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Research paper

An analysis of pavement heat flux to optimize the water efficiency of a pavement-watering method

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HIGHLIGHTS

- The thermal effects of pavement-watering were investigated in Paris, France.
- Pavement-watering was found to significantly affect pavement heat flux 5 cm deep.
- When insolated, a linear relation was found between heat flux and solar radiation.
- Pavement-watering did not alter its slope, but introduced a negative intercept.
- Subsequent improvements of the watering period, frequency and rate are proposed.

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ABSTRACT

Pavement-watering as a technique of cooling dense urban areas and reducing the urban heat island effect has been studied since the 1990's. The method is currently considered as a potential tool for and climate change adaptation against increasing heat wave intensity and frequency. However, although water consumption necessary to implement this technique is an important aspect for decision makers, optimization of possible watering methods has only rarely been conducted. An analysis of pavement heat flux at a depth of 5 cm and solar irradiance measurements is proposed to attempt to optimize the watering period, cycle frequency and water consumption rate of a pavement-watering method applied in Paris over the summer of 2013. While fine-tuning of the frequency can be conducted on the basis of pavement heat flux observations, the watering rate requires a heat transfer analysis based on a relation established between pavement heat flux and solar irradiance during pavement insolation. From this, it was found that watering conducted during pavement insolation could be optimized to 30-min cycles and water consumption could be reduced by more than 80% while reducing the cooling effect by less than 13%.

1. Introduction

Watering horizontal or vertical urban surfaces as a method for cooling urban spaces has been studied in Asia since the 1990s [1–6] and is only a recent topic in French cities such as Paris and Lyons [7–9]. With reported air temperature reductions ranging from 0.4 °C at 2 m [8] to 4 °C at 0.9 m [3], this technique is viewed as an efficient means of reducing urban heat island (UHI) intensity. In France and especially Paris, the predicted increases in heat wave intensity and frequency due to climate change [10], combined with the high sensitivity of dense cities to such episodes [11,12], have focused efforts on the development of appropriate adaptation tools. In parallel to techniques such as green space development, pavement-watering is seen as one of these potential tools for heat-wave adaptation in mineral areas.

Pavement-watering implies the choice of a watering method and a corresponding urban infrastructure. For any given target-area, every watering method can be characterized by three parameters: the watering period, the watering rate and the watering frequency. The former indicates the period of each day during which pavement-watering is active, the second is the average

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amount of water delivered per unit area and per unit time (expressed in mm/h, equivalent to L/m^2 h) and the last indicates the frequency of the watering cycles. Of these parameters, the watering rate is the one that defines the method's water consumption and is therefore important for decision-makers who face growing public pressure to reduce urban water use.

Several watering methods have been proposed or studied in the existing literature. For methods including vertical surface watering, a closed-loop watering system is usually designed. He and Hoyano [5] describe a building surface water supply of 12 kg/(m^2 h) for watered building walls. Wei and He [6] conduct a similar simulation but include pavement-watering of a water-retaining pavement. The simulated water-retaining pavement is saturated at midnight, but no detail is given as to the amount of water required to saturate the water-retaining pavement. In 2008, the City of Paris funded a numerical research program aimed at testing different climate change adaptation strategies for heat wave events [7]. This work analyzed a daytime pavement-watering method based on a hypothetical infrastructure connected to the city's non-potable water network. Pavements and sidewalks were watered at a rate of 0.2 mm/h for a duration of 3 min and frequency of every hour. During this work, a nighttime watering experiment was conducted over the summer of 2012 [8]. A single watering cycle of the pavement and sidewalk was conducted by cleaning truck around 10 pm sprinkling 1 L/m^2, which is estimated by city officials as the maximum retention capacity of standard Parisian pavements. Field studies conducted in Nagoaka City, Japan used an existing snow-melting infrastructure which consists of a ground-water network used to water the road surface. Kinouchi and Kanda [1] ran this system continuously at a rate of 11 mm/h, while Takahashi et al. [3] ran it intermittently to deliver an average 2 mm/h with 3-min sprinkles, every 30 min. Yamagata et al. [4] used reclaimed waste water sprinkled onto a water-retentive pavement by temporary pipes placed on a central road planter. The watering method parameters are not specified in this study or in any of the other cited studies not mentioned in this paragraph.

Of these, only Takahashi et al. [3] and Météo-France and CSTB [7] describe attempts to optimize the watering method with atmospheric cooling parameters. Takahashi et al. [3] optimize both watering rate and frequency based on surface and 90-cm air temperature observations over a period of 1 h after watering. Météo-France and CSTB [7] base their own optimization on findings from Takahashi et al. with the hypothesis of a pavement water-holding capacity of 1 mm. They optimize the watering rate based on 2-m air temperature simulations with a 1-h time step.

This paper looks into the optimization of an adapted version of Bouvier et al.'s [8] pavement-watering method by studying the pavement's thermal behavior. We will demonstrate how pavement heat flux measurements can be used to fine-tune the watering frequency, and how a surface heat transfer analysis combined with a linear relation found between heat flux and solar irradiance during pavement insolation can provide information on the watering rate. Measurements were obtained from one of two experimental sites in Paris over the summer of 2013. For this campaign, the rue du Louvre was equipped with a ground heat flux sensor which was placed 5 cm below the pavement surface as well as a pyranometer, and was watered several times during the day.

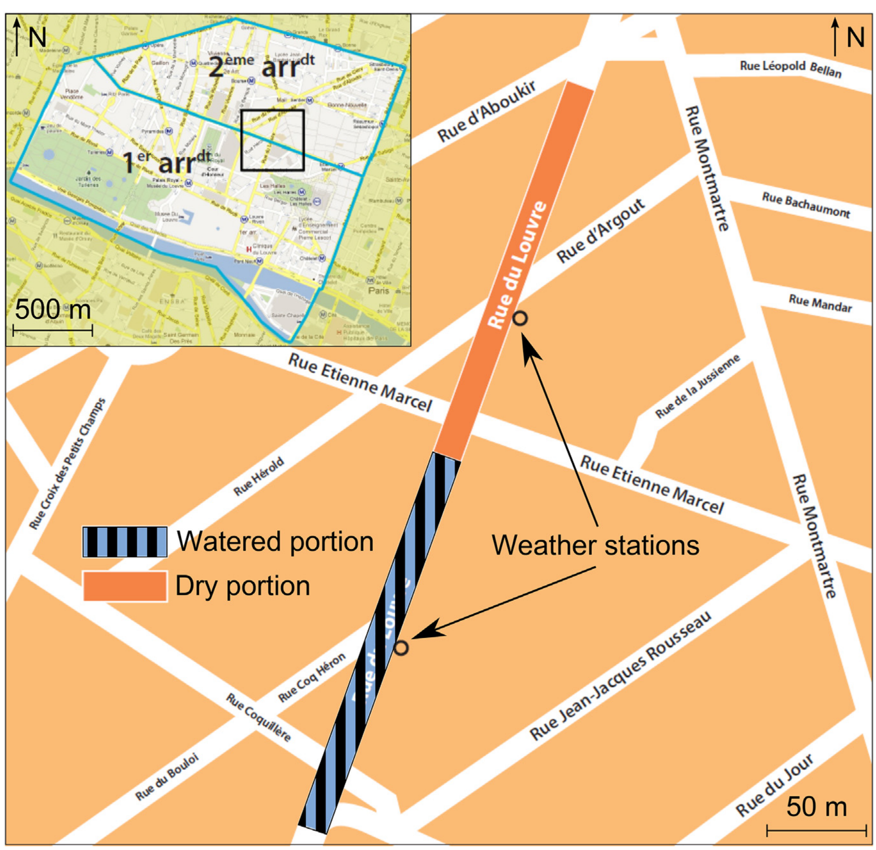

Fig. 1. Map of the rue du Louvre site.