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Impacts of green infrastructures on aerodynamic flow and air quality in Porto's urban area

S. Rafael*, B. Vicente, V. Rodrigues, A.I. Miranda, C. Borrego, M. Lopes

CESAM, Department of Environment and Planning, University of Aveiro, 3810-193 Aveiro, Portugal

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ABSTRACT

Air pollution is an environmental and social issue at different spatial scales, especially in a climate change context, with an expected decrease of air quality. Despite the technological evolution of the last decades in the transport sector, road traffic emissions are still one major source of air pollution at the city level. The main goal of this study was to evaluate the influence of a set of resilience measures, based on nature-based solutions, in the wind flow and in the dispersion of air pollutants, in a built-up area in Portugal. For that, two pollutants were analysed (NO_X and PM10) and four scenarios were developed: i) a baseline scenario, ii) an urban green scenario, iii) a green roof scenario, and iv) a "grey" scenario (without trees). Two models were used, namely the Weather Research and Forecasting model (WRF) and the CFD model VADIS (pollutant dispersion in the atmosphere under variable wind conditions). The WRF model was used to initialize the CFD model, while the last was one used to perform the set of numerical simulations, on hourly basis. The implementation of a green urban area promoted a reduction of air pollutants concentrations, of about 16% [PM10] and 19% [NOx] in the overall domain; while the application of green roofs showed an increase of concentrations (reaching 60% during specific time periods). Overall the results showed that a strategic placement of vegetation in cities has the potential to make an important contribution to the improvement of air quality and sustainability of urban environments.

1. Introduction

Air pollution in urban environments with dense population has become an important research issue in the past decades, which led to the enforcement of several studies of the airflow and dispersion patterns in cities (Borrego et al., 2003; Buccolieri et al., 2011; Amorim et al., 2013; Salmon et al., 2013). In Europe, the atmospheric pollutants emissions have decreased substantially over the last years, resulting in an improved air quality across the region. However, air pollutants concentrations are still too high in many European cities, showing exceedances of air quality standards still occur, and so air quality problems persist (EEA, 2016).

More recently, the interaction among climate change, air pollutant emissions and atmospheric concentrations has been considered a crucial research field. As Markakis et al. (2014) denote, the impact of climate change on air quality at the local scale is still a current research challenge since much has still to be explored in order to understand and accurately predict the changes in pollutant levels under future climatic conditions and at different spatial scales. This is especially relevant since there is consistent research that projects an increase of the atmospheric concentrations under climate change scenarios (Lacressonnière et al., 2014). In this sense, it is crucial that cities are able to absorb the impacts related to climate change and poor air quality. The inclusion of green infrastructures, such as green roofs, urban green areas, green walls, have been pointed as low-cost and easily applicable strategies to deal with extreme weather events (Carvalho et al., 2017; Rafael et al., 2017), as well as to improve air quality and mitigate air pollution (EC, 2015; EEA, 2011).

Roadside vegetation barriers have been widely evaluated as a potential mitigation strategy for near-road air pollution (Tong et al., 2016). Those studies revealed that the aerodynamic effects of trees on near-road air quality, that are primarily governed by two physical mechanisms, dispersion and deposition, are more important than the chemical effects (i.e. uptake) (Nowak et al., 2006) and, dispersion appears to be more important than deposition (Jeanjean et al., 2016; Steffens et al., 2012). In fact, modelling studies have shown a modest impact of vegetation on air pollutants deposition with less than a few percent reduction (Nowak et al., 2006; Tallis et al., 2011; Selmi et al., 2016). Also, previous findings shows that there is a large variability about the effectiveness of road-side vegetation barriers on reducing air pollution. For example, Vos et al. (2013) investigate the role of roadside urban vegetation on the local air quality, and have been concluded that

* Corresponding author.
E-mail address: sandra.rafael@ua.pt (S. Rafael).

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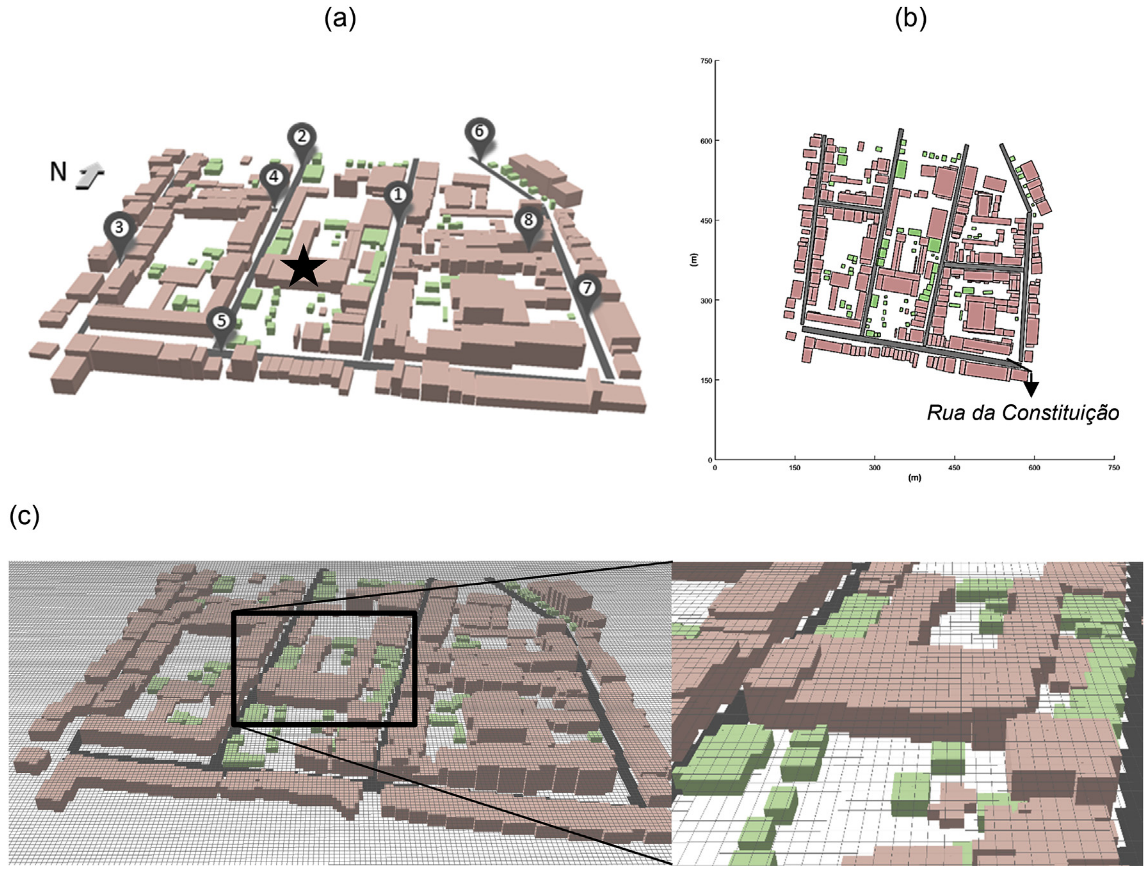

Fig. 1. 3D (a) and 2D (b) study domain showing the set of buildings (in pink), trees (in green) and roads (in grey, numbered from 1 to 8) (images on the top). The black star indicates the location of a meteorological station (wind velocity). Computational grid domain (with a horizontal and vertical resolution of 3-m) is also showed (c). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

roadside urban vegetation leads to increased pollutant concentrations. This is explained with the fact that in the presence of trees or other types of vegetation, the ventilation process, responsible for the dilution of traffic emitted pollutants, is reduced. Despite of this conclusion, the authors also mentioned that the fact that roadside trees negatively affect the local air quality does not mean that trees in urban backyards, urban parks or traffic free streets have a similar effect (Vos et al., 2013). In fact, the benefits of vegetation on air quality is demonstrated in studies such as Amorim et al. (2013), Tong et al. (2016) or Lee et al. (2018). Thus, previous findings are inconsistent potentially due to the high variability associated with local microclimate, vegetation characteristics and design options.

This certain level of uncertainty related to the street scale mitigating capacity of urban trees, creates a knowledge gap regarding the application of green infrastructures to improve local air quality at city scale, which is a critical issue for policy makers. Inspired in this need, two research questions were formulated: (i) Can green infrastructures be used to an effective improvement of local air quality in a complex city morphology? and (ii) Which are the best design options to improve local air quality?

To address these questions, a set of numerical simulations, at street level, have been performed to assess the aerodynamic effect of different resilience measures, based on green infrastructures, in the flow (wind velocity) and dispersion (air pollutant concentrations) processes. A complex built-up area in the city of Porto, Portugal, was selected as case study. A modelling system composed of the WRF-VADIS models (mesoscale-Computational Fluid Dynamics (CFD)) was used. An urban canopy parameterization scheme was used in the WRF simulation to better simulate urban meteorological conditions. The work was focused on the main pollutants emitted by the road traffic, namely nitrogen oxides (NO_X) and particulate matter with an aerodynamic diameter less than 10 µm (PM10). These are also the most critical air pollutants in the study area, which frequently exceeded the annual limit value for NO_2 and the daily limit value for PM10 (Monteiro et al., 2007; Borrego et al., 2012; Miranda et al., 2016).

Although similar studies (Buccolieri et al., 2011; Wania et al., 2012; Vos et al., 2013) have been already published, from a scientific point of view the current study differs in the following sense: (i) provides a holistic approach to deal with air quality problems, by adapting the concept of resilience to air pollution and evaluating the ability of a city to tackle air pollution issues through green urban planning; (ii) focus on multiple and traffic related pollutants; previous studies are often limited to a single and non-traffic specific pollutant such as PM10; (iii) applies a quite recent methodology to perform air flow and dispersion analyses in cities, by using a CFD model with initial conditions given by mesoscale models; Tewari et al. (2010) and Miao et al. (2013) demonstrated that by using outputs from the Weather Research and Forecast (WRF) model as the initial and boundary conditions, the CFD model capability applied over an urban area can be improved; and (iv) different types of urban designs; instead of roadside trees the study is focused on urban parks and green roofs implementation.

This paper is presented as follows: section 2 describes the modelling setup methodology including a brief description of the applied models and their configuration for the simulations. Also in section 2 the case study is characterized and the green resilience scenarios are defined. A comparative analysis between the different scenarios, as well as a model validation, are presented in section 3. Summary and conclusions follow in section 4.