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Use of cool materials and other bioclimatic interventions in outdoor places in order to mitigate the urban heat island in a medium size city in Greece

A. Dimoudi[a,*], S. Zoras[a], A. Kantzioura[a], X. Stogiannou[a], P. Kosmopoulos[a], C. Pallas[b]

[a] Laboratory of Environmental and Energy Efficient Design of Buildings and Settlements, Department of Environmental Engineering, Democritus University of Thrace, Vas. Sofias 12, Greece
[b] Division of Technical Services, Serres Municipality Karamanli 1, 62 122 Serres, Greece

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ABSTRACT

The materials that are used in outdoor spaces are of prime importance as they modulate the air temperature of the lowest layers of the urban canopy layer, they are central to the energy balance of the surface and they form the energy exchanges that affect the comfort conditions of city people. Paved surfaces contribute to sunlight's heating of the air near the surface. Their ability to absorb, store and emit radiant energy has a substantial affect on urban microclimate. The thermal behaviour of typical construction materials in an urban center of North Greece, at Serres, was investigated. The thermal fluctuation during the day and the surface temperature differences between different materials in a selected area inside the urban centre of the city was monitored. The replacement of conventional materials with cool materials was evaluated to have significant benefits. CFD simulations showed that materials replacement, accompanied by other mitigation techniques in the area, result at reduction of the mean surface temperature in the streets of the area of 6.5 °C. The results of the measurements and the CFD simulations are presented in the paper.

1. Introduction

Urban heat island is the more documented phenomenon of climate change. Daily mean UHI typically ranges between 2 and 5 °C while UHI intensities up to 12 °C were registered under particular conditions (Zinzi & Agnoli, 2012). Research has provided data on the amplitude and specific characteristics of the heat island phenomenon in many Greek cities like Athens (Santamouris et al., 2001), Thessaloniki, (Giannaros, Melas, & Kontogianni, 2009), Agrinio (Vardoulakis, Karamanis, Fotiadi, & Mihalakakou, 2013), Hania (Kolokotsa, Psomas, & Karapidakis, 2009), Serres (Dimoudi et al., 2013) and other European cities like London (Kolokotroni & Giridharan, 2008), Barcelona (Carmen Moreno-Garcia, 1993), Aveiro, Portugal (Pinto & Orgaz Manso, 2000), Bassel, Switzerland (Christen & Vogt, 2004), in Rome (Bonacquisti, Casale, Palmieri, & Siani, 2005) and Padua in Italy (Busato, Lazzarin, & Noro, 2014), in Stuttgard, Germany (Ketterer & Matzarakis, 2014).

The thermo-physical properties of covered and construction materials in contemporary cities and the urban geometrical characteristics affect the microclimatic conditions inside the urban centres (Lau, Yang, Tai, Wu, & Wang, 2011). According to Wong et al. (2011), there are three elements that affect urban temperature on a local scale: buildings, green spaces and pavement. The radiant balance of the urban space, the convective heat exchange between the ground and the buildings, the air flowing above the urban area and the heat generation within the city (Mihalakakou, Flocas, Santamouris, & Helmis, 2002; Santamouris, Mihalakakou, Papanikolaou, & Assimakopoulos, 1999) increase the air temperature in the city.

In order to improve the urban microclimate conditions, various mitigation techniques have been proposed involving the use of highly reflective materials, use of cool sinks and increased plantation (Gaitani, Michalakakou, & Santamouris, 2007; Rosenfeld, Akbari, Romm, & Pomerantz, 1998; Santamouris, 2007) as well as urban morphology (Gago, Roldan, Pacheco-Torres, & Ordóñez, 2013). Trees and green areas have a large effect at moderating the microclimate and also contribute at cooling the cities (Dimoudi, 1996; Santamouris, 2001) as evapotranspiration from vegetation foliage reduces air temperature and increases humidity

* Corresponding author. Tel.: +30 2541079388.
E-mail address: adimoudi@env.duth.gr (A. Dimoudi).

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(Dimoudi & Nikolopoulou, 2003). Vegetated areas are known to be comparatively cooler during daytime than most other urban elements (Zoulia, Santamouris, & Dimoudi, 2009). Mitigating the heat islands effect is therefore a key element to achieving sustainability in a city and it can be done by improving the urban microclimate (Gaitani et al., 2011).

The materials, which are used for the pavements streets and of urban spaces and for the external renderings of vertical (facades) and horizontal (flat roofs) surfaces of the buildings, constitute, the "skin" of a city. These materials play a decisive role on the heat transfer processes, which take place between the city and the environment. Materials influence the absorption of solar radiation, the emission of thermal radiation, the heat storage, and the evaporation processes that take place in practically every city surface.

By increasing the reflectiveness of urban surfaces, solar radiation is removed that would otherwise be converted into heat. Rosenfeld et al. (1998) estimated the cooling potential of the albedo increase in 1250 km^2 of pavements in Los Angeles by 0.25 and a temperature reduction of 1.5 K. Materials presenting a high reflectance to solar radiation together with a high emissivity factor are known as 'cool' materials. Alternative pavement materials for outdoor spaces were studied (Doulos, Santamouris, & Livada, 2004) and it was shown that 'cold' materials are preferable in urban environments with a hot climate whereas 'warm' materials should be used in areas with a cold climate. It was shown (Akbari & Matthews, 2012) that using cool roofs and cool pavements in urban areas, the mean albedo of an urban area can be increased by about 0.1 and thus, increasing the albedo of urban roofs and paved surfaces worldwide was estimated that a negative radiative forcing equivalent to offsetting at least 40–160 Gt of emitted CO_2 will be induced. Synnefa, Santamouris, and Livada (2006) evaluated the effect of cool materials in the reduction of the UHI in Athens by the MM5 climate model by comparing two modified albedo scenarios and they found out a maximum effect, in terms of temperature decrease, up to 2.2 K.

There are very limited examples, only in the last few years, that cool materials have been applied in outdoor urban spaces and their mitigation potential was evaluated. Applying 4500 m^2 of cool paving materials in the urban park Flisvos, in the greater Athens area together with other mitigation techniques, it was estimated that it contributes to a reduction of the peak ambient temperature during a typical summer day by up to 1.9 K and a surface temperature reduction in the park by 12 K while comfort conditions have been improved considerably (Santamouris, Gaitani, et al., 2012). A bioclimatic rehabilitation was proposed for a large area in the historic centre of Tirana, Albania where cool pavement materials were proposed (Fintikakis et al., 2011) and the maximum expected temperature drop varies between 3 and 8 °C as a function of the pavement colour. Another study was also proposed for a 4160 m^2 square in a densely built and populated area in the centre of Athens (Gaitani et al., 2011). Replacement of the conventional materials in the area was calculated to result at a highest surface temperature decrease of about 6.3 °C for the cool asphalt and 4.1 °C for the cool pavements. Replacement of conventional street and pavement materials with cool ones was also proposed for another urban area in the suburban city Marousi in NE of Athens (Santamouris, Xirafi, et al., 2012) and the results indicate that all the proposed bioclimatic measures contribute to decrease of local temperatures up to 3.4 °C for summer conditions.

Table 1
Investigated materials for each measurement point.

Material	Measurement Point (MP)
Road asphalt	MP1–MP11, MP14–MP17
Light grey pavement tiles (both sides of road)	MP 1, MP3–MP11, MP13–MP17, MP19
Grey pavement tiles	MP8
Yellow pavement tiles	MP8
Red ground cover pavers	MP8
White pedestrian tiles	MP8

The current study investigates the thermal behaviour of construction materials inside an urban centre and the improvement of thermal conditions induced by replacement of conventional with cool materials. The extensive use of cool materials together with other mitigation techniques was evaluated and the effect on the reduction of surface temperatures is analyzed. A rehabilitation project of outdoor spaces in a part of an urban centre, by extensive use of cool materials together with other urban heat island mitigation techniques, was proposed in a city at North Greece, which is considered as one of the warmest cities during summer in North Greece. Temperature measurements of the existing conventional materials and detailed modelling of the rehabilitated area are discussed in this paper. This study aims to add evidence on the potential of cool materials to mitigate the urban heat island.

2. Measurements methodology

2.1. Site description

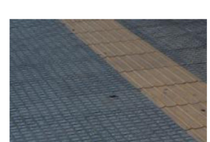
The investigation was conducted in Serres city (Greece), located at 41°05′ N and 23°33′ E, in North Greece, in an altitude of about 61 m above the sea level. The city has intense heat problem during summer and presents thermal episodes of high air temperature that exceed the 40 °C. The study area is located in the central parts of the city which contains a densely urban structure. The buildings are characterized by four to five floors height and are built in the decade of 1970s. The streets are covered by asphalt and the pavements are covered mainly by light colour, conventional pavement (concrete) tiles.

Table 1 describes the investigated materials for each measurement point and Table 2 presents photos of the existing materials in the area.

2.2. Monitoring procedure

A number of monitoring procedures were carried out during hot summer days, in order to investigate the thermal behaviour of construction materials which are used on buildings' envelope, for covering pavements and open spaces. The thermal fluctuation during the day and the surface temperatures is analyzed.

Table 2
Photos of investigated materials.

			
Asphalt	Light gray pavement tiles	Gray pavement tiles Yellow pavement tiles	White pedestrian tiles Red ground covers pavers