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► **To cite this version:**

Maxime Frere, Martin Hendel, Simon Pouget, Julien van Rompu, Laurent Royon. Urban heat island mitigation: a field evaluation of a pervious pavement combined with pavement watering. COBEE, Jun 2022, Quebec (Canada), Canada. hal-04495980

HAL Id: hal-04495980

<https://hal.science/hal-04495980v1>

Submitted on 8 Mar 2024

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Urban heat island mitigation : a field evaluation of a pervious pavement combined with pavement watering

Maxime Frere^{1,2*}, Martin Hendel^{1,2}, Simon Pouget³, Julien Van Rompu³, and Laurent Royon¹

¹Université de Paris, LIED, UMR 8236, CNRS, France

²Univ Gustave Eiffel, ESIEE Paris, Département SEN, France

³Eiffage, Corba Lyon, EIFFAGE ROUTE, France

*Corresponding email: maxime.frere@u-paris.fr

Keywords: urban heat island, heat stress, pervious pavement, cool pavement, pavement watering

SUMMARY

In the context of global warming, cities need to be prepared to mitigate thermal stress in city, especially during heat wave, when it's become to be a health issue. This study is focused on evaluating the cooling effects of a pervious, ochre pavement combined with pavement-watering in response to the urban heat island effect and extreme heat events to offering permanent cooling effect and stronger effect with water mitigation, although punctual. A micro-climatic study was conducted following a Before After Control Impact (BACI) design to evaluate the effect of the new pavement and watering on pedestrian heat stress during typical heat-wave conditions. The surface temperature of the 100m² test site was also monitored. Since the pervious pavement have a low albedo, we see no significant effect compared to standard pavement although with the use of water we are able to see a cooling effect of -15°C on the surface imputing a -1°C refreshing effect on air temperature at 1.6m height.

INTRODUCTION

Cities are subject to the urban heat island (UHI) [1] phenomenon which, coupled with climate change, can lead to critical health situations during summer and heat waves [2] [3] [4]. In response, many cities are interested in urban cooling techniques, including urban greening [5] [6], cool materials [7] and energy efficiency measures [8].

Among other methods, pavement-watering has been shown to provide cooling of up to 3°C UTCI-eq (Universal Thermal Climate Index) temperature during heat-wave conditions in France [9] [10]. Water consumption for densely-populated cities also remains reasonable [11]. However, impervious pavement surfaces, which are designed for water to runoff as quickly as possible, dry quickly and require frequent watering cycles during direct insolation [12]. Pervious asphalt concrete offers the possibility of retaining more water than standard impervious asphalt concrete and thus lengthening drying times. However, it is unclear how much sprinkled water would be retained as opposed to drained into the pavement structure. Further work are needed to estimate the quantity that can be retained inside the pervious pavement.

The following article focuses on such a design seeking to improve the performance of pavement-watering by combining a pervious pavement with a closed-circuit and automated watering system. To this aim, a 100 m² test site located in Hyères, France is studied to evaluate the impacts of a pervious ochre pavement with and without watering on pavement surface temperature, microclimatic parameters (air temperature, humidity, ...) and pedestrian heat stress.

METHODS

The 100 m² test site is located in Hyères, France, at the boundary between different urban fabrics. It is located at the Western end of an industrial area of locale climate zone (LCZ) class 8 [13]. To the North, it is bordered by an agricultural zone (LCZ D), and by a forest (LCZ A) to the South. It is surrounded by three 2.5m tall walls on the North, East and West sides and open to the South. The ground was initially paved with standard asphalt concrete of albedo 0.09, paved a few months later with a pervious ochre pavement of albedo 0.13 at deployment (see Figure 1). A watering system to conduct pavement-watering experiments allows for watering of the pavement, the North wall or both simultaneously.

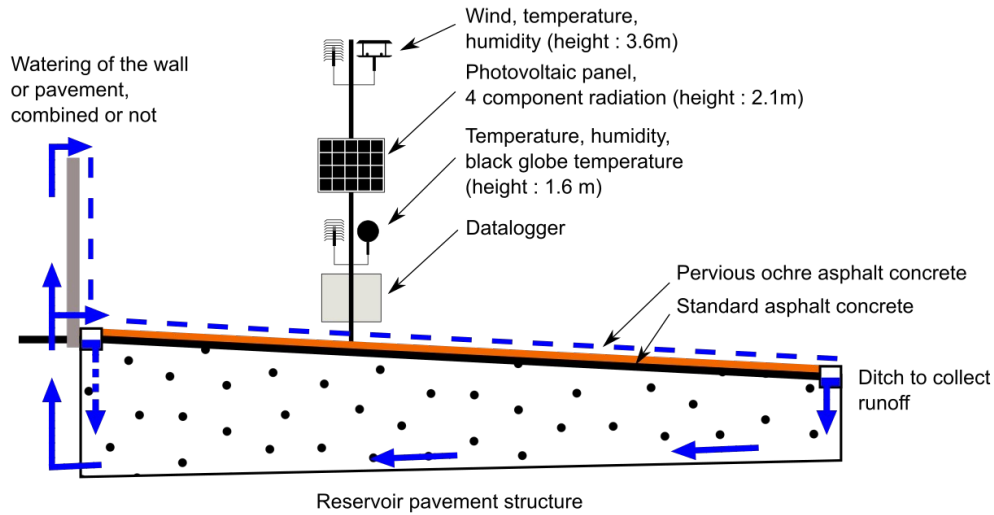


Figure 1: Diagram of the test site and weather station.

Watering was conducted for 15 minutes every hour from 8 am to 6 pm on days with clear skies, low wind and high temperatures, with a flowrate of about 45 mm/h. Water fills an overflowing gutter located at the top of the pavement slope. Runoff is collected in a gutter located downstream and seeps back to the water reservoir, thus allowing semi-closed circuit operation.

Two weather stations are deployed: one at the test site (Figure 1), the other is placed in a nearby parking slot and serves as a control. The control site remains unchanged throughout the experiments, while the test site is repaved and watered (Figure 2). These states are used with the pair of weather stations to determine the microclimatic performance of the ochre pavement and its pavement-watering.

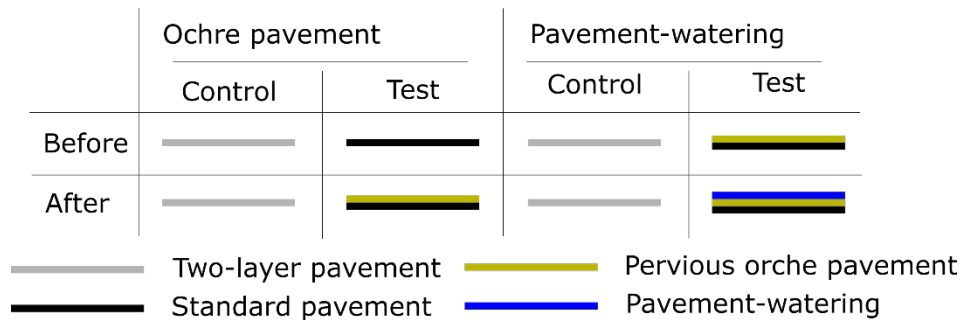


Figure 2: Illustration of the studied site states

Weather station instrumentation is detailed in Table 1: Instrumentation, type and uncertainties in addition to a mobile albedometer and infrared camera. The measured microclimatic parameters

are used to evaluate pedestrian heat stress using the Universal Thermal Comfort Index (UTCI) [14]. A Before-After-Control-Impact (BACI) method in combination with a Linear-Mixed-Model (LMM) are used to evaluate the cooling impact [15]. This method allows us to eliminate most uncontrollable weather parameters by studying the interstation difference between study and control stations. This interstation difference is compared before and after cooling solution implementation (ochre pavement and/or pavement-watering). Finally we extract relevant data with a fixed effect model (FEM) with a significance level of 0.05.

Table 1: Instrumentation, type and uncertainties

Parameter	Symbol	Instrument	Height	Uncertainties
Air temperature	T_{air}	Sheltered Pt100	1.6 m 3.6 m	0.1+0.17%
Relative humidity	RH	Sheltered capacitive hygrometer	1.6 m 3.6 m	0.25%
Globe temperature	T_g	Pt100 black globe thermometer	1.6 m	0.1+0.17%
Wind speed	v	2D ultrasound anemometer	3.6 m	0.1
Longwave radiation	LW-down, LW-up	Pyrgeometer	2.1m	2%
Shortwave radiation	SW-down, SW-up	Pyranometer	2.1m	2%
Surface temperature	T_{surf}	IR Camera	-	2°C

RESULTS

First we focus on the impact of the pervious ochre pavement on its own, followed by the impact of its combination with pavement-watering.

Pervious ochre pavement impact

The impact of repaving with the ochre pavement on the microclimate and pedestrian heat stress are presented in Figure 3 and summarized in Table 2. The mean effects are plotted with the solid blue line Table 2. Unfortunately, after the pervious ochre pavement was paved onto the test site, the study/test weather station was not replaced in exactly the same position, slightly changing the insolation pattern of the sensors. Therefore, the periods where this impact occurs are removed from the dataset and appear as blank in Figure 3.

Table 2: Impacts of the ochre pervious pavement on the radiative balance

Parameter	Maximum Effect	Time of maximum	Mean effects	N_{ref}	N_{study}
T_{air}	+0.57°C	13:16pm	0.2°C	14	18
RH	+1.6%	21:02pm	-0.4%		
SW up	+23.4W/m ²	13:45pm	+3.4W/m ²		
LW up	-20.2W/m ²	16:45pm	-10.5W/m ²		

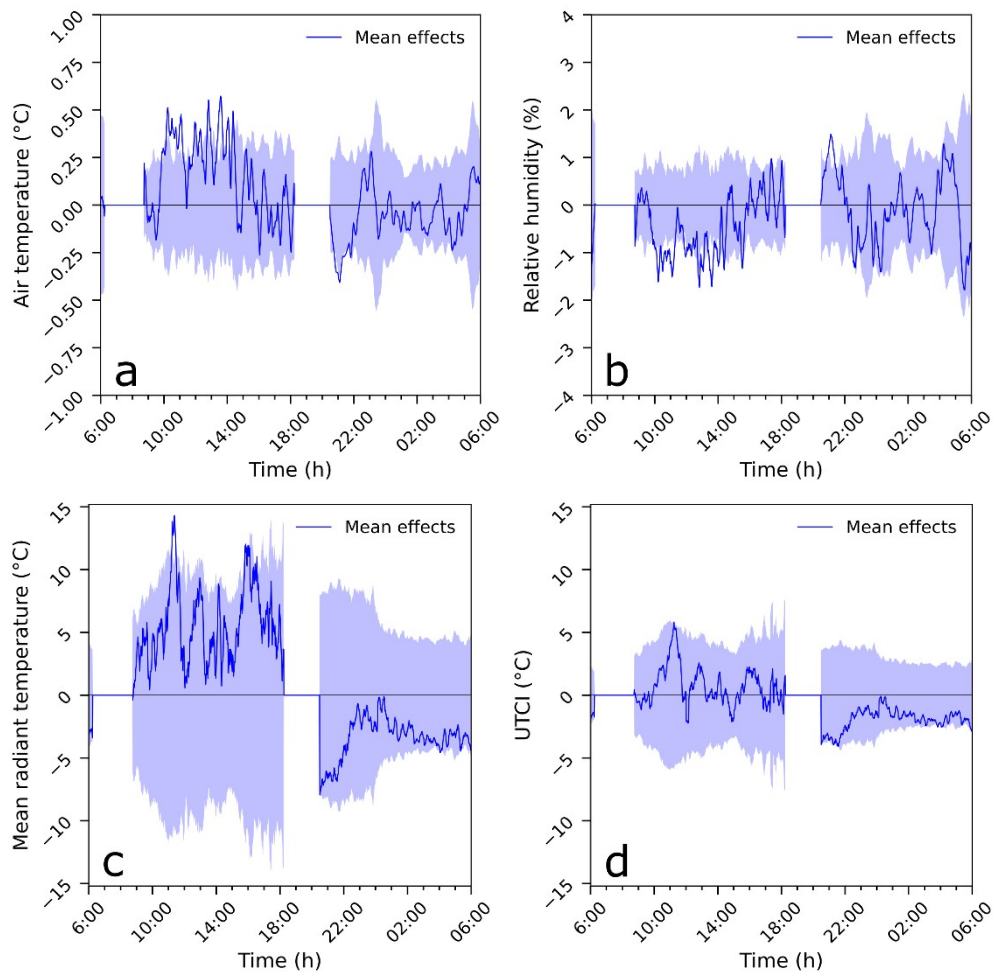


Figure 3: Microclimatic effect of ochre pavement on air temperature (a), relative humidity (b), mean radiant temperature (c) and on UTCI (d).

Few statistically significant (stat. sign.) microclimatic are visible. Stat. sign. increases in air temperature of up to 0.5°C are apparent in Figure 3a between 9 am and 3 pm, with a corresponding drop in relative humidity of up to 1.5% (Figure 3b). However, no stat. sign. impacts on pedestrian heat stress are observed. This is expected given the similar albedo offered by the ochre pavement and standard asphalt concrete. In the absence of pavement-watering, pervious asphalt concrete surface temperatures are even expected to be higher than those of standard asphalt concrete due to its lower conductivity.

Pavement-watering impacts

We now analyze the impact of pavement-watering. Microclimatic effects are shown in Figure 4. As can be seen, pavement-watering has a notable effect in the middle of the day, with an air temperature reduction of up to 1°C . As expected, relative humidity increases up to 3.5% due to the evaporating water. While this effect tends to deteriorate pedestrian heat stress, it remains limited.

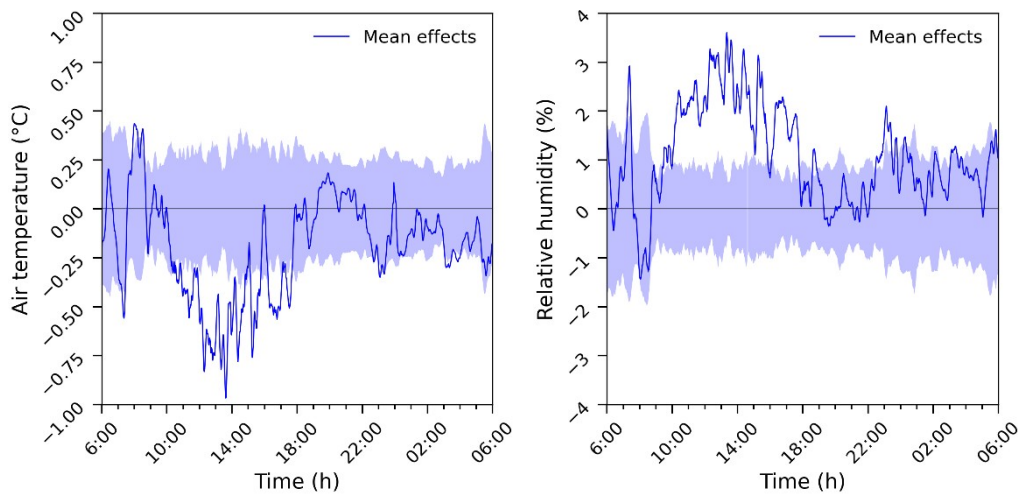


Figure 4: Pavement-watering effect on air temperature (left), relative humidity (right)

Figure 5 presents surface temperature and upwards long- (LW) and shortwave (SW) radiation. Surface temperature is strongly affected by watering with a surface temperature drop of up to 15°C. This decrease lasts throughout the night, resulting in a next day 6 am surface temperature 2°C cooler than on a day not preceded by watering. This surface temperature reduction is the origin of the observed drop in air temperature in Figure 4.

Focusing on the radiative effect of watering, it is observed that watering reduces upwards LW radiation from the ground as well as upwards SW radiation, resulting in a total decrease of net radiation of approximately 100W/m². The drop in LW radiosity is expected as pavement temperature drops with watering. On the other hand, the drop in upwards SW radiation is associated with the increased absorbance of the wet pavement [16]. It should be noted that watering cycles are visible in Figure 5b and c in the form of spikes. These impacts are summarized in Table 3.

Table 3 : Extended information on weather measurement for water mitigation effect

Parameter	Maximum Effect	Time of maximum	Mean effects	N _{ref}	N _{study}
T _{air}	-0.9°C	13:45pm	-0.5°C	18	17
RH	+3.7%	13:05pm	+1.7%		
SW up	-59.7W/m ²	14:15pm	-13W/m ²		
LW up	-52.1W/m ²	14:27pm	-16.9W/m ²		

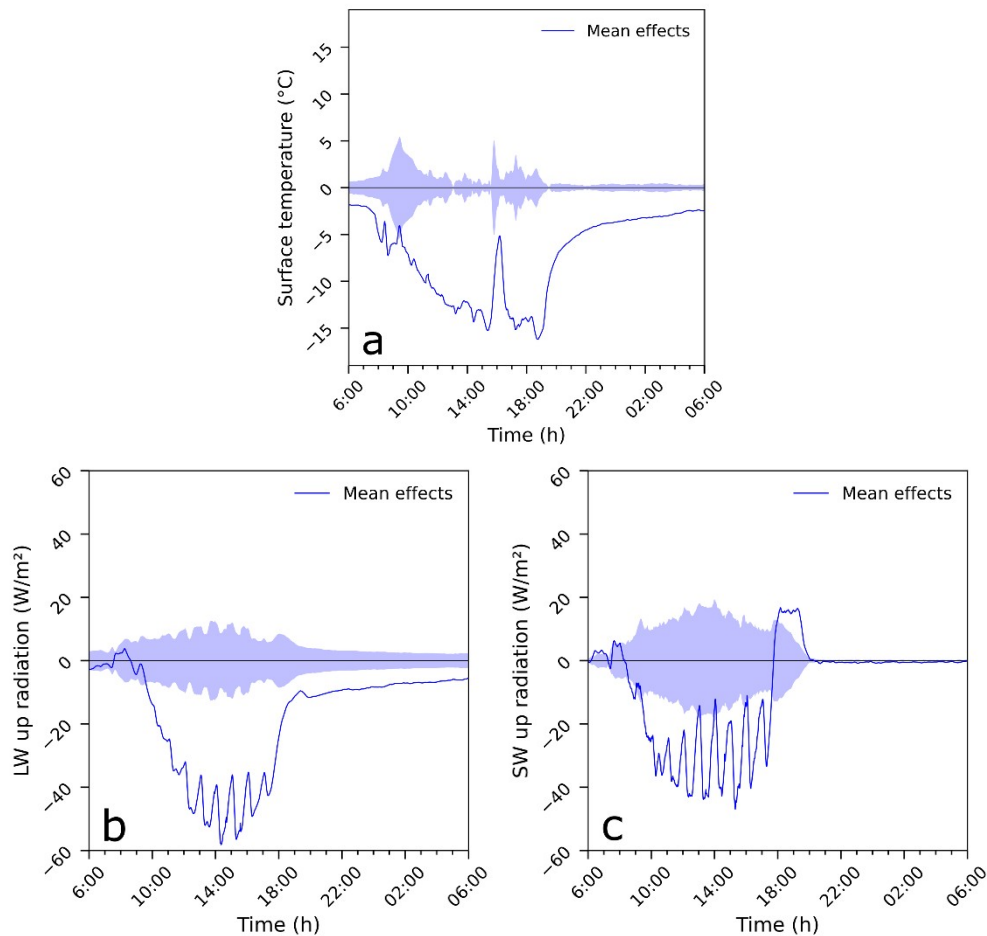


Figure 5: Impact of pavement-watering on surface temperature (a), upwards longwave (b) and shortwave radiation (c).

Other analyses from the experiment show that pavement-watering has lasting effects due to water retention. Indeed, even when the surface dries, it was observed in previous work that the surface temperature remains 5°C cooler for up to 45 minutes, when the next watering cycle begins [17].

DISCUSSION

On the whole, these results are consistent with previous work on pavement-watering conducted in Paris, France [9]. Furthermore, it should be noted that the ochre pavement albedo increases over time, from 0.13 to 0.26 as limestone and dust accumulate on the ochre pavement surface. This tends to increase the estimated cooling effect of resurfacing with time. While it is typical for asphalt concrete albedo to increase with ageing [18], the final albedo depends on the specific ageing factors and dust composition of a given site. The test site's industrial activity generates large amounts of dust compared with a regular urban setting, thus exacerbating this effect.

Further microclimatic analyses are ongoing that will help increase the statistical robustness of the presented results and will help shed light on the impact of different watering schemes (wall-only, pavement-only and combined). Efforts are being pursued to correct the measurement errors generated by not replacing the study weather station in exactly the same location after resurfacing.

CONCLUSIONS

The microclimatic effects of an ochre pavement combined with pavement-watering were explored, based on an experiment conducted at a test site located in the South of France (Hyères). The pervious ochre pavement had no significant impact on pedestrian heat stress. Pavement-watering of the pervious ochre pavement reduces its surface temperature by up to 16°C, providing air temperature reductions of up to 1°C and reducing the pavement's radiosity, contributing to improving pedestrian heat stress.

Further microclimatic analyses are ongoing that will help increase the statistical robustness of the presented results and will help shed light on the impact of different watering schemes (wall-only, pavement-only and combined). On top on that a laboratories experiments are planed to find a way to extend these result on different LCZ, by making a complete thermal characterization of existing outside pavement completed with convective observation with a Schlieren experiment.

ACKNOWLEDGEMENTS

This research was funded by Eiffage group and Université Gustave Eiffel in the framework of the E3S program. This program has received support under the program "Investissement d'Avenir" launched by the French Government and implemented by ANR, with the reference ANR-16-IDEX-0003. The authors would like to acknowledge the contribution of Jean-Marc LHUILLIER and the Eiffage staff at the test site.

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