POLLUTANT DISPERSION IN DEEP STREET CANYONS – COMPARISON BETWEEN CFD AND OPERATIONAL MODEL SIMULATIONS

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INTRODUCTION

Deep street canyons are a common feature of densely populated urban areas in Southern Europe. In these locations, multi-storey residential and/or office buildings surround relatively narrow streets reducing natural air ventilation. That may result in high concentrations of traffic-related pollutants, such as CO, in heavily congested streets and/or streets with high density of two-stroke motorcycles. Well calibrated and user-friendly dispersion models are needed for assessing air quality under these conditions. In the present study, two different modelling techniques are used to simulate CO concentrations at different heights within a deep street canyon (Via Nardones) in Naples, Italy.

METHODOLOGY

Experimental measurements

The results of a one-week continuous monitoring campaign *(Murena F. and Favale G. 2007)* of carbon monoxide in Via Nardones were modelled using both a Computational Fluid Dynamic (CFD) program (FLUENT) and an operational street pollution model (WinOSPM). The geometric features of the selected street canyon (Fig.1) were: width W = 5.8 m and height H = 33 m (Aspect Ratio, H/W = 5.7). CO concentrations were measured at pedestrian level (h = 2.5 m) and close to the roof-top level (h = 25 m). In the same period, traffic flow in the street canyon was manually measured and the CO emission rate from vehicle exhausts was estimated using the COPERT procedure. Meteorological conditions (temperature, atmospheric pressure, solar irradiance, wind velocity and direction) were also measured at roof-top level.

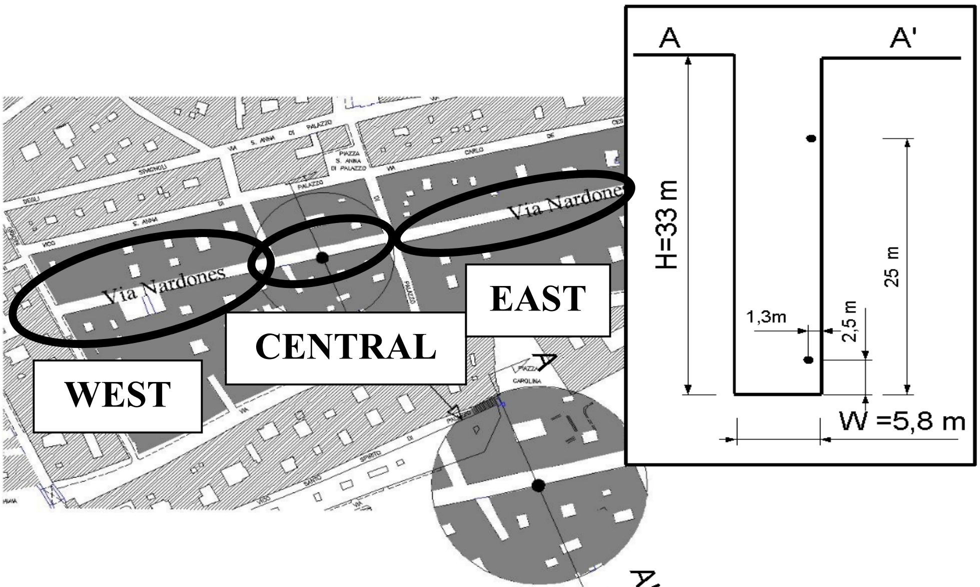

Figure 1 The street canyon

CFD simulations and results

Three dimensional (3D) CFD simulations were carried using FLUENT. The computational grid of the 3D domain representing the street canyon and its surroundings was developed using GAMBIT. The street canyon was subdivided into three parts: east, central and west (Fig.1). Each part was divided into two volumes: the bottom volume from 0 to 4 m and the upper volume from 4 m to roof top level. Then, FLUENT was used to simulate the flow field inside the canyon, taking into account the atmospheric and traffic conditions during the monitoring campaign. We used an unsteady RANS model with a κ-ε RNG turbulent closure method and the wind inflow velocity end turbulent profile were approximated using the following function:

$$v = v_r\left(\frac{z}{z_r}\right)^{\alpha} \quad ; \qquad k = \beta v^2 \qquad ; \qquad \varepsilon = C_\mu^{3/4}\left(\frac{k}{k_v z}\right)^{3/2} \qquad (1)$$

where: α=0.28; β=0.03; C_μ=0.09; κ_v (Von Karman constant)=0.41. The CO input flow was modelled assuming the road surface as an inflow surface from which a mixture of air and CO exits with a constant vertical velocity of 0.1ms^{-1} in order to model the pollutant rise due to the buoyancy effect. In Fig. 2 a comparison of CFD results with monitoring data is reported. On the left the effect of background concentration is reported. Two different kind of simulations were carried out: i) assuming as background concentration that measured at 25 m; ii) assuming background concentration=0. On the right of Fig.2 the modelling results for bottom and upper volume are compared with monitoring data at h=2.5m and h=25 m. Data reported in Fig. 2 refer to the central part of the street canyon where sampling was carried out. CFD results indicate that in the other parts of the canyon (East and West) CO concentration were very similar to the central one.

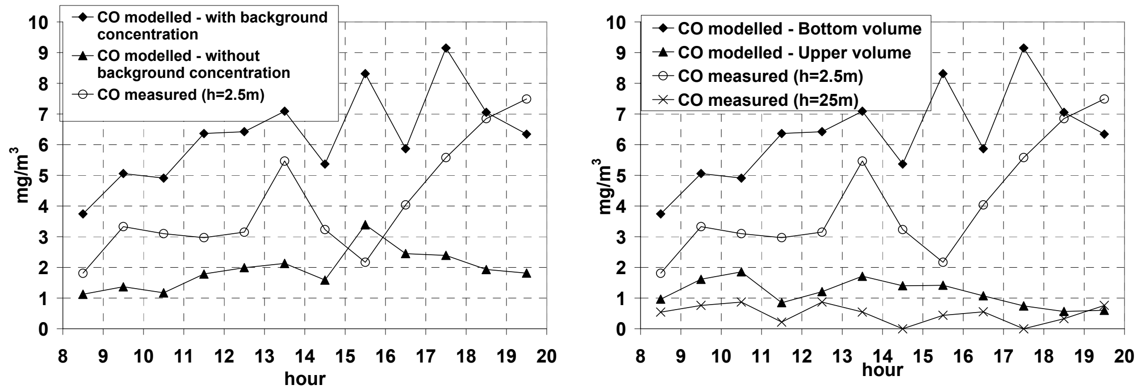

Figure 2 Comparison between CFD simulations and monitoring data

WinOSPM simulations and results

OSPM (Berkowicz, 2000) is a practical tool for estimating traffic-related pollution dispersion in urban street canyon-type geometries. The Windows version of the Danish Operational Street Pollution Model (WinOSPM) is a fast-response operational model that has been proved to be a reliable tool in predicting concentrations of inert (e.g. CO) and fast reacting pollutants (e.g. NO_2). WinOSPM combines a plume model for the direct impact of pollutants emitted in the street ("direct" contribution), with a box model that accounts for the additional impact of pollutants trapped within the wind vortex formed inside the canyon ("recirculation" contribution). The parameterisations of flow and dispersion conditions in street canyons are empirically deduced from extensive analysis of experimental data and model tests. It is important to note that WinOSPM has been mainly tested for regular street canyons (with height-to-width ratio of about one), where the flow within the canyon is vortical and almost entirely driven by the external wind flow at roof level (skimming flow regime) (Oke, 1988; Vardoulakis et al., 2003). Application to deep street canyons, for which the flow field significantly differ from the regular case, is rather challenging and requires dedicated analyses and model tests. The CO measurements obtained at 2.5 m above street level showed almost no dependence on wind speed. On the other hand, the model results showed a decrease of CO concentrations with increasing roof-level wind speed, as expected. This behaviour was also reflected in the poor agreement between measured and modelled concentration produced with WinOSPM (Fig.3a). The CFD simulations of wind speed mean components showed that the velocity magnitude of the wind flow at street level was reduced by almost a factor of 10, with respect to the roof top wind speed. WinOSPM applies a logarithmic-based function to the wind profile within the canyon, to account for the reduction of the wind velocity from roof to ground level. This reduction is not sufficient for very deep canyon, such as Via Nardones. By applying a further reduction of the street level wind speed by an empirical factor of 10 within the model, WinOSPM results were remarkably improved (Fig. 3b). Moreover, due to the very weak penetration of the wind flow into the canyon, it is expected that modelled concentrations depend very strongly on the dilution induced by moving vehicles at street level. For this reason, detailed parameterisation of the turbulence induced by traffic (TPT) is required (Solazzo et al., 2007).

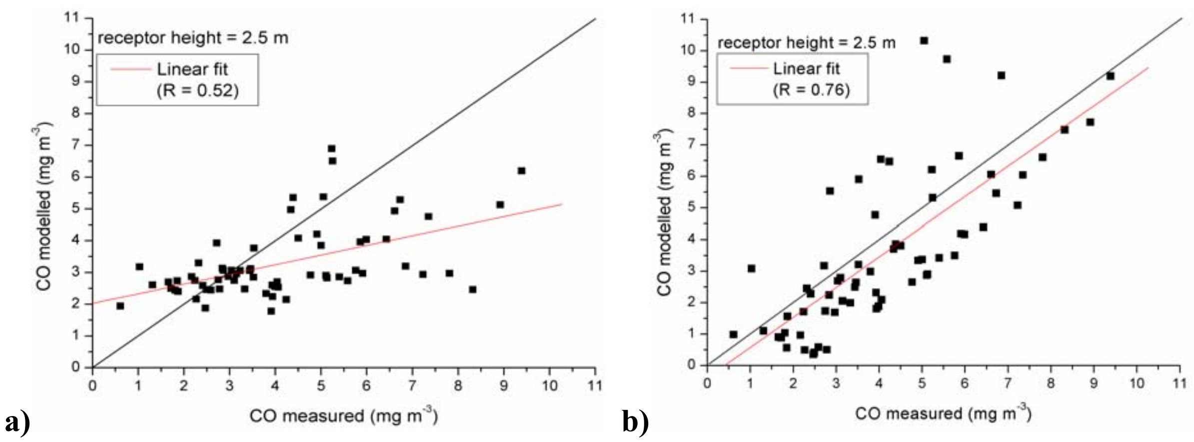

Figure 3. Measured vs. modelled CO concentration at receptor location (z = 2.5 m) by using a) an unmodified version of WinOSPM, and b) a reduction factor for the wind speed 10 times higher than the default value set in WinOSPM. Linear fit and correlation coefficients (R) are reported for both cases.

COMPARISON BETWEEN WINOSPM AND CFD CALCULATIONS OF CO VERTICAL PROFILES.

Comparisons between CO vertical profiles produced with WinOSPM (North and South side of the canyon) and CFD profiles (FLUENT) are shown in Fig. 4. Since the TPT was not included in the CFD calculation, and in order to compare similar outputs form the two models, the TPT term was set to zero in WinOSPM.

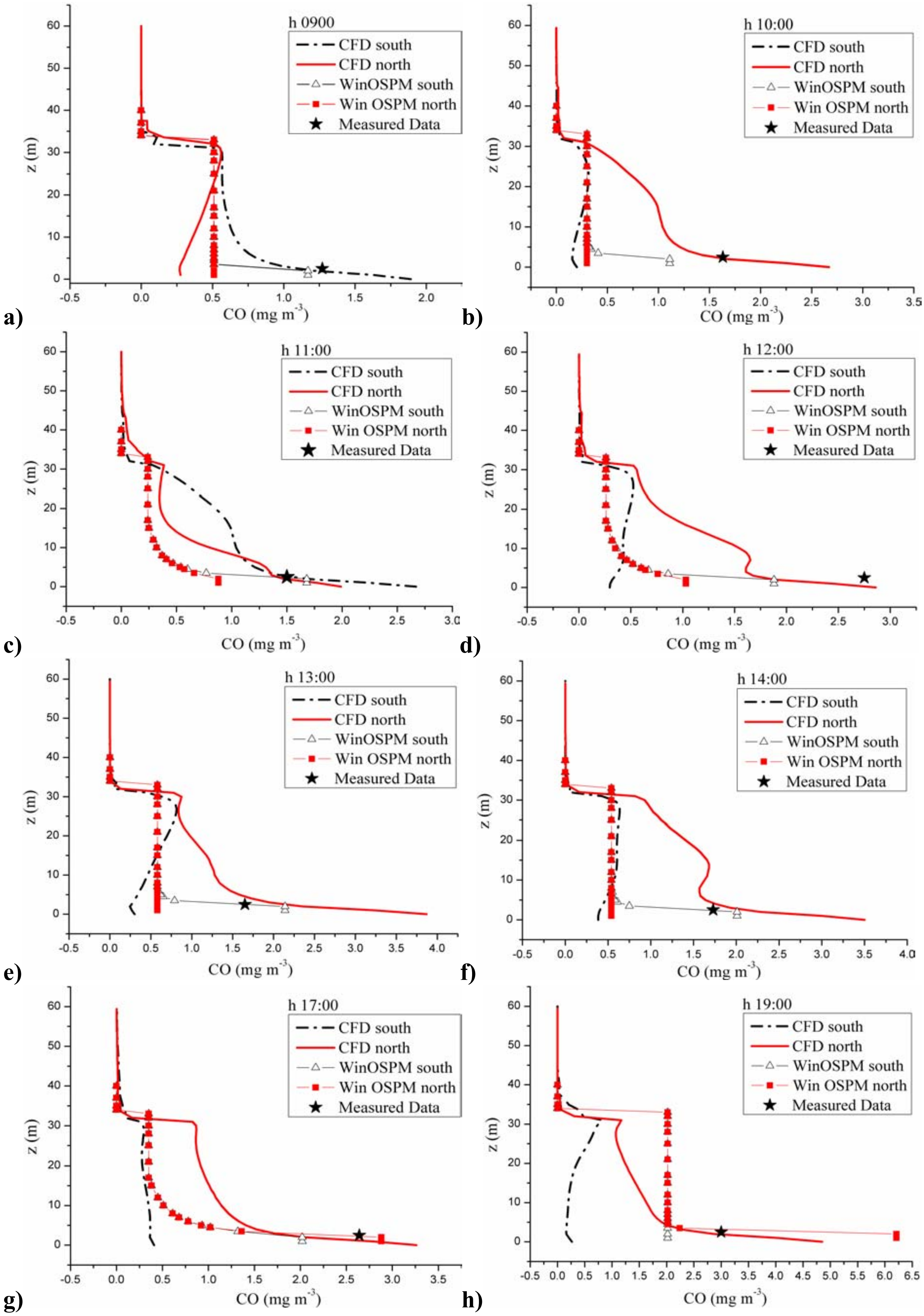

Figure 4. Vertical CO concentration profiles computed with WinOSPM and CFD on the North and South sides of the canyon.

Furthermore, the background concentration was not taken into account in this comparison, so that only the contribution of the vehicular traffic to the CO profiles was analysed. Particular attention was given to the estimation of the CO emission inputs, which were the same for both models. North and South vertical CO concentration profiles for selected hours of one day (15/06/2006) are shown in Fig. 4. Measured CO concentrations at 2.5 m (after subtracting the background contribution) are also included in Fig. 4. Overall, the two models predicted similar CO magnitudes. A closer inspection of the results shows that the two models had a very good agreement in the region close to the roof of the buildings, where the gradient of CO concentrations was rather pronounced. Similarly, at street level, profiles in Figs. 4c,d,g show a common trend by the two models in predicting a sharp decrease of CO levels with height. It should be noted that in the case of the aforementioned profiles, the wind direction was almost parallel to the street canyon. For these time periods, WinOSPM predicts a symmetric pollutant distribution, resulting in similar CO vertical concentration profile on both side of the canyon. For wind direction not aligned with the street axis, CO concentration profiles predicted by WinOSPM exhibit a constant behaviour above street level and up to the top of the canyon (Fig. 4a,b,e,f,h). This is probably because the recirculation zone modelled by WinOSPM covers the whole depth of the canyon, while the direct contribution affects only pollutant concentrations close to the bottom of the canyon. Consequently, the modelled concentrations are constant within this region (approximately 3-33 m above the ground). It should be noted that the direct contribution (i.e. plume emitted by vehicles) has a limited effect on the leeward side of the canyon and close to the bottom of the street only.

Furthermore, it is interesting to note that when the wind is not parallel to the street axis, the CFD results on the North side are close to those produced by WinOSPM for the South side. Such a behaviour may be due to the prediction of multiple counter-rotating vortexes for this very deep canyon by the CFD model, which may have resulted in reversed crossroad pollution gradients near the bottom of the canyon.

CONCLUSIONS

WinOSPM is not currently designed to handle complex in-canyon flow fields that may comprise more than one wind vortexes. It should also be remembered that this model adopts a very simple methodology to calculate the spatial distribution of pollutant concentration, whilst the CFD model calculates the flow field and the concentration patterns using a much more advanced grid approach to resolve their spatial variability. Nevertheless, WinOSPM provides a reliable first estimation of pollutant concentration at variable receptors location within the canyon.

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