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Procedia Engineering 121 (2015) 2075 – 2082
Procedia Engineering
www.elsevier.com/locate/procedia

9th International Symposium on Heating, Ventilation and Air Conditioning (ISHVAC) and the 3rd International Conference on Building Energy and Environment (COBEE)

Effects of Orientation of Urban Roads on the Local Thermal Environment in Guangzhou City

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Abstract

The continuous Guangzhou expansion leads to more and more construction of the city road, which is a special underlying surface. In 2012, the total length of the road in Guangzhou is 9050.715 km. Among them, the total length of the highway is 652.6 km and the remaining 6044 km is urban roads. There are 47 main roads with a distance of 5685km and area of 3953.63 million square meters.

The roads are commonly constructed by asphalt and cement concrete whose heat absorption rate is higher than that of the green land and water body, while the thermal capacity of the asphalt and cement concrete is smaller than that of the green land and water body. This means that the roads with asphalt and cement concrete can absorb the solar radiation largely and cause the big temperature increase itself, which will increase the summer energy consumption of vehicles on the road and affect the outdoor thermal comfort of pedestrians. Nowadays, the construction of roads has become one of the main-reasons for urban heat island.

In another hand, road provides the broad path for urban ventilation, which makes it become an important element for the construction of urban wind corridor. According to above negative impact on urban heat island and positive impact on urban ventilation, great difficulties still remain when urban planners attempt to design the urban roads to realize the comfortable outdoor thermal environment.

The orientation of urban roads is an important element for the road design. Its relationship with the prevailing wind direction can somehow affect the city temperature distribution and ventilation efficiency. Fazia Ali-Toudert from University of Freiburg concludes that in urban street the roads with east-west orientation are less efficient in releasing heat compared with the north-south orientation (Fazia Ali-Toudert, 2006). Andreou concludes that, under the same condition of shade and solar energy, street geometry, height/width ratio, orientation and trees can affect urban canyon microclimate (Fazia Ali-Toudert, 2014). They do not have a detailed study of the relationship between the orientation towards the prevailing wind, as well as to the impact on the surrounding thermal environment

This paper uses the method of numerical simulation to analyze the impact of road orientation on the thermal environment of Guangzhou Zhujiang New Town. Some implications for the urban road design are obtained. Orientation of the road has a great influence on the local thermal environment for example in windless area or with respect to high-rise buildings in low-lying areas.

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Peer-review under responsibility of the organizing committee of ISHVAC-COBEE 2015
doi:10.1016/j.proeng.2015.09.209

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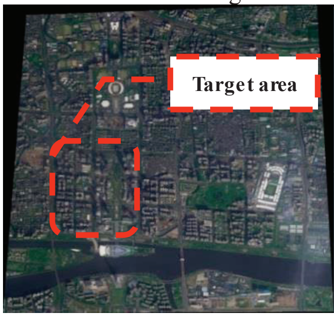
Keywords: Urban road; Orientation; Thermal Environment; CFD

1. Methods

The object of this study is Guangzhou Pearl River New City area (shown in Fig.1). This area includes four streets which are Middle Guangzhou Avenue, Linjiang Avenue, Xiancun Road and West Whampoa Avenue. The length of north-south of the area is about 1.5 km while the length of east-west of the area is about 1.3km. The total area is about 2 square kilometers (shown in Fig. 3). In this area, West Whampoa Avenue, Middle Guangzhou Avenue, Huaxia Road, Huacheng Avenue and Linjiang Avenue belong to the urban trunk and Jinsui Road, Huasui Road, Xiancun Road belong to the subsidiary road. In my study, the ratio of all the building height is the same with the ratio of actual object in the numerical modeling of the region (shown in Fig. 2).



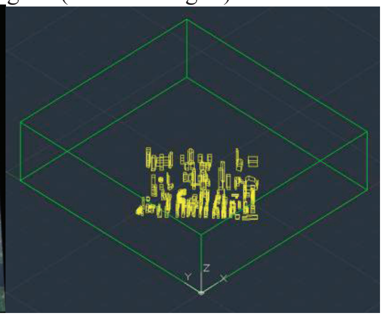


Fig. 1. Pearl River New City area Fig. 2. CAD Model

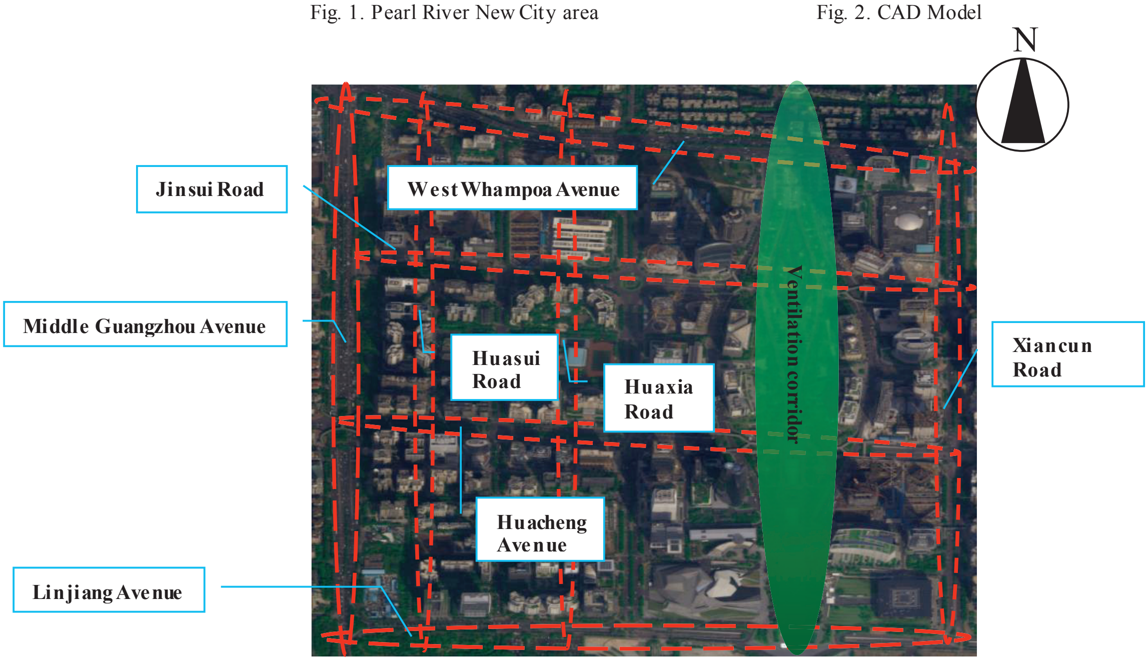


Fig. 3. plan view of the target area

1.1. Simulation software selection

Fluent is one of the CFD Professional Software which is used for simulation and analysis of a fluid flow and heat exchange in a complex set of issue (Tingting Wei, 2010). It is widely used in fluid dynamics associated with Aeronautics and Astronautics, Hydraulic Engineering, engineering design and other fields. We can establish various models of buildings and streets with pre-processor Gambit and give them a reasonable mesh. In this paper, the architectural model in Guangzhou Pearl River New City uses unstructured mesh (Di le, 2012).

1.2. Parameter settings

Computational domain: when calculating the outdoor wind environment, the size of the computational domain can affects the accuracy of the simulation results. In order to set reasonable boundaries, the computational domain should be delineated based on the real size of the studied district. The experience value is that 2 times of the building height is used for the distance in front of buildings, 3 times of the building height is used for the distance from the rear of buildings. Vertical size of the computational domain is 3 times of the building height. The analysis results of many single buildings and building clusters show that such settings can basically guarantee the results close to real mostly (Tingting Wei, 2010).

Boundary conditions: 1) Inlet velocity: ,v_0 is the wind speed at the h_0 which is standard height. Generally, we pick up the wind speed at 10m height. Here we take average outdoor wind speed 1.5m/s at Guangzhou in the summer. n is related to surface roughness and wind climate (Ministry of housing and urban-rural development of the people's republic of China, 2012). In this paper, n takes 0.30 according to Table 1.

Initial temperature: we take summer air conditioning design temperature 30.6℃ of Guangzhou as the initial temperature.

Table 1. Category of surface roughness and the corresponding values of n

Ground roughness category	Description	n
A	Coastal waters surface, islands, coastal, lakeshore and desert areas	0.12
B	Fields, villages, jungles, hills and the township or suburban which house is relatively sparse	0.16
C	City centre with high-density of building clusters	0.22
D	City centre with high-density of building clusters and higher building	0.30

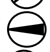
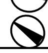
2) Outflow boundary: Free flow

3) Ground and building surfaces: nonslip

1.3. Case introduction

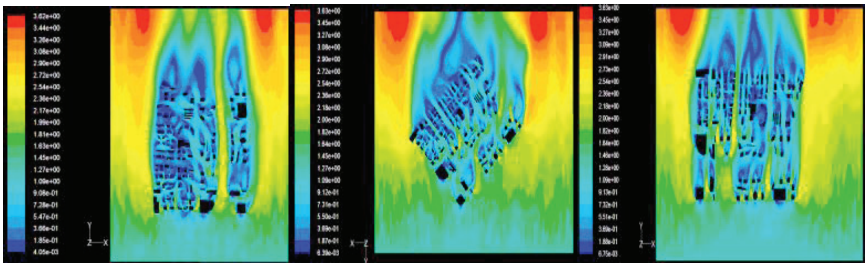
As shown in Table 2, 8 cases with different road orientations are simulated. The wind direction for 8 cases is all in south. The different road orientation is indicted using the angle between wind direction and major axis of the studied area.

Table 2. Case introduction

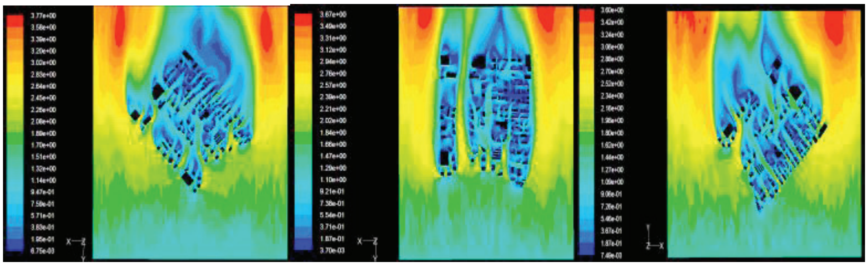
Cases	Introduction		Cases	Introduction	
Case1	0°		Case5	180°	
Case2	45°		Case6	225°	
Case3	90°		Case7	270°	
Case4	135°		Case8	315°	

2. Simulation results analysis

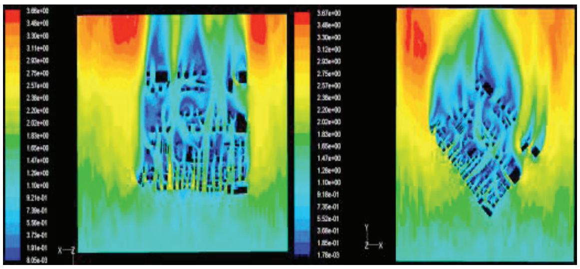
2.1. Wind speed distribution



(a) Case 1 (b) Case 2 (c) Case 3



(d) Case 4 (e) Case 5 (f) Case 6



(g) Case 7 (h) Case 8

Fig.4 Wind speed distribution at the 1.5m height above ground for different cases

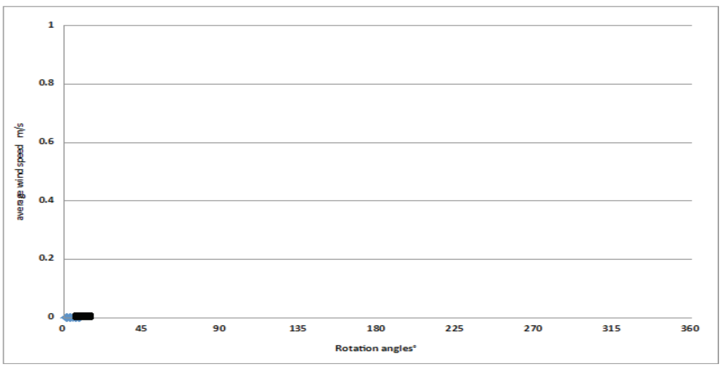


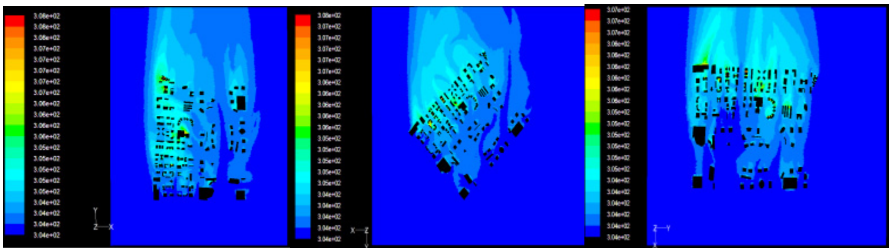
Fig.5 Relationship between rotation angle and average wind speed

The wind speed distribution at the 1.5m height above the ground for 8 cases is shown in Fig.4. Fig.5 shows the relationship between rotation angle and average wind speed at the 1.5m height above the ground. We can see that the average wind speed at 1.5m plane under different angles are 1.68m/s, 1.72m/s, 1.64m/s, 1.74m/s, 1.70m/s, 1.80m/s, 1.67m/s, 1.82m/s.

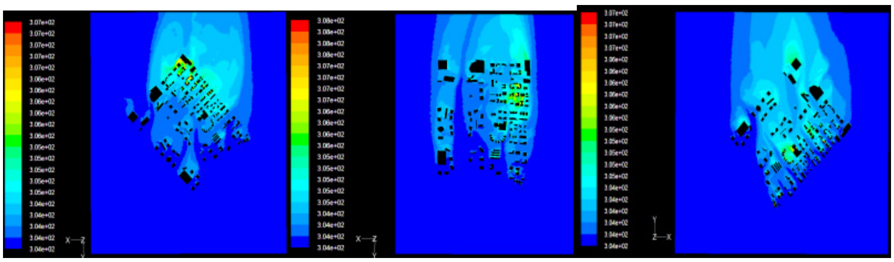
As shown in Fig.5, the average wind speed is small when angle is 0°, 90°, 180°, 270°. Figs.4(a),4(c),4(e),4(g) show that roads are in an orthogonal or parallel direction to the wind direction. The average wind speed is big when angle is 45°,135°,225°,315°. Figs.4 (b), 4(d), 4(f), 4(h) show that roads and wind direction are at some angle. The average wind speed on the road will be relatively larger when the road is at an angle with the wind direction.

In Figs. 4(a) and 4(e), Figs. 4(b) and 4(f), Figs. 4(c) and 4(g), Figs. 4(d) and 4(h), although positions of the road are different, the orientations of roads are the same. I found that the average wind speed in latter picture is larger than the former. The velocity at 180° is 0.02m/s quicker than velocity at 0°.The velocity at 270° is 0.03m/s quicker than velocity at 90°.The velocity at 225° is 0.08m/s quicker than velocity at 45°.The velocity at 315° is 0.08m/s quicker than velocity at 135°. The reason why come out the small difference 0.02m/s and 0.03m/s is that average wind speed at orthogonal or parallel direction is smaller relative to other cases. When there is an angle between the road and the wind direction, densely architectural district is closer to the windward entry. As a result, the average wind speed is larger. Figs. 6 and 8 are respectively the case of ventilation corridors orthogonal and parallel to the wind direction. The average velocity difference is 0.06m/s. Therefore orthogonal should be avoided between ventilation corridor and leading wind direction.

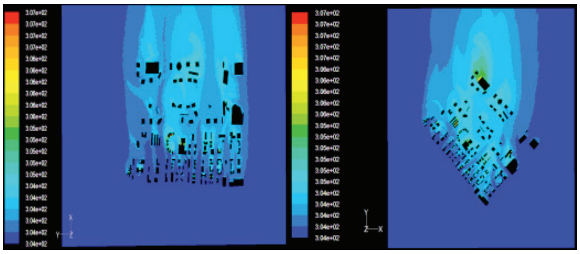
2.2. Temperature distribution



(a) Case 1 (b) Case 2 (c) Case 3



(d) Case 4 (e) Case 5 (f) Case 6



(g) Case 7 (h) Case 8

Fig.6 Temperature distribution at the 1.5m height above ground for different cases

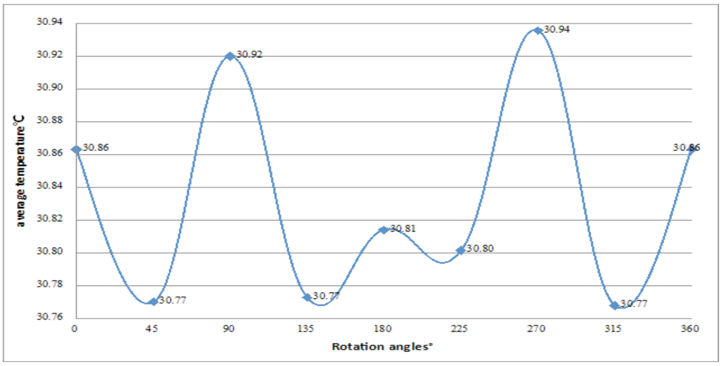


Fig.7 Relationship between rotation angles and average temperature

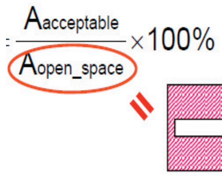
The temperature distribution at the 1.5m height above the ground for 8 cases is shown in Fig.6. Fig.7 shows the relationship between rotation angle and average temperature at the 1.5m height above the ground. We can see that the average temperature at 1.5m plane under different angle are 30.86℃, 30.77℃, 30.92℃, 30.77℃, 30.81℃, 30.80℃, 30.94℃, 30.77℃.

As shown in Fig.7, the average temperature is at the peaks when angle is 0°, 90°, 180°, 270°. Figs.6(a),6(c),6(e),6(g), show that roads are in an orthogonal or parallel direction to the wind direction. The average temperature is at the bottom when angle is 45°, 135°, 225°, 315°. Figs.6 (b), 6(d), 6(f), 6(h), shows that roads and wind direction are at some angle. The average temperature on the road will be relatively smaller when the road is at the angle into the planning.

From Figs.5 and 7, such a conclusion can be drawn that temperature and wind speed change in opposite direction. This trend is most obvious especially when the ventilation corridor is perpendicular to wind direction. As shown in the result, the average wind speed is the lowest in all 8 conditions, while the average temperature is the highest, the temperature difference can be up to 0.168℃.

2.3. Assessment approach

According to Reference(Yingli Xuan, Qiong Li, Akashi Mochida,2010), simulation results were compared in three different assessment approaches, (1)acceptable area in estimated area, (2)acceptable area ratio in estimated area, (3)acceptable area ratio in the whole area(estimated area + building area). Figs. 8 and 9 are schematic diagrams for assessment approaches (2) and (3).



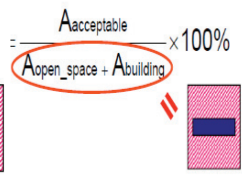


Fig.8 Assessment approach (2) Fig.9 Assessment approach (3)

In this paper, we use assessment approach (2) to evaluate the entire simulation area.

2.3.1 Wind environment assessment

As shown in Fig.4, the outdoor average wind speed at the 1.5m height above ground ranges from1~5m/s. Outdoor static wind zone refers to wind speed is less than 1.0m/s(Guangzhou Municipal Committee of Urban and Rural Construction, 2012). The area with the outdoor wind speed at the 1.5m height higher than 1.0m/s is looked as acceptable area. Using above assessment approach (2), the velocity acceptable area ratios for different cases are calculated, as shown in Fig.10.

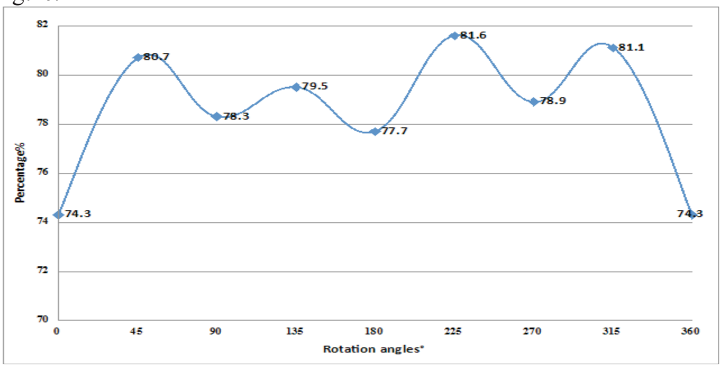


Fig.10 The velocity acceptable area ratio at different angles

Fig.10 shows that for wind direction orthogonal or parallel with the road, that is 0°,90°,180°,270°,the qualified rate is the lowest, at the same time, the average wind speed on the road is relatively low.

2.3.2 Heat island assessment

According to the definition of the heat island intensity (Oke TR, C.East, 1971), the temperature difference between the city center (peak) and suburb is the heat island intensity (usually from the ground 1.5m high). In this paper, the inlet temperature 30.6℃ is the reference temperature, draw the ratio of the area of 1.5℃ heat island intensity, as shown in Fig.11.

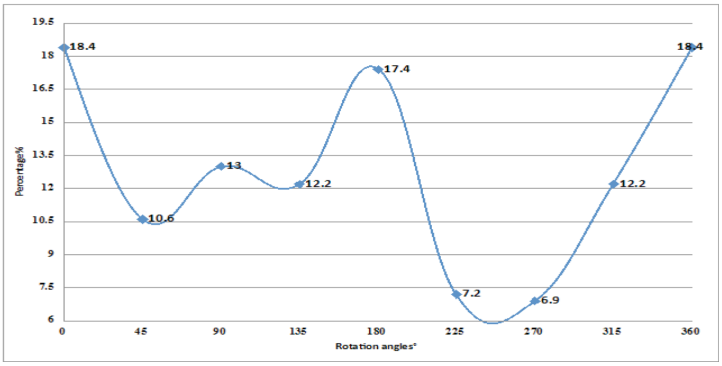


Fig.11 The percentage of heat island intensity at different rotation angles

Fig.11 shows that when the wind and the road into an angle, heat island intensity is relatively low, the average temperature on the road at this time is relatively low.

3. Conclusions

The main findings of this study are as follows:

(1)Roads and wind direction should be in a specific angle to increase the average wind speed and reduce the average temperature.

(2)When road and wind direction are arranged in vertical angle, heat island intensity and the percentage of unqualified wind speed are both the worst.

(3)If the dense building district is close to the windward entry, the average wind speed is higher when the road is at the same orientation but different position.

Acknowledgements

The study is supported by National Natural Science Foundation of China (Projects No.51378214, 51008127), Pearl River Nova Program of Guangzhou(Project No.2014J2200065)，Hong Kong Scholars Program (Project No.XJ2013017)，China Postdoctoral Science Foundation(Project No.2014M560662)，the project funded by State Key Laboratory of Subtropical Building Science, South China University of Technology (Project No.2014ZC15),the Fundamental Research Funds for the Central Universities, South China University of Technology (Project No.2014ZG0018), National Key Technology R&D Program of China (Projects No.2012BAC21B03).

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