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Using reflective pavements to mitigate urban heat island in warm climates - Results from a large scale urban mitigation project

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ABSTRACT

UHI is the most studied phenomenon of climate change and refers to the increased ambient temperature of cities compared to rural settings. Implementation of reflective materials to urban structures, such as roads and pavements, reduces the surface and ambient temperature and contributes to counterbalance the impact of the phenomenon. The present paper describes the design and the experimental evaluation of a large scale implementation of cool asphaltic and concrete pavements in a major traffic axis of Western Athens covering a total zone of 37,000 m^2. To our knowledge, this project is one of the largest urban mitigation projects in the world. Extended monitoring was performed in the area during the entirety of the summer period, while Computational Fluid Dynamics (CFD) simulation was used to evaluate the thermal impact of the application. It was concluded that the use of cool non-aged asphalt can reduce the ambient temperature by up to 1.5 °C and the maximum surface temperature reduction could reach 11.5 °C, while the thermal comfort conditions can improve considerably. Ageing phenomena may reduce substantially and up to 50% the mitigation potential of cool asphaltic materials.

1. Introduction

The urban heat island phenomenon refers to the increase of the ambient temperature of cities compared to their surrounding suburban and rural environment. Increased urban temperature is the result of the positive thermal balance of cities caused by the additional heat released and stored in the urban structure, and the lack of low temperature environmental sinks (Santamouris, 2001). The urban heat island is the most studied phenomenon of climate change, and there are more than 400 cities around the world where experimental documentation is available (Santamouris, 2015a, 2016b). The amplitude of the phenomenon varies as a function of the local characteristics and of the strength of the heat sources and may exceed 6–7 K (Santamouris and Kolokotsa, 2016).

Local climate change has a significant impact on the energy consumption of buildings, it increases the concentration of local pollutants, deteriorates indoor and outdoor thermal comfort conditions, increases the vulnerability of low-income

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population and affect health conditions, while it raises the global ecological footprint of cities (Baccini et al., 2008; Pantavou et al., 2011; Sakka et al., 2012; Santamouris, 2015b; Santamouris and Kolokotsa, 2015; Santamouris et al., 2007; Stathopoulou et al., 2008). Recent studies have shown that the urban heat island increases the peak electricity demand during the summer period between 0.45% and 4.6% per degree of temperature increase (Santamouris et al., 2015b), while the annual energy consumption for cooling may increase up to 100% (Hassid et al., 2000; Santamouris et al., 2001). Compilation of the existing data on the energy penalty induced by the urban heat island has shown that it is close to 0.8 kW h per unit of city surface and degree of temperature increase or almost 68 kW h per person and degree (Santamouris, 2014b).

Forecasts of future cooling energy consumption of residential and commercial buildings reveal that by 2050 it may increase up to 750% and 275%, respectively, because of the local and global climate change, the tremendous increase of the population and the expected increase penetration of the cooling systems around the world (Santamouris, 2016a). To counterbalance the temperature increase in the urban environment and reduce as much as possible its impact on energy and environment, advanced and efficient mitigation technologies have been developed and applied widely (Akbari et al., 2016). Proposed mitigation technologies involve the use of reflective materials to solar radiation, additional urban greenery integrated into buildings and the city structure, dissipation of the excess urban heat into low temperature heat sinks like the ground and the water, solar shading, reduction of the anthropogenic heat and use of evaporation technologies (Akbari and Kolokotsa, 2016).

Highly reflective materials to solar radiation when used in the urban environment present a significantly lower surface temperature and contribute to reducing the sensible heat released in the atmosphere and mitigating the urban heat island (Doulos et al., 2004). Reflective or cool materials may be used on the roofs of urban buildings, cool roofs, and as pavements in the open urban spaces,cool pavements. Several types and technologies of cool materials for buildings and pavements have been developed involving reflective materials in the visible or infrared part of solar radiation (Synnefa et al., 2007, 2006), thermochromic coatings (Karlessi et al., 2009), reflective asphaltic products (Synnefa et al., 2011) reflective membranes and retroreflective materials (Pisello et al., 2016; Rossi et al., 2015; Santamouris et al., 2011), etc. Analysis of tens of studies and large scale applications have shown that the use of cool materials in the urban environment may decrease the average and peak ambient temperature up to 1.0 K and 2.5 K respectively (Santamouris, 2014a).

The development of reflective and/or pervious pavement may contribute significantly reducing the urban temperature and mitigating the urban heat island. Several technologies of reflective pavements have been developed and are commercially available while important research is carried out on the topic (Santamouris, 2013). Hundreds of large scale applications of reflective pavements are available around the world and their experimental evaluation shows that their mitigation potential is quite high (Castaldo et al., 2015; Fintikakis et al., 2011; Gaitani et al., 2011; Huynh and Eckert, 2012; OMalley et al., 2015; Santamouris et al., 2012; Tumini, 2014; Wang et al., 2016b). A recent analysis of 15 large scale mitigation projects involving the use of various types of reflective pavements has shown that the average and the peak temperature drop achieved was 1.3 K and 2.5 K, respectively (Santamouris et al., 2016), while the average and peak temperature drops per 10% increase of the albedo was close to 0.27 K and 0.94 K.

The existence and the characteristics of the urban heat island phenomenon is very well documented in the city of Athens, Greece (Livada et al., 2002; Mihalakakou et al., 2004). The phenomenon is more intense in the Western part of the city characterized by high urban density, increased anthropogenic heat, and lack of green spaces, and its magnitude may exceed 6–7 K (Giannopoulou et al., 2014; Mihalakakou et al., 2002). To counterbalance the significant impact of the high ambient temperatures in the area, a large scale rehabilitation program involving the use of various mitigation technologies has been designed and implemented (Santamouris et al., 2015a).

The present paper presents the design and the experimental evaluation of a large scale implementation of cool asphaltic and concrete pavements on a major traffic axis of Western Athens, covering a total zone of 37,000 m^2. The project is, to our knowledge, one of the largest urban mitigation projects in the world.

2. Description of the site

The rehabilitative area is the main traffic axis (Thivon Avenue) of the Municipality of Egaleo, situated in the western suburbs of Athens with the long axis in a NE′N-SW′S direction (6 7° from real North counter-clockwise) as Fig. 1 depicts. The geometrical characteristic of the traffic axis was $L/W = 8$. It consists of four traffic lanes separated with a refuge island with planted trees along its axis. Furthermore, both sides of the road are covered with pavements and there are three-to four-story buildings adjacent to them, which characterize the area as a mixed residential and industrial zone. The axis supports intensive traffic while the anthropogenic heat released is quite high. The road was initially covered with conventional black asphalt, while grey concrete tiles were used as pavements. The climate of the area corresponds to very hot and dry summers and it is influenced by the presence of mount Egaleo which acts as a natural obstacle against the northern winds, which dominate during the summer period in the Athens area. Detailed climatic monitoring of the area, has shown that the specific urban zone presents the high ambient temperature in the city of Athens (Giannopoulou et al., 2011). The project was carried out by the Prefecture of Athens in collaboration with the local Municipality and was built between 2014 and 2015. The renovation covers a total area of 37,000 m^2 and is the greatest recorded in Greece. It involves the implementation of approximately 18,000 m^2 of cool coloured thin layer asphalt and of approximately 19,300 m^2 of reflective concrete pavements.

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