NATURAL VENTILATION AROUND OPEN GROUND FLOORS WITH PILOTIS IN HIGH-RISE RESIDENTIAL BUILDINGS IN TROPICAL AREAS: HARMONIZATION OF MODERN AND TRADITIONAL HOUSING IN TROPICAL AREAS

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Introduction

In Malaysian villages, traditional Malay houses are the most common type of housing. One of the main features of these traditional houses, which are located in hot and humid areas of Malaysia, is an open ground floor created by using pilotis, which raises the first floor of the house, leaving the ground floor open (Fig. 1). Thus, a shaded free space with good air circulation is obtained, which can be used by residents and their neighbors for working and leisure activities.

These traditional Malay houses are not suitable for cities because the availability of land in urban areas is limited. Although high-rise residential buildings accommodate a large number of residents in a limited area, and the airflow on the higher floors of these buildings is adequate, the fact that sufficient airflow cannot be expected near the ground floor must be taken into consideration.

On the other hand, residents need space for many social activities, even in a city. The open ground floor is popular in Malaysia because it provides a common area for social activities, such as wedding receptions, a play area for children, social interactions, and so on (Fig. 2).

Fig. 1: Open ground floor of traditional Malay house

a. A wedding reception b. A children's playground c. A communal area

Fig. 2: An open ground floor underneath a high-rise residential building is used for multifunctional activities.

The open ground floor was first used by Le Carbousier in two of his well-known projects, (i.e., the Unitéd d'Habitation Marseilles [1] and Pavillion Sussie, Cité Universitaire, Paris [2]). The open ground floor was formed by constructing pilotis, which raises the first floor, and thus the ground floor remains open. The free space is designed to provide a shaded communal area with good air circulation, which can be used for parking vehicles or for other purposes. Like Le Carbousier, today's housing designers do not take into consideration cross ventilation when designing high-rise buildings. Airflow may be disadvantageous depending on the climate.

Object of Research

In this paper, we propose using pilotis in tropical urban areas to harmonize the benefits of modern and traditional housing.

The thermal and airflow conditions of a building that has pilotis are compared with those of a building that does not have pilotis, and we examine how the thermal and airflow conditions near the ground floor of the high-rise building can be improved by constructing the pilotis. Furthermore, the notion that natural ventilation on the upper floors is not seriously worsened by constructing pilotis is also examined by computational fluid dynamics (CFD) analysis.

Numerical Calculation of Flow Field around High-Rise Building

Simplified building configuration and CFD simulation

The simplified building configuration used in the CFD simulation was based on the basic typology of an existing high-rise building [3]. Two sets of simplified building configurations were prepared. The first building did not have pilotis and was identified as Test Building 1 (TB1), while the second building (Figs. 3 and 4) that had pilotis was identified as Test Building 2 (TB2). TB1 was used as the reference building to evaluate the effect of the pilotis.

The software used in this research was Star-CD. The building was located within an overall domain with a size of 318 m (width) × 450 m (length) × 240 m (height) (Fig. 5).

The conditions for a site located in the hot, humid, tropical Kuala Lumpur urban area are as follows:

a. Both high-rise and low-rise buildings are present throughout the Kuala Lumpur urban area. Therefore, the empirical exponent (α) is 0.40–0.67, the roughness length (Z_o) is ≥ 2.0 m, and the gradient height (Z_g) is 460 m [4].

b. The reference wind speed is considered to be 1.0 m/s at a reference height of 10 m. This reference wind is estimated using the log law equation and the corrected wind data of Subang meteorological station.

Kuala Lumpur can be described as a city center with high- and low-rise buildings. Therefore, Z_o of 2.0 is used [4]. The *k-ε* model (standard KE) is adopted [5].

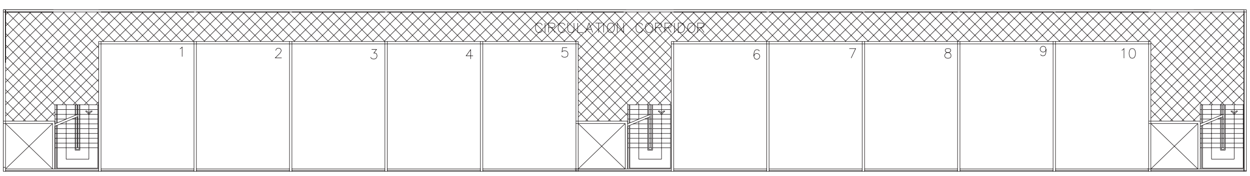


Fig. 3: Typical floor plan of test buildings, TB1 and TB2

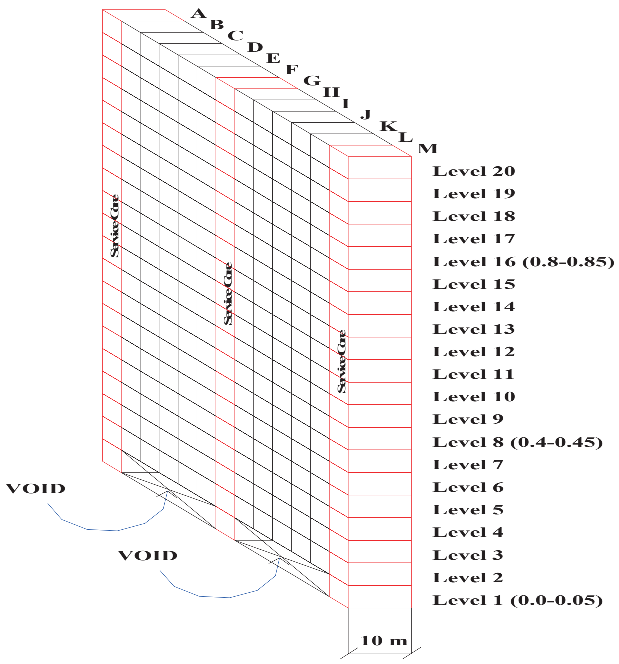


Fig. 4: Building with pilotis (TB2)

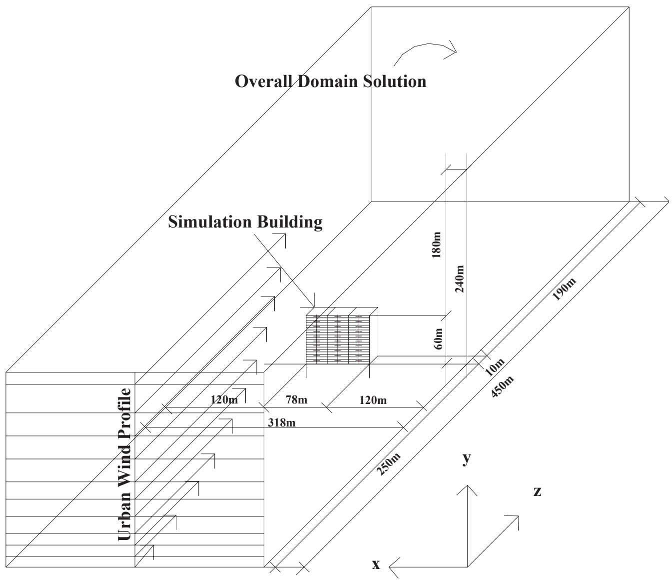


Fig. 5: Overall simulation modeling

Results of CFD Calculation

Horizontal airflow distribution at ground level around buildings with and without pilotis

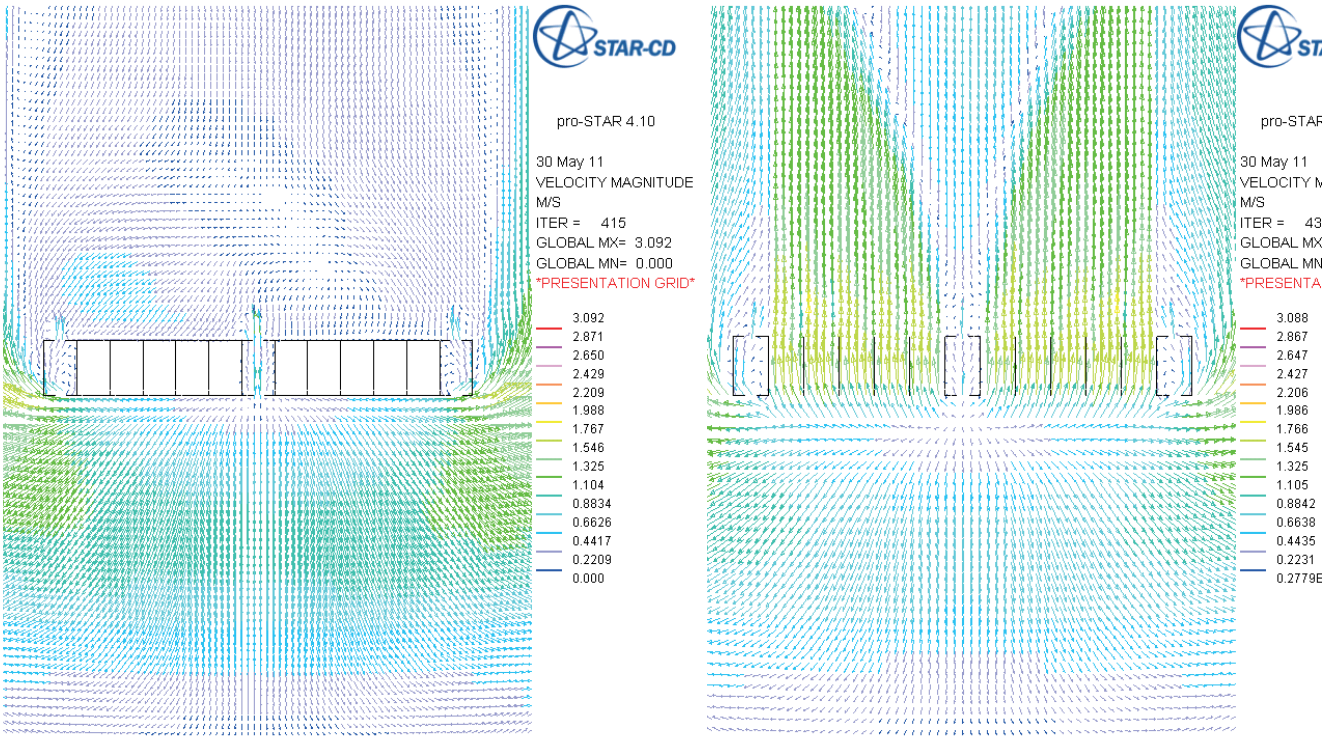
Figure 6 shows the wind speed distributions around the buildings. The left figure shows the results in a building without pilotis, while the right figure shows the results in a building with pilotis. In the building without pilotis, strong wind regions appear in the windward and both sides of the building. On the contrary, the air velocity in the leeward area is very low. Since most of the region in the vicinity of the building is exposed to very weak airflow; sufficient natural ventilation cannot be expected at ground level. At the same time, on both sides of the building, people may suffer from non-uniform wind velocity when walking.

In contrast, a relatively high speed of airflow can be expected at ground level in the building with pilotis. The narrow areas with non-uniform velocity distribution on both sides of the building disappear, and rather large areas with a relatively uniform air velocity distribution can be formed. Along with the ground level of the building, we can also find an area with a relatively strong and uniform airflow in the leeward. At certain times of the day when the sunlight is diminished, people can enjoy a breeze blowing through the shaded area [6].

Vertical airflow distribution around buildings with and without pilotis

In Figure 7, the vertical distributions of airflow are shown around and inside both buildings without (left) and with (right) pilotis.

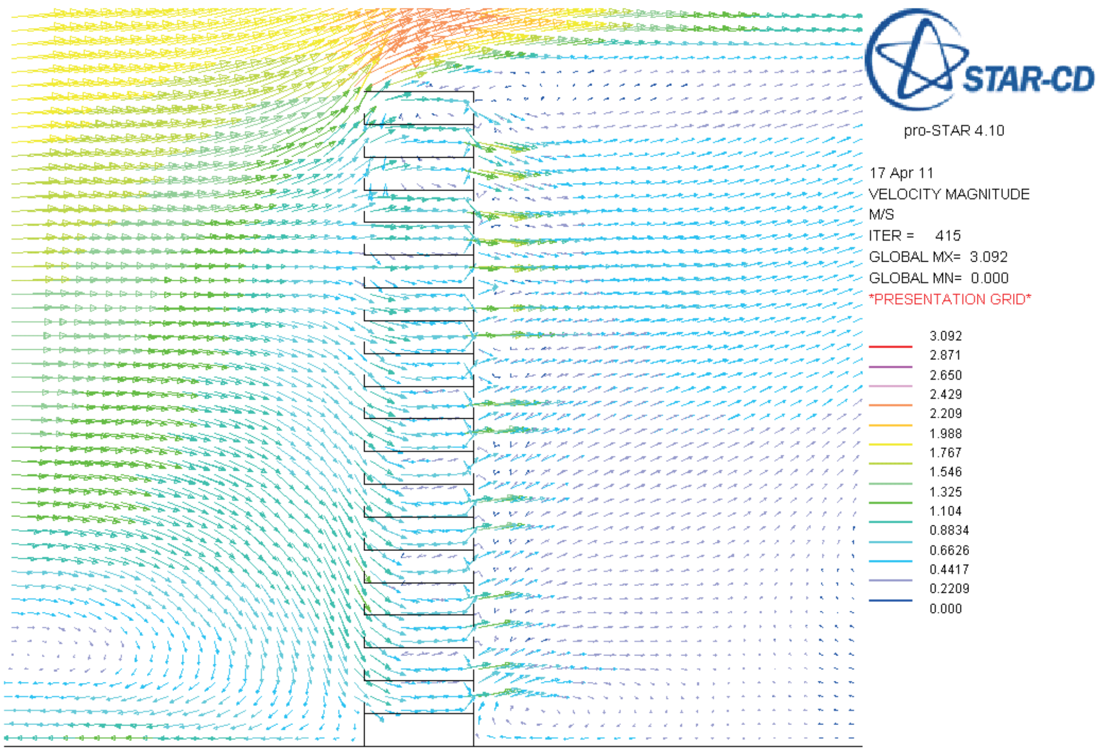
The air velocity in the windward rises higher in the building and is highest at the top of the building. Near the ground level, the wind becomes stronger in the building with pilotis than in the one without. The airflow inside the building with pilotis is only



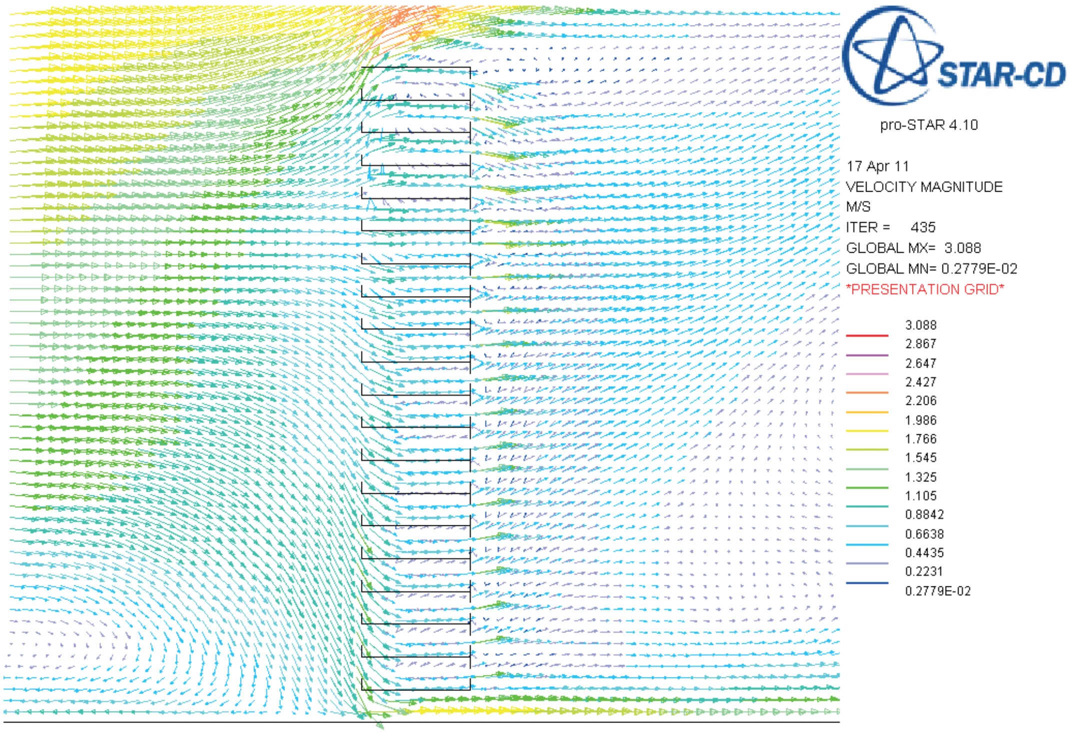
a. Without pilotis

b. With pilotis

Fig. 6: Horizontal velocity distribution around building (1.5m above ground level)



a. Without pilotis



b. With pilotis

Fig. 7: Vertical distribution of airflow around and inside buildings

slightly different from that in the building without pilotis. A nearly uniform air velocity of approximately I m/s is obtained on all floors, and thus a sufficient natural ventilation can be expected. It means that the construction of the pilotis inflicts no serious damage on floors other than the ground floor.

The large amount of wind energy flowing on both sides of the building, which is not used for ventilation in buildings without pilotis, can be effectively utilized for natural ventilation on the ground floor by constructing the pilotis. The pilotis also works for reducing very strong airflow, which sometimes makes it difficult for pedestrians to walk around the building.

Conclusions

The concept of an open ground floor with pilotis, which was incorporated in traditional Malay houses and used by Carbousier in his first high-rise building, can be applied in the design of new modern high-rise residential buildings. By introducing pilotis in high-rise residential buildings, the microclimate of the space becomes pleasant because of the airflow, which can offset the heat; furthermore, the additional space on the ground floor is already shaded. Results of simulation show that the internal air velocity in areas near or above an open floor is better than that in buildings without an open floor. The air velocity is around 1.0 m/s, which is within the acceptable range for thermal comfort of the Malaysian people. Incorporating this traditional concept results in harmonization between modern high-rise building designs and traditional building designs of tropical areas. Furthermore, there is optimal utilization of the available space as public and common space for communal activities, which is not possible in the case of enclosed public spaces. This same concept can also be applied in the design of high-rise buildings in regions in Asia, Africa, and America that have similar hot and humid climatic conditions.

References

[1] Jenger, J. (1996). *Le Corbousier: Architect of A New Age*. London: Thames and Hudson.

[2] Baker, G.H. (1996). *Le Corbusier: An Analysis of Form*. New York: Van Nostrand Reinhold.

[3] Abdul Razak Sapian (2009), *Validation of The Computational Fluid Dynamics (CFD) Method for Predicting Wind Flow Around A High-Rise Building (HRB) in an Urban Boundary Layer Condition.* Journal of Construction in Developing Countries. ISSBN: 1823-6499, eISSBN: 1985-8329, Vol. 14 No. 2 (2009).

[4] American Society of Civil Engineers (ASCE) (1999). *Wind Tunnel Studies of Buildings and Structures*. ASCE Manuals and Reports on Engineering Practice No. 67. USA.

[5] Blocken B. and Carmeliet J. (2004), *A review of wind-driven rain research in building science*, Journal of Wind Engineering and Industrial Aerodynamics, 9213, PP.1079-1130.

[6] Noor Hanita Abdul Majid & Abdul Razak Sapian (2000). *Air Movement Pattern and Behaviour at Tropical Urban Plazas Adjacent To Tall Buildings: A Case Study of Kuala Lumpur.* Proceedings Sustainable Environmental Architecture, International Seminar, 23 - 24 October 2000, Surabaya, Indonesia.