roof exposed floor (fourteenth floor), and the corresponding indoor temperatures were examined. A comparative analysis was done based on the observations of the three envelope materials in the three floors. The air velocities 1 m/s to 10 m/s were used in the computational analysis and natural heat transfer was investigated at 30 °C and 23 °C.

2.1 Physical model

The REVIT software was used to create the physical model of block- A, block – B, block – C and block- D as shown in Figure 1. The computational domain and geometry shown in Figure 2 was created assuming 5 times the distance from the boundary using STARRCCM+.

Figure 1. REVIT 3D model

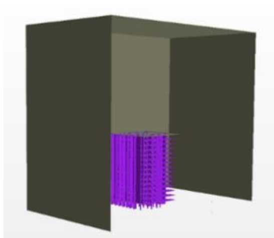


Figure 2. The computational domain and geometry

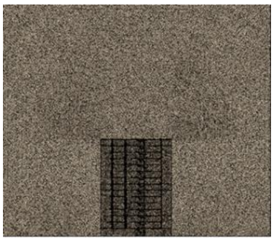


Figure 3. Meshing details

The Grid Independence Study for Block A was performed as shown in Figure 4 for the three floor levels, the first floor, seventh floor, and fourteenth floor to create the geometry. The following assumptions were considered regarding the properties of air: dynamic viscosity of 1.85508E-5 Pa-s, density of 1.18415 kg/m3, specific heat of 1003.62 J/kg-K, thermal conductivity of 0.0260305 W/m-K, Prandtl number of 0.9, and thermal expansion coefficient of 0.0033 /K.

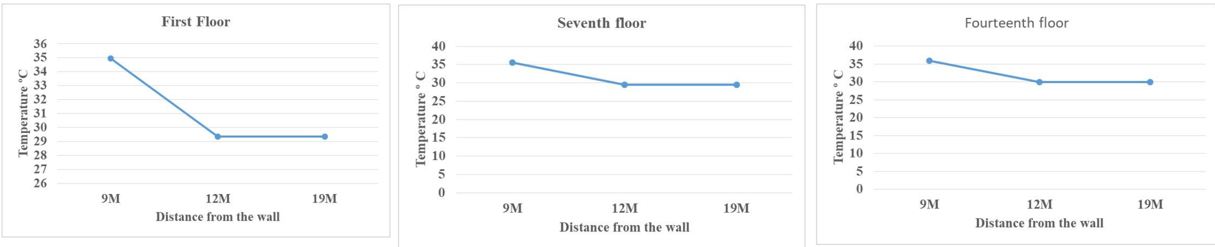


Figure 4. Findings of the grid independence at the first floor, seventh floor and roof exposed floor

3. Results and Discussion

According to the simulation model's results, the thermal resistance and inlet air velocity both had a significant impact on the interior space. The outdoor air velocity 2m/s and 5m/s were assumed from the 30 year wind data collected from the Indian Metrological Department (IMD). The minimum outdoor velocity 1m/s is nil air condition or no air condition. The velocities 8m/s and 10m/s were assumed to check the heat transfer during these conditions. From Figure 5a and Figure 5b it is observed that at 23 ºC and 30 ºC outdoor air temperature, the air velocities at 1m/s and 2m/s, the process of convection is very slow and there is a marginal variation in the indoor air temperature with exterior wall materials SCB and Bk.

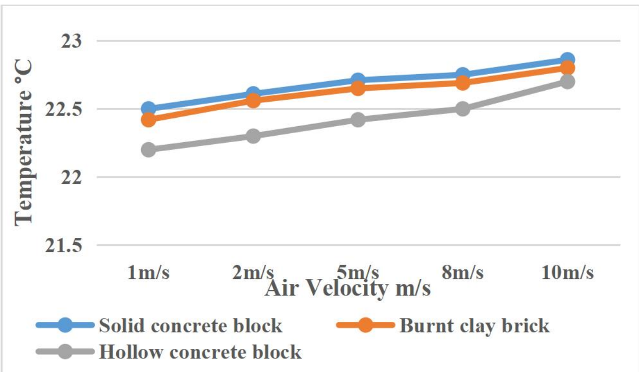


Figure 5a. Lower floor temperature at 23 ºC

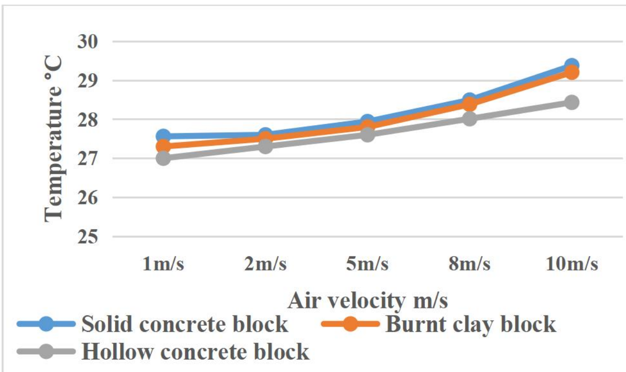


Figure 5 b. Lower floor temperature at 30 ºC

From figure 5c, the indoor temperature at 5m/s in the HCB wall was found to be 0.2 °C to 0.3 °C lower than the SCB and BK walls. However in all cases of air velocities, the air temperature in the indoor spaces of the SCB wall is highest. All most the same condition as Figure 5a is observed in Figure 5c at 23 ºC in the mid - floor. In Figure 5d at 30 ºC it is observed that there is a 0.2 ºC to 0.3 ºC difference between the BK wall and HCB wall through the varied velocities. This condition indicates the effect of height and the corresponding atmospheric conditions around the building. Similarly in the roof exposed floor, from Figure 5e at outdoor temperature is 23º C, it is observed that the temperatures in the indoor spaces of BK and SCB wall have a marginal difference at velocities 2m/s and 5m/s.

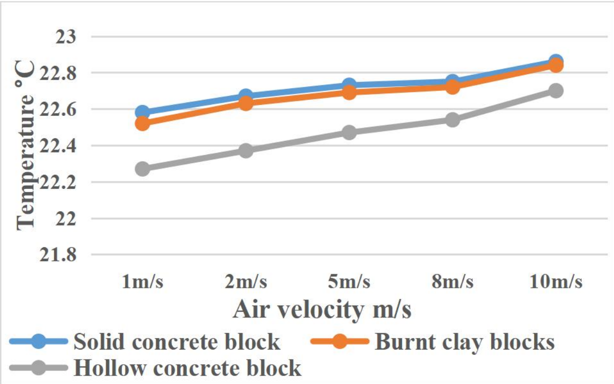


Figure 5c. Mid floor temperature at 23 ºC

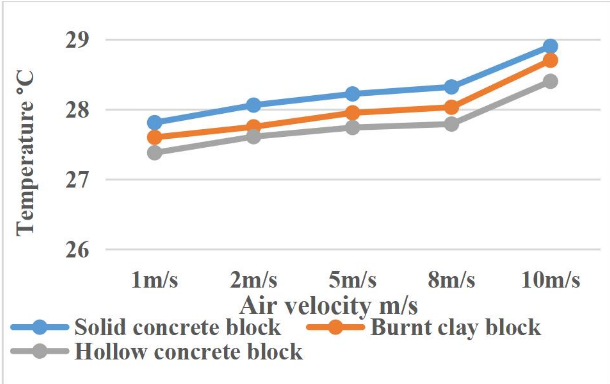


Figure 5d. Mid floor temperature at 30 ºC

From Figure 5f at 10m/s velocity the temperature is high in all the 3 floors at 12 noon. This clear indicates the influence of height over the climatic variables – air temperature and air velocity. However even the minimum difference between the indoor spaces shows the influence of the thermal conductivity and thermal resistivity of the different building materials. SCB has the highest conductivity and low resistivity.

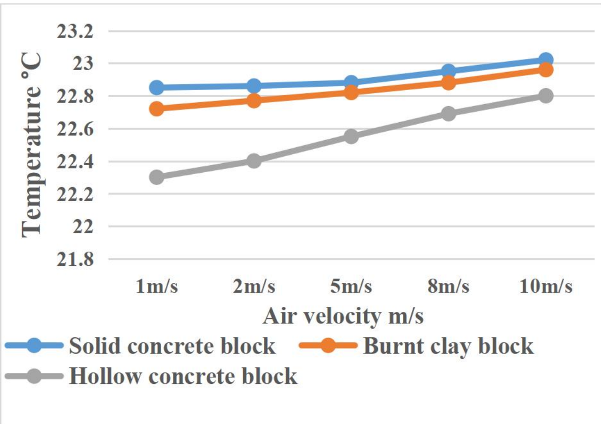


Figure 5e. Roof exposed floor temp. at 23 ºC

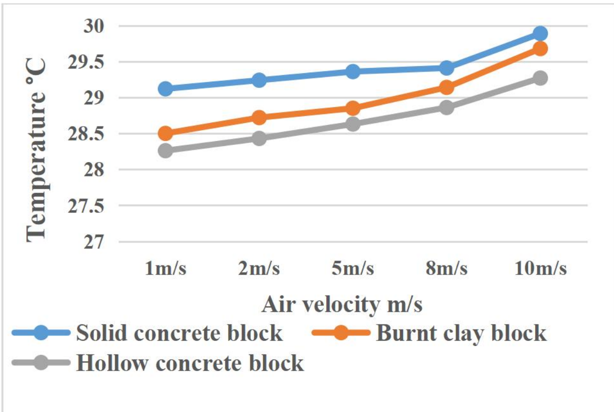
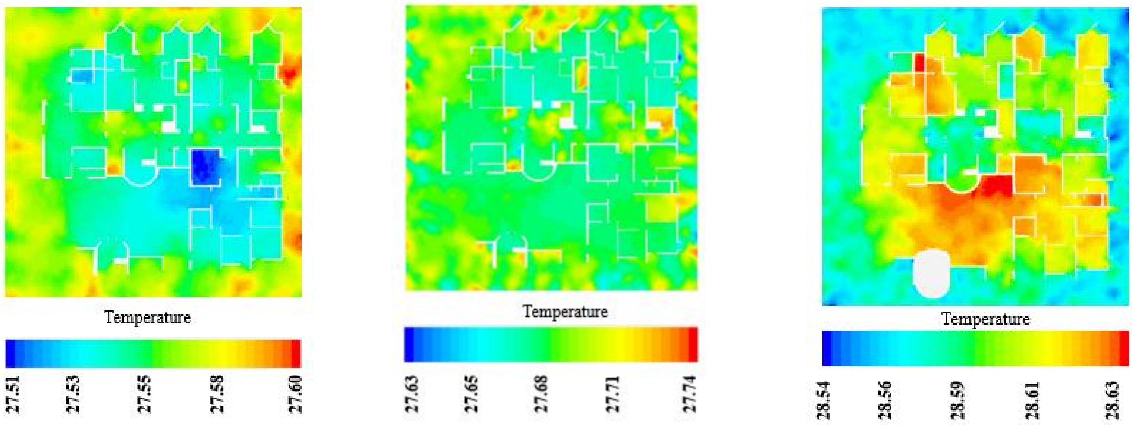


Figure 5f. Roof exposed floor temp. at 30 ºC

The heat transfer plans depicted in Figure 6 indicate that the temperature is higher in areas where the inner air is in touch with the outside environment. When compared to the interior spaces, the sections nearer to window and balcony door openings have a higher temperature and a faster spreading rate. Similar to this, regardless of the materials used for the envelope, it has been noted that where ever air is in contact, particularly through windows, the room temperature is lower than the inlet air temperature. Because of the predominant inflow of air velocity, the dominance of the environment is felt in these indoor spaces.

Hollow concrete block wall



First floor Seventh floor Fourteenth floor

Figure 6. Plan of the heat transfer plots at 30°C with air velocities –5m/s

4. Conclusion

From the simulation analysis it is appreciated that the velocity acts as a catalyst in forced convection to transport the outdoor temperature to the interior parts of the building irrespective of the building envelope material. In comparison to the other floors, the temperature is always higher at the exposed level of the roof. Small pockets of air is inbuilt in the hollow concrete block, which reduces process of heat transfer and apparently the temperature in the indoor spaces is also reduced. Thus, the results clearly indicate that the hollow concrete block building envelope has the least thermal conductivity and higher resistivity when compared to the burnt clay blocks and solid concrete wall envelope and it can be used as sustainable building envelope material for energy efficient naturally ventilated high-rise buildings. The results obtained from the simulation analysis will be very useful for the designers and practicing engineers to achieve energy efficient passive cooling systems.

NOMENCLATURE

IMD Indian Meteorological Department
BEE Bureau of Energy Efficiency
ECBC Energy Conservation Building Code
PCM Phase Change Material
CFD Computational Fluid Dynamics
BK Burnt Clay Bricks
SCB Solid Concrete Block
HCB Hollow Concrete Block

Reference

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