Monitoring and evaluation of thermal behaviour of permeable pavements under the northern Spain climate

Suivi et évaluation du comportement thermique des pavés poreux sous le climat du nord de l'Espagne

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RÉSUMÉ

Les chaussées perméables offrent une solution au traitement du ruissellement de l'eau de pluie dans les zones urbaines, en combinant la gestion des eaux avec la réutilisation de celle-ci. D'autre part, l'observation du comportement thermique de ces systèmes a démontré que les trottoirs perméables peuvent, d'une part, atténuer les îlots de chaleur urbains durant la saison la plus chaude et, d'autre part, retarder le gel pendant la saison froide. L'analyse de la réponse thermique de la couche de base des chaussées perméables permet d'envisager leur utilisation en tant que ressource énergétique, complétant ainsi leur fonction première de réservoir d'eau de pluie. L'objectif de la présente étude est d'étudier le comportement thermique des chaussées perméables, en particulier la distribution de température dans la couche de base, où l'eau de ruissellement est stockée pour une utilisation ultérieure, éventuellement dans un système de régulation énergétique. Les résultats obtenus montrent que les températures de la couche de base étaient différentes de la température de l'air ambiant pendant la période d'étude et que la couche de base était moins affectée par la température ambiante que la base de la chaussée perméable.

ABSTRACT

Permeable pavements offer a solution to rainwater runoff treatment in urban areas, combining water management with re-use water purposes. On the other hand, the thermal behaviour observation of these systems have proven their contribution to palliate the urban heat island effect in the hottest season and to delay freezing during the coldest season. Deepening knowledge of the thermal response of the subbase of permeable pavements brings a background reference of using these structures as an energy resource in addition to the actual well-known applications as a rainwater reservoir. The aim of the present study is going into the thermal response observations of permeable pavements with special attention to the temperature distribution of the subbase, where rain water is stored for further uses involving the possibility to make a regulatory energy system. The results showed that subbase temperatures were different from the air temperature during the period of study and that the subbase was less affected by the ambient temperature than by the base of the permeable pavement.

KEYWORDS

Permeable pavements, thermal behaviour, re-use water, urban heat island

1 INTRODUCTION

Sustainable urban drainage systems (SUDS) or best management practices (BMPs) are a well developed urban runoff control instrument. The use of SUDS to control urban rainwater quantity and quality aspects has been proven for 20 years in countries such as USA or Japan (Yang and Jiang, 2003; Brattebo and Booth, 2003). Although the relevance of these techniques was not very important at the beginning, nowadays the investigations in these areas have increased over the world, distinguishing pervious pavements as a complete solution. Permeable pavements are also capable of reducing the heat island effect by means of evaporative cooling; since porous layers retain a significant amount of water, which is released back into the atmosphere through evaporation during sunlight hours (Wanphen and Nagano, 2009).

Permeable pavements in parking lots combine the site utilisation with a storm water retention area; pollutant removal and groundwater recharge (Pratt, 1999). This sustainable urban drainage system could be utilised moreover as an energy storage device as part of a geothermal or solar energy system (Scholz and Grabowiecki, 2007).

Geothermal energy is widely being introduced all over the world in order to comply with reduction of harmful gas emissions and renewable energy source use policies. Actually, the feasibility of this technology is proven even when local geological site conditions are unfavourable (Blue Book on Geothermal Resources, 1999). Therefore, the permeable pavement subbase could be a geothermal resource if the appropriate technology is used, enhancing the rainwater harvesting techniques with energy application before water is re-used. The use of geothermal resources is based on the nearly constant temperature of subsoil at some depth, close to the mean annual air temperature in the same area. For this reason, shallow or low enthalpy geothermal energy resources are combined with geothermal heat pumps which extract or inject heat to the subsoil at relatively low temperatures through heat exchangers filled with fluid, usually water. Geothermal heat pumps in closed horizontal loop systems do not need deep excavations and one meter depth is enough to apply this technology.

2 BACKGROUND AND OBJECTIVES

Researchers at the University of Coventry are beginning to develop systems for the use of rainwater stored in the subbase of permeable pavements, providing sustainable drainage systems that integrate these water reservoirs with geothermal heat pumps. This is accomplished by introducing heat exchangers at the bottom of the subbase to recover and deposit the heat in a similar way to geothermal systems (Coupe and O Nnadi, 2007). The operation of this technology is to introduce pipes within the subbase with a heat transfer fluid inside. Investigations in the University of Edinburgh have shown the effect of temperature fluctuations of such systems on water quality (Scholz and Grabowiecki, 2009) highlighting the influence on biological growth and nutrient degradation, which resulted in a better performance at high temperatures. However, the occurrence of a potential transfer of pathogens onto humans must be considered..

To develop these systems it is necessary to know the temperature response of permeable pavements. The heat transfer involves convection and radiation in the pores, and conduction in the solid aggregates. The heat flows from points of higher temperature to cooler regions.

Several studies have developed models based on energy balance in pavements, which include heat transfer by convection, conduction and radiation (Gui et al. 2007; Hermansson, 2004). Solar and infrared radiation, wind, and air temperature are climate factors of great importance in pavement surface temperatures, as well as rain events and evaporation patterns. Observations of temperature in pervious concrete pavement have shown how surface temperatures are higher than the air temperature due to solar radiation absorption. At the same time the insulating capacity of the air mass in the pervious pavement and aggregate base means that the effect of temperature changes is more buffered as depth increases (Kevern et al, 2009).

The temperature within a permeable pavement is strongly influenced by the air temperature; however, the air produced an insulating effect more significant than the one observed in impervious pavement (Bäckström, 2000). Part of the solar radiation is employed in evaporating the water retained in the porous material, which explains the lower temperatures obtained in permeable pavements surfaces. However, permeable materials with great void size can drain more easily to down layers so less water is placed on the surface available for being evaporate, which implies the pavement to be warm as an impervious pavement (Asaeda and Ca.2000).

On the other hand, the porosity provides insulating abilities to soils, but water saturation of pores increases the soil thermal conductivity. For that reason, soils of bigger porosity and more insulating abilities are more influenced in the increment of thermal conductivity due to water saturation (Zhang et al. 2007).

The main objective of this study is to evaluate the temperatures distribution through the subbase composed by aggregates and water with different permeable pavements surfaces. If the subbase temperatures keep nearly constant values compared with air temperature, the subbase could be used in geothermal energy recovery purposes. Otherwise, higher temperature values than air temperature give an idea of the insulating abilities of different types of permeable pavements and their contribution to the thermal urban environment.

3 SITE INVESTIGATION

The University of Cantabria is involved in the design, construction and monitoring of a unique experimental pervious pavement parking area in Santander (Spain). Different pervious pavement types have been applied, in order to study water quantity and quality aspects simultaneously. The experimental parking lot is being monitored since 2008 and temperature sensors were added during construction to evaluate the long term thermal response inside the pavements.

The experimental parking lot of Las Llamas Park (Santander) consists of 45 parking bays built of different types of permeable pavements: paving-stone, porous asphalt, porous concrete and reinforced grass in plastic and concrete grid. Permeable pavements allow the water to pass through the pavement and the base into the aggregate subbase where rainwater is stored. There is a geotextile installed in most of the parking bays between the base and the subbase in order to prevent fine particles to pass and clog the voids. The common structure is formed with a 35cm subbase of limestone aggregate and has voids ranging from 33% to 35%; moreover, the base is formed by limestone gravel. A diagram of these structures is showed in the Figure 2.

The reinforced grass permeable pavement type is considered as the less known in relation with thermal behaviour and contributes to the construction of green areas in urban cities. For this reason, it was decided to focus on this type of pavement and 3 reinforced grass parking bays were selected in order to study their thermal behaviour versus the site climate conditions; Figure 1 shows the parking bays in the experimental parking lot.

Figure 1. Parking lot in Santander, Spain

The surface areas of each parking bay are 4.2 x 2.4m. The characteristics of the monitored parking bays are shown in Table 1.

PARKING BAY	SURFACE	BASE	GEOTEXTILE	SUBBASE
RG-MP	Reinforced grass with Montserrat® concrete grid	Limestone gravel (4-8mm)	Polifelt® TS30	Limestone aggregate (4-20mm)
RG-MD	Reinforced grass with Montserrat® concrete grid	Limestone gravel (4-8mm)	Danofelt® DY150	Limestone aggregate (4-20mm)
RG-PD	Reinforced grass with Hauraton® plastic grid	Limestone gravel (4-8mm)	Danofelt® DY150	Limestone aggregate (4-20mm)

Table 1. Parking bays characteristics

The temperature measurements of the parking bays called RG-MP, RG-MD and RG-PD obtained during three consecutive months are presented in this paper.

4 MONITORING LAYOUT

Six Pt100 temperature probes were used to collect the measurements in the three parking bays, which were recorded by a MadgeTech OctRDT datalogger (with eight channels). The datalogger has been installed within a watertight box to be protected from getting wet and The temperature sensors are conducted by pairs to the measurement devices at the corner of each parking bay through corrugated tubes to be placed inside the permeable pavement. The air temperature, wind velocity and precipitation were recorded by a meteorological station located at 10-12m height in a lamppost of the parking lot. Solar radiation information was obtained from the State Meteorological Agency (AEMET).

Initially, 3 parking bays were monitored during 3 months. The probes were programmed to register the permeable temperatures at 15cm and 50cm depth under climate conditions during the hottest season. Surface temperature was not measured because the investigation was focused on the subbase temperature behaviour during one year.

The temperature measurements were made with temperature probes immersed in the base and the subbase of the each parking bay. Two horizontal tubes allowed the introduction of the probes and protected them from the granular material. One sensor was located at 15cm depth, just above the geotextile and the other sensor was situated at 50cm depth at the bottom of the subbase (Figure 2).

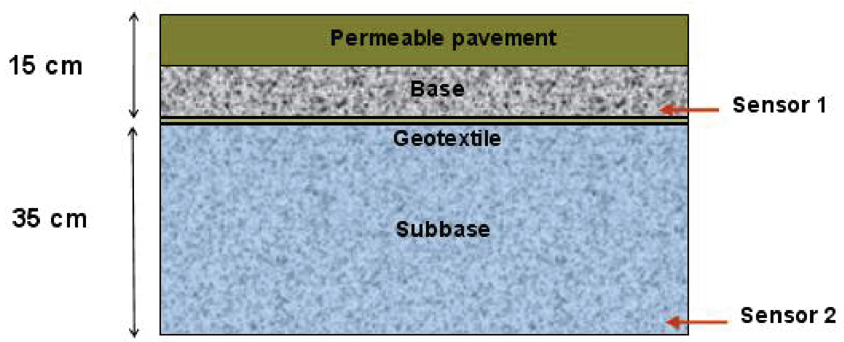

Figure 2. Parking bay cross section

5 RESULTS AND DISCUSION

Figures 3, 4, and 5 a-b show the temperature records over a three months period for the three parking bays RG-MP, RG-MD and RG-PD.

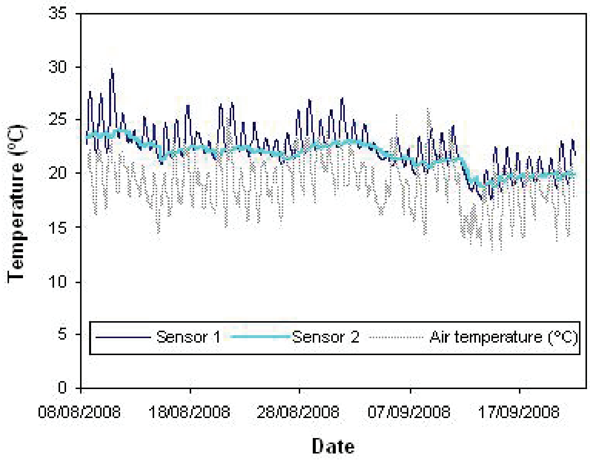

Figure 3a. Temperature measurements of parking bay RG-MP

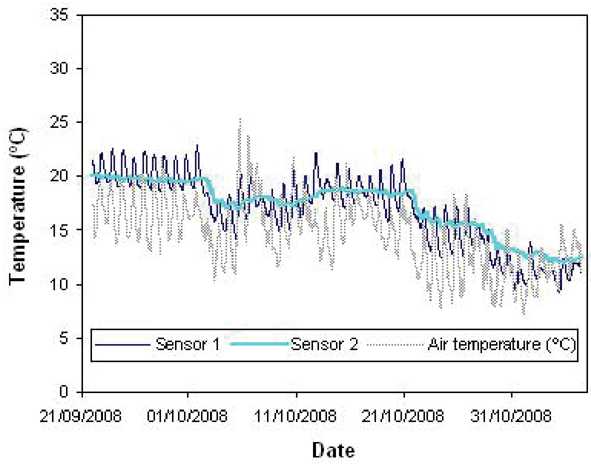

Figure 3b. Temperature measurements of parking bay RG-MP

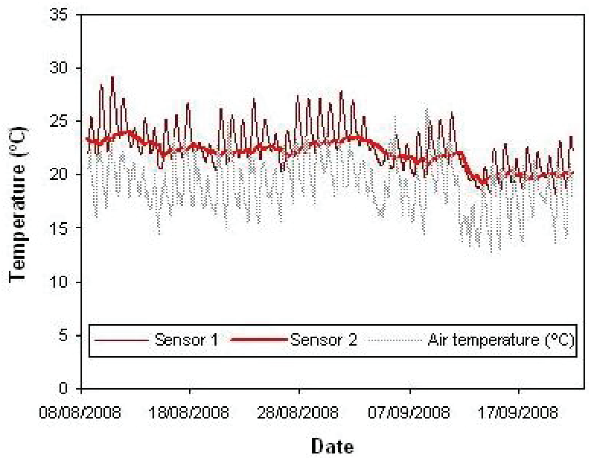

Figure 4a. Temperature measurements of parking bay RG-MD

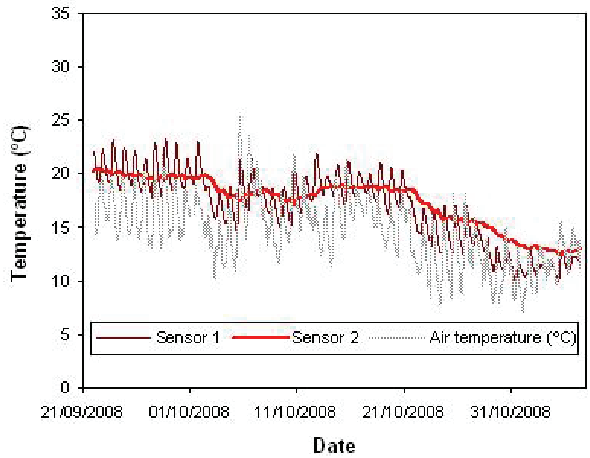

Figure 4b. Temperature measurements of parking bay RG-MD

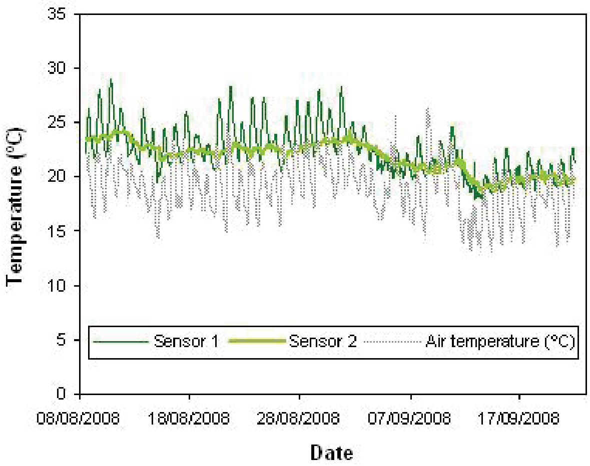

Figure 5a. Temperature measurements of parking bay RG-PD

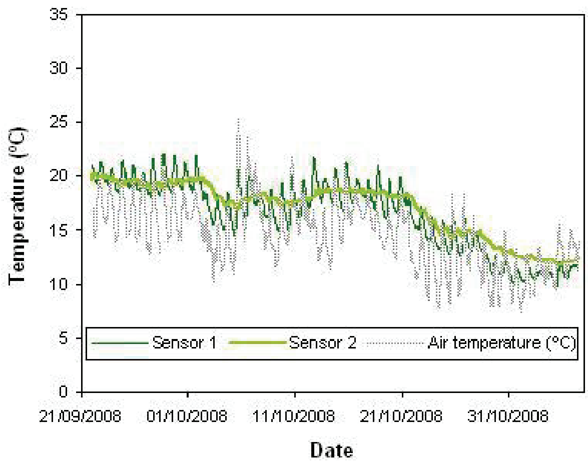

Figure 5b. Temperature measurements of parking bay RG-PD

It can be seen that the pavement temperatures depend greatly on the weather, normally changing every hour and daily. However, some differences exist during the measurement period. Most of the days, the daily air temperature was cooler than the pervious pavement temperatures at the depths measured; moreover, sunlight absorption causes the maximum pavement temperatures registered in the 15cm depth sensor to be significantly higher than the surrounding air temperature. The temperature measurements in the subbase, at 50cm depth, were also higher than the air temperature but the daily variations were much less notable.

The graphics presented show strong temperature oscillations in the sensor measurements at 15cm depth and softer oscillations in the sensor measurements at 50cm, corresponding to the subbase. During warm and sunny summer days (Figure 3a, 4a and 5a), the temperature of the pavement base under the permeable pavement may reach high values, and the experiment shows that base and subbase temperature measurements were greater than the air temperature. This could be explained by heat transfer mechanisms produced inside the pavement. For pavements, conduction is the most important factor for heat transfer; thermal conductivity decreases with increasing porosity but increases with increasing degree of water saturation. During sunny days the pavement surface temperature will present strong daily oscillations and in pavement materials with a high thermal diffusivity this oscillation penetrates to greater depths. The solar radiation reaches the pavement surface, and evaporation occurs when water is retained in the pores from capillarity or previous rain events. Therefore, heat transfer is conducted basically by conduction inside the pavement although convection takes place in the porous layers as well.

At twilight, when the solar radiation is diminished, the surface emits heat to the atmosphere by convection and radiation which implies a temperature increment in urban areas, also known as the urban heat island effect. The cooling process due to the temperature differences between air and pavement surface is delayed in deeper layers which present a porous structure that provides insulating capacity to the permeable pavement and aggregate base. Maximum temperature peaks at 15cm were observed between 6 – 9 pm while air temperature maximum peaks were observed between 3 – 6 pm or even before.

At the beginning of the next season (Figures 3b, 4b, and 5b), the differences between air temperature and the registered pavement temperatures were not so pronounced, getting closer in the following months. Besides, an increment of the temperatures in the subbase is observed at the end of the second period of study, reaching values over the base and air temperatures.

For the subbase temperatures obtained in the two periods of study, heat transfer through the pavement and the insulating ability of the pervious pavement and the base produce a buffered temperature response with increasing depth, as it is showed in the graphics. The heat transfer capacity and the pervious pavement turn the subbase into a possible medium to keep the water temperature significantly different from the air temperature.

The 3 monitored parking bays (RG-MP, RG-MD and RG-PD), present a similar thermal response at both depths, as it is shown in Figure 6, because no great differences appear in the temperatures obtained during the three months of study. For better observation, the daily mean temperatures of the permeable pavements at both depths and the daily mean air temperatures are represented in Figure 7. The mean temperature within the permeable pavements is always greater than the mean air temperature for the period of study in the conditions of the investigation, which implies the construction of permeable pavement structures of 50cm depth. The preliminary results suggest that the ground source heat pumps technology could not be employed under the constructions characteristics, being recommended deeper subbases for energy applications. Investigations could be also focused on the introduction of new building materials in the permeable pavements construction.

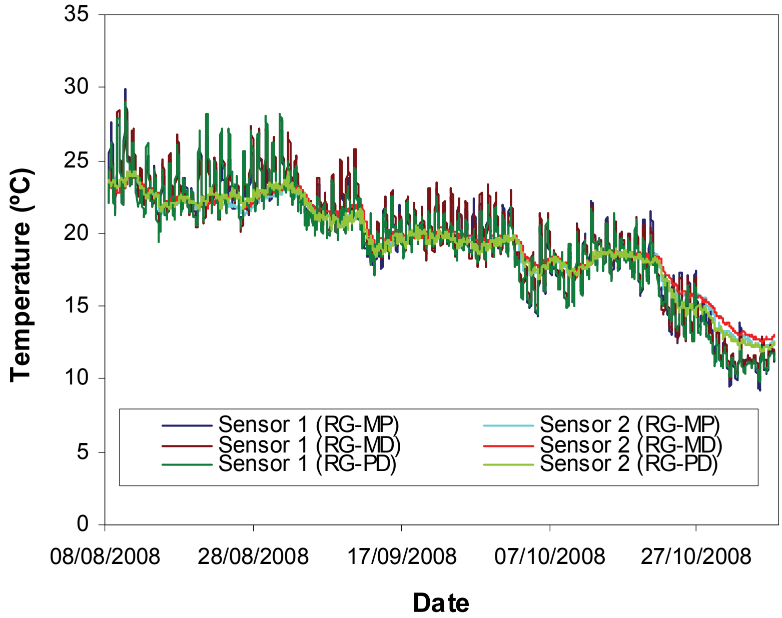

Figure 6. Total temperature measurements registration in the parking bays selected

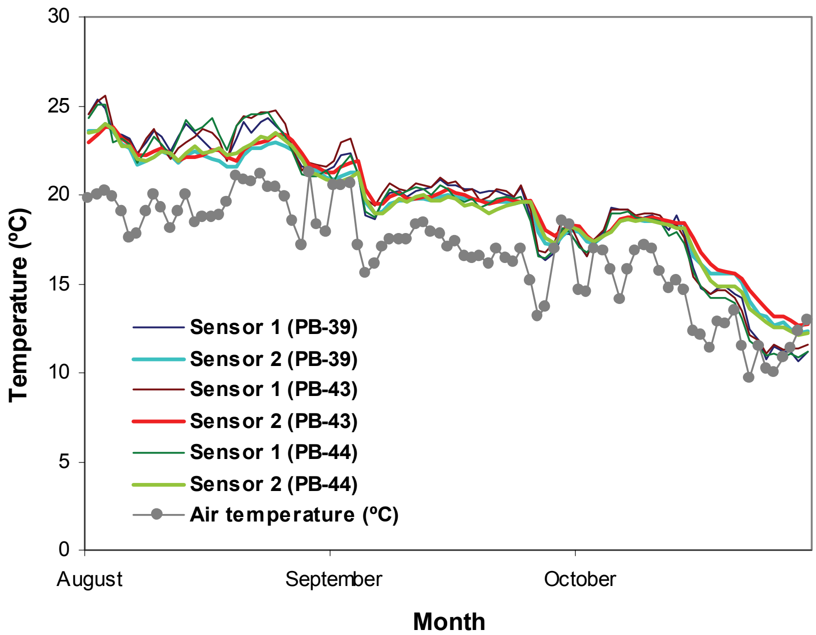

Figure 7. Daily mean temperatures measured during the period of study

6 CONCLUSIONS

The thermal response of reinforced grass permeable pavements has been monitored for three months and results obtained have shown the thermal behaviour of the parking bays selected and the different values in respect to the air temperature at the investigation site. Higher temperatures of the subbase can be associated to the insulating ability of these types of pavement.

The insulating capacity of the pervious pavement is more pronounced at the hottest season, when more solar radiation hits the surface, and could be caused by water evaporation which let pavement and aggregate voids fill with air. When solar radiation diminishes during the day due to the change of season and more rain events are accounted for, pavement voids are probably occupied by water, increasing the thermal conductivity of pavement and aggregate base and registered temperatures are more similar to ambient temperatures. However, the subbase temperatures keep higher values than base temperatures even when they are still influenced by the ambient temperature.

The results obtained provide an indication of the heat transfer processes occurring in the pavement and highlight the insulating capacity of permeable pavements for further researches. Actual investigations related to this paper involve a complete year monitoring of four types of permeable pavements and a detailed study of the influence of climate variables on the temperature responses. The information obtained will provide a wide overview of the thermal behaviour of different types of permeable pavements to evaluate their possible application as a low enthalpy system, in addition to an instrument for rainwater management.

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