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Improving a pavement-watering method on the basis of pavement surface temperature measurements

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Abstract: Pavement-watering has been studied since the 1990's and is currently considered a promising tool for urban heat island reduction and climate change adaptation. However, possible future water resource availability problems require that water consumption be optimized. Although pavement heat flux can be studied to improve pavement-watering methods (frequency and water consumption), these measurements are costly and require invasive construction work to install appropriate sensors in a dense urban environment. Therefore, we analyzed measurements of pavement surface temperatures in search of alternative information relevant to this goal. It was found that high frequency surface temperature measurements (more than every 5 minutes) made by an infrared camera can provide enough information to optimize the watering frequency. Furthermore, if the water retaining capacity of the studied pavement is known, optimization of total water consumption is possible on the sole basis of surface temperature measurements.

Keywords

Pavement-watering; evaporative cooling; pavement temperature; urban heat island; climate change adaptation

1. Introduction

Pavement-watering, is only a recent topic in French cities such as Paris and Lyon [1]–[4], while it has been studied as a method for cooling urban spaces in Japan since the 1990's [5]–[11]. This technique is viewed as a means of reducing urban heat island (UHI) intensity, with reported air temperature reductions ranging from 0.4°C at 2-m [2] to 4°C at 0.9-m [7]. In France and especially Paris, the predicted increases in heat wave intensity and frequency due to climate change [12] and the high sensitivity of dense cities to such episodes [13], [14] have focused research efforts on the search for appropriate adaptation tools. In parallel to techniques such as developing green spaces and improving urban energy efficiency, pavement-watering is seen as one of these potential tools.

As climate change is also expected to create modifications in regional rain patterns, water use optimization of this technique is crucial. The City of Paris has taken an interest in pavement-watering and numerical and experimental studies of the method have been conducted over the last few years [1]–[3]. Previous work by the authors based on these experiments revealed that pavement heat flux and solar irradiance measurements could be used to optimize a pavement-watering technique applied to an approximately N-S street with an aspect ratio of one ($H/W=1$) [3]. It was found that the optimum watering method consisted in watering the exact water-holding capacity of the pavement at the frequency which prevents the surface from drying between watering cycles. In the case of the studied street configuration and pavement materials, sprinkling 0.24-0.30 mm (equivalent to l/m^2) at a

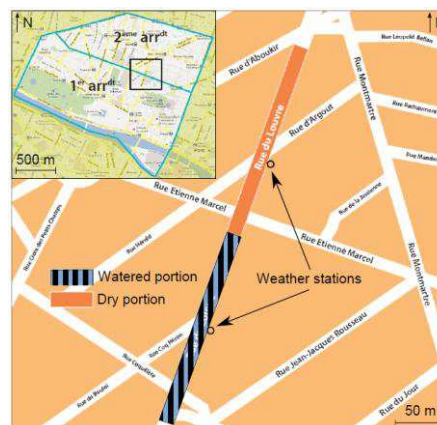
43 frequency of every 60 minutes during shading and every 30 minutes during insolation was
44 recommended.

45 Unfortunately, streets within the same city often have different configurations or use
46 different materials which prevent the generalization of conclusions drawn from a single site. It
47 is therefore recommended to study several characteristic streets before a city-wide strategy
48 can be developed. However, installing a heat flux sensor in combination with solar
49 instruments over long periods of time is an expensive and invasive procedure and requires
50 close cooperation with the relevant city services to avoid acceptability issues. It is therefore
51 difficult to install large quantities of these sensors in a dense urban environment.

52 In order to overcome these issues, we propose to investigate the potential for pavement
53 surface temperature measurements to provide enough information to improve or even
54 optimize a pavement-watering method.

55 2. Materials and Methods

56 Temperatures at the street surface and at a depth of 5 cm were investigated on rue du
57 Louvre, near Les Halles in the 1st and 2nd Arrondissements in Paris, France over the summer
58 of 2013. Measurements were collected during the same experiment as that described by
59 Hendel et al. [3]. Watered and control weather station positions are illustrated in Figure 1.
60 Both watered and dry portions of the street are approximately 180 m long and 20 m wide. Rue
61 du Louvre has an aspect ratio approximately equal to one and has a N-NE-S-SW orientation.



62
63 Figure 1: Map of the rue du Louvre site

64 All data is presented in local daylight savings time (UTC +2). Statistical analyses were
65 conducted using the R software environment, version 3.0.1.

66 2.1. Instruments

67 Surface temperature measurements were made by a Flir B400 thermal camera with a
68 spectral range of 7.5-13 μm . The camera was placed on the roof terrace of 46, rue du Louvre.
69 The camera recorded false-color I.R. thermal and visible images simultaneously every hour
70 on non-watered days and every 10 or 15 minutes on watered days. These images were used to
71 estimate pavement surface temperature.

72 Apparent (measured) surface temperatures were corrected with the parameters indicated in
73 Table 1, as measured by a weather station installed in front of 46, rue du Louvre. The
74 instruments included and their characteristics are summarized in Table 2. The emissivity of
75 the studied surfaces was obtained by the reference black body method, using an adhesive with
76 a known emissivity of 0.95.

Emissivity	0.97
Distance to target	20 m
Reflected temperature	Mean radiant temperature (MRT) measured by weather station
Relative humidity	As measured at 1.5 m by weather station
Air temperature	As measured at 1.5 m by weather station

77 Table 1 : *Parameters used to correct apparent surface temperature*

78 The weather station instruments within pedestrian reach were protected behind a
79 cylindrical white-painted steel cage. Black globe temperature, air temperature and wind speed
80 measurements from the weather station were used to estimate mean radiant temperature
81 (MRT) using the method described by Thorsson et al. [15]. MRT is used as the apparent
82 reflected temperature for I.R. camera measurement corrections. Errors introduced by the use
83 of 4-m rather than 1.5-m wind speed in the calculation of MRT are neglected, as well as the
84 influence of the steel cage.

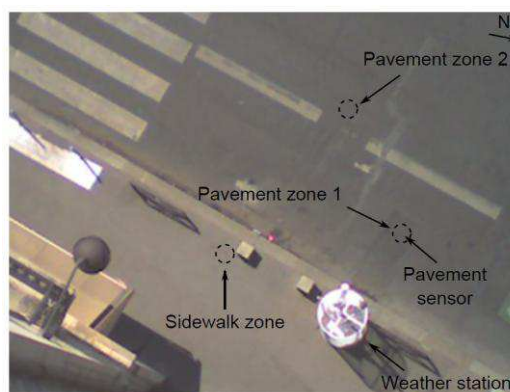
85

Parameter	Instrument	Height	Accuracy
Surface temperature	Flir infrared camera (7.5 – 13 μ m)	Surface	2°C
Relative humidity	Capacitive hygrometer	1.5 m	1.5% RH
Air temperature	Pt100 1/3 DIN B	1.5 m	0.1°C
Black globe temperature	Pt100 1/2 DIN A ISO 7726	1.5 m	0.15°C
Wind speed	2D ultrasonic anemometer	4 m	2%

86 Table 2: *Instrument type, measurement height and accuracy*

87 The camera operated continuously from 8 am on July 8th until 8 am on September 6th.
88 Interruptions occurred between 7:20 pm on July 8th until 6 pm on July 11th and from 6 pm on
89 July 12th until 2:30 pm on July 15th. These are due to failures of the camera's time-lapse
90 computer.

91 Three street areas were surveyed for their surface temperature as can be found in Figure 2:
92 pavement zone 1, located above the pavement sensor, pavement zone 2, located further
93 towards the street's center and a sidewalk zone. All three had an emissivity of 0.97.



94

95 Figure 2: *Surface temperature measurement zones*

96 **2.2. Watering method**

97 **2.2.1. Weather conditions**

98 Watering was started if certain weather conditions were met according to Météo-France’s
99 three-day forecast. These as well as those for heat-wave warnings are presented in Table 3.
100

Parameter	Watering starts	Heat-wave warning level
Mean 3-day minimum air temperature (BMI_{Min})	$> 16^{\circ}\text{C}$	$>21^{\circ}\text{C}$
Mean 3-day maximum air temperature (BMI_{Max})	$> 25^{\circ}\text{C}$	$>31^{\circ}\text{C}$
Wind speed	$< 10 \text{ km/h}$	-
Sky conditions	Sunny (less than 2 oktas cloud cover)	-

101 Table 3: *Weather conditions for pavement-watering and heat-wave warnings*

102 Cleaning trucks were used to sprinkle approximately 1 mm every hour from 6:30 am to
103 11:30 am and every 30 minutes from 2 pm until 6:30 pm on the sidewalk and pavement. This
104 amount of water is considered to be the maximum water-holding capacity of the road surface
105 in Paris by urban managers. Exact watering times were reported by truck operators, cross-
106 checked against visible images taken by the rooftop camera when available. Resulting
107 watering time precision is estimated to be no better than 5 minutes. A picture of pavement-
108 watering is presented in Figure 3.

109 Water used for this experiment was supplied by the city’s 1,600 km non-potable water
110 network, principally sourced from the Ourcq Canal. This water network is currently regarded
111 by urban managers as having high sustainability potential for urban uses that do not require
112 potable water such as green space irrigation [16].



113
114 Figure 3: *Pavement- and sidewalk-watering on July 8th by a cleaning truck and its operators*

115 **3. Street Surface Temperatures**

116 I.R. camera measurements from July 8th, 22nd (watered), 20th and 21st (control) will now be
117 considered. As no surface temperature data was collected on July 7th or 11th, it is not possible
118 to compare wet pavement surface temperatures from July 8th with dry pavement surface
119 temperatures made a few days before or later in comparable weather conditions. July 20th is
120 the closest control day with available data.

121 Although sun trajectories can change very rapidly during certain periods of the year, these
 122 changes are relatively small during the month of July. The daytime period on July 20th is
 123 approximately 25 minutes shorter than on July 8th, while solar zenith is reduced by less than
 124 2°. For the purpose of this discussion, we consider these changes to be negligible.

125 3.1. Results

126 Figure 4 through Figure 7 present corrected apparent surface temperature measurements
 127 for three different areas of the street: the (x) series represents pavement zone 1; the (+) series
 128 represents pavement zone 2; the (o) series represents the sidewalk. Some data points are
 129 missing due to passing or parked vehicles over the measurement area. Vertical dot-dashed
 130 lines indicate watering cycles for July 8th and 22nd. It should be noted that afternoon watering
 131 on July 8th occurred about every 45 minutes, while it was every 30 minutes on July 22nd.

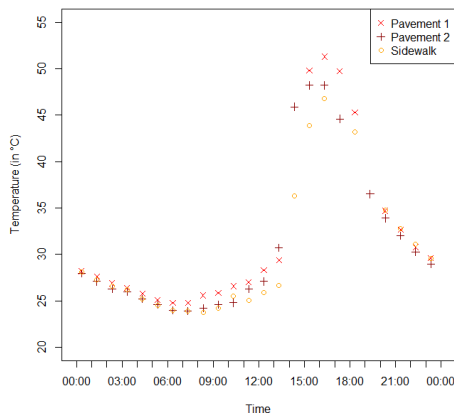


Figure 4 : Corrected Apparent Pavement Surface Temperature on July 20th

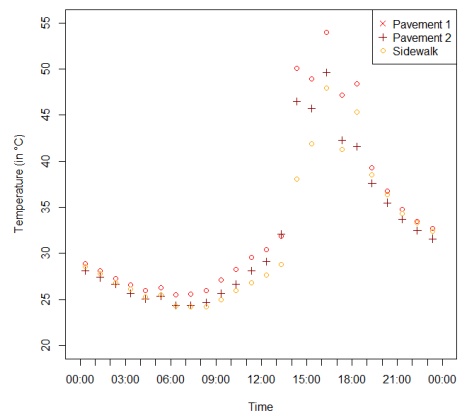


Figure 5 : Corrected Apparent Pavement Surface Temperature on July 21st

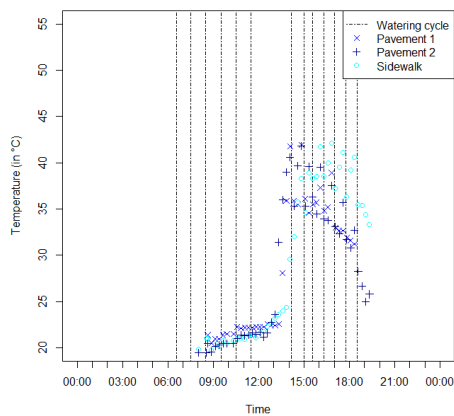


Figure 6 : Corrected Apparent Pavement Surface Temperature on July 8th

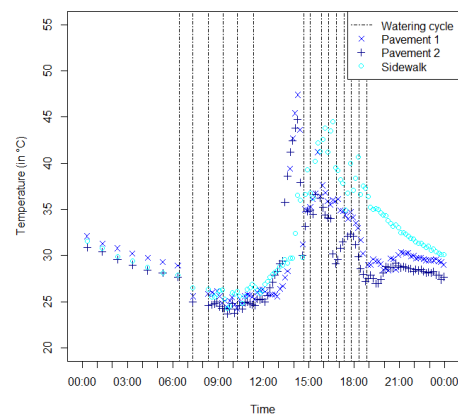


Figure 7 : Corrected Apparent Pavement Surface Temperature on July 22nd

132 On July 20th and 21st, surface temperatures reach a low of 24°C between 6 am and 7 am
 133 and a high of 50-54°C at 4 pm. All three surfaces follow a very similar trend, with nocturnal
 134 temperatures being almost the same for each zone. Differences are more pronounced during
 135 the day, particularly during insolation. During the day, pavement zone 1 is the warmest,
 136 followed by pavement zone 2, while the sidewalk is the coldest.

137 On July 22nd, the daily low was also about 24°C, but this temperature was maintained from
 138 7:30 am until 12 pm. A maximum temperature of about 47°C was reached just before
 139 afternoon pavement-watering began. After watering begins, the temperature of all surfaces

140 remains below 45°C. Similar temperatures and trends are observed in available data from July
141 8th. Unlike on control days, the sidewalk is the warmest area once afternoon watering begins.

142 On both July 8th and 22nd, several temperature spikes are visible just before watering
143 cycles. For pavement zones 1 and 2, these are mainly found on July 8th while for the sidewalk
144 these can be found on both watered days. On July 8th, almost all occur once afternoon
145 watering is underway. On July 22nd, when watering occurs more frequently, only one
146 pavement temperature spike is observed after pavement-watering resumes in the afternoon.
147 Spikes which are found before afternoon watering occur for the pavement zones only. The
148 amplitude of these local maxima is in the order of 5°C on July 8th for all three zones. On July
149 22nd, the amplitude of the sidewalk maxima is reduced to about 2-3°C.

150 Table 4 summarizes the average changes in surface temperatures between 6:30 am and 1
151 pm and between 3 pm and 6:30 pm on July 22nd (watered) compared to the average
152 observations from July 20th and 21st (control).
153

	Pavement 1 (x)	Pavement 2 (+)	Sidewalk (o)
6:30 am – 1 pm	1.6°C	0.73°C	-1.1°C
3 pm – 6:30 pm	13°C	11°C	6.2°C

154 Table 4: Average temperature reductions observed on July 22nd (watered) compared to average
155 control day temperatures (July 20th and 21st)

156 Temperature reductions are most important in the afternoon and most pronounced for
157 pavement zone 1 followed by pavement zone 2. The sidewalk has the lowest temperature
158 reductions of the three zones and even has higher surface temperatures in the morning of July
159 22nd despite pavement-watering. This is interpreted as being caused by significantly higher
160 atmospheric temperatures as well as by higher surface temperatures before 6 am on July 22nd.

161 3.2. Discussion

162 Surface temperatures were found to be lowered by pavement-watering by between 6° and
163 13°C. The daily minimum temperature was found to be unchanged despite warmer morning
164 temperatures and was maintained over several hours. The daily maximum temperature was
165 also several degrees lower on watered days. In addition, temperature spikes were observed on
166 watered days, both before and during afternoon pavement-watering, which were not present
167 on control days.

168 The local temperature spikes found on watered days, both before afternoon watering began
169 and in between cycles afterwards, allow us to make recommendations to improve the effect of
170 pavement-watering: afternoon watering should begin just before surface insolation to limit the
171 initial temperature increase, while a watering cycle period of 30 minutes for the pavement is
172 sufficient to erase spikes which occur during afternoon pavement-watering. However, 30
173 minutes remains too long for the sidewalk which requires higher frequency watering.

174 Indeed, the first spikes in surface temperatures are reached because the first afternoon
175 watering cycle occurs too late compared to the last morning watering cycle. With more than
176 two hours since the last watering cycle, the studied surface areas were dry when they became
177 exposed to direct sunlight. Had watering begun a few minutes before insolation, the surfaces
178 would have been wet when they became insolated. The water would then have limited the
179 initial temperature increase and lowered the maximum surface temperature reached. This is
180 also the case of the sidewalk, even though no maxima are visible before afternoon watering
181 began. This is due to the fact that the sidewalk remained shaded until watering resumed.

182 The spikes reached once afternoon watering is underway indicate an insufficient watering
183 frequency. They occur in between watering cycles, only if the surface has had enough time to
184 dry out, as is confirmed by corresponding visible images. Increasing the watering frequency
185 should therefore erase these temperature spikes. This is confirmed when comparing pavement
186 temperatures from July 8th and 22nd, when the watering cycles occurred every 45 and 30
187 minutes, respectively. While 45 minutes was too long, 30 minutes was sufficient for the
188 pavement. Since spikes are still visible even with 30-minute watering for the sidewalk, a
189 shorter watering period is necessary. This is due to the sidewalk's surface texture which is
190 significantly smoother and therefore retains less water than the pavement.

191 Pavement temperature observations are consistent with those made by Kinouchi & Kanda
192 [5], [6] and Yamagata et al. [8]. Differences in surface temperatures in zones 1 and 2 may be
193 explained by differences in pavement materials and geometry (different surface slopes). In
194 addition, observations made on pavement zone 1 are quite similar to those made by Hendel et
195 al. on pavement heat flux [3].

196 **4. Conclusion**

197 The field study conducted on rue du Louvre in Paris over the summer of 2013 has allowed
198 us to explore the effects of pavement-watering on street surface temperatures. They were
199 found to be reduced by several degrees, both during and after watering.

200 Surface temperature measurements were found to provide useful information for
201 optimizing the watering method. Namely, it appears that for pavement surfaces in Paris in the
202 month of July, watering can be conducted every 30 minutes during insolation of the pavement
203 and every hour during pavement shading. However, 30 minutes is too long for the sidewalk
204 during insolation.

205 The pavement-watering frequency can therefore be optimized on the basis of time-lapse
206 infrared camera temperature surveys. A pyrometer, which measures spot surface temperatures
207 and is significantly cheaper, could also be used, but unlike I.R. cameras they do not allow the
208 simultaneous survey of different areas, however, given their lower cost, it may still be feasible
209 to install several in order to compensate for this. Installation of either instrument in the street
210 is simple and non-invasive compared to pavement sensors, provided that access to sufficient
211 electrical power is simple as well. Street lamps make for a suitable candidate for the power
212 supply requirements, but many Parisian streets have street lamps mounted directly onto
213 building façades where adding additional weight is difficult. To ensure that no relevant data is
214 omitted, the measurement frequency should be every 5 minutes at least.

215 Finally, if this method is combined with an independent measurement of the water-holding
216 capacity of the pavement, the overall water consumption of the pavement-watering method
217 can be optimized.

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223 during the preparation phase of this experiment.

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225 the City of Paris.

226

227 **Nomenclature**

- 228 *APUR* Parisian urban planning agency
229 *BMI_{Min}* Minimum biometeorological index, 3-day mean of daily low temperature, °C
230 *BMI_{Max}* Maximum biometeorological index, 3-day mean of daily high temperature, °C
231 *MRT* mean radiant temperature, °C
232 *UHI* urban heat island

233 **References**

- 234 [1] Météo-France and CSTB, “EPICEA - Rapport final,” 2012.
235 [2] M. Bouvier, A. Brunner, and F. Aimé, “Nighttime watering streets and induced effects on the
236 surrounding refreshment in case of hot weather. The city of Paris experimentations,” *Tech. Sci.*
237 *Méthodes*, no. 12, pp. 43–55 (In French), 2013.
238 [3] M. Hendel, M. Colombert, Y. Diab, and L. Royon, “An analysis of pavement heat flux to
239 optimize the water efficiency of a pavement-watering method,” *Appl. Therm. Eng.*, no. Under
240 review, 2014.
241 [4] J. Nicolas, “Reducing the urban heat island effect,” *Le Moniteur*, 2013. [Online]. Available:
242 [http://www.lemoniteur.fr/133-amenagement/article/actualite/22580961-experimentation-](http://www.lemoniteur.fr/133-amenagement/article/actualite/22580961-experimentation-reduire-l-effet-d-ilot-de-chaaleur-urbain)
243 [reduire-l-effet-d-ilot-de-chaaleur-urbain](http://www.lemoniteur.fr/133-amenagement/article/actualite/22580961-experimentation-reduire-l-effet-d-ilot-de-chaaleur-urbain) (In French). [Accessed: 22-Jan-2014].
244 [5] T. Kinouchi and M. Kanda, “An Observation on the Climatic Effect of Watering on Paved
245 Roads,” *J. Hydrosoci. Hydraul. Eng.*, vol. 15, no. 1, pp. 55–64, 1997.
246 [6] T. Kinouchi and M. Kanda, “Cooling Effect of Watering on Paved Road and Retention in
247 Porous Pavement,” in *Second Symposium on Urban Environment*, 1998, pp. 255–258.
248 [7] R. Takahashi, A. Asakura, K. Koike, S. Himeno, and S. Fujita, “Using Snow Melting Pipes to
249 Verify the Water Sprinkling’s Effect over a Wide Area,” in *NOVATECH 2010*, 2010, p. 10.
250 [8] H. Yamagata, M. Nasu, M. Yoshizawa, A. Miyamoto, and M. Minamiyama, “Heat island
251 mitigation using water retentive pavement sprinkled with reclaimed wastewater,” *Water Sci.*
252 *Technol. a J. Int. Assoc. Water Pollut. Res.*, vol. 57, no. 5, pp. 763–771, Jan. 2008.
253 [9] T. Nakayama and T. Fujita, “Cooling effect of water-holding pavements made of new materials
254 on water and heat budgets in urban areas,” *Landsc. Urban Plan.*, vol. 96, no. 2, pp. 57–67, May
255 2010.
256 [10] T. Nakayama, S. Hashimoto, and H. Hamano, “Multiscaled analysis of hydrothermal dynamics
257 in Japanese megalopolis by using integrated approach,” *Hydrol. Process.*, vol. 26, no. 16, pp.
258 2431–2444, Jul. 2012.
259 [11] J. He and A. Hoyano, “A numerical simulation method for analyzing the thermal improvement
260 effect of super-hydrophilic photocatalyst-coated building surfaces with water film on the
261 urban/built environment,” *Energy Build.*, vol. 40, no. 6, pp. 968–978, Jan. 2008.
262 [12] A. Lemonsu, R. Kounkou-Arnaud, J. Desplat, J.-L. Salagnac, and V. Masson, “Evolution of the
263 Parisian urban climate under a global changing climate,” *Clim. Change*, vol. 116, no. 3–4, pp.
264 679–692, Jul. 2012.
265 [13] J.-M. Robine, S. L. K. Cheung, S. Le Roy, H. Van Oyen, C. Griffiths, J.-P. Michel, and F. R.
266 Herrmann, “Death toll exceeded 70,000 in Europe during the summer of 2003.,” *C. R. Biol.*,
267 vol. 331, no. 2, pp. 171–178, Feb. 2008.
268 [14] D. Li and E. Bou-Zeid, “Synergistic Interactions between Urban Heat Islands and Heat Waves:
269 The Impact in Cities Is Larger than the Sum of Its Parts,” *J. Appl. Meteorol. Climatol.*, vol. 52,
270 no. 9, pp. 2051–2064, Sep. 2013.
271 [15] S. Thorsson, F. Lindberg, I. Eliasson, and B. Holmer, “Different methods for estimating the
272 mean radiant temperature in an outdoor urban setting,” *Int. J. Climatol.*, vol. 27, no. 14, pp.
273 1983–1993, Nov. 2007.
274 [16] APUR, “Étude sur le devenir du réseau d’eau non potable - Partie 1 : Analyse et diagnostic.”
275