The effect of water-sprinkling on the surface temperatures of the materials used on the "skin" of greek cities

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ABSTRACT

This paper focuses on the effect of water sprinkling on the fluctuation of the surface temperatures of materials, which are widely used in the urban open spaces of Greek cities, and are exposed to solar radiation. The assessment is based on experimental measurements, which were conducted during the summer period of 2004 on samples of building materials. The materials were placed on a flat roof and were periodically sprinkled with water.

1. INTRODUCTION

Water has always been linked to the improvement of thermal comfort during the summer around the Mediterranean. Trucks of water used to wet the streets of post-war Athens in the afternoon hours of the summer months, while the elders wetted the porches of their houses. These applications were spontaneous and practical. In this paper, the effect of water on the surface temperatures of samples of building materials, which are commonly used in the urban open spaces and on the flat roofs of buildings in Greece is examined through an experimental, preliminary field study.

2. GENERAL DATA ON EVAPORATION

2.1 Definition and description

Evaporation is the physical process during which a liquid changes phase and is transformed into vapour or gas. Evaporative cooling is defined as "the process that uses the effect of evaporation as a natural heat sink" (Santamouris and Asimakopoulos, 1996). The effect of the evaporation of water is that it requires a certain amount of heat in order to occur. This energy is called latent heat of evaporation and varies according to the ambient temperatures (Oke, 1995).

2.2 Effect on the temperatures of materials

When the materials, which are used in the open spaces of the city, are sprinkled or sprayed with water, the evaporation causes a reduction in their temperature (Velasquez et al., 1991). This reduction can be calculated based on the data cited by Kimura in (Kimura, 1991). This strategy can be very efficient concerning the reduction of the surface temperatures of roofs (Watson and Labs, 1983) and light-weight coverings (Velasquez et al., 1991).

3. EXPERIMENTAL MEASUREMENTS

3.1 Presentation of the study

The measurements took place during the daytime period of the last week of July 2004, from the 25th to the 30th of July. The surface temperature readings were taken with an Optex Thermo-Hunter Infrared Thermometer (IR Thermometer) at one-hour intervals from 08:00 in the morning until 20:00 in the evening. As this was a preliminary study, five different patterns of water sprinkling (referred to, from now on, as P1 to P5) were applied (Table 1), on a variety of samples of building materials, which were placed on a flat roof (Fig. 1).

In this paper, the effects of sprinkling will be presented only for a few groups of materials, which are commonly used in the urban open spaces of Greek cities (Table 2).

Table 1: Different sprinkling patterns, which were applied on samples of building materials on July, 2004.

P	Date	Intervals	Hours	Tair mean
1	25th	30 min	12:00-13:30 and 16:00-17:00	31.7
2	26th	Once	15:30	31.4
3	27th	Twice	16:30, 17:30	30.8
4	28th	Three times	15:30, 16:30, 17:30	30.6
5	30th	60 min	8:30-12:30	30.2

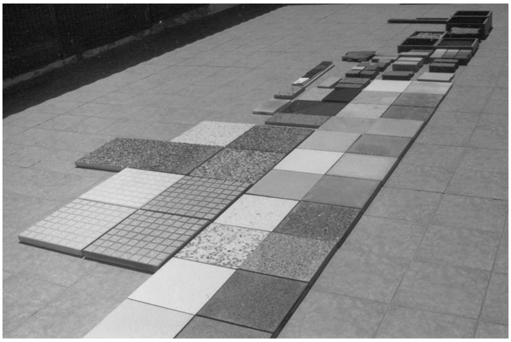

Figure 1: Samples of materials placed on a flat roof.

Table 2: Different groups of building materials.

Asphalt	: Old and New
Simple cement slabs	: W, Y, R and G
Street mosaic slabs	: W, Y, R and G
Porous cement blocks	: W, Y, R and G
Earth	: Ochre and Brown

W: white, Y: yellow, R: red, G: grey

It should be noted that earth is seldom found in the city centres. Nevertheless, due to its increased water permeability, it can be used as a basis in order to compare the effect of sprinkling in permeable and impermeable materials.

3.2 Experimental measurements

The effect of water-sprinkling on the surface temperatures of samples of building materials is assessed through the comparison of the absolute maximum and mean surface temperatures to the respective values, which were measured on the same samples one week earlier, on July 10th, 2004. This was a day with particularly overheated conditions (mean air temperature: 33.2 degrees C). The difference in the air temperatures of each day does not allow the overall comparison of the results of the five sprinkling patterns. Consequently, for each group of materials, each pattern is separately presented and compared to the "base" temperatures of July 10th.

3.2.1 Sprinkling patterns P2, P3 and P4

Patterns P2, P3 and P4 were confined to the afternoon hours, when the maximum surface temperatures of the materials develop, and aimed at reducing them. For most of the materials, P2, P3 and P4 produced similar results on both the absolute maximum (Table 3) and the mean surface temperatures (Table 4).

It can be seen that the effect of limited water-sprinkling depends mainly on the porosity of the materials. In the cases of cement and mosaic slabs, independent of their colour, the effect is approximately 2 to 5 degrees C, for the absolute maximum temperatures, and 3.5 to 5 for the mean temperatures. For the porous cement blocks, the reduction of the maximum temperatures compared to July 10th is about 4 to 6 degrees C, and of the mean temperatures 5 to 6.5

Table 3: Effect (difference in degrees C) of P2, P3 and P4 on the absolute maximum temperatures of the materials, compared to the surface temperatures of July 10th.

Samples	P2	P3	P4
Asphalt, L	5	5	3
Asphalt, D	5-7	7-10	2-4
Cement slabs, L	2-3	3-4	3
Cement slabs, D	3	3-4	3
Mosaic slabs, L	2-5	2-5	2-3
Mosaic slabs, D	2-4	4-5	3-4
Porous blocks, L	5	6	5
Porous blocks, D	4-5	5-6	3
Earth, L	9	9	7
Earth, D	4	8	4

L: light-coloured / D: dark-coloured

Table 4: Effect (difference in degrees C) of P2, P3 and P4 on the mean temperatures of the materials, compared to the surface temperatures of July 10th.

Samples	P2	P3	P4
Asphalt, L	5.6	5.1	5.3
Asphalt, D	6.4-6.7	6.9-7.4	6.1-7.5
Cement slabs, L	4.1-5.4	3.7-4.6	4.5-5.6
Cement slabs, D	3.8-4.2	3.3-4.6	3.8-4.7
Mosaic slabs, L	3.5-5.1	3-4.5	3.8-4.9
Mosaic slabs, D	3.6-4.5	3.5-4.2	4.1
Porous blocks, L	5.6-5.7	6.3-6.6	6.6-6.8
Porous blocks, D	4.6-5.6	5.9-6.6	5.2-6.3
Earth, L	8.3	8.5	9.4
Earth, D	4	5.3	6

L: light-coloured / D: dark-coloured

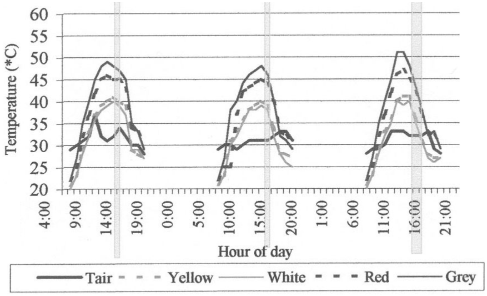

Figure 2: Effect of P2, P3 and P4 on mosaic slabs.

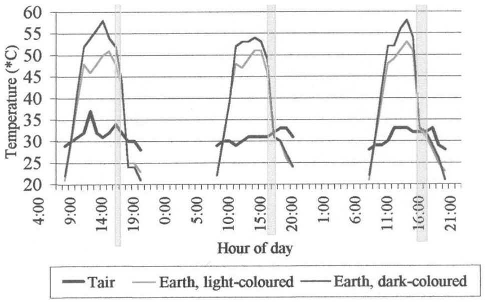

Figure 3: Effect of P2, P3 and P4 on earth samples.

degrees C. It is interesting to note that the effect of P2, P3 and P4 on the dark-coloured asphalt samples was similar to that on the porous cement blocks. This is probably due to the fact that the samples were poured on site and did not have the final sealing coating.

Finally, as was expected, the effect of all three patterns was more pronounced in the case of the earth samples, where it caused a mean reduction of 8 and 6 degrees C, respectively, in their absolute maximum temperature. This reduction was even more significant in the mean surface temperatures of the two samples.

3.2.2 Sprinkling pattern P1 and P5

The feature, which differentiates P1 and P5 from the rest of the patterns, is the fact that the sprinkling took place before noon. For this reason, the results of those two sprinkling patterns are presented together (Tables 5 and 6).

It can be seen that for the different samples of building materials, patterns P1 and P5 provided the most pronounced reduction in both the absolute maximum and the mean surface temperatures, compared to the measurements of July 10th. This reduction was quite impressive for the absolute maximum temperatures of the two samples of earth (12 to 13 degrees C for the light-coloured sample and 16 to 18 degrees C for the dark-coloured one). P5 caused a slightly larger reduction in the mean temperatures of the earth samples than P1. In the cases of cement and mosaic slabs, independent of their colour, the effect is approximately 4 to 7 degrees C, for the absolute maximum temperatures, and 4.5 to 7.5 for the mean temperatures. For the porous cement blocks, the reduction of the maximum temperatures compared to July 10th is about 7 to 9 degrees C, while the mean reduction of the mean surface temperatures is about 6.5 to 11.5 degrees C. It is interesting to note that the effect of P1 and P5 on the absolute maximum temperatures of the dark-coloured asphalt samples was similar to that on the porous cement blocks.

Table 5: Effect (difference in degrees C) of P1 and P5 on the absolute maximum temperatures of the materials, compared to the surface temperatures of July 10th.

Samples	P1	P5
Asphalt, L	6	8
Asphalt, D	7-8	9-10
Simple cement slabs, L	5-7	6-7
Simple cement slabs, D	4-9	5-6
Street mosaic slabs, L	5-6	4-5
Street mosaic slabs, D	5-7	6
Porous cement blocks, L	9	9
Porous cement blocks, D	7-9	9
Earth, L	13	12
Earth, D	16	18

L: light-coloured / D: dark-coloured

Table 6: Effect (difference in degrees C) of P1 and P5 on the mean temperatures of the materials, compared to the surface temperatures of July 10th.

Samples	P1	P5
Asphalt, L	5.6	7.9
Asphalt, D	5.4-6.1	9.3-9.7
Cement slabs, L	5-7.2	7.1-8.1
Cement slabs, D	4.2-6.8	6.2-6.4
Mosaic slabs, L	5.3-6.4	6.2-7
Mosaic slabs, D	4.5-6.8	6.4-7.5
Porous blocks, L	7.6-9	5.8-8.6
Porous blocks, D	10.2-12	8.6-10.9
Earth, L	13.4	15
Earth, D	11	13.3

4. CONCLUSIONS

4.1 Some preliminary findings

First of all, it should be noted that the air temperatures of the five measuring days vary considerably, not only compared to one another, but also compared to the base-case day. On the first day (July 25th) the mean air temperature was lower by about 2 degrees C than on July 10th.

Water-sprinkling patterns P2, P3 and P4 had almost identical results on the surface temperatures, while the same observation was also made concerning the patterns P1 and P5. In all the groups of materials, the surface temperatures, which were measured during the first and the fifth day of the study, were found to be significantly reduced compared to those, which were measured on July 10th.

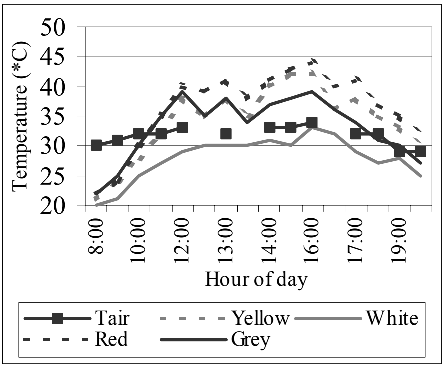

Figure 4: Effect of P1 on simple cement slabs.

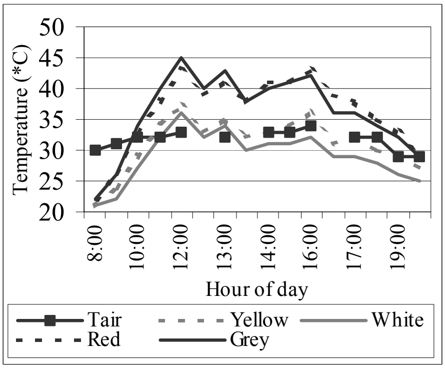

Figure 5: Effect of P1 on porous cement blocks.

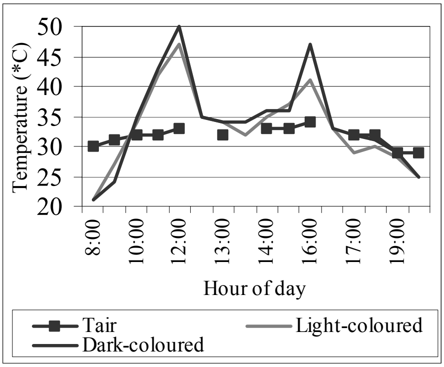

Figure 6: Effect of P1 on earth samples.

The efficiency of P1 and P5 is most probably due to the fact that the temperature rise of the materials is delayed by the sprinkling effect until the hours around noon. As the materials begin to heat up so late in the morning, both their mean and absolute maximum temperatures are significantly reduced. The second half of P1 contributed to the quicker cooling down of the material, and thus affected the mean surface temperatures.

In whole, the measurements and the diagrams clearly demonstrate that it is more important to use water-sprinkling as a means of delaying the appearance (“pushing” them further in the afternoon) of the absolute maximum temperatures, than as a way to reduce them when they appear early in the afternoon. This explains the inefficiency of P2, P3 and P4 to reduce the absolute maximum temperatures of the materials. Nevertheless, in the case of porous materials, even the smallest reduction was still better than that of non-porous materials.

Concerning the results of the study, a distinction should be made concerning the effect of water-sprinkling on light-coloured and dark-coloured materials. The reduction of the surface temperatures, which was measured, was of the same magnitude in both light- and dark-coloured materials. Nevertheless, even the significant reduction achieved in all the groups of materials by P5 cannot be considered as very efficient, in the case of dark-coloured materials, where absolute maximum temperatures may well exceed 50 degrees C.

Another important point, which should be taken into consideration is the effect of the material porosity on the efficiency of the water sprinkling patterns. Even though the effect of the various sprinkling patterns on the absolute maximum temperatures of both porous and non-porous building materials was similar, the effect on the mean surface temperatures of porous materials was far more significant. Of course, the effect of water-sprinkling is even more remarkable on permeable earthen materials, such as earth.

4.2 Limitations of implementation

The most important drawback for the implementation of water sprinkling in the urban open spaces of Greek cities in order to reduce the surface temperatures of the materials is the limited availability of water in many cities of Greece during the summer. This problem could be solved with the use of non-potable water. The use of processed grey water is also possible (Wakabayashi et al., 1998), as well as the use of water coming from rainwater reservoirs, drilling and wells. Nevertheless, the use of seawater is not recommended due to the destructive effect of salt on certain groups of materials, and especially those made of cement and natural stone (Landsberg, 1981).

4.3 Possible disadvantages

A possible problem of water-sprinkling is the appearance of efflorescence in certain groups of materials. During this field study, efflorescence was observed on the surface of slabs and blocks made of cement. This fact is consistent with the observations of Cook et al. (Cook et al., 2003).

Another point, which should be taken into consideration, is the resultant increase in the relative humidity of the ambient air, which is caused by the evaporation of water. This increase does not provide a reduction in the air temperature, similar to this, which is produced with the use of micronisers (Rodriguez et al., 1991). This observation together with the fact that water-sprinkling is less efficient in reducing the surface temperatures of materials compared to shading resulted in the ruling out of this strategy from the design of the urban open spaces of the Expo'92 site in Seville, Spain (Alvarez et al., 1991).

4.4 Parallel advantages

The combination of the use of water-sprinkling with the use of water-permeable surfaces (earthen materials, or materials placed on a substrate of earth, gravel or sand) can have considerable parallel advantages concerning the water cycle in the city. This increase of the water-permeability of the soil can help enrich the underground water bodies and, most important alleviate the acute consequences of severe showers during the summer (Landsberg, 1981).

4.4 Architectural parameters of consideration

Water-sprinkling cannot be applied universally to all the urban spaces of the city. It should constitute an integral part of the design concept e.g. incorporation of jet fountains or micronisers in the pavements of central squares (Asencio Cerver, 2000), with a *mineral* character and lack of shading elements.

4.5 Setting the guidelines for a full-scale study

The aim of the study was to reach some preliminary conclusions concerning the effect of water sprinkling on the surface temperatures of materials. Consequently, the sprinkling patterns, which were applied and assessed, were not the result of a detailed methodology, but aimed at providing some general indications on a variety of sprinkling patterns, ranging from more frequent to more scarce. These sprinkling patterns should also include night-time applications, especially for materials, which are used on the flat roofs of buildings. It is obvious that for the formulation of more concrete conclusions, a detailed and systematic sprinkling schedule should be followed.

In deciding the various schedules, what should be considered is the ability of a water-sprinkling pattern to reduce the absolute maximum temperatures, which coincide with the most thermally stressed hours of the day, after solar noon (13:30 Local Clock Time). Another point, which should be taken into consideration when deciding on a water-sprinkling pattern, is the ability to reduce the surface temperatures of materials around sunset. The materials, which are exposed to full sun during the day, retain their elevated surface temperatures until early in the evening, and in this way heat adjacent air layers.

Finally, it is certain that the fact that the samples were placed on an impermeable surface (flat roof with ceramic tiles) had an effect on the efficiency of the strategy. As a result, a full-scale study should take seriously into consideration the substrate, on which the samples of building materials would be placed.

ACKNOWLEDGEMENT

The author would like to thank the Greek State Scholarships Foundation (I.K.Y.) for supporting

the on-going Ph.D. thesis, of which this study forms part.

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