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SIMULATION OF STREET CANYON EFFECT IN A STREET OF BARREIRO CITY IN PORTUGAL

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Abstract: Pollutant dispersion in urban areas is very important issue since pollutants have negative impacts on health and welfare, structures and natural environment. Topography and urban obstructions such as buildings have great influence in the atmospheric flow and consequently on the pollutants dispersion. The Street Canyon effect changes the pollutant dispersion, particularly vehicle exhaust pollutants, which cannot be carried away by the wind, due to buildings which act as barriers, avoiding the wind circulation. Dispersion cannot occur since air and consequently air pollutants, are trapped within the street canyon, raising the concentration of this contaminants. This study shows the street canyon effect on a busy street of Barreiro City in Portugal. With this purpose, Fluent, a CFD flow modelling software, was used to simulate the air flow and turbulence in Bocage street. Building high, width, breadth, length and geometry, as well as buildings distance and road width were considered in the simulation work. Winter and summer most predominant meteorological conditions were simulated, namely, wind direction and velocity and temperature. Also, particle matter with less than 10µm (PM_{10}) were measured, to know the concentration of this pollutant in the abovementioned street. Wind direction and intensity, temperature and humidity were also measured, to characterize meteorology in the measurement days. When wind direction has the same orientation of the street (West or East), a good dispersion is promoted, however, since the buildings aren't all of the same size, some recirculation is noticed after the first and highest building, affecting mainly the residents. If the wind direction is from the North, some recirculation is noticed, since the highest buildings are on the other side of the street making a barrier. In spite of the clear air drawn by the wind, smoke from traffic sources is trapped by the recirculation, increasing pollutants concentration. Wind from South, causes also recirculation, however and since the smaller buildings are on the other side of the street, pollutants are carried over these buildings, by the whirlwind caused in the recirculation.

Key words: *Street Canyon, Pollutants dispersion, Traffic, Fluent.*

INTRODUCTION

Nowadays the concern about air quality has grown, manly due to the increase of atmospheric pollutants sources. These sources can be anthropogenic, caused by man, like industrial activities and traffic, or can be natural, caused by nature through chemical reactions, erosion or other phenomenon. With population growth, the urban environment is frequently contaminated by industries and traffic pollutants, like NOx, PM, CO and SO_2. Vehicle numbers have increased enormously in the past years raising the pollutants concentration near the surface where citizens circulate. Most serious pollution episodes, mainly in urban environments, are a mix of high pollutants level and adverse meteorological conditions. This is a fundamental parameter to understand pollutants behaviour, since it is in the atmosphere that most of chemical reactions are made, as well as the transportation and dispersion of pollutants. For this reason it is important to know the capacity of the atmosphere to disperse and transport pollutants. In European cities, the geometry of the streets plays a very important aspect in the dispersion of pollutants inside the street. Items like the direction of the wind, the geometry of the buildings and the geometry of the roads, represent critical aspects that can make the difference between good air quality and bad air quality. For this reason, the purpose of the study is to investigate the effect of Urban Street Canyon in a street of Barreiro city in Portugal.

STUDY AREA

This study was performed in a street (Av do Bocage) of Barreiro city which is about 40km of Lisbon (Fig.1). This is a small city, over $34km^2$ and 80000 inhabitants, with industry near the centre and typical city traffic. Due to the proximity, some pollution effects from Lisbon are felt, with the right meteorological conditions. Barreiro is almost flat, with the highest point at approximately 10 meters above sea level. The weather is temperate, with no severe seasons.

Figure 1. Location of Barreiro city in Portugal and Av. do Bocage.

The street considered in this study was Avenue do Bocage which is a hardly traffic road with some habitation buildings and a school.

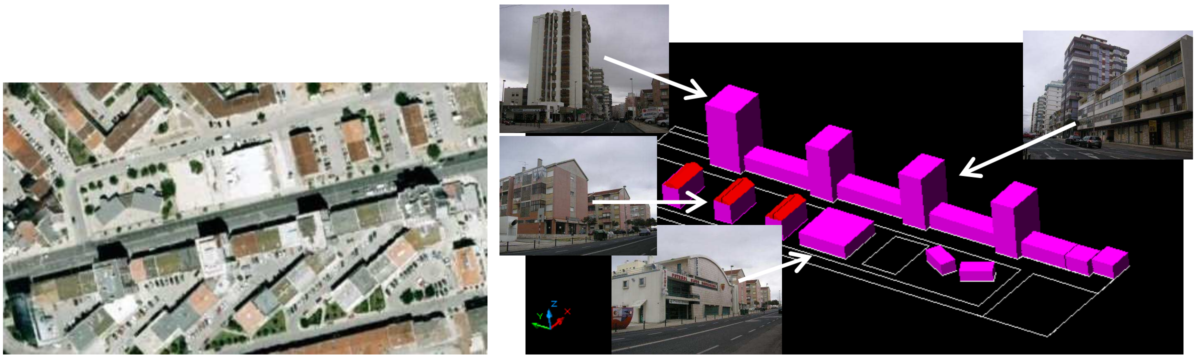


Figure 2. Av. do Bocage in Barreiro city and its model.

POLLUTANTS CARACTERIZATION

The main industrial activity is developed in the industrial area, near the city centre. A power plant and some chemical industries are the main industrial sources. The most important pollutants released from this source are NOx, SO_2 and PM. These pollutants are monitored periodically and the concentrations, as well as some effluent characteristics and chimney dimensions were given by the industries. Traffic is the major pollutant source, like in other cities, due to the continuous population growth in urban areas and lack of efficient public transport. Light duty vehicles (LDV) constitute the most important traffic fraction, however and due to the proximity of the industrial area, high duty vehicles (HDV) have an important contribution in pollutants concentration. A traffic characterization was carried out in Barreiro city streets, considering the number of vehicles per type, used fuel, velocity, street characteristics and the time of the day when the field campaign was made. Other sources, such as residual, poorly-defined or diffuse emissions in urban areas, like minor roads, were also considered, as well as the background pollutant concentrations.

PARTICLE MEASUREMENTS

To choose the study object, a characterization of particles with diameter less than $10\mu g/m^3$ (PM10) was made in a field campaign, measuring PM10 in several busy streets with the Beta Gauge Dust Monitor equipment. The wind speed and direction were also registered. The values obtained are shown in the figure below (figure 3). In red are represented the values that exceed Portuguese legal limits ($50\mu g/m^3$).

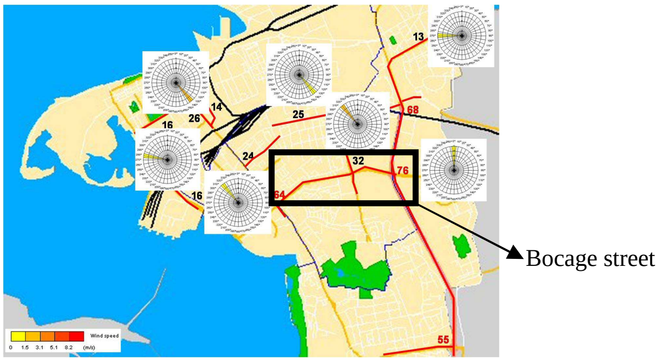


Figura 3: PM10 Concentration in Barreiro city ($\mu g/m^3$)

From the results it is possible to conclude that there are two streets with high concentrations of PM10. One of the streets is a highway and doesn't have many buildings. The other one, Av. Bocage, has also some high values and the street canyon effect is the case study.

THE SIMULATION MODEL

For this study, Fluent software was used, since it has been widely used in this kind of application and constantly validated through comparison of the results with other validated models [1] or through wind tunnel experiments [2]. Fluent is a computational fluid dynamics (CFD) software that allows the simulation of fluids flow and the heat transfer in complex geometries. It allows also a great flexibility to build complex grids and to refine the mesh on the spot where the results are more important. The complex grid can be made using Gambit and then exported to Fluent.

To fulfill the aim of this study, a tetrahedral grid was used, refined near the buildings. The geometry of the street is shown in figure 4 and also the domain regarding wind from west. As different wind directions were studied, different domains were used, to assure sufficient distance between the buildings and the domain boundaries in the simulation.

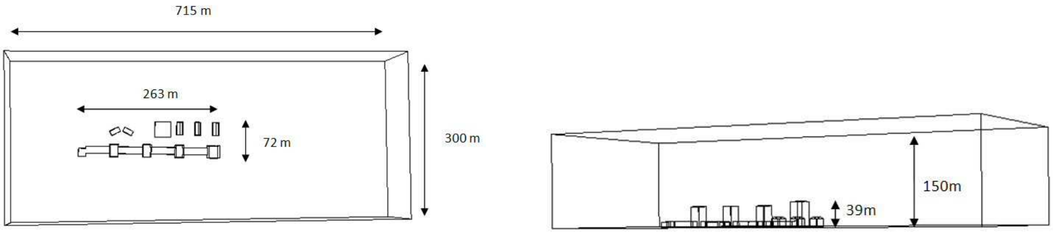


Figure 4. Street geometry and domain to wind from west conditions

The k–epsilon turbulence model is the most used for modeling flow and turbulence in street canyons [3] and it was also used in this study, more precisely the RNG k–epsilon turbulence model. This model derived from the standard k–epsilon turbulence model, using a mathematical technique called "renormalization group" (RNG) methods. This model improves the accuracy for rapidly strained flows and for swirling flows, provides an analytical formula for turbulent Prandtl numbers and an analytically-derived differential formula for effective viscosity that accounts for low-Reynolds-number effects [4].

As known, the wind velocity at the inlet is not uniform due to roughness and topography and for this reason a wind profile, turbulent kinetic energy and turbulence dissipation rate was introduced as a user defined function (UDF). The wind profile is represented by the following equations:

$$U_{(y)} = \frac{U_f}{k} \ln\left(\frac{y+y_0}{y_0}\right) \tag{1}$$

Where $U_{(y)}$ is the wind speed at the height y (m/s); k is the Von Karman constant (0.42); y_0 is the roughness (m) and U_f is the friction velocity (m/s) defined by:

$$U_f = \frac{kU_{10}}{\ln\left(\frac{10+y_0}{y_0}\right)} \tag{2}$$

Where U_{10} is the wind speed at 10m height (m/s).

Turbulent kinetic energy and turbulence dissipation rate were calculated as follow:

$$k = 3.33U_f^2 \text{ and } \varepsilon = \frac{U_f^3}{k(y+y_0)} \tag{3}$$

RESULTS

The results obtained for wind velocity are show in figures below. Contours of wind velocity (magnitude) in m/s and velocity vectors colored by velocity magnitude in m/s are shown for the predominant wind directions in the city: North direction (12.2% of frequency) and West direction (35.1% of frequency) and for the most unfavorable wind direction for the street in study: South direction (4% of frequency).

Figure 5 shows the wind velocity from North modeled along the street.

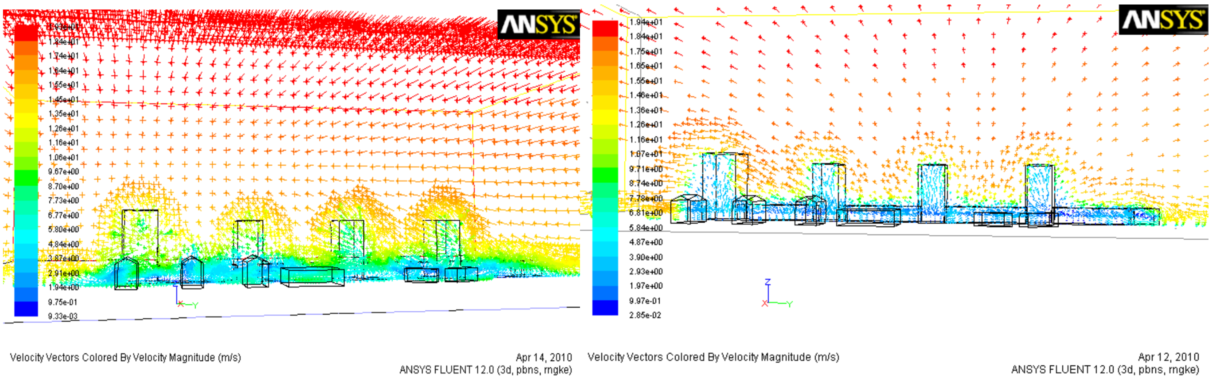
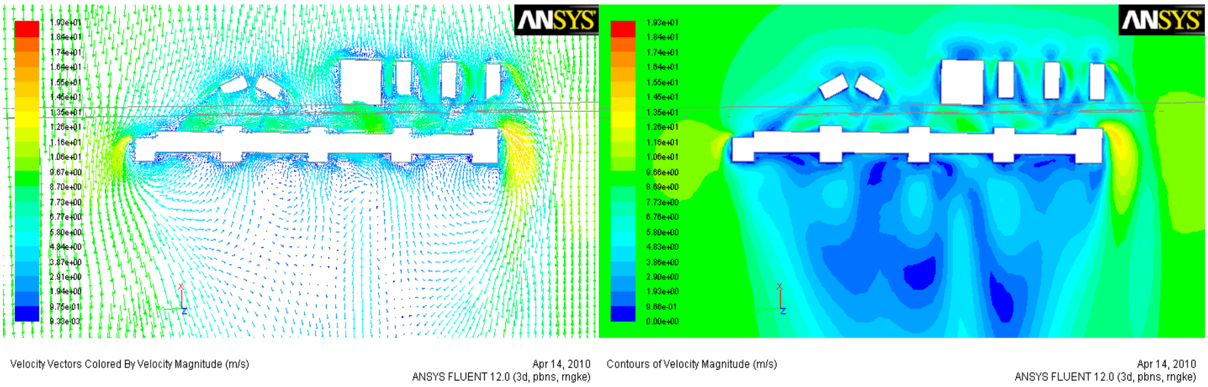


Figure 5. Wind velocity from North and South respectively (view along the street)

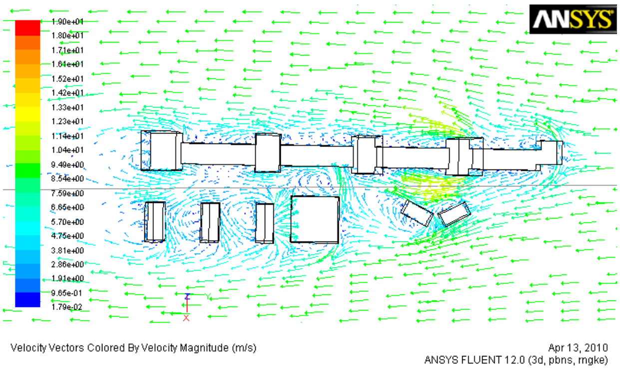
This figure is illustrative of the street geometry. It is possible to see the slower velocity around the buildings, showing the street canyon effect. With north wind the geometry is favourable to pollutants dispersion since the configuration allows a recirculation of the wind carrying the pollutants with higher velocity. Also the smaller buildings between the biggest ones act like a transport channel for pollutants. This effect is smaller with South wind due to opposite geometry configuration, that is, as the tallest buildings are the first barrier and the smallest ones are in the opposite side, the wind flows through and the recirculation is not created. Also the effect of transport channel created by the smallest buildings between the tallest ones is annulated in this case.

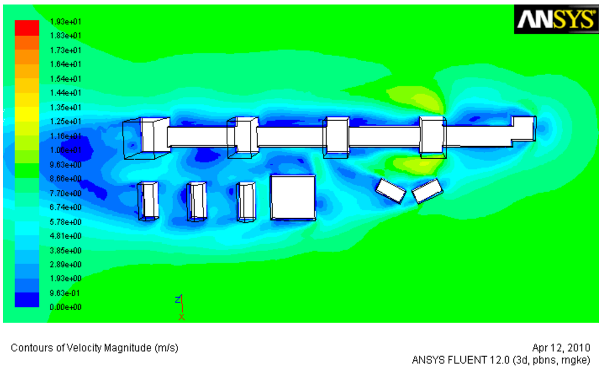
Figure 6 shows the wind velocity modeled at 1.5m height, corresponding approximately to the human respiratory cotes, for different wind directions, North, West and South.

North wind



West wind





South wind

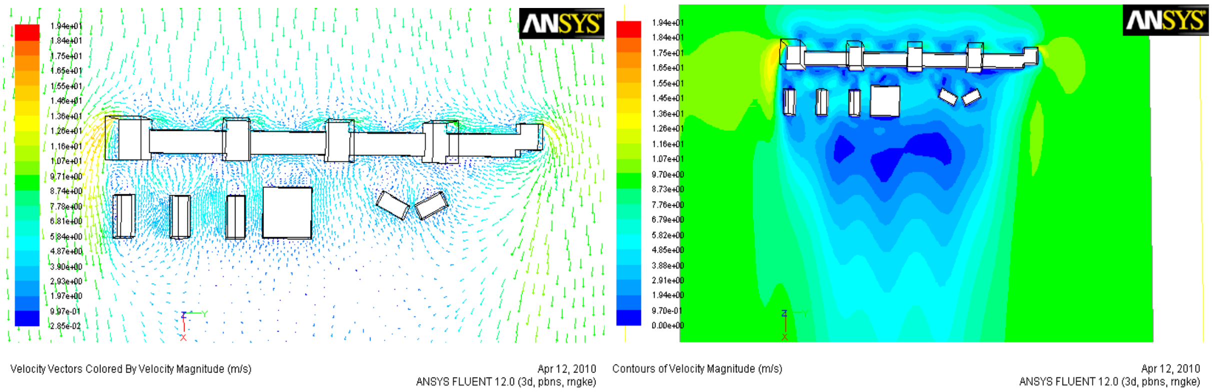
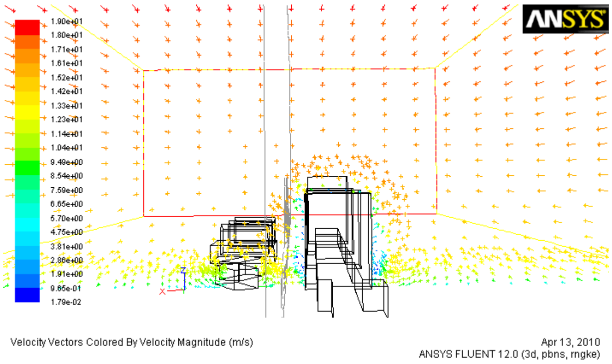


Figure 6. Wind velocity from North, West and South at 1.5m height (superior view).

The results of figure 5 are well shown also in this figure. It is possible to see that the wind velocity in the street is lower for south wind emphasizing the street canyon effect. This is due to the street configuration as discussed above. In this figure it is also possible to see the effect of the wind from west. This wind blows along the street which is favorable for dispersion, however, in this case the recirculation effect is negative since there are many points of recirculation annulling the possible positive effect in the dispersion. This can be seen especially near the end of the street. Another possible problem is that the buildings are not in the same line causing some resistance to the wind.

Figure 7 shows the wind velocity modeled at a lateral view for different wind directions, West, North and South.

West wind



North and South wind

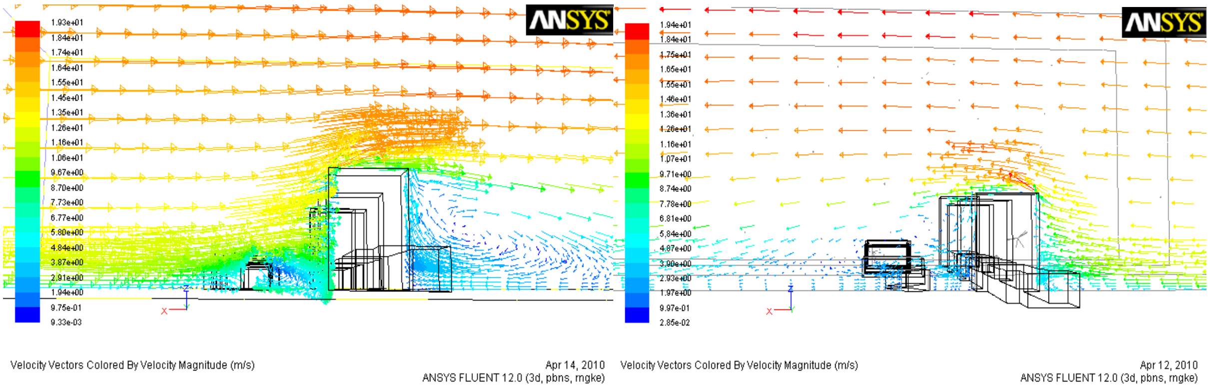


Figure 7. Wind velocity from North, West and South at 1.5m height (superior view).

Once again the results of figure 5 are well illustrated in this figure. It is possible to see the increase of wind velocity passing over the small buildings and the recirculation caused by the tallest buildings. From south the wind finds a tall barrier and the recirculation is smaller.

CONCLUSIONS

By the observation of the results it is possible to conclude that this is an efficient method to study the street canyon effect on the wind velocity and consequently on pollutant dispersion. Wind directions from west and north are the most frequent, which is positive since the results shows the possibility of better pollutant dispersion due to bigger wind speed. The south direction is the most unfavourable, nevertheless is also less frequent. As a major conclusion, this street seems to have a good geometry considering the most frequent wind direction. As next steps, the introduction of a pollutant in the model is necessary to confirm the dispersion conclusions and to study the concentration of the pollutants in the street. Also different configurations can be studied in order to help local authorities in case of a street restructuration.

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