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Surface Temperature Reduction of Porous Concrete Pavers Using a Water Retention Layer

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ABSTRACT

Porous pavements are now used to reduce urban heat even though previously it was designed specifically to reduce stormwater runoff. To qualify the pavement as a cold pavement, the pavement needs to be modified either as evaporative pavement, reflective pavement, and heat storage pavement. This study used porous concrete pavers as evaporative pavement by adding wetted retention layer underneath the pavers and investigated the temperature reduced. Three materials of water retention layers were investigated and material with higher water retention was selected. The pavement temperature changes are studied using selected water retention material with different layer thicknesses. The result shows that felt wool material absorbed more water compared to palm oil fiber and geotextile. While as for the selection of the thickness, water retention layer with 8 mm thick was selected due to its optimal evaporation rate and gives higher temperature reduction on the block pavers compared to 4 mm thick and 12 mm thick.

1. Introduction

Pavements and buildings in are the elements of urban surfaces in urban areas which have lower albedo and higher absorptivity compared to rural areas. The decreasing of permeability and vegetation in urban surfaces reduced the infiltration and evapotranspiration [1]. Elements such as sun radiation, air temperature, pavement texture, and wind speed effected the fluctuation in pavement surface temperature [2]. Pavements is one of the largest urban surfaces exposed to solar radiation in urban surfaces [3]. Dark surfaces pavements such as asphalt pavements absorbed the heat coming from the sun and causing an increase in pavement temperature and ambient temperature [4].

The usage of cool pavements is currently known as one of the techniques to mitigate urban heat by modifying the surfaces of cities [5]. Cool pavements can be either reflective pavements or evaporative pavements or both [3].

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The reflective pavements are the pavements that able to reflect more solar energy [6]. The reflective pavements are the pavements with higher reflectance or albedo compared to conventional dark-coloured pavements [7,8]. Light colour coating or light colour materials were used for the surface to increase the reflectance of the pavements. Increased solar reflection on the pavement surface can reduce pavement temperature and air temperature near the surface [8]. The example of paving materials with higher reflectance are light coloured painting, slurry coating, and chip seal [9].

While evaporation pavements are pavements with higher evaporation or has been modified to remain cooler than conventional impermeable pavements [6] which it holds water either at the surface or at the lower layer of the pavements [7]. The evaporation helps to decrease the pavement surface temperature with the present of moisture on the pavements or underneath the pavements [8,10]. Sprinkling water on the surface of the pavement is one of the methods to give moisture to the pavement [10]. The concept of evaporative cooling has been widely used in the building air conditioning systems [11,12]. Basically, there are two types of evaporative pavements which are permeable pavements and water-retentive pavements [13].

Permeable pavement is defined as a pavement with void structure (porous structure) which allowing water to infiltrate and reducing the water runoff during storm event [14,15]. Permeable pavement can significantly reduce the effects of urban heat which is when the water retained on the pavement or underlying soil evaporated during the hot weather. The effect of evaporation can reduce the pavement temperature [16]. Figure 1 shows the infiltration and evaporation of water in porous concrete block pavers.

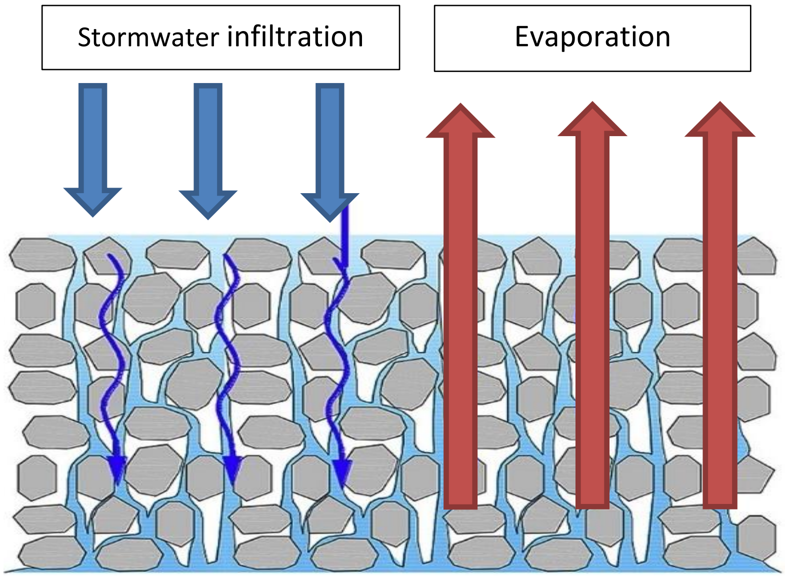


Fig. 1. Illustration of infiltration and evaporation of permeable pavements [15]

While water-retentive pavement is the pavement that can hold and retain water or moisture for a certain period of time and the latent heat released to the air through evaporation [18,19]. Minimal solar absorption on water-retentive pavements makes the pavement to stay cool. In addition, permeable pavements, porous pavements, and pervious pavements are also considered as the type of water-retentive pavements [20]. Water-retaining pavements also can be classified according to their base materials which can be called as water-retaining concrete pavements, water-retaining brick or block pavers, and water-retaining asphalt pavements [19].

Some of the pavements are added with water holding materials to increases the ability of the pavement to hold water or moisture [21]. Other than that, water-retentive fillers have also been used to keep the moisture on the pavements [22]. In addition, impermeable layers are also added on the bottom of permeable pavements to store the moisture for evaporation [23].

The use of additives or fillers to hold water on the pavement requires the pavement to be made using a new mixture which is not suitable to be used for existing block or brick pavers. While the usage of impermeable layer underneath the pavement layer may lead to flooding. Therefore, the purpose of this study is to study water retention materials that are able to absorb and hold more amount of water. This study used the existing porous concrete paver blocks and the changes on the block temperature was also monitored.

2. Methodology

This research studied the water absorption of several water retention materials to select the suitable material as water retention layer. After the selection of materials, several thicknesses of layer were studied in order to get the suitable thickness which is able to evaporate more moisture and give higher temperature reduction. Figure 2 shows the experimental test and analysis carried out in this study.

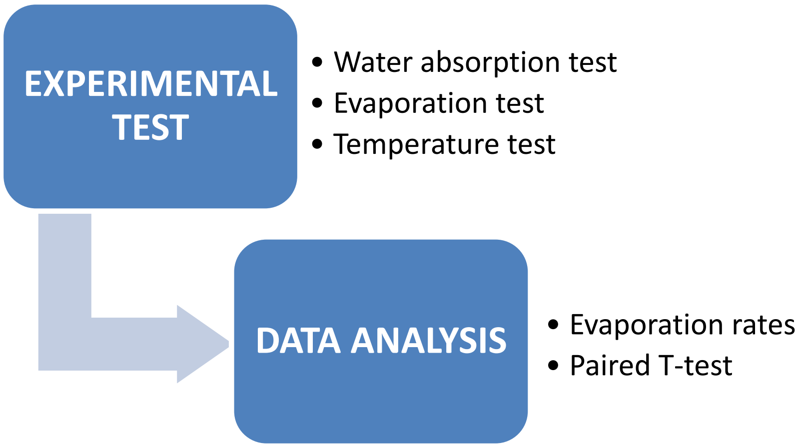


Fig. 2. Flowchart of experimental test and data analysis

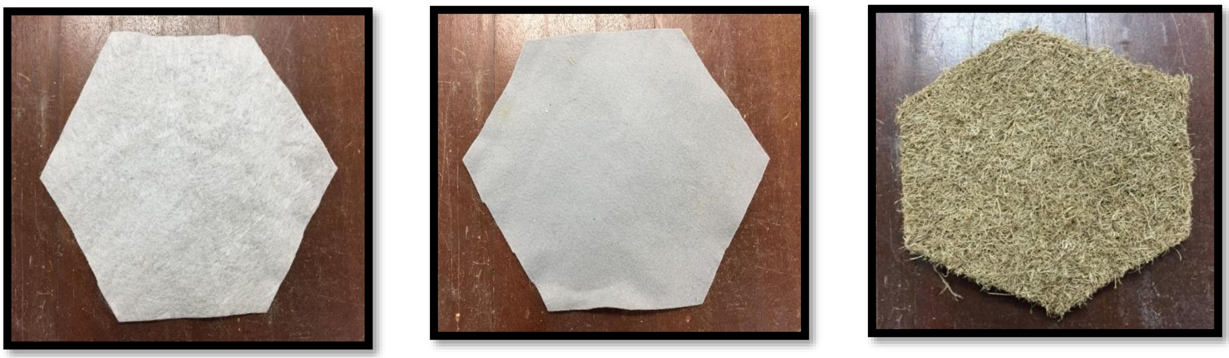
As shown in Figure 2, first, the water absorption test was carrier out to select the suitable water retention materials. Secondly, the water absorption test was repeated together with the evaporation test and temperature test for the selection of suitable thickness to be use as water retention layer. Data from the experimental test were analyzed using descriptive analysis and inference analysis. For the descriptive analysis, the average value and maximum value of water absorption, evaporation, and temperature were analyzed. While for the inference analysis, the correlation analysis and regression analysis were analyzed to select the suitable thickness of the layer. Then paired t-test analysis was carried out to analyze the effect of water retention layer on the block pavements.

2.1 Materials

There are three water retention materials used in this study, which is geotextile, palm oil fiber, and felt wool. The specification of the water retention materials is shown in Table 1 while Figure 3 shows the water retention materials with a hexagon shape.

Table 1
Specification of water retention materials

Materials	Specifications		
	Shape	Thickness	Colour
Geotextile	Hexagon	4, 8, 12 mm	Light grey
Felt wool	Hexagon	4, 8, 12 mm	Dark brown
Palm oil fiber	Hexagon	4, 8, 12 mm	Light grey



(a) (b) (c)
Fig. 3. Water retention materials (a) Geotextile (b) Felt wool (c) Palm oil fiber

2.1.1 Geotextile

Geotextile is widely used in green roof as water retention materials because its capability to absorb water. Geotextile is also usually used as protection mat, drainage mat, and also water retention mat. Therefore, a non-woven geotextile was selected in this study due to its capability for absorbing water and its durability.

2.1.2 Felt wool

Wool is one of the largest natural protein fibers and one of the important materials used in textile productions [24]. Wool has high water absorption and capable of absorbing 30% more moisture than its weight [24,25]. Felt wool material was selected in this study due to its water absorption ability.

2.1.3 Palm oil fiber

One of the waste products produced by the palm oil industry is Empty Fruit Bunches (EFB) fibre [26]. The palm oil fibers were also known for its ability to absorb water [27]. Hence, palm oil fiber was selected in this study as water retention materials.

2.2 Method and Analysis

Several experimental tests were conducted to select the suitable water retention materials and suitable thickness of selected water retention material. Firstly, water absorption test was conducted to select the suitable water retention materials. According to ASTM D 123 – 03, absorption is a process where one material absorbs or takes up another or in other word is the capability of materials to take in moisture [28].

The water absorption test was conducted to measure the quantity of water absorbed by the water retention materials for the selection of the suitable water retention materials. The formula for water absorption is shown in Eq. (1).

$$\text{Water absorption (\%)} = \frac{Wet\ mass - Dry\ mass}{Dry\ mass} \times 100 \quad (1)$$

After selecting the water retention material, the evaporation and temperature variation test were conducted to select the suitable thickness of water retention layer. Three thickness of water retention layers were used in this study, which are 4 mm, 8 mm, and 12 mm thick. The temperature stone was set up at 45 °C for all thickness. The temperature reading was taken using NTB-500A data logger for 300 minutes while the evaporation rates taken by measuring the wetted water retention layer's weight before and after the test is carried out. The formula for evaporation rates is shown in Eq. (2).

$$\text{Evaporation rates (\%)} = \frac{Initial\ mass - Final\ mass}{Initial\ mass} \times 100 \quad (2)$$

Figure 4 shows the experimental set up for evaporation and temperature variation tests. The infrared lamp acted as a heat source to heat the paving blocks. While thermocouple was placed inside the block paver and measures the temperature changes on block paver. Load cell was placed under the block paver to measure the changes on the block paver and retention layer mass.

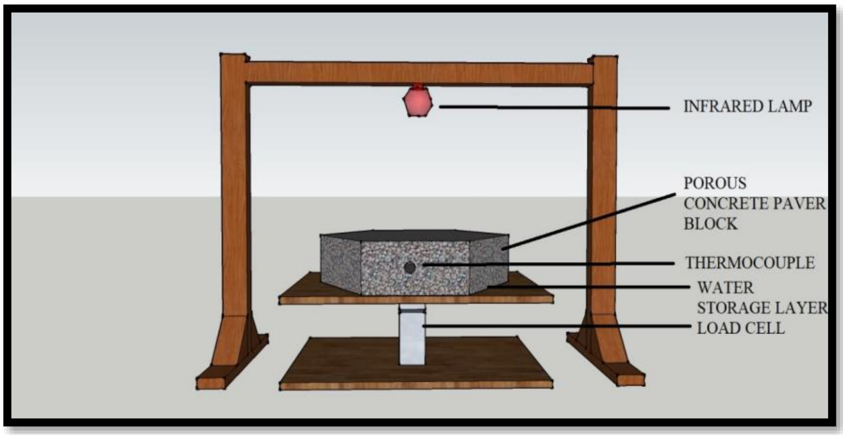


Fig. 4. Experimental setup for evaporation and temperature variation tests

3. Results and Discussions

3.1 Water Absorption of Water Retention Materials

Three water retention materials which are geotextile, felt wool, and palm oil fiber were used in this experiment to measure the water absorption of each material. The thickness of each material was standardized to 4mm thick, and duration of water flow was 10 minutes for each sample. As can be seen in Table 2, felt wool material shows the highest percentage of water absorption which about 84.8%, followed by geotextile which about 65.0% and palm oil fiber which about 63.8%. Based on then water absorption results, it can be seen that felt wool material is suitable to be used as a water retention layer because it can absorb more water than geotextile and palm oil fiber.

Table 2
The average of water absorption

Water retentive materials	Geotextile	Felt wool	Palm oil fiber
Average dry mass (g)	59.5	40.6	34.0
Average wet mass (g)	171.2	267.7	94.0
Mass of water absorbed (g)	111.2	227.0	60.0
Percentage of water absorbed (%)	65.0	84.8	63.8

3.2 Selection of Water Retention Layer Thickness

In order to obtain the suitable thickness of selected water retention layer, evaporation test and temperature changes test were conducted. As the result from water absorption test, felt wool materials was selected as water retention material for this study. The felt wool was divided into three thickness which are 4 mm, 8 mm, and 12 mm thick to investigate the appropriate thickness to be used as a water retention layer. The temperature stone was set up at 45°C which is the range of ground cover temperatures for high density urban areas [29].

3.2.1 Evaporation tests

Evaporation test was conducted to investigate the evaporation rates of each thickness of water retention layer. The recorded total evaporation rates for 4 mm thick are 24.7 gram, while for 8 mm and 12 mm thick are 30.5 gram and 30.6 gram. As can be seen in Figure 5, the water retention layer of 4 mm thick shows the lowest evaporation rates while 8 mm and 12 mm thick shows insignificant difference of evaporation rates.

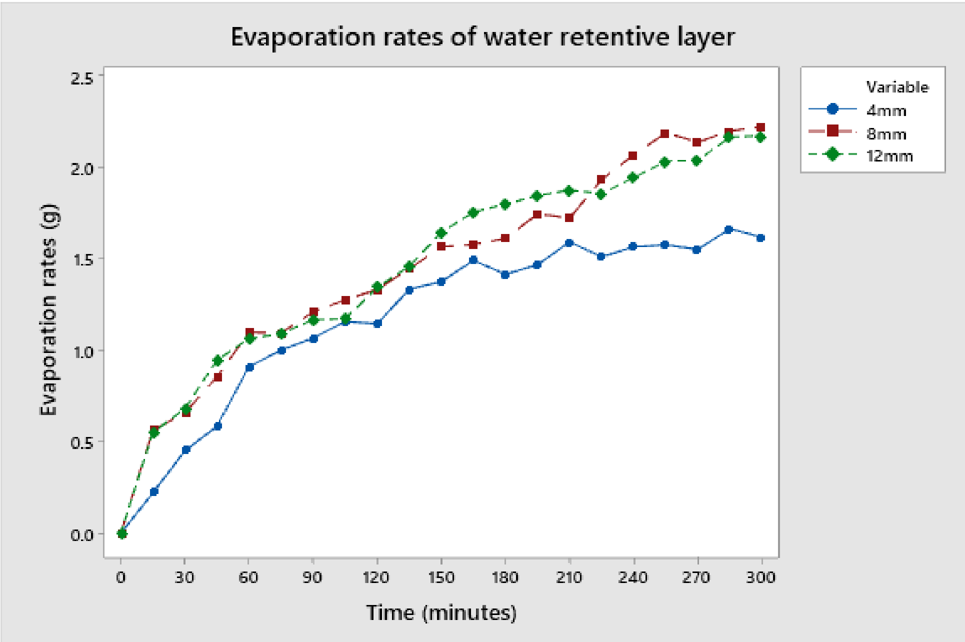


Fig. 5. Evaporation rates of water retention layer for 4mm, 8mm, and 12mm thick

3.2.2 Temperature changes test

The changes of block temperature were also measured in order to select the suitable thickness of water retention layer. Thermocouples were placed at the surface of the block samples and inside the block samples. Figure 6 shows the differences of temperature reading between inside block temperature and surface block temperature. As for surface block temperature, it can be seen the temperature reading was fluctuated. However, water retention layer with 4 mm and 8 mm thick show not much difference in temperature changes while for 12 mm thick shows the highest temperature changes reading compared to control block (surface temperature without water retention layer).

While the inside block temperature shows a consistent reading of temperature changes for all samples. Therefore, the temperature measurement inside the block samples were used for the selection of water retention layer thickness. As can be seen in Figure 6, all thicknesses of the water retention layer used showed lower temperature readings compared to the control block (inside block temperature without water retention layer). The maximum temperature reduction for 4 mm thick of water retention layer is 1.8°C, while both 8 mm and 12 mm thick are 2.4°C. Among all thicknesses of water retention layer, the 4mm thick showed the least temperature reduction compared to 8 mm and 12 mm thick. Meanwhile, the temperature reduction on the water retention layer with a thickness of 8 mm and 12 mm is not seen to be no different. Hence, based on this temperature test, 8 mm thick of water retention layer was selected as suitable thickness for the block pavers.

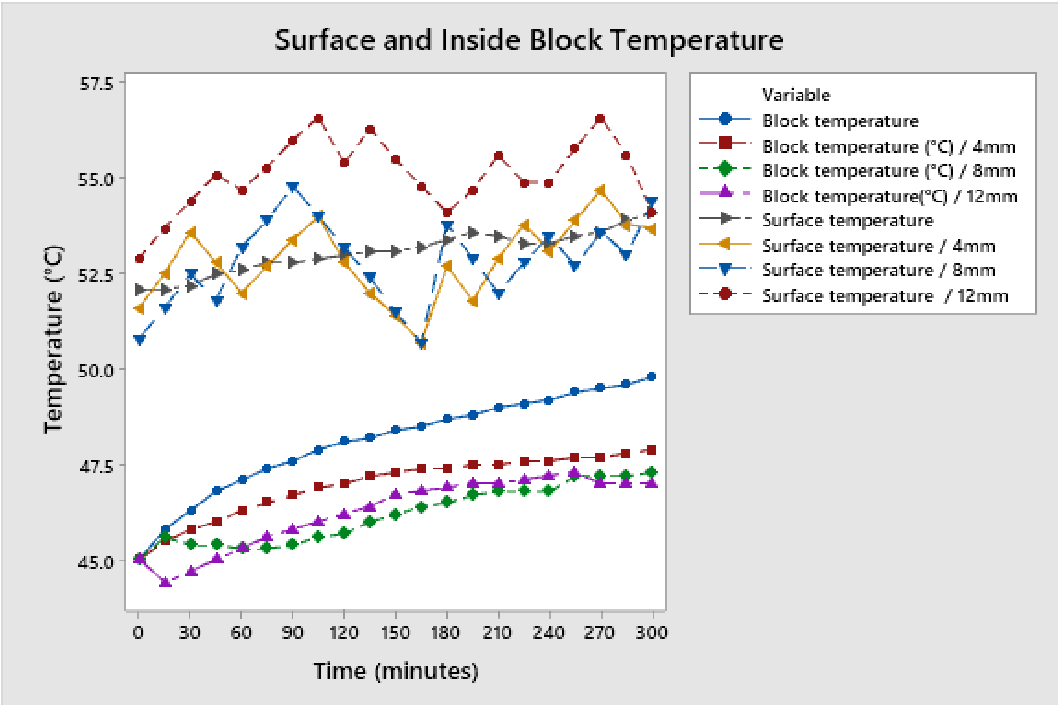


Fig. 6. Surface and inside temperature of block paver samples

3.3 Effectiveness of Water Retention Layer on Porous Concrete Pavers

A t-test analysis was conducted to examine the effectiveness of the presence of a water retention layer to the pavement temperature. Table 3 shows the results of the t-test analysis where each thickness of the water retention layer is analyzed using the results before and after the presence of the water retention layer on the pavement block. The t-test analysis of block temperature shows a significant result (where $t = 10.34$, 12.47, and 15.76, $p < 0.05$). This shows the effectiveness of the water retention layer in reducing the temperature of the pavement block.

Table 3
Paired t-test analysis of block paver before and after the presence of water retention layer

Water retention layer thickness (mm)	N	Mean	T-value	P-value
4	21	1.138	10.34	0.000
8	21	1.924	12.47	0.000
12	21	1.848	15.76	0.000

4. Conclusions

Water retention material and the thickness were finalized in this study. Felt wool material was selected as the suitable water retention layer due to its higher water absorption rate compared to geotextile and palm oil fiber. Even though geotextiles were able to absorb water, but the absorbed water was unable to retain in it. While palm oil fiber able to absorb and retain water but it is not durable because after wetting for several times, the palm oil fiber swelled and damaged. As for the selection of thickness of water retention layer, though the maximum temperature reduction of 8 mm and 12 mm are the same, but 8 mm thick was selected because it is seen more suitable, and optimum compared to 12 mm thick. In conclusion, from this study, it can be seen that the usage of water retention layer helps to mitigate the temperature of porous concrete block pavers. However, further experiments need to be carried out based on the actual weather conditions.

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