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A Case Study of Thermal Environment in Urban Street Canyon in Hot and Humid Climate City based on Vehicle Effect

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Abstract. Vehicle traffic is an important factor affecting the urban thermal environment, and most of them are mainly concentrated in urban street canyon. Through field measurement and numerical simulation, thermal environment of urban street canyon based on vehicle's impact was studied in this paper. The research works are as follows: 1) The numerical simulation method for the thermal environment of urban street canyon considering the vehicle' impact was established and verified by experimental results. Next, the impact of vehicles on the thermal environment in the urban street canyon was analysed. The simulation results showed that the air temperature in the street canyon increased gradually with the increase of vehicle exhaust heat. When vehicles heat generation rate increased 10W/m^3 , the 1.5m-height air temperature in the street canyon raised about $0.02\text{ }^{\circ}\text{C}$. With the increase of vehicle exhaust heat, its impact on the increase of air temperature in the garage area is weakened while that in the pedestrian area is improved. 2) The 1.5m-height air temperature rising effect in urban street canyon as a results of vehicle exhaust was found to be increased with the decrease of street canyon aspect ratio (height to width ratio) and the increase of length to height ratio. And the impact of length to height ratio is greater than that of aspect ratio. Then, the height to width and length to height ratios of street canyon should be designed in a reasonable range. And the reasonable distance from pedestrian area to road cars should be guaranteed to reduce the adverse effects of vehicle exhaust on pedestrian area.

1. Introduction

Since the reform and opening up, the motor vehicle population in China has continued to grow, so that the proportion of vehicle exhaust heat in China's anthropogenic heat is increasing, and the impact of vehicles on the urban thermal environment is becoming more and more important.

Urban street canyons are places where people and vehicles are concentrated. The close distance and height between vehicles and pedestrians greatly increase the possibility and intensity of people affected by vehicles, which has an important impact on the safety, comfort and health of pedestrians in the street canyons. In previous study, the effect of pollution from traffic on the street canyon were studied popularly [1]. Mochida developed a vehicle canopy model to simulate the aerodynamic effect of vehicle on wind environment and pollution diffusion in the street canyon [2,3]. Some researchers made field



experiment to analyze the effect of traffic on outdoor wind or thermal environment [4-6]. Some researchers used numerical simulation to analyze the thermal environment of street canyon with traffic and air conditioning exhaust heat [7]. But their analyzed case is limited and the quantitative conclusion about the effect of traffic on outdoor thermal environment in street canyon is not obtained completely. In this study, based on the actual street canyons in Guangzhou, the impact of vehicle exhaust heat on the thermal environment of urban street canyon in hot and humid climate was systematically and quantitatively analyzed.

2. Research methods

2.1. Geometry model of street canyon

Based on the classification results of geometry of street canyons in literature [1,4] and taking into account the specifications of building sunshine and fire protection, the following numerical simulation study selects the symmetric street canyons with geometric shapes of $H/W=1$ (H:height, W:width) and $L/H=5$ (L:length, H:height) as the standard street canyon model, and the trend of street canyons was the east-west (E-W) trend. According to the survey results of cross-section planning and design of urban roads in Guangzhou shown in literature [8] and combined with traffic flow survey, branch roads with 4 motor vehicle lanes and the road width of 20 m are selected, the distance of the setback boundary line of the construction is 5 meters. According to the selected street canyons' geometry (the $H/W=1$, $L/H=5$ symmetric street canyons), the basic parameters of the standard street canyon model are determined. The height of the buildings on both sides of the street canyon is 30m ($H=30m$), and the width of the street canyon is 30m ($W=30m$). The length of the street canyon is 150m ($L=150m$).

2.2. Simulation method

The software of FLUENT is utilized for numerical simulation, and the RNG k- ϵ turbulence model is selected. The standard wall functions are used, and the buoyancy effects are considered. The QUICK scheme for space discretization is used to avoid the large numerical diffusion of the widely used upwind difference scheme. The coupling between pressure and velocity is obtained using SIMPLE procedure. The inflow boundary uses the wind profile with power law. The power law exponent determined by terrain category is 0.22. The velocity in the reference height of 10m uses the meteorological data from nearby weather station. The 8:00 on July 14th of typical meteorological year is selected as the calculation time because it is the traffic rush hour in the hottest day of Guangzhou. The inflow velocity in 10m height is 2m/s and the wind direction is SE. The inflow temperature is 27.5°C. The total solar radiation intensity is 206W/m². The thermal performance parameters of the building wall and ground adopts the data in literatures [9, 10]. The vehicle exhaust heat is given to the ground. The numerical grid is determined to include about 1,004,971 unstructured elements after detailed mesh dependency examination. The minimum and maximum sizes of all elements in the whole computational domain are 1m and 20m respectively. The numerical simulation method was verified in advance using the measured results of the actual street canyons in Guangzhou [11].

According to the survey on the vehicles' type distribution in the street canyon of Guangzhou [11], the heat generation rate of road vehicles is defined as 100W/m³ in the standard case. Based on this, 10% of the ups and downs are used to establish the comparative simulation cases, and a case in which no vehicle exists is set as a comparative case. All simulation cases are shown in Table 1. In view of the fact that the street canyons are located in the city, considering the actual situation of urban street canyons, the street canyons with the same geometric shape and basic size were built around the key research street canyon, forming an area similar to a block.

The established block model is shown in Figure 1. In the E-W direction (parallel to the street canyons), there are three columns of buildings and two roads between them. In the N-S direction (perpendicular to the street canyons), there are four rows of buildings and three roads between them. The focused street canyon is in the middle of the second column, the third row, as shown in the dotted line in the figure.

The road in the second row, included in the focused street canyon, are divided into sidewalks and roadways in different directions, and the roads in different directions are defined separately, as indicated by the arrows in the figure, while there is no distinction between other road surfaces and no heat exhaust is defined.

Table 1 Simulation cases

| Cases | Heat Generation Rate (W/m ³) | Cases | Heat Generation Rate (W/m ³) |
|-------------------|---|----------------|---|
| Comparative cases | 0 | Standard cases | 100 |
| Case 1 | 50 | Case 6 | 110 |
| Case 2 | 60 | Case 7 | 120 |
| Case 3 | 70 | Case 8 | 130 |
| Case 4 | 80 | Case 9 | 140 |
| Case 5 | 90 | Case 10 | 150 |

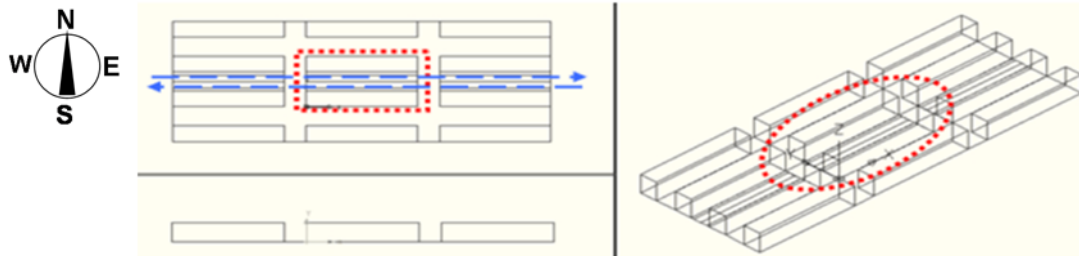


Fig. 1 Geometric model of block space

3. Analysis of the results

The temperature difference of the average air temperature between the simulation cases and the comparative case at 1.5m-height from the ground is shown in Table 2.

The standard simulation case is an approximation of the actual street canyons. Comparing the street canyons without vehicles, we can see the effect of the vehicle exhaust heat on the 1.5m-height air temperature in the street canyons: The air temperature in the garage area increased by about 0.33 °C, and that in the E-W and W-E directions increased by about 0.22 °C and 0.44 °C, respectively, while the air temperature in the pedestrian area increased by about 0.1 °C, which was about 0.2 °C near the W-E. The measured result is that the 1.5m-height air temperature in the street canyon is higher than the meteorological temperature by about 1.5°C, mainly because the measured temperature difference is the difference between the measuring point and the meteorological station in the street canyon, affected by the street canyon's geometry, direction, material properties and vehicle exhaust heat. The comprehensive comparison of each case shows that, with the increase of vehicle exhaust heat, the 1.5m-height air temperature gradually increases and its gradient increases. When the heat generation rate of road vehicles is 100W/m³, the 1.5m-height air temperature in the driving area increases by about 0.4°C, and the 1.5m-height air temperature in the pedestrian area increases by about 0.2°C. The air temperature in the E-W vehicle direction is slightly lower than the W-E vehicle direction, which is mainly because when the direction of the traveling vehicle is consistent with the wind direction, the heat is relatively easy to emit, and is also related to the angle of solar radiation. The temperature rising range of the pedestrian area gradually enlarges.

Table 2 Temperature difference between each simulation case and the comparative case

| Simulation cases | 1.5m-height air temperature difference (°C) | | | |
|---------------------------|---|-----------------------|-------------|-----------------|
| | E-W vehicle direction | W-E vehicle direction | garage area | pedestrian area |
| case 1 | 0.21 | 0.24 | 0.23 | 0.05 |
| case 2 | 0.21 | 0.31 | 0.26 | 0.05 |
| case 3 | 0.20 | 0.38 | 0.29 | 0.07 |
| case 4 | 0.20 | 0.42 | 0.31 | 0.08 |
| case 5 | 0.21 | 0.44 | 0.33 | 0.10 |
| standard simulation cases | 0.22 | 0.44 | 0.33 | 0.11 |
| case6 | 0.23 | 0.45 | 0.34 | 0.15 |
| case7 | 0.25 | 0.44 | 0.35 | 0.19 |
| case8 | 0.25 | 0.43 | 0.34 | 0.21 |
| case9 | 0.24 | 0.43 | 0.34 | 0.22 |
| case10 | 0.25 | 0.42 | 0.34 | 0.23 |

The variation trend of the 1.5m-height air temperature difference in different vehicle directions with the heat generation rate of road vehicles is shown in Fig. 2. It can be seen from the figure that the 1.5m air temperature difference in the W-E vehicle direction is increasing rapidly in the process of increasing the heat generation rate of road vehicles from 50 W/m³ to 100 W/m³, increasing from 0.24 °C to 0.44 °C, and then tending to be gentle; air temperature difference in the E-W garage area has been increasing slowly. Thus the effect of vehicle exhaust heat on the 1.5m-height air temperature in the driving area is obvious.

The trend of the 1.5m-height air temperature difference between the driving area, the pedestrian area and the entire street canyon along with the heat generation rate of road vehicles is shown in Fig. 3. It can be seen from the figure that the 1.5m-height air temperature range of the entire street canyon and pedestrian area is 0.23-0.35°C and 0.05-0.23°C, respectively, and the variation ranges are 0.12°C and 0.18°C respectively. Vehicle exhaust heat has significant effect on the 1.5m-height air temperature in the driving area, while the pedestrian area is relatively weak. For every 10W/m³ increase in the heat generation rate of road vehicles, the 1.5m-height air temperature in the driving area increases by about 0.03°C, and gradually decreases with the increase of vehicle exhaust heat; while the 1.5m-height air temperature in the pedestrian area increases by about 0.02°C, and as the vehicle exhaust heat increases, it gradually increases. It can be seen that as the vehicle exhaust heat increases, the temperature rising in the driving area gradually decreases and that in the pedestrian area gradually increases under the effect of vehicle exhaust. The 1.5m air temperature difference in the entire street canyon area varies from 0.14 to 0.29 °C with a variation of 0.15 °C. For every 10W/m³ increase in heat generation rate of road vehicles, the air temperature difference increases by about 0.02 °C, and the air temperature difference increases slightly as the vehicle exhaust heat increases.

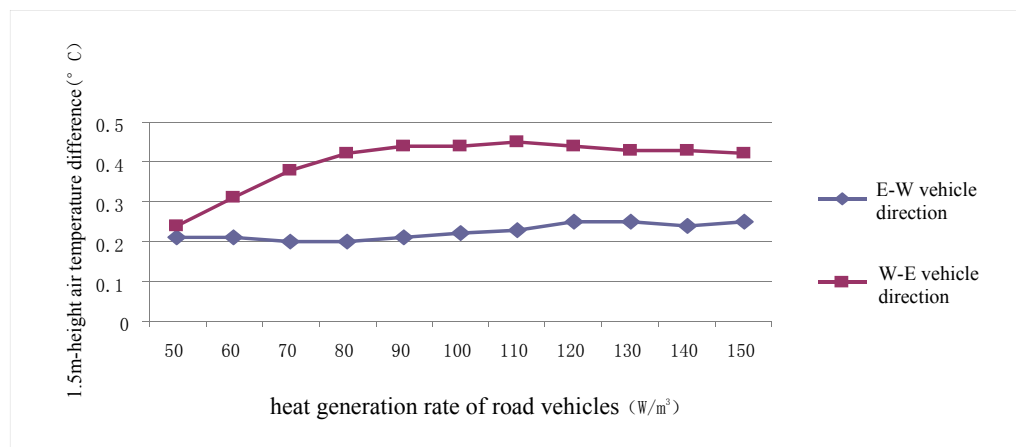


Fig. 2 Relationship between the air temperature difference of 1.5m above the ground in different directions and the heat generation rate of road vehicles

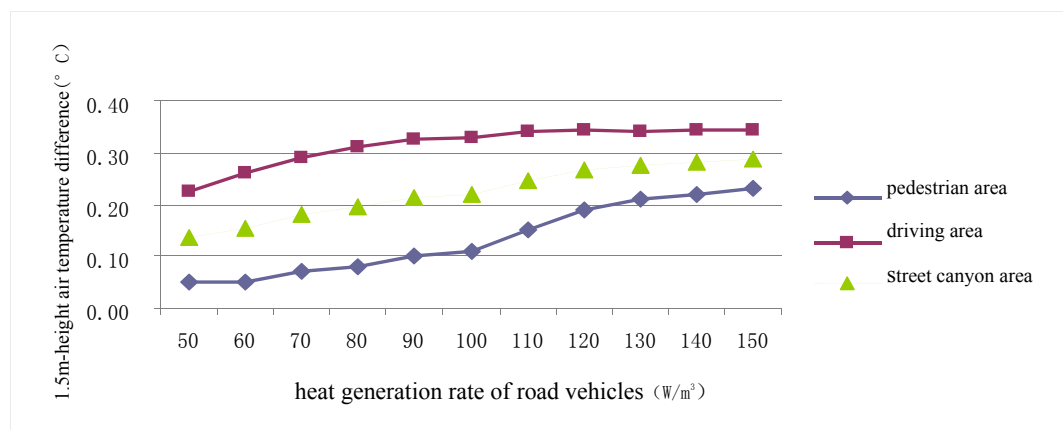


Figure 3 Relationship between the air temperature difference of 1.5m above the ground and the heat generation rate of road vehicles

4. Conclusion

By simulating the thermal environment of different street canyons, the effect of vehicles on the thermal environment of street canyons was analysed in this paper. The following conclusions are obtained:

(1) With the increase of vehicle exhaust heat, the temperature rising of vehicle exhaust heat on the pedestrian area gradually weakens while that on the pedestrian area gradually increases.

(2) The air temperature difference of 1.5m-height from the ground in the whole street canyon area varies from 0.14 to 0.29 $^{\circ}C$, and the variation range is 0.15 $^{\circ}C$. For every 10 W/m^3 increase in heat generation rate of road vehicles, the air temperature difference increases by about 0.02 $^{\circ}C$, and the air temperature difference increases slightly as the vehicle exhaust heat increases.

(3) With the increase of vehicle exhaust heat, the 1.5m-height air temperature difference in the pedestrian area of the street canyons gradually increases, and the range of pedestrian area affected by vehicle exhaust heat gradually increases. When planning and designing the pedestrian area, the reasonable distance from pedestrian area to road cars should be guaranteed to reduce the adverse effects of vehicle exhaust on pedestrian area.

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