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A new structure of permeable pavement for mitigating urban heat island

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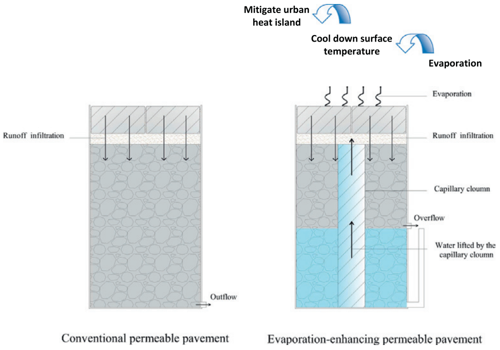
HIGHLIGHTS

- The capillary column enhances evaporation of the new pavement.
- The new pavement is cooler 9.4 °C in maximum than conventional pavement.
- The new pavement provides a longer cooling duration.
- Figuline pavers present a better cooling effect than fine concrete pavers.

GRAPHICAL ABSTRACT



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ABSTRACT

The urban heat island (UHI) effect has been a great threat to human habitation, and how to mitigate this problem has been a global concern over decades. This paper addresses the cooling effect of a novel permeable pavement called evaporation-enhancing permeable pavement, which has capillary columns in aggregate and a liner at the bottom. To explore the efficiency of mitigating the UHI, bench-scale permeable pavement units with capillary columns were developed and compared with conventional permeable pavement. Criteria of capillary capacities of the column, evaporation rates, and surface temperature of the pavements were monitored under simulated rainfall and Shanghai local weather conditions. Results show the capillary column was important in increasing evaporation by lifting water from the bottom to the surface, and the evaporation-enhancing permeable pavement was cooler than a conventional permeable pavement by as much as 9.4 °C during the experimental period. Moreover, the cooling effect of the former pavement could persist more than seven days under the condition of no further rainfall. Statistical analysis result reveals that evaporation-enhancing permeable pavement can mitigate the UHI effect significantly more than a conventional permeable pavement.

1. Introduction

The urban heat island (UHI) effect has become a global issue and a great threat to human habitation and the urban environment as urbanization advances. This has been conceptualized and studied thoroughly since 1982 (Oke, 1982). The UHI effect, characterized by higher temperatures in urban areas than those in rural areas, is a most documented phenomenon of climate change and is a major factor in observed temperature increments (Santamouris, 2007; Nakayama and Fujita, 2010; Founda, 2011). The effect occurs because of the changing nature of a city and consequent reduction in vegetation and evapotranspiration. This results in a heat balance between natural ground and building materials different than before (Arnfield, 2003; Stone et al., 2010). The UHI increases air temperature in urban areas with temporal and regional variability, and the value of this excess has been accurately shown to be 5–15 °C in recent research (Santamouris, 2013a). Up to now, quantities of researches on UHI including carbon footprint and energy

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consumption have been conducted (Rossi et al., 2016), and more studies on effective countermeasures still need to be explored.

Cool pavement is one method to mitigate the UHI effect by changing city surfaces and has been well researched in recent years (Qin, 2015). Existing methods of cool pavement mainly include increasing solar reflectance, enhancing evaporation, and reducing sensible heat transfer to the urban atmosphere. These methods are respectively associated with reflective, evaporative, and heat-harnessing pavements (Qin, 2015). To keep pavement cool, reflective pavements usually resurface the pavements with light-colored materials or mix them with light-colored aggregates and whitish cementitious material when constructed to increase pavement albedos (Levinson and Akbari, 2002; Levinson et al., 2010), besides, retroreflective materials were also proposed recently (Morini et al., 2017). Heat-harnessing pavements usually extract absorbed heat as renewable energy to reduce surface temperature (Mallick et al., 2011; Wu and Yu, 2012). Evaporative pavements typically use water-holding pavers to suppress surface temperatures, and mainly include permeable and water-retentive pavements (Qin, 2015).

Typically, permeable pavement cooling durations are only 1–2 days following rainfall (Li et al., 2013). Sometimes water is sprayed on the pavement to stay cool (Yamagata et al., 2008), which has substantial cost and is inconvenient. In the present study, a new permeable pavement called evaporation-enhancing permeable pavement was developed as a potential method of UHI mitigation. This pavement is designed to manage stormwater in a region where the groundwater table is high. Therefore, a liner is necessary for the permeable pavement to prevent infiltration from polluting groundwater. In the new pavement, capillary columns are installed in aggregate to lift runoff captured by the liner to the surface, which can promote evaporation and cool the pavement for a longer period. Moreover, cooling effects of two kinds of pavers (figuline and fine concrete) were investigated, which are usually applied to sidewalks and light parking lots respectively, considering compressive strength.

2. Materials and methods

2.1. Evaporation-enhancing permeable pavement

The structures of common and evaporation-enhancing permeable pavements are shown in Fig. 1. A common permeable pavement consists of a permeable paver, laying course, geotextile, and aggregate in sequence. In the new permeable pavement, there are capillary columns inbuilt in aggregate, and all of its materials are hydrophilic, including hydrophilic geotextile, fine sand laying course, and water-holding pavers. These promote the lifting of water by capillary columns to reaching the surface of pavers. In the present study, several bench-scale permeable pavement units were made with PVC with dimensions 210 mm × 210 mm × 400 mm (length × width × height). These were then loaded with a 30-cm graded aggregate with nominal maximum size 19 mm, geotextile, 2-cm laying course, and pavers of height 6 cm in turn. There was a transparent U-pipe placed at the bottom to monitor water level in each unit. At height 15 cm from the bottom, another pipe was placed to overflow captured runoff.

2.2. Capillary column and capillary capacity measurement

The capillary columns were made of figuline with dimensions 300 mm × 100 mm × 50 mm (length × width × height), from a brickyard in Yixing, Jiangsu Province, China. Measured compressive strength of the capillary column was 20 MPa. To evaluate the capillary effect of the column, water absorption capacity and capillary height variation were measured. The water absorption capacity was evaluated by weighing the mass of water absorbed by the columns at a given time, and capillary height was determined by the maximum saturated height that water could reach. First, the columns were dried in a drying oven for 24 h at a temperature of 105 °C. After cooling to room temperature, the columns were weighed and then put in a tank with a constant 10-mm water depth. Finally, the masses of columns and column capillary

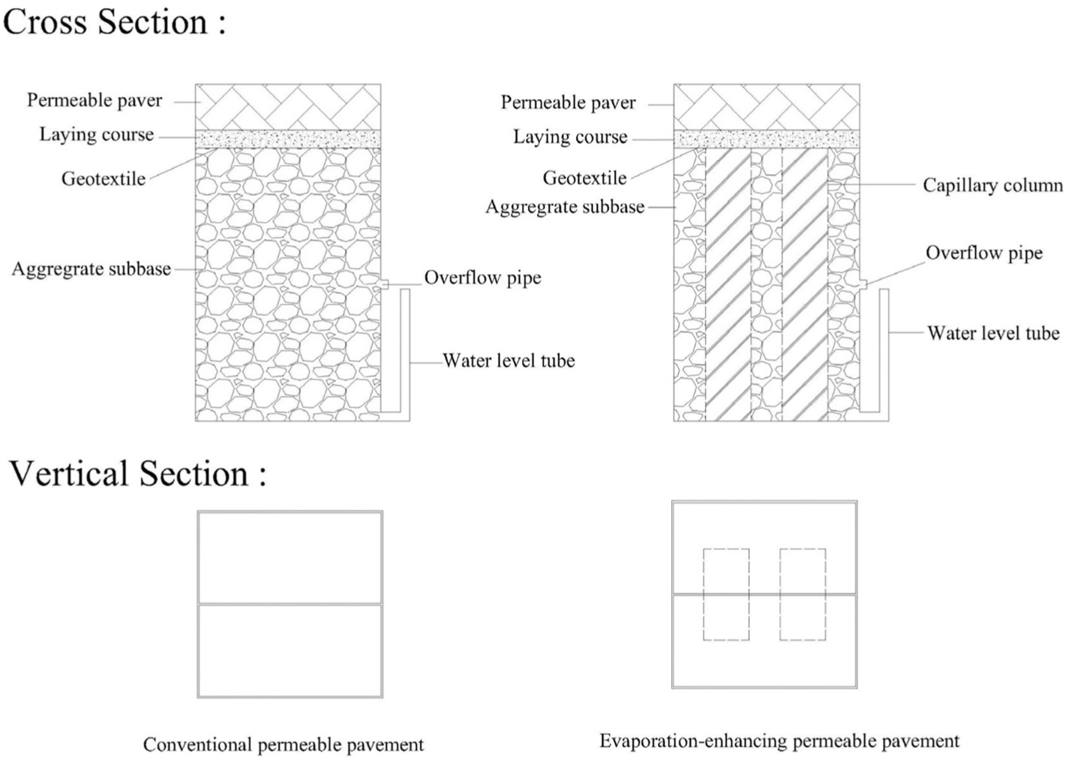

Fig. 1. Sections of conventional and evaporation-enhancing permeable pavement units.