FROM LOCAL-SCALE TO MICRO-SCALE ASSESSMENT OF THE ATMOSPHERIC IMPACT OF THE POLLUTANT PLUME EMITTED FROM A POWER-PLANT STACK

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Abstract: The atmospheric dispersion of NO_x emitted from a power-plant stack is simulated both by a micro-scale model and by local-scale model, and the simulation results are compared. The plant is located in a residential urban area in the central Po valley (Northern Italy), often characterized by low wind events and thermal inversions. In these conditions, pollutant dispersion is more influenced by turbulence effects due to the urban canopy than by advective transport and convective fluxes. Similar conditions can be better taken into account with a micro-scale simulation, able to predict the 3D dispersion patterns among the urban obstacles. The NO_x concentration maps obtained by micro-scale simulation show significant difference from NO_x local-scale results, because the near-field influence of the buildings can strongly affect the dispersion process.
The micro-scale and local-scale simulation of NO_x dispersion in atmosphere are both simulated by ARIA INDUSTRY software packages.

Key words: *Micro – scale simulation, urban obstacles, tri-generation power plant, low wind conditions.*

INTRODUCTION

In a previous work (Ghermandi *et al.*, 2012) the atmospheric dispersion of the NO_x emissions from the stacks of a power plant were investigated using the software package ARIA INDUSTRY featuring the Lagrangian Particle Dispersion Model Spray (Tinarelli *et al.*, 1998). Simulation results, whose period spans over the whole 2010 winter season, clearly show that maximum average concentration values fall a few hundred meters nearby the plant stacks in a densely populated urban area.
The present study deals with the same plant studied by Ghermandi *et al.* (2012) investigating dispersion patterns of NO_x in the urban area close to the plant. Aim of this study is to highlight if any increase in NO_x concentrations occurs at urban micro-scale, where pollutants dispersion is strongly influenced by building location, distance and height, and if the micro-scale simulated concentration fields are similar to local-scale simulation results.
Simulations were performed by means of the Micro-Swift-Spray code including the mass-consistent diagnostic wind-field model Micro-Swift (Aria Tech., 2010) and a new version of Spray code (Arianet, 2010) developed for micro-scale applications, i.e. horizontal dimensions up to 1-2 km and horizontal grid up to 1-5 m, so as to consider buildings texture in urban environment.
Micro-Swift firstly interpolates 3D wind-field from on-site observations by taking into account buildings geometry; then Micro- Spray simulates the airborne pollutant dispersion also taking into account plume rise effects (Anfossi *et al.*, 1993) and stochastic velocity fluctuations (Thomson, 1987).
In order to point out how meteorology could differently affect dispersion patterns at micro-scale, two different days have been selected in order to perform simulations under most critical atmospheric conditions for winter season. As shown in the following, critical atmospheric impacts at micro-scale may occur even in windy conditions.

CASE STUDY

The power plant that will be installed at the General Hospital of Modena (Northern Italy) consists of six devices, all supplied by methane gas: a tri-generation unit powered by an internal combustion four-stroke engine, three conventional boilers and two industrial steam generators. Stack heights are all equal to 10 m except for the tri-generation unit (15 m). The plant was sized using safety criteria, and only three devices will be active to supply the energy demand: the tri-generator, one boiler and one steam generator. Features and operating conditions have been described by Ghermandi *et al.* (2012), who estimated the emitted exhaust gas flows from stacks on the basis of the hourly average fuel consumption in the monthly mean day. For a daily micro-scale simulation, spanning over a period of 24 hours, a hourly modulation of emission patterns for boilers and steam generators has been considered. For the tri-generator unit, which operates at steady-state conditions, even the emission pattern remains constant all day long.

MODEL SETUP

MSS simulation has been performed over a 500 x 500 m^2 horizontal domain, centred at plant stack position and divided into a grid of 2 m square cells, representing the urban district of Modena nearby the General Hospital where the highest atmospheric impact from future power plant is expected. First layer for concentration computing is 2 m thick, starting at ground level. The red numbered points in Figure 1a show source position within the micro-scale domain: Boiler (1), Steam Generator (2) and Tri-generator (3). Buildings geometry (Figure 1b) has been deduced in a GIS from a high resolution 3D cartography.

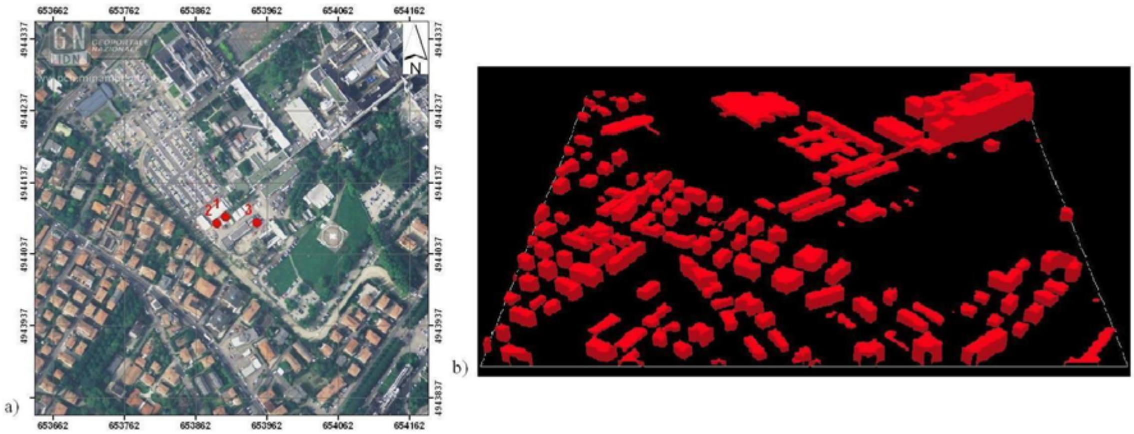

Figure 1. Map of the investigated area in Modena (Italy) (a); block-shaped structures in MSS (b).

Two days, January 14th and February 6th, have been selected from winter 2010 meteorological dataset in order to perform simulations in different meteorological conditions. Daily patterns for hourly average wind speed and mixing height are plotted on diagrams in Figure 2.

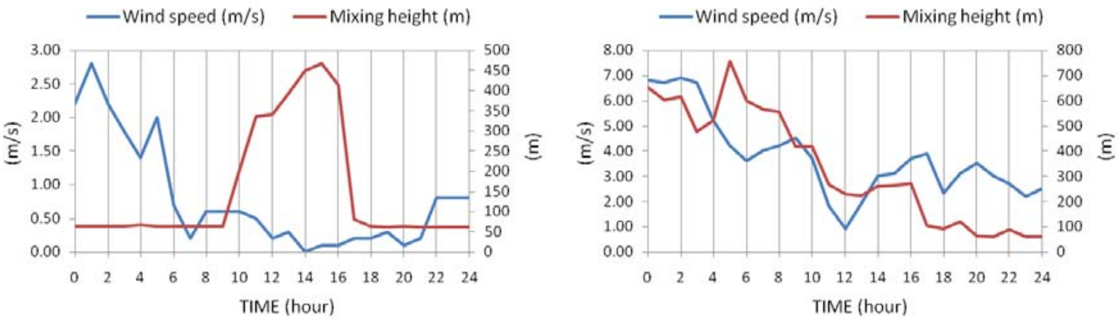

Figure 2. January 14th (left) and February 6th (right) 2010 wind speed and mixing height hourly average values.

Wind speed data come from a meteorological station in urban environment (ground observations by Osservatorio Geofisico of Modena and Reggio Emilia University); mixing height data derive by CALMET model simulation (ARPA E. R., 2008). Average winter values in 2010 for wind speed and mixing height are equal to 1.65 m/s and 310.48 m respectively.

Table 1. Emitted gas data and NO_x emission rates for the three devices in the "typical day" of January and of February

Device	January			February		
	NO_x flow (kg/h)	Exit temp. (°C)	Exit speed (m/s)	NO_x flow (kg/h)	Exit temp. (°C)	Exit speed (m/s)
Boiler	0.66	93.0	2.35	0.39	75.8	1.34
Steam Generator	0.28	195.4	2.55	0.26	192.3	2.30
Tri-generator	2.13	125	16.14	2.13	125	16.14

Table 1. reports exit gas data and NO_x emission rates for a "typical day" in January and February. Exit speed and temperature have been directly used in the simulations as daily average input data, while NO_x mass flows are hourly modulated according to the daily emission pattern for each device.

RESULTS

The maps of average daily NO_x concentration in the first atmospheric layer, obtained from the simulation of the emissions of all planned sources, are shown in Figure 3: simulation periods correspond to January 14th (Figure 3, left) and February 6th (Figure 3, right) 2010 respectively.

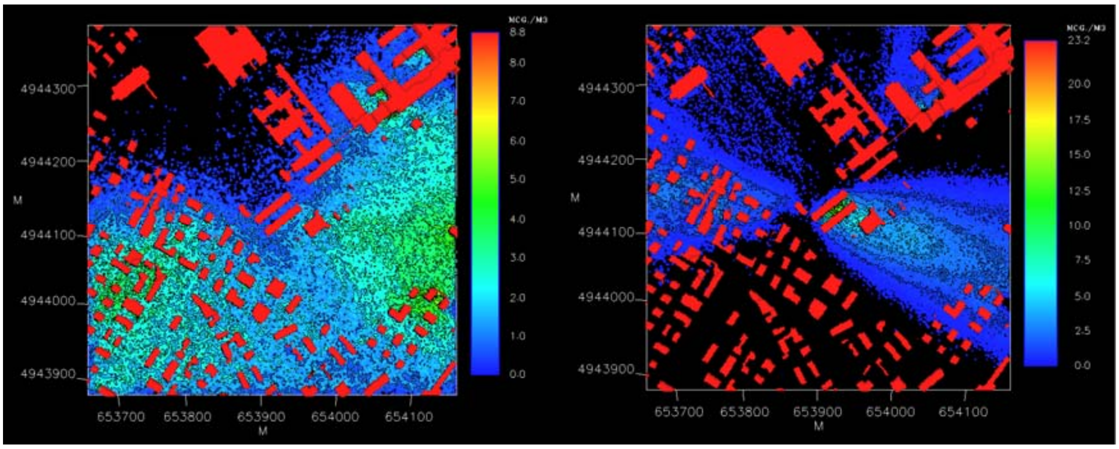

Figure 3. NO_x daily average concentration maps on January 14th (left) and February 6th (right) 2010,
in the first layer from the ground, for the overall contribution of all plant sources (boiler, steam generator, tri-generator).

Because of low wind conditions occurring on January 14th, the plumes are mainly driven by dispersion and spread at ground with no preferential direction while, on February 6th, the prevailing wind direction is clearly visible since moderate wind conditions occur. Although it should be expected that pollutant accumulation may be enhanced in the 14th January scenario, the maximum average daily concentration value is an order of magnitude higher in February than in January. This is probably due to the fact that, because of exit gas conditions (Table 1.), plume rise effects become more relevant in February than in January; in addiction, the wind force in February stretches the plumes and probably impairs their vertical dispersion. In Figure 3 (right) pollutant stagnation occurs among two buildings with a local increase of concentration values. Therefore, even if atmospheric conditions seem to enhance pollutant dispersion, similar phenomena may easily occur due to the buildings shielding effect.

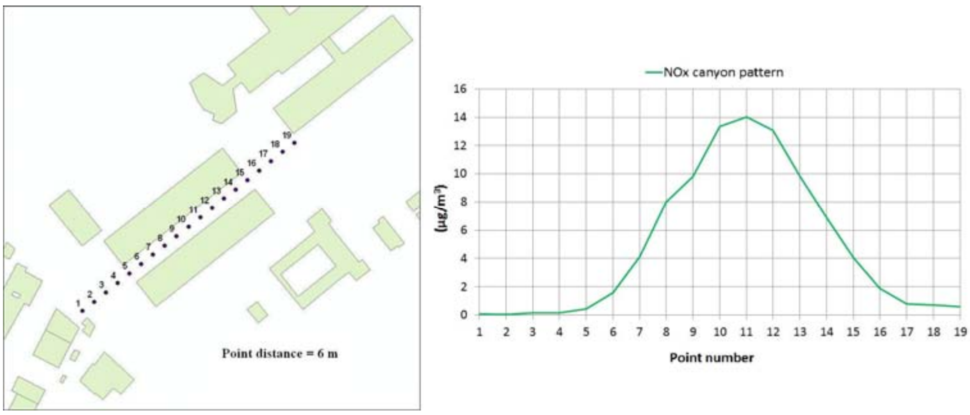

Figure 4. NO_x daily average concentration pattern on February 6th 2010 within the urban canyon (right) and interpolation points (left).

Oke (1987) and Vardoulakis (2003) classified different air-flow conditions within urban canyons by introducing a building *aspect ratio*, which is the height (H) of the canyon divided by the street width (W). For the present case H and W are equal to 8 and 7 m respectively, so that the aspect ratio is H/W ≈ 1. According to that classification this is a condition of skimming flow canyon where the formation of a single eddy occurs and, consequently, turbulent recirculation prevents pollutants removal.

The pattern of daily average NO_x concentrations within the urban canyon was estimated by interpolation of simulation results at 19 points along a longitudinal cross-section of the canyon (Figure 4, left); the concentration gradient between the cavity and the open field is quite evident (Figure 4, right).

NO_x concentration maps from boiler and steam generator plumes are reported in Figure 5 for January 14th (left) and February 6th (right) 2010 simulations. NO_x concentration maps from tri-generator plume are reported in Figure 6 for January 14th (left) and February 6th (right) 2010 simulations.

In low wind conditions (January 14th), when mixing is confined nearby the sources, the impact at ground by auxiliary devices and tri-generator are similar. On the contrary, in windy conditions (February 6th), the plumes stretching along main wind directions outlines the effects of different stack heights between tri-generator and auxiliary devices; hence the contribution of boiler and steam generator is prevailing at ground level, while tri-generator emissions remain mainly confined at higher level from the ground.

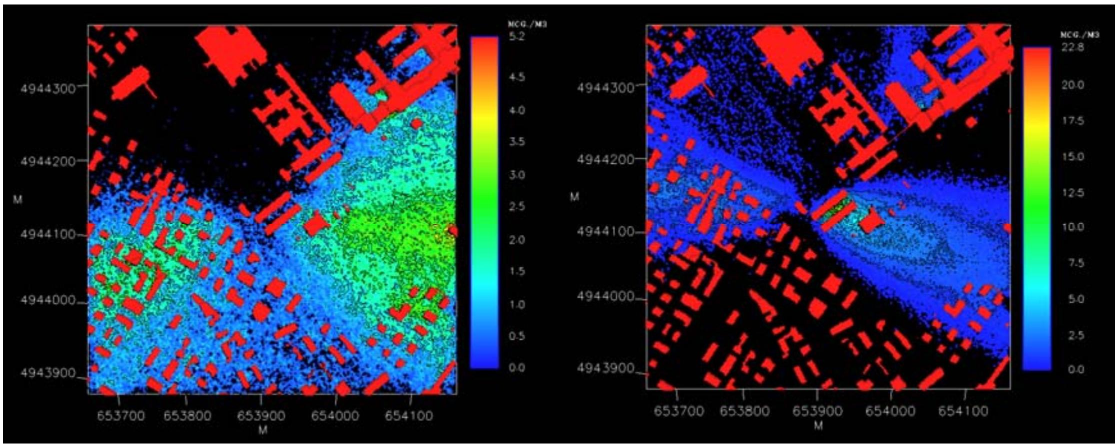

Figure 5. NO_x daily average concentration maps on January 14th (left) and February 6th (right) 2010, in the first layer from the ground, from the plant auxiliary devices emissions (boiler and steam generator).

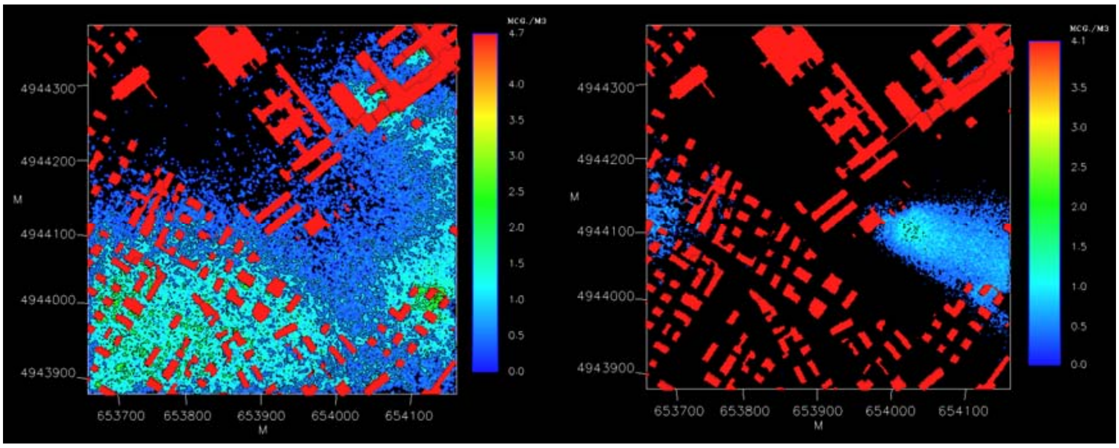

Figure 6. NO_x daily average concentration maps on January 14th (left) and February 6th (right) 2010, in the first layer from the ground, from the emissions of tri-generator only.

COMPARISON WITH LOCAL-SCALE SIMULATION RESULTS AND CONCLUSIONS

This study deals with a micro-scale simulation of atmospheric dispersion for NO_x emissions from a power plant, designed to supply the energy demand of Modena General Hospital (central Po valley, Italy). Emission data were deduced from the yearly plan of operation according to daily fuel consumption.

Simulations span over two daily periods (24 hours) which were chosen by analyzing the winter 2010 meteorological dataset. The goal was to identify the different role of urban obstacles in affecting dispersion patterns under different meteorological scenarios, depending on whether moderate or low wind conditions occur. Simulations were performed via the software package Micro-Swift-Spray provided by Arianet s.r.l for micro-scale applications.

Previously, for the same power plant, a local-scale simulation was performed for the whole 2010 winter season (Ghermandi *et al.*, 2012). The results showed that atmospheric impact of auxiliary devices is the most relevant in the first 10 m from ground level. This is mainly due to the combined effect of the emitted gas exit speed and the stack height, which are higher for the tri-generator unit than for the auxiliary devices. The aforesaid difference is fairly evident even at the high resolution of a micro-scale simulation.

When atmospheric mixing conditions are weak (January 14th), because of the absence of wind, pollutant plumes tend to stagnate and merge in the surroundings of the sources. In the February 6th meteorological scenario, when windy conditions occur, plumes appear more stretched along wind prevailing direction and building influence on air flow becomes more visible through ground concentration maps. A *skimming flow* canyon phenomenon occurs and causes a local increase of NO_x concentration for the emissions from the auxiliary devices, while the tri-generator emissions appear almost unaffected by building presence.

For the auxiliary devices in fact, on both considered days, maximum values for average daily concentrations at local-scale are less than 10 μg/m^3, instead of values higher than 20 μg/m^3 which are reached at micro-scale in moderate wind conditions (February 6th).

Such results show that, at micro-scale, the combined effect of urban obstacles with bottom stacks may cause pollutant stagnation in urban canyons, especially in windy conditions when, on the contrary, more favourable conditions for pollutant dispersion should be expected. Hence the contribution of auxiliary devices to ground concentrations, if compared to tri-generator unit, would result further higher at micro-scale than at local-scale. This is not due only to the gap between stack heights, but also to the different plume rise effects which are more intensive for the tri-generator unit than for the other devices (Ghermandi *et al.*, 2012), according to different exit conditions of exhaust gas (Table 1.).

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