14.3 LOCALIZED EFFECT OF BUILDING HEIGHT ON STREET LEVEL FLOWS AND CONCENTRATION: WATER CHANNEL MODELING

Sam Pournazeri*, Hansheng Pan, Erik Pellereau, and Marko Princevac
University of California, Riverside, CA 92521

1. Introduction

Human health is negatively impacted by many types of pollutants. Air pollution mainly from vehicles, industries, and power plants, raises the chances of variety of health problems in people exposed to it long, and even short term. One of the main sources of pollution is the vehicular emission especially in metropolitan cities. The type of surrounding built environment has a significant effect on how resulting pollution can be dispersed.

Current models are mostly focused on the effect of vehicular emission on air quality near highways, freeways or simple terrain.

Previous studies considered the street canyon with a turbulent shear flow perpendicular to the axis of the street canyon above a rectangular cavity (Britter and Hanna, 2003). Due to the momentum transport, there is recirculating flow dominating the street level flow. This recirculating flow spreads throughout the whole cavity when aspect ratio is low, as the aspect ratio gets higher, the recirculating flow may not reach the street level.

In horizontal direction there is lateral channeling flow (Princevac et al., 2009). This flow includes sideways mean outflow from the building array behind the first row of buildings followed by the mean inflow in the lee of all succeeding rows of buildings in urban areas. This flow is very sensitive to the position and height of the tall buildings. Inflows through the urban area can be blocked by increasing the height of the central building. The intensity of the inflows and outflows is one of the dominant factors in dispersing the pollutants released upwind and within the urban array.

Chan et al. (2001) carried out a numerical study to simulate the flow and concentration in urban street canyons. They have found that tall buildings do not necessarily make blockage as long as the ratio of the street width, w, to the height of the building, h, and also the height ratio of two building surrounding street canyon h_2/h_1 stay in the region between stagnation and leeward blockage, .

Also Oke (1987) mentioned that in the case of tall buildings situated above the general roof level building, the faster moving upper air is deflected to the ground, therefore, there is an increase in the lower level vortex flow which enhances the dispersion of pollutants at the street level.

Despite of all of these studies, effects of urban morphology on dispersion in urban areas are still not very well understood especially for the distances of the orders of meters and tens of meters from the source. Therefore, there is a need to study the dispersion of pollutants released from vehicles, industries and distributed generators in urban areas where the main sources are in close proximity of the recipients, people.

The objective of the present work is to find out the effect of building heights on the street level flow and concentration in the small distances between source and receptors. Therefore, a complex urban morphology, Los Angeles downtown and simple geometry 5x5 array of cubes has been modeled and tested in the water channel.

2. Laboratory Setup

2.1 Water Channel

The laboratory experiments were done in a water channel (Fig.1) with 1.5 m long, 1 m wide and 0.5m deep test section in the Laboratory for Environmental Flow Modeling (LEFM) at the University of California, Riverside. The axial pump (Carry Manufacture, Inc.) drives a flow from the settling tank with a maximum velocity of 0.5 m/s. Flow can be controlled through a variable frequency controller with a resolution of 1/100Hz. Two flow conditioner in the shape of honeycombs are placed at the entrance of the water channel in order to minimize the pump effect and make the desired inflow velocity profile. The channel flow can be considered as steady and fully developed in the test section.

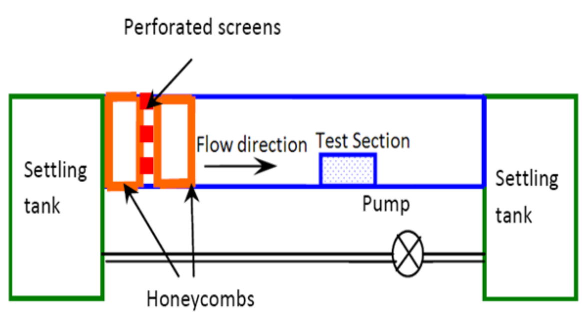

Fig. 1a. Water Channel Schematic

* *Corresponding author address:* Sam Pournazeri, Univ. of California, Riverside, Dept. of Mechanical Engineering, Riverside, CA 92521;
e-mail: spournazeri@engr.ucr.edu

Fig. 1b. Water channel

2.2 PIV/PLIF setup

The velocity field is measured by TSI's Particle Image Velocimetry (PIV) system. This system consists of 400 mJ Nd-YAG laser (Big Sky Laser Technologies Inc.) producing 532 nm wavelength laser beam with the frequency of 1 HZ which is expanded into a laser sheet using a sheet forming optics, Laser pulse synchronizer (TSI Inc.) and a PowerView Plus 11M camera. Pliolite Ultra 100 particles are used as seeding particles in the water channel. In order to measure the fluid's velocity, at least two separate exposures must be recorded. This typically involves producing a pair of laser pulses which are recorded onto a pair of camera frames . The frames are then split in a large number of interrogation areas, often called tiles. Through image processing it is then possible to calculate a displacement vector for each tile. This displacement is converted to a velocity using the time step between consecutive images (in our case Δt=*1.2 ms*). Insight 3G (TSI Inc.) software is used for data collection and image processing.

Concentration field is measured using Planar Laser-Induced Florescence (PLIF) system. The Laser illuminates florescent dye so the dye absorbs the light in one wavelength (532nm) and re-emits it in different wavelengths (555nm). the intensity of the re-emitted light which is recorded by a high resolution (1600 x 1192) POWERVIEW 2M CCD camera (TSI Inc.) is proportional to the concentration of the florescent dye at that specific area. Fig.2. shows the configuration of laser and cameras with the building arrangement to measure the velocity and concentration in horizontal and vertical plane.

2.3 Building Arrangement

Development patterns and the nearness of buildings were the key factors for selecting the arterial study area. In this study two different building arrangements were used:

1. Downtown Los Angeles (Fig.3a)
2. Simple Mock downtown of 5x5 array of cubes (Fig.3b)

Downtown Los Angeles has one of the most heavily trafficked roads with more than 40,000 vehicles per day and building heights of more than twenty stories.

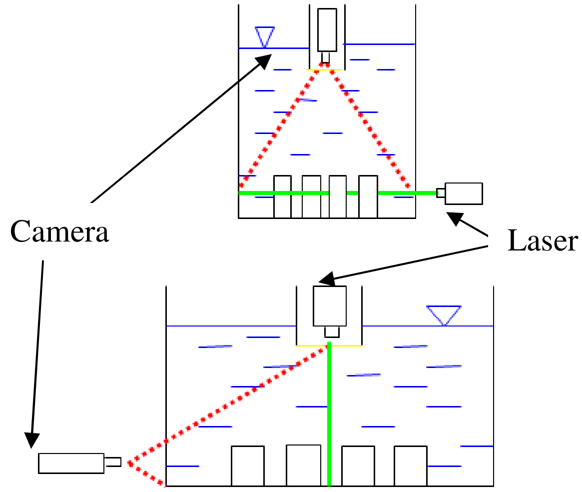

Fig. 2. Schematic of laser-camera configuration

In order to simulate this building environment in laboratory, the database of the dimensions of buildings in Los Angeles downtown area was supplied by the Los Alamos National Laboratory. Highly polished acrylic models which can minimize the refraction and attenuation of laser sheet were used to build high rise settlements. A 480 m x 480 m area, including two major arterials (6th and 7th streets) perpendicular to the wind direction, was scaled down to 60 cm x 60 cm (1:800 scales).

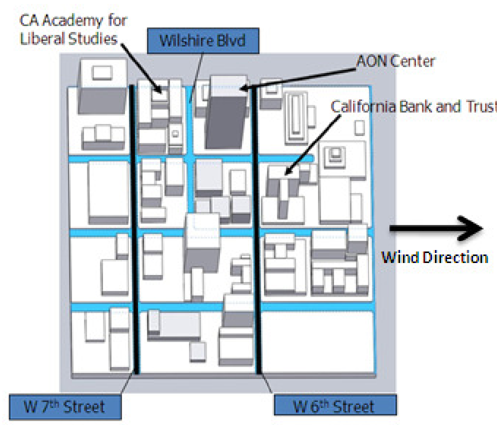

Fig. 3a. High rise settlement in Downtown Los Angeles modeled in water channel

As the Los Angeles model downtown is relatively complex and the result may be a challenge to interpret, we also tested a simple mock urban downtown in which buildings are represented with 5cm x 5cm cubes and the central building with a same or double height.

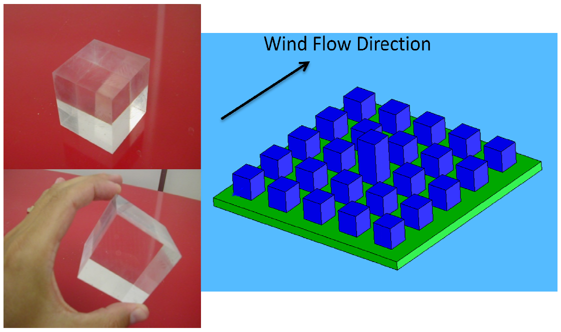

Fig. 3b. Mock Downtown

2.4 Line Source

The two major arterials in the downtown Los Angeles are 6th and 7th street. To simulate emissions from these two streets, porous tubes were placed and fixed on the board to act as a dye line source. A fluorescent dye, Rhodamine 610 Chloride; with a wavelength of 555 nm is mixed with water so the concentration of the solutions is 60 mg/l and 6mg/l. The mixture is pumped into the porous tubes using a digital gear pump (Cole-Parmer Instrument Co.) with the flow rate of 220 ml /min.

3. Experimental Results

3.1 Flow and concentration measurement through the LA downtown model

Initial experiments were conducted by measuring the flow and concentration near the Bank and Trust building (Fig.4a). Fig. 4b and Fig. 4c show the concentration and schematic of the measured flow with and without the building. As can be seen, the ground level concentration is lower in the presence of the building. Physical explanation is that tall building deflects the upper level flow and causes a strong downdraft flow which dilutes the plume trapped in the wake of the upwind building and directs it toward the sideways of the building. Fig.5. shows the detailed measured flow and concentration in the horizontal plane. As can be seen from the schematic of the measured flow, in the absence of building, there is inflow through the area which increases the ground level concentration, however when the building is in the setup, the outflows caused by tall building enhances the dispersion of pollutants in that area and lowers down the ground level concentration.

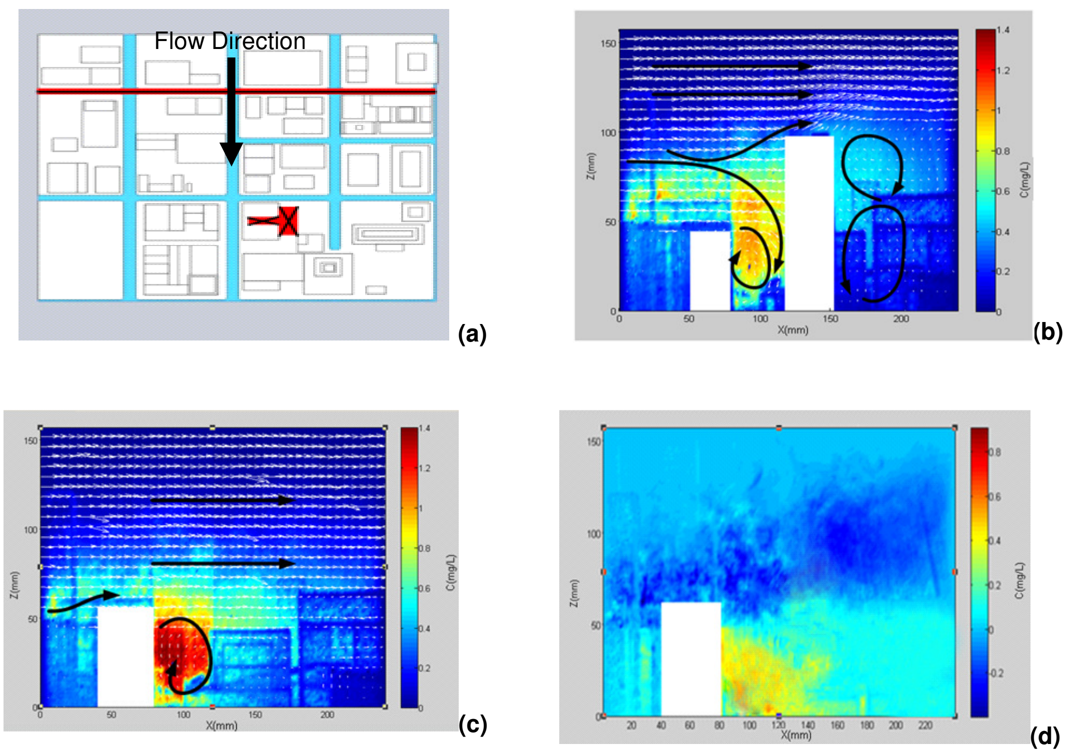

Fig. 4. Effect of Bank and trust building on release from 7th street vertical plane (a) Schematic (b) Presence of tall building (c) Absence of tall building (d) difference in street level concentration in presence and absence of tall building

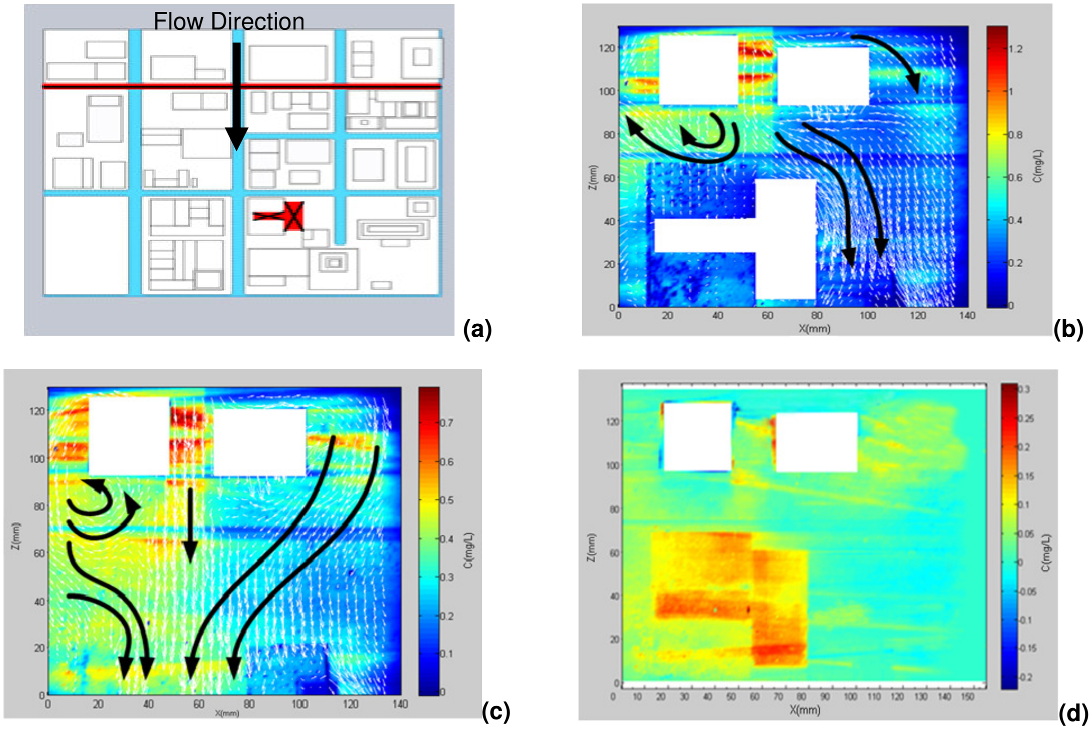

Fig. 5. Effect of Bank and trust building on release from 7th street horizontal plane (a) Schematic (b) Presence of tall building (c) Absence of tall building (d) difference in street level concentration in presence and absence of tall building

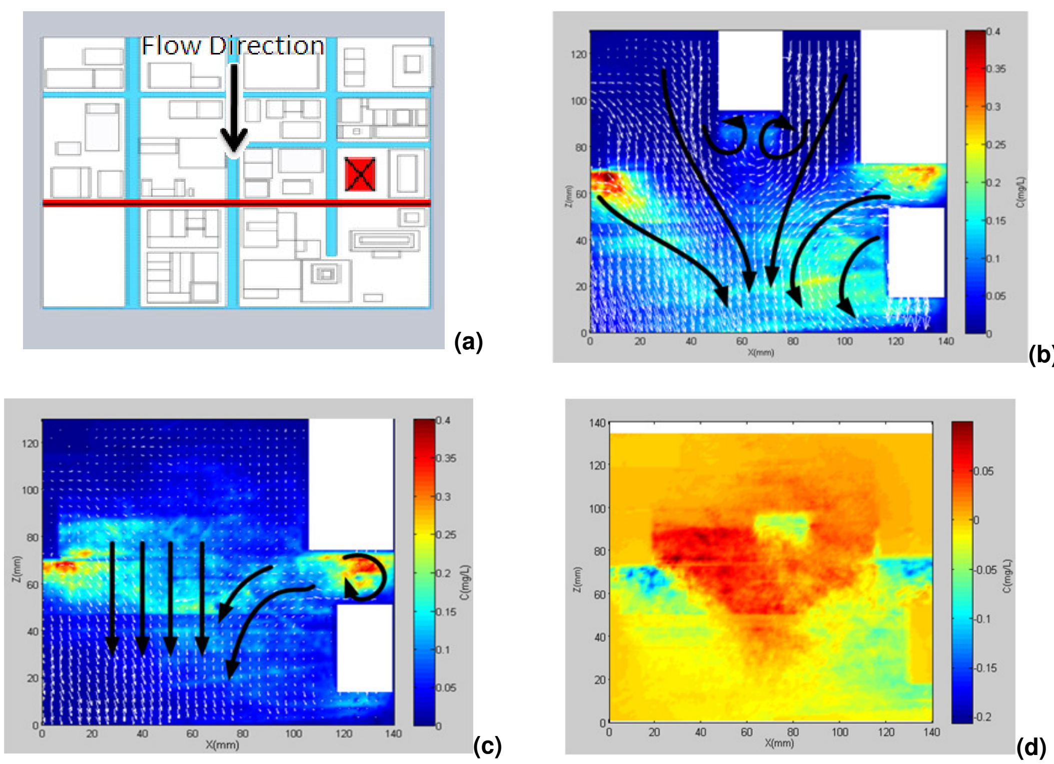

Fig. 6. Effect of AON center on release from 6th street horizontal plane (a) Schematic (b) Presence of tall building (c) Absence of tall building (d) difference in street level concentration in presence and absence of tall building

The next case study is the tall building adjacent to the major arterial. Therefore, the effect of AON center on the release from the 6th street (located on the leeside of AON center) is investigated. From Fig.6. it can be seen when the tall building is present, there is a higher velocity flow, flushing through the area. When the tall building is removed the flow is slower and more uniform. This high velocity flow and highly turbulent wakes downwind of the tall building help the pollution released in the downwind street to disperse more efficiently.

3.2 Flow and concentration measurement through 5x5 array of cubes

5x5 array of cubes was placed perpendicular to the flow in the water channel. The cubes have Height of $h = 5cm$5c and the distance between cubes was $w = 5cm$ which provides street canyons with aspect ratio of unity. A line source was placed one block (5cm) upwind from the first row of cubes. All the building heights were the same except for the central building which has the double height.

The detail flow and concentration field near the central tall building in vertical plane is shown in Fig.7. It can be seen that the presence of tall central building creates strong vortices upwind of the building and increases low level winds especially in the vortex flow where pollutant from the source may be trapped in. However, in the absence of the building no such flow can be seen and the street level flows are much slower. This difference in street level flows in two investigated cases is one of the main reasons for low ground level concentration in the presence of tall buildings.

We proceeded with the same measurements in horizontal plane (Fig.8). Note again that the lateral spreading of the downdraft flow near the ground which is caused by the tall building, block the inflow in the region. Actually this downdraft flow is strong enough to reverse the inflow to outflow from the region. As was mentioned earlier, this outflow would be highly concentrated and will get mixed with the lower concentration flow out of the urban area and result in lowering the maximum ground level concentration. It can be seen that the presence of tall building can decrease the maximum ground level concentration by 40% in this case.

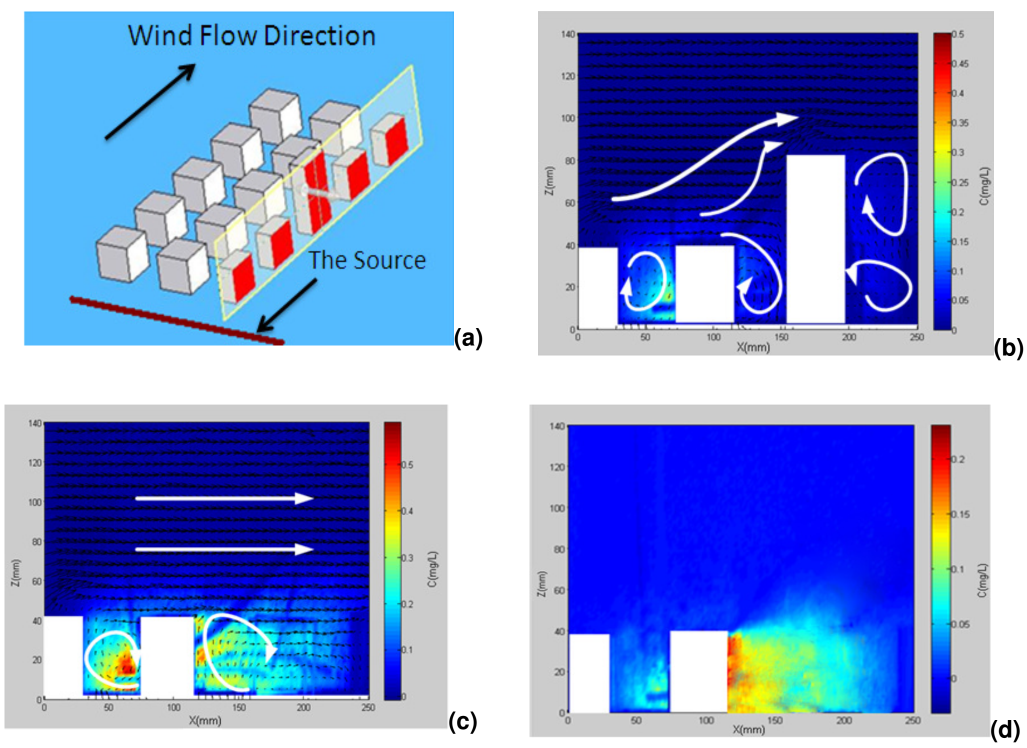

Fig. 7. Effect of central tall building on street level concentration in mock downtown vertical plane (a)Schematic (b) Presence of tall building (c) Absence of tall building (d) difference in street level concentration in presence and absence of tall building

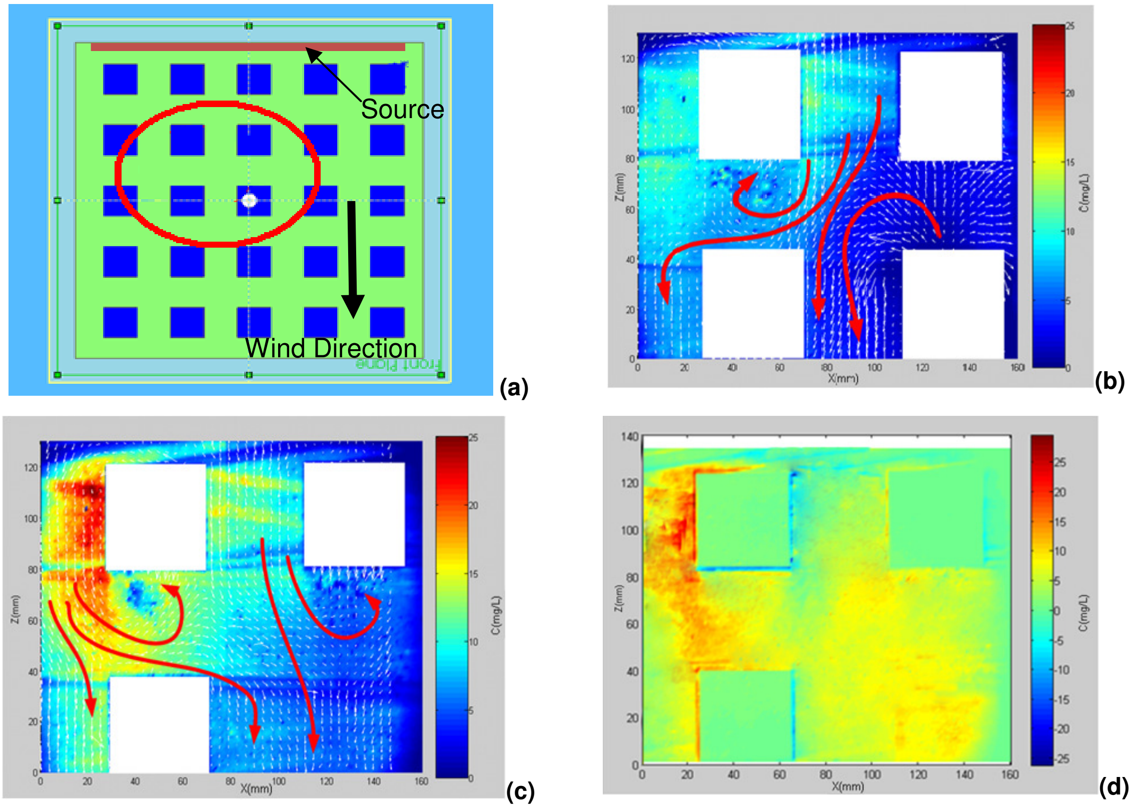

Fig. 8. Effect of central tall building on street level concentration in mock downtown horizontal plane (a)Schematic (b) Presence of tall building (c) Absence of tall building (d) difference in street level concentration in presence and absence of tall building

4. Summary

Urban dispersion simulation has been done in laboratory for environmental flow modeling (LEFM). A water channel was utilized to measure the flow and concentration field in different regions of test section.

Scaled model of downtown Los Angeles was created and tested in a water channel and detailed velocity and concentration fields in regions of interest were measured. Due to the complexity of the modeled urban area, a simple, mock downtown, in which all buildings were presented by regular cubes, has been developed and the dispersion of pollutants within the arrays with/without the presence of tall building in the center of array has been investigated.

Results have shown that tall buildings in urban areas will enhance the dispersion of pollutants. In investigated configurations concentration increase of up to 140% were measured in the absence of tall buildings.

Also, one of the important flow features which considerably affect the maximum ground level concentration is lateral flow channeling. This flow is extremely sensitive to location and height of tall buildings. The inflows and outflows caused by this flow can increase/decrease the maximum ground level concentration.

The AON center case study shows that the location of highly trafficked arterials is preferred to be close to the high rise buildings so the strong downdrafts followed by lateral channeling flows (in case building located downwind of the street) and highly turbulent wakes downwind of the building (in the case that building is upwind the street) can enhance the dispersion of pollutants and lower down the maximum ground level concentration.

Acknowledgments

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