5.16 3-D STREAM AND VORTEXES IN AN URBAN CANOPY LAYER AND TRANSPORT OF MOTOR VEHICLE EXHAUST GAS – WIND TUNNEL EXPERIMENT

Hitoshi Kono and Kimiyo Kusunoki
Hyogo Prefectural University, 1-1-12 Shinzaike-honcyo, Himeji-shi, Hyogo, Japan

INTRODUCTION

The stream in the urban canopy layer is thought to be complicated. Therefore, modelling the vortexes in street canyons is an attractive subject for predicting the transport of motor vehicle exhaust gas. For predicting the concentration of air pollutants within a street canyon, one or twin vortex model is used in OSPM (Hertel and Berkowicz, 1989). The vortex is created on the vertical cross-section of the street canyons ("vertical vortex"). The axis of rotation is along a street. It transports and mixes air pollutants emitted in the street canyon. However the OSPM is applicable to a 2-D street which has large distance between intersections. The effect of the transport of air pollutants through intersecting streets is not included in the model.

The effect of the intersecting streets is important to predict the dispersion in the vicinity of the street. The OMG model (Kono and Ito, 1990), a micro scale dispersion model which predict the dispersion of motor vehicle exhaust gas within 200 m from a street, includes the effect of intersecting streets in the height of an imaginary boundary, below which buildings interrupt the horizontal transport. If the intervals between buildings along a street are small, the height of imaginary boundary is almost same as the height of buildings. If the intervals between buildings are larger, the height of imaginary boundary becomes lower than the building height. The OMG model employs a volume-source to model the mixing of pollutants within the street canyon. The ratio of the thickness of the volume source to the building height along the street varies with intervals between buildings.

This paper presents the wind tunnel experiments which were conducted by using a tracer for visualizing the transport. It visualized the stream and the vortexes in street canyons for several wind directions, and several dimensions of building length, height and street width. The dispersion of air pollutants in the vicinity of a street was discussed.

EXPERIMENTAL SET-UP

The experiments were carried out in the atmospheric boundary-layer wind tunnel of our laboratory. The length, width and height of the working section are 2m ×0.3m × 0.3m. Details of the wind tunnel are shown in Fig. 1. In the wind tunnel the neutral atmospheric boundary layer was simulated. At the upstream of street canyon models, wind velocity was set to be u=2.3m/s in free atmospheric layer. The boundary layer was 0.20 m in height and had a vertical wind profile of the power law with p=0.24. The turbulent intensity was $\sigma_u/u=0.17$ at the height of a building of H=27mm. The building Reynolds number was $Re_H=U_H \times H/\nu=2800\sim8300$, with H=18～54mm, where U_H is wind speed at the height of buildings, $\nu$is the coefficient of kinematic viscosity. The model scale was 1: 500. Smoke of incense sticks was released in a street canyon for visualizing the dispersion. The incense stick was located at a bottom of the street canyon. A video camera was used for recording the dispersion.

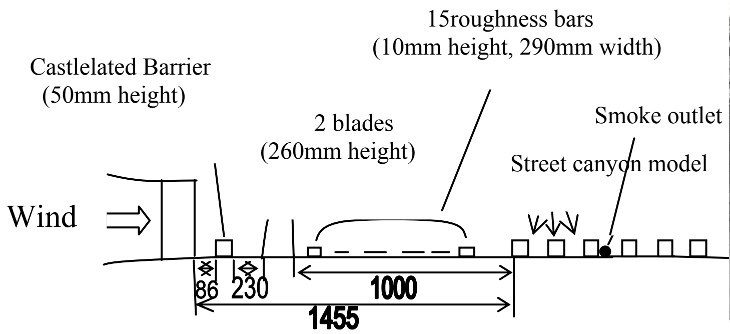


Figure 1. Wind tunnel (working section, mm)

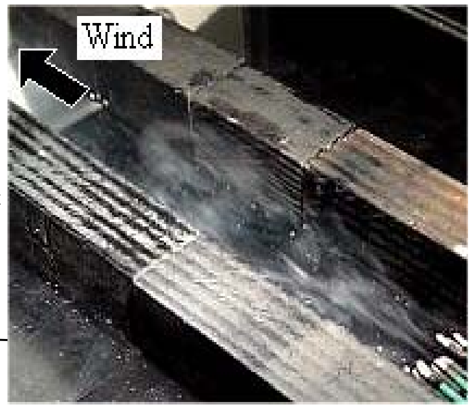


Figure 2. Flow for wind direction parallel to the street

RESULTS

2-D street model

A 2-D street model has a large distance between intersections of L/W>5 and H/W=0.67 where L is the distance between intersections, W is the street width and H is the building height (=27mm). When wind direction above buildings was parallel to the street, vortexes were not existed in the vertical cross-section of the street. (Fig. 2) Therefore, air pollutants were transported in the street canyon and were not transported above the street canyon within a short distance from a source. However, for wind direction perpendicular to the street, a vortex existed in the vertical cross-section of the street ("vertical vortex"). The vortex transported air pollutants above the street canyon. For wind direction oblique to the street, a spiral flow existed in it. (Fig. 3) The results are almost same as TNO videotapes of flow visualization experiments by Builtjes(1983).

Figure 3. A spiral flow for wind direction oblique to the street (θ=45°)

Comparing the average plume height, the height was lower for wind direction parallel to the street than wind direction perpendicular or oblique to the street. Therefore the mean transport speed is smaller for wind direction parallel to the street than the other wind directions. The OMG model uses the wind speed measured above buildings for all wind directions. (Fig. 4) The OMG model underestimates 40 to 50 % of concentration of pollutants when the wind direction is parallel to the street. It is expected to improve the OMG model for wind direction parallel to the street if the horizontal transport speed in the street canyon is used for the wind direction.

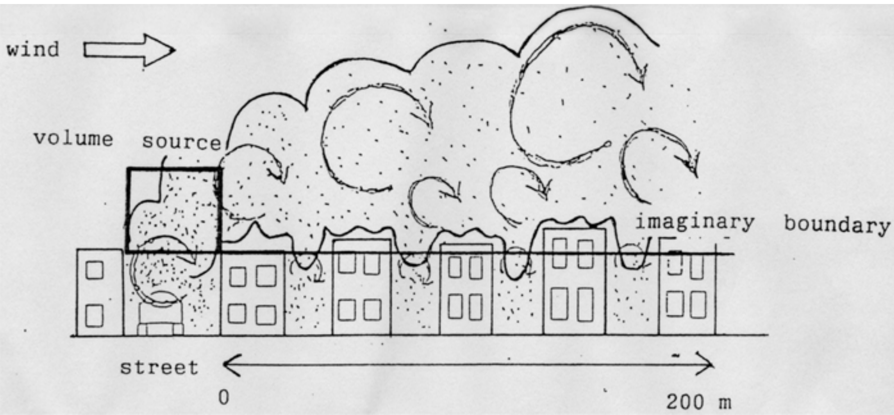


Figure 4. Schematic diagram of the OMG Volume-Source Dispersion Model

We observed that the "vertical vortex" transported the upper air pollutants into the street canyons. (Fig. 5) It shows the reason why observed vertical distribution of the concentration of air pollutants at downwind small streets, becomes uniform between the ground level and the height of buildings.

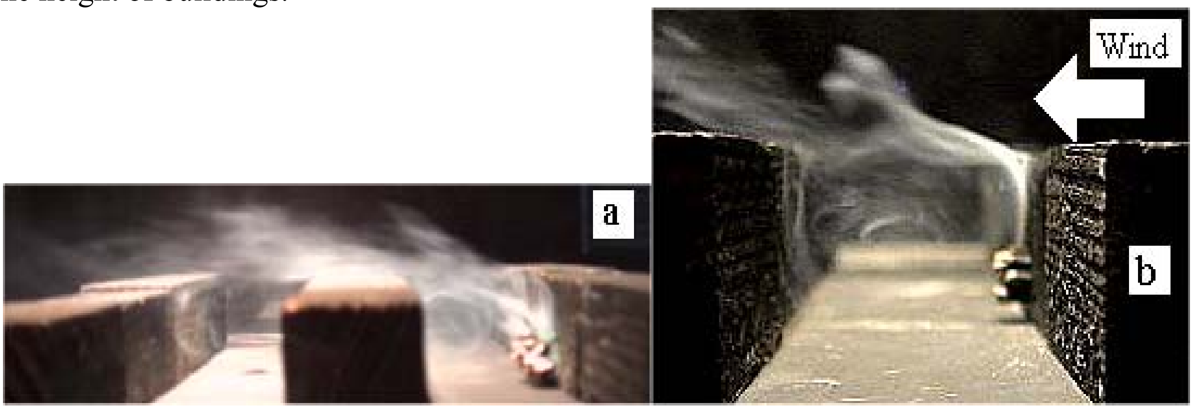
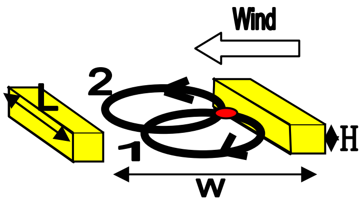


Figure 5. (a) The" vertical vortex" transported the upper air pollutants into the street canyons. (b)The "vertical vortex"

3-D street model for wind direction perpendicular to the street

The 3-D street model has a relatively small distance between intersections. For wind direction perpendicular to a street (wind direction / street orientation angle, 80°<θ<90°), two types of vortex were mixed in a 3-D street canyon. One was a "vertical vortex". The other was a vortex on the horizontal section whose axis of rotation was vertical to the ground ("horizontal vortex"). On the horizontal section, two types of "horizontal vortex" whose rotating direction was opposite, were created and interchanged periodically in the street canyon. (Fig. 6) The "horizontal vortex" transported air pollutants to a street which intersect this street. As a result, the amount of air pollutants transported upward decreased.



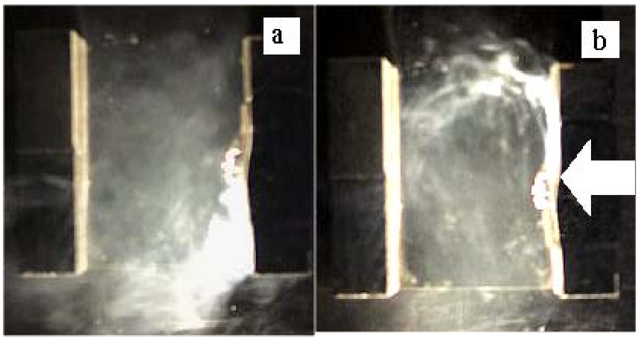


Figure 6. A pair of horizontal vortexes (a)clockwise vortex, (b)anticlockwise vortex (The photographs are top-view. L/W=1.2)

We investigated the relation between the type of a vortex which existed stably in a street canyon, and dimensions of L/W and H/W. The "vertical vortex" existed stably in the street whose distance between intersections was long enough. The "horizontal vortexes" and the "vertical vortex" were mixed in the street whose distance between intersections was short.

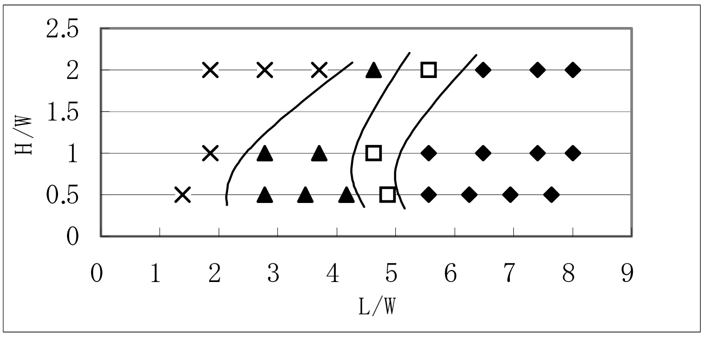


Figure 7. The relation between the type of a vortex which stably existed in a street canyon, and dimensions of L/W and H/W for perpendicular wind direction, H=54mm

- ◆ A vertical vortex existed stably.
- □ A vertical vortex swayed large along the street.
- ▲ Sometimes a vertical vortex collapsed and a horizontal vortex was created.
- × A pair of horizontal vortex existed stably. A horizontal vortex and a vertical vortex were mixed.

If the intervals between buildings become smaller, a 3-D street becomes a 2-D street and "horizontal vortexes" may disappear and a "vertical vortex" is created for wind direction perpendicular to the street. We investigated the relation between the swing period of the "horizontal vortex" and the intervals between buildings, I/L. The model is shown in Fig. 8. The results are shown in Table 1. The swing period was inversely proportional to the intervals of I/L. Note that the results will show the general tendency and will not show the precise conclusion because the effect of viscosity may become larger in the small interbuilding spaces.

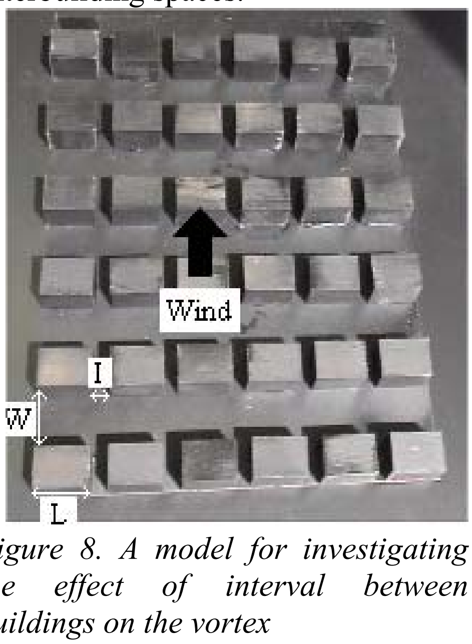


Figure 8. A model for investigating the effect of interval between buildings on the vortex

Table 1. The relation between the swing period of the "horizontal vortex" and I/L where I is an interval between buildings and L is the length of a building. Wind direction is perpendicular to the street. (H=20mm, W=30mm, L=30mm, I=9mm, 5mm, 3mm)

I/L	Period (s)
0.30	1.8
0.17	7.5
0.10	No swing

For oblique wind direction (θ=45°), we investigated the effect of the interbuilding space on the transport of air pollutants. The results are shown in Fig. 9. The larger the space, the amount of air pollutants transported through intersecting streets increased.

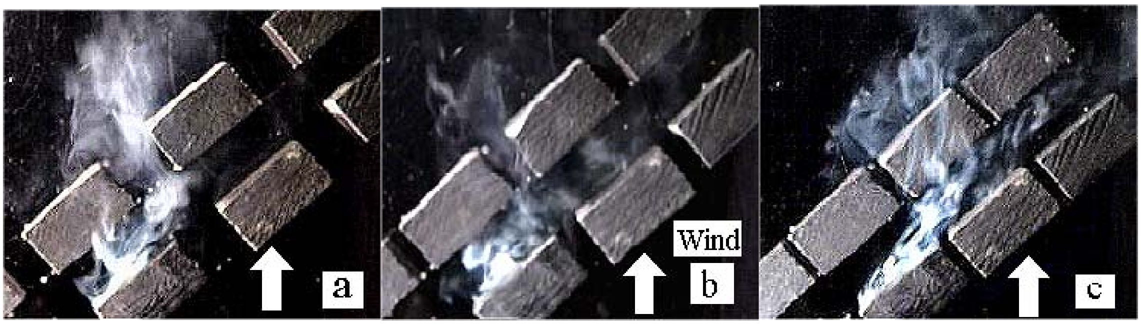


Figure 9. The effect of inter building space on the transport of air pollutants for wind direction oblique to the street (θ=45°) (a) I/W=1, (b) I/W=0.5, (c) I/W=0.25

CONCLUSIONS

Wind tunnel experiments were conducted for investigating the transport of air pollutants in the vicinity of a street. The stream and the vortexes in street canyons were visualized by using smoke and recorded by video camera. The “vertical vortex” has important roles for the initial mixing of pollutants in the street canyon and the transport of pollutants in the vertical direction. The plume height becomes higher by the “vertical vortex”. The average plume height is lower for wind direction parallel to the street than that for wind direction oblique or perpendicular to the street at 2-D streets. At 3-D streets the “horizontal vortexes” are created when wind direction is perpendicular to the street. For perpendicular wind direction, the “horizontal vortex” has important role for transporting air pollutants in the horizontal direction. When wind direction is oblique to the street, transport of air pollutants by the mean flow is larger than that by the “horizontal vortex”. It is expected to improve the underestimation of the OMG model for wind direction parallel to the street.

ACKNOWLEDGEMENTS

The authors thanks to Mr. Osamu Kanechika (Sogo Kagaku Co.) for his useful comments on the manuscript.

REFERENCES

Hertel, Ole. And R. Berkowicz,1989: Modelling pollution from traffic in a street canyon. Evaluation of data and model development, pp.1-77, National Environmental Research Institute DMU LUFT-A129.

Kono, H. and S. Ito,1990: A micro-scale dispersion model for motor vehicle exhaust gas in urban areas- OMG volume-source model, Atmospheric Environment, **24B**, pp.243-251.

Builtjes P.J.H.,1983: Determination of the flow field in a street canyon by means of wind tunnel experiments. TNO Progress Report 83-09553.