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Comparative analysis of green actions to improve outdoor thermal comfort inside typical urban street canyons

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ABSTRACT

Urban microclimate analyses are being used more and more to address the planning decision process to create livable and healthy public spaces. The study, conducted in collaboration with the municipality of Bilbao (Basque Country, Spain), presents a comparative analysis of green actions to improve outdoor thermal comfort conditions. The evaluation was performed in three typical urban street canyons characterized by different geometric proportions and five urban greenery scenarios in typical summer day conditions. For each scenario, the mean radiant temperature, relative humidity, air temperature, surface temperature and wind speed have been analyzed using ENVI-met model. The study quantitatively confirms that the vegetation elements such as grass, green roofs and trees, improves the thermal comfort at pedestrian level. Thermal comfort is assessed using the PET (Physiological Equivalent Temperature) thermal index. The highest PET reduction occurs by combining the presence of trees and grass, which can lead to a reduction of about two PET thermophysiological assessment classes during the daily maximum values. Additionally, the work demonstrates how aspect ratio and ground surface materials can affect the intensity and the duration of discomfort period (PET > 23 °C). The outcomes will be used by the municipality of Bilbao to improve the actual planning recommendations.

1. Introduction

This work, which is the first part of a wider study conducted in collaboration with the municipality of the city of Bilbao (Basque Country, Spain – latitude 43.25°N, longitude 2.96°W), presents a comparative analysis of green actions to improve the outdoor thermal comfort inside typical urban street canyons. Several studies demonstrate how green actions have a crucial role in the process of sustainable passive cooling of urban planning as well as in saving energy and progressing human thermal comfort (Shashua-Bar et al., 2010; Steemers, 2003; Yezioro et al., 2006). Fahmy and Sharples (2009) describe how the presence of vegetation within the urban environment is an important element for improving the quality of urban spaces. Despite the presence of gardens around buildings, cities need parks and green corridors framed in the planning communities' scales (Yu and Hien, 2006; Oke, 1989). The cooling effect of the green parks is remarkable not only locally in vegetated areas but it can also be extended to the surrounding built environment (Shashua-Bar and Hoffman, 2000). Furthermore, several studies confirm that the integration of urban trees within the fabric and urban canopies has a relevant cooling effect (Dimoudi and Nikolopoulou, 2003; Chudnovsky et al., 2004). Other studies underline the benefits given by the

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presence of vegetation in some American and European cities: the cooling effect created by the shading of trees during the summer time can have a relevant impact in reducing the cooling demands of buildings (Matsuoka and Kaplan, 2008; Huang et al., 1987), as well as on the reduction of CO_2 emissions and in increasing thermal comfort conditions. In that respect, Akbari (2002) demonstrated that in urban areas the shade that trees offer creates significant benefits not only in reducing a building's air-conditioning demand but also improving urban air quality by decreasing the air pollution. Axarli and Chatzidimitriou (2012) conducted a study based on bioclimatic criteria for improving pedestrians' thermal comfort using different types of trees, low vegetation, green walls, water elements and different ground surfaces. Gehl and Gemzøe (2004) observed the influence of the microclimate on outdoor activities by counting people sitting on benches in the sun and under the shade of the trees. The study showed that local sunny or shady conditions significantly affect the desire of people to either stay or leave. Another study conducted in Taiwan investigated people's behavior in outdoor spaces: 93% of people visiting a public square in summer chose to stay under shady trees or in a building's shade, indicating the importance of shade in outdoor environments (Yu and Hien, 2006). As a result, the conclusion is that planting of vegetation in urban areas is one of the main strategies employed to regulate the urban climate and create cooler urban spaces (Lin et al., 2010).

1.1. Bilbao background

In the past two decades in Bilbao, a relevant transformation process has already started to convert some areas into a friendlier public environment. Some recovery interventions and creation of new green areas were key actions of the transformation of the city. Furthermore, the users have become aware of the benefits that green and natural areas provide and their use has therefore increased. Aware of this reality, the city has gradually been increasing the amount of green areas in Bilbao: it has significantly grown from 6 m^2 per person in 1999 to 24 m^2 per person today (Bizkaia Tour S.L., 2012; Bilbao Council's Website, 2015). A strategy for increasing Bilbao's vegetation system through the improvement of green infrastructures, such as tree-lined corridors, parks and green belt, has been planned. In that respect, an integrated project of urban and forest parks is under development: the "*Anillo Verde de Bilbao*" – "*Gran Recorrido de Bilbao*", which is well known as the "Green belt". It is a green path that encircles the city across the five municipal forest parks and completes a course of around 100 km in a closed loop between paths, roads and streets (Bilbao Council's Website, 2015). The access from the city center of Bilbao will be guaranteed through 11 auxiliary routes. They will become new green corridors linking the green belt with the urban parks. This work presents a feasibility study about how the design of the 11 auxiliary routes could be developed to improve the thermal comfort inside urban street canyons.

The effects of five green actions in three typical urban street canyons by using a numerical urban microclimate model, ENVI-met version 4.0 (v4.0) Bruse (2015), Bruse and Fleer (1998), and Huttner (2012) have been evaluated. Results allowed testing, comparing and predicting the benefits of different green actions during a typical summer day in Bilbao. The heat sensation at the pedestrian level has been assessed using the Physiological Equivalent Temperature (PET) index. The PET index gives the measure of thermal comfort considering the meteorological parameters such as air temperature, air humidity, wind velocity and radiation fluxes. It also takes into account the physics of the human body: gender, age, height, weight, activity, clothing resistance for heat transfer, shortwave and longwave radiation of the surface affected by the physical surface properties, such as albedo and emissivity (Fanger, 1970; Höppe, 1999). The calculated values of the PET level in the urban canyons refer to the thermophysiological assessment classes of PET developed by Matzarakis and Mayer (1997).

This research, conducted in collaboration with the municipality of Bilbao, aimed to bridge the actual gap between the urban planning regulations and the applied actions. In that respect, the microclimate analyses conducted are the scenarios elaborated with urban planning division of the city of Bilbao. This dialogue was useful for setting the configuration of the green actions within the urban canyons in order to meet, on the one hand, the principles of the urban planning of the city; and on the other hand, the needs of improving the human thermal comfort at pedestrian level.

2. Climate in the metropolitan area of Bilbao

The area of Greater Bilbao, located in the Basque Country, Spain, is characterized by a humid temperate climate with no dry season, moderate in terms of temperatures and precipitation level. However, the temperature can exceed 40 °C (Acero et al., 2013a). The data provided by Euskalmet, Agencia Vasca de Meteorologia (Basque Meteorological Agency), demonstrate that during the last decade, the air temperature in Greater Bilbao has continuously increased. A maximum value of 42 °C was reached in August 2012 when the average monthly value was 2 °C above the historical series collected from 1971 to 2000. Year 2011 was the hottest year: the average air temperature value registered in the entire territory of the Basque Country was 1.5 °C higher of the average value registered from 1971 (Euskalmet, 2011). A study conducted by González-Aparicio et al. (2013) confirmed that the air temperature will continue to increase in Bilbao: (i) in summer, it is expected to rise by 0.7 °C from 2020 to 2050 and by 1.6 °C from 2070 to 2100; (ii) in winter, it is expected to rise by 1.1 °C from 2020 to 2050 and by up to 2.5 °C from 2070 to 2100. Moreover, from 2070 onwards, the cold waves are expected to disappear, while the phenomenon of heat waves will be more frequent and longer (Acero, 2012; González-Aparicio et al., 2013). In this scenario, urban green actions become urgently necessary due to the consequences of climate change.