CFD Simulation of Concentration and Flow Distribution by Different Arrangements of Building Height in Urban Street Canyon.

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ABSTRACT: Air pollution in big city areas resulting from exhaust emissions is a major urban problem. Often traffic pollution excess controls air pollution management decisions. There are a number of elaborate predictive models of pollutant dispersion and diffusion that address the effects of variable shapes of city buildings on pollutant concentrations, but few are fully validated. This study presents ventilation behavior in different street canyon configurations. To evaluate dispersion in a model urban street canyon, a series of tests with various street canyons with different height in upwind and downwind of street canyon are presented. These buildings were arranged in 2-D and 3-D configurations with different height in upwind and downwind of street canyon. The results show that a higher concentration of pollutants accumulates under the leeward of the street canyon due to the occurrence of a clockwise vortex inside the street canyon when the street canyon aspect ratio (B/H) is 2. On the contrary, over the windward of the street canyon, a lower concentration of pollutants accumulates due to the occurrence of an anti-clockwise vortex. The flow and dispersion of gases emitted by a line source located between two buildings inside of the urban street canyons were also determined by numerical model. Calculations are compared against fluid modeling in an Environmental Wind Tunnel at Tamkang University.

KEYWORDS: Keywords: urban street canyon, dispersion, air pollution aerodynamics, numerical modeling

1. INTRODUCTION

The majority of populations congregate in major modern cities where the conditions are more likely for people to gather due to the prosperity of both industrial and commercial activities in those areas. The increase of population demands more frequent use of transportation, which would generate a higher concentration of pollutants emitted from
transportation activities. Furthermore, in order to ultimately develop lands in urban areas, the heights of buildings have been raised as high as possible. Under such conditions, emitted pollutants would have direct impact on the health of the urban population, especially on pedestrians, motorcyclists, residents, or workers in the urban areas where high-rise buildings can shape urban street canyons. In a study related to air pollutants transportation in street canyons [1], Meroney (1996) carried out wind tunnel tests with the same building heights, but with different street widths. When the street width to building height ratio was 1 (B/H=1) and the wind speed was changed from 0.5 to 5 m/sec, the results showed that the changes of pollutant concentration were not significant. However, with the line source of pollution, Meroney reveals that the concentration at the leeward side of the street canyon is twice as high if the aspect ratios were B/H=2 and B/H=4. From smoke flow visualization, it can be clearly observed that a more stabilized vortex is formed in the street canyon, but with poor ventilation.

2. EXPERIMENT SETUPS AND NUMERICAL SIMULATIONS

The study used the Atmospheric Boundary Layer Wind Tunnel at Tam Kang University in Taiwan to conduct a series of simulated wind tunnel tests. The test section was 18.7 m long ×3.2 m width ×2.0m height. The Wind Tunnel is an open-suction type. The typical size of the street canyon (Fig.1) in the study was 75 cm long × 8 cm width. The heights from left to right are 4, 8, 12, 16 cm, respectively. Wind Tunnel inlet flow velocity measurements were surveyed at the front of the street canyon. The W.T. inlet flow velocity profile data were regressed to find the best power law fit. The power law regression found an exponent, $p =0.14$.

FLUENT was used for numerical simulations. The line source inlet was modeled at a constant velocity and no turbulence. A tracer mass fraction of 1 was applied to the source inlet during the calculation. In presenting the results from the calculation, tracer gases concentration was normalized to facilitate comparison with experiments and other numerical results.

3. RESULTS AND DISCUSSION

3.1 Case of the street canyon with heights of 4, 8, 12, 16 cm, heights from low to high

In Figure 2, the leeward of the buildings arranged in the downwind site of the street canyon from low to high are rake 1, rake 3, and rake 5, respectively. The windward of the buildings arranged accordingly in the upwind site of the street canyon are rake 2, rake 4, and rake 6. From the experimental data shown in Figure 2, the concentration in the leeward side is higher than the concentration in the windward side. As for rake 1, the variation of the dimensionless concentration is relatively unstable. The increase of the wind speed will lower the concentration due to the fact that the wind can sweep pollutants away.
The numerical simulation can also predict dimensionless concentration as Figure 3 shows. The result depicts that the dimensionless concentration mainly is detected in the leeward side. In other words, the dimensionless concentration in the leeward side is higher than the dimensionless concentration in the windward side. The result also matches the result from the wind tunnel test. The factor that affects the accumulation of pollutants is viscosity.

3.2 Case of the street canyon with heights of 16, 12, 8, 4 cm, heights from high to low

The experimental data seen in Figure 4 shows that the result from rake 2 is greater than rake 1; rake 4 is greater than rake 3; and rake 6 is greater than rake 5. The results are totally opposite from the results derived from the test in the street canyon with heights from low to high. In a model of a street canyon that is high in the front and low in the end, the rooftop corner of the higher buildings in the upwind site would generate separation flow. In addition, the wind speed around the rooftop corner of higher buildings would also increase due to having higher buildings in the upwind site. In the downwind site, however, inverting wind would flow on the top of the lower buildings as can be seen in Figure 5. Figure 6 presents the pollutant accumulation caused by viscosity. The vortex on top is close to the leeward side. This can cause an inverting vortex at the bottom of the windward side. Pollutants in the bottom of the vortex cannot be easily removed by wind. This could also cause higher dimensionless concentration at the bottom of the leeward side.

4. CONCLUSION

In this study, a wind tunnel test in a symmetric height street canyon was conducted. The results from the test were compared with the experimental data from a numerical simulation using the software FLUENT 6.1. From the three dimensional symmetric street
canyon CFD model, the prediction from the standard turbulence model is similar to the results from the wind tunnel. From the tests in a street canyon with various heights from high to low and in a street canyon with various heights from low to high, the results indicated that with different height arrangements the geometric shapes changed directions of the flow fields. Eventually, accumulation of the dimensionless concentration would also change. CFD simulation can simulate the changes of the flow field and the distribution of pollution concentration in a street canyon. In the street canyon with different heights, pollutant transportation and accumulation was considerable. The dimensionless concentration in the nearby areas reached the highest level. The health of people such as pedestrians, residents or workers who live or work in the nearby areas would be seriously affected by the pollution.

5. REFERENCES