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Urban Heat Island Effect: thermal response from different types of exposed paved surfaces

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Abstract: Pavement surface temperature could reach up to be 20-30℃ higher than the air temperature due to solar-energy absorption by pavement during the daytime, especially in hot climates. The heat energy absorbed by the paved surfaces is then stored inside and subsequently released as heat into the atmosphere, mostly at night. This interactive process increases the intensity of the Urban Heat Island effect: a phenomenon whereby urban regions experience warmer temperatures than their rural surroundings.

In this paper, different conventional and modified paved surfaces (both cement and asphalt bound) have been reproduced and tested in exposed environment to evaluate and compare their thermal performances by calculating thermal parameters such as such as emissivity, albedo, and solar reflective index. The testing was conducted with a thermal infrared camera, a pyranometer, a weather station and with a set of thermocouples. The results showed that concrete releases internal temperatures slowly during the day and asphalt material releases superficial heat quicker than the concrete. The phenomenon of heat storage and release was also evaluated by artificial heating/cooling in the laboratory environment. It was found that painted (yellow) paved surfaces generate a positive, although a different, reflective and cooling effect on both asphalt and concrete material. The extent of respective painted surfaces could be considered in urban paving design and management to reduce the Urban Heat Island phenomenon.

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***Key words**: Albedo; Emissivity; Paving materials; Thermogram; Solar Reflectance Index (SRI); Urban Heat Island (UHI) mitigation.*

The Concept of Urban Heat Island

Although urbanization and industrialization are the consequences of improving our lives and comfort, they alter the Earth's surface causing city-scale climate modifications [1, 2]. Buildings, roads, and other infrastructures replace open land and vegetation. Surfaces that once were permeable and moist tend to become impermeable and dry. This development leads to the formation of so-called Urban Heat Islands (UHI), thus many urban and suburban areas experience higher temperatures compared to their outlying rural surroundings [3].

UHIs are particularly a problem during summer months when heat waves can negatively impact human health as well as other living beings. The heat retained in pavements not only impacts the air temperature in urban areas, but it also impacts energy usage. Five to ten percent of electricity demand is frequently used to cool these impacts from elevated temperatures [4].

A study conducted by the U.S. Environmental Protection Agency highlighted that the annual mean air temperature of a city with one million or more inhabitants could be 1 to 3℃ warmer than the surrounding areas and on a clear, calm night, this temperature difference could be as much as 12℃. UHI can also be found in smaller cities and towns, though the effect often declines as city size decreases. On a hot, sunny summer day, the temperature of exposed urban surfaces, like roof and pavement, could be 25 to 50℃ higher than the air temperature, while shaded or moist surfaces - often in the more rural surroundings - remain close to air temperature. On average, the difference in daytime surface temperatures between urbanized and rural areas is 10 to 15℃; the difference at night time surface temperatures is typically less, i.e. 5 to 10℃ [3].

The generation of UHI is the mutual response of controllable and uncontrollable factors. The controllable factors are built environment, and other men made heat sources. The uncontrollable factors are like sun light, wind speed and cloud. The UHI could also be affected by temporary variables, such as air speed and cloud cover, the permanent variables such as green areas, building materials and sky view factor and the cyclic effect variables such as solar radiations and anthropogenic heat sources.

The mechanism of UHI generation is a complex process. The heat generated and contained within an area comes from the sun in the form of solar radiations and from power plants, vehicles, air-conditioners and other sources as anthropogenic heat. Almost all anthropogenic heat enters into the environment instantly and directly. On the other hand, only part of solar radiations heats up the environment directly; the remaining is absorbed by the complicated urban built structures and indirectly heats up the environment. The basic heat transfer and energy conservation processes, such as conduction, convection and radiation play their characteristic roles in this heat exchange. The structures close to ground level, such as walls and roof facets, irrigated gardens, non-irrigated green spaces, lawns and paved areas etc. capture solar radiation to a different extent. These natural and man-made structures continuously absorb and store radiations in the form of heat energy from sunrise till the late afternoon. Afterwards, the sun starts setting aside and the environment starts cooling down [1]. The heat energy absorbed by

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the paved surfaces is then stored in the subsurface and subsequently released as heat into the atmosphere at night [5].

The releasing process and the amount of heat released by the urban elements, however, depends on other controllable factors such as the sky view factor and building materials. In a typical urban area, massive construction material is placed within a very small space that captures high intensity of solar radiation. The ability of heat release by long-wave radiation in cities is low due to decreased sky view which results in high-heat heat storage in building structures. It is believed that the albedo, defined as the reflected light in comparison to the incident light, is also very low in cities due to typical street canyon scenarios, and is one of the main reasons of elevated air temperatures. Therefore, the design values of albedo and sky view factor are reported as two important factors in controlling UHI. Many studies have reported that the UHI is negatively correlated with wind speed and cloud cover and positively correlated with the city population [1]. In fact, the number of inhabitants could have a direct effect on heat generation as more people means more metabolisms and an indirect effect as number of buildings, vehicles, factories etc. will likely be increased with the increasing population. As the UHI would be a mutual response of many factors which includes the population, a comparison should take into account all controllable factors and should not be limited to population or any other factor. A comparison of controllable factors and the relevant UHI intensity of different areas might help to quantify the significance and the sensitivity of individual variables on UHI [1].

One of the major controllable elements in UHI is the extension and type of paved surfaces, considering that in most urban areas pavements cover a large percentage of the public and private surfaces [6]. It was estimated that the contribution from pavement surfaces reaches 30% of the total UHI. The paved surfaces are mostly roads, footpaths, squares and parking areas. Different colors and types of materials are used for these areas. The thermo-physical properties of these materials, especially the albedo, the infrared emissivity and the thermal capacity made significant contribution to the UHI effect [7]. It is therefore, useful to understand the heat related parameters of these pavement surfaces in the UHI genesis. A brief overview of these parameters is presented in the "thermal parameters and measurement" section.

Aims and Scopes

The aim of this study is to evaluate thermal properties of conventional and modified paved surfaces in order to better understand the relationship between different pavements and urban climate and evaluate their propensity to store less heat and/or to release it quickly during the daytime. In this way the pavement might emit less heat during the night time in order to mitigate the UHI effect.

In this paper, thermal properties measured from a laboratory study undertaken on exposed asphalt and concrete paved surfaces are presented. The surface temperatures were measured by a thermal imaging camera and supplemented by recording temperatures at various depths of the slabs by thermocouples. A brief description of thermal imaging technique is given in "thermal parameters and measurement section.

Results are presented to address the following objectives;

- A comparative study of the main thermal properties such as Emissivity, Albedo and Solar Reflectance Index (SRI) between asphalt and concrete surfaces;
- An application of infrared thermography to evaluate the feasibility of using this technology as a means of a routine investigation tool;
- A study of temperature distribution on the pavement surface under natural sunlight and in the simulated heating and cooling in the laboratory environment.
- An evaluation on the benefits of surface treatment for UHI mitigation purposes.

The experimental programme was divided into two phases. In Phase 1, the thermal properties of conventional and modified asphalt and concrete surfaces were determined in exposed environment (in summer 2011). In Phase 2, a laboratory simulation was conducted to evaluate whether any surface treatment improves the thermal performance and how asphalt and concrete pavement absorb and release heat during the respective heating and cooling processes.

Thermal Parameters and Measurements

The main thermal engineering parameters are: Emissivity, Albedo and Solar Reflectance Index. A brief description of these parameters follows.

Emissivity, also known as emittance of a surface, is a measure of how well a surface emits or releases heat. Emittance for a sample at a given temperature is the ratio of the radiant flux emitted by the sample to that emitted by a blackbody radiator at the same temperature, under the same spectral and geometric conditions of measurement [8]. It is a value ranging between 0 and 1. Highly polished aluminum has an emittance less than 0.1. A black non-metallic surface, on the other hand, has an emittance greater than 0.9 [9].

Albedo, which in this case is synonymous with solar reflectance, is the ratio of the amount of solar radiations reflected from a surface to the total amount reaching that surface. Solar reflectance is measured using a pyranometer and following the ASTM E1918 procedure described in section 9.4. Briefly, the procedure consisted of facing the pyranometer upward (that is, looking directly away from the surface) to read incoming solar radiation. After that, flip the pyranometer downward to read reflected solar radiation. Make sure the readings are constant for at least 10s. The measurements of incoming and reflected radiation are performed in a time interval not exceeding 2 minutes. Solar reflectance is then calculated by taking the ratio of the reflected radiation to incoming radiation." The albedo scale goes from zero, for no reflecting power of a perfectly black surface, to 1 for perfect reflection of a white surface [9].

The temperature of a surface depends on the surface's reflectance and emittance, as well as on solar radiation. The Solar Reflectance Index (SRI) is used to determine the effect of the reflectance and emittance on the surface temperature and varies from 100 for a standard white surface to zero for a standard black surface. This index measures how hot a surface would get compared to a standard black and a standard white surface [10]. The SRI is calculated using the ASTM E1980, "Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces." The materials with the highest SRI are the coolest and the most appropriate choice for mitigating the heat island effect [9].

Infrared thermography is a non-destructive testing method [11]. Recent advancements in infrared technology both in-terms of availability, price and functionality have made it a useful tool for many industrial, scientific, and medical applications [12, 13]. Thermal analysis is a broad field with a plethora of tools and techniques; hence, it is impossible to reasonably summarise it within the context of this paper. Briefly, thermal energy (heat) is a part of the electromagnetic spectrum of a material and takes upper portion of the infrared light spectrum, which is undetectable to the human eye. Each material emits some form of thermal energy. The infrared imaging camera utilises a special lens designed to capture infrared radiation (thermal energy) and then transforms it into an image representing the temperature distribution at the investigated surface.

In the past decades, the application of infrared thermography in built environment, were mostly limited to passive investigations to assess the quality of thermal insulation of building envelopes. In recent years there has been a limited amount of research where active thermography has been successfully applied to concrete and asphalt defect detection methodologies [14].

The infrared camera has the advantage of showing, real time, the whole surface temperature profile. As thermal imaging cameras capture infrared radiation emitted from an object, no light source is necessary to operate this device [13]. In this respect, it could be a very effective tool to deploy during night time operations.

Experimentation

Equipment

A high resolution thermal imaging camera**,** type FLIR B200 (Fig. 1 left), was used for recording all the superficial temperatures. The thermal image was then analyzed to calculate the Emissivity of the different paving surfaces. In addition, the Albedo values of the tested paved surfaces were acquired with the Sunshine Pyranometer, a patented meteorological class instrument with built-in heater designed for long-term outdoor exposure (Fig. 1 right) [15]. The measurements were taken following the ASTM E1918 procedure [16].

Thermocouples w*ere* installed at specific heights *of t*he specimens in order to monitor the internal heat transfer mechanisms. These were connected with a data logger to collect outside and inner temperature at regular intervals.

The measurements of the climatic conditions were made with a meteorological station installed at the outdoor experimental site to record time and date, indoor/outdoor temperature (℃), indoor/outdoor humidity (%), absolute pressure (hPa), wind (m/s), gust (m/s), direction relative pressure (hPa), and rainfall (mm). The meteorological station was able to record the atmospherical data every 15 minutes.

Materials and Methods

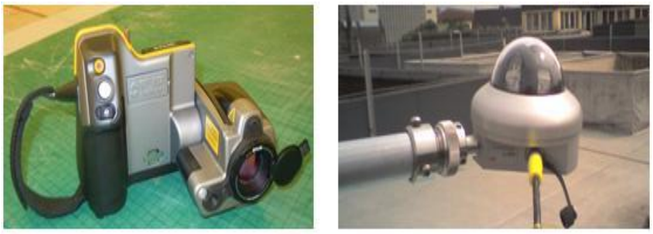

Fig. 1. Thermal imaging camera FLIR B200 and SPN1 Delta-T Sunshine Pyranometer.

Table 1. Materials.

ID	Material	Type	Maximum Aggregate Size (mm)
1	Concrete	C30 Plain Concrete (Compressive Strength is 30N/mm^2)	10
2	Rubberized Concrete	C30 Concrete with Replacement of Fine Aggregate by 10% by Mass of 1-5mm Recycled Rubber Particles	10
3	Concrete	C30 Concrete Painted with Yellow Color	10
4	AC	Polymer Modified Dense Bitumen Macadam (DBM)	14
5	AC	Enrobe a Module Élevé (EME)	20
6	AC	Dense Bitumen Macadam (DBM)	20
7	AC	Painted Dense Bitumen Macadam (DBM)	20

Testing was conducted on seven different paved surfaces. Table 1 and Fig. 2 present the material and slabs identification.

The concrete slabs were made using a wooden form cast (dimension 300x300x100 mm), while the asphalt slabs were larger (dimensions 500x200x100 mm) and made with a laboratory roller compactor. It should be noted that the asphaltic material was oven-aged and trafficked in the laboratory in order to simulate the in-service color and condition of the material.

The choice of using a yellow color paint was based on the statistical analysis of the surface temperatures conducted in the paper "*Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate*" [6]. It was found that all the colored thin layer asphalt samples demonstrate lower surface temperatures compared to conventional asphalt [6], particularly the yellow color.

Thermocouples were inserted at 10 mm (position A in Fig. 3), 50 mm (position B) and 90 mm (position C) depths from the top surface. Each thermocouple was positioned into the slabs at half across its width (150 mm) to ensure that the temperature near at the center of the slab is recorded.

Testing

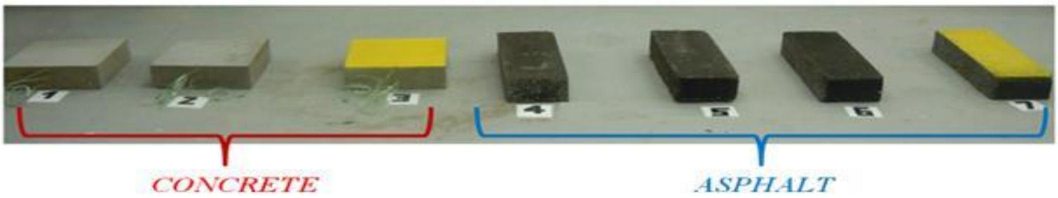

Fig. 2. Experimental Concrete and Asphalt Slabs.

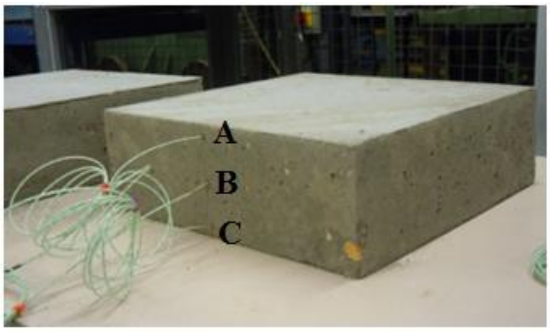

Fig. 3. Concrete Slab: Thermocouples at 10 (A), 50 (B) and 90 mm (C) Depths from the Top Surface.

Fig. 4. Roof Positioning and Pyranometer Measurements.

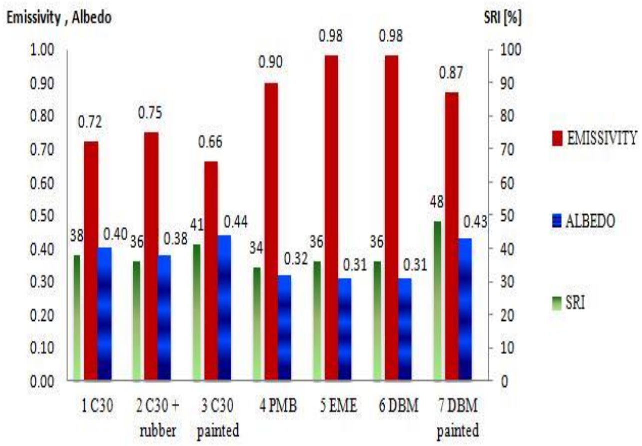

Fig. 5. Emissivity, Albedo and SRI for DifferentTypes of Slabs.

Phase 1: all slabs were placed on a horizontal roof top, as shown in Fig. 4, to get continuous sunlight and undisrupted wind during the experimental period. Other sources of heating were excluded or considered as negligible. Wind effect was found to be minor and data are not reported.

A layer of insulating material (polystyrene) was laid between the samples and the roof. This was done to avoid that the heating of the roof effected the measurements. Samples were covered when not tested. Pictures of the paved surfaces were taken with the FLIRB200 thermal camera at regular intervals. Specific software was used to acquire temperature data at regular intervals (10 min) from the thermocouples inserted inside the concrete slabs during the days between 26-07-2011 and 03-08-2011. The testing took place during 5 non consecutive days in July and August 2011.

Phase 2: Other tests have been conducted in the controlled laboratory condition to avoid the fluctuation of outside temperature and wind. One concrete slab (Slab 1) and one asphalt slab (Slab 5) were tested at 22°C room temperature simulating a possible summer temperature in the UK. The specimens' surfaces were artificially heated by a direct flow of heated air for 90 minutes, measuring the surface temperature by the thermal camera and the distribution of temperatures across the depth by means of the thermocouples. The heating was applied from a fixed position at 20 cm above the surface. The temperatures were continuously measured during both the heating and cooling periods. It was possible to compare the heat release of the two different slabs. The testing was conducted in two phases: first, 90 minutes heating and second, cooling period starting from the stop of heating until the specimens reached the room temperature.

Results and Analysis

Phase 1: Thermal properties in the open air

Thermal parameters

Emissivity: in Fig. 5, it can be seen that a surface like asphalt have higher emissivity than a surface of concrete. The application of paint tends to decrease emissivity for both asphalt and concrete. The reduction is approximately 12% for rubberized concrete compared to the 9% of normal concrete. In the asphalt mixture the reduction, due to the surface painting, was in the same magnitude.

Albedo: the pyranometer was positioned at 25 cm from the sample surface on the vertical axis for each measurement. The measurements were taken during different days at various times. The Albedo values calculated for each paved surface are also shown in Fig. 5. It can be seen that concrete material has higher Albedo than asphalt. It is interesting to note that the yellow painted slabs have the highest values. In this study the Albedo for asphalt were higher than those found in literature ranging between 0.01 and 0.20 [3]. Such higher values might be due to the actual dark gray shade of the asphalt samples surface color, which was obtained after oven aging of the samples and polishing caused by simulated trafficking.

Solar Reflectance Index: the SRI index for each material is also shown in Fig. 5. It is possible to observe that the yellow paint increases the paving surface ability to reject heat, and this is particularly evident on asphalts (DBM painted) where SRI increased from 0.31 to 0.43. It should also be noted that due the trafficking the SRI on asphalt surfaces is higher than standard black surface (close to zero) [10]. In general, concrete surfaces have higher SRI, but the value is marginally lower in rubber modified concrete due to the isolated rubber particles on the surface.

Thermal Analysis in Open Air

On 28-07-2011, four consecutive thermal pictures were taken for each paving material placed on building roof. The thermal pictures are shown in Fig. 6. All the thermograms are characterized by a specific setting of Emissivity and by the same scale of minimum and maximum temperature values (15-50℃). It can be seen that the temperature gradually increases from morning until midday (first three pictures in Fig. 6) and then gradually cools in late afternoon (fourth picture in Fig. 6). This indicates a gradual heating process of the samples in the first hours of the day and successive cooling process starting in the mid-afternoon. It could be noticed that temperature distributions are not homogeneous because of the different directions of solar radiation during the day.

Fig. 7 shows all the average temperatures obtained from thermal images (Table 2) together with the air temperature data during the test duration. The asphalt slabs reach temperatures 2-3℃ higher than the concrete slabs during daytime except for slab 7 (painted DBM). This one always shows average temperatures 3-4℃ lower than other asphalt slabs surfaces.

The concrete surfaces have very similar temperature profile, except for slab 3 (painted), which reached 1-1.5℃ higher in the afternoon than the other concrete slabs. Slabs 1 and 2 (C30 and C30 + rubber) show similar thermal behavior meaning that the thermal effect of rubber, if present, is not detected by the camera. In general, the asphalt slabs reach temperatures 2-3℃ higher than concrete slabs. Fig. 8 shows the thermal scenario after the peak of heat at 16.24 hours. Asphalt and concrete samples have similar surface temperatures: only the painted asphalt was found few degrees cooler than other specimens. When the sun heat transfer (radiation or air convection) is not active, both materials cool down on the surface, the asphalt being quicker and reaching the concrete surface temperatures; slab 7 is still the coolest.

A deeper analysis could be given for the concrete samples where internal measurements were taken. In Fig. 9, the temperature results of all concrete slabs recorded with the thermal camera and the embedded thermocouples are shown.

The dotted and dashed lines in the graph were plotted from the most superficial thermocouples, positioned 10 mm from the three concrete slabs surfaces. These curves show a relation with the air temperature (continuous line). Also, the internal temperatures of slab 3 (painted C30) are lower than the other two concrete slabs

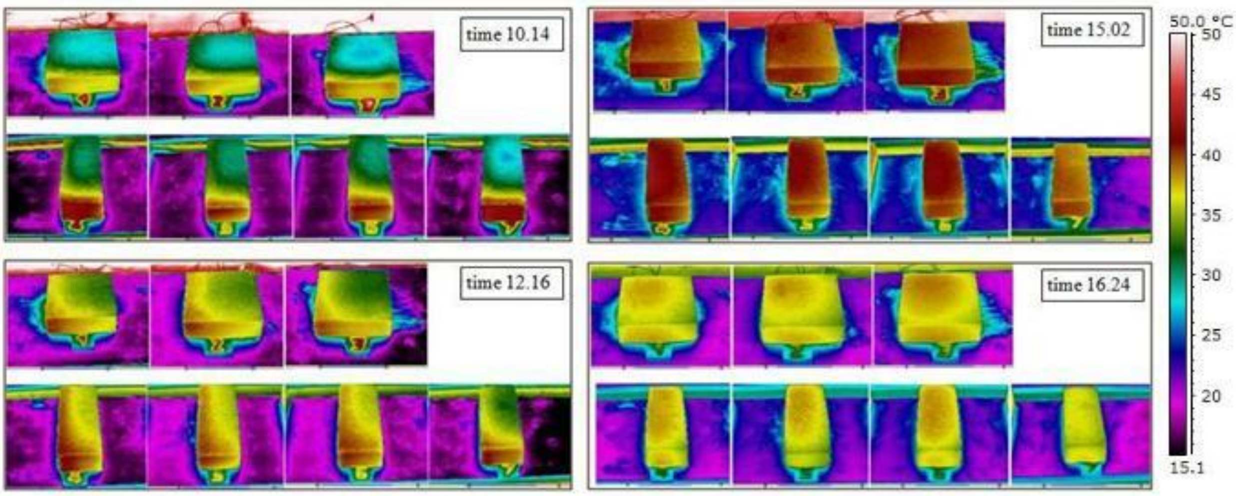

Fig. 6. Thermal Images of the Samples at Different Hours of 28-07-2011.

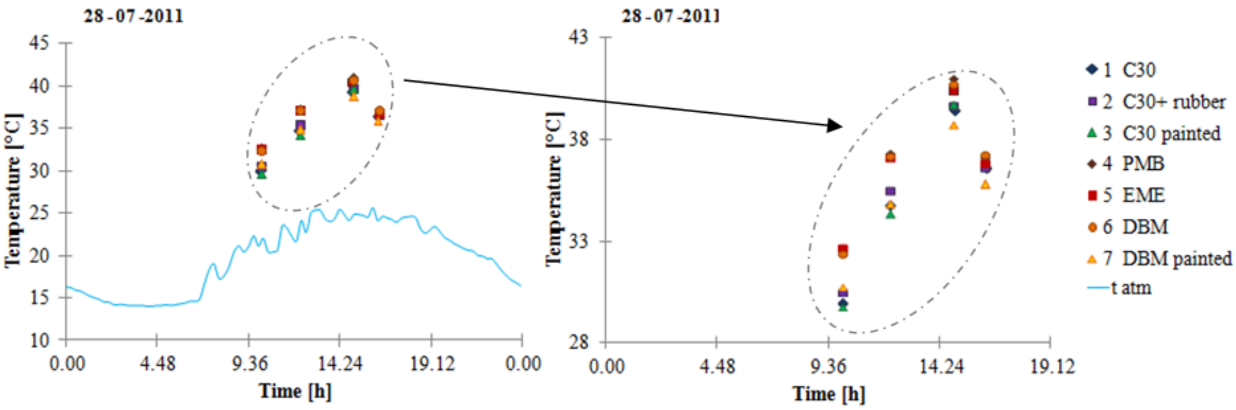

Fig. 7. Temperature Distribution of Different Paved Surfaces.

Table 2. Average Temperatures Obtained from Thermal Images.

	C30	C30 + rubber	C30 Painted	PMB	EME	DBM	DBM Painted
TIME	1	2	3	4	5	6	7
10.14	30	30.5	29.8	32.7	32.7	32.4	30.8
12.16	34.8	35.5	34.4	37.4	37.2	37.2	34.9
15.02	39.5	39.7	39.8	41.1	40.4	40.8	38.8
16.24	36.6	36.6	37.3	37.2	36.9	37.3	35.8

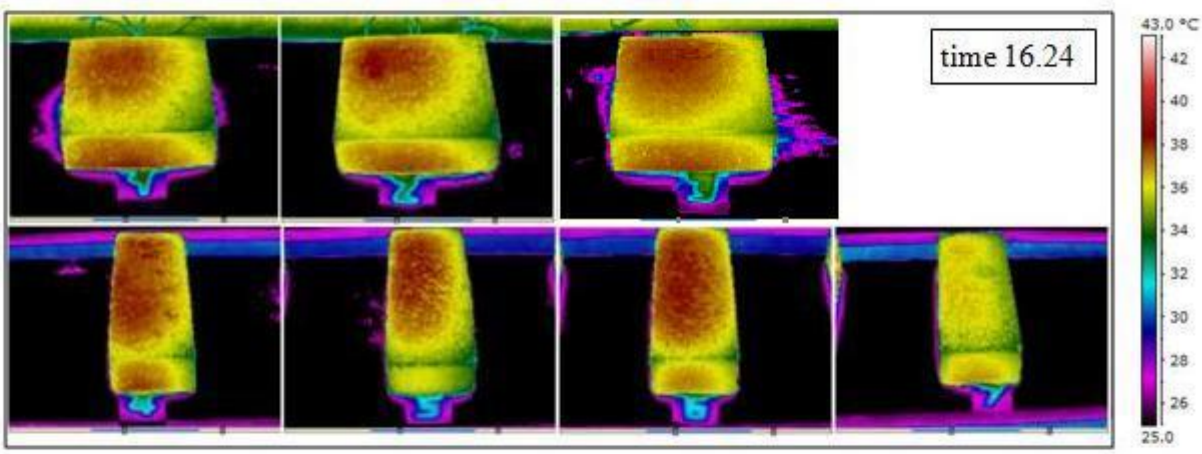

Fig. 8. 16.24 Thermal Pictures with 25 - 43℃ Temperature Range.

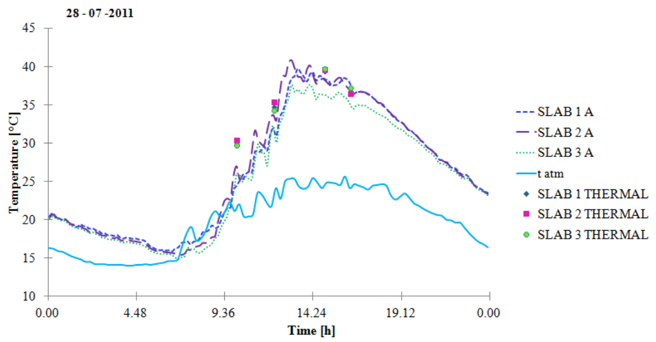

Fig. 9. Concrete Slabs: Position A (10 mm from the top), Surface and Air Temperatures vs. Time.

The single data points represent the average temperatures obtained from the four thermal pictures taken during the day. The considerable difference in temperature between air and surfaces proves that urban pavements do store heat during the day: in these tests the temperature of the samples is more than 15℃ warmer than the air temperature. It should be noted that early in the morning there is a period of time during when pavements and air attain the same temperature.

It is also interesting to see how the internal temperatures of slabs 1 and 2 gradually reach the superficial ones. This effect is mostly caused by the high thermal conductivity of concrete. On the other hand, the internal temperatures of slab 3 are always lower than the surface temperatures measured with the thermal camera, hence showing a contribution of the superficial painting in reducing the heat transmission through the concrete surface; the effect should be mainly attributed to the surface reflections of the paint.

Thermal Analysis of Concrete Painted Slab

This part of investigation was aiming to evaluate the effects of the surface treatment on the paving materials. The use of surface paint for functional purposes is diffused especially in urban areas, thus leaving the structural task to the underlying layers. HOV lanes, BUS lanes, bike lanes, footpaths and also other specific areas of the paved surfaces may require the use of colors, either painted or impregnated. Generally, structural materials range from concrete to traditional asphalt concretes to be painted afterwards; more innovative solutions can foresee the use of multifunctional materials with colored aggregates like e.g. micro-surfacing [17].

The thermocouples data obtained from outside measurements in the concrete materials are shown in Fig. 10. A single day record is represented.

The graph of slab 1 shows that the highest temperature through the concrete slab thickness is recorded by thermalcouple in position A (10 mm from the surface). The temperature decreases from the surface to the bottom of the sample. In the early hours of the morning the thermalcouple in A reaches a temperature that is 2-3℃ degrees higher than the temperatures in B and C (Fig. 10 left). This effect could be caused by the initial heating of the sample after the rising of the sun. The sun's rays intensly heat the surface and the first millimitres of the material below it with a certain gradient, including the thermocouple. A similar behaviour can be noticed also in slab 2 both in the early hours of the morning and during the early afternoon when the air temperature reaches its peak. This effect is hardly visible on slab 3 during the all measurement (Fig. 10 right).

This proves that the material's temperature is more homogeneous through the painted sample. It could be inferred that the yellow paint on the surface of slab 3 reduces the amount of heat that enters the bulk of the material. In particular, this is proven by the lower temperatures attained at the three levels of depth below the slab surface if compared to the other specimens.

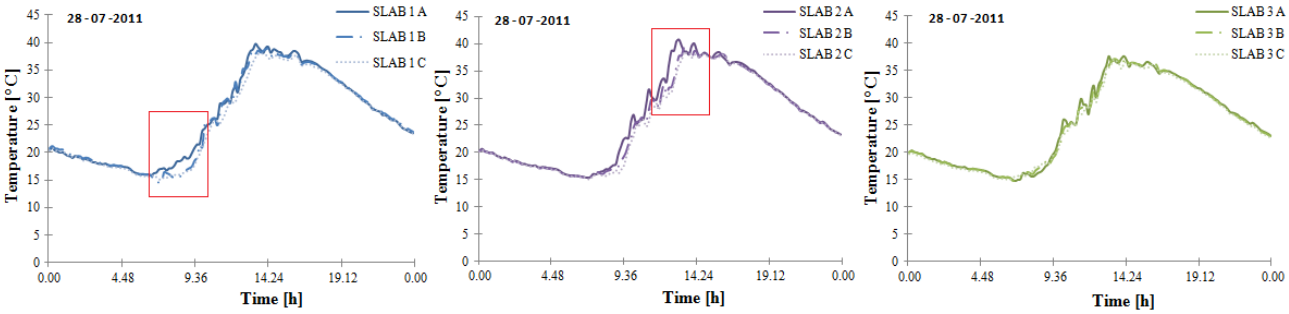

Fig. 10. Time – Temperature Graph of Slab 1 (C30), Slab 2 (C30+rubber) and Slab 3 (Painted C30).

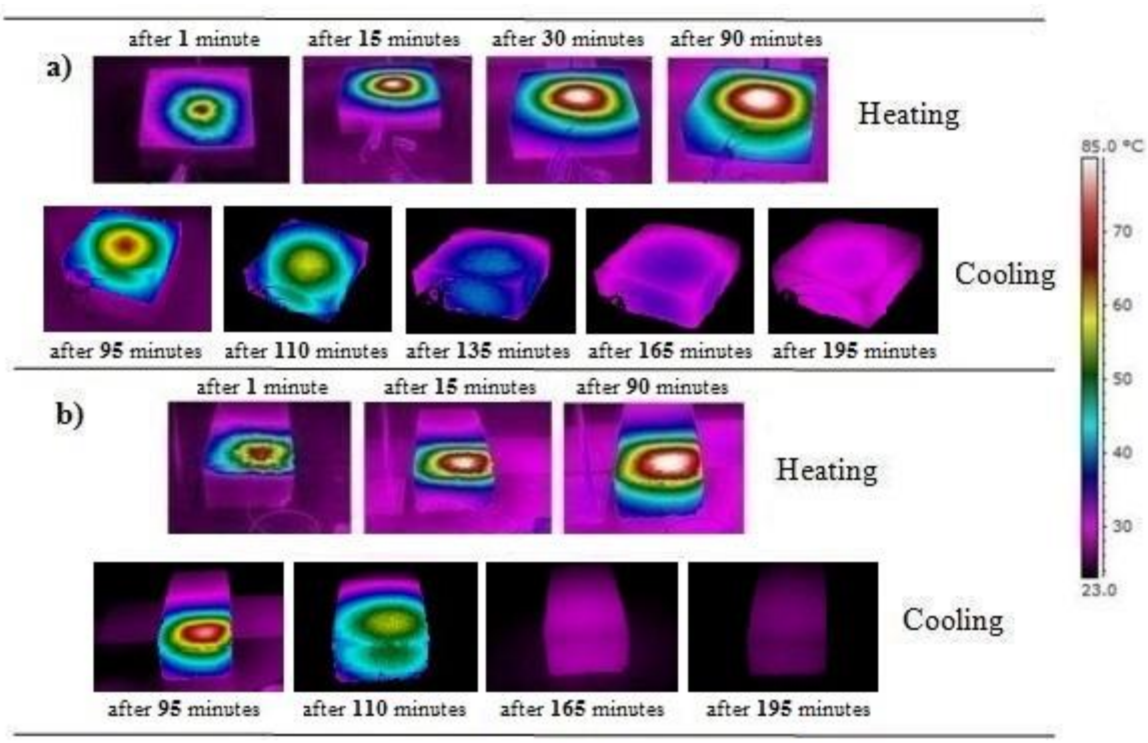

Fig. 11. Laboratory Thermal Imaging: a) Concrete Specimen and b) Asphalt Specimen.

Phase 2: Thermal Analysis in the Laboratory

One of the main objectives of this research was to determine which material (concrete or asphalt) would be able to release the stored heat more quickly. For this purpose, a specific laboratory testing procedure was set up in order to have the air temperature controlled as well as the heating process (90 minutes of direct air blow). In this case, heat was transmitted through the specimen surface by the convective transfer of heated air. It is possible to observe that the concrete and asphalt slabs have approximately same volume but different geometry. This problem was solved by analyzing a reduced portion of the samples and choosing a different position of the artificial heater for each material. The heater was positioned in correspondence of the thermocouple’s tip, located inside the asphalt slab at 100mm from the shorter external side and at half of the concrete slab’s width (150 mm).T The e thermocouples were inserted in both materials at the same depth, 90 mm (position C as shown in Fig. 3) from the top surface. Hence, thermocouples reading at point C in asphalt and concrete were recording at regular intervals.

Fig.11 shows the thermal images taken at time intervals during the heating and cooling of one concrete (a) and one asphalt (b) sample.

The average superficial temperatures were obtained by analyzing a specific area of thermal images, 100 cm^2 around the vertical projection of the heater’s position, whereas the internal temperatures were collected from the thermocouples and summarized in Fig. 12 and Table 2. Given that the heating process was kept constant for both samples, the following observations can be made. Both concrete and asphalt samples are able to store heat. At minute 1, the surface temperature is equivalent to the air blow temperature (62-63°C) for both samples and the internal temperature is equivalent to the room temperature (22-23°C). Warming up is internally slower but superficially faster for the concrete and, after 90 minutes, maximum surface temperatures differ of no more than 1°C, while internally a 3°C difference was recorded. Surface cooling rates are initially comparable, however after 200 minutes of testing the asphalt attains an average temperature that is 3°C lower than concrete, indicating that asphalt is able to release superficial heat quicker than concrete. This phenomenon was also observed in

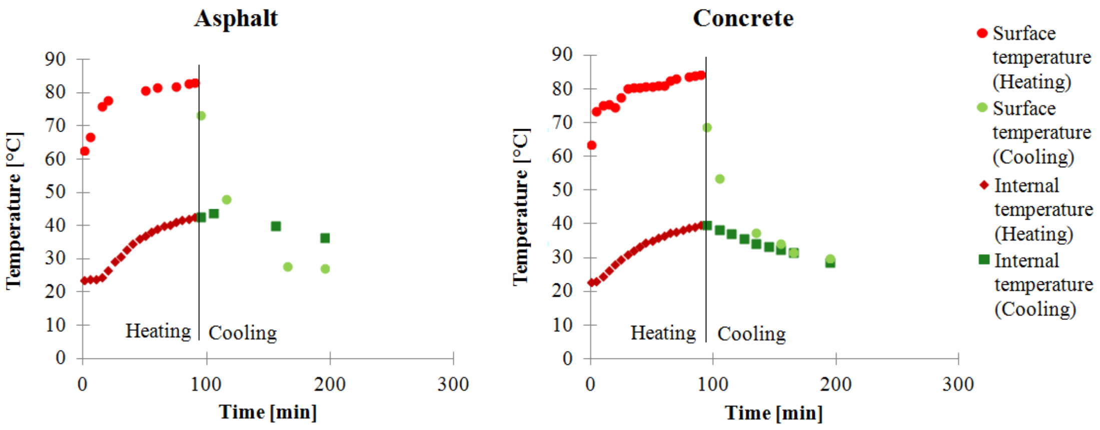

Fig. 12. Artificial Heating and Cooling Phases in Asphalt and Concrete Slabs.

Table 3. Summary of Temperature Distribution in Asphalt and Concrete Samples.

Slab	Max Surface Temperature [°C]	Max internal Temperature [°C]	Min Surface Temperature after 195 Minutes [°C]	Min Internal Temperature after 195 Minutes [°C]
Concrete	84.1	39.6	30.1	28.7
Asphalt	83.1	42.5	27.1	36.4

open air testing (shown in Fig. 7). On the contrary, internal cooling of asphalt is slower and at 195 minutes asphalt is still at 36.4°C while concrete reaches 28.7°C. It could be inferred that the roughness of asphalt surface facilitates the superficial reduction in temperature, while the low thermal conductivity obstacles the internal-to-surface heat transfer.

According to these findings, the effects of non-painted asphalt and concrete pavements on UHI generation are clearly different and they should be addressed with reference to the day-time and night-time heat release.

Summary and Conclusions

The observations from this investigation are:

- The analysis of thermal image and thermocouples data showed consistency between the measurements from different instruments. The thermal imaging technique could be a viable option as a routine assessment tool.
- The calculation of the thermal parameters such as Emissivity, Albedo and SRI for the tested paving materials has confirmed that a traditional asphalt concrete has higher aptitude to emit heat. Both painted specimens, either concrete or asphalt, are characterized by higher reflective surfaces if compared to non-painted ones and remain cooler compared to others. SRI is an effective parameter when describing the potential contribution of paving materials to UHI generation. Higher SRI means that the material is less prone to heat up and remains colder during the day. Thermal analysis confirms that the samples with higher SRI are cooler. The increment of SRI given by the paint is higher on the tested asphalt concrete compared to plain concrete (Fig. 5). Pavement surface texture, method and rate of paint application play an important role in obtaining high SRI.
- The open air results showed that the maximum air temperatures range between 15°C and 25°C. On the contrary, the temperature of the specimens could be as high as 40°C. This shows a substantial difference of 10-20°C between air and pavement, and that part of the heat is stored within the pavements' bulk. This was verified with the internal measurements of temperature in the concrete specimens.
- Both open air and controlled laboratory testing demonstrated that compared to concrete, asphalt reaches high temperature during the day-time in outside (heating in the laboratory). However, it appears that asphalt is able to release surface heat quicker despite internal temperature was marginally warmer than concrete.
- Painted asphalt samples are superficially cooler (3-4°C) than non-painted asphalt and concrete. The paint on concrete is less effective in reducing the surface temperature compared to non-painted concrete. Internal measurements on concrete samples show that a significant gradient of temperature across the depth in non-painted samples. The painted C30 concrete is cooler with more homogeneous distribution than non-painted concrete, supporting the fact that the painted surface is shielding the material from heating (see Fig. 9).The paint significantly improves the superficial thermal properties of asphalt related with UHI generation. This could be taken into account when the UHI problem is addressed during urban planning and transportation infrastructure design and management e.g. roads, parking lots, bituminous footpaths, etc.
- The effect of non-painted asphalt and concrete pavements on UHI generation is different and it should be addressed with reference to the day-time and night-time heat release in the urban built environment. In urban environment, the amount of asphalt paved surface is generally larger than the concrete paved surfaces. Therefore, the potential extent of respective painted surfaces will be different, which could be considered in

urban paving design and management to reduce the UHI phenomenon.

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