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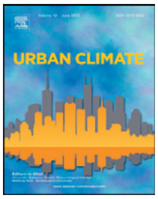

Urban resilience to future urban heat waves under a climate change scenario: A case study for Porto urban area (Portugal)

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ABSTRACT

This work aimed to assess the effectiveness of several resilience strategies to mitigate extreme urban heat episodes in Porto (Portugal). Different resilience scenarios were studied with the WRF urban modelling system, using as case-study a future heat wave occurring in Porto urban area. The resilience factors considered were the increase of urban green areas and the application of cool (green and white) roofs.

The results showed that the most effective resilience strategies to mitigate high urban temperatures are the application of cool roofs. These resilience strategies produced the strongest reduction in the average and maximum surface temperatures over Porto urban area under a future heat wave. Considering that white roofs are considerably easier and cheaper to apply in urban areas than green roofs, this resilience strategy can be seen as the most viable, cost-effective and economically attractive approach for mitigating extreme urban temperatures.

This study proposed several different urban resilience strategies to extreme temperature episodes for the first time for Porto urban area, proved their effectiveness and compared their ability to reduce urban heat. Such findings can be of great importance for Porto urban planning stakeholders given the expected increase in the heat waves frequency and intensity in future climate.

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1. Introduction

Currently over 70% of the European population live in cities, and this figure is expected to rise to more than 80% in the upcoming decades. By 2050, this means over 36 million new urban citizens. In Portugal, the current urban population is 61% (6 million) of the total population and is expected to grow to 75% by 2050, representing 1.4 million new inhabitants in Portuguese cities, mainly within Lisbon and Porto urban areas. Porto urban area, one of the largest and most densely populated urban areas in Portugal, represents almost 25% of Portugal in terms of its area and contains near 3.7 million inhabitants. It was identified as one of the European cities where the urban fringe has grown faster (EEA, 2011), resulting in a depletion of agricultural land and forests. At the same time, the latest Intergovernmental Panel on Climate Change (IPCC) Assessment Report (IPCC AR5, 2013) confirms the negative role of anthropogenic emissions on climate change, consequential to the daily life of citizens. Despite the global efforts to mitigate climate change, its negative effects are already underway and the future scenario is grim. Several authors refer changes in the regime of extreme weather events (including heavy rain, storms, tropical cyclones, drought, floods and heat waves), which will become more frequent and severe (Kharin and Zwiers, 2000; Santos and Corte-Real, 2006). One of the most worrisome is the occurrence of heat waves, due to their negative impacts on public health in urban areas (Monteiro et al., 2012). Specifically for Porto, Monteiro et al. (2013) related excess mortality and morbidity with the occurrence of a heat wave in July 2006. Watkiss et al. (2009) reported that the death rate related to extreme heat episodes in Europe could double by 2040 and even increase up to ten times by the end of the current century, with southern Europe experiencing the highest increases in the summer. More recently, Lau et al. (2015) reported that anthropogenic climate changes would likely increase the frequency, duration and magnitude of severe heat stress events mainly in highly populated urban areas, being Porto one of the cities that can expect the exacerbation of future heat waves.

Besides these meteorological extreme events, urban environments are usually exposed to higher ambient and surface temperatures when compared to their rural, or less urbanized, surroundings. Urban built surfaces, mainly composed of materials with low solar radiation reflectance and high heat storage capacities such as concrete and asphalt, build up significant amounts of sensible heat during the day that is released during the night to their surroundings. This originates a strong thermal gradient between the urban area (warmer) and its surroundings (cooler), an effect known as urban heat island (UHI). Although heat waves and UHI are two distinct meteorological phenomena, given that a heat wave typically results from large-scale, stagnant, high pressure systems that produce a temporal temperature anomaly for an entire region (urban and/or rural), while an UHI is a local process that occurs due to the different characteristics between urban and rural terrain (albedo, heat capacity and fluxes, land use), several studies showed that heat waves and UHI episodes are strongly connected and that, not only heat waves increase the ambient temperatures, but they also intensify UHI effects (Basara et al., 2010; Cheval et al., 2009; Founda et al., 2015). Li and Bou-Zeid (2013) showed that heat waves are expected to become more frequent, intense and long-lasting under a warming climate, and their non-linear interaction with UHI will originate extreme heat stress events in urban environments. Furthermore, other urban issues such as air pollution and anthropogenic heat sources (traffic, industry, etc.) significantly increase the thermal load inside the urban canopy layer (Papangelis et al., 2012). This additional thermal stress will induce, in a snowball effect, higher energy consumption to cool the building's interior that will further release additional heat and air pollutants into the urban canopy layer (hot air exhaustion from air conditioning devices, higher greenhouse gases emissions due to higher energy consumptions, etc.).

Thus, the combination of rapid urban growth, urban characteristics that favour thermal stress and climate change poses critical challenges to urban environments, and highlights the need for investigating resilience measures to mitigate high urban temperatures (Borrego et al., 2015). The inclusion of urban green areas (such as city parks) and the application of cool (green and/or white) roofs in built-up surfaces are efficient strategies to lower urban temperatures (Susca, 2012). These types of resilience measures mainly rely on the reduction of sensible heat fluxes between the lower atmosphere and the urban artificial surfaces (walls and roofs of buildings, roads and sidewalks surfaces, etc.). The ability of urban green areas and green roofs to reduce urban temperatures is mainly related to two properties of trees and vegetation: evapotranspiration and shading. While the first one cools the air by using heat from the air to evaporate the water (redirecting the energy to the form of latent heat, rather than sensible heat), the second allows the reduction of the solar radiation that reaches the area below the tree canopy. This cooler surface, in turn, reduces the heat transmitted into the surrounding buildings and atmosphere. The application of surfaces with high levels of solar reflectance, such as white roofs, increases the solar radiation reflection due to their higher albedo (Li et al.,