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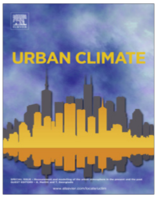


# The breathability of compact cities

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ABSTRACT

Breathability in dense building arrays with packing densities similar to those of typical European cities is investigated using laboratory measurements and numerical simulations. We focus on arrays made up by regularly spaced square buildings forming a network of streets with right-angle intersections. It is shown that breathability can be evaluated using building ventilation concepts (mean flow rate and age of air) and from vertical mean and turbulent fluxes quantifiable through a bulk exchange velocity. Mean age of air reveals that varying wind angles result in different ventilation, which we explain through mean flow streamlines and exchange velocity. For low wind angles (wind direction almost parallel to the axes of half of the streets of the network), vertical transfer and mean transversal transfers are at minimum and removal of pollutants is associated with mean longitudinal fluxes. Larger wind angles result in better ventilation due to an increase of transversal fluxes and vertical exchange. The latter, for which a formulation is derived, shows a non-negligible contribution of the mean flow which increases with increasing wind angle. Ventilation conditions can be further altered by small differences in the array geometry. These observations are useful for the development of simple urban dispersion models.



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## 1. Introduction

In recent years, health risks associated with microclimate variations and exposure to concentrations of harmful pollutants in cities have inspired a large number of studies focusing on the mechanisms that drive momentum, mass and heat transfer within urban canopies. According to recent studies (e.g. Fernando et al., 2010; Dallman et al., 2013; Zajic et al., 2015) at the core of these studies there is the relationship between turbulent transfers of both active and inactive variables and urban morphology in real atmospheric conditions. Given the high complexity of the problem, often the interpretation of field measurements is backed up by numerical simulations and controlled laboratory experiments. The choice of the modelling approach depends somewhat upon the level of details of the atmospheric processes represented and therefore upon the chosen spatial scales, namely the street, the neighbourhood and the city scale (Britter and Hanna, 2003).

At the street and neighbourhood scale, experiments and numerical simulations have been carried out to evaluate the effect of a wide range of features affecting pollutant dispersion. These include the street aspect ratios, the roof-shape, the length of the canyon, the building packing density, and the wind direction (e.g. Yim et al., 2009; Gousseau et al., 2011; Salim et al., 2011). For recent reviews on these topics the reader is referred to Di Sabatino et al. (2013) and Tominaga and Stathopoulos (2013).

At the neighbourhood scale, most of the studies on pollutant dispersion focus on the case of obstacle arrays with low obstacle density (e.g. Yee and Biltoft, 2004; Coceal et al., 2007) in which wakes developing downwind of each obstacle interact with each other (Oke, 1988). The geometry of low density obstacle arrays is similar to that of North American or European suburban neighbourhoods (Di Sabatino et al., 2010). In contrast, these configurations are very different from central neighbourhoods of most European cities (Fig. 1), where buildings are regularly and densely packed. Flow and dispersion within these densely packed neighbourhoods have been rarely studied (e.g. Garbero et al.,

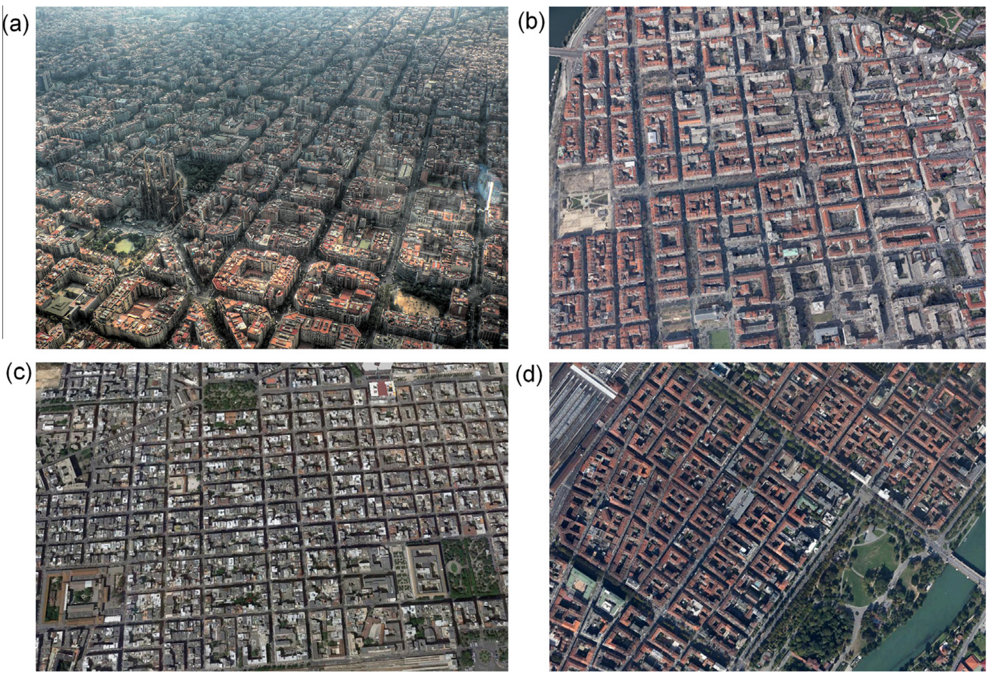


**Fig. 1.** View of typical European city neighbourhoods: (a) Barcelona, Spain, (b) Lyon, France, (c) Bari, Italy and (d) Turin, Italy.