ARTICLE IN PRESS

Atmospheric Pollution Research xxx (2016) 1–9

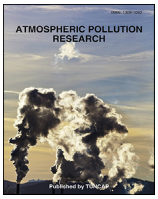
HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr



Original article

Effect of balconies on air quality in deep street canyons

F. Murena [a], *, B. Mele [b]

[a] Department of Chemical Engineering, Materials and Production Engineering, University of Naples “Federico II”, Italy
[b] Department of Industrial Engineering, University of Naples “Federico II”, Italy

ARTICLE INFO

Article history:
Received 23 March 2016
Received in revised form
31 May 2016
Accepted 14 June 2016
Available online xxx

Keywords:
Street canyon
Balconies
Operational models
CFD
SAS

ABSTRACT

This study discusses the effect of balconies on the dispersion of vehicular pollutants inside a deep street canyon and on the mass transfer rate between the canyon and the above atmosphere. 3D computational fluid dynamics (CFD) simulations were performed considering the presence of balconies of different dimensions in a deep street canyon with aspect ratio $H/W = 3$. The effect of two geometrical parameters has been investigated: the balcony depth and the horizontal distance between two balconies, the other geometrical parameters remaining constant. CFD simulations have been carried out adopting the scale adaptive simulation (SAS) model. Results show that the presence of balconies can determine a significant modification in the flow field inside the street canyon with a less homogeneous dispersion of pollutants emitted by vehicles circulating in the street and a less effective mass exchange with the above atmosphere. At the present models developed to assess pollutant concentration levels in street canyons do not consider the presence of balconies. As consequence, an underestimation of real concentration levels could occur. Therefore, results obtained can give a contribution in the development of more feasible air pollution models in urban areas at local scale, and useful information for design of building facades that minimize the entrapping of vehicular pollutants at pedestrian level in street canyons.

1. Introduction

The development of models to predict accurate evaluation of pollutant concentration at street level in urban areas is hindered by the complexity of urban areas, the differences between each other and the difficulty in modelling traffic flows and on-road vehicular emissions. Moreover, even though the technology in the treatment of vehicular exhaust has drastically reduced the emission factors of new vehicles, atmospheric pollution in urban areas is still an issue in many cities all over the world.

Pollutant dispersion in urban areas is determined by several phenomena at different scales: from regional (≈100 km) to local (≈1 m). Local scale is typically referred to a single road named as “street canyon”. The solution of problems at local scale can be achieved by numerical modelling using CFD (Computational Fluid Dynamics). Its application is however limited by high computational costs. Moreover, CFD simulations can be operated only by highly qualified personnel. The alternative to numerical models is represented by “operational models” (Vardoulakis et al., 2003). Operational models can be used also by non-specialist users and can treat a large variety of situations with limited computing resources (Soulhac et al., 2013).

In the most of cases operational models are “box models” including as many mass balances equations as the number of boxes defined in the street canyon (Murena et al., 2011). Homogeneous concentration and steady state conditions are generally assumed in each box. The assessment of hourly averaged time values of pollutants concentration in the street canyon is the final goal of these models.

Operational models developed for a single road can be the basis of models for application in urban areas as: ADMS-URBAN (McHugh et al., 1997) and SIRANE (Soulhac et al., 2011).

In the case of an urban area, or a district, each street is involved in several mass transfers: i) with the above atmosphere; ii) along the street (Soulhac et al., 2008); iii) with other streets at intersections (Soulhac et al., 2009). This paper deals with the mass transfer between the street and the above atmosphere.

The mass transfer between the canyon and the atmospheric boundary layer (ABL) has been studied by several authors. A rather

---

* Corresponding author.
E-mail address: murena@unina.it (F. Murena).

Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2016.06.005

Please cite this article in press as: Murena, F., Mele, B., Effect of balconies on air quality in deep street canyons, Atmospheric Pollution Research (2016), http://dx.doi.org/10.1016/j.apr.2016.06.005

incomplete list includes: Sini et al. (1996), Bentham and Britter (2003), Barlow et al. (2004), Hamlyn and Britter (2005), Salizzoni et al. (2009), Murena et al. (2011), Chung and Liu (2013).

The mass exchange between the street canyon and the atmosphere above takes place through the shear layer which forms between the cavity and the ABL (Caton et al., 2003). It is widely assumed that the instantaneous (turbulent) contribution to mass transfer velocity is higher than the mean (advective) contribution. However, the latter can be significant when the building height is not uniform (Hamlyn and Britter, 2005) or the wind has a component parallel to the street axis (Yaghoobian et al., 2014). Salizzoni et al. (2009) observed that mass transfer is entirely governed by the fluctuating component of the turbulent flow. Murena and Mele (2014) observed a significant influence of short-time variations of wind velocity on mass transfer rate.

In a box-model approach the mass transfer rate between the street and the atmosphere is expressed through the definition of a spatially averaged mass transfer velocity u: $Q = uWL(C_{street} - C_{ext})$ where Q is the emission rate of the pollutant in the street [$g\ s^{-1}$]; W and L are the canyon width and length respectively; $(C_{street} - C_{ext})$ is the difference in pollutant concentration between the canyon and the atmosphere (hourly average values); and u represents the velocity of the mass transfer [$m\ s^{-1}$]. In the case of deep street canyons (H/W > 1.6–2) it would be more appropriate to use a multi-box model (Murena et al., 2011), because of the formation of two or more counter-rotating vortices. However, also in this case, the mass balance equation can be written as before defining an overall mass transfer velocity (Murena et al., 2011) to quantify the overall mass transfer process from the bottom volume of the canyon to the ABL.

For a large application of operational models, it is mandatory to obtain precise evaluation of mass transfer rate between street canyon and ABL from commonly available meteorological and geometrical data. In many cases mass transfer rate has been evaluated using a reference velocity. In the OSPM model (Berkowicz et al., 1997), when H/W ≥ 1, the concentration of pollutant in the street canyon is evaluated as: $c = \frac{Q}{W\sigma_{wt}}$ where σ_{wt} is the canyon ventilation velocity $\approx 0.1u_w$ where u_w is wind speed at the top of the canyon. Soulhac et al. (2013) examined the parametric relations needed to estimate spatially averaged pollutant concentration in street canyons with a box model approach. They found a good agreement between model and wind tunnel data when the wind direction was >45° with the road axis, showing the skills of this approach in modelling pollutant dispersion in urban areas. In their model the mass transfer velocity is proportional to friction velocity (u_*) and concentration of pollutant in the street canyon is $c = \frac{Q}{W}\frac{\pi\sqrt{2}}{u_*}$. Their result is analogous to that obtained by Berkowicz et al. (1997) and by Hotchkiss and Harlow (1973). These results may be applied to a single ideal street canyon. If an urban street canopy, more similar to real conditions, is considered some modifications take place. Applying the box model approach for the interpretation of wind tunnel data of a urban canopy realized by an array of square buildings with H/W = 1 and L = 5H, Soulhac et al. (2013) observed that better results are obtained if the box model equation is modified as $c = \frac{Q+Q_{up}}{u_wWH+u_dWL}$ where Q_{up} is the mass flux entering in the canyon from the upwind intersection and L is the street length.

It must be observed that results above reported make reference to idealised street canyons where buildings are represented as parallelepipeds. In some cases, but not always, an equivalent roughness is imposed at building facades (Vernay et al., 2014). In wind tunnel experiments low roughness surface are often adopted for a more accurate near wall modelling with CFD (Allegrini et al., 2013) but this does not always correspond to real cases.

The real building facades geometry, and particularly the presence of balconies, can have an effect: i) on the flow field inside the street canyon as shown in studies focused on the wind induced ventilation (Mohamed et al., 2009); ii) on the external noise (Lee et al., 2007); iii) on the heat exchange (Lignarolo et al., 2011). It is logical to guess an effect also on mass transfer rate inside the canyon and with the above ABL. As a matter of fact, studies considering the presence of trees inside the street canyon (Gromke et al., 2008; Buccolieri et al., 2009) showed an effect on the flow field.

Therefore, a more realistic representation of building facades could be necessary as reported by Soulhac et al. (2013) in their conclusions.

The aim of this study is to verify the effect of real building facades geometry on flow field inside the deep street canyon and on mass transfer rate between the canyon and the above ABL. In particular, the presence of balconies has been studied.

The analysis has been carried out by performing 3D CFD simulations with periodic boundaries adopting the recently proposed scale adaptive simulation (SAS) model of Menter and Egorov (2010). The SAS model can be ascribed to the category of hybrid models such as DES (detached eddy simulation) by Spalart et al. (1997), Spalart (2000), however SAS model has been proved to have a less sensitivity to grid spacing (Egorov et al., 2010).

Depth of balconies and balcony to balcony distance were varied to verify their effect on flow field inside the canyon and on mass transfer rate.

Due to the few availability of experimental data, validation was performed comparing results with an LES simulations. CFD modelling has shown in other different studies to fit quite well the observations from wind tunnel data (Santiago and Martin, 2008) or real world data (Santiago et al., 2010, 2013).

The results obtained give a contribution for a better evaluation of the mass transfer rate between a deep street canyon and the atmosphere which is a key parameter in the development of operational models.

2. Methodology

The procedure adopted to perform the simulations is analogous to that of previous papers (Murena et al., 2011; Murena and Mele, 2014) but with some differences that will be highlighted.

The computational domain is reported in Fig. 1 with a zooming on the canyon with balconies. Boundary conditions applied for all simulations are also reported in Fig. 1. It is a 3D model with periodic boundaries that are represented by dashed lines in the front view picture of the street canyon in Fig. 2. We have adopted this model also for those cases that could be studied as 2D geometry: e.g.; absence of balconies ($L_b = 0$) or continuous balconies ($\Delta_b = 0$).

The geometrical description of the street canyon is reported in Fig. 2. In all simulations the aspect ratio, the ratio between building height H and street width W, was H/W = 3 with H = 18 m and W = 6 m. Following the usual classification of street canyons (Oke, 1987) this is a deep street canyon.

The dimension of balconies is defined by the following geometrical parameters: balcony depth (L_b); balcony width (W_b), balcony height (h_b); vertical distance between two balconies (H_b) and horizontal distance between two balconies (Δ_b).

Some geometrical parameters were kept constant in all simulations: $W_b = 1.5$ m, $h_b = 1$ m; and $H_b = 3.5$ m. These values are typical of buildings in the historical centre of Naples characterized by two typologies of streets: the principal roads have H ≈ 30 m and W = 20–30 m. The secondary streets have W = 6–7 m and H = 18–30 m. Dimension of balconies are: depth 0.5–1 m; length 1–2 m; and horizontal distance between two balconies from 1 to 3 m.

Please cite this article in press as: Murena, F., Mele, B., Effect of balconies on air quality in deep street canyons, Atmospheric Pollution Research (2016), http://dx.doi.org/10.1016/j.apr.2016.06.005