Rajkumar, R., *et al.*: Computational Modelling in a High Rise Building with ...
THERMAL SCIENCE: Year 2023, Vol. 27, No. 6B, pp. 4801-4806

4801

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

by

Rupa RAJKUMAR[a*], Vasanthi PADMANABHAN[a*], Velraj RAMALINGAM[b], and Nagaraj MEENAKSHISUNDARAM[c]

[a] Department of Civil Engineering, School of Infrastructure,
B.S. Abdur Rahman Crescent Institute of Science and Technology,
Chennai, Tamil Nadu, India
[b] Institute for Energy Studies, Anna University, Chennai, Tamil Nadu, India
[c] Institute of Agriculture Engineering, Saveetha School of Engineering,
Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

This research focuses on identifying a sustainable material for building envelope for energy efficacy in naturally ventilated high rise residential buildings through CFD. Convective heat transfer is observed in three levels 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 CFD 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 1 m/s to 10 m/s, were varied and simulated at 12 noon condition. Simulation results reveal, higher indoor temperatures in the roof exposed floor. At 30 °C it is observed that there is a 0.2-0.3 °C temperature 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 is slow and apparently the temperature in the indoor spaces is reduced. Thus, the results clearly indicate that the temperature in the indoor spaces of the hollow block building envelope was comparatively low when compared to the other two building materials.

Key words: *heat transfer, natural-convection, CFD,*
building envelope material, building height

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. The 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

---
* Corresponding authors, e-mail: rupaarajj@gmail.com, vasanthi@crescent.education

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 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 air-flow 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 CFD stimulations, building energy stimulation 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 0-45°, energy consumption was found to be steady, and it was lowest at 15° [18].

Effect of PCM 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 due to night coolness storing. Lowest transition temperature led to PCM complete freezing and hence PCM 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 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 (SCB), burnt clay brick, and hollow concrete block (HCB). In the problem, Dirichlet Boundary Conditions were used, and the inlet air velocities of 1 m/s to 10 m/s were employed while the maximum temperature and minimum temperature were constant at 30 °C and 23 °C, respectively.

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,

Rajkumar, R., *et al.*: Computational Modelling in a High Rise Building with ...
THERMAL SCIENCE: Year 2023, Vol. 27, No. 6B, pp. 4801-4806

4803

India. Building materials, burnt clay bricks (BK), SCB, and HCB 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.

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 fig. 1. The computational domain and geometry shown in fig. 2 was created assuming fiwe times the distance from the boundary using STARCCM+.

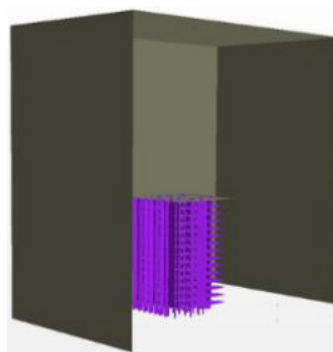
Figure 1. The REVIT 3-D model

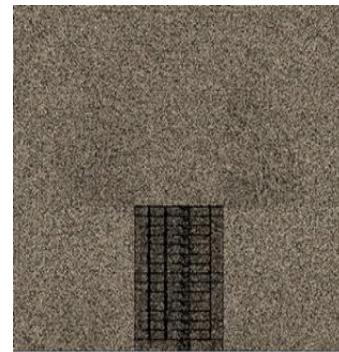**Figure 2. The computational domain and geometry**

Figure 3. Meshing details

The Grid Independence Study for block-A was performed as shown in fig. 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/m^3, specific heat of 1003.62 J/kgK, thermal conductivity of 0.0260305 W/mK, Prandtl number of 0.9, and thermal expansion coefficient of 0.0033 K.
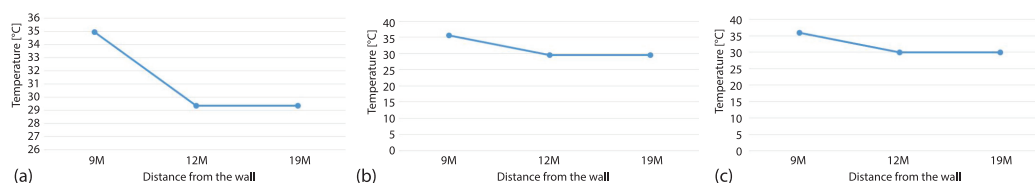

Figure 4. Findings of the grid independence at; (a) the first floor, (b) seventh floor, and (c) roof exposed floor – seventeenth floor

Results and discussion

According to the simulation model, the thermal resistance and inlet air velocity both had a significant impact on the interior space. The outdoor air velocity 2 m/s and 5 m/s were assumed from the 30 year wind data collected from the Indian Metrological Department. The minimum outdoor velocity 1 m/s is nil air condition or no air condition. The velocities 8 m/s and 10 m/s were assumed to check the heat transfer during these conditions. From figs. 5(a) and 5(b) it is observed that at 23 °C and 30 °C outdoor air temperature, the air veloci-

ties at 1 m/s and 2 m/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.

From fig. 5(c), the indoor temperature at 5 m/s in the HCB wall was found to be 0.2-0.3 °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 fig. 5(a) is observed in fig. 5(c) at 23 °C in the mid-floor. In fig. 5(d) at 30 °C it is observed that there is a 0.2-0.3 °C 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 fig. 5(e) at outdoor temperature is 23 °C, it is observed that the temperatures in the indoor spaces of BK and SCB wall have a marginal difference at velocities 2 m/s and 5 m/s.

From fig. 5(f) at 10 m/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. The SCB has the highest conductivity and low resistivity.

The heat transfer plans depicted in fig. 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 spaces 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.
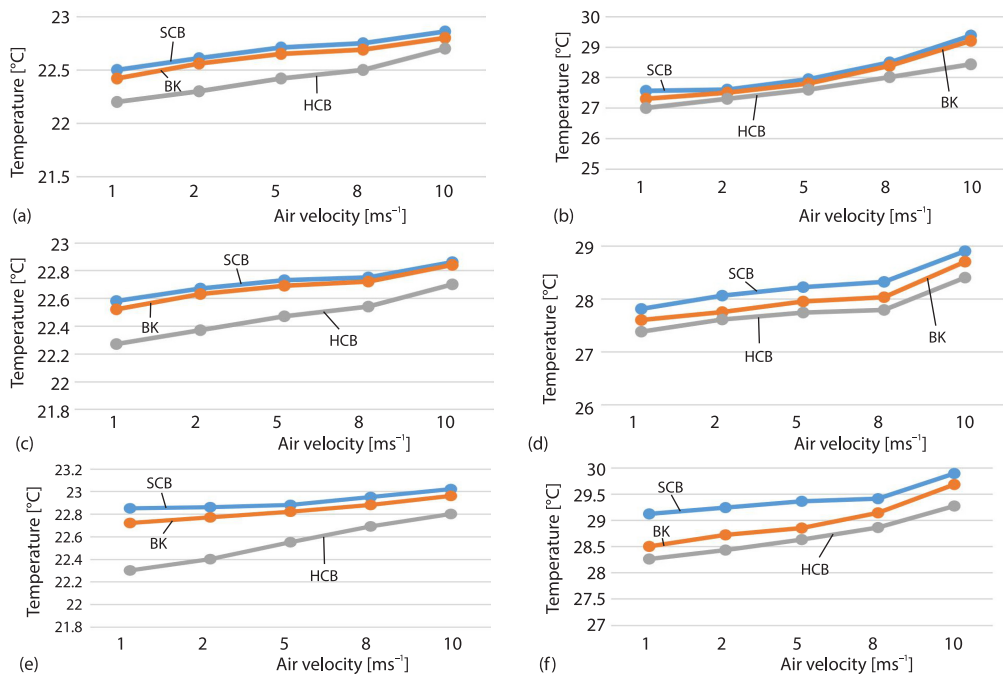

Figure 5. (a) Lower floor temperature at 23 °C, (b) lower floor temperature at 30 °C, (c) mid-floor temperature at 23 ºC, (d) mid-floor temperature at 30 ºC, (e) roof exposed floor temperature at 23 °C, and (f) roof exposed floor temperature at 30 °C

Rajkumar, R., *et al.*: Computational Modelling in a High Rise Building with ...
THERMAL SCIENCE: Year 2023, Vol. 27, No. 6B, pp. 4801-4806
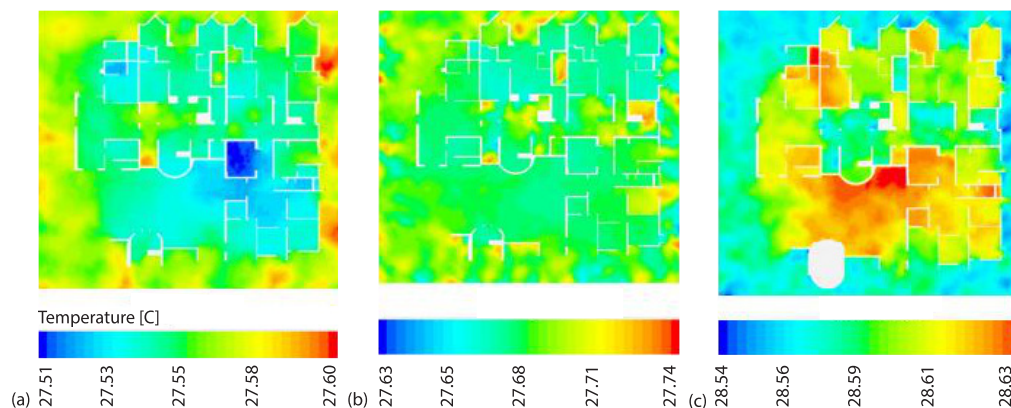
4805

Figure 6. Plan of the heat transfer plots at 30 °C with air velocities – 5 m/s, HCB wall; (a) the 1st floor and (b) the 7th floor, and (c) the 14th floor

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 HCB, which reduces the process of heat transfer and apparently the temperature in the indoor spaces is also reduced. Thus, the results clearly indicate that the HCB 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 building. 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

BK   – burnt clay bricks
HCB – hollow concrete block
SCB – solid concrete block

Reference

[1] Seifert, J., *et al.*, Calculation of Wind-Driven Cross Ventilation in Buildings With Large Openings, *Journal Wind Eng. Ind. Aerodyn.*, *94* (2006), 12, pp. 925-947
[2] Gourav, K., *et al.*, Studies Into Structural and Thermal Properties of Building Envelope Materials, *Energy Procedia*, *122* (2017), Sept., pp. 104-108
[3] Aflaki, A., *et al.*, A Review on Natural Ventilation Applications through Building Façade Components and Ventilation Openings in Tropical Climates, *Energy Build.*, *101* (2015), Aug., pp. 153-162
[4] Wang, Z., *et al.*,A Field Study of The Thermal Comfort in Residential Buildings in Harbin, *Build. Environ.*, *41* (2006), 8, pp. 1034-1039
[5] Suresh, B., *et al.*., Passive Building Energy Savings: A Review of Building Envelope Components, *Renewable and Sustainable Energy Reviews*, *15* (2011), 8, pp. 3617-3631
[6]   Cheung, J. O. P., Liu, C. H., The CFD Simulations of Natural Ventilation Behaviour in High-Rise Buildings in Regular and Staggered Arrangements at Various Spacings, *Energy Build.*, *43* (2011), 5, pp. 1149-1158
[7] Sheng, W., *et al*., Envelope Performance of Residential Building in Cool, Warm and Hot Climatic Zones: Results from Self-Designed in-Situ Monitoring Campaigns, *Energy and Buildings*, *232* (2021), 110655

4806

Rajkumar, R., *et al*.: Computational Modelling in a High Rise Building with ...
THERMAL SCIENCE: Year 2023, Vol. 27, No. 6B, pp. 4801-4806

[8] Wu, H., *et al*., Engineering a Superinsulating Wall with a Beneficial Thermal Non-Uniformity Factor to Improve Building Energy Efficiency, *Energy and Buildings*, *256* (2022), 111680

[9] Office, C. S., Energy Statistics, Cent. Stat. Off. Minist. Stat. Program Implement, Gov. INDIA, *24* (2017), 109

[10] Van Hooff, T., Blocken, B., Coupled Urban Wind Flow and Indoor Natural Ventilation Modelling on a High Resolution Grid: A case stfor The Amsterdam Arena Stadium, *Environ Modell Softwer*, *25* (2010), 1, pp. 51-65

[11] Kato, S., *et al*., Velocity-Pressure Field of Cross Ventilation with Open Windows Analyzed by Wind Tunnel and Numerical Simulation, *Journal of Wind Engineering and Industrial Aerodynamics*, *44* (1992), 1-3, pp. 2575-86

[12] Jiang, Y., *et al*., Natural Ventilation in Buildings: Measurement in a Wind Tunnel and Numerical Simulation with Large-Eddy Simulation, *Journal of Wind Engineering and Industrial Aerodynamics*, *91* (2003), 3, pp. 331-353

[13] Heiselberg, P., *et al*., Experimental and CFD Evidence of Multiple Solutions in a Naturally Ventilated Building, *Indoor Air*, *14* (2004), 1, pp. 43-54

[14] Etheridge, D. W., Sandberg, M., *Building Ventilation: Theory and Measurement*, John Wiley and Sons, Chichester, New York, USA, 1996

[15] Evola, G., Popov, V., Computational Analysis of Wind Driven Natural Ventilation in Buildings, *Energy Build*, *38* (2006), 5, pp. 491-501

[16] Blocken, B., *et al*., Computational Analysis of the Performance of a Venturishaped Roof for Natural Ventilation: Venturi-Effect vs. Wind-Blocking Effect, *Comput Fluids*, *48* (2011), 1, pp. 202-213

[17] Weerasuriya, A. U., *et al*., The 26 A Holistic Framework to Utilize Natural Ventilation Optimize Energy Performance of Residential High-Rise Buildings, *Building and Environment*, *153* (2019), Apr., pp. 218-232

[18] Huifen, Z., *et al*., Research on the Impact of Wind Angles on the Residential Building Energy Consumption, *Mathematical Problems in Engineering*, *2014* (2014), ID794650

[19] Al-Absi, Z. A., et al., Case Studies, *Thermal Engineering*, *22* (2020), 100762

[20] Jiang, Y., *et al*., Natural Ventilation in Buildings: Measurement in a Wind Tunnel and Numerical Simulation with Large-Eddy Simulation, *Journal Wind Eng. Ind. Aerodyn.*, *91* (2003), 3, pp. 331-353

[21] Sivaprakash, M., *et al*., Support Vector Machine for Modelling and Simulation of Heat Exchangers, *Thermal Science*, *24* (2020), 1B, pp. 499-503

[22] Haribabu, K., *et al*., Investigation of Air Conditioning Temperature Variation by Modifying the Structure of Passenger Car Using Computational Fluid Dynamics, *Thermal Science*, *24* (2020), 1B, pp. 495-498

[23] Sathish, T., *et al*., Teaching Learning Optimization and Neural Network for the Effective Prediction of Heat Transfer Rates in Tube Heat Exchangers, *Thermal Science*, *24* (2020), 1B, pp. 575-581

[24] Sakthivel, P., *et al*., Experimental Study about Thermal Resistance of Windows with Air Gap between Two Glasses Used in Single Houses, *Thermal Science*, *24* (2020), 1B, pp. 575-581

[25] Saravanan, P., *et al*., An Experimental Investigation on a Low Heat Rejection Diesel Engine Using Waste Plastic Oil with Different Injection Timing, *Thermal Science*, *24* (2020), 1B, pp. 453-461