STUDY ON OUTDOOR THERMAL ENVIRONMENT AROUND THE RESIDENTIAL BUILDINGS IN GUANGZHOU, CHINA WITH COUPLED SIMULATION OF CONVECTION, RADIATION AND CONDUCTION

Qiong Li*[1], Qinglin Meng[1], Lihua Zhao[1], Yingli Xuan[2], Akashi Mochida[2], Hiroshi Yoshino[2]
1. South China University of Technology, Guangzhou, China; 2. Tohoku University, Sendai, Japan

Abstract

The summer outdoor thermal environment of a real residential building cluster in Guangzhou, China is investigated by the coupled simulation of convection, radiation and conduction. The effects of gross building coverage ratio, floor area ratio and first floor overhead ratio on outdoor thermal environment are discussed. The simulation results show: (1) with the increase of gross building coverage ratio from 10% to 70%, the summer pedestrian-level average wind velocity decreases; air temperature increases at first then decreases and relative humidity decreases at first then increases when gross building coverage ratio is over 40%; while thermal comfort is becoming worse gradually and when gross building coverage ratio goes over 40%, this trend becomes milder. (2) when building coverage ratio is fixed, all the buildings are homogeneous and floor area ratio increases from 0.8 to 7.6, average building height increases from 7.5m to 60m, the pedestrian-level average wind velocity increases at first then decreases when floor area ratio is over 5.6 and average building height is over 45m; air temperature decreases and relative humidity increases; but thermal comfort is best when floor area ratio is 5.6 and average building height is 45m. (3) piloti improves the outdoor thermal comfort around buildings effectively.

Key words: thermal environment, outdoor, CFD, residential building, coupled simulation

1. INTRODUCTION

In recent years, heat island is very severe in the big cities of China, especially in the southern city such as Guangzhou, Shanghai and etc (Xue, 2002). With the quick urbanization of these cities, a large amount of buildings are constructed each day and make the city become more and more close-packed. Unreasonable arrangement and design of buildings is considered to be one of the crucial factors which worsened heat island. This paper selects an actual residential building cluster in Guangzhou, China as an example, tries to discuss the impacts of planning and design factors such as gross building coverage ratio, floor area ratio and first floor overhead ratio on outdoor thermal environment by the method of numerical simulation. From the discussion, the relationship between above factors and outdoor thermal parameters such as temperature, humidity, wind velocity and thermal comfort index would be obtained and provided to urban planners as one guide for their planning.

2. PROBLEM DESCRIPTION

As shown in Fig.1, Region A is the studied residential building cluster. It has the size of 300m (length)*300m (width) in the horizontal. 40 buildings with the size of 60m (length)*15m (width)*22.5m (height) are arranged inside of it in parallel layout. The ground surfaces include lawn and concrete road. The gross building coverage ratio, green coverage ratio and road coverage ratio are 40%, 40% and 20% respectively. The floor area ratio is 2.8.

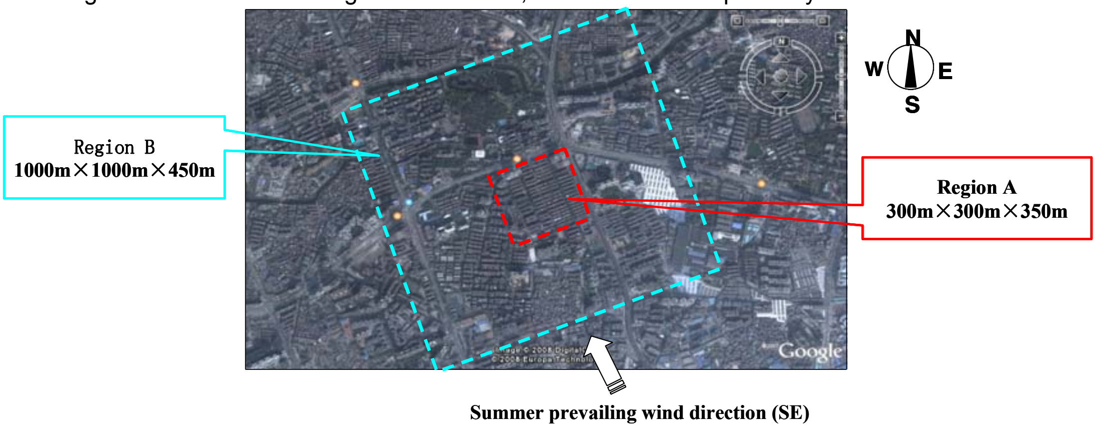
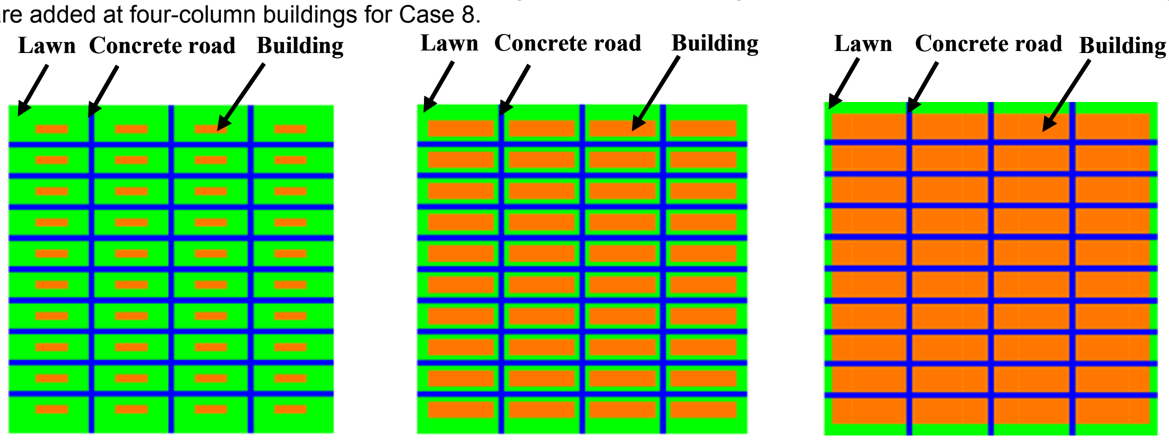


Fig.1 Analysis target (From Google Earth)

Above condition represents the actual properties of the residential building. It is entitled as Case 1 in the numerical simulation. As shown in Table 1, another 6 cases also will be calculated. Among all the cases, Cases 1, 2, 3 will be compared together to discuss the impact of building coverage ratio on outdoor thermal environment. The horizontal arrangements of these three cases are displayed in Fig.2. Cases 1, 4, 5, 6 will be compared to discuss the impact of floor area ratio or building height on outdoor thermal environment. Cases 4, 5 and 6 have

*Corresponding author. Email address: joanli97@163.com

the same horizontal arrangement as Case 1 while different building height in vertical. At last, cases 1, 7, 8 will be compared together to discuss the impact of first floor overhead ratio on outdoor thermal environment. For the building cluster in Case 1(shown in Fig. 2(a)), there are four-column buildings in horizontal direction. Compared with it, the first floor of middle two-column buildings is open in the height of 4m for Case 7 while pilotis (4m high) are added at four-column buildings for Case 8.



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

Fig.2 Horizontal arrangements of cases with different building coverage ratio

Table 1 Description of calculation cases

Case	Building coverage ratio (%)	Green coverage ratio (%)	Road coverage ratio (%)	Floor are ratio	First floor overhead ratio (%)	Average building height (m)
1	40	40	20	2.8	0	22.5
2	10	70	20	0.7	0	22.5
3	70	10	20	4.9		
4				0.8		7.5
5	40	40	20	5.6	0	45
6				7.6		60
7	40	40	20	2.6	50	20.5
8				2.4	100	18.5

3. METHOD

A two-nested grid is used for the calculation. And the method of coupled simulation of convection, radiation and conduction is applied for analysis to ensure high prediction accuracy (Yoshida, Murakami, Mochida and etc., 2000). At the first step, non-isothermal steady CFD analysis is performed for Region B with the size of 1000m(length)*1000m(width)*450m(height) shown in Fig.1.Using the calculation results at this step, the side boundary conditions for the wind velocity and air temperature of Region A are obtained. At the second step, the surface temperatures of the ground and building in Region A are calculated using an unsteady radiation and conduction computations. At the same time, the artificial heat release from the air-conditioned building is also calculated. Finally, a non-isothermal steady CFD analysis is performed for Region A based on the outcomes of Step 1 and Step 2. In Step 1 and Step 3, a cubic non-linear k-ε model proposed by Suga (Craft, Launder and Suga, 1996) is adopted for convection analysis.

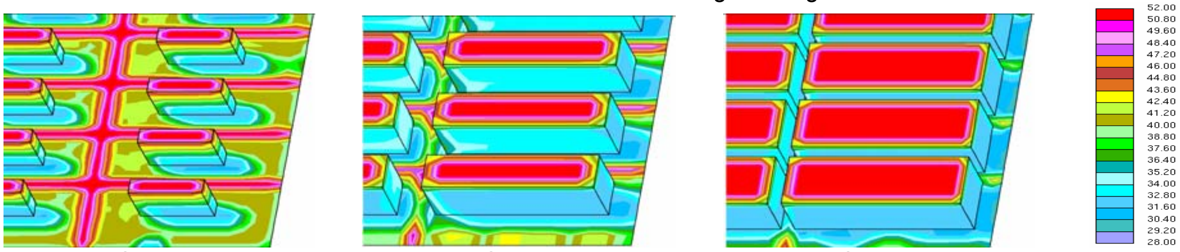
From the analysis to meteorological data of typical meteorological year, July 14 can represent the average level of whole summer in Guangzhou and air temperature arrives the daily maximum value of 32.4℃ at 15:00 of July 14.Hence, in this study, 15:00 on July 14 in the typical meteorological year is targeted as the time for steady analysis in Step 1 and Step 3. The radiation and conduction analysis is performed for 24h from 0:00 on July 14 to 24:00 on July 14 in Step 2. The meteorological relative humidity at 15:00 on July 14 is 77%, wind velocity at the height of 10m is 2m/s and wind direction is southeast, which is also the summer prevailing wind direction in Guangzhou, perpendicular to the studied buildings as shown in Fig.1.

4. RESULTS

After the calculation, the average wind velocity, average air temperature, average relative humidity, average SET* at the height of 1.5m above ground in Region A for each case are counted and taken as the evaluation indices to numerical results.

4.1. EFFECT OF BUILDING COVERAGE RATIO ON OUTDOOR THERMAL ENVIRONMENT OF BUILDINGS

The surface temperatures of part of ground and buildings for cases with different building coverage ratio are demonstrated in Fig.3. It shows that with the increase of building coverage ratio, the ground surface temperature around the buildings decrease obviously because of the increase of shade area. For Case 2, the surface temperature of lawns in the west side of the buildings is about 40℃. For Case 1, it changes to be about 36℃.For Case 3, it is about 30℃. The pedestrian-level calculation results of these three cases are shown in Table 2. It can be found that with the increase of gross building coverage ratio from 10% to 70%, the summer pedestrian-level average wind velocity decreases; air temperature increases at first then decreases and relative humidity decreases at first then increases when the gross building coverage ratio is over 40%; while the SET* increases gradually, which means that pedestrian-level thermal comfort around buildings is becoming worse with the increase of building coverage ratio. But it also can be seen that when the building coverage ratio goes over 40%, the trend of thermal comfort's deterioration with the increase of building coverage ratio becomes milder.



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

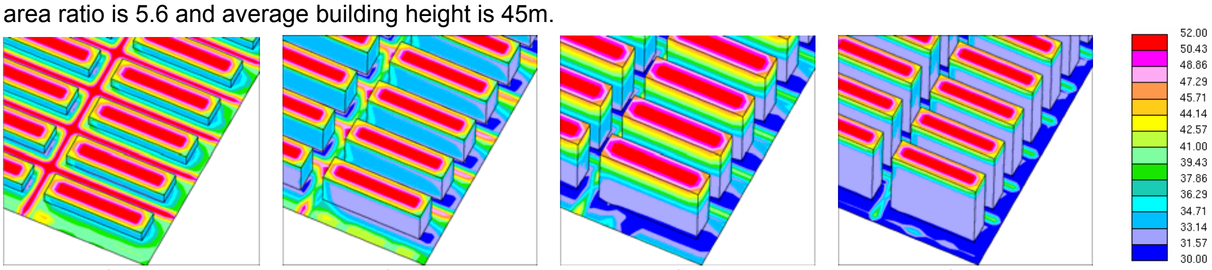
Fig.3 Surface temperature of part of ground and buildings for cases with different building coverage ratio (℃)

Table 2 Pedestrian-level calculation results of cases with different building coverage ratio

Case	Building coverage ratio (%)	Average velocity (m/s)	Average temperature (℃)	Average relative humidity (%)	Average SET* (℃)
2	10	1.385	33.15	82.05	44.3
1	40	1.3	33.98	78.32	45.02
3	70	1.209	33.82	78.47	45.3

4.2. EFFECT OF FLOOR AREA RATIO ON OUTDOOR THERMAL ENVIRONMENT OF BUILDINGS

The surface temperatures of part of ground and buildings for cases with different floor area ratio are shown in Fig.4. It can be seen that with the increase of floor area ratio and building height, the shade area around the building increases obviously, then the surface temperature of grounds around the buildings decrease largely. The pedestrian-level calculation results of these cases are shown in Table 3. When the building coverage ratio is fixed and floor area ratio increases from 0.8 to 7.6, all the buildings' height increases from 7.5m to 60m, the pedestrian-level average wind velocity increases at first then decreases when the floor area ratio is over 5.6 and average building height is over 45m, the air temperature decreases and the relative humidity increases. But the pedestrian-level thermal comfort improves at first then becomes worse. It arrives at the optimum when the floor area ratio is 5.6 and average building height is 45m.



(a) Case 4 (b) Case 1 (c) Case 5 (d) Case 6

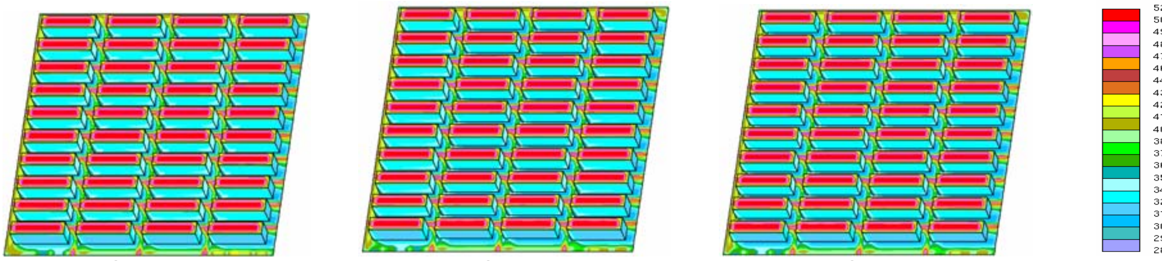
Fig.4 Surface temperature of part of ground and buildings for cases with different floor area ratio (℃)

Table 3 Pedestrian-level calculation results of cases with different floor area ratio

Case	Floor area ratio	Average building height (m)	Average velocity (m/s)	Average temperature (℃)	Average relative humidity (%)	Average SET* (℃)
4	0.8	7.5	1.188	33.99	78.42	45.48
1	2.8	22.5	1.3	33.98	78.32	45.02
5	5.6	45	1.39	33.28	80.44	44.41
6	7.6	60	1.294	32.85	82.16	44.74

4.3. EFFECT OF FIRST FLOOR OVERHEAD RATIO ON OUTDOOR THERMAL ENVIRONMENT OF BUILDINGS

The surface temperatures of all the grounds and buildings for cases with different first floor overhead ratio are shown in Fig.5. But the surface temperature's differences among them for most of grounds are not obvious. The pedestrian-level calculation results of these cases are shown in Table 4. It can be seen that with the increase of first floor overhead ratio, the average velocity at pedestrian-level increases, average temperature decreases, average relative humidity increases and average SET* decreases largely. The average SET* of Case 8 with 100% first floor overhead ratio is about 3℃ lower than Case 1 without piloti. The results show that piloti can improves the outdoor thermal comfort around buildings effectively.



(a) Case 1 (b) Case 7 (c) Case 8

Fig.5 Surface temperature of ground and buildings for cases with different first floor overhead ratio (℃)

Table 4 Pedestrian-level calculation results of cases with different first floor overhead ratio

Case	First floor overhead ratio (%)	Average velocity (m/s)	Average temperature (℃)	Average relative humidity (%)	Average SET* (℃)
1	0	1.3	33.98	78.32	45.02
7	50	1.432	33.75	79.62	43.9
8	100	2.266	33.17	81.19	41.9

5. CONCLUSION AND IMPLICATION

This study indicates that:

1. With the increase of gross building coverage ratio from 10% to 70%, the summer pedestrian-level average wind velocity decreases; air temperature increases at first then decreases and relative humidity decreases at first then increases when the gross building coverage ratio is over 40%; while the pedestrian-level thermal comfort around buildings is becoming worse gradually and when the gross building coverage ratio goes over 40%, the trend of thermal comfort's deterioration with the increase of building coverage ratio becomes milder.
2. When the building coverage ratio is fixed and floor area ratio increases from 0.8 to 7.6, all the buildings' height increases from 7.5m to 60m, the pedestrian-level average wind velocity increases at first then decreases when the floor area ratio is over 5.6 and average building height is over 45m; the air temperature decreases and the relative humidity increases; but the pedestrian-level thermal comfort improves at first, then becomes worse, it arrives at the optimum when the floor area ratio is 5.6 and average building height is 45m.
3. Piloti improves the outdoor thermal comfort around buildings effectively. When the first floor of all the buildings are open, the average SET* at the pedestrian-level can decrease about 3℃ compared with the case without piloti.

Acknowledgements
The study was supported by National Natural Science Foundation of China (Project No. 50538040, 50720165805), Natural Science Foundation of Guangdong Province of China (Project No. 8251064101000006), National Key Technology R&D Program of China (Project No. 2006BAJ02A05-05), the 111 Project (Project No. 111-2-13) and the project funded by the State Key Laboratory of Subtropical Building Science, South China University of Technology, China (Project No. 2008ZB14, 2008ZC18) and the China Scholarship Council Program (No. [2006]3037).

References
Xue, Z.C., 2002. Heat island threatening to human health, *Safety and Health*, 7, 15-16 (in Chinese).
Yoshida, S., Murakami, S., Mochida, A., Ooka, R., Tominaga, Y., Kim, S.,2000. Influence of green area ratio on outdoor thermal environment with coupled simulation of convection, radiation and moisture transport, *Journal of Architecture Planning Environment and Engineering, AIJ*, 529, 77-84 (in Japanese).
Craft, T.J., Launder, B.E., Suga, K., 1996. Development and application of a cubic eddy-viscosity model of turbulence, *International Journal of Heat and Fluid Flow*, 17, 108-115.