Natural ventilation around open ground floor with pilotis in high-rise residential buildings in tropical areas

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Introduction

Ventilation affects the air temperature and relative humidity within the building

⇒it affects the health and comfort of the occupants, especially in hot and humid countries like Malaysia.

Wind-induced natural ventilation is influenced by the wind conditions.

However, architectural factors such as an open ground floor of a building also influence natural ventilation.

Architectural design promoting natural ventilation in traditional Malays House

In Malay houses, several architectural design elements are included for promoting natural ventilation.

a. External balcony with a projection that provides shade and promotes natural ventilation.

b. Optimized window size, position, orientation, and control that promotes natural ventilation.

c. Open ground floor (Pilotis) that improves natural ventilation.

Wind-induced cross ventilation in high-rise residential buildings

However, these design elements are not incorporated in the designs of modern housing such as terrace houses and high-rise residential buildings,
which are preferred today because of rapid urban development and the limited availability and high cost of land.

In high-rise residential buildings, the airflow at the higher floors is sufficient.

Open ground floor (Pilotis)

Pilotis provides an open ground floor for use as children's play area or a communal area for social activities. ⇒an open space underneath a building is pleasant in hot and humid climate because shaded with good air circulation.

a. Vehicle-parking area

b. An area for walking

c. A children playground

d. A communal area

e. Area for social meetings

f. Wedding reception

Objectives

The open ground floor was first used by Le Carbousier.

Free space is designed to provide a shaded communal area with good air circulation, which can be used for parking vehicles etc.

Airflow may be disadvantageous depending on the climate.

Acceleration of wind in an open floor would be high, resulting in cross-flow of air.
This cross-flow modifies the vertical pressure distribution around a high-rise building and affects the wind flow and natural ventilation.

In this study,

- Role of pilotis in improving the thermal and airflow conditions near the ground floor of a high-rise building is examined.
- Effect of pilotis on the natural ventilation in the upper floors is also examined by computational fluid dynamics.

Numerical calculation of pressure distribution around high-rise building

Procedures

- CFD simulation for estimating the vertical pressure distribution and the wind flow.
- Internal-air velocity is predicted using an empirical method; the pressure estimated by the CFD simulation is used:

$$V_{pi} = C_d \times [V_{ref}^2 \times (\Delta Cp)]^{0.5}$$

where

V_{pi} : internal-air velocity (m/s) to be predicted,

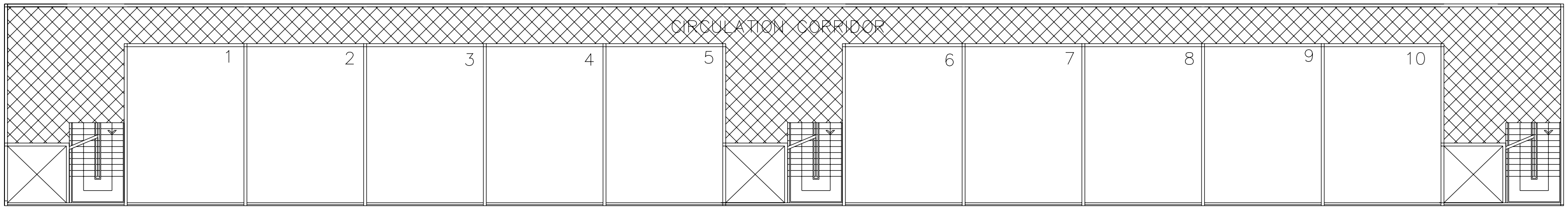
C_d :discharge coefficient,

Vref : air velocity (m/s) at a reference height (10 m),

ΔCp *:* difference between the pressure coefficients in the windward and in the leeward facades (Cp difference).

Simulated building configuration 1

Simplified building configuration used in the CFD simulation was based on the basic typology of an existing high-rise building.



Typical floor plan of test buildings

Simplified building configuration 2

Two sets of simplified building configurations were prepared.

- first building : not having pilotis

  Test Building 1 (TB1),
- second building : having pilotis

  Test Building 2 (TB2).

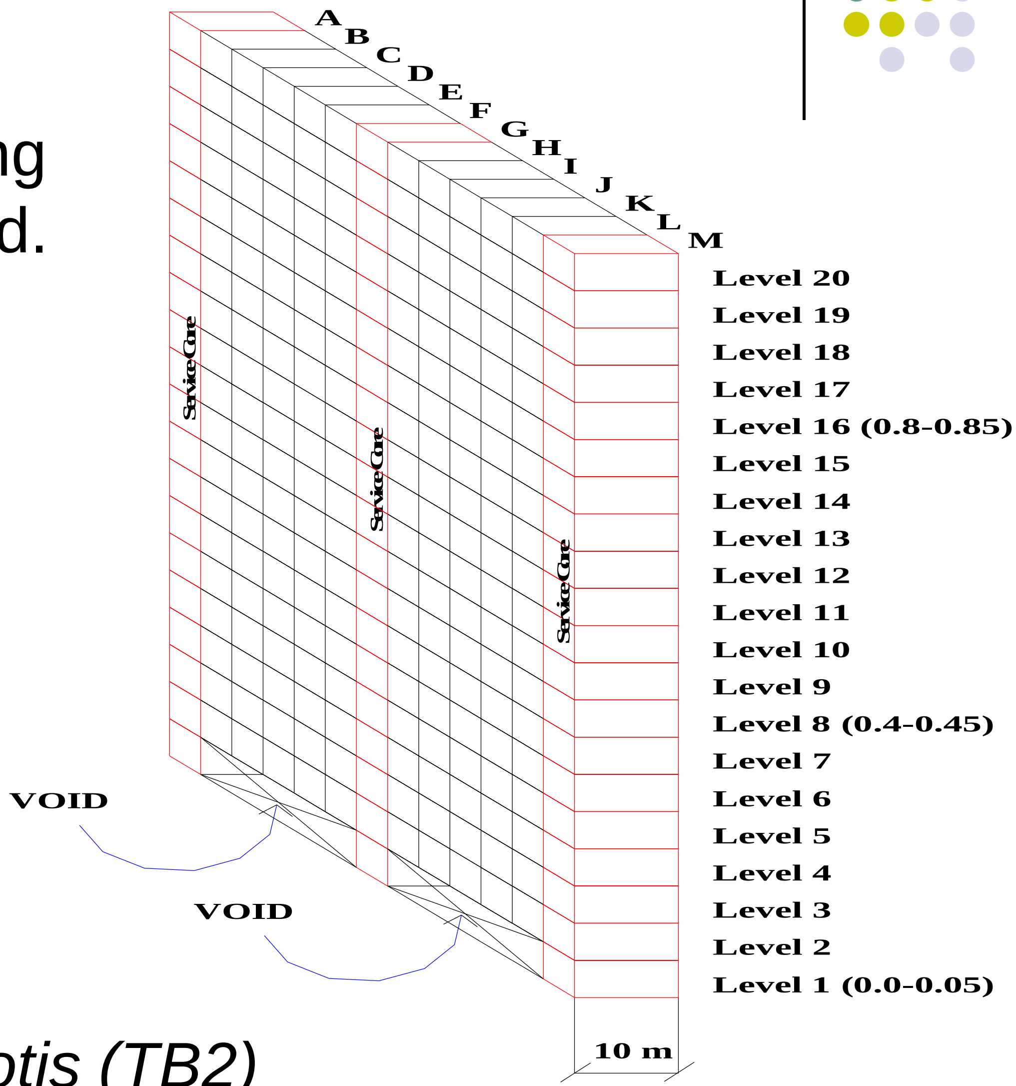


FIG. 4. Building with pilotis (TB2)

Calculated domain

The software used in this research was FloVent.

The building was located within an overall domain with a size of
318 m (width) ×
450 m (length)×
240 m (height)

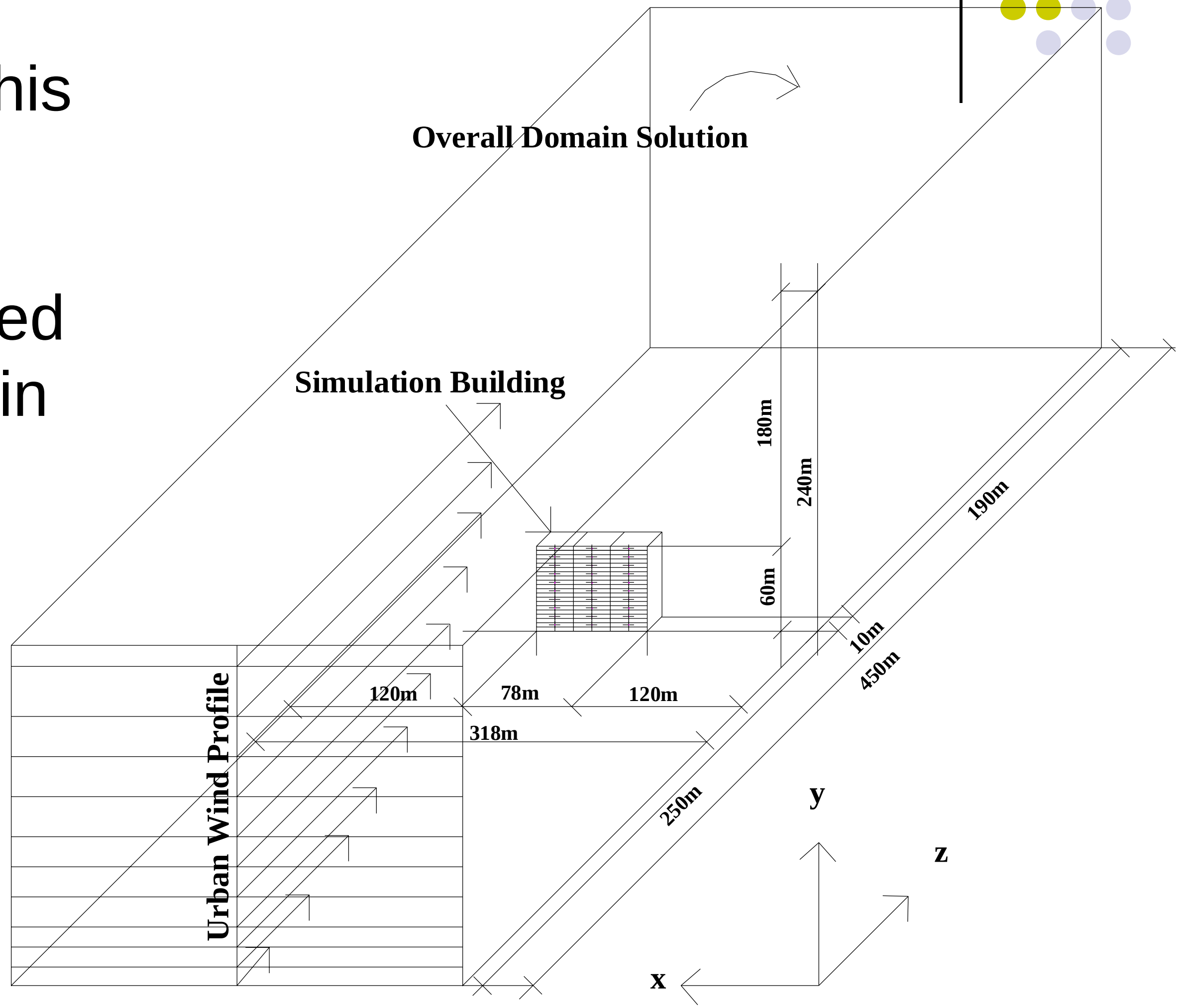


FIG. 5. Overall simulation modeling

CFD simulation

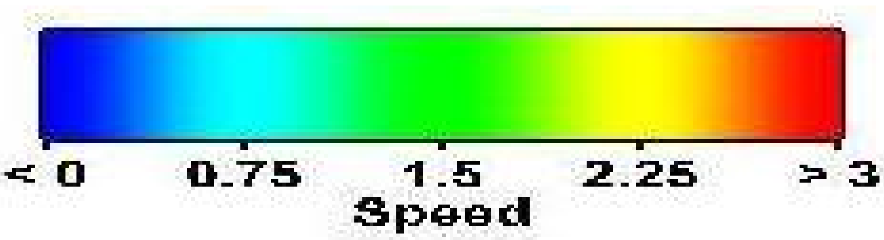
Site conditions : Kuala Lumpur urban area

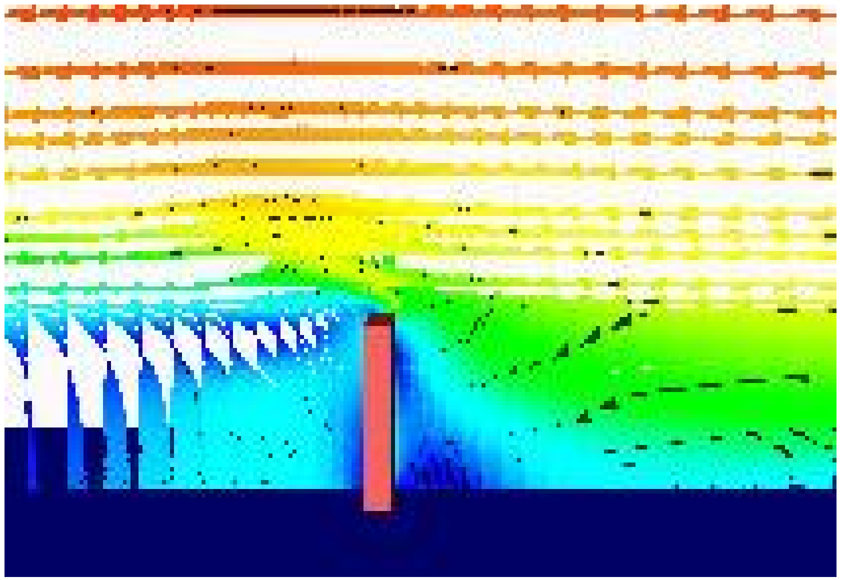
a. Both high-rise and low-rise buildings are present throughout the Kuala Lumpur urban area.
   empirical exponent (α) is 0.40–0.67,
   roughness length (Z_o) is ≥2.0 m,
   gradient height (Z_g) is 460 m.

b. The reference wind speed is considered to be 1.0 m/s at a reference height of 10 m, which is estimated using the corrected wind data of Subang meteorological station.

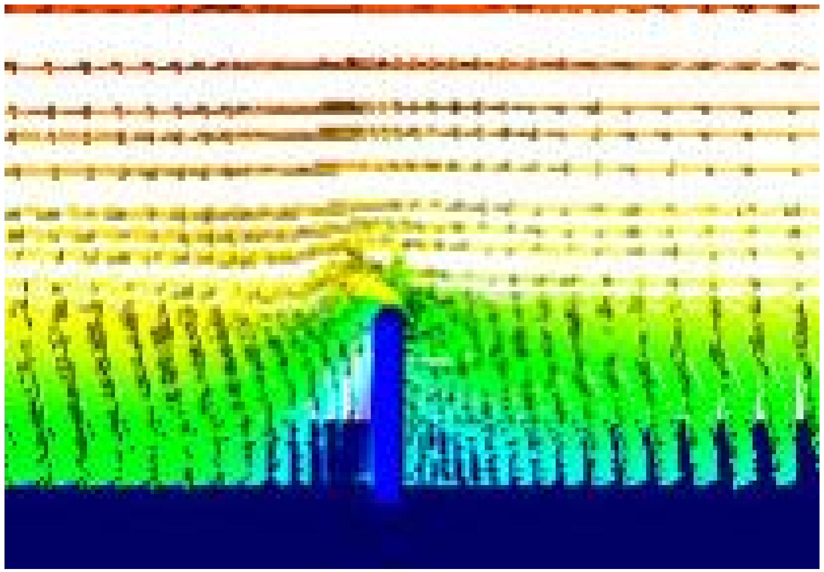
The standard k-ε model (standard KE) is adopted.

TB1 : Building Without Pilotis
wind speed distribution





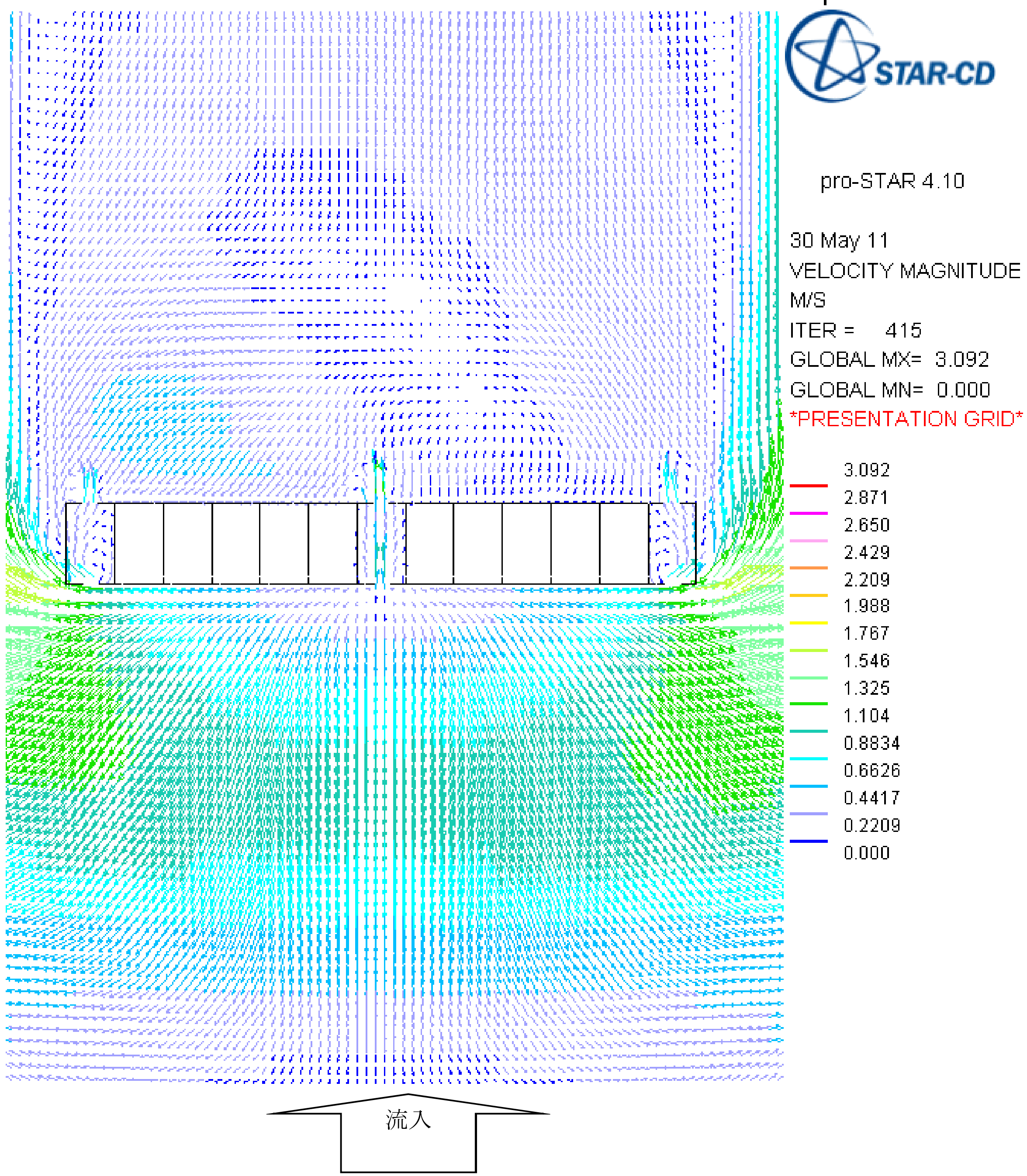
0º Wind Direction



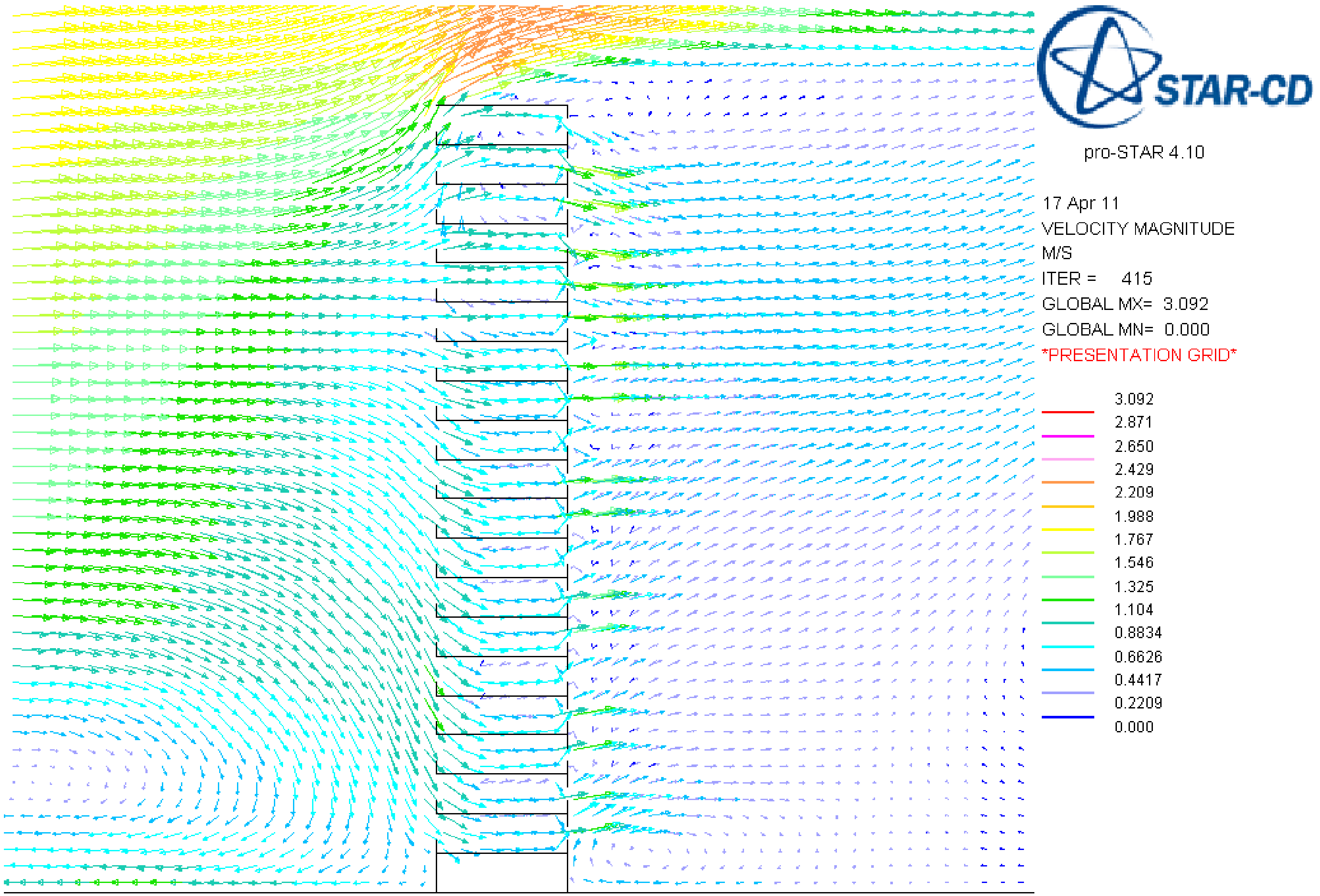
45º Wind Direction

Wind Speed Distribution (horizontal plane)

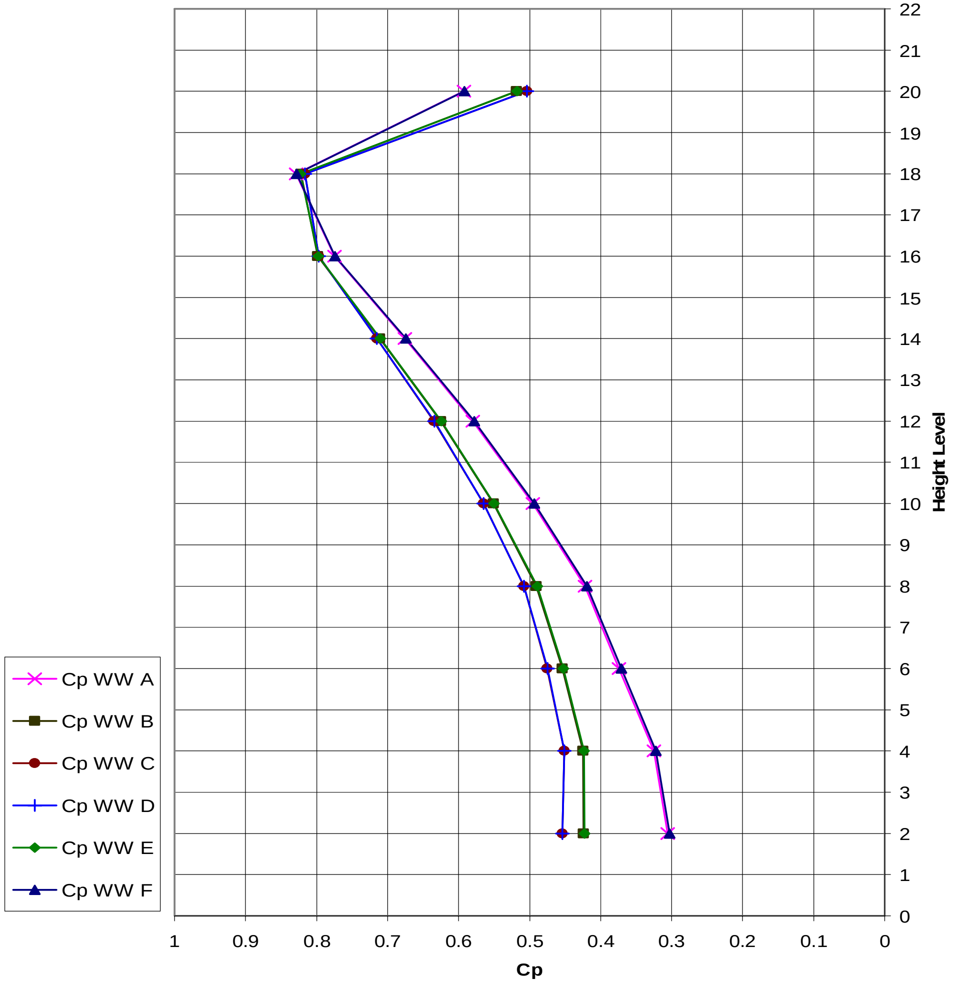
Building without Pilotis (TB1)



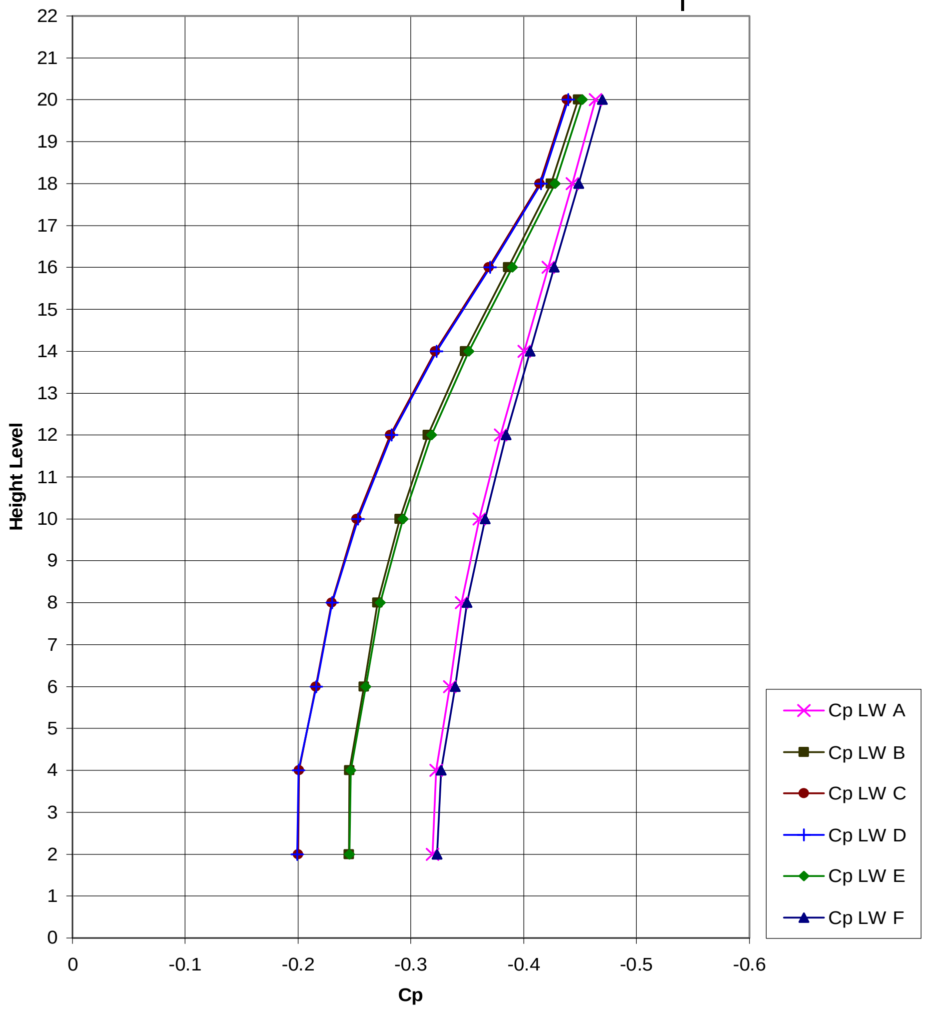
Wind Speed Distribution (vertical section) without Pilotis (TB1)



Vertical distribution of the Cp values corresponding to 0°



Windward



Leeward

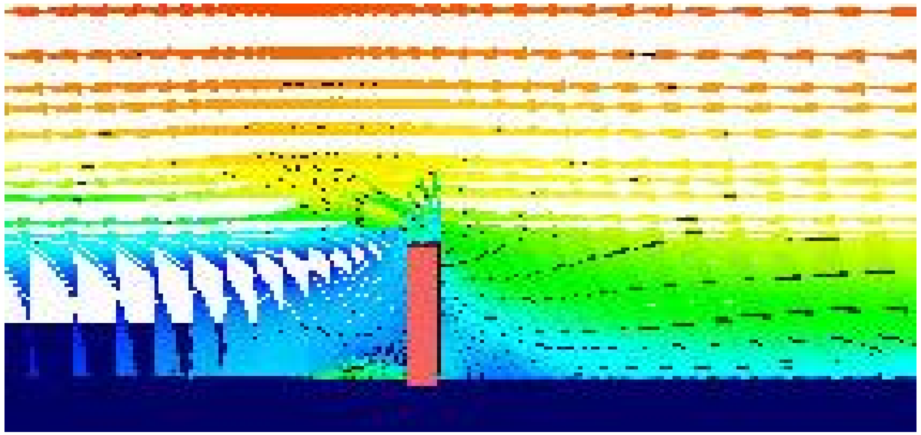
In the case of the 0°wind direction

- On the windward side, the Cp value is highest at floor 18 (around 0.82 to 0.83).
- The Cp value is highest at the center and decreases from the centre to the sides of the building.
- At the leeward façade, the maximum suction is observed at floor 20 (top) of the building (Cp = -0.44 to -0.47), and it decreases towards the lower floors of the building.

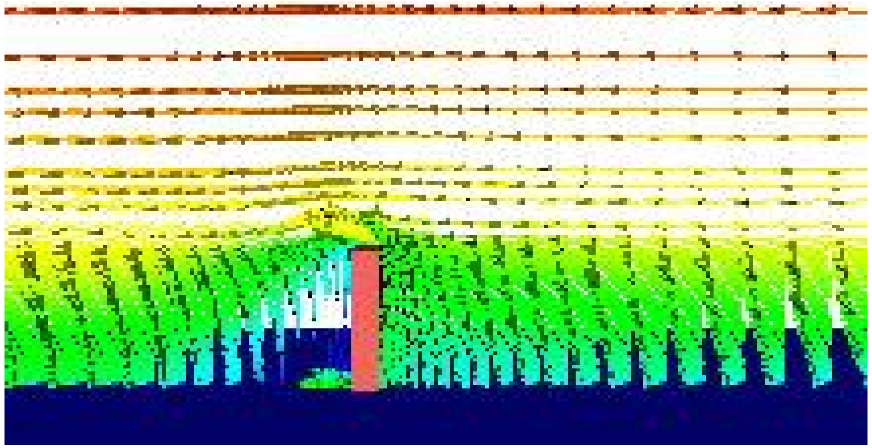
TB2 :Building with Pilotis

Wind speed distributions

Wind speed distributions corresponding to the 0°and 45°wind directions



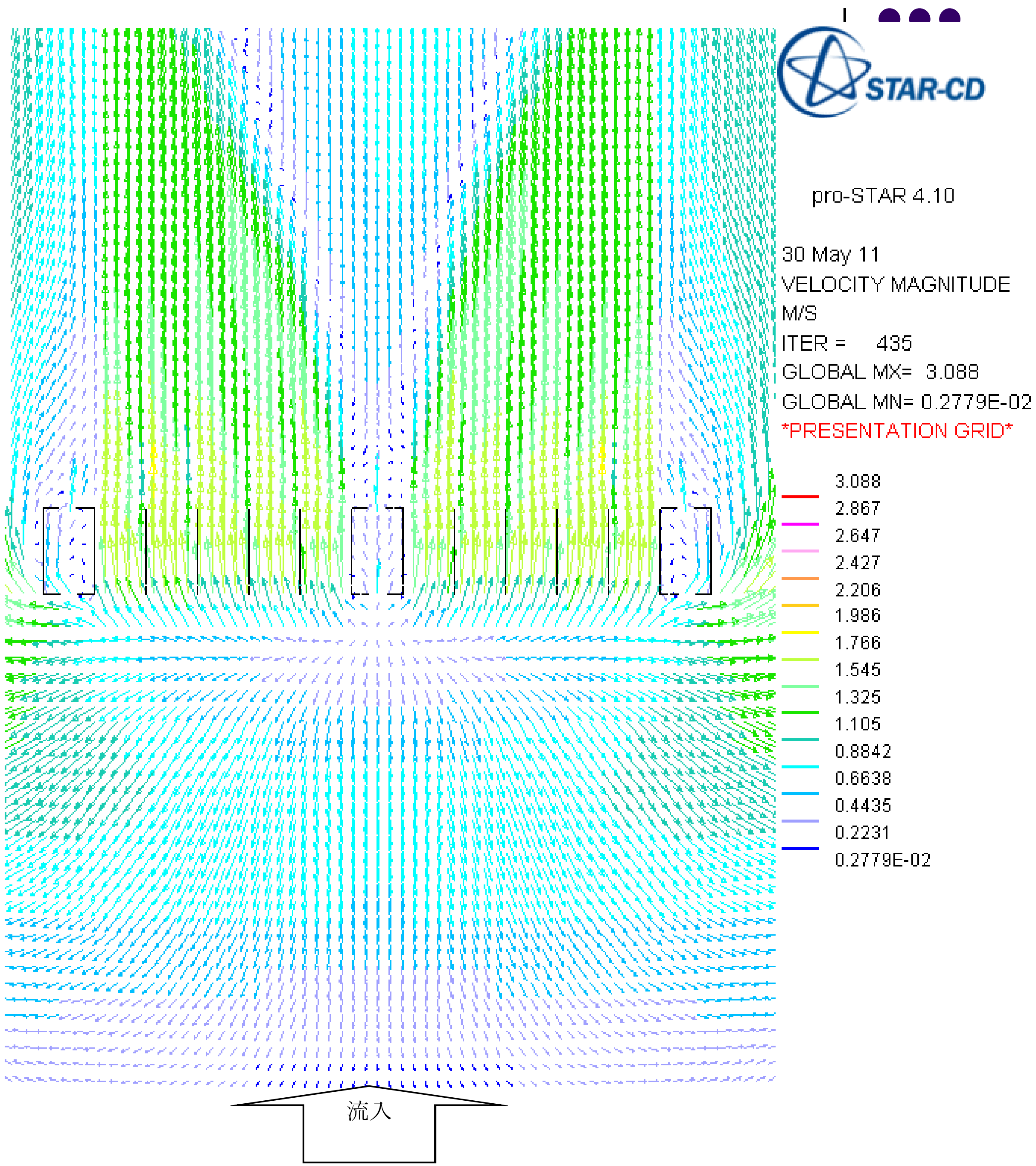
0º Wind Direction



45º Wind Direction

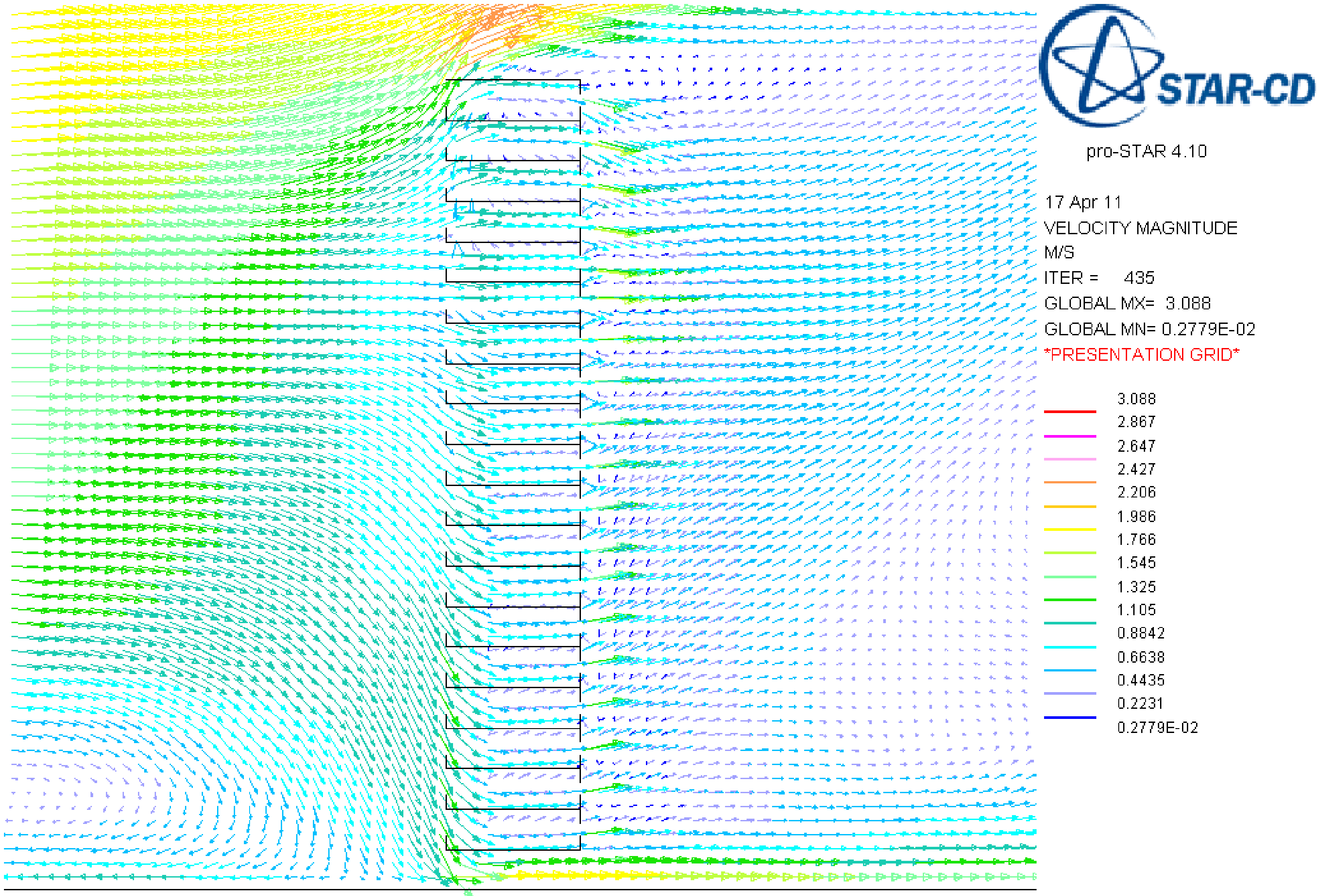
Wind Speed Distribution (horizontal plane)

Building with Pilotis (TB2)

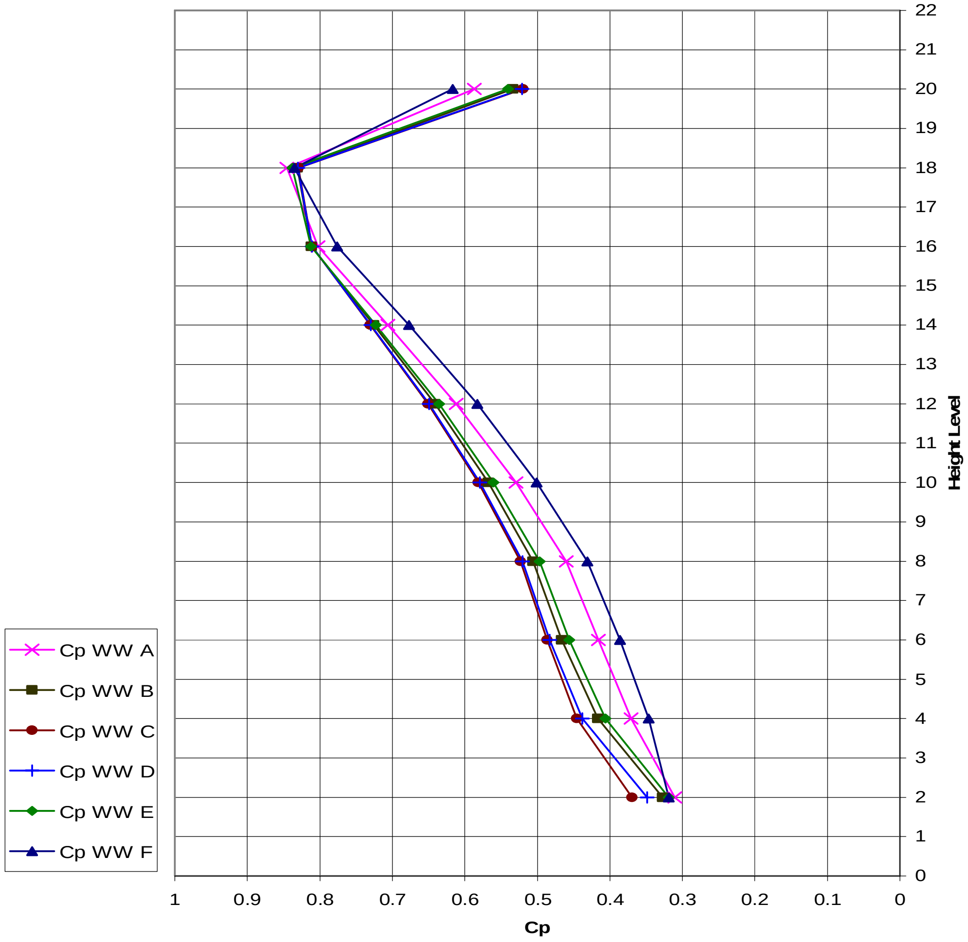


Wind Speed Distribution

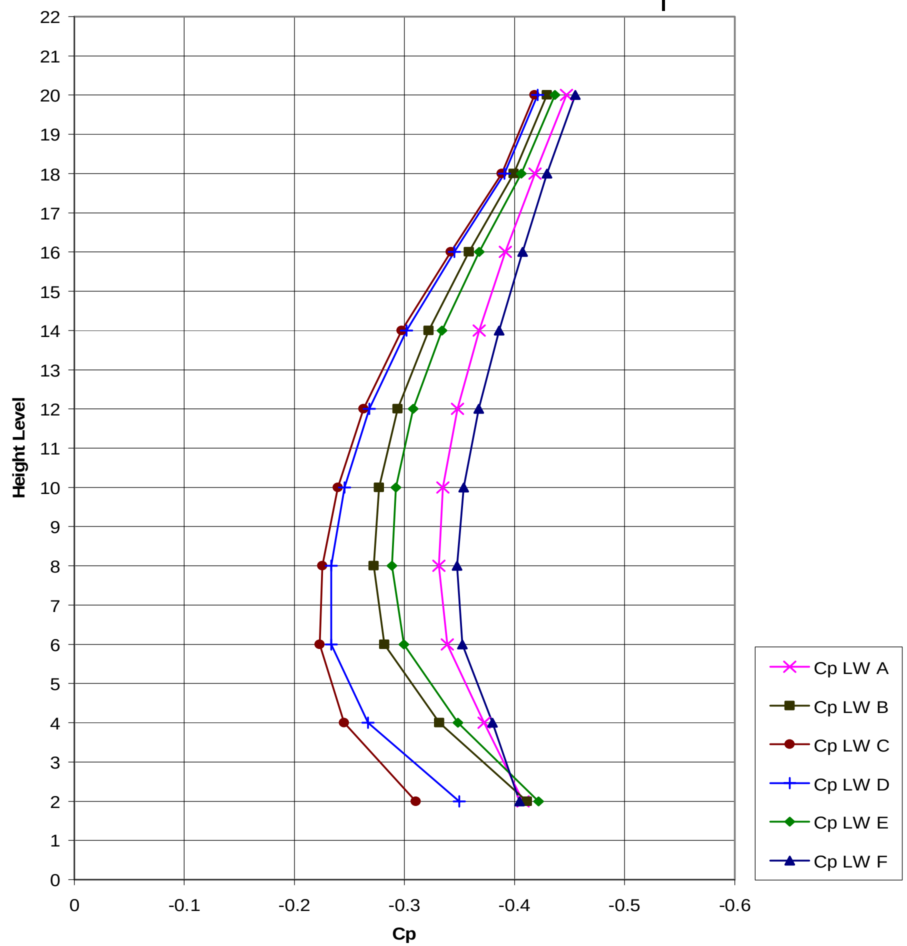
(vertical section) with Pilotis (TB2)



Vertical distribution of Cp values for 0°wind directions



Windward



Leeward

In the case of 0°wind direction

- The Cp value reduces at floors 2 to 4 at the windward façade.

  The most significant reduction occurred at floor 2 (grid WW (B) to (E)). The percentage of reduction ranges from 18.6% to 24.6%. However, at other floors, the Cp value increases although the increment is less than 10%.

- The Cp values at the leeward façade decrease at most of the lower floors.

Difference between the Cp values in the windward and leeward facades

Building	Wind Direction = 0º		
	Difference between Cp values for WW and LW (ΔCp)	Difference between Cp values of TB1 and TB2	Difference between Cp values of TB1 and TB2 (%)
Building without Pilotis (TB1)	0.62 to 1.28	Ref.	Ref.
Building with Pilotis (TB2)	0.68 to 1.26	0.05 to -0.01	9.0 to -1.0

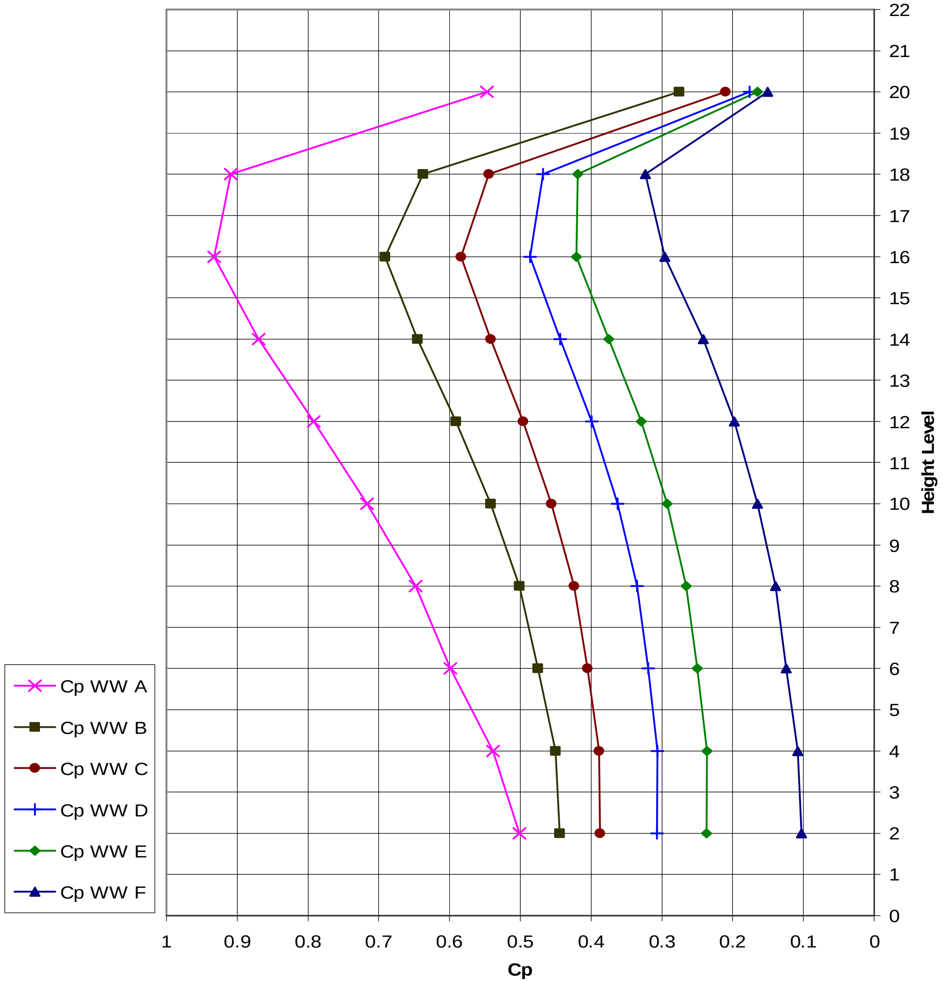
Internal air velocity

Building	Wind Direction = 0º	
	Range of Internal Air Velocity (m/s)	Range of % of deviation from 1.0 m/s Preferred Air Velocity (%)
Building without Pilotis (TB1)	0.63-0.90	(-37.0%)-(-10.0%)
Building with Pilotis (TB2)	0.66-0.90	(-34.0%)-(-10.0%)

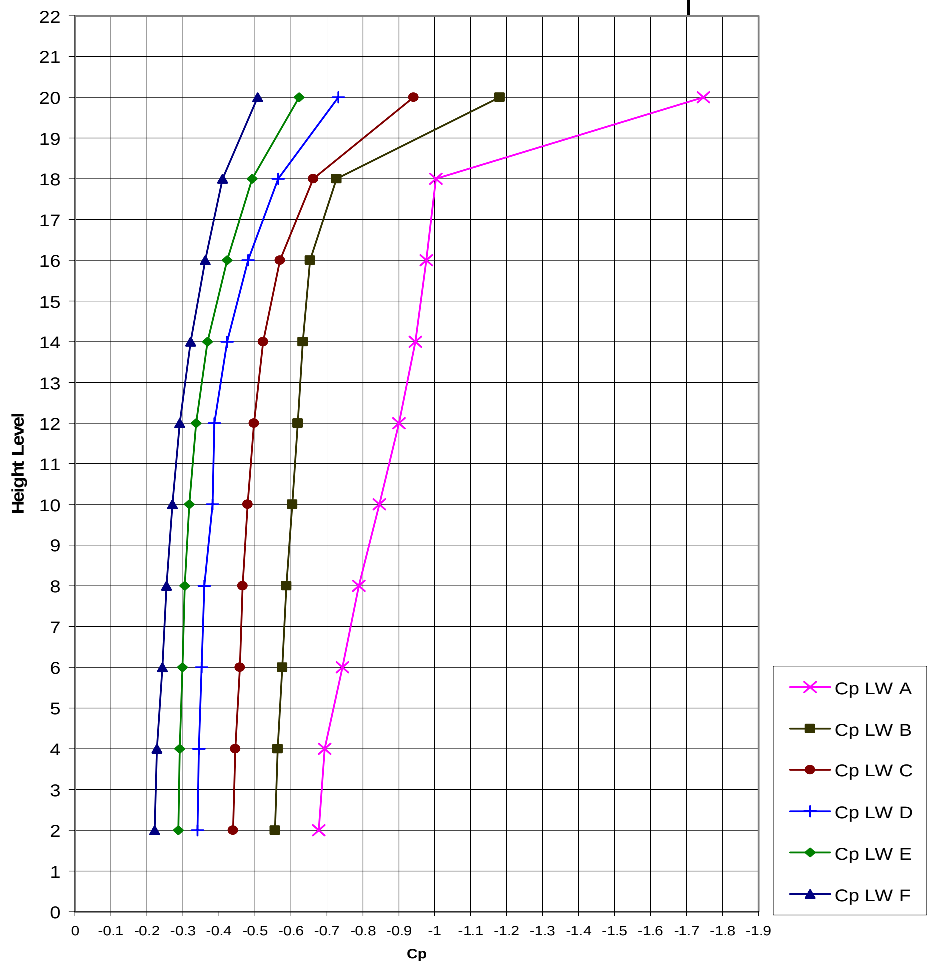
Conclusions

1. The concept of an open ground floor with pilotis that was incorporated in traditional Malay houses and used by Carbousier can be applied in the design of new modern high-rise residential building.
2. By introducing pilotis in high-rise residential building, the microclimate of the space becomes pleasant because of the airflow; furthermore, the obtained space on the ground floor is already shaded.
3. The air velocity in the areas near an open floor is better than that in buildings without an open floor, which is within the acceptable range for thermal comfort of the Malaysian people.

Vertical distribution of the Cp values corresponding to 45°



Windward

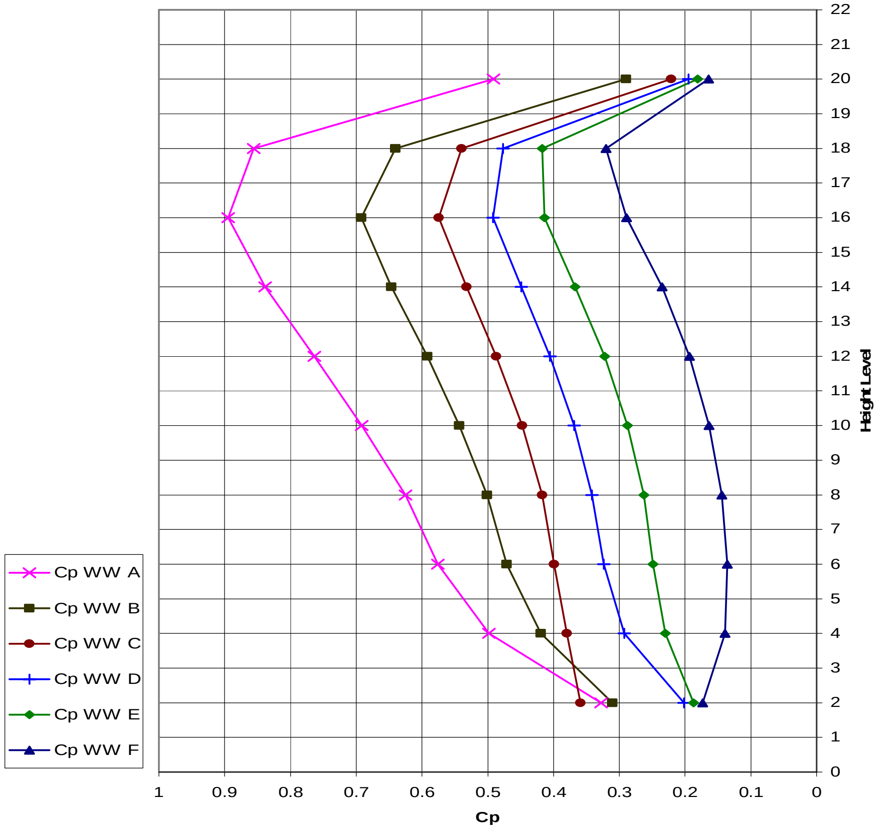


Leeward

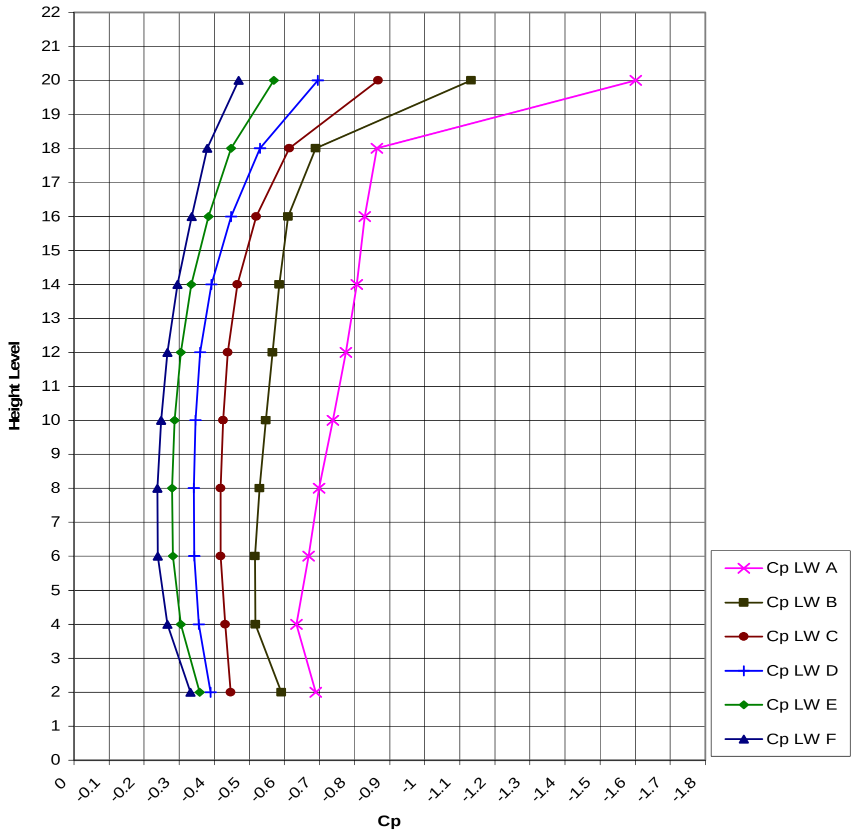
In the case of the 45°wind direction

- The vertical distribution of Cp values shows that the area corresponding to grid (A), located upwind (i.e., in the direction opposite to that of the wind), experiences a high pressure.
- The pressure gradually decreases from the upwind to the downwind side (from grid WW (A) to grid WW (F)). The highest Cp value is observed at floor 16. The Cp values range from 0.29 to 0.93.
- At the leeward façade, negative pressure (suction) exists in a manner similar to that at the leeward façade in the case of the 0°wind direction. However, the overall suction at the 45°wind direction is greater than that at the 0°wind direction.

In the case of 45°wind direction



Windward



Leeward

In the case of 45°wind direction

- The Cp value at the windward facade is significantly changed at floor 2.
- The reduction in the Cp values from the upwind (grid WW(A)) to the downwind (grid WW(E)) direction at floor 2 is more than 20% (20.9 to 34.7%) and at grid WW(F) the increment is 68.3%.
- The difference between the Cp values at other floors of TB1 and TB2 is less than 10%.
- At the leeward facade, a significant change occurs at floors 6 to 18, especially at grid LW(A), which is at the upwind side.

- The difference between the Cp values of TB1 and of TB2 in this area ranges from 10.0% to 13.9%.

Building	Wind Direction = 0º		
	Difference between Cp values for WW and LW (ΔCp)	Difference between Cp values of TB1 and TB2	Difference between Cp values of TB1 and TB2 (%)
Building without Pilotis (TB1)	0.62 to 1.28	Ref.	Ref.
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Building	Wind Direction = 0º	
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Discussions (Continued)

- The results and findings of the test revealed that in the case of the 0°wind direction, TB2 has better internal-air velocity distribution (0.66 m/s to 0.90 m/s) and external wind pressure distribution for the floors above the open ground which is at a height of two-third of the building height.
- On the other hand, in the case of the 45°wind direction, the air velocity is 0.43–1.01 m/s, which is considered to be quite good.

Discussions (Continued)

- The internal air velocity is predicted on the basis of the Cp difference. The results of the predicted internal air velocity at 0°and 45°wind directions is shown in Table 2.

- The predicted internal air velocity for the test buildings are in the range of 0.25 to 1.0 m/s that is suitable for thermal comfort in hot and humid condition.

- The introduction of pilotis also increases the minimum air velocity of the areas near or above the open ground floor from 0.63 m/s to 0.66 m/s.

  This confirms the findings of Noor Hanita & Abdul Razak (2000) that the spaces or plaza on the open ground floor of a tall building promotes good air circulation.

  Thus, a thermally comfortable and pleasant multipurpose space is obtained on the ground floor of a high-rise residential building.