Modeling of urban greening effects on air quality in an undeveloped residential area

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dated: 15 June 2015

1. Introduction

Urban green development has influence on pedestrian comfort and pollutant dispersion. For this reason, the development of public open spaces is adapted to the new lifestyle in compact cities by upgrading the public environments used by pedestrians. Not only visual aspects like compacity, technical or social criteria, but also environmental, urban climate, air quality and thermal comfort must be highly considered.

In this context, a framework for urban greening in a new undeveloped area in Madrid was developed in the 'ECO-Valle Mediterranean Verandahways' project within LIFE Program. Previous studies were focused on evaluate the influence of the passive systems on thermal conditioning [1], [2] and [3]. In the present work the same undeveloped urban zone in Madrid is studied, but it is focused on the effect of different types of vegetation in the main boulevard on pedestrian wind comfort and air quality.

2. Numerical simulation description: cases of study.

The study was conducted in an undeveloped area located in the southeast of Madrid with 15-20 m high buildings. A computational fluid dynamics (CFD) model was developed to evaluate the effect of different urban green design on air quality in the main boulevard of this residential area.

Based on previous studies evaluating wind comfort in urban areas [4], the dimensions of the analyzed domain were fixed to an area of 1km x 0.8 km and 200m high. A three million computational grid with polyhedral cells and a resolution down to 0.5m near the buildings was selected. Simulations were performed for steady state conditions applying 3D RANS equations with realizable k-ε turbulence model. Based on previous studies of urban air quality [5], a transport equation for passive scalars was solved to obtain pollutant concentration. The inlet profiles were modeled using local measured wind velocity at 18 m height and considering logarithmic wind profiles. The aerodynamic roughness length was set to 0.025 m on the surrounding terrain. The prevailing wind orientation is Northeast and the corresponding average wind velocity is 2.6m/s.

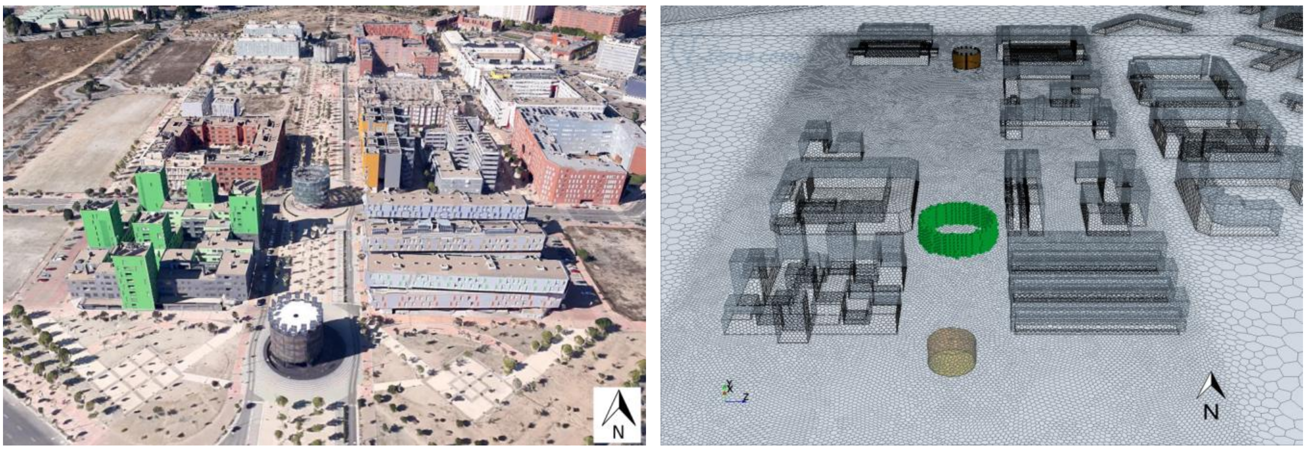


Fig. 1 *From left to right: digital orthophoto image of the studied area, mesh detail of the numerical domain with artificial trees (case B_1).*

Three main scenarios have been simulated considering different phases of urban greening development:

- Initial conditions: a base case without vegetation is studied (case A). This base case is an example of the influence of inlet meteorological conditions on pedestrian comfort and air quality.
- Current development conditions: a case with three artificial trees located at the main boulevard (case B_1; Fig.1) and a case replacing them with natural vegetation (case B_2) are studied.
- Future developed area: two additional cases with different green spaces at the main boulevard are analyzed (Fig. 2). Case C_1 evaluates vegetation 2- 5m high and case C_2 evaluates vegetation 4-18m high.

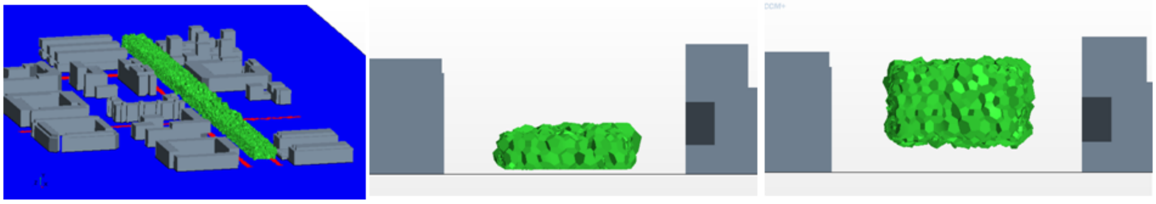


Fig. 2 *From left to right: numerical domain in green vegetation (case C), detail of vegetation* 2- 5m high *(caseC_1) and vegetation 4-* 18m high *(case C_2).*

The vegetation modifies the flow within the neighborhood and changes the pollutant dispersion. Therefore, the design of vegetation can improve or get worse the pedestrian wind comfort and the air quality of this urban zone. The objective of this study is to quantify this effect inside the boulevard.

Before evaluating all the scenarios described, a model validation is required. An experimental evaluation of the developed simulation model has been done evaluating case B_1. Wind velocity has been monitored in six points located inside the northern artificial tree (Fig. 3) during winter period.

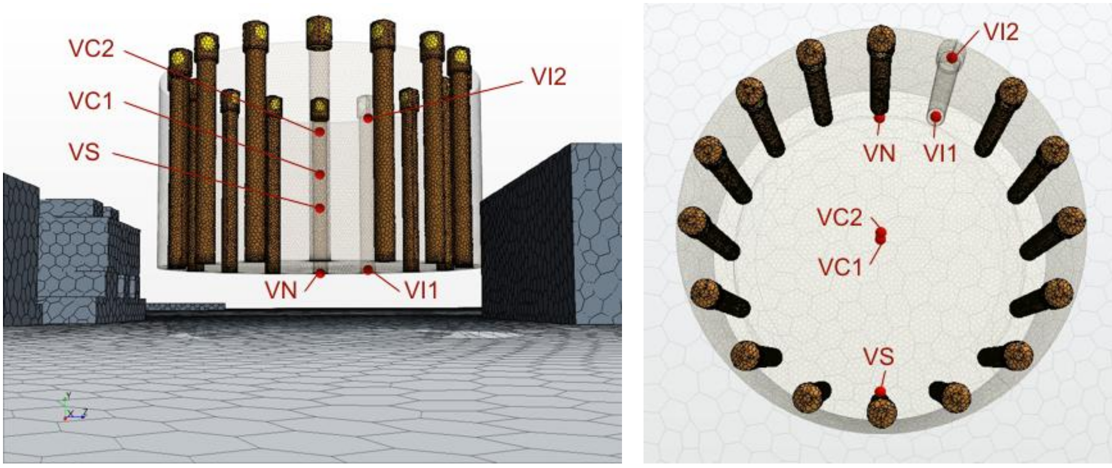


Fig. 3 From left to right: front and top view of the sensors location in the artificial measured tree.

Results of the simulated velocity for case B_1 are compared to the experimental data (Fig. 4). The scatter plot shows a good correlation between simulated and measured wind speed monitored in six points located inside the northern artificial tree

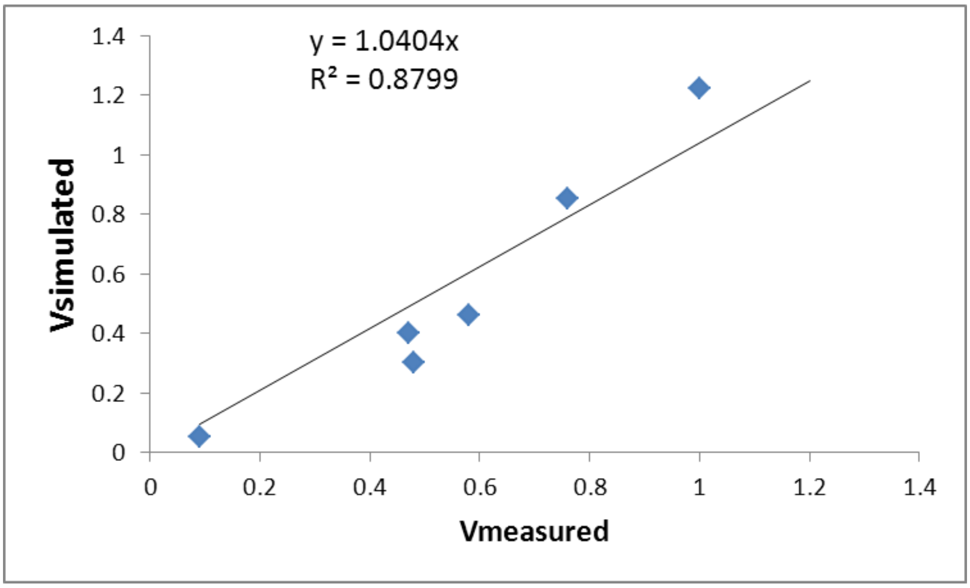


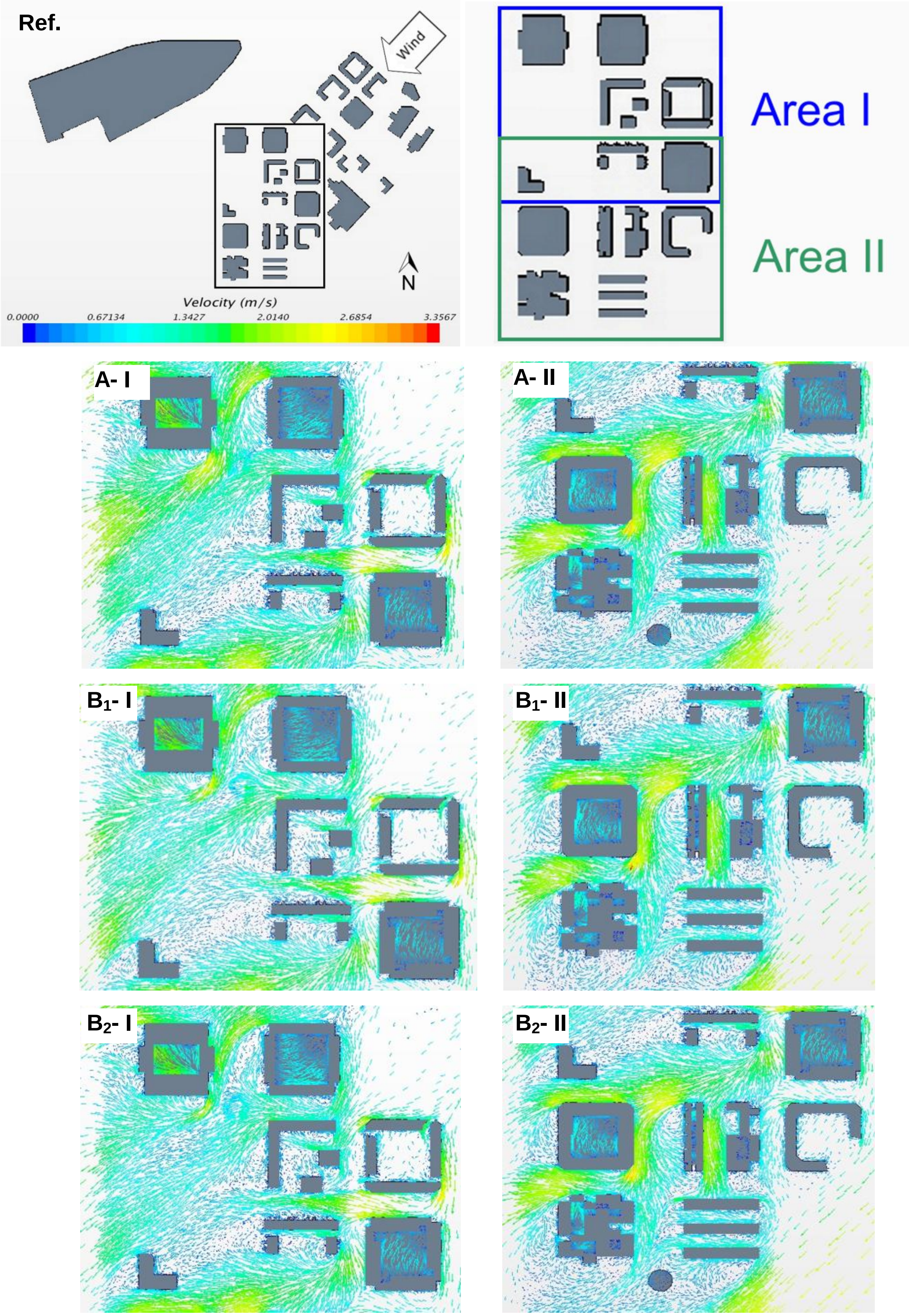
Fig. 4 Scatter plot of simulated vs measured wind velocity at six points shown in Fig. 3.

After the model evaluation, rests of the cases are simulated in order to obtain wind velocity field and total pollutant concentration at pedestrian level (1.5 m) for prevailing NorthEast wind direction. The emissions are considered proportional to traffic intensity. Assuming the same traffic intensity in all streets, total pollutant concentration is computed. Cnorm is the normalized concentration. Cnorm = C/Cmax(at z=1.5m for case A).

3. Results and conclusions

3.1 Wind velocity

The study determines the effect of different urban green designs on wind air velocity in the main boulevard of the residential area. Evaluated area is dividing in two improving images comparison (Area I and II).



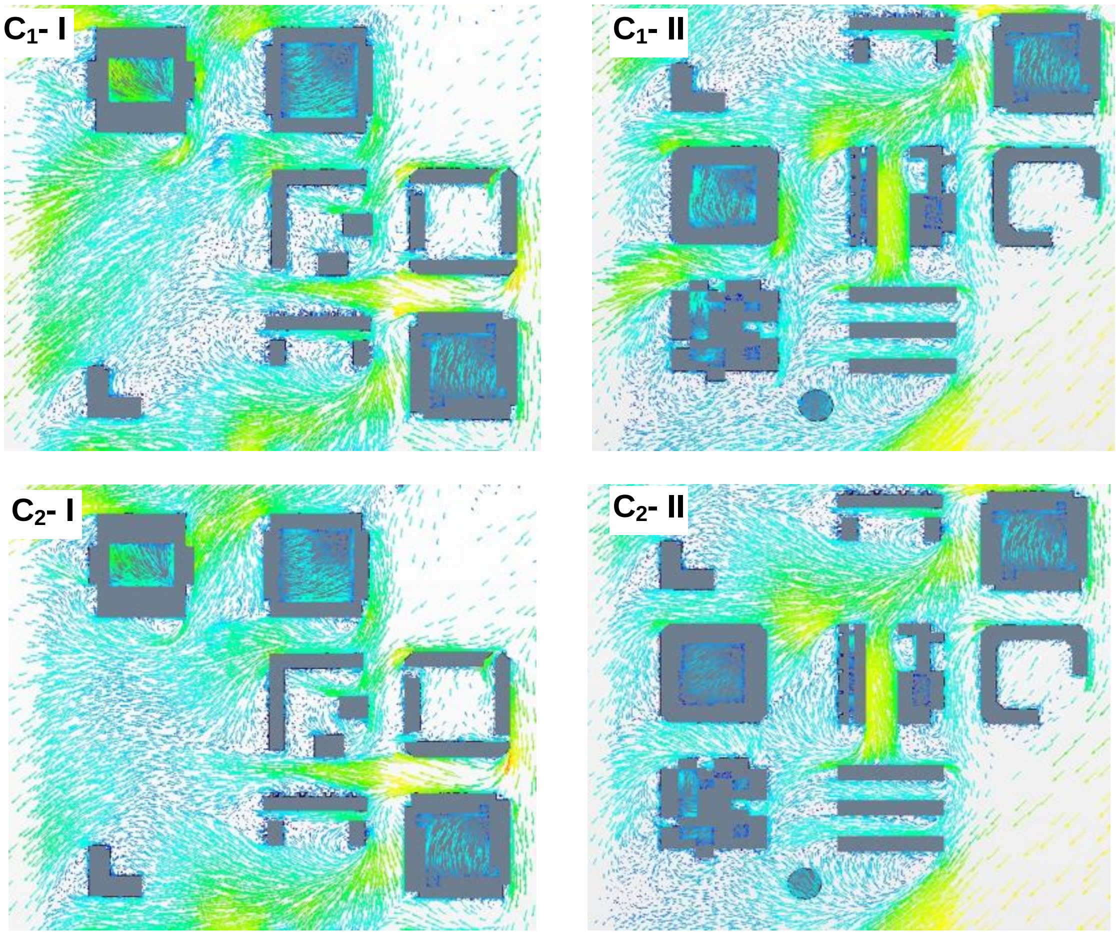
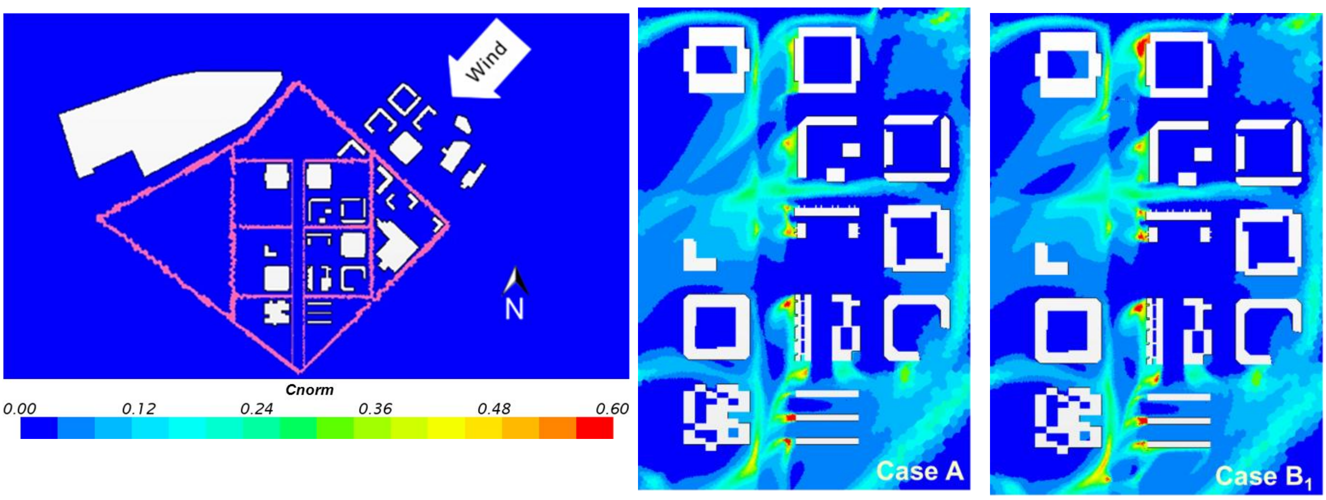


Fig. 5. Average wind velocity field for prevailing Northeast wind direction and considering all cases of study.

Results show the influence of urban green design on wind velocity is relevant in cases of green spaces at the main boulevard (C_1 and C_2). The natural vegetation decreases the air flow velocity within the main boulevard especially in case C_2.

3.2 Pollutant dispersion

In Figure 6, streets in pink color highlighted where passive tracers are emitted in the boulevard, representing traffic emissions. Total pollutant concentration is calculated at pedestrian level (1.5 m) for prevailing Northeast wind direction. Concentration maps are compared for each scenario in order to determine the influence of the presence of vegetation (Fig.6).



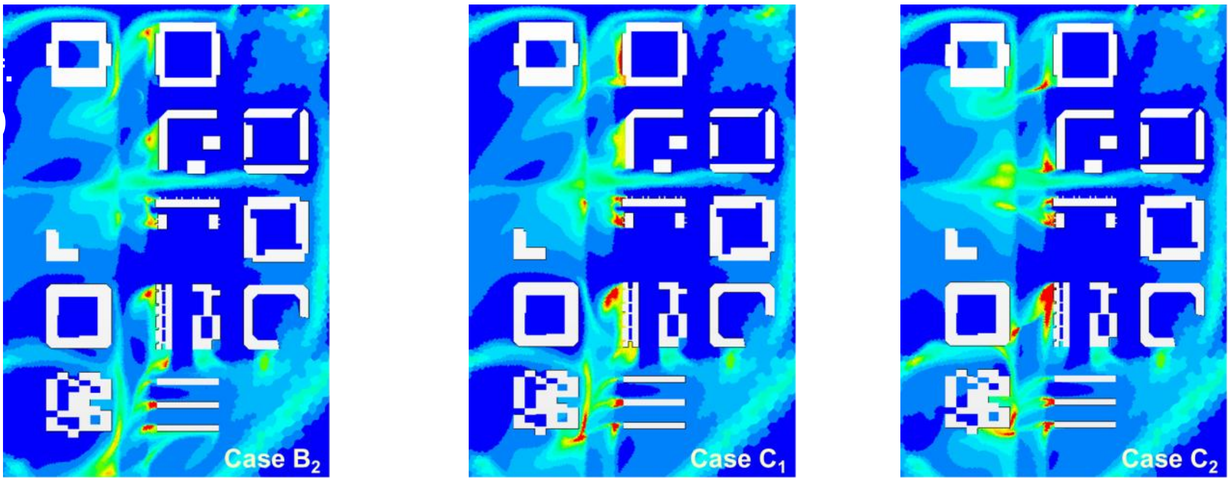


Fig. 6. Normalized pollutant concentration for prevailing Northeast wind direction, considering all cases of study.

Changes in flow fields induce variation in the concentration within the main boulevard. The presence of vegetation reduces the ventilation and increases the concentration. The influence of urban green design on concentration is more relevant in cases of green spaces at the main boulevard (C_1 and C_2). Respect to base case, the maximum increase 72% in case C_1 and 45% in case C_2 and the area with Cnorm>0.5 is 3.55 higher in the case C_1 and 4.98 in case C_2 (see Table 1) Therefore, selecting suitable urban vegetation designs are important for air quality.

	$\frac{Cmax\ (case)}{Cmax\ (case\ A)}$	$\frac{Area\ (Cnorm\ (case) > 0.5)}{Area\ (Cnorm\ (case\ A) > 0.5)}$
Case A	1	1
Case B_1	1.02	2.13
Case B_2	1.19	1.40
Case C_1	1.72	3.55
Case C_2	1.45	4.98

Table1. Maximum concentration respect to base case (A) and area with Cnorm >0.5 respect to this area for the base case (A).

Acknowledgments

The authors thank the ‘Empresa Municipal de la Vivienda y Suelo’ de Madrid (EMVS) and the ‘Ecosistema Urbano’. This study has been partially supported by the project Modelización de la Influencia de la Vegetación Urbana en la Calidad del Aire y Confort Climático (CGL2011-26173) funded by Spanish Ministry of Economy and Competitiveness and by the project LIFE+RESPIRA funded by EU.

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