Numerical modelling and wind tunnel experiments to assess wind climate modifications due to urban growth and its environmental consequences

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Abstract

Knowledge of the wind systems is very important to understand the dispersion of pollutants, thermal regulation and human comfort in the city. Wind field modifications brought about by the growth of the city of Lisbon and the possible urban environmental impacts are presented. In the last years the city has been growing towards the northern districts but deficient urban planning policies lead to the construction of new high rise suburban areas that act as a barrier to the north wind. This can bring an environmental problem, because the city center looses an efficient way to remove pollutants as well as an effective system to control thermal comfort. WAsP software was used to estimate wind fields and a methodology is proposed to assess future modifications. A model of a Lisbon neighbourhood was used in a wind tunnel to validate the results. It was concluded that until the eighties of the 20th century, there was a 30% reduction of the surface summer wind speed over Lisbon and that in the near future the increase of the aerodynamic roughness (z_0) from 0.02m to 1.5m windward of the city will cause a 40% reduction of the wind speed above the buildings.

Key-words – Mesoscale wind, urban growth; urban environmental modelling; roughness length; urban climate modifications; Lisbon.

1. Introduction

Wind flow around buildings is a well known subject (Gandemer, 1975; Hunter et al. 1990; Johnson et al., 1998) and several wind tunnel experiments and environmental software (CFD) have been recently produced and improved (Bruse et al. 1998). Most of them provide information on the problem of pollution dispersion inside urban canyons (Chu et al. 2005; Yang et al., 2008) or in large cities (Rebolj et al., 1999) as well as long term pollution (Arvanitis, 2006). Some efforts also were made to predict the behaviour and movement of pedestrians in urban areas under the influence of different environmental factors in order to try to design comfortable outdoor spaces (Bruse, 2007). However wind field modifications due to the growth of the city, especially those reproducing real environmental conditions, have not yet been fully understood in a mesoscale perspective despite the importance of this topic for urban sustainability and planning.
City roughness diminishes the air flux and therefore the urban wind profile is different from that of open areas (Oke, 1987). From a micro climate point of view, this reduction

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Based on the differences of roughness length and differential wind speed decrease in the city it was possible to draw an "aerodynamic line" through the city of Lisbon (fig. 14), that divides the north (with z_0 values between 0.01m and 0.05m), where the wind speed is not significantly affected, from the south of the city (with z_0 values between 0.7 and 1.0m), where a significant reduction of wind speed occurs. The north wind penetrating areas, visible in figure 14, correspond to paths along which the winds are "channeled", and therefore ventilation along the valley beds must absolutely not be hindered.

Fig. 14 - "Aerodynamic limit" (dash line) in Lisbon: to the north of this line the aerodynamic roughness length (z_0) was less than 0.02 m until the 1980's. To the south a range between 0.5 and 1 m is predominant in the built environment. The grey area represents the "potential" area/barrier to the north wind. In the next years the airport area can complete this barrier because this infrastructure will be relocated to another place outside the city.

The decrease of the north wind speed (generally seen as a cleaning air agent) could lead to an increase in human discomfort and health problems, especially related with summer heat waves, and an increase in high pollution episodes. Regarding this environmental problem the future mean wind speed can, therefore, decrease even more in the city centre. Growth in the northern area of Lisbon should therefore be guided by measures that will mitigate and, if possible, prevent future implications to the south. These measures should include: i) the construction of large north/south avenues in the direction of the prevailing winds; ii) the reduction of building volumetry or the enlargement of the streets, creating ventilation paths (Alcoforado et al. accepted).
Although some of the conclusions obtained with this research might seem evident by reasoning, they have now the physical support needed to be applied in urban planning (concerning airflow). This kind of information could be an example of what is missing for "planning communities" and must be presented in the clearest way possible in order to disseminate information to non-specialists (Oke, 1984; Eliasson 2000; Alcoforado et al, accepted).

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