H14-227

STUDYING THE EFFECT OF STREET GEOMETRY IN PARTICLE CONCENTRATION

J. Garcia, R. Cerdeira, N. Tavares, L. M. R. Coelho

Escola Superior de Tecnologia de Setúbal, Instituto Politécnico (ESTSetubal-IPS), Setúbal, Portugal

Abstract: This paper shows the influence of the street geometry in particle concentration on a busy street of Barreiro City in Portugal. Fluent, was used to simulate the air flow and turbulence and the particle dispersion in Bocage Street in Barreiro city in Portugal. Buildings high, width, breadth, length and geometry, as well as inside gap between 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, PM_{10} concentrations were measured, to know the concentration of this pollutant in the abovementioned Street. The results show that when the building have the same orientation has the wind, a good dispersion is promoted, and low particle concentrations are achieved. 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 North, some recirculation is noticed, since the highest buildings are on the other side of the street making a barrier. However this recirculation has a positive effect since it raises the wind velocity, promoting the pollutant dispersion. Wind from South causes higher particle concentration, since the highest buildings are the first barrier promoting the wind flow over the buildings in the studied street, trapping the pollutants released by traffic source in the street. Different geometries were also studied and it was possible to conclude that some gaps between buildings can help the pollutants dispersion.

***Key words:** Particle concentration, Fluent, Street Geometry, Buildings, Traffic.*

INTRODUCTION

Urban planning is a matter of major importance nowadays. Aspects like environment, sustainable development, public health, leisure and work, and its connections are growing its importance to decision makers. One of most important items on public health in cities is the Urban Air Quality levels (Borrego et al 2004). In this matter particle concentration in streets is one major issue. Topography and urban obstructions such as buildings and other construction have great influence in the atmospheric flow and consequently on the pollutants dispersion. This effect change 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. So for decision makers, is important to know what is the influence of building volume and geometry, in air quality in a street. Nowadays, numerical tools like Computational Fluid Dynamics (CFD) models have been highly developed and are now a very reliable tool for simulating wind and dispersion fields in urban areas which are characterized to have complex geometries. Also the complex effect of meteorology, with critical aspects like wind (orientation and intensity) can be considered in modern computational tools. Very satisfactory modelling accuracy is now possible, mainly due to the continuous important development of very powerful numerical codes, parallel to fantastic increases in hardware performances. Complementary with this computational tools measurement campaigns are also very important, because they contribute to validate de simulations and help understanding the accuracy rate of computational results.

In the range of air pollutants, particular attention was dedicated to Particulate Matter (PM) considering both PM_{10} and $PM_{2,5}$(Martins et al 2009, Amorim et al 2010)and more recently nanoparticle (Kumar et al 2011). Most epidemiological studies have focused on PM_{10} and $PM_{2,5}$ and there is a certain evidence that short term exposure to high concentrations of PM_{10} can aggravate pulmonary diseases and have influence in paediatric asthma (Garcia et al 2010), and long term exposure to high concentrations on PM_{10} may increase the risk of cardiovascular disease and pulmonary disease.

THE STUDIED DOMAIN

The studied domain is located in Avenida do Bocage which is a street located in Barreiro city about 40km south of Lisbon (Fig.1). This is a small city, over $34km^2$ and 80000 inhabitants, with industry near the centre and typical city traffic. Barreiro is almost flat, with the highest point at approximately 10 meters above sea level. The weather is temperate, with no severe seasons. Avenida do Bocage is an important strategic key point in the city, because connects the city center of Barreiro with an important motorway from the capital of Portugal, Lisbon. So the traffic flux is very important especially in rough hours, representing the main source of pollution.

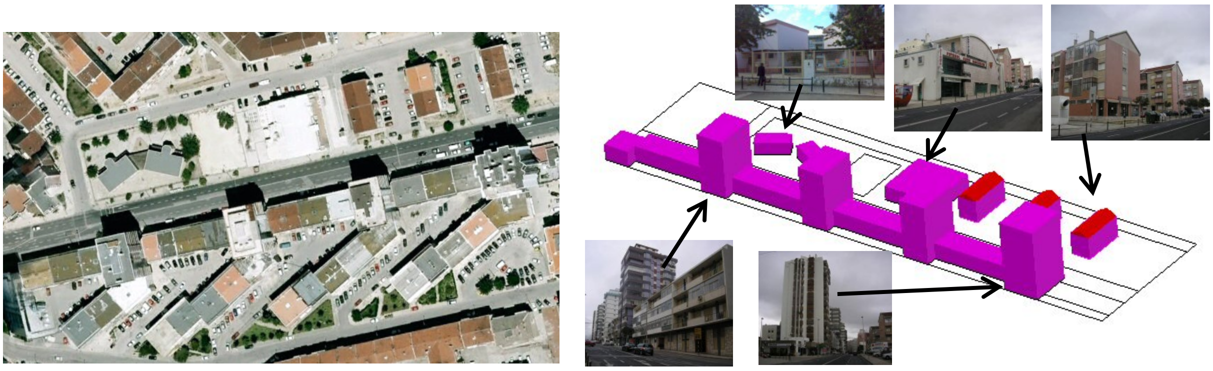

Figure .1 Avenida do Bocage, the studied domain

THE CFD MODEL

The CFD model used in this study was Ansys Fluent 12.0 software. This multi-purpose commercial software has been widely used in this kind of application and constantly validated through comparison of results with other validated models (Di Sabatino, et al, 2008) or through wind tunnel experiences (Awasthi, et al, 2009). To fulfill the aim of this study, the spatial discretisation of the computational domain a tetrahedral grid was used, refined near the buildings. The geometry of the street is showed in figure 2 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.

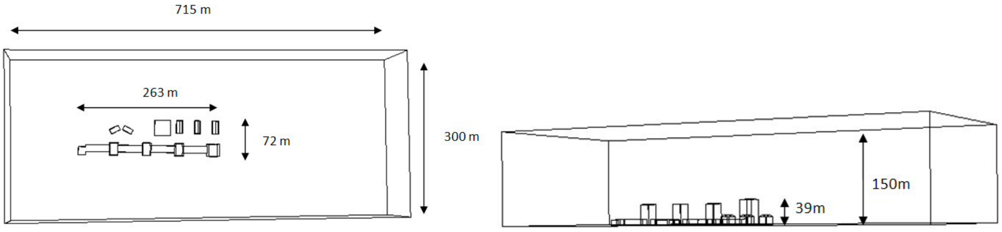

Figure 2. Street geometry and domain to wind from west conditions

A 3D flow simulation with a Lagrangian approach was used, assuming steady state conditions, and for the turbulence, the k–epsilon turbulence model was used, more precisely the RNG k–epsilon turbulence mode providing an analytical formula for turbulent Prandtl numbers and an analytically-derived differential formula for effective viscosity that accounts for low-Reynolds-number effects (FLUENT, 2009).A wind profile, turbulent kinetic energy and turbulence dissipation rate was introduced as a user defined function (UDF) considering a power-law vertical wind profile. The 2-way street PM10 car emission rate was considered, using the ADMS-Urban model, and considering the traffic that crosses the street.No chemical reactions were considered for pollutants emissions. In terms of boundary conditions, a no-slip condition was imposed at all solid surfaces (the flow in the near-wall region was represented by the law-of-the-wall for mean velocity), at the top a symmetry boundary was considered, assuming a zero flux of all quantities across the horizontal plane. For this study the simulation domain considered was a 715 x 300 m^2 centered in the Av Bocage with approximately 160200 cells.

THE BUILDING DISPOSITION SCENARIOUS

With the objective of studying the possibility of improving the air quality in this street, four building disposition scenarios were considered. One corresponding to the real actual geometry of the street, with the actual architectural layout, disposition and volumetric configuration of buildings, designed as Disposition A. Three other virtual dispositions for the street buildings were simulated, considering the alteration of the buildings configurations, with the objective of trying to improve the air quality in this street. The first new virtual configuration, designed as Disposition B, considersanew gap of 4m between the buildings along the street. The scenario designed as Disposition C was also tried, considering gaps of 6m between the buildings along the street. Finally the scenario designed as Disposition D, considerer the same volumetry as actual real disposition for the buildings along the street, but considers the same high and width for all buildings along the street without gap between buildings. The four building disposition scenarios are shown if figure 3.

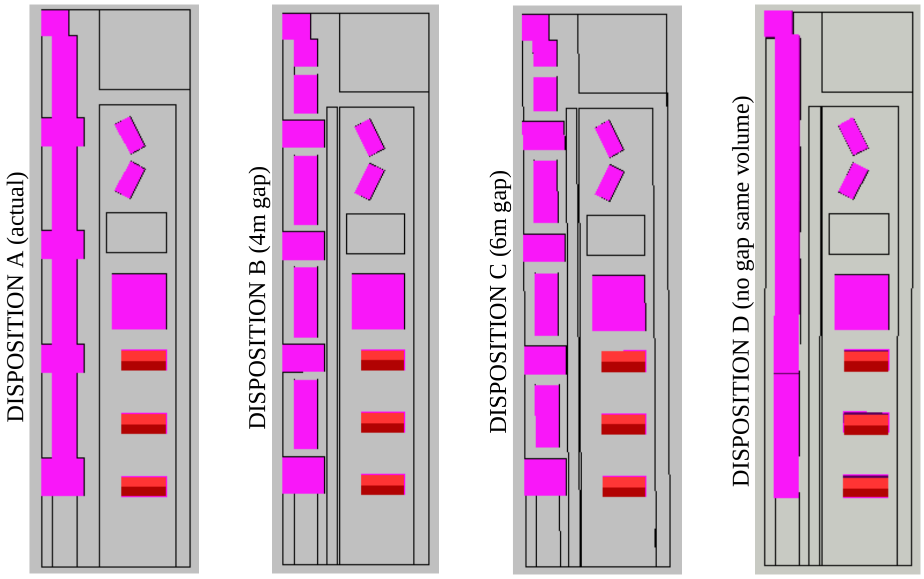

Figure 3.The four building disposition scenarios considered, the actual (real) and three others

EMISSIONS CHARACTERIZATION

Rua do Bocage is one of the most important road connections from Barreiro to Lisbon. So the main emission source in the considered domain is the traffic emissions from this road that crosses the street. For the characterization of the traffic emissions in this road, a traffic counting campaign was carried out. The counting was carried in periods of one hour and the vehicle characterization was aggregated according to its typical vehicle categories (light duty, heavy duty,buses and motorcycles). PM_{10} emissions were calculated by the model ADMS Urban, considering traffic as line sources and considering the mean traffic number of vehicles in rough hours as the baseline scenario for traffic emissions. The other emissions considered in the domain, were introduced as background concentrations in the model, and summed to the Fluent results. The value for background concentrations was collected from the Portuguese Air Quality Stations system. The Fidalguinhos Air Quality station data for PM_{10} was used, as this station is classified as urban background station.

RESULTS

The concentration results obtained forPM_{10} simulations are presented in figure 4, for the concentrations horizontal fields of the actual (real) configuration (Disposition A) of the street, considering the four wind directions. In this figure, are shown contours of PM_{10} concentrations at 1,5m high (considered the medium typical human noselevel and used in frequent exposure studies) considering only traffic emissions considered (no background concentrations).

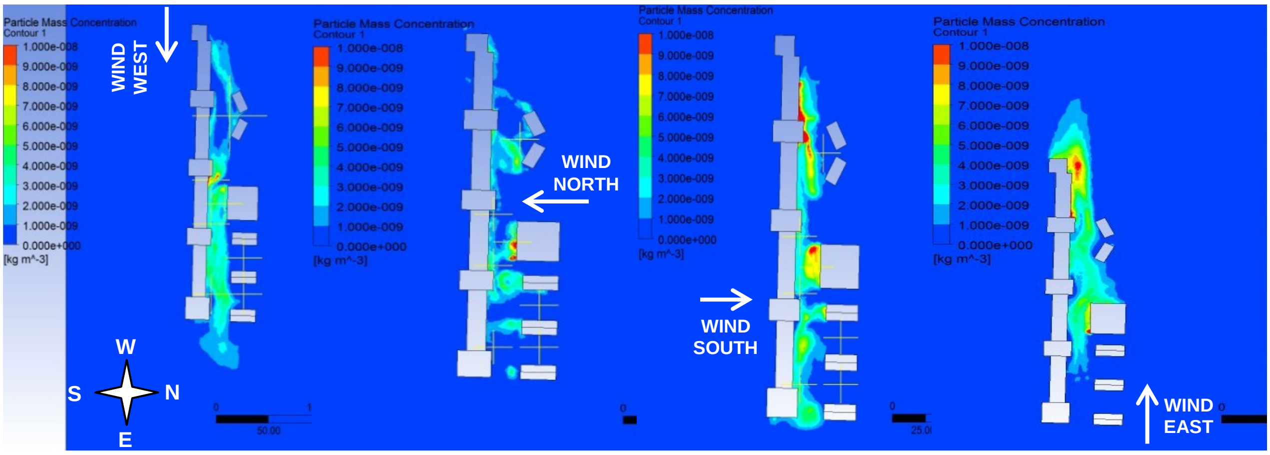

Figure 4.Contours of PM_{10} concentrations at 1,5m high for the four wind directionsfor disposition A (actual configuration)

Figure 4shows that the worst values of PM_{10}concentrations are obtained for the conditions of south wind and east wind, with hot-spots appearing respectively at the center and at the end of the street. In the case of south wind this hot spot is result of the transversal vortex induced by the high building located at the middle of the street. In the case of east wind the hot-spot is achieved due to the difficulty in the dissipation of the pollutant, due to a large building on the north part of the street, that acts as a barrier causing recirculations.

In table 1 are shown the values of PM_{10}simulated concentrations at 1,5m high considering all the emissions (traffic + background) for the actual (real) configuration of the street (Disposition A) compared with real data measurements for PM_{10} concentrations. These concentrations are shown for seven strategic points located in the street. Additionally it is also shown the mean concentration value for a plane located 1,5m high and also for the mean concentration at 1,5m high weighted by the wind frequency, this value is designed by AQ index.

Table 7.PM_{10} concentrations at 1,5m high for disposition A (actual real configuration)

Designation	Location	PM_{10}Concentration ($\mu g/m^3$) West wind	PM_{10}Concentration ($\mu g/m^3$) North wind	PM_{10}Concentration ($\mu g/m^3$) South wind	PM_{10}Concentration ($\mu g/m^3$) East wind	PM_{10}Measurements ($\mu g/m^3$) West wind
Point 1	School	21,6	21,2	20,7	22,3	33,0
Point 2	Bingo	23,0	28,6	27,1	27,0	31,0
Point 3	Car park(border)	20,1	20,0	20,1	20,0	29,0
Point 4	Car park (middle)	20,4	20,0	20,1	20,0	29,0
Point 5	High building corner	20,5	20,6	22,7	20,0	27,0
Point 6	Residential building (east)	22,2	21,5	21,9	21,0	28,0
Point 7	Residential building (west)	25,0	20,9	22,5	20,7	28,0
Mean value	1,5m plane (all domain)	20,8	20,5	21,0	21,1	----
AQ Index	1,5m plane (all domain)	20,3	20,1	20,1	20,1	----

The simulation results shown that the highest value of PM_{10} concentration is achieved in point 2 (Bingo building) with a value of 28,6$\mu g/m^3$in North wind conditions. But if we consider the mean value of concentrations at 1,5m high plane for all the domain, the highest value is achieved for east wind conditions with a mean value of 21,1$\mu g/m^3$.

The results obtained for the simulations with the new configurations are shown in figures 5, 6 e 7. Figure 5 shows the results obtained for the simulations for PM_{10} concentrations horizontal fields for Disposition B,which corresponds to have a gap of 4m between the buildings along the street. Figure 6 shows the results obtained for the simulations for PM_{10} concentrations horizontal fields for Disposition C, which corresponds to have a gap of 6m between the buildings along the street. Figure 7 shows the results obtained for the simulations for PM_{10} concentrations horizontal fields for Disposition D, which corresponds to no gap between buildings but considering same high and width for all buildings. In these figures, contours of PM_{10} concentrations at 1,5m high, considering only traffic emissions (no background concentrations), are shown for thefour wind directions studied.

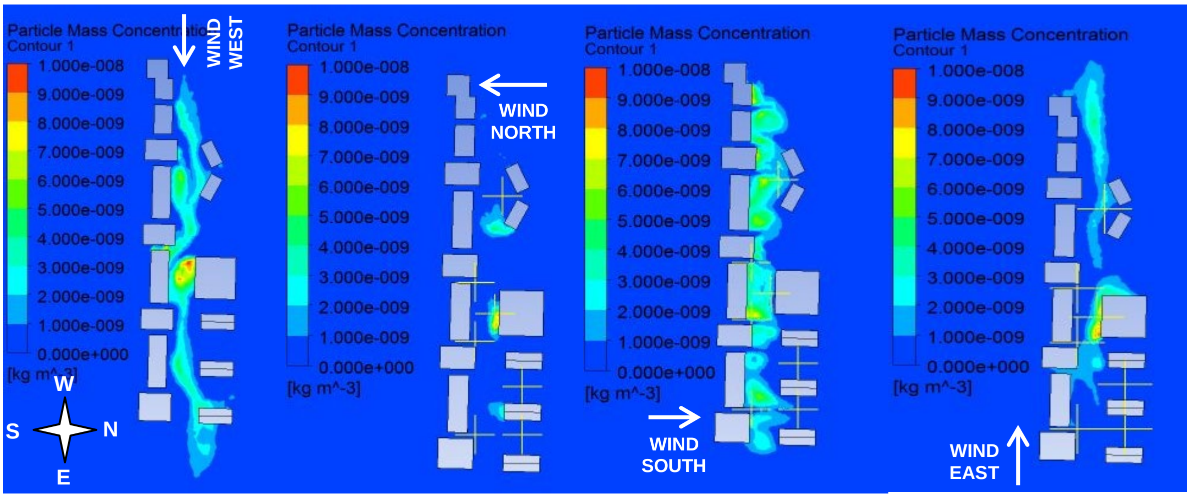

Figure 5.Contours of PM_{10} concentrations at 1,5m high for the main four wind directions (configuration B)

These PM_{10} horizontal contours show that with the implementation of a 4m gap between buildings generically decrease significantly the concentrations of PM_{10} in the street. This is due to the fact that these gaps between the buildings reduce the effects of creation of vortex inside the street since there is no barrier to the wind, resulting in a better capacity of pollutants dispersion along the street decreasing the PM_{10} concentrations.

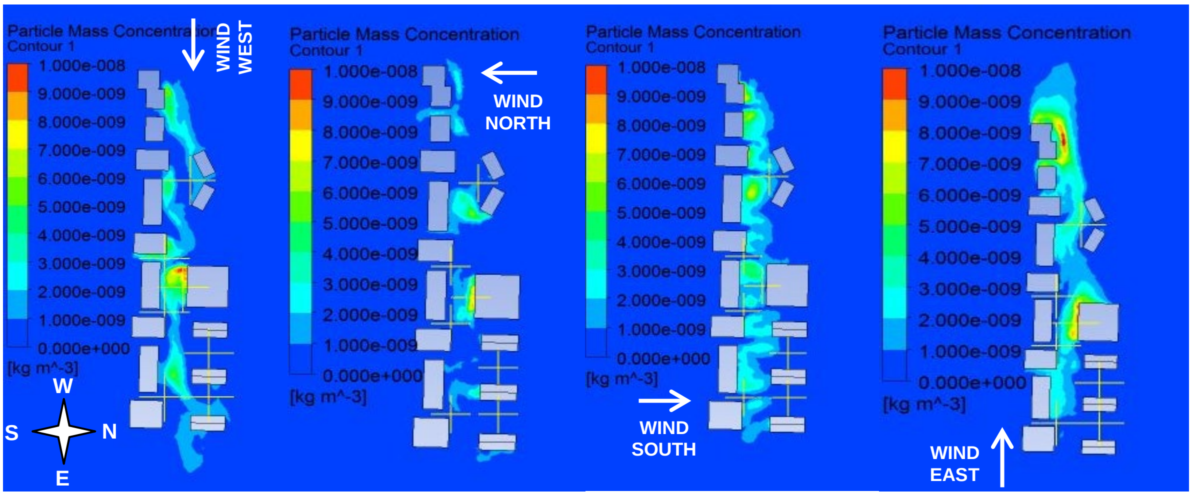

Figure 6.Contours of PM_{10} concentrations at 1,5m high for the main four wind directions (configuration C)

These PM_{10} horizontal contours shown that with the implementation of a 6m gap between buildings (disposition C) comparing to the scenario of having 4m gap between buildings (disposition B) doesn't represent a visible decrease in PM_{10} concentrations along the street, concluding that increasing gaps lengthdoesn't bring any improvements in the street air quality.

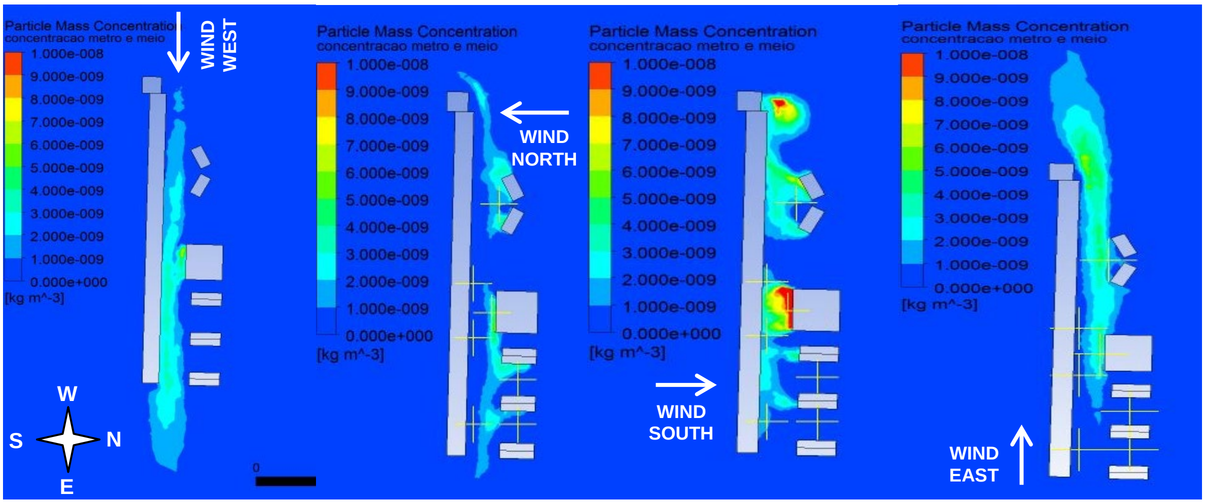

Figure 7.Contours of PM_{10} concentrations at 1,5m high for the main four wind directions (configuration D)

Table 2 resumes the results obtained for PM_{10}mean concentrations for a plane located at 1,5m high,considering all the emissions (traffic + background) and for the 4 different disposition considered and different wind directions. It is possible to observe that the lower values for concentrations are obtained for configurations D when considering north wind direction, and configuration B for all other directions.

Table 2.PM_{10}mean concentrations for a 1,5m highplane for the different dispositions and four wind directions

West wind PM_{10}concentrations (μg/m^3)				Northwind PM_{10}concentrations (μg/m^3)				Southwind PM_{10}concentrations (μg/m^3)				Eastwind PM_{10}concentrations (μg/m^3)			
Conf A	Conf B	Conf C	Conf D	Conf A	Conf B	Conf C	Conf D	Conf A	Conf B	Conf C	Conf D	Conf A	Conf B	Conf C	Conf D
20,8	20,6	20,6	20,4	20,5	20,2	20,4	20,4	21,0	20,6	20,6	20,8	21,1	20,4	20,9	20,6

CONCLUSIONS

The CFD commercial software Ansys Fluent was used to simulate and study the particle concentrations (PM_{10}) in a busy street with high road traffic, in Barreiro city in Portugal. Four different configurations for the street, considering various building configurations and gaps between buildings were tested. Looking to the results obtained, it is possible to conclude that the street configuration and building geometry have influence in the particle concentration in the street. It was shown that it is possible to reduce the PM_{10} concentrations improving the Air Quality in the street, only by the alteration of geometry configuration of buildings, although the concentration obtained are strongly dependent of the predominant wind direction. For west wind direction the better concentrations levels are obtained with configuration D (no gaps between buildings but same volumetry) because this geometry promotes the dispersion of pollutants as the wind is oriented with buildings. For north wind, south wind and east wind directions, configuration B is the one that results in lower concentrations. For these wind directions there are no visible improvements in having higher gaps (6m) between buildings instead of 4m gaps.So the best configuration for this street considering the wind direction and the frequencies of occurrence is configuration B.

REFERENCES

Awasthi S., Chaudhry, K.K., (2009) “Numerical simulation and wind tunnel studies of pollution dispersion in an isolated street Canyon”, International Journal of Environment and Waste Management, Volume 4, 1-2, 243-255.

Amorim, J.H., Lopes, M., Borrego, C., Tavares, R., Miranda, A.I., (2010) “Air quality modelling as a tool for sustainable urban traffic management”, Ecology and the Environment, volume 136.

Di Sabatino, S. Buccolieri, Pulvirenti B, Britter (2008), “Flow and Pollutant Dispersion in Street Canyons using FLUENT and ADMS-Urban”, Environ Model Assess, 13:pp.369–381.

FLUENT (2009) Manual, Chapter 4. Turbulence ANSYS, Inc. January

Garcia, J., Coelho, L.,Gouveia C.,, Cerdeira, R.,Louro, C., Ferreira, T.,Baptista M. (2010), “Analyses of human exposure to urban air quality in a children population”, International Journal of Environment and Pollution, 1/2/3, 40:pp94-108.

Kumar, P., Ketzel M., Vardoulakis S., Pirjola L., Britter R., (2011), “Dynamics and dispersion modeling of nanoparticles from road traffic in the urban atmospheric environment – a review”, Journal of Aerosol Science, 42, pp.580-603.

Martins, A., Cerqueira M., Ferreira F., Borrego C.,Amorim J. H. (2009), “Lisbon air quality: evaluating traffic hot-spots”, International Journal Environment and Pollution, Volume 39, 374, pp.306-320