6.4 PASSIVE TRACER DISPERSION OVER A REGULAR ARRAY OF CUBES USING CFD SIMULATIONS

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1. INTRODUCTION

Nowadays, air pollution is considered a great environmental problem in many cities. Thus, it is important to study pollutant dispersion inside urban canopy, where there are complex patterns of air flow that determine pollutant concentration. During last decades, a large number of investigations has been carried out by means of field experiments (e.g, Rotach, 1995; Vachon *et al.*, 2001), wind tunnel models (e.g., Brown *et al.*, 2001; Meroney *et al.*, 1996) and numerical simulations (e.g., Baik and Kim, 2002; Santiago and Martin, 2005; Sini *et al.* 1996) to contribute our understanding about meteorology and pollutant dispersion inside urban environment.

In this contribution, CFD simulations of pollutant dispersion over a regular three dimensional array of cubes are carried out representing a regular configuration of streets (canyons) and buildings. Simulations are based on Reynolds Averaged Navier-Stokes equations (RANS) using standard k-e turbulent closure. Pollutants are modeled by a passive tracer emitted at ground inside regular array of cubes. Our study is focused on the location of maximum and minimum of passive tracer concentration and the relation of pollutant concentration to flow pattern. In addition, several passive tracers are emitted inside each canyon to study the effect of emissions inside a street on concentration inside the other ones. Thus, some information on the contribution of neighbor canyon emissions on pollutant concentration is obtained.

2. MODEL DESCRIPTION AND SET UP

The numerical model used is FLUENT (FLUENT Inc., 2005). Simulations are based on Reynolds Averaged Navier-Stokes equations (RANS) with standard k-e turbulent scheme. In addition a transport equation for passive scalar is solved to simulate pollutant dispersion.

Numerical domain consists of a 7 cubes row in streamwise direction with symmetry boundary conditions at limits in spanwise direction to simulate a 3D array of cubes. The cube edge length (H = 0.15 m) and street aspect ratios are all equals to 1, obtaining a regular array. Non-uniform grid system with 202 cells in the x-direction, 44 in the y-direction and 40 in the z-direction (Figure 1). For further details of the numerical set up see presentation J5.1. in the *Sixth Symposium on the Urban Environment* (Santiago et al., 2005).

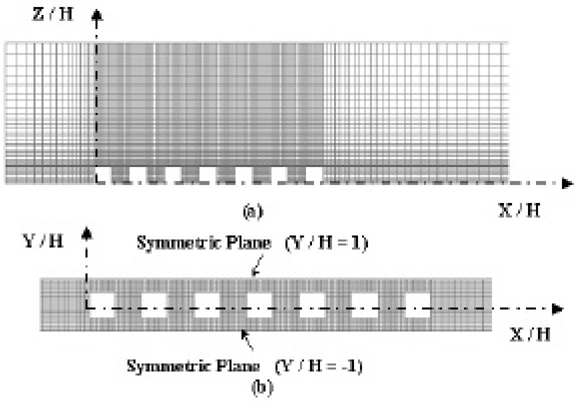

Figure 1. The a) side view and b) top view of the numerical domain and grid system.

The regular array can be divided into 6 cube canyon units and a zone with one more cube. 8 passive tracer are released. All sources are located at ground where tracer 1 is emitted only in the first cube canyon unit (Figure 2b), tracer 2 in the second unit and so on. Tracer 8 is emitted in the whole array region (Figure 2a).

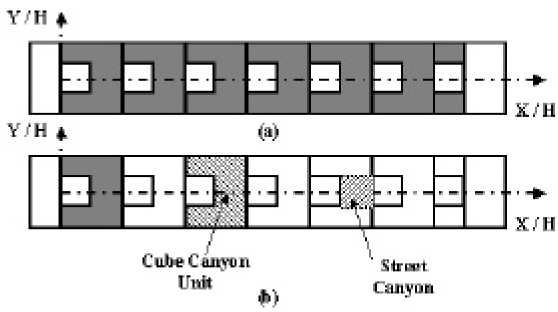

Figure 2. *X-Y* view at *Z* / *H* = 0 of a) location of tracer source in the case of emissions in the whole array region (Tracer 8) and b) location of tracer source in the case of the first unit emitting (Tracer 1). Sources: shaded regions. Scheme of a Cube Canyon Unit: backward slash and Street Canyon: forward slash.

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In all cases the emissions are uniform and with a value of S_C = 1 Kg^{2}m^{-6}s^{-1} corresponding to a emission (S_C/r) of 1/1.225 Kgm^{3}s^{-1}. This is a reference value since we are not interested in absolute value of tracer concentration. The interesting point is focused on location of maximums and minimums, relationship between emission inside a canyon and concentration induced in other, distribution of pollutant, etc.

3. NOTATION

To simplify the expressions used in the following a new notation is introduced. $C_T(u_i)$ represents total concentration of tracer 8 (emissions in the whole array region) in points which belongs to unit *i* and $C_{TRACER\,j}(u_i)$ indicates the same but for the tracer *j*. In addition, SC_i indicates street canyon number *i*, in other words, the zone between the cubes number *i* and *i+1* (see Figure 2b). Also, we use brackets (<>) to indicate an average value over the volume of air inside a street canyon

4. RESULTS

4.1 *Emissions in the whole array region (Tracer 8)*

Maximum values of concentration, as expected (source close to the ground), are located at lower region (*Z/H*=0.25), and decrease with height. At *Z/H*=0.25 the maximum inside each unit are outside of canyons. This fact is explained by the flow pattern which near the street bottom is outward. Near the downwind cube in each canyon the flow is downward and inward in the upper region and outward, as commented above, in the lower region. The downward motion of clean air creates a zone with low concentration close to the downwind cubes (Figure 3). For further details of flow pattern see presentation J5.1 in the *Sixth Symposium on the Urban Environment*.

Highest values of concentration are located in the last units due to pollutant advection from the upwind region. However in the sixth unit, this behavior is slightly different because the flow pattern is affected by unit location (at the end of array). Due to the same reason, the flow pattern and pollutant dispersion is also different in the first unit (Figure 3).

4.2 *Emissions inside each cube canyon unit (Tracer 1-7)*

In this section, the influence of source location over concentration is studied by means of the release of 7 tracers. Each tracer is only emitted from one unit (tracer 1 from unit 1, tracer 2 from unit 2,…).

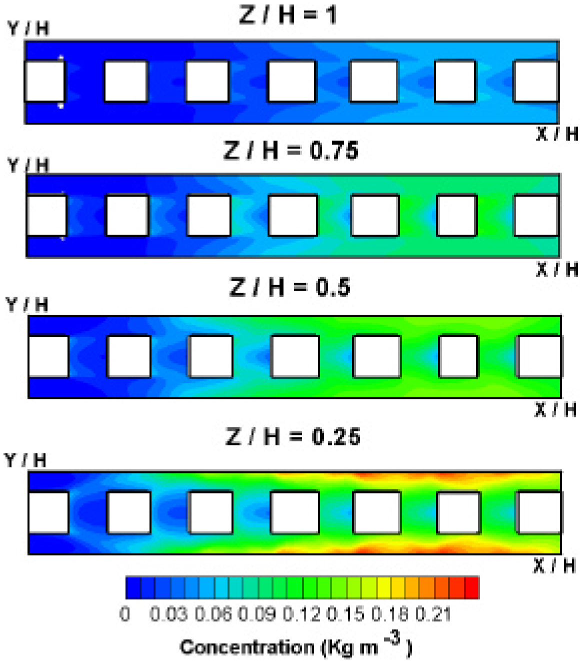

Figure 3. Total concentration (tracer 8) at *Z/H*=0.25, 0.5, 0.75 and 1.

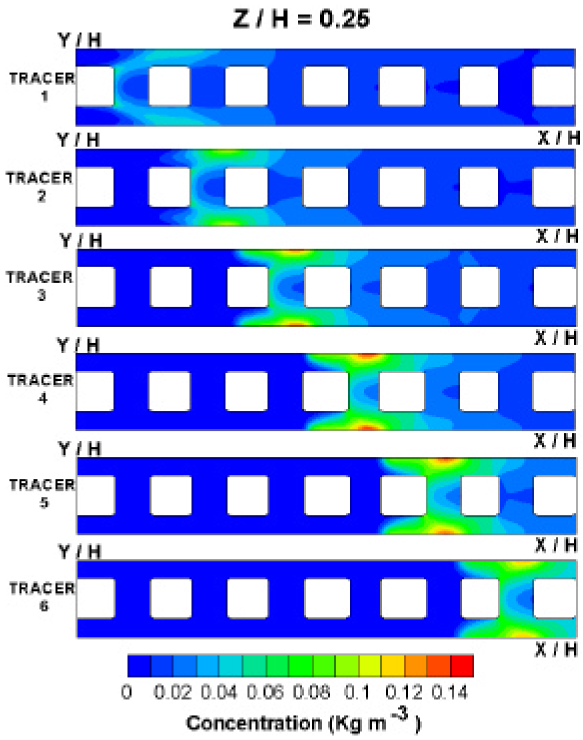

Figure 4. Concentration produced by one unit emissions (tracer 1, tracer 2, tracer 3, tracer 4, tracer 5 and tracer 6) at *Z/H*=0.25.

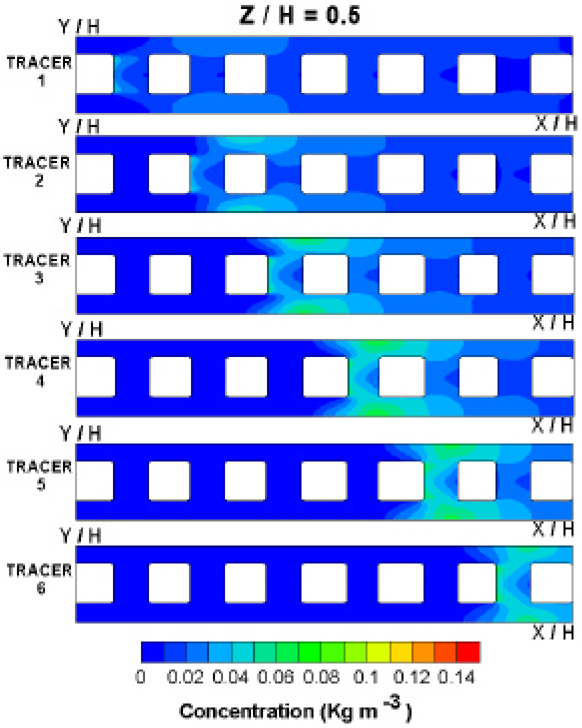

Figure 5. Same as Figure 4 but for *Z*/*H*=0.5.

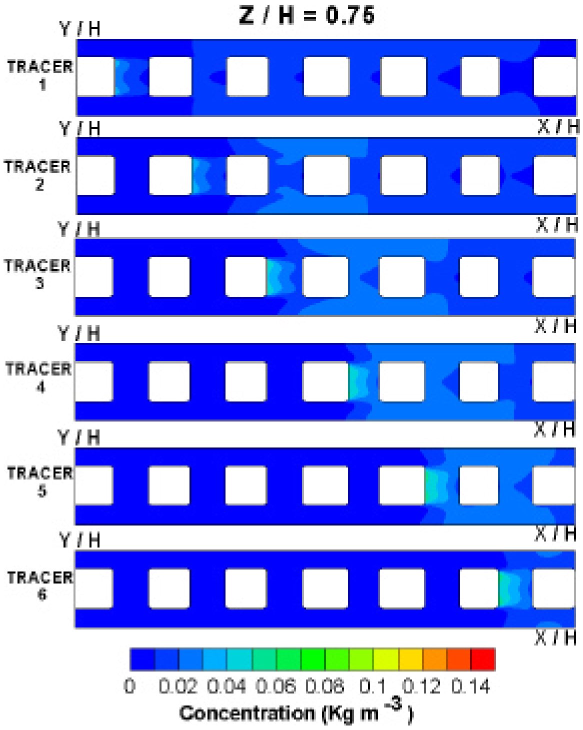

Figure 6. Same as Figure 4 but for *Z*/*H*=0.75.

Following the notation above explained, $C_T(u_i) = \sum_{j=1}^{N} C_{TRACER\,j}(u_i)$, where *N* is the number of units, is fulfilled due to linearity of transport equation and the emissions which are equal in all cases. This statement has been checked with the computed results. In all cases the emissions inside each cube canyon unit only affect the concentration in downwind units (Figures 4, 5 and 6).

The influence of emissions in each case can be large inside the downwind neighbor unit and inside further downwind units can be non negligible in certain zones increasing this contribution at higher heights (Figures 4, 5 and 6).

Concentration patterns of tracer 1 are very different in comparison with other cases. The flow inside the first unit (higher wind velocity and turbulence) affects pollutant dispersion. In this case relatively low concentration appears and at *Z*/*H*=0.25 the highest values are located in two bands from the corners of upwind cube (Figure 4).

The most similar patterns are obtained in the cases of tracer 4 and 5 also indicating a similar flow pattern inside these units.

4.3 *Average concentration*

In this section, pollutant concentration is averaged over the volume of air inside street canyons to search for relationships between average concentration inside a street canyon and emission locations. We take the cases of the tracer 4 and 5 as the most representatives due to these flow and concentration patterns are very similar between them.

The average total concentration (tracer 8) increases with the number of street canyon (in downwind direction). Average concentration is higher in a street canyon than in the previous one, but the difference of concentration between them is less in the last street canyons (Figure 7a) $(<C_T(SC_i)> - <C_T(SC_{i-1})> < <C_T(SC_{i-1})> - <C_T(SC_{i-2})>)$. There are more upwind emitting units in the last street canyons. The sixth street canyon is the exception and it does not follow this tendency due to its location, at the end of the array, affects tracer dispersion.

To study the contribution of unit emissions in average concentration inside a street canyon, we select the fourth and fifth street canyons and compare average concentration inside them produced by the different tracers.

$\frac{<C_{TRACER\,j}(SC_i)>}{<C_{TRACER\,i}(SC_i)>}$ (with j from 1 to i) is fitted for the 4th and 5th street canyon to a function as $\frac{B}{X+A}$, where X is (i + 1 - j). Fitting gives A = 0.1 and B = 1.1 with a correlation coefficient of 0.99 in both cases (Figure 7b and 7c). The fitting function gives a simple relationship between pollutant source location and average concentration inside a street canyon, i.e. the influence of emissions of other areas (or units) in the selected street canyon.

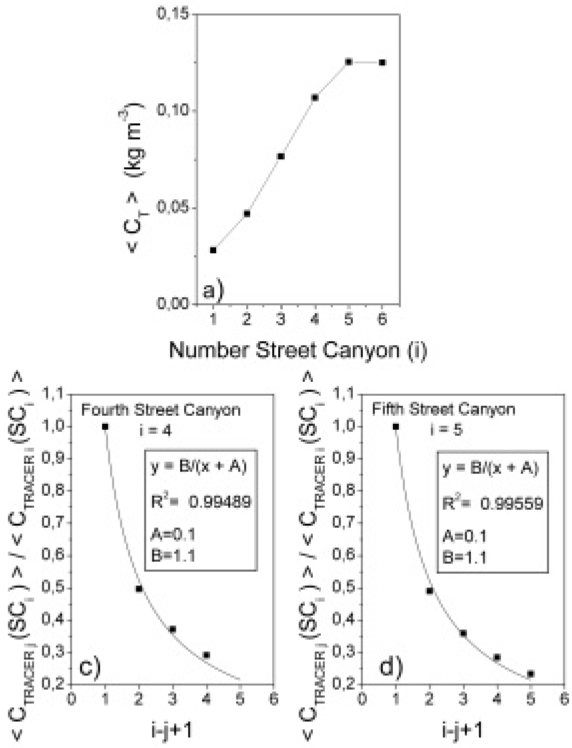

Figure 7. a) Average total street canyon inside each street canyon. b) Average concentration due to individual unit emissions (tracer j) inside the 4th street canyon normalised by average concentration of tracer 4 inside the same street canyon ($\frac{<C_{TRACER\,j}>(SC_4)}{<C_{TRACER\,4}>(SC_4)}$). Also, fitting function ($\frac{B}{X+A}$) is plotted. c) Same as b but for the 5th street canyon.

5. CONCLUSIONS

Pollutant dispersion is determined by flow patterns. Highest concentration values appear at lower levels and decrease with height. At lower levels they are situated outside of street canyons. These locations are due to flow patterns which is outwards in this region. In addition, lower concentration zones are created at downwind face of street canyons.

Total tracer concentration in the last units is higher due to an accumulative effect, more upwind emitting units contribute to total concentration. Inside a selected unit, the emissions located just upwind can notably contribute to total concentration while the downwind unit emissions are negligible.

A simple relationship between average concentration inside a street canyon and emission locations has been proposed.

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