22

The Summer Thermal Behaviour of “Skin” Materials in Greek Cities as a Decisive Parameter for Their Selection

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1. Introduction

The materials, which are used for the pavements of urban spaces and the external renderings of vertical (facades) and horizontal (flat roofs) surfaces of buildings, constitute, the "skin" of a city. In Greece, the selection of these materials is most of the times, based on economic and aesthetic criteria. While the importance of these selection parameters is clear and irrefutable, it should be noted that paving and facade materials play a decisive role on the heat transfer processes, which take place between the city and the climatic environment.

Greece has a warm Mediterranean climate, where the long hours of sunshine and the intensity of solar radiation during the summer result in elevated temperatures of the horizontal and vertical city surfaces in different periods of the day. These high temperatures largely affect the deterioration of the urban heat island (Oke, 1995; Akbari, 1992; Santamouris, 2001a) and thermal comfort conditions in urban open spaces. For the city of Athens, the development of the urban heat island during the summer has grave consequences on the energy consumed for cooling (Santamouris, 2001), and negatively influences many aspects of the citizens’ everyday life.

The thermal behaviour of paving materials has been documented by various researchers, both in-situ in urban open spaces (Givoni, 1998; Marques de Almeida, 2002; Cook, et al., 2003; Labaki, et al., 2003) and experimentally on samples building materials (Cook, et al., 2003; Doulos, et al., 2004; Atturo and Fiumi, 2005, Synnefa, et al., 2006). The thermal behaviour of the materials, which form the outer surfaces of building facades, has been investigated in studies. The studies, which were concerned with the effect of shading, and the surface temperatures of various façade materials were carried out by such workers as Hoyano, 1988; Cadima, 1998; Papadakis, et al., 2001; Cantuaria, 2002; Boon Lay, et al., 2000, as well as in a previous study by the author Bougiatioti, et al.(2009).

The study presented in this chapter attempts to combine the two different approaches. It examines the thermal behaviour of paving and façade materials during the summer period, both in-situ in urban open spaces and buildings in Athens, Greece, and samples of building materials placed on a flat roof and exposed to solar radiation during the summer period. The aim of the research is to provide a large set of experimental data (surface temperatures), which can help better in understanding the summer thermal behaviour of the most commonly used surfacing materials in Greece. This experimental data can be qualitatively incorporated as input to the total “image” of each material, in such a way as to be easily evaluated and understood by architects and planners.

The study is divided into two parts: the first part presents the results that concern paving materials and the second presents those involving the facade materials. In each, both the in-situ and the experimental measurements are presented in a cumulative way, in order to draw conclusions on the thermal behaviour of the various building materials during the summer period and the parameters that affect and determine it.

For paving materials, in-situ measurements were conducted in a number of selected urban open spaces in Athens, while experimental measurements involved samples of building materials placed on a flat roof. The materials, which were measured during both the in-situ and the experimental study, were classified into the following general categories: Loose, earthen materials, Natural stone products (slabs of marble, granite), Cement products (gavel concrete, slabs and blocks,), Ceramic products (tiles and blocks), Wooden products (boards), Asphalt products (asphalt concrete), Vegetal surfaces (in-situ measurements) and Water surfaces (in-situ measurements).

For façade materials, in-situ measurements were conducted on the facades of a number of selected buildings, while experimental measurements involved samples of building materials placed on an experimental setting facing, first towards the West and then towards the South. The materials of which temperatures were measured during both the in-situ and the experimental study, were classified into the following general categories: Natural stone products (slabs of marble, granite), Cement products (lime-cement mortar on selected building facades), Ceramic products (tiles and panels), Wooden products (composite panels), Metal products (metal sheets and composite panels), Vegetal surfaces (in-situ measurements of wall covered with climbing plants) and Photovoltaic (PV) panels (in-situ measurements).

The in-situ surface temperatures of paving, as well as of facade materials, are influenced by their contact with the substrate, which, in turn, influences thermal storage and time lag. As a result, the surface temperatures, which are measured on placed materials, can be different from those measured on samples of building materials (Cook, et al., 2003). On the other hand, conducting measurements on samples of building materials exposed to the same environmental conditions provides the ability to simultaneously measure the surface temperatures of a large number of materials. While the measurements on samples of building materials might not reflect their real thermal behaviour, they provide comparative information on the fluctuation of their surface temperatures. Either way, due to the large number of parameters, which influence the surface temperature of building materials in the urban context, it goes without saying that the experimental measurements presented in this chapter should be considered as indicative and not absolute.

The results of the in-situ measurements are presented in Table 1 for paving materials and Table 3 for facade materials, while those of the experimental surface measurements are presented in Table 2 for paving materials and Tables 4 and 5 for facade materials with west and south orientations, respectively.

For all the materials, the differences from the respective air temperature values were calculated in order to obtain a more accurate understanding of the results of the measurements. Furthermore, the air temperature around sunset ($T_{19:30}$) is also mentioned, as it is considered to be indicative of the effect that the materials have on the development of the urban heat island and thermal comfort conditions in the evening.

2. The thermal behaviour of paving materials

2.1.1 Methodology of the in-situ measurements

The choice of the urban open spaces, where the measurements were conducted, is based on a number of criteria, such as: use of commonly applied materials, construction details, reduced overshadowing by adjacent buildings and increased insolation during the day, presence in the same space, of both exposed and shaded areas of the materials and architectural issues, concerning design and patterns of use.

The measurements were conducted in 20 open spaces in Athens, Greece for a month, from June 11th to July 8th. The measurement for each space was carried out for one day. The surface temperature readings were taken with an Optex Thermo-Hunter PT-5LD Infrared (IR) thermometer every half an hour, from 8:00 in the morning until 19:30 or 20:00 in the evening. Only days, which were characterised by predominantly clear skies (0/8) and elevated air temperatures (29.6 ^{o}C to 34.5 ^{o}C), were chosen. Relative humidity values were rather low (28.5 % to 52 %), whereas air velocities ranged from 0.6 m/s to 3.2 m/s.

2.1.2 Methodology of the experimental measurements

During the experimental study, the temperatures of a large number of materials that are usually used for the open spaces in Greek cities, as well as for the flat roofs of buildings, were measured. The experimental measurements were conducted on the flat roof of a building. The temperatures of all the materials were measured for a total period of two weeks. The first day measurements included the night-time readings. The measurements were taken with an Optex Thermo-Hunter PT-5LD Infrared (IR) thermometer from 8:00 to 20:00 at 1-hour intervals. Furthermore, for a one-day period, a contact thermometer (Technoterm 9500) was used simultaneously with the IR one, in order to confirm the accuracy of the IR readings and reveal possible discrepancies. Air temperatures, relative humidity and air velocity were also measured on the site.

In order to define the methodology of the experimental study, a small-scale preliminary study was conducted with samples of cement and ceramic products (slabs and tiles), in order to define the placing mode, which is closest to that of actual conditions (materials placed on a concrete substrate). This was as a result of the fact that the placement of the materials influences their surface temperatures. Three identical cement slabs and three identical ceramic tiles were used with the following placement details: fastened with sand-cement mortar on a dense concrete slab, 30cm thick (base case), set directly on a flat roof constructed with light blue-grey ceramic tiles and laid on a 3cm slab of extruded polystyrene (XPS) painted white.

The results of the preliminary study showed that the samples which were placed on the insulating layer, tended to overheat and develop surface temperatures that were significantly higher than those of the base case. The surface temperatures of the samples, which were directly placed on the flat roof, were higher than those of the base case, but quite close to them. Based on these results, all the samples should have been set on a concrete substrate or placed on gravel or sand substrate. Nevertheless, for the large number (80) of examined materials that the study involved, this was not possible. Consequently, it was decided that the materials would simply be placed on the flat roof of the building, without the interference of another layer.

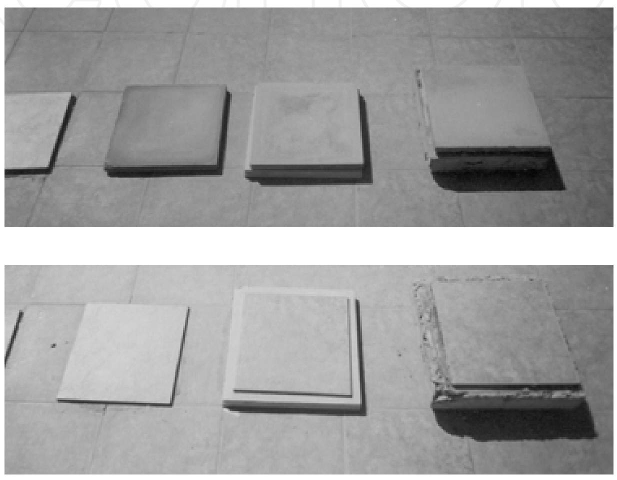


Fig. 1. Short-scale preliminary study. Different placing modes.

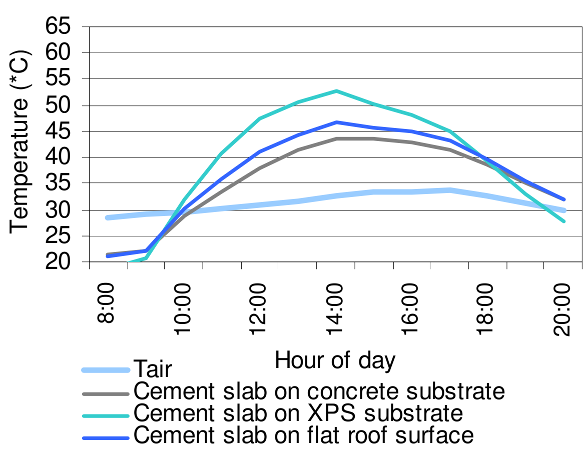


Fig. 2. Short-scale preliminary study. Mean daily temperature fluctuation.

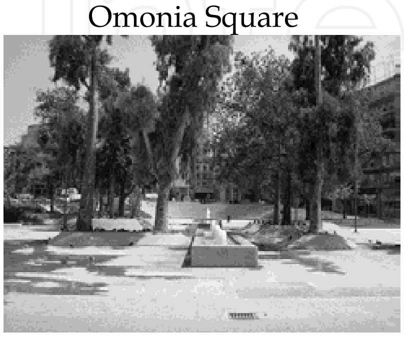
2.2 Results of the in-situ measurements of paving materials

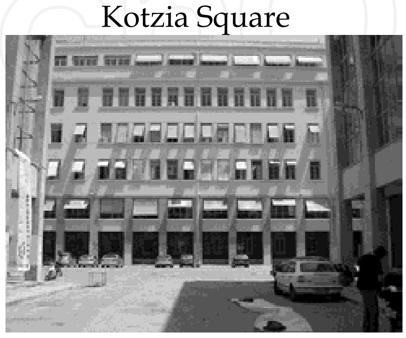
The results of the in-situ measurements, reported here constitute an overview of the overall study. For this reason, the analysis does not cover every urban space separately, but covers the different categories of materials, in general. The results of the measurements are presented in Table 1.


Omonia Square

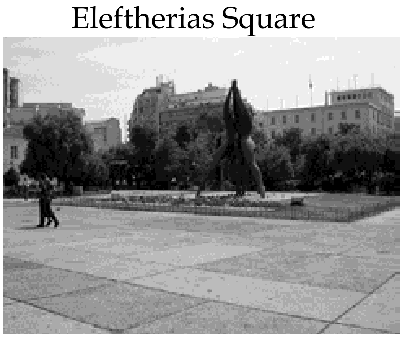

Kotzia Square


Aiolou Street


Eleftherias Square


NTUA Patission Complex


NTUA Zografou Campus


Klafthmonos Square


Dikaiosinis Square


Korai Street

Fig. 3. Pictures of the some of the urban open spaces, where the in situ measurements were conducted.

2.2.1 Loose, earthen materials

Surfaces of loose materials, such as soil, sand and gravel, are seldom found in the urban open spaces of Athens. The few surfaces that were noted and whose temperatures were measured in this study were completely dry. Until solar noon (around 13:30 local time for Athens, Greece near the summer solstice), the measured surface temperatures were very high (Table 1). After this time, most loose materials surfaces cooled down by 2 to 3 ^{o}C every half hour, reaching the air temperature by sunset (19:30 to 20:00).

2.2.2 Natural stone products

Slabs made of natural stone (mainly granite and marble) are used in urban squares, while stone blocks are used mainly in pedestrian and low-traffic streets. As was expected, white marble slabs were cooler than all the other natural stone materials. But dark grey marble and granite slabs recorded very high maximum surface temperatures, which were over 20 degrees above the corresponding air temperature. At 19:30 these materials were about 8 to 9 ^{o}C hotter than the air. Finally, it was observed that the surface temperatures of the shaded materials were very low.

2.2.3 Cement products

Cement products are the most widely used materials for the open spaces of Athens, and of every other Greek city. Concrete with visible aggregates of various sizes (gravel cement), which is poured on site, is mainly used for the paving of squares, pedestrian streets and urban furniture, such as sitting areas. Slabs are used in sidewalks, while blocks are used in pedestrian and low-traffic streets. As was expected, the light-coloured materials (gravel cement and the white slabs) were cooler than the dark-coloured ones (the grey cement slabs, the red mosaic slabs, the gravel cement slabs and the grey cement blocks). It should be noted that the surface temperatures of all the materials, except of the white slabs, were 3.5 to 5.5 ^{o}C hotter than the air around sunset. Also, that the differences in the surface temperatures of exposed and shaded materials were in all the cases significant.

2.2.4 Ceramic products

Ceramic blocks are used in the urban open spaces of Athens in very few cases, mainly in pedestrian streets. In this study, the temperature of the beige ceramic blocks were measured in Korai Pedestrian Street. Due to their colour, the materials did not exhibit very high surface temperatures (Table 1).

2.2.5 Wooden products

Wood is very seldom used in the open spaces of Greek cities. In this study, the temperature of wood surfaces was measured in three cases. Wooden surfaces showed very high surface temperatures, which were comparable even with the surface temperatures of asphalt (Table 1). The mean maximum temperature of wood was 60 ^{o}C, its mean temperature was 46.2 ^{o}C, while its surface temperature at 19:30 was 28.7 ^{o}C, and much lower than the air temperature at that time.

2.2.6 Asphalt products

In the urban open spaces, asphalt products are only used in the form of asphalt concrete, which is widely used for the paving of streets. Asphalt surfaces's temperatures were measured in most urban open spaces. In most cases, their surface temperatures in the afternoon (13:30 - 16:30) were over 50 ^{o}C, in some cases, greater than 60 ^{o}C. At this point, a distinction should be made between newly and old paving. The weathering of asphalt concrete causes the appearance of its aggregates to be usually white, crushed, light-coloured stone and a subsequent increase in its reflectivity. Apart from the apparent differences in the maximum and mean temperatures, it is interesting to note the surface temperatures of the material around sunset (about 19:30). At this time, air temperatures are around 32 ^{o}C, while surface temperatures of new asphalt are 7 ^{o}C higher, and that of old asphalt are about 4.5 ^{o}C higher, while of shaded asphalt are 2.5 ^{o}C lower.

2.2.7 Vegetal surfaces

Vegetal surfaces, such as grass and shrubs, are continuously becoming scarce in the centre of Athens, and their temperatures were measured in few open spaces. As it can be seen in Table 1, in general, vegetal surfaces remain relatively cool during the day. Only the dry grass surface had maximum and mean temperatures equal to 45 and 34.5 ^{o}C, while the evergreen shrubs had low maximum and mean temperatures of 34 °C and 29.5 °C, respectively. The differences in the surface temperatures of dry and irrigated grass are significant: 10.5 °C for the maximum temperatures and 6.1 °C for the mean temperatures. This fact indicates the dependency of the surface temperatures of vegetal surfaces on their irrigation.

2.2.8 Water surfaces

Water surfaces are encountered in the centre of Athens mainly in the form of fountains. The water surfaces, of which temperature were measured in this study were fountains in Kotzia Square and in Eleftherias Square, which showed very low surface temperatures. The obtained maximum and mean surface temperatures were 25.5 and 25.6 °C, respectively, while their surface temperature around sunset was 25.5 °C. It was noted that water surfaces, even in the case of non-functioning jet fountains, were constantly cooler than the air.

	T range 13:30 - 16:30 [°C]	*Abs max T [°C]*	*Abs min T [°C]*	*Mean T [°C]*	*Mean T_{air} [°C]*	*T at 19:30 [°C]*	*T_{air} at 19 :30 [°C]*
Loose, Earthen materials							
Earth, dry	49-54.6	54.6	26.4	42.5	32.5	32.8	32.2
Earth, shade	28.3-31.3	31.5	22.0	28.0	32.1	28.3	32.0
Earth-cement mix	45.8-49.4	49.4	24.4	40.4	34.1	35.0	32.0
Earth-cement mix, shade	30-32.5	32.5	26.5	29.1	33.5	31.0	32.0
Gravel	44-47,3	47,3	22,7	37,7	32,5	31,0	32,0
Gravel, shade	31-32,5	32,5	26,0	29,1	32,4	30,0	32,0
Natural stone slabs and blocks							
Marble slabs, white	41.2-44.7	44.7	23.0	36.3	32.6	33.5	31.5
Marble slabs, white, shade	26-31	31.0	20.0	25.0	29.7	25.0	28.0
Marble slabs, dark grey	53.7-58	58	24.7	44.2	33.1	38.7	32.7
Marble slabs, dark grey, shade	29-32	32.0	26.0	28.7	32.4	29.7	32.0
Stone block, grey	50.9-54.4	54.4	26.4	43.9	32.3	37.7	32.0
Stone block, grey, shade	31-34	34.0	25.0	30.1	32.5	29.3	32.0
Stone block, red	48-51	51.0	25.0	42.3	34.5	37.7	32.0
Stone block, red, shade	31-33	33.0	23.0	29.4	34.5	31.0	32.0
Concrete surfaces, Cement slabs and blocks							
Gravel concrete, white	50-52.3	52.3	26.3	41.6	32.2	38.0	32.0
Gravel concrete, white, shade	27-31	31.0	24.0	27.8	32.2	29.0	32.0
Gravel concrete, black	52.3-56	56.0	23.3	43.9	32.2	38.7	32.0
Gravel concrete, black, shade	28-32	32.0	25.0	28.5	32.2	30.0	32.0
Seating areas made of concrete	45.4-48	48.0	25.4	40.1	33.2	35.8	32.2
Cement slabs, white	40.6-47.2	47.2	23.6	37.6	33.5	33.6	32.2
Cement slabs, grey	49-53	53.0	27.3	42.9	33.2	38.3	32.0
Cement slabs, grey, shade	27.3-29	29.0	23.3	26.8	33.2	27.7	32.0
Terrazzo slabs, red	46-51.8	51.8	24.3	41.2	33.6	35.3	32.0
Terrazzo slabs, red, shade	29-31.5	31.5	25.0	29.2	33.8	30.0	32.0
Gravel cement slabs	48.6-52.3	52.3	26.1	42.8	32.6	37.6	31.7
Gravel cement slabs, shade	27.8-30.5	30.5	24.3	27.8	32.8	28.0	31.3
Cement blocks, grey	50.5-53.8	53.8	24.5	43.5	34.1	37.5	32.0
Cement blocks, grey, shade	27.5-29	29.0	23.5	27.0	33.8	28.0	32.0

Ceramic blocks							
Ceramic blocks, brown	46-49	49.0	24.0	37.1	34.5	33.0	32.0
Ceramic blocks, beige, new	43-45	45.0	23.0	35.5	32.2	30.0	32.0
Ceramic blocks, beige, old	46-47	47.0	25.0	39.0	32.2	31.0	32.0
Ceramic blocks, beige, shade	26-29	30.0	24.0	26.7	32.2	28.0	32.0
Wooden surfaces							
Wood (mean)	53.3-59	59.0	29.3	46.2	32.6	28.7	32.3
Asphalt concrete							
Asphalt, old (mean)	48.4-51.4	51.4	27.0	42.1	31.6	36.4	31.7
Asphalt, new (mean)	55.3-59.1	59.1	26.8	46.9	33.7	39.0	32.2
Asphalt, shade (mean)	29.8-32.7	32.7	24.8	28.4	32.7	29.5	32.3
Vegetative cover and Water							
Grass, green, irrigated	31.3-34.5	34.5	19.7	28.8	32.6	24.5	32.0
Grass, dry	41-45	45.0	23.0	34.9	30.8	34.9	32.0
Grass, shade	27-30.5	30.5	18.5	25.0	33.4	25.5	32.0
Bushes, evergreen	29-34	34.0	24.0	29.5	33.8	29.0	32.5
Water (mean)	24.6-26	25.5	24.5	25.6	33.8	25.5	32.0

Table 1. Overview of the in-situ surface temperature measurements in urban open spaces.

2.3 Results of experimental measurements of paving materials

The results of the experimental measurements, are presented in Table 2.

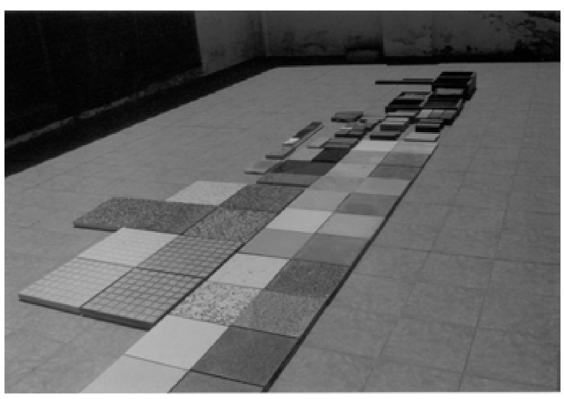


Fig. 4. Experimental measurements of paving materials. Placement of samples on a flat roof surface.

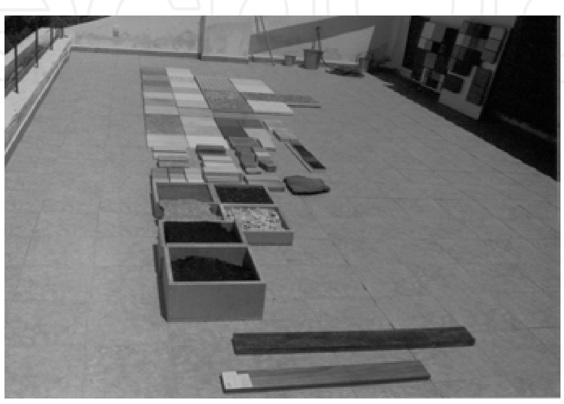


Fig. 5. Experimental measurements of paving materials. Placement of samples on a flat roof surface.

2.3.1 Loose, earthen materials

Loose materials (gravel, light brown sandy soil and dark brown peat soil) were placed in 30x30x4 cm wooden boxes in order to achieve similar dimensions to those of the rest of the materials' samples. The gravel surface was significantly cooler than the other two samples (Table 2). The earth samples' temperature reached mean maximum surface temperatures of between 57.2 °C and 63 °C, depending on their colour. These temperatures were very high (22.7 °C and 28.5 °C higher) compared to the respective mean maximum air temperature. It should be noted that after 15:00 hr, the surface temperatures of the earth samples began to drop steeply, by 4 to 6 °C every hour. As a result, after sunset, the materials were cooler than the air by 2 to 3 °C. The mean temperatures of the earth samples were equal to 42 °C and 45,3 °C and were higher than the mean air temperature by 11.4 °C and 14 °C, respectively.

2.3.2 Natural stone products

The temperature of two different categories of natural stone products were measured: marble and granite slabs and different limestone blocks. As was expected, the white marble slab recorded the lowest surface temperatures (mean maximum 34.8 °C, mean 29.8 °C). Among the marble samples, the dark grey sample was the warmest, measuring maximum temperatures of 53.8 °C, which is 19.3 °C higher than the air temperature, and mean temperatures of 42.9 °C (Tair + 11.6 °C). The surface temperatures of the rest of the marble slabs were between the two above-mentioned extremes (Table 2). Red-black, black and dark grey granite samples recorded higher maximum temperatures than the dark grey marble one, which were 56.4 °C, 56.4 and 58.6 °C, respectively. The mean surface temperatures of these three samples were 43.9 °C, 44.4 °C and 45.1 °C. Finally, the surface temperatures of the various stone blocks, were observed to be mainly dependent on their colours and were similar to those of the corresponding marble samples (Table 2).

2.3.3 Cement products

The concrete samples, which were tested, comprised of white, light-weight concrete (density = 320 kg/m^3) and of grey, dense concrete (density = 2400 kg/m^3). It is interesting to note (Table 2) that even though the light-weight sample had a lighter colour than the dense concrete one, its surface temperatures were higher (47.1 °C and 12.6 °C higher than the air temperature, compared to 44.4 °C, i.e. Tair+9.9 °C). The mean surface temperatures of the materials were similar and about 36.5 to 37 °C (5 to 6 °C higher than the mean air temperature).

Among the various cement slabs, the coolest was, as expected, the simple, white one. Its mean maximum surface temperature was higher than the air temperature by only 3.3 °C (37.8 °C), while its mean temperature was higher than the mean Tair by only 1 °C (32.3 °C). From the four samples (white, yellow, red and grey), the one with the highest mean maximum temperatures was the red sample (46.5 °C, Tair+12 °C). The striped / textured cement slabs had similar temperature fluctuation with the simple ones (Table 2). This is consistent with the findings of Doulos et al.(2004) who demonstrated that the effect of texture on the surface temperatures of building materials exposed to solar radiation is not statistically important.

The temperatures of Mosaic (terrazzo) slabs with two different grain sizes, and four different colours (white, yellow, red and grey), were measured. The white slabs were obviously the coolest, with mean maximum temperatures of 38.1 °C (Tair+3.6 °C) for the light grain and 39 °C (Tair+4.5 °C) for the heavy grain sample, While the grey samples had high surface temperatures, reaching 55.6 °C (Tair+21.1 °C) for the light grain sample, and 54.8 °C (Tair+20.3 °C) for the heavy-grain one.

From the pebble cement slabs, the coolest was the one with a surface of white gravel (39.6 °C, Tair+5.1 °C), while the warmest was the one with green and grey gravel (53.7 °C, Tair+19.2 °C).

The cement blocks used had two different shapes, rectangular and square. The lower limit of the temperature of the white samples and that of the upper limit of the grey-coloured ones determined the range of the surface temperatures of the different colours. White cement blocks reached mean maximum surface temperatures of 41 to 42 °C (Tair+7 to 7.5 °C), while the grey ones were significantly warmer, and their mean maximum temperatures around noon were about 50 °C (Tair+15 to 17 °C).

2.3.4 Ceramic products

This study consisted of four ceramic blocks, two beige and two brown ones, with different thickness (3 and 5 cm). It can be seen (Table 2) that the different thickness of the samples had an insignificant effect (less than 1 °C difference) on their mean maximum and mean surface temperatures. The beige samples had mean maximum temperatures of about 43 °C around noon, while the brown-coloured ones were warmer, with 48 °C.

2.3.5 Wooden products

The timber products, which were included in this study, were boards of tropical hardwood (teak and merbau). The merbau sample recorded very high mean maximum surface temperatures, of about 57.4 °C (Tair+22.9 °C) and were comparable to those of the light-coloured, sandy earth sample. The teak sample was relatively cooler with mean maximum temperature of about 52,9 °C, i.e, Tair+18.4 °C. Obviously the wood samples had high mean surface temperatures of 40.8 °C and 43.9 °C, for the teak and merbau, respectively.

2.3.6 Asphalt products

The new asphalt concrete sample was black, and for this reason had very high mean maximum temperature of 61.8 °C, Tair+27.3 °C and mean temperature of 46.7 °C, Tair+15.5 °C, While the weathered asphalt sample was significantly cooler, having a mean maximum temperature of 50.6 °C (Tair+16.1 °C) and a mean temperature of 40.3 °C (Tair+9 °C). The differences between the new and the weathered samples were larger than 10 °C, for the mean maximum, and around 7 °C, for the mean surface temperatures.

Asphalt water-proofing membranes recorded the highest surface temperatures among all the samples. All the samples apart from the one with the polished aluminium facing (mean maximum temperature equal to 46.8 °C, Tair+12.3 °C) recorded temperature exceeding the mean maximum surface temperature of 65.5 °C (Tair+31 °C). It should be noted, though, that the samples were placed on an extruded polystyrene slab, which differs from their actual placing practice on a concrete substrate. As a result, the temperatures that were measured may be higher than those, which would have been measured if the materials were placed on a more conductive substrate.

2.3.7 Vegetal surfaces

The vegetal surfaces used for the study were two samples of grass placed on a 4cm thick earth substrate. One of the samples was regularly irrigated, while the other was not. The mean maximum surface temperatures of the samples were very close, about 40 ^oC (Tair+5.5 ^oC), while their mean temperatures were lower than the air temperature by less than 1 ^oC. After sunset (20:00), the samples were significantly cooler (about 5 ^oC) than the air.

	Mean maximum T [^oC]		*Mean minimum T [^oC]*		*Mean mean T [^oC]*	
Air	34.5		28.5		31.3	
Loose, earthen materials						
Gravel	45.5	(+11.0)	22.7	(-5.8)	35.9	(+4.6)
Sandy soil, light brown	57.2	(+22.7)	22.6	(-5.9)	42.7	(+11.4)
Peat soil, dark brown	63	(+28.5)	22.7	(-5.8)	45.3	(+14.0)
Natural stone slabs and blocks						
Marble, 20x30x2 cm, white	34.8	(+0.3)	21.8	(-6.7)	29.8	(-1.5)
Marble, 20x30x2 cm, light grey	41.4	(+6.9)	22	(-6.5)	34	(+2.7)
Marble, 20x30x2 cm, beige	44.8	(+10.3)	23.4	(-5.1)	36.6	(+5.3)
Marble, 20x30x2 cm, grey-beige	49.4	(+14.9)	23.7	(-4.8)	39.4	(+8.1)
Marble, 20x30x2 cm, grey	49.4	(+14.9)	24	(-4.5)	40	(+8.7)
Marble, 20x30x2 cm, ochre	50	(+15.5)	23.4	(-5.1)	39.8	(+8.5)
Marble, 20x30x2 cm, dark red	52.4	(+17.9)	23.8	(-4.7)	40.6	(+9.3)
Marble, 20x30x2 cm, dark grey	53.8	(+19.3)	23.9	(-4.6)	42.9	(+11.6)
Granite, 20x30x2 cm, white-beige	47.6	(+13.1)	26.3	(-2.2)	38.8	(+7.5)
Granite, 20 x 30 x 2 cm, salmon	48.2	(+13.7)	25.9	(-2.6)	39.2	(+7.9)
Granite, 20 x 30 x 2 cm, red-black	56.4	(+21.9)	25.9	(-2.6)	43.9	(+12.6)
Granite, 20 x 30 x 2 cm, black	56.4	(+21.9)	26.2	(-2.3)	44.4	(+13.1)
Granite, 20 x 30 x 2 cm, dark grey	58.6	(+24.1)	27.4	(-1.1)	45.1	(+13.8)
Blocks, 10 x 10 x 3 cm, white	42.5	(+8)	22.5	(-6)	35	(+3.7)
Blocks, 10 x 10 x 3 cm, white-black	45.9	(+11.4)	20.3	(-8.2)	36.2	(+4.9)
Blocks, 10 x 10 x 3 cm, grey-red	46.9	(+12.4)	21.2	(-7.3)	37.3	(+6)
Blocks, 10 x 10 x 3 cm, red	47.9	(+13.4)	21.4	(-7.1)	38	(+6.7)
Blocks, 10 x 10 x 3 cm, grey	48.3	(+13.8)	21	(-7.5)	37.7	(+6.4)
Blocks, 10 x 10 x 3 cm, red	49.2	(+14.7)	21.4	(-7.1)	38.4	(+7.1)
Blocks, 20 x 10 x 5 cm, beige	45.3	(+10.8)	22.2	(-6.3)	36.3	(+5)
Blocks, 20 x 10 x 5 cm, dark red	48.4	(+13.9)	21.6	(-6.9)	38	(+6.7)
Blocks, 20 x 10 x 5 cm, grey	51.3	(+16.8)	21.9	(-6.6)	39.9	(+8.6)
Concrete surfaces, Cement slabs and blocks						
Light-weight concrete, white	47.1	(+12.6)	22.2	(-6.3)	37.1	(+5.8)
Dense concrete, (30x30x9 cm), grey	44.4	(+9.9)	21.7	(-6.8)	36.4	(+5.1)
Slabs, 30x30x3 cm, simple, white	37.8	(+3.3)	22.6	(-5.9)	32.3	(+1)
Slabs, 30x30x3 cm, simple, yellow	45	(+10.5)	23.2	(-5.3)	37	(+5.7)
Slabs, 30x30x3 cm, simple, grey	45.6	(+11.1)	23.3	(-5.2)	37.4	(+6.1)
Slabs, 30x30x3 cm, simple, red	46.5	(+12)	24.5	(-4)	38.2	(+6.9)
Slabs, 30x30x3 cm, striped, yellow	44	(+9.5)	22.6	(-5.9)	36.1	(+4.8)
Slabs, 30x30x3 cm, striped, red	46.7	(+12.2)	22.9	(-5.6)	37.9	(+6.6)
Slabs, 30x30x3 cm, striped, grey	48	(+13.5)	23.1	(-5.4)	38.9	(+7.6)
Slabs, 30x30x3 cm, mosaic, white	38.1	(+3.6)	22.1	(-6.4)	32.5	(+1.2)
Slabs, 30x30x3 cm, mosaic, yellow	42	(+7.5)	22.5	(-6.0)	35	(+3.7)
Slabs, 30x30x3 cm, mosaic, red	52.5	(+18)	23.3	(-5.2)	42	(+10.7)
Slabs, 30x30x3 cm, mosaic, grey	55.6	(+21.1)	23.2	(-5.3)	43.7	(+12.4)

Slabs, 30x30x3 cm, mosaic, white	39	(+4.5)	22.1	(-6.4)	33	(+1.7)
Slabs, 30x30x3 cm, mosaic, yellow	42.6	(+8.1)	22.4	(-6.1)	35.4	(+4.1)
Slabs, 30x30x3 cm, mosaic, red	50.4	(+15.9)	23.1	(-5.4)	40.3	(+9)
Slabs, 30x30x3 cm, mosaic, grey	54.8	(+20.3)	23.3	(-5.2)	43.2	(+11.9)
Slabs, 40x40x3,5 cm, mosaic, white	39.6	(+5.1)	21.6	(-6.9)	32.6	(+1.3)
Slabs, 40x40x3,5 cm, mosaic, yellow	43	(+8.5)	21.4	(-7.1)	34.8	(+3.5)
Slabs, 40x40x3,5 cm, mosaic, red	46.7	(+12.2)	21.8	(-6.7)	37.1	(+5.8)
Slabs, 40x40x3,5 cm, mosaic, grey	52.2	(+17.7)	22.1	(-6.4)	40.8	(+9.5)
Slabs, 40x40x3,5 cm, pebbles, white	39.6	(+5.1)	21.7	(-6.8)	32.6	(+1.3)
Slabs, 40x40x3,5, pebbles, various	50.2	(+15.7)	22.1	(-6.4)	39.4	(+8.1)
Slabs, 40x40x3,5cm, pebbles, grey	51.3	(+16.8)	22.2	(-6.3)	40	(+8.7)
Slabs, 40x40x3,5cm, pebbles, grey	53.4	(+18.9)	22.8	(-5.7)	41.4	(+10.1)
Slabs, 40x40x3,5cm, pebbles, green	53.7	(+19.2)	22.8	(-5.7)	41.8	(+10.5)
Blocks, 20x10x6 cm, white	42	(+7.5)	22.3	(-6.2)	34.7	(+3.4)
Blocks, 20x10x6 cm, yellow	43	(+8.5)	22.8	(-5.7)	35.6	(+4.3)
Blocks, 20x10x6 cm, red	47.7	(+13.2)	23	(-5.5)	38.8	(+7.5)
Blocks, 20x10x6 cm, grey	51.7	(+17.2)	23.1	(-5.4)	41.3	(+10)
Blocks, 10x10x6 cm, white	41	(+6.5)	22.3	(-6.2)	33.9	(+2.6)
Blocks, 10x10x6 cm, yellow	41.8	(+7.3)	22.8	(-5.7)	34.7	(+3.4)
Blocks, 10x10x6 cm, ochre	44	(+9.5)	23.1	(-5.4)	36.2	(+4.9)
Blocks, 10x10x6 cm, beige	44.6	(+10.1)	22.8	(-5.7)	36.6	(+5.3)
Blocks, 10x10x6 cm, light brown	44.7	(+10.2)	23.1	(-5.4)	36.8	(+5.5)
Blocks, 10x10x6 cm, red	46.3	(+11.8)	23.5	(-5)	38.1	(+6.8)
Blocks, 10x10x6 cm, grey	46.7	(+12.2)	23.3	(-5.2)	38.2	(+6.9)
Blocks, 10x10x6 cm, dark brown	49.6	(+15.1)	23.5	(-5)	40.2	(+8.9)
Blocks, 10x10x6 cm, dark grey	49.6	(+15.1)	23.6	(-4.9)	40.3	(+9)
Ceramic blocks						
Beige, 3 cm-thick	42.7	(+8.2)	21.8	(-6.7)	35.2	(+3.9)
Beige, 5 cm-thick	43.6	(+9.1)	21.9	(-6.6)	35.7	(+4.4)
Brown, 5 cm-thick	47.5	(+13.0)	22.4	(-6.1)	37.9	(+6.6)
Brown, 3 cm-thick	48.3	(+13.8)	22.8	(-5.7)	38.7	(+7.4)
Firebrick, ochre	45.1	(+10.6)	22.7	(-5.8)	36.3	(+5.0)
Firebrick,, brown	48.4	(+13.9)	23	(-5.5)	38.2	(+6.9)
Wooden surfaces						
Teak	52.9	(+18.4)	22.7	(-5.8)	40.8	(+9.5)
Merbau	57.4	(+22.9)	23.3	(-5.2)	43.9	(+12.6)
Asphalt						
Asphalt concrete, old, grey	50.6	(+16.1)	22.5	(-6)	40.3	(+9)
Asphalt concrete, new, black	61.7	(+27.2)	23.4	(-5.1)	46.4	(+15.1)
Asphalt concrete, new, black	61.9	(+27.4)	23	(-5.5)	47.1	(+15.8)
Asphalt membrane, alu cover	46.8	(+12.3)	28.1	(-0.4)	38.7	(+7.4)
Asphalt membrane, black	67.2	(+32.7)	21.3	(-7.2)	47	(+15.7)
Asphalt membrane, grey light-grain	70	(+35.5)	21.8	(-6.7)	48.7	(+17.4)
Asph. membrane, grey heavy-grain	65.5	(+31)	20.7	(-7.8)	45.9	(+14.6)
Asphalt membrane, black	72.7	(+38.2)	22.7	(-5.8)	50.3	(+19)
Vegetative cover						
Grass, well-irrigated	39.9	(+5.4)	20	(-8.5)	31.1	(-0.2)
Grass, not irrigated	40.4	(+5.9)	20.1	(-8.4)	30.9	(-0.4)

Table 2. Overview of the experimental surface temperature measurements on samples of paving materials.

3. The thermal behaviour of facade materials

3.1.1 Methodology of the in-situ measurements

The choice of the buildings selected for the study was based on a number of criteria, which are summarised below:

- Buildings with facades oriented towards the four basic orientations (north, south, east and west).
- Free-standing buildings with more than one facades which is -as far as possible-from obstruction of solar access, which would allow the comparison of the surface temperatures recorded at the different orientations.
- Buildings with western orientation, and are most thermally stressed during the summer months.
- Buildings with facades constructed of contemporary materials (e.g. panels of granite, composite aluminium panels, etc.) mainly with the ventilated facade system.
- Groups of buildings, which would allow the comparison of the surface temperatures of the different materials with the same orientation.

The surface temperature readings were taken with an Optex Thermo-Hunter PT-5LD Infrared (IR) thermometer every half-hour, from 8:00 in the morning until 19:30 or 20:00 in the evening. The measurements were limited to a height of not more than 6 meters, due to restrictions posed by the instrument. On each of the facades, IR readings were taken at different heights and at different parts of the facade, in order to ensure that recorded surface temperature was representative. Finally, air temperatures, relative humidity and air velocity were also measured on the site. Indoor air and surface temperature measurements were not possible, as there was no access to the buildings in question. The environmental conditions during the days of the measurements were characterised predominantly by clear skies (0/8), high air temperatures (29.6 ^{o}C to 34.4 ^{o}C), low relative humidity (28.5 % to 52 %) and various air velocities (0.6 m/s to 3.2 m/s).

3.1.2 Methodology of the experimental measurements

The materials, which temperatures were measured during the experimental study, were mainly materials that are used for building facades with ventilated facade system. Forty-four (44) samples were selected and mounted on two experimental arrangements, which aimed at simulating the ventilated facade system. Each experimental arrangement comprised a 30mm insulating board (extruded polystyrene - XPS), which was fixed on an 18mm chipboard. The samples for surfacing materials were mounted with the use of metal screws, which suspended the materials at a distance (air gap) of 20 to 30 mm from the insulation layer. The distance between the samples was to ensure that there was no contact between them, while each screw was individually "planted" into the insulating to avoid thermal bridges. In all the temperatures of seven (7) samples of marble slabs and five (5) samples of granite slabs were measured, making a total of 56 samples.

The measurements took two weeks: one week (7 days) for the western orientation (10-17/07/2004) and the other week for the southern orientation (31/07-06/08/2004). The measurements were by an Optex Thermo-Hunter PT-5LD Infrared (IR) thermometer, from

8:00 to 20:00 at 1-hour intervals. One day of the measurements included night-time readings (from 20:00 to 08:00) in order to examine the cooling rate of the materials. Furthermore, for a one-day period, a contact thermometer (Technoterm 9500) was used simultaneously with the IR one, in order to confirm the accuracy of the IR readings and account for possible discrepancies. Air temperatures, relative humidity and air velocity measurements were also done at the site.

3.2 Results of the in-situ measurements of facade materials

The results are presented in Table 3.

3.2.1 Natural stone products

Light-coloured stone panels, such as white marble and beige sandstone did not record high surface temperatures in any of the four basic orientations (north, south, west and east). Furthermore, for all the examined orientations, their temperature at $T_{19:30}$ was higher than the corresponding air temperature by only 1 to 2 ^{o}C. However, the panels of dark-coloured stone, namely grey and black granite, tended to overheat, with surface temperatures that may well exceed 50 ^{o}C for facades which face towards the east and the west. It is also important to note that for west-facing facades, clad with grey or black granite, the surface temperatures around sunset ($T_{19:30}$) were a lot higher than the air temperature (15 ^{o}C and 17 ^{o}C, respectively).

3.2.2 Cement products

The west-facing reinforced concrete surface, recorded a surface temperature of 47 ^{o}C, and was, at 19:30 warmer than the air by 10 ^{o}C.

The building facades of typical construction (brick wall with external rendering of lime-cement mortar painted in different colours), were of the following colours: white, beige, grey and dark red. As was expected, the white-painted surfaces remained relatively cool, with maximum temperatures that did not exceed 40 ^{o}C and mean temperature that was similar to the mean air temperature. The beige surfaces with western orientation had relatively low mean temperatures, maximum temperatures around 45 ^{o}C and were warmer than the air by 4 ^{o}C, around sunset. The highest temperatures on western facades were measured by the dark red and grey surfaces. Their maximum temperatures were 56 ^{o}C for the dark red facade and 60 ^{o}C for the grey one, while their respective $T_{19:30}$ temperatures were higher than the air temperature by 6 ^{o}C and 12 ^{o}C. Finally, these surfaces had observed mean temperatures, which were higher than the respective air temperature by 3 ^{o}C and 7.5 ^{o}C.

3.2.3 Ceramic products

The in-situ study was a building, whose four facades were covered with dark brown ceramic blocks. Based on the IR readings, the eastern facade reached a maximum temperature of 38 ^{o}C, and the western one, a temperature of 44 ^{o}C. Around sunset, the ceramic blocks of the western facades were warmer than the air by 6 ^{o}C.

Material	*Orientation*	*Abs max T [°C]*	*Abs. min T [°C]*	*Mean T [°C]*	*Mean T_{air} [°C]*	*T at 19:30 [°C]*	*$T_{ai}r$ at 19:30 [°C]*
Marble slabs							
Marble, white	N	36.0	21.0	28.3	29.7	29.0	28.0
Marble, white	S	33.0	20.0	28.0	29.7	25.0	28.0
Marble, white	W	38.0	18.0	27.4	29.7	30.0	28.0
Sandstone slabs							
Sandstone	N	35.8	25.5	30.7	32.6	31.5	31.5
Sandstone	S	39.5	26.0	33.9	33.2	34.0	33.0
Sandstone	E	39.5	25.5	34.5	33.2	34.0	33.0
Sandstone	W	41.6	23.6	30.8	31.8	32.2	31.0
Granite slabs							
Granite, black	N	42.0	21.0	30.7	29.7	34.0	28.0
Granite, black	S	43.5	26.5	36.6	32.1	31.0	30.0
Granite, black	E	53.0	32.5	40.7	34.4	32.5	32.0
Granite, black	W	57	23.0	36.9	32.1	46.5	30.0
Granite, grey	N	41.0	30.0	36.1	34.4	33.5	32.0
Granite, grey	S	52.0	27.0	40.5	34.4	31.5	32.0
Granite, grey	E	49.5	31.5	39.5	34.4	31.5	32.0
Granite, grey	W	62.0	25.0	42.6	34.4	47	32.0
Reinforced concrete							
Reinforced concrete	N	31.0	27.0	29.0	30.8	30.0	32.0
Reinforced concrete	S	38.0	22.0	30.3	30.8	31.0	32.0
Reinforced concrete	E	36.0	29.0	33.3	30.8	30.0	32.0
Reinforced concrete	W	47.0	20.0	33.1	30.8	42.0	32.0
Standard Greek construction (Lime-cement mortar and painting with different colours)							
Standard construction, white	S	33.0	25.7	29.8	32.8	32.0	30.7
Standard construction, white	E	35.0	29.0	32.2	34.4	30.0	32.0
Standard construction, white	W	40.0	20.0	29.5	29.7	28.0	28.0
Standard construction, beige	N	34.0	25.5	31.1	33.2	32.0	33.0
Standard construction, beige	S	38.3	25.3	32.9	32.7	32.6	32.3
Standard construction, beige	E	42.0	25.8	35.8	33.2	33.3	33.0
Standard construction, beige	W	45.3	25.0	33.3	33.4	36.7	32.9
Standard construction, grey	S	44.0	29.0	36.8	34.4	32.0	32.0
Standard construction, grey	W	60.0	27.0	41.9	34.4	44.0	32.0
Standard construction, dark grey	N	36.0	26.0	32.2	33.2	33.0	33.0
Standard construction, dark grey	S	41.0	25.0	34.8	33.2	36.0	33.0
Standard construction, dark grey	W	56.0	28.0	36.2	33.2	39.0	33.0
Composite aluminium panels							
Composite alu panel, dark grey	S	40.0	26.0	32.8	29.7	25.0	28.0
Composite alu panel, dark grey	E	49.5	23.5	32.5	29.7	25.0	28.0
Composite alu panel, dark grey	W	45.0	21.0	31.7	29.7	31.0	28.0
Ceramic bricks (veneer)							
Ceramic bricks, brown	N	36.0	22.0	28.2	29.7	32.0	28.0
Ceramic bricks, brown	S	36.0	22.0	30.7	29.7	27.5	28.0
Ceramic bricks, brown	E	38.0	23.0	30.8	29.7	27.0	28.0
Ceramic bricks, brown	W	44.0	21.0	31.9	29.7	34.0	28.0
PV panels and Climbing plants							
PV panels (hybrid facade)	S	39.2	24.4	31.5	34.0	28.8	33.0
Wall with climbing plants	S	34.0	26.0	30.7	34.0	30.0	33.0

Table 3. Overview of the in-situ measurements on building facades.

3.2.4 Metal products

The metal products involved were grey-coloured composite aluminium panels. In the case of east-facing panels, the maximum surface temperature recorded was 49.5 °C, but for the west-facing ones, it was 45 °C. The temperature, $T_{19:30}$ of the panels was higher than the respective air temperature by 3 °C.

3.2.5 Vegetal surfaces

The vegetal surface was a reinforced concrete wall covered with Virginia creeper (Parthenocissus spp). Its temperatures remained lower than the air temperatures throughout the day.

3.2.6 Photovoltaic (PV) panels

The PV panels used were blue-coloured poly-crystalline ones. These were integrated into a south-facing, ventilated PV façade. Their mean surface temperature was lower than the mean air temperature, while their absolute maximum temperature reached 44 °C. It is important to note that, around sunset, the PV panels were cooler than the air by 4.2 °C. These findings are considered very important because they show that during the summer period, southern facades clad with PV panels do not affect thermally the microclimate, while contributing to the use of renewable energy.

3.3 Results of the experimental measurements of facade materials

The results of the experimental measurements are presented in Table 4 for the western orientation and in Table 5 for the southern orientation.

3.3.1 Western orientation

The environmental conditions throughout the week of measurements were characterised by predominantly clear skies (0/8), high air temperatures (mean maximum air temperature of 34.5 °C, mean minimum air temperature of 28.5 °C and mean air temperature of 31.3 °C).

3.3.1.a Natural stone products

When facing towards the west, marble panels recorded mean maximum surface temperatures of 39.6 °C (Tair + 5.1 °C) for white marble and 58.1 °C (Tair + 23.6 °C) for dark grey marble. The mean surface temperatures of these materials were 31.6 °C (Tair + 0.3 °C) and 39.8 °C (Tair + 8.5 °C), respectively. It should be noted that at 20:00 (after sunset) the surface temperatures of all the samples except of the white one were over 35 °C, indicating that their temperatures were higher than the corresponding air temperature, by more than 5 °C.

All the west-facing granite panels, overheated during the afternoon, reaching mean maximum temperatures of 48.1°C that were well above 45 °C for the white-beige sample, 59.1 °C for the black one. The mean surface temperatures of the samples range from 35.5 °C

(Tair + 4.2 °C) to 40.3 °C (Tair + 9 °C). Similar to the marble samples, the granite samples were, at 20:00, warmer than the air by 5 °C to 10 °C. It is noted that the dark-coloured granite surfaces, were warmer than the air by more than 15 °C.

3.3.1.b Ceramic products

Thin ceramic panels and tiles that face towards the west recorded maximum surface temperatures, which may range from 44 °C (for white) to 56.6 °C (for black) and are from 9.5 °C to 22.1 °C higher than the mean maximum air temperature. The mean surface temperature of the white sample is 33.6 °C (Tair + 2.3 °C) and of the black sample 38.8 °C (Tair + 7.5 °C). The mean surface temperatures of the rest of the samples are between the above-mentioned limits. Finally, the surface temperatures of all the samples of thin ceramic tiles and panels after the sunset (at 20:00) were between 30 °C and 35 °C, i.e., no more than 5 °C higher than the corresponding air temperature.

Ceramic panels of increased thickness (13 mm) recorded surface temperatures similar to the thin ceramic tiles and panels with similar colours. The white-coloured sample has a mean maximum temperature of 44.1 °C (Tair + 9.6 °C) and a mean temperature of 33.8 °C (Tair + 2.5 °C), while the brown-coloured one has mean maximum temperature of 52 °C (Tair + 17.5 °C) and a mean temperature of 37.4 °C (Tair + 6.1 °C).

3.3.1.c Wooden products

West-facing composite wood panels recorded very high surface temperatures. The light-coloured and the intermediate samples reached a maximum temperature of about 52 °C, while the dark-coloured one had a mean maximum temperature of 59.6 °C, which was 25 °C higher than the mean maximum air temperature. Concerning the mean surface temperatures, the samples were warmer than the air by 6 °C to 9.4 °C. After the sunset, the surface temperatures of all three samples were close to the air temperature.

	Mean maximum T [°C]		*Mean minimum T [°C]*		*Mean mean T [°C]*	
Air	34.5		28.5		31.3	
Composite aluminium panels 20 x 30 cm facing West						
White colour	44.5	(+10)	24.5	(-4)	33.7	(+2.4)
Yellow colour	48.7	(+14.2)	25.9	(-2.6)	36.3	(+5)
Red colour	51	(+16.5)	25.7	(-2.8)	37.0	(+5.7)
Silver colour	52.9	(+18.4)	25.2	(-3.3)	37.4	(+6.1)
Green colour	55.6	(+21.1)	26.2	(-2.3)	39.1	(+7.8)
Blue colour	56.9	(+22.4)	25.7	(-2.8)	39.3	(+8)
Black colour	66.3	(+31.8)	26.1	(-2.4)	42.4	(+11.1)
Composite wood panels 20 x 30 cm facing West						
Light-coloured	51.8	(+17.3)	26	(-2.5)	37.3	(+6)
Intermediate	52.5	(+18)	25.9	(-2.6)	37.8	(+6.5)
Dark-coloured	59.6	(+25.1)	26.2	(-2.3)	40.7	(+9.4)
Metal sheets 10 x 10 cm facing West						
Copper, natural colour	41.6	(+7.1)	27	(-1.5)	34.0	(+2.7)
Copper, verdigris	48.2	(+13.7)	25.7	(-2.8)	35.7	(+4.4)
Titanium	40.1	(+5.6)	25.4	(-3.1)	32.5	(+1.2)
Zinc	41	(+6.5)	25.4	(-3.1)	31.9	(+0.6)

Quartz zinc, beige	47.1	(+12.6)	26.2	(-2.3)	35.7	(+4.4)
Quartz zinc, turquoise	48.2	(+13.7)	26.1	(-2.4)	36.2	(+4.9)
Quartz zinc, light blue	48.8	(+14.3)	26.1	(-2.4)	36.5	(+5.2)
Quartz zinc, natural, light grey	44.7	(+10.2)	25.7	(-2.8)	35.0	(+3.7)
Quartz zinc, natural, dark grey	49.5	(+15)	26	(-2.5)	36.8	(+5.5)
Ceramic tiles / panels 10 x 10 cm facing West						
White colour (glazed)	44	(+9.5)	25.1	(-3.4)	33.6	(+2.3)
Ochre colour	48.4	(+13.9)	25.1	(-3.4)	35.9	(+4.6)
Beige colour	48.8	(+14.3)	25.5	(-3)	36.4	(+5.1)
Light grey colour	49.8	(+15.3)	25.1	(-3.4)	36.4	(+5.1)
Brown colour	51.9	(+17.4)	25.8	(-2.7)	38.1	(+6.8)
Red-Dark red colour, black spots	52.4	(+17.9)	25.6	(-2.9)	37.1	(+5.8)
Olive green colour, black spots	52.5	(+18)	25.3	(-3.2)	37.2	(+5.9)
Dark grey colour	52.8	(+18.3)	26.2	(-2.3)	38.0	(+6.7)
Blue colour	53.1	(+18.6)	25.9	(-2.6)	38.2	(+6.9)
Black colour	54.3	(+19.8)	26.2	(-2.3)	39.0	(+7.5)
Black colour, with white spots	56.6	(+22.1)	25.8	(-2.7)	38.8	(+7.5)
Ceramic panels 25 x 13 x 1,3 cm facing West						
White colour	44.1	(+9.6)	25.9	(-2.6)	33.8	(+2.5)
Beige colour	46.4	(+11.9)	25.9	(-2.6)	35.3	(+4)
Light grey colour	47.2	(+12.7)	25.7	(-2.8)	35.2	(+3.9)
Brown colour	52	(+17.5)	25.2	(-3.3)	37.4	(+6.1)
Marble panels 20 x 30 cm facing West						
White colour	39.6	(+5.1)	24.2	(-4.3)	31.6	(+0.3)
Light grey colour	46	(+11.5)	24.5	(-4)	34.2	(+2.9)
Beige colour	49.1	(+14.6)	24.6	(-3.9)	35.5	(+4.2)
Grey-Beige colour	51.2	(+16.7)	24.6	(-3.9)	36.5	(+5.2)
Grey colour	54.4	(+19.9)	24.5	(-4)	37.7	(+6.4)
Ochre colour	55.4	(+20.9)	24.9	(-3.6)	38.1	(+6.8)
Dark grey colour	58.1	(+23.6)	25	(-3.5)	39.8	(+8.5)
Granite panels 20 x 30 cm facing West						
White-Beige colour	48.1	(+13.6)	24.7	(-3.8)	35.5	(+4.2)
Salmon colour	47.7	(+13.2)	25.6	(-2.9)	35.3	(+4)
Red-Black colour	56.6	(+22.1)	26.1	(-2.4)	39.4	(+8.1)
Black colour	57.5	(+23)	25.7	(-2.8)	39.8	(+8.5)
Grey colour	59.1	(+24.6)	26	(-2.5)	40.3	(+9)

Table 4. Overview of the experimental measurements on samples of building materials facing West.

3.3.1.d Metal products

When facing towards the west, even light-coloured composite aluminium panels (white colour) recorded surface temperatures, which were higher than the corresponding air temperature by more than 10 °C. For the range of colours, mean maximum temperatures were 10 °C (for white colour) to 31.8 °C (for black colour) higher than the mean maximum air temperature. Mean surface temperatures range from 33.7 °C for white to 42.4 °C for black panels, and are thus 2.4 °C to 11.1 °C higher than the mean air temperature. Finally, the surface temperatures at 20:00 (after the sunset) are between 30 °C and 35 °C and are no more than 5 °C higher than the air temperature at that time.

The mean maximum surface temperatures of west-facing samples of different metal sheets had a temperature range from 40.1 °C (titanium) to 49.5 °C (quartz zinc, dark grey natural). Their mean surface temperatures ranged from 31.9 °C (polished zinc) to 36.8 °C (quartz zinc, dark grey natural), and were higher than the respective air temperature by 0.6 °C to 5.5 °C.

3.3.2 Southern orientation

The atmospheric conditions throughout the week of measurements were clear skies (0/8), high air temperatures (mean maximum air temperature of 34.7 °C, mean minimum air temperature of 28.3 °C and mean air temperature of 31.2 °C).

3.3.2.a Natural stone products

South-facing marble panels measured lower surface temperatures than west-facing ones. The mean maximum temperature of the white sample was equal to 36.7 °C (Tair + 2 °C), which is 3 °C lower than respective temperature of the west-facing one. Similarly, the mean maximum temperature of the dark grey sample was 51.7 °C (Tair + 17 °C), and 6.6 °C lower than the temperature of the one facing west. The mean surface temperatures of both samples were almost equal to those measured for the western orientation, namely 31.1 °C (Tair - 0.1 °C) and 39.7 °C (Tair + 8.5 °C), respectively. The surface temperatures of the rest of the samples fall between the above-mentioned extremes.

When granite panels have a southern orientation (Figure 23), their surface temperatures are lower compared to those measured when they faced towards the west. The mean maximum temperatures of all the five south facing samples were 6 °C to 9 °C lower than the "western" ones. The white-beige sample had a mean maximum temperature of 39.3 °C (Tair + 4.6 °C), while the grey-coloured samples had 50.3 °C (Tair + 15.6 °C). Contrary to the marble and the granite samples with southern orientation had lower mean surface temperatures than those of western orientation. The mean surface temperatures of the samples range from 32.8 °C (Tair + 1.6 °C) to 38.3 °C (Tair + 7.1 °C). The marble and the granite samples, when placed facing south, gradually cool down during the afternoon. As a result, their surface temperatures after the sunset (20:00) are close to the corresponding air temperature, surpassing it by only 1 °C to 2 °C.

3.3.2.b Ceramic products

Thin ceramic panels and tiles that face towards the south recorded maximum surface temperatures, which may range from 38.1 °C (for white) to 50.5 °C (for black) and are from 3.4 °C to 15.8 °C higher than the mean maximum air temperature. The mean maximum temperatures of all the samples were approximately 6 °C to 7 °C lower than the mean maximum values, which were measured when the materials had a western orientation. The mean surface temperature of the white sample is 31.6 °C (Tair + 0.4 °C) and of the black sample 37 °C (Tair + 5.8 °C). The mean surface temperatures of the rest of the samples lie between the above-mentioned limits. Finally, the surface temperatures of all the samples of thin ceramic tiles and panels after the sunset (at 20:00) were close to the corresponding air temperature.

South-facing ceramic panels of thickness 13 mm recorded similar surface temperatures to that of the thin ceramic tiles and panels with similar colours. The white-coloured sample had a mean maximum temperature of 39.7 ºC (Tair + 5 ºC) and a mean temperature of 32.6 ºC (Tair + 1.4 ºC), while the brown-coloured one has mean maximum temperature of 48.9 ºC (Tair + 14.2 ºC) and a mean temperature of 37 ºC (Tair + 5.8 ºC). Compared to the temperatures, which were measured when the samples were facing west, the above-mentioned surface temperatures are considerably lower.

3.3.2.c Wooden products

The surface temperatures of the composite wood panels with southern orientation were not very high. The light-coloured and the intermediate sample reached a maximum temperature of about 42.3 ºC, while the dark-coloured one had a mean maximum temperature of 47.6 ºC, which was 12.9 ºC higher than the mean maximum air temperature. Concerning the mean surface temperatures, the samples were warmer than the air by 2.6 ºC to 5.1 ºC. A quick comparison with the temperatures measured for the western orientation reveals that the mean maximum temperature of the light-coloured sample is lower by about 10 ºC, while that of the dark-coloured one by about 12 ºC. Concerning the mean surface temperatures, the differences between the "western" and the "southern" surface temperatures range between 2.4 ºC for the light-coloured sample and 4.3 ºC for the dark-coloured one. Again, the observed differences due to the change of orientation are significant.

3.3.2.d Metal products

When facing towards the south, light-coloured composite aluminium panels (white colour) recorded low surface temperatures, but higher than the corresponding air temperature by only 2.6 ºC. For the range of colours, mean maximum temperatures ranged from 2.6 ºC (for white colour) to 16.5 ºC (for black colour) higher than the mean maximum air temperature. The differences with the measured mean maximum temperatures of the western orientation are impressive and range from 7.4 ºC, for the white colour, to 15.3 ºC, for black colour. Mean surface temperatures ranged from 31.5 ºC for white to 38.7 ºC for black panels, and are thus 0 ºC to 7 ºC higher than the mean air temperature. The differences between the "western" and the "southern" mean surface temperatures of the two extreme colours (white and black) are 2.7 ºC and 4.1 ºC, respectively. Finally, the surface temperatures at 20:00 (after the sunset) are below 5 ºC than that of the air temperature at that time.

	Mean maximum T [ºC]		*Mean minimum T [ºC]*		*Mean mean T [ºC]*	
Air	34.7		28.3		31.2	
Composite aluminium panels 20 x 30 cm facing South						
White colour	37.3	(+2.6)	22.5	(-5.8)	31.5	(-0.3)
Yellow colour	41.6	(+6.9)	23.8	(-4.5)	33.6	(+2.4)
Red colour	42.5	(+7.8)	24.3	(-4)	34.4	(+3.2)
Silver colour	44.3	(+9.6)	23.6	(-4.7)	34.8	(+3.6)
Green colour	46.4	(+11.7)	24.5	(-3.8)	35.8	(+4.6)
Blue colour	47.2	(+12.5)	24.5	(-3.8)	36.8	(+5.6)
Black colour	51.2	(+16.5)	25.1	(-3.2)	38.2	(+7)
Composite wooden panels 20 x 30 cm facing South						
Light-coloured	42.3	(+7.6)	24.1	(-4.2)	33.8	(+2.6)
Intermediate	43.3	(+8.6)	24.2	(-4.1)	34.1	(+2.9)
Dark-coloured	47.6	(+12.9)	24.8	(-3.5)	36.3	(+5.1)

Metal sheets 10 x 10 cm facing South						
Copper, natural colour	41.2	(+6.5)	26.6	(-1.7)	34.7	(+3.5)
Copper, verdigris	44.1	(+9.4)	24.8	(-3.5)	34.4	(+3.2)
Titanium	39.5	(+4.8)	26.1	(-2.2)	33.1	(+1.9)
Zinc	40.1	(+5.4)	26.6	(-1.7)	33.6	(+2.4)
Quartz zinc, beige	40.9	(+6.2)	24.6	(-3.7)	32.8	(+1.6)
Quartz zinc, turquoise	42.6	(+7.9)	24.9	(-3.4)	34	(+2.8)
Quartz zinc, light blue	42.9	(+8.2)	24.7	(-3.6)	33.8	(+2.6)
Quartz zinc, natural, light grey	43.9	(+9.2)	26.4	(-1.9)	35.4	(+4.2)
Quartz zinc, natural, dark grey	45.7	(+11)	26.2	(-2.1)	35.8	(+4.6)
Ceramic tiles / panels 10 x 10 cm facing South						
White colour (glazed)	38.1	(+3.4)	22.7	(-5.6)	31.6	(+0.4)
Ochre colour	42.1	(+7.4)	23.4	(-4.9)	34.3	(+3.1)
Beige colour	42.6	(+7.9)	23	(-5.3)	34.1	(+2.9)
Light grey colour	43.3	(+8.6)	23.1	(-5.2)	34.4	(+3.2)
Brown colour	45.7	(+11)	24.4	(-3.9)	36	(+4.8)
Red-Dark red colour, black spots	45.8	(+11.1)	24	(-4.3)	36	(+4.8)
Olive green colour, black spots	46.6	(+11.9)	24	(-4.3)	36.1	(+4.9)
Dark grey colour	46.7	(+12)	23.5	(-4.8)	36	(+4.8)
Blue colour	47.1	(+12.4)	23.5	(-4.8)	36.3	(+5.1)
Black colour	47.1	(+12.4)	24.3	(-4)	36.5	(+5.3)
Black colour, with white spots	50.5	(+15.8)	24.3	(-4)	38	(+6.8)
Ceramic panels 25 x 13 x 1,3 cm facing South						
White colour	39.7	(+5)	23.2	(-5.1)	32.6	(+1.4)
Beige colour	40.8	(+6.1)	23.5	(-4.8)	33.3	(+2.1)
Light grey colour	41.8	(+7.1)	23.4	(-4.9)	33.6	(+2.4)
Brown colour	48.9	(+14.2)	22.6	(-5.7)	37	(+5.8)
Marble panels 20 x 30 cm facing South						
White colour	36.7	(+2)	22	(-6.3)	31.1	(-0.1)
Light grey colour	42	(+7.3)	22.3	(-6)	33.9	(+2.7)
Beige colour	44	(9.3)	21.3	(-7)	34.6	(+3.4)
Grey-Beige colour	45	(10.3)	22.3	(-6)	35.8	(+4.6)
Grey colour	46.3	(+11.6)	21.7	(-6.6)	36	(+3.4)
Ochre colour	50	(+15.3)	22.7	(-5.6)	37.8	(+6.6)
Dark grey colour	51.7	(+17)	22.7	(-5.6)	39.7	(+8.5)
Granite slabs 20 x 30 cm facing South						
White-Beige colour	39.3	(+4.6)	22.3	(-6)	32.8	(+1.6)
Salmon colour	42	(+7.3)	23	(-5.3)	33.8	(+2.6)
Red-Black colour	47.7	(+13)	23	(-5.3)	36.5	(+5.3)
Black colour	49.7	(+15)	23.3	(-5)	37.7	(+6.5)
Grey colour	50.3	(+15.6)	23.3	(-5)	38.3	(+7.1)

Table 5. Overview of the experimental measurements on samples of building materials facing South.

4. Conclusions

4.1 The effect of orientation

For paving materials, the horizontal placement, in combination with the high sun altitude angles during the summer period and the large amounts of solar radiation result in maximum absorption of solar radiation and the overheating of the materials, depending on their colour and thermo physical properties. For facade materials, the orientation determines the angle of incidence of the solar rays, the duration of insolation, as well as the hours of the day when it occurs.

In the case of northern facades, the solar radiation, which is received throughout the summer period, is limited. Consequently, the surface temperatures of north-facing materials, as the in-situ measurements show, are lower than or equal to the air temperatures throughout the summer days.

The insolation of southern facades is largely affected by the high sun altitude angles (74,4^o for Athens, at noon on June the 21st). As a result, most south-facing materials do not record very high absolute maximum surface temperatures in summer.

Eastern and western facades receive large sums of solar radiation at angles which are nearly normal to their surfaces. Western facades may record higher surface temperatures than eastern ones due to the fact that during the afternoon, the large sum of solar radiation, which impinge on western facades, coincide with the highest daily air temperatures.

4.2 The effect of colour

The material property that defines its behaviour under the effect of solar radiation is reflectivity, which depends mainly on its colour (Givoni, 1998). Light-coloured materials record lower surface temperatures than dark-coloured ones. This fact has been largely documented by many researchers (Givoni, 1998; Akbari, et al., 1992; Doulos, et al., 2004) and was also evident from the results of this work shown above.

However, an important concern regarding light-coloured paving materials, is the effect of soiling and weathering on colour and, therefore, on their thermal behaviour. This fact is evident from the comparison of the maximum and the mean surface temperatures of the in-situ and the experimental measurements carried out with light-coloured materials in this study.

4.3 The effect of thermo physical properties

Even though orientation (see 4.1) and colour (see 4.2) affect the surface temperatures of the materials exposed to solar radiation, so also their thermo physical properties. This fact is evident from the maximum surface temperatures and the daily temperature variation of certain groups of materials, such as loose, earthen materials, light-weight concrete and wood.

The high surface temperatures (Tables 1 and 2) of loose earthen materials directly depend on their thermo physical properties. Dry earth has low thermal conductivity (0.25 to 0.30 W/mK) and density (300 to 1600 kg/m^3) (Oke, 1995) values, depending on the composition of the soil (Oke, 1995). The values for wood are similar (about 0.09 W/mK for softwood and 0.19 W/mK for hardwood) (Oke, 1995). Consequently, the ability of these materials to diffuse heat through their mass (Oke, 1995; Givoni, 1998) and their ability to store heat (Oke, 1995; Szokolay, 1980), which are expressed by the theoretical properties of diffusivity and admittance, respectively, are relatively low. As a result, earthen materials and wood have a rather contradictory thermal behaviour. They heat up considerably until noon, but cool down rapidly (3 to 4 °C every half hour) after 13:00 to 14:00, with their surface temperatures dropping below the air temperature by sunset (19:30 to 20:00).

4.4 The effect of shading

The measurements in the in-situ study clearly demonstrate that the effect of shading is of utmost importance in the case of dark-coloured materials (e.g. asphalt, dark-coloured stone, etc.). The differences in the surface temperatures of exposed and shaded dark-coloured materials are very large, ranging from 19 to 28 °C for the absolute maximum temperatures, and from about 13 to about 21 °C for the mean temperatures. In comparison to the mean ambient temperatures, the mean surface temperatures of the exposed materials are approximately 10 to 18 °C higher, whereas shaded materials are, most of the time, cooler than the air temperature. Finally, around sunset, exposed materials are 5 to 9 °C warmer than the air temperature, while shaded materials are considerably cooler. A detailed report on the effect of shading on the surface temperatures of materials is given by Bougiatioti (2005).

4.5 The effect of vegetation cover and water surfaces

Vegetation significantly affects the overall environmental conditions that prevail in the city centres (Givoni, 1998) in two distinct, and equally important ways. Firstly, by shading the various materials (see 4.4) and secondly, by maintaining low surface temperatures through the process of transpiration. However, it should be noted that the surface temperatures of vegetative cover depend on the characteristics of the species, and mainly their ability to withstand drought. In this study, the grass surfaces measured temperatures according to their thickness and irrigation patterns. The temperature of surfaces of thick and regularly irrigated grass was lower than the environmental temperatures throughout the day. This was also the case for various surfaces of evergreen shrubs. On the contrary, a grass surface, which was fairly worn and dry, developed a maximum surface temperature of 45 °C, which was approximately 10 °C higher than the air temperature.

Water has a very positive contribution to the microclimate, because of its high heat capacity (1160 Wh/m^3K (Oke, 1995)), and its ability to evaporate, which causes considerable air and surface temperature reduction with a simultaneous increase of relative humidity levels (Oikonomou, 2004). In this study, the temperatures of water surfaces (mainly fountains in two squares in Athens) measured were very low (mean maximum T=25,5 °C) compared to the corresponding air temperatures.

5. Selection of "skin" materials based on their thermal behaviour

5.1 Selection of paving materials

Apart from all the afore-mentioned parameters, the overheating of paving materials depends on the geometrical characteristics of the urban open spaces. A preliminary effort to define those "worst-case scenario" instances, namely the instances of urban open spaces where full -or almost full- insolation occurs during the summer months, is presented in a previous study by the author Bougiatioti (2006). The cases of urban canyons with North-to-South direction and with NW-to-SE direction, where the materials of the horizontal surfaces were bound to overheat during the summer, comprise of height-to-width (referred to from now on as H/W) ratios from 0 to 0.5 (or 1). For canyons with NE-to-SW direction, including narrower canyons, have H/W ratio of 1 (or 1.5). Finally, the horizontal surfaces of urban configurations, whose main axis runs East-to-West are prone to overheating in the summer, even in the case of a H/W ratio of 2.

In all the above cases, the negative contribution to the urban microclimate and to thermal comfort is important, and material selection should, thus, aim for:

- Materials which will measure low surface temperatures, compared to the air temperature, namely light-coloured materials
- Materials shaded by permanent or temporary shading structures and/or vegetation (trees or climbing plants) (Bougiatioti, 2005)
- Porous materials combined with an appropriate system of periodic water-sprinkling (Bougiatioti, 2005)
- Vegetative cover (e.g. grass, shrubs)
- Water surfaces
- Materials with low heat capacity and diffusivity, such as dry soil, light-weight concrete, ceramic blocks and wooden boards, which overheat during noon, but cool down quickly during the afternoon.

The application of one or more of the above solutions depends on the character and the use of the urban space, as well as on its design principles. Issues of visual comfort should also be taken into consideration, as the choice of certain materials (i.e. materials with light colours and/or glossy surfaces) can cause glare.

Finally, the materials for urban space should be chosen according to its peculiarities, its character and its patterns of use. During summer days, there should be shaded areas, where the solar radiation is blocked and the surface temperatures of the materials remain low (Khandaker Shabir, 2000). Similarly, during winter and the intermediate seasons (spring and autumn), there should be areas with no obstruction for solar radiation access.

5.2 Selection of facade materials

The overheating of facade materials facing East and West mainly occurs in buildings, which form part of wide urban canyons with H/W ratios smaller than 0.5. (Bougiatioti, 2006) In more narrow canyons, the overshadowing of the facades by the opposite buildings prevents the materials from heating to high surface temperatures.

In general, the materials, which form the outer layer of eastern and western facades, may heat up to very high surface temperatures. For the above-mentioned reasons, the choice of materials for eastern and western facades should aim for:

- Materials, which record low surface temperatures compared to the air temperature, namely light-coloured materials or materials painted with "cool paints" (Pomerantz, et al., 1998; Heat Island Group, 2005; Synnefa, et al., 2006; Synnefa, et al., 2007).
- Materials, irrespective of their surface temperatures, shaded by permanent or temporary shading structures and/or vegetation (trees or climbing plants).
- Vegetative cover with climbing plants).

- Vertical water surfaces. (Oikonomou, 2005)
- Materials with a low heat capacity and diffusivity, such as composite wood, aluminium and copper panels, which may overheat during the morning, but cool down quickly afterwards.
- Materials placed at a distance from the walls (ventilated facade system).

The effect of the overheating of east and west-facing materials on the internal climate of buildings can be minimised with the use of thermal insulation. (Bougiatioti, 2007).

5.3 Conclusion

It should be noted that the application of one or more of the afore-mentioned proposals to urban open spaces and buildings facades mainly depends on their use and design. For instance, for building facades, it is important to examine the aesthetic result of the application of one or more solutions to street frontages with a certain orientation at the scale of one or more building blocks. A good example is the redesign of the southern facades of city streets with shading devices and solar systems (e.g. PV panels for wall cladding or for shading). Such an intervention could help not only to improve the urban microclimate and the interior climate of buildings, but also to educate the public on issues of sustainability and energy conservation.

Finally, it should be noted that the choice of surfacing materials for both horizontal and vertical city surfaces affects visual comfort conditions in the urban open spaces, as well as the possibility of taking advantage of daylight for the illumination of the interior spaces of buildings (Givoni, 1993). Consequently, for narrow urban streets, where solar radiation penetrates for a limited period during the day, the use of light-coloured materials can help improve visual comfort conditions in the interior spaces of the buildings. (Yannas, 2001) On the contrary, in wide urban canyons with a small height-to-width (H/W) ratio, the use of light-coloured materials can cause glare and degrade visual comfort conditions at the level of pedestrian circulation.

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7. References

Akbari, H., Davis, S., Dorsano, S., Huang, J. & Winnett, St., (Eds.) (1992). *Cooling Our Communities,* U.S. E.P.A., ISBN 0-16-036034-X, Washington, U.S.A.

Atturo, C. and Fiumi, L. (2005). Thermographic analyses for monitoring urban areas in Rome to study heat islands, In: *Proceedings of 1st International Conference. Palenc 2005*, Santamouris M. (Ed.), vol. 2, Heliotopos Conferences Ltd, ISBN 960-88153-5-5, 960-88153-3-9, Athens, Greece, pp. 145-150.

Boon Lay, O., Guan Tiong, L. & Yu, C. (2000). A survey of the thermal effect of plants on the vertical sides of tall buildings in Singapore, In: *Proceedings of the 17th PLEA Conference*, Steemers K., Yannas S. (Eds.), James & James Science Publishers Ltd., ISBN 1-902916-16-6, London, UK, pp. 495-500.

Bougiatioti, F. (2005). The effect of shading on the surface temperatures of the materials used in the skin of greek cities. In: *Proceedings of 1st International Conference. Palenc 2005*, Santamouris, M. (Ed.), vol. 2, Heliotopos Conferences Ltd, ISBN 960-88153-5-5, 960-88153-3-9, Athens, Greece, pp. 775-780.

Bougiatioti, F. (2005). The effect of water-sprinkling on the surface temperatures of the materials used in the skin of greek cities, In: *Proceedings of 1st International Conference. Palenc 2005*, Santamouris, M. (Ed.), vol. 2, Heliotopos Conferences Ltd, ISBN 960-88153-5-5, 960-88153-3-9, Athens, Greece, pp. 749-754.

Bougiatioti, F. (2006). The effect of urban geometry on the surface temperatures of materials' used in the "skin" of greek cities, In: *Proceedings of PLEA 2006. 23rd International Conference*, Compagnon R., Haefeli P., Weber W., (Eds.), vol. 1, PLEA, HesSo, Universite de Geneve, ISBN 2-940-156301, Geneva, Switzerland, pp. 471-476.

Bougiatioti, F., Evangelinos, E., Poulakos, G. & Zacharopoulos, E. (2009). The summer thermal behaviour of ''skin" materials for vertical surfaces in Athens, Greece as a decisive parameter for their selection. *J. Solar Energy*, 83, pp. 582-598.

Cadima, P. (1998). The effect of design parameters on environmental performance of the urban patio: a case study in Lisbon, In: *Proceedings of. PLEA 98*, Maldonado, Yannas S. (Eds.), James & James Science Publishers Ltd., ISBN 873936818, London, UK, pp. 171-174.

Cantuaria, G.A.C. (2000). A comparative study of the thermal performance of vegetation on building surfaces, In: *Proceedings of the 17th PLEA Conference*, Steemers K., Yannas S. (Eds.), James & James Science Publishers Ltd., ISBN 1-902916-16-6, London, UK, pp. 312-313.

Cook, J., Bryan, H., Agarwal, V., Deshmukh, A., Kapur, V. & Webster, A. (2003). Mitigating the Heat Impact of Outdoor Urban Spaces in a Hot Arid Climate, In: *Proceedings of 20th PLEA International Conference*, Bustamante W., Collados, E. (Eds.), ISBN (-), Santiago, Chile, E-16 [CD-ROM].

Doulos, L., Santamouris, M. & Livada, I. (2004). Passive Cooling of open urban areas. The role of materials, *J. Solar Energy*, 77, pp. 231-249.

Eymorfopoulou, A. & Aravantinos, D. (1998) The contribution of a planted roof to the thermal protection of buildings in Greece, *J. Energy and Buildings*, 27, 1, pp. 29-36.

Givoni, B. (1998). *Climate Considerations in Building and Urban Design*, Van Nostrand Reinhold, ISBN 0442009917, New York, U.S.A.

Heat Island Group, 2005, Available from:
<http://eetd.lbl.gov/Heatisland /Pavements/LowerTemps/>

Hoyano, A. (1988). Climatological uses of plants for solar control and the effects on the thermal environment of a building, *J. Energy and Buildings*, 11, 3, pp. 181-199.

Khandaker Shabir, A. (2000). Comfort in urban spaces: defining the boundaries of thermal comfort of outdoor thermal comfort for the tropical environments, In: *Proceedings of the 17th PLEA Conference*, Steemers K., Yannas S. (Eds.), Cambridge, 2000, James & James Science Publishers Ltd., ISBN 1-902916-16-6, London, UK, pp. 571-576.

Labaki, L.C., et al. (2003). The effect of pavement materials on thermal comfort in open spaces, In: *Proceedings of 20th PLEA International Conference*, Bustamante W., Collados, E. (Eds.), ISBN (-), Santiago, Chile, E-5. [CD-ROM]

Labaki, L.C., Oliveira M.C.A. & Freire A.P. (2003). The effect of pavement materials on thermal comfort in open spaces, In: *Proceedings of 20th PLEA International Conference*, Bustamante W., Collados, E. (Eds.), ISBN (-), Santiago, Chile, E-5. [CD-ROM]

Markus, T.A. & Morris, E.N. (1980). *Buildings, Climate and Energy,* Pitman Publishing Ltd., ISBN 0-273—00268-6, London, UK.

Marques de Almeida, D. (2002). Pedestrian Streets. Urban design as a tool for microclimate control, In: *Proceedings of PLEA 2002. Design with the Environment*, GRECO and ACAD (Eds.), vol. 1, ISBN (-), Toulouse, France, pp. 437-439.

Oikonomou, A. (2004). *Water in the city of Athens. An environmental and bioclimatic approach*, In: Ecological Design for an Effective Urban Regeneration, Babalis, D. (Ed.), Firenze University Press, ISBN 88-8453-179-9, Florence, Italy, pp. 129-136.

Oikonomou, A. (2005). Bioclimatic design of water elements in mediterranean cities, In: *ECOPOLIS: Sustainable Planning and Design Principles*, Babalis, D. (Ed.), Alinea Editrice, ISBN 88-6055-006-8, Florence, Italy, pp. 125-132.

Oke, T. R. (1995). *Boundary Layer Climates*, Routledge, ISBN 0-415-04319-0, London and New York.

Papadakis, G., Tsamis P. & Kyritsis S. (2001). An experimental investigation of the effect of shading with plants for solar control of buildings, *J. Energy and Buildings*, 33, pp. 831-836.

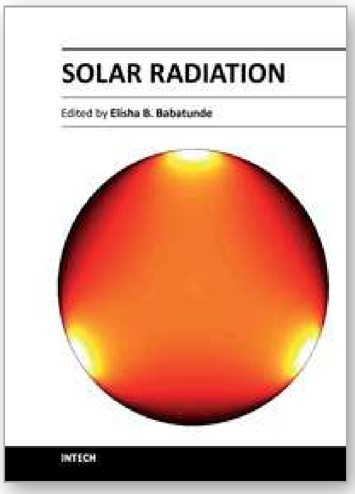
Pomerantz, M., et al. (1996). *Paving materials for heat island mitigation*, LBNL Report, LBL-38074, cited in Rosenfeld, A.H., Akbari, H., Romm, J.J. & Pomerantz, M. (1998). Cool communities: strategies for heat island mitigation and smog reduction, J. *Energy and Buildings*, 28, 1, pp. 51-62.

Santamouris, M. (Ed.) (2001). *Energy and Climate in the Urban Built Environment*, James and James Science Publishers Ltd., ISBN 1-873936-90-7, London, UK.

Synnefa, A., Santamouris, M. & Livada, I. (2006). A study of the thermal performance of reflective coatings for the urban environment, *J. Solar Energy*, 80, 8, pp. 968-981.

Szokolay, S. V. (1980). *Environmental Science Handbook*, The Construction Press, ISBN 0-86095-813-2, Lancaster / London / New York.

Yannas, S. (2001). Bioclimatic urban design principles, In: *Environmental Design of Cities and Open Spaces*, vol. 1, Amourgis, S. (Ed.), Hellenic Open University, ISBN 960-538-311-X, Patras, Greece, pp. 175-234.



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The book contains fundamentals of solar radiation, its ecological impacts, applications, especially in agriculture, architecture, thermal and electric energy. Chapters are written by numerous experienced scientists in the field from various parts of the world. Apart from chapter one which is the introductory chapter of the book, that gives a general topic insight of the book, there are 24 more chapters that cover various fields of solar radiation. These fields include: Measurements and Analysis of Solar Radiation, Agricultural Application / Bio-effect, Architectural Application, Electricity Generation Application and Thermal Energy Application. This book aims to provide a clear scientific insight on Solar Radiation to scientist and students.