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AERODYNAMIC EFFECTS OF POLLUTION CONCENTRATIONS IN URBAN STREET CANYON USING CROSSING UNDER BUILDING AND LOW BOUNDARY WALLS

Faddia Baghlad[1*], Benouada Douaiba[2] and Abbes Azzi[3]

Laboratoire d'Aero-hydrodynamique naval, Faculté de génie mécanique, Université des sciences et de la technologie d'Oran, BP 1505, Oran El M'Naouer, 31000, Oran, Algeria.

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Abstract: The present work, focused on the Atmospheric boundary-layer airflows and their interactions with obstacles, particularly in relation to urban air quality, therefore two passive control methods are represented in barriers solid LBWs (Low Boundary Walls) and crossings under building, in order to investigate the dynamic impacts in the center urban canyon road. These passive control solutions are designed for reducing the concentrations airflows polluted necessary, while a correct air quality in the urban areas. For these reasons, the passageways under building and LBWs models have been performed with a two dimensional numerical ANSYS-CFX code, rendering it ideal for examining the concentration distribution within street canyons of H_1/H_2 = 0.5-1-1.5 and the dynamics effects of pollution concentrations of vehicle emissions of sulfur hexafluoride (SF_6), which it is taken as a tracer gas within the symmetrical urban street canyon. However the Reynolds-averaged Navier–Stokes equations and the k-ε turbulence model are applied in order to close the equations system. The results achieved are evidence about the diminishing of the pollutant concentrations normalized in in the leeward and windward of the urban street canyon.

Keywords: Passive Methods, Barriers, Street Canyon, Pollutant Dispersion, Numerical Simulation.

* Correspondence to: Faddia Baghlad, E-mail: faddialamarin@yahoo.fr

INTRODUCTION

The evaluation of spatial and temporal distribution of different pollutants dispersion and concentrations inside urban street canyons levels have attracted much attention from the scientific community; from the both monitoring and modeling points of view (Cai et al., 2012; Baik et al.,2007), mainly due to the increasing of particulate matter concentration. However the atmospheric wind direction perpendicular to the street length axis plays a dominant role to drive particulate matter and to accumulate the pollutants in the street canyon (Baik et al, 1999; Chang and Meroney, 2003; Di Sabatino et al., 2008; Eliasson et al., 2006; Kastner-Klein et al., 2001; Pavageau and Schatzmann, 1999; So et al., 2005).

Hence, these pollutants are very important problems in human health (Vardoulakis et al., 2003; Li et al., 2006; Allegrini et al, 2013), as well as their impact on the atmospheric air quality (Tsai et al, 2004; Nazridoust et al., 2006).

In many urban areas of growth populations and industrial activities, the particulate matter resulting from combustion processes, abrasion of brake discs and tires, as well as road dust suspension contribute to a deterioration of air quality (Gromke et al., 2008). In densely built up areas, air exchange between street level and the atmospheric wind above roof top level is limited. Near ground traffic-released, emissions are not effectively diluted and removed, but remain at street level, resulting in high pollutant concentrations.

A building is an obstacle to wind flow whereas the wind exerts pressure on the various walls of the urban envelope, these pressures push air through openings as passageways under building, without opening air flow under building for example, it can be created overpressures on the windward facade and depressions on the roof and on the leeward facade, in any way the distribution of pressures on the envelope depends on the shape of the building and its details, but also on the environment around the building.

Consequently, continuous increase of the pollutants concentration in the urban street canyon has become necessary to implement wise strategies and solutions for urban street canyon, for providing a clean environment, in this context, the question arises, how can the method of control passive has decrease the concentration of pollutant and their exchange processes in urban street canyon?.

A number of recent researches and studies (McNabola et al, 2010; Gallagher et al, 2015; Lateb et al., 2016) have been recognized and investigated the potential passive control to improve air quality in the urban areas.

Various wind tunnel in both, experiments and numerical investigations have been carried out into the impact of tree planting on the dispersion of traffic emissions on the street canyon; in this way, some researchers studies of the wind flow patterns such as (Meroney et al., 1996; Pavageau and Schcatzmann, 1999; Xie et al., 2003, Gromke et al., 20015; Jeanjean et al., 2015; Marakinyo et al.,2016) and others studies interested about the canyon aspect ratios and the impact of particulate matter on different configurations of built (Xie et al., 2005; Yang et al., 2007; Mohamed et al, 2013).

In addition to their influence on the street canyon, others academic works shows that trees and other vegetations that have an act to induce the deposition of particulate matter PM in both, natural and anthropogenic depositions such as desert dust (Douaiba et al, 2014) and the vehicle exhaust emissions, thus proceed to reduce the concentration of pollution over the street canyon, from the among these studies, for example (Gromke et al., 2009; Salim et al., 2011; janhall., 2015). Furthermore, these investigations (McNabola et al., 2009; Gallagher et al., 2012; Wang et al 2016) have been carried out into the effect of low boundary walls (LBWs) on pollutant dispersion.

Similar researches have been carried out into the effect of noise pollution barriers on air pollution dispersion. These have in effect been shown to be dual purpose in the urban environment, providing reduction in noise and air pollution (Bowker et al, 2007; Baldauf et al., 2008; King et al., 2009; Finn et al., 2010; Hagler et al., 2011; Jeong et al., 2014).

Using low boundary walls, trees, on street parking, hedgerows, noise pollution barriers, passageways under building and other common urban features, studies and investigators revealed that the capability of these methods to increase local dispersion, therefore to reduce air pollution concentrations from traffic in a typical street canyon.

In general terms passive controls can be considered as an act in the air flow patterns over the street canyon, nerveless, with the passive control, the air pollution emissions are redirected away from the edge of the roadway, resulting in very significant reductions in the urban areas.

In this work, a two models with potential passive control have been performed with a two dimensional numerical CFD code and their major characteristics are discussed, whereas the volume of pollutants emitted from the road surface was simply to provide a generic of pollutant concentrations, in this way, considering a crossings under building and low boundary walls center (LBWs) models that implemented in a the symmetrical urban street canyon, on behalf of determining the amount of pollutant concentration, therefore to assure the air quality of the areas building in question.

$$\rho\overline{u}_j\frac{\delta\varepsilon}{\delta x_j}=\frac{\delta}{\delta x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\delta\varepsilon}{\delta x_j}\right]+C_{1s}\frac{\varepsilon}{k}\tau_{ij}\frac{\delta\overline{u_t}}{\delta x_j}-C_{2s}\rho\frac{\varepsilon^2}{k} \qquad (1)$$

MATERIALS AND METHODS

Numerical method

In order to investigate physical processes of the dynamic impacts of barriers solid and crossings under building in the urban canyon road, the governing equations of standard k–ε model of turbulent flow field is represented by finite volume schemes, while an unstructured grid was applied, these equations can be written in the following form:

The continuity equation: $$\frac{\delta \overline{u}_i}{\delta x_i} = 0 \quad (2)$$

The momentum conservation equation:

$$\overline{u}_j \frac{\delta u_1}{\delta x_j} = -\frac{1}{\rho}\frac{\delta \overline{p}}{\delta x_j} + \upsilon \frac{\delta}{\delta x_j}\left[\frac{\delta \overline{u}_1}{\delta x_j}\right] - \overline{u'_j \frac{\delta u'_1}{\delta x_j}} \quad (3)$$

where ρ [$kg.m^{-3}$] is the density, u [s/m] is the velocity and p [atm] is the pressure, where subscript i denotes direction. The overbear variables are the Reynolds time-average which represented the velocity components $\overline{u_t}$, the pressure $\overline{p}$ and the kinematic molecular viscosity υ [$m^2.s^{-1}$] of the ambient air and without vehicle emissions of sulfur hexafluoride (SF_6).

The equation for the transport of TKE, k: The turbulence kinetic energy k **Eq. (3)** and its rate of dissipation ε (**Eq. 4**) are obtained from the following transport equations:

$$\rho \overline{u}_j \frac{\delta k}{\delta x_j} = \tau_{ij}\frac{\delta u_i}{\delta x_j} + \frac{\delta}{\delta x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\delta k}{\delta x_j}\right] - \rho\varepsilon \quad (4)$$

The turbulent viscosity*:*

$$\mu_t = C_\mu \frac{k^2}{s} \quad (5)$$

where, u_i and u_j are velocity components in i and j direction, respectively; μ the laminar viscosity [$kg/m.s$]; σ_k and σ_s are the turbulent Prandtl numbers for k and ε respectively; C_i mean the pollutant concentration [$kg.m^{-3}$], however the coefficients taken for the model chosen are: C_μ = 00.9, C_{1s} = 1.44, C_{2s} = 1.92, σ_s = 1.2 and σ_k = 1.0.

Dispersion modeling

Using ANSYS-CFX code, the diffusion of passive tracer is solved by computing the diffusive mass flux J in turbulent flows, which it is expressed as the following:

$$J = -\left(\rho D + \frac{\mu_t}{sc_t}\right)\nabla M_t \quad (6)$$

where D is the molecular coefficient, μ_t is the dynamic eddy viscosity, his value obtained from the **Eq. (5),** while ∇M_t is the mass fraction passive scalar of pollutant and $sc_t = \frac{\mu_t}{\rho D_t}$ is the turbulent Schmidt number, hence and according to (Rossi *et al.*, 2009), the sc_t default value is assumed 0.7

MODELING APPROACH

Experimental Setup

The Laboratory of Building and Environment Aerodynamics (Karlsruhe Institute of Technology) has been set up to provide detailed information about pollutant concentration in the atmospheric boundary layer, mainly in street canyons, knowing as *CODASC* (COncentration DAta of Street Canyon), shows a configuration of street canyon in wind tunnel and the position of their line source in the road.

The horizontal homogeneity of the turbulent boundary layer is achieved under "empty" computational domain conditions. The term "horizontal homogeneity" refers to the absence of streamwise gradients in the vertical profiles of wind velocity and turbulence quantities, however the inlet profiles are maintained with downstream distance as discussed in (Blocken et al. 2007). The surface roughness is expressed in terms of a sand grain roughness, while K_s instead of the aerodynamic roughness of z_0 as well as in the most meteorological codes. (Gromke et al. 2008) set K_s equal to the aerodynamic roughness length z_0 which founded to be z_0 = 0.0033 m in the wind tunnel experiment. They agreed that setting $K_s = z_0$ was not correct in a strong sense, but justified the choice from the results obtained.

According to the power law formulas **Eq. (7)** and **Eq. (8)** were reproduced in the experiment test (Salim et al., 2011; Gromke and Ruck., 2007 and 2009), the boundary layer of database, concerning level measurements of pollutants concentrations and flow fields were obtained from street canyon are the velocity *u(y)*, profile exponent (α = 0.30) and turbulence intensity I_u, profile exponent (α_I = 0.36).

$$\frac{u(y)}{u(y_{ref})} = \left(\frac{y}{y_{ref}}\right)^{\alpha} \quad (7)$$

$$\frac{I_u(y)}{I_u(y_{ref})} = \left(\frac{y}{y_{ref}}\right)^{-\alpha_I} \quad (8)$$

The line sources exceed the width of building by approximately 10% on each side; for taking into account the traffic exhausts released on sidewise street intersections .The tracer gas were carried out in this study was sulfur hexafluoride (SF_6) to simulate the vehicle emissions in this context the emission rate Q was maintained at 10 $g.s^{-1}$, while C^+ signify the pollutant concentrations of the gas were measured at the canyon walls and normalized according to the **Eq. (9)**:

$$C^+ = \frac{CHu_H}{Q/l} \quad (9)$$

with C being measured concentration, u_H flow velocity at height H in the undisturbed approaching flow and Q/l tracer gas source strength per unit length; l is the length of the line source.

Simulation Setups and boundary conditions

The geometrical configuration studied, is similar to that studied experimentally**.** In this study, two methods of passive control are selected, to get the estimations of effects range of these methods onto the air quality in symmetrical urban roads. For this purpose a barrier solid (LBWs) and crossings under the building were introduced in ICEM-CFX code **Fig. 1** shows the computational domain, whereas, H and W are the height and the width of the building, of specifying the street canyon. The base model **Fig. 1** was created with a width of 0.06 m a height of 0.06 m the height to width ratio was 1.0; these dimensions are applied in all cases. This base model was used to establish a baseline set of personal exposure concentrations for the pedestrian for varying building height ratios (H_1/H_2) ranging from 0.5 to 1.5 intervals in perpendicular wind conditions; These concentrations were then used for comparison with models containing LBWs and Crossing under building to assess the reductions in pedestrian personal exposure. The model with low boundary walls **Fig. 2** was constructed to investigate the impact of locating two LBWs adjacent of the road; the height of each low boundary wall is 0.5 m. As shown in **Fig. 3**, this model containing passageways under building in each building side, with 0.02 m the height.

Model validation

The experimental data used for validation of the present model were obtained from a wind tunnel experimentation has been carried out at the Laboratory of Building and Environmental Aerodynamics in Karlsruhe Institute of Technology; the experimental setup and results have also presented and detailed by Gromke and Ruck (2007, 2009). A logarithmic law takes into account, to show the vertical wind velocity profile of inflow under a neutral stability condition and according to the Eq. (7), the inlet wind speed was assumed as a given equation:

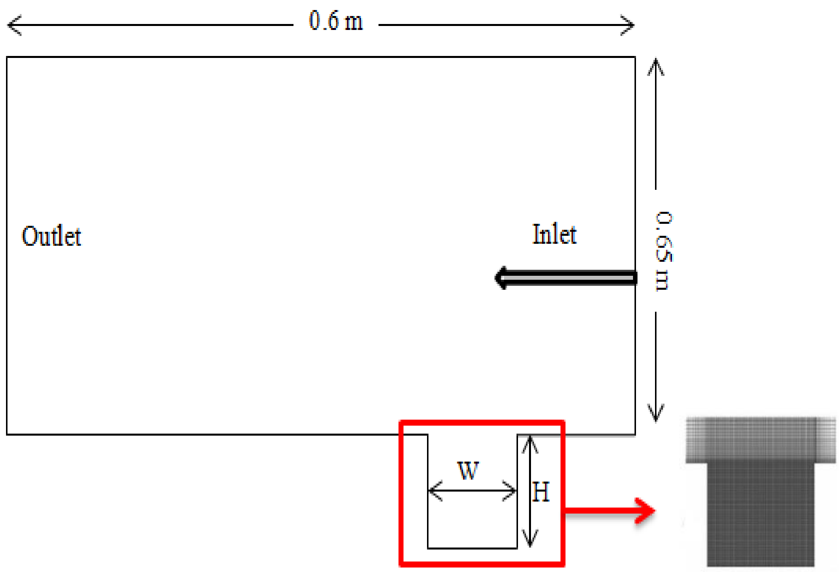
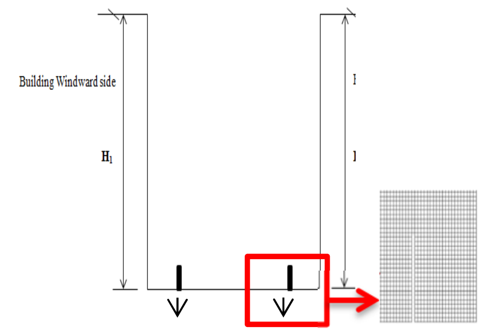


Fig.1 Computational domain and boundary conditions.



Low Boundary Wall

Fig.2 (a) Street canyon model with two adjacent boundary walls (b) Grid used in CFD simulations for local case.

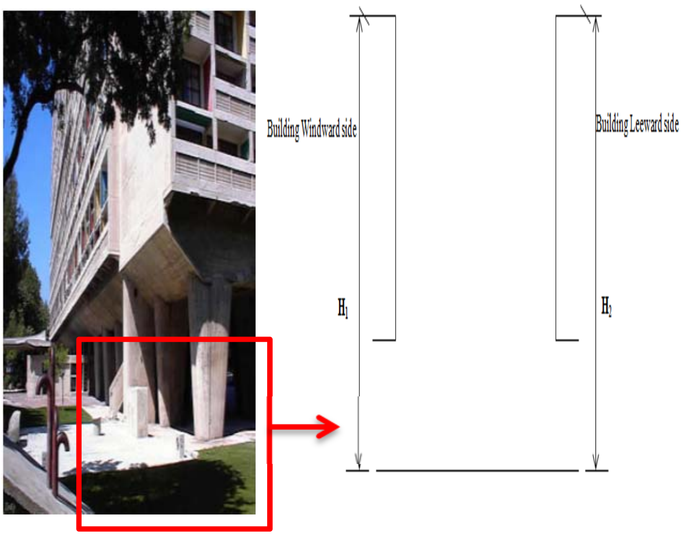


Fig.3 (a) Cross section view of real-life street canyons with passageways under building. (Photos from: Louvain-la-neuve, Belgium 2017), (b) Street canyon model with crossing under building.

$$u(y) = 4.7\left(\frac{y}{0.12}\right)^{0.3} \quad (9)$$

where $u(y_{ref}) = 4.7$ m. s^{-1}, is the velocity at y , a higher above the ground, whereas the equations concerning k and ε are givens as:

$$k = \frac{u_*^2}{\sqrt{C_\mu}}\left(1-\frac{y}{\delta}\right) \quad (10)$$

$$\varepsilon = \frac{u_*^3}{Ky}\left(1-\frac{y}{\delta}\right) \quad (11)$$

K = 0.4, represent Von-Karman coefficient, u_* =0.54 m.s^{-2}, is the friction velocity and the depth of the boundary layer is δ =0.5 m.

The No-slipping boundaries are set for the solid boundaries, knowing as wall function boundaries used on the closest grids to the wall. The calculations were performed using the second order accurate upwind schemes; the well-known SIMPLEC algorithm which discussed by (Van Doormal., 1984); used for pressure-velocity coupling while the convergences for scaled residuals criteria were set at 10^6.

The grid characteristics of the computational domain concerning each model are meshed, using hexahedral element; the mesh was carried out using different grid sizes. The minimum size of 0.05 m was selected for each model; a surface grid mesh was selected for the canyon floor with a uniform volumetric mesh; the interest region was finer than other region to ensure a good resolution which was used for line source and for building.

RESULTS AND DISCUSSION

Air flow fields

Figure 4 shows the vectors and distribution of the vertical velocity inside the street canyon for the reference model; for the aspect ratio equal to 1(H_1/H_2=1) a large unique clockwise vortex can be found and a direct comparison reveals that the upward vertical velocities near the leeward wall are higher than the downward vertical velocities near windward wall. For the aspect ratio equal to 0.5 and 1.5, the progress of two superpose vortex.

The influence of low boundary wall at the air quality, in the urban street canyon has been attracting attention by many research; among them, John Gallagher et al., 2012 and 2011; they established that an adding of low boundary wall (LBWs) in the road improved the air quality of vicinity of the building and surrounding spaces like breathing for childs and adults. Fig. 4 shows the streamlines of vertical velocity distribution in street canyon with flat roof-shaped and with LBWs (H_1/H_2=1; 0.5; 1.5); for aspect ratio equal to 1,the progress of the secandry vortex near the leeward wall has been noticeable when the Low Boundary walls are used. For aspect ratio equal to 0.5-1.5, the secondary vortex (corner eddies) located at the two ends of the street canyon are generated, the highest vertical velocity is observed in the windward side, while the lowest vertical velocity is observed in the leeward side.

Fig.6 shows the effect of the passageways under building by the presentation of contour of vertical velocity and distribution of the vertical velocity inside the street canyon with different aspect ratios from 1 to 1.5. The incidence of wind by the crossing create zone of the air jet with high speed whose volume is of the same order of magnitude as the passage; it can be observed that the single clockwise vortex, with its moving upward on the roof of the building, thus

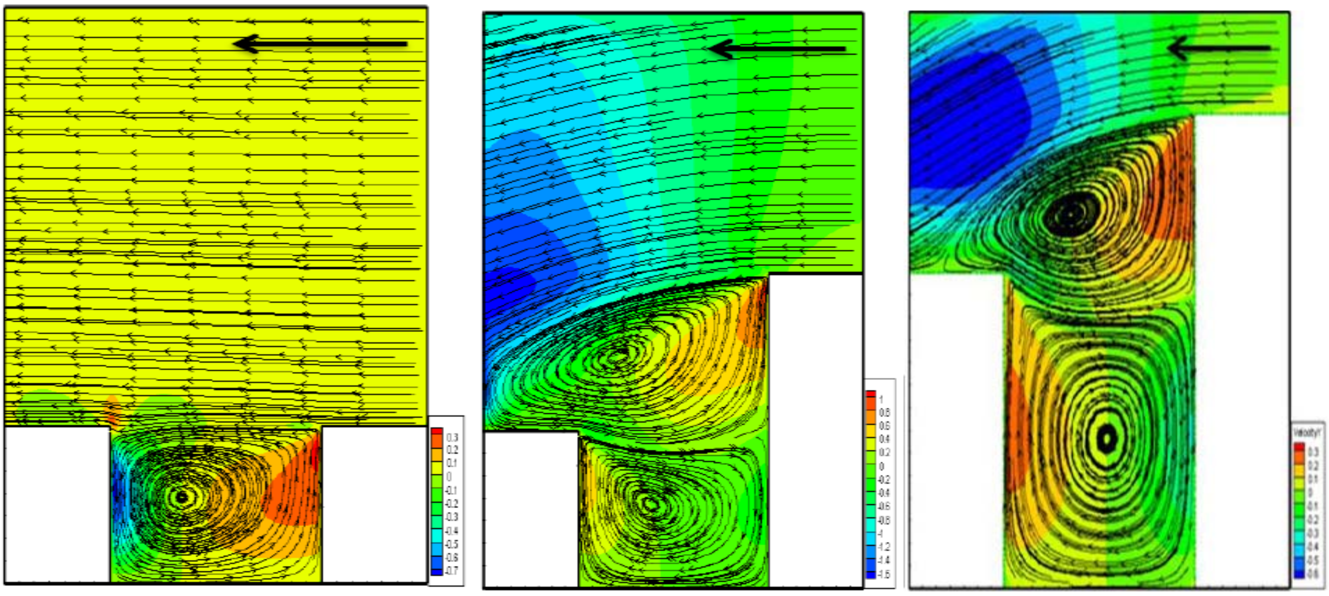


Fig.4 Contour of vertical Velocity and distribution of the vertical velocity inside the street canyon for the model flat roof-shaped (reference model) H_1/H_2=1; 0.5; 1.5.

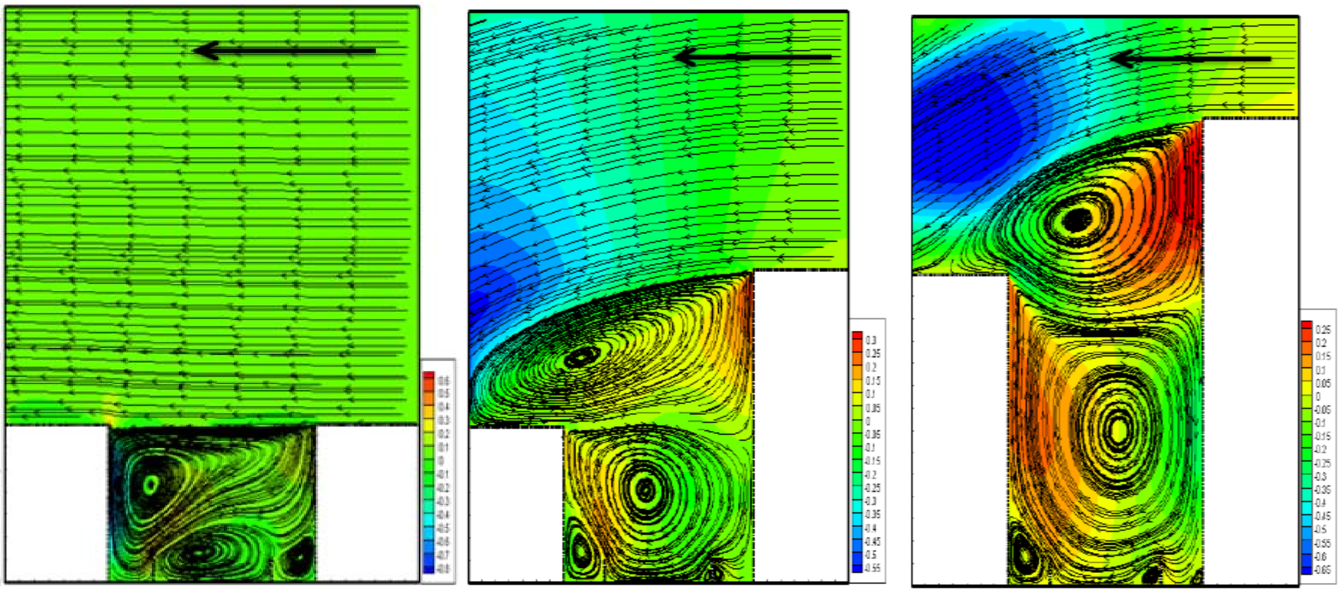


Fig.5 Contour of vertical Velocity and distribution of the vertical velocity inside the street canyon for the model with two adjacent boundary walls H_1/H_2=1; 0.5; 1.5.

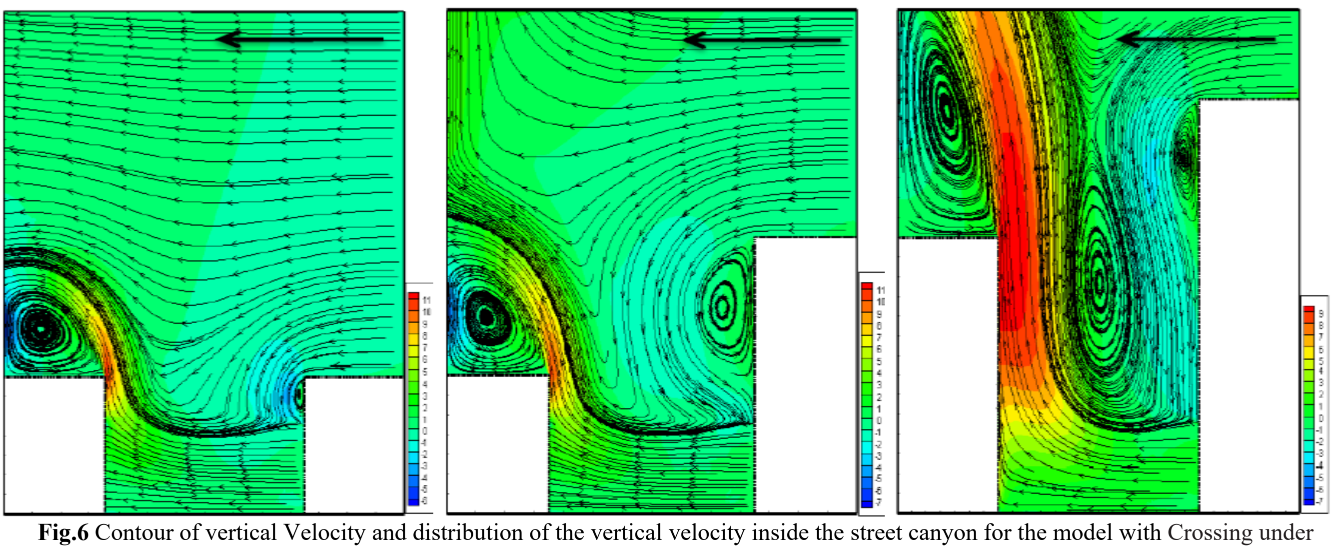


Fig.6 Contour of vertical Velocity and distribution of the vertical velocity inside the street canyon for the model with Crossing under building H_1/H_2=1; 0.5; 1.5.

enhancing the air exchange between the outer flow and the canyon interior. The highest velocity is seen near the downwind building roof of the street canyon.

Pollutant dispersion

The numericall results concerning the dimensionless pollutant concentration C^+ that are obtained with ICEM-CFD, shown in **Figs. 7–9**; from the last fig it can be done the diminishing of pollutant concentration at the windward wall when we compared to windward wall measurments data, however the same thing happens for leeward side, this may explain that the more intense movement of the flow appeared near the upwind region, associated to the vertical velocity when it increased over the roof canyon and it decreased down at the ground surface. Furthermore, the Fig. 8, represents the quantitative analysis of the concentration profiles on the windward wall and the leeward wall for the model with two adjacent boundary walls, H_1/H_2=1; 0.5; 1.5, hence the evolution of patterns mean concentration profiles on the windward wall and leeward wall, related to different altitude. From the numerical results that have been compared by the measurement data, it can be found that a high pollutant concentration appeared on the leeward walls , this is due to the wind intensity circulation close to the building; the maximum concentration levels at the leeward side are in the range of $C^+ = 140$ for LBW model; this value has decreased up to the level $H = 0.6m$ approximately and stabilized out of this height to the value of $C^+ = 25$; however, in the experiment data, the maximum concentration levels are in the range of $C^+ = 50$; this value is constant up to the height of $0.5m$ and start decreasing out of that height; When the LBW model is applied and away from the critical region (center of the road), the maximum concentrations are in the range of $C^+ = 120$.

The comparison of the measurement data to different numerical results of the LBW model, large amounts of pollutant concentration can be founded onto the canyon walls from the experiment, however, at the leeward wall, the normalized traffic pollutant concentration has been decreased once the LBW model be practical in the street canyon, whereas the pollutant charge resulting from traffic released emissions is considerably lower at Windward wall than leeward wall. Consequently, the implementation of passive control as low boundary wall provide reduction in pollutant concentration therefore it can improve air quality in the urban street canyon.

The numerical results obtained from the simulation concerning the mean concentration profiles on the leeward and windward walls for testing the model of crossings under building are presented in the Fig. 9, whereas the simulations about crossing and several crossings under building has been evaluated by those taken from the measurement data without including the crossing model (without control passif). From the Fig. 9, it can be observed that the pollutant concentrations occurred at the both windward walls and leeward wall has been decreased compared with the measurement data. From the mean concentration plot, it can be observed that the maximum concentration ($C^+ = 1.5$) established at the leeward side, and windward side. The Concentrations decreases towards the ends of street are evidently at the both canyon walls; the results show a better agreement to the model with the passageways under building than the measurement data. The results presented in last figure are confirmed by normalized vertical velocity; however the distributions of vertical velocity. The flow fields in street canyon is dominated by a vortex and not by corner eddies; however, on the outside of the canyon, a superposition of two vortexes structures occurs, forcing the laterally incoming air to move in a helix-type motion into the canyon center, it appears onto the windward wall of the wind experiment. Other than the introduced the model of passageways under building provide a falling of pollutant concentrations onto the leeward wall, where the lateral air flow exchanged between the ends and the center of the street canyon, even as the model of passageways under building provoke a natural ventilation around the street canyon, therefore it to permit to cleared the pollutant away from the area buildings. account the dynamic effects of pollution concentrations at different altitude. The primitive vortex situated at the right of the top corner of the canyon derived by the shear layer is moving in clockwise direction while the secondary vortex to be found at the right bottom corner of the canyon is progressed in anti-clockwise direction, dominated by the primitive vortex. The progress of the secandry vortex near the leeward wall has been noticeable when the LBW centre is used, consequently the pollutant concentration amount has been reduced in leeward wall, therefore the traffic emission was dispersed far from the street canyon.

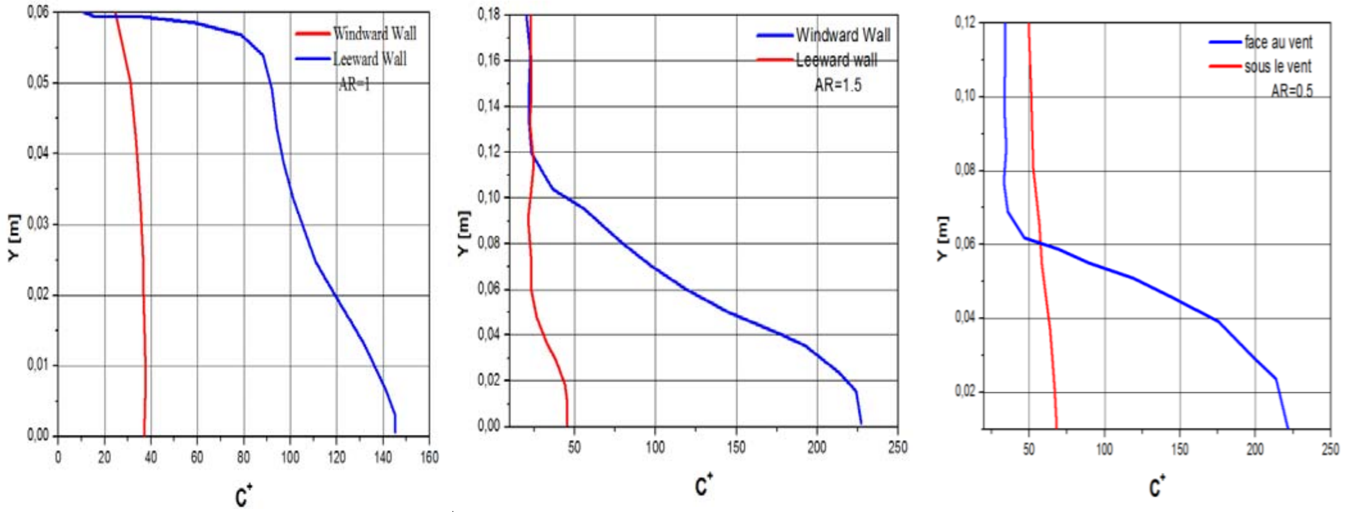


Fig.7 Dimensionless pollutant concentration C^+, on the windward wall and the leeward wall for the model with two adjacent boundary walls, H_1/H_2=1; 0.5; 1.5.

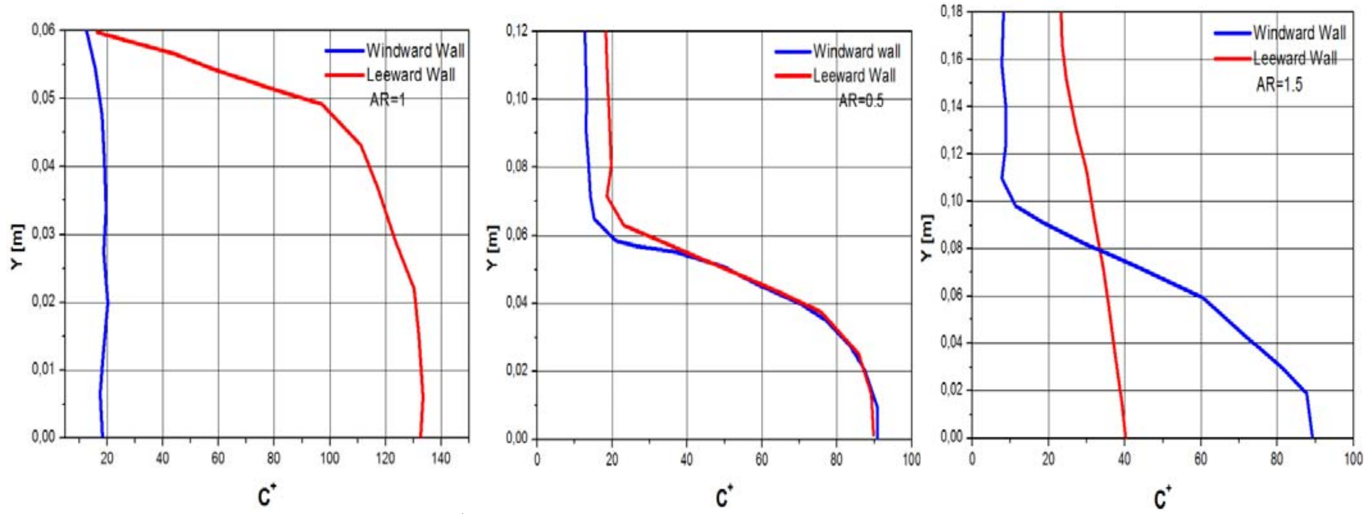


Fig.8 Dimensionless pollutant concentration C^+, on the windward wall and the leeward wall for the model with two adjacent boundary walls, H_1/H_2=1; 0.5; 1.5.

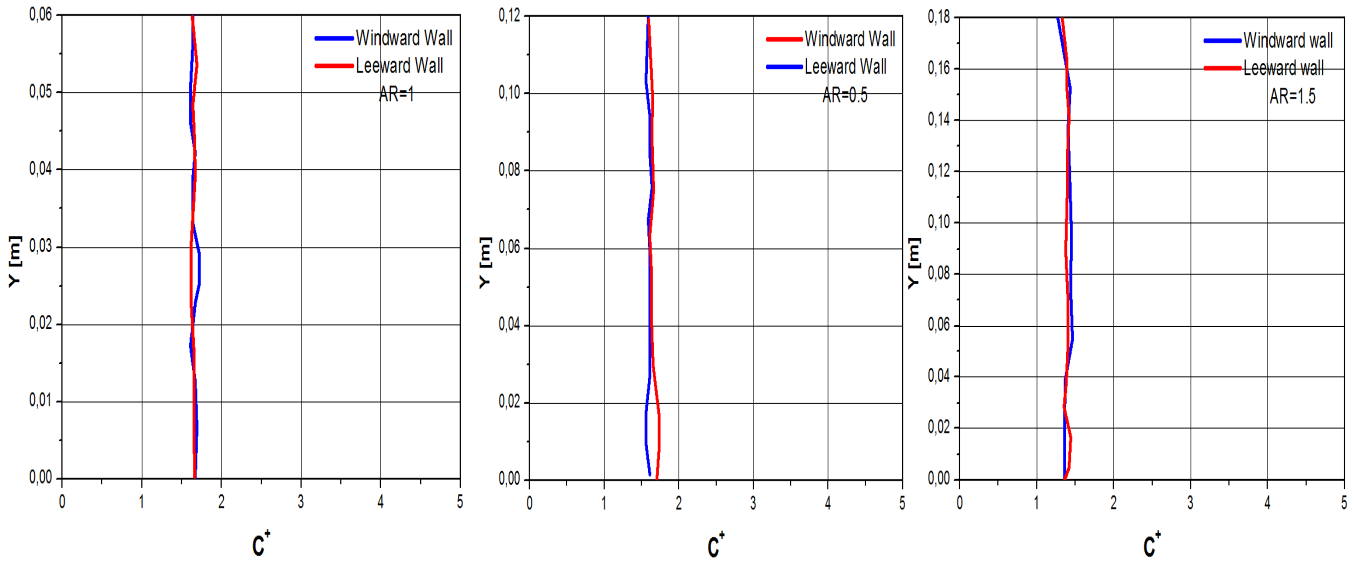


Fig.9 Dimensionless pollutant concentration C^+, on the windward wall and the leeward wall for the model with crossing under building, $H1/H_2$=1; 0.5; 1.5.

CONCLUSIONS

The interaction of atmospheric boundary layer with the implementations of crossings under building and LBWs, particularly in the urban street canyon, is commonly investigated. The numerical ANSYS-CFX code, rendering it ideal for examining the aerodynamic effects of pollution concentrations, while the employed of Reynolds-averaged Navier–Stokes equations and the enhancement by k-ε turbulence model provides numerical predictions of qualitative agreement to experimental observations. As a result, it is reasonable to assure that under dynamic wind field and traffic flow, the presence of crossings under the building and LBWs alters the distribution of the airflow structure inside the street canyon, forming a major vortex affect the pollutant distributions inside and outside the street canyon. The diminishing of pollutant concentration at the leewards and windward sides, caused by the intense movement of the flow appeared near the upwind region, associated to the vertical velocity when it increased over the roof canyon and it decreased down at the ground surface. A good correlation was found between the model simulation concerning the normalized concentration where different altitudes are tested and measurement data. Large amounts of pollutant concentration can be found onto the canyon walls from the experiment, however, the normalized traffic pollutant concentration has been decreasing at the leeward wall, once the LBWs model and crossings under building have been practicing in the street canyon, from the results the peak of mean concentrations on the leeward and windward walls are jointly affected by wind speed, LBWs, crossings under building band vehicle flow. In the deep street canyon (H1/H2 =0.5 and 1.5) the flow splits into two counter-rotating vortices, and the concentration of pollutants increases as they accumulate inside the urban canyon. The variations concerning the wind speed are due to passageways where the major vortex expanded inside the street canyon, in this manner when the air is at the compressing stage, the presence of passageways under building and LBW increases the pollutant concentrations at the bottom center, but reduces the pollutant concentrations at the windward and leeward. The model of passageways under building provoke natural ventilation around the street canyon while the LBWs is used to create a vortex near the leewards, allows the change of wind speed which would induce a mass exchange between the internal and external air. Such exchange could improve the pollutant diffusion inside the street canyon, therefore the realization of the both models inside the urban street canyon permit to disperse the traffic emission pollutant away from the area buildings. Consequently, the implementation of passive control as low boundary walls and passageways under building reduction the pollutant concentration, therefore it can improve air quality in the urban street canyon.

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REFERENCES

Allegrini, J., Dorer, V., Carmeliet, J. (2013) Wind tunnel measurements of buoyant flows in street canyons. Building and Environment .59, 315-326.

Baik, J.J., Kim,J.J.(1999) A numerical study of flow and pollution dispersion characteristics in urban street canyons. Journal of applied Meteorology .38, 1576-1589.

Baik, J.J., Kang, Y.S., Kim, JJ. (2007) Modeling reactive pollutant dispersion in an urban street canyon. Atmospheric Environment. 41, 934-949.

Baldouf, R., Thoma, E.,Khlystov, A.,Isakov,V.,Bowker, G., Long, T., Snow, R.(2008) Impacts of noise barriers on near-road air quality. Atmos Environ. 42, 7502-7507.

Blocken, B., Carmeliet, J., Stathopoulos, T. (2007) CFD evaluation of wind speed conditions in passages between parallel buildings-effect of wall function roughness modifications for the atmospheric boundary layer flow. Journal of Wind Engineering and Industrial Aerodynamics. 95, 941-962.

Bowker , G.E.,Baldauf, R., Isakov, V., Khlystov, A.,Petersen,W.(2007) The effects of roadside structures on the transport and dispersion of ultrafine particles from highways. Atmos Environ. 41, 3128-8139.

Cai, X.M. (2012) Effects of differential wall heating in street canyons on dispersion and ventilation characteristics of a passive scalar. Atmospheric Environment. 51,268-277.

Chang, C.H., Meroney, R.N. (2003) Concentration and flow distributions in urban street canyon: Wind tunnel and computational data. Journal of Wind Engineering and Industrial Aerodynamics. 96, 1789-1804.

Di Sabatino, S., Buccolieri, R., Pulvirenti,B., Bitter,R.(2008) Flow and pollutant dispersion in street canyons using FLUENT and ADMS-Urban. Environmental Modeling and Assessment.13, 369-381.

Douaiba, B., Azzi A., Khorsi, A., Benlefki, A.(2014) Dry Deposition from Sahara Sources Regions of Western Africa. Advances in Meteorology. doi.org/10.1155/2014/419838.

CODASC. (2008) Concentration Data of Street Canyons. Laboratory of Building- and Environmental Aerodynamics, IfH, Karlsruhe Institute of Technology.

Eliasson, I., Offerle, B., Grimmond , CSB.,Lindqvist ,S.(2006) Wind fields and turbulence statistics in an urban street canyon. Atmospheric Environment.40, 1-16.

Finn, D., Clawson, K.L ., Carter, RG., Rich, J.D., Eckman, R.M., Perry ,S.G., Isakov, V., Heist, D.K.(2010) Tracer studies to characterize the effects of roadside noise barriers on near-road pollutant dispersion under varying atmospheric stability conditions. Atmos Environ.44, 204-214.

Gallager, J. Gill, L.W. McNabola, A. (2012) Numerical modeling of the passive control of air pollution in asymmetrical urban street canyons using refined mesh discretization schemes. Build Environ.45, 332-240.

Gallager, J. (2015) Review on passive methods for improving air quality in the built environment: A review of porous and solid barriers. Atmospheric Environment.120, 61-70.

Gromke, C., Ruck, B. (2007) Influence of trees on the dispersion of pollutants in an urban street canyon –Experimental investigation

of the flow and concentration field. Atmospheric Environment. 41, 3287-302.
Gromke, C., Ruck, B. (2008) On the Impact of Trees on Dispersion Processes of Traffic Emissions in Street Canyons. Boundary-Layer Meteorol. 131, 19–34.
Gromke, C., Buccolicri, R., Di Sabatino,S .,Ruck, B.(2009) Dispersion study in a street canyon with tree planting by means of wind tunnel and numerical investigations evaluation of CFD data with experimental data. Atoms Environ. 42, 8640-8650.
Gromke, C., Blocken, B. (2015) Influence of avenue-trees on air quality at the urban neighborhood scale. Part I: Quality assurance studies and turbulent Schmidt number analysis for RANS CFD simulations. Environmental Pollution. 196 , 214-223.
Hagler, G.S.W., Tang, W., Freeman, M.J.,Heist,D.K.,Perry,S.G.,Vette,A.F.(2011) Model evaluation of roadside barrier impact on near-road air pollution.Atmos.Environ.45,2522-2530.
Janhall, S. (2015) Review on urban vegetation and particle air pollution-deposition and dispersion.Atmos.Environ.105.130-137.
Jeanjean, A.P.R., Hinchliffe, G., McMullan, W.A., Monks, P.S., Leigh, R.J. (2015) A CFD study on the effectiveness of trees to disperse road traffic emissions at a city scale. Atmospheric Environment. 120, 1-14.
Jeong, S.J. (2014) Effect of double noise-barrier on air pollution dispersion around road using CFD. Atmos Environ.8, 81-88.
Kastner-Klein, P., Fedorovich, E., Rotach, M.W. (2001) A wind tunnel study of organised and turbulent air motions in urban street canyons. Journal of Wind Engineering and Industrial Aerodynamics. 89, 849–861.
King, E.A.,Murphy,E.,McNabola,A.(2009) Reducing pedestrian exposure to environmental pollutants : a combined noise exposure and air quality analysis approach. Transp. Rse Part D Transp Environ.14, 309-316.
Lateb,M.,Meroney,R.N.,Yataghene,M.,Fellouah,H.,Saleh,F.,Boufad el,M.C.(2016) On the use of numerical modeling for near-field pollutant dispersion in urban environments. Environmental Pollution. 208, 271-283.
Li, X.X., Liu, C.H., Leung, D.Y.C., Lam ,K.M.(2006) Recent progress in CFD modeling of wind field and pollutant transport in street canyons. Atmospheric Environment. 40, 5640-58.
McNabola, A., Broderick, B.M., Gill, L.W. (2009) A numerical investigation of the impact of flow boundary walls on pedestrian exposure to air pollutions in urban street canyon. SCi Total Environ .407, 760-769.
McNabola, A. (2010) New Directions: passive control of personal air pollution exposure from traffic emissions in urban street canyons. Atmos Environ .44(24), 2940-1.
Morakinyo, T.E., Lam, Y.F. (2016) Study of traffic-related pollutant removal from street canyon with trees: dispersion and deposition perspective. Environ Sci Pollut Res. doi. 10.1007/s11356-016-7322-9.
Meroney, R.N., Pavageau, M., Rafailidis, S., Schatzmann, M. (1996) Study of line source characteristics for 2-D physical modelingof pollutant dispersion in street canyons. Journal of Wind Enginering and Industrial Aerodynamics. 62, 37–56.
Mohamed, F.,Yassin, M.F.,Ohba, M.(2013) Effect of street geometrical layout on dispersion emissions of traffic exhaust: experimental simulation. Clean Techn Environ Policy.15, 167-177.
Nazridoust, K., Ahmadi, G. (2006) Airflow and pollutant transport in street canyons. Journal of Wind Engineering and Industrial Aerodynamics. 94, 491–522.
Pavageau, M., Schcatzmann, M. (1999) Wind tunnel measurements of concentration fluctuations in an urban street canyon. Atmospheric Environment .33, 3961–3971.
Rossi, R., Iaccarino G. (2009) Numerical simulation of scalar dispersion downstream of a square obstacle using gradient – transport type models. Atmospheric Environment.43, 2518-31.
Salim, S.M., Ricardo, B.,Adrew ,C., Siew, C.C., Andrew C.(2011) Numerical simulation of atmospheric pollutant dispersion in an urban street canyon: Comparison between RANS and LES. Journal of Wind Engineering and Industrial Aerodynamics. 99 .103–113.
So, E.S.P., Chan, A.T.Y., Wong, A.Y.T. (2005) Large-eddy simulation of wind flow and pollutant dispersion in a street canyon. Atmospheric Environment .39, 3573-82.
Tsai, M.Y., Chen, K.S. (2004) Measurements and three-dimensional modeling of air pollutant dispersion in an Urban Street Canyon. *Atmospheric Environment*. **38**, 5911–5924.
Van Doormal, J.P.,Raithby ,G.D.(1984) Enhancement of SIMPLE method for predicting incompressible fluid flows. Numerical Heat Transfer.7, 147-163.
Vardoulakis, S, Fischer, B.E.A, Pericleous, K, Gonzalez-Flescaling, N. (2003) Modeling air quality in street canyons: a review. Atmos Environ .37, 155–82.
Wang, L., Qiang, P., Xi-Peng, Z., Shun-Sheng, Y. (2016) Effects of low boundary walls under dynamic inflow on flow field and pollutant dispersion in an idealized street canyon, Atmospheric Pollution Research. doi.org/10.1016/j.apr.12.004.
Xie, S., Zhang, Y., Qi, L., Tang, X. (2003) Spatial distribution of traffic-related pollutant concentrations in street canyons. Atmospheric Environment .37, 3213–3224.
Xie, X.,Huang,Z.,Wang,J.S.(2005) Impact of building configuration on air quality in street canyon. Atoms Environ.39 (25), 4519-30.
Yang, R., Zhang, J,Shen,S.,LI,X.,Chen,J.(2007) Numerical investigation of the impact of different configurations and aspect ratios on dense gas dispersion in urban street canyons. Tsinghua Science and Technology. 12 (3), 345-351.