



International High-Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

## Aerial survey and in-situ measurements of materials and vegetation in the urban fabric

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### Abstract

The integration of microclimatic information and energy balance of the materials into urban design is essential for adequately addressing the challenges related to climate change and to adaptation of urban environment to new climatic loads. Several studies model the urban climate from multispectral satellite measurements. However, the remotely sensed measurements usually have a spatial resolution of several meters and are not suitable for determining microclimate effects in urban areas and on individual buildings. Moreover, they require consideration of the intervening atmosphere and the surface radiative properties that influence the emission and reflection of radiation within. The present research approach includes in-situ measurements and aerial surveys with VIS/NIR multispectral camera and IR camera mounted on a UAV. Analysis presented here, aims (1) to identify physical characterization of reflectance properties in a variety of urban settings in Athens, (2) to explore the response of vegetation, cool and conventional materials in the NIR region (3) to study climate parameters essential to the bio-climatic design in this urban cover (4) to elaborate observational studies for obtaining better validation of the surface effective parameters derived. The sensors on UAVs provide a unique perspective of urban features for revealing the complex mechanisms that lead to microclimatic modifications and to quantify their relative contribution. The application of NIR images in building and urban scale analysis is innovative and reveals different properties of the surface of the objects.

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Peer-review under responsibility of the organizing committee iHBE 2016.

*Keywords:* Urban microclimate; UAV; IR; NIR; aerial survey; vegetation; materials; surface temperature;

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## 1. Introduction

Globally, more than half of the population lives in urban areas [1]. Consistent knowledge about cities, their structure, materials and vegetation is of high relevance for urban based adaptation and mitigation strategies in response to climate change [2]. IPCC [3] notes the dearth of information on urban areas at detailed spatial and temporal resolution and the importance to derive comprehensive databases on cities and develop urban climate models. To understand the urban climate a thorough consideration of many parameters, such as urban morphology, land cover, moisture availability, anthropogenic heat and material properties, is required.

The properties of the materials used in the urban fabric play an essential role in the energy balance which modifies the microclimate [4]. Their thermal performance is mainly determined by the physical characteristics, optical and thermal [5]. The most significant factors related to radiation exchange are the albedo to solar radiation and the emissivity to long wave radiation [6]. The application of materials that present high reflectivity during summer period has gained a lot of interest during the last years as a mitigation strategy of the heat island effect [7]. These materials namely cool are characterized by high solar reflectance and infrared emittance values resulting in lower surface temperatures. Cool pavements refer to a range of established and emerging materials that tend to store less heat and have lower surface temperatures compared to conventional ones [8,9]. The vegetation influences the urban climate by moderating the solar and terrestrial radiation wind and rain, mitigates the greenhouse effect, filters pollutants, masks noise and prevents erosion [10]. Sufficient surface water permeability is vital for urban hydrology as intense rainfall can trigger local flooding in densely urbanized areas [11].

The surface temperature is of prime importance as it modulates the temperature of the lowest atmospheric layers and is central to the surface energy balance [12]. A great deal of information on surface temperatures can be obtained through thermal remote sensing imagery, e.g. Voogt and Oke [13] give a scientific overview of thermal remote sensing capabilities in urban climate. When remotely-sensed imagery is available, valuable information can be extracted on the properties of the materials.

However, as the remotely sensed measurements usually have a spatial resolution of several meters, they are not suitable for modeling microclimate effects in urban areas and on individual buildings. Moreover, they require consideration of the intervening atmosphere and the surface radiative properties that influence the emission and reflection of radiation within. The development of Unmanned Aerial Vehicles (UAVs) and of small spectral imaging sensors makes it possible to obtain spectrally resolved images at very high spatial resolution in an easy and flexible way. The UAVs as a sensor platform to support microscale measurements provide flexibility in the timing of data captured and the scale of the images obtained [14].

The use of Infrared sensors is an important tool in many close range applications. Thermal infrared cameras (in the bandwidth  $3.5\mu\text{m} < \lambda < 14\mu\text{m}$ ) provide the visualization of thermal differences on the surface of an object [15]. Moreover, the integration of near infrared (NIR) camera ( $0.75\mu\text{m} < \lambda < 3\mu\text{m}$ ), accumulates further radiometric info on the thermal properties of the materials and is a well-established tool for the analysis of vegetation [16]. In addition, the Normal Difference Vegetation Index (NDVI) is widely adopted in vegetative studies [17] and ground parameters such as ground cover and surface water.

The aim of this study is to address all these issues with a high definition surveying. This paper presents a classification-based methodology for surface emissivity mapping and surface temperature distribution over the examined area by combing airborne data, in-situ measurements and emissivity values.

## 2. Description of the site

The study area was in Ymittos Municipality, which is a suburb, situated 2.5 km southeast from the center of Athens, Greece. Subsequent to the administrative reform of Kallikratis Plan in 2011, it is part of the municipality Dafni-Ymittos. The Municipality has according to the official census of 2011, 33628 inhabitants and occupies an area of 2.35 square kilometers. The typical Mediterranean climate in this area is characterized by hot, dry summers and cool, wet winters.



Fig. 1 Photo of the study area (taken from the Unmanned Aerial Vehicle\_UAV) with selected points of interest

**Rehabilitation Plan:** Works started in late 2012 and completed during the fall of 2014. The central square is where the town-hall is located, with a park of 34800m<sup>2</sup> on the west side and an old unused industrial area of 157000m<sup>2</sup> are situated on the east. The initial pavements were made of degraded asphalt, concrete and dark paving materials, with albedo varying from 0.05 to 0.22. At final form 5170m<sup>2</sup> of pavement and 4000m<sup>2</sup> of asphalt were replaced. In total over 9000 m<sup>2</sup> of cool paving coating and 555 m<sup>2</sup> of PV pavement have been applied to the area. The study area has been selected to combine:

- a. An area with a small green space/Park;
- b. An area with reflective pavements/Square of Ymittos;
- c. A reference area/Neighborhood at Municipality of Ymittos



Fig. 2 Photo of the park



Fig. 3 Photo of the central square



Fig. 4 Photo of the neighborhood

### 3. Materials and methods

The experimental campaign was carried out 11<sup>th</sup> to 15<sup>th</sup> of April 2016. The research approach considered in this study included aerial survey with an RGB camera, a rebuild RGB camera where the blue channel is replaced by a NIR channel (*Canon PowerShot* rebuild by *Maxmax.com*) and an IR camera (*Optris 640*) mounted on a UAV.



Photo 1. The Unmanned Aerial Vehicle

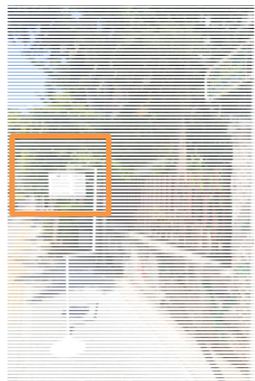


Photo 2. A typical weather-station



Photo 3. The mobile weather station

A standardized grey calibration plate reflecting 60% of the solar radiation was recorded before and after each set of VIS/NIR images. Close-up images of the different materials were also performed with a RGB camera, an IR camera and the VIS/NIR camera where the calibration plate was included in each frame. In addition, in-situ measurements were conducted under sunny, calm and clear atmospheric conditions, as listed in Table 1.

Table 1 In-situ measurements

Air Temperature $T_{\text{ambient}}$ and Relative Humidity RH%	(A) Data loggers (Tiny Tag TGP-4500) dual channel temperature and relative humidity, placed into weather stations (at 1.80 m height) at 3 selected sites (A, B, C) (B) Thermometer Vector Instruments type T351- PX and Hygrometer placed on telescopic mast at 3.5 m height (mobile meteorological station). The accuracy of the thermometers is 0.5C
Direct Solar Radiation	Pyranometer Kipp & Zonen
Albedo	Albedometer Kipp & Zonen
Surface temperature	Surface thermometer (HP23-A, Hygropalm 23-Rotronic) and Thermocamera (Agema Thermovision 570. Spectral range 7.5 to 13 micrometers)
Wind speed and direction	Anemometer A100K Pulse & W200 Porton Windwane, placed on telescopic mast at 3.5 m height (mobile meteorological station)

### 4. Data analysis

The RGB, VIS/IR and NIR images from the aerial surveys were all stitched together using Microsoft Image Composite Editor and then transformed to geo-referenced raster images with ERDAS Imagine [18]. The VIS/NIR images were calibrated with the grey reference plate on the first and last images from each flight. For the close-up images with the RGB camera and the VIS/NIR camera the calibration plate in each frame was similarly used.

The intensity of infrared radiation, which is emitted by each body, depends on the temperature as well as on the radiation features of the surface material of the measuring object. For the estimation of surface temperature, the spatial distribution of urban surface emissivity is site specific, depending mainly on vegetation and man-made materials at the area.

A classification map of four materials, water, asphalt, soil and vegetation, was created from the NDVI map and a value of the emissivity was assigned to each class of materials [19]. The NDVI algorithm subtracts the red reflectance values from the NIR and divides it by the sum of NIR and red bands according to the equation:

$$NDVI = (NIR - R) / (NIR + R) \tag{1}$$

Where: NIR and R are the reflectance values in the near infrared and red wavebands, respectively. This formulation allows to cope with identical patches shaded (cloud sky) and non-shaded (bright sunshine), by dividing by the sum of reflectances. The NDVI values and the corresponding emissivity are listed in Table 2. For the analysis, the selected examined points are non-shaded during the whole day.

Table 2 Values NDVI and Emissivity

NDVI	Emissivity Class	Emissivity
-0.90 to -0.15	Water	0.99
-0.15 to 0.10	Asphalt	0.95
0.10 to 0.25	Soil	0.98
> 0.25	Vegetation	0.97

An NDVI map is shown in Fig.5 where the values are represented as a ratio, ranging from -1 to 1.

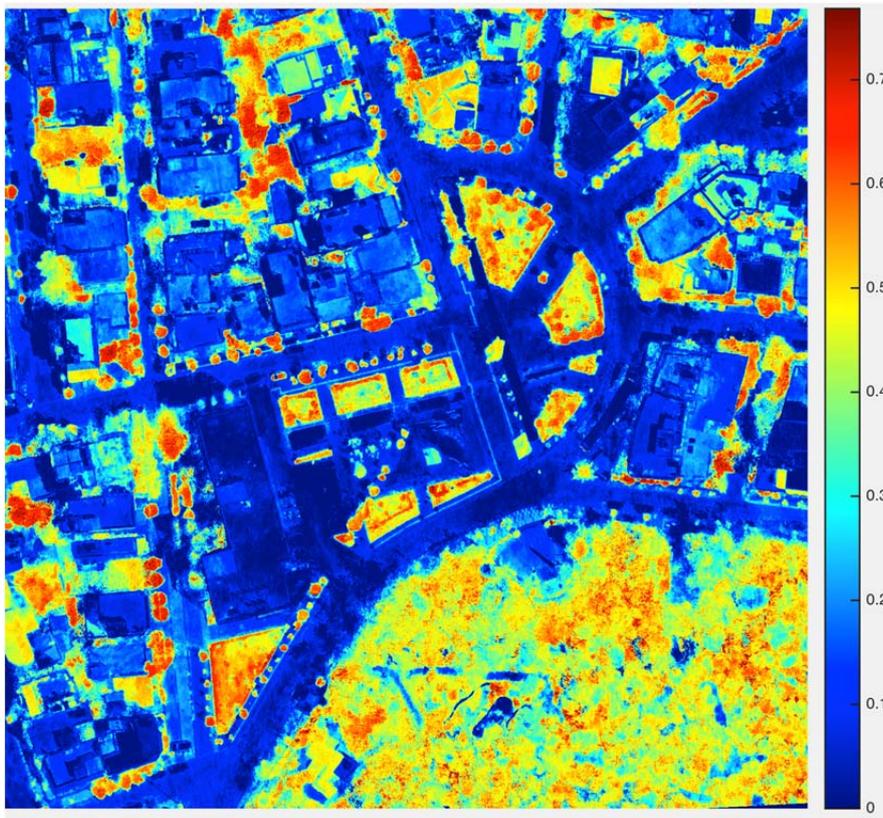


Fig. 5 The NDVI Map of the examined area

Indicative points of different materials were selected (see Fig.1): asphalt with cool coating (Point 8), marble (Point 9 & 10), old conventional asphalt (Point 1, 3, 5, 6), new conventional asphalt (Point 4), paving tiles (Point 7) and

vegetation (Point 2).

Albedo depends on the optical properties of the surface layer of the materials and can change over time or with additives. The albedo of new paved asphalt usually ranges between 0.04-0.06 [20, 21] and rises with aging and aggregative exposure to 0.09-0.18 [22]. On the contrary, the albedo of concrete has the opposite trend, with higher value at construction and decreasing over time to 0.06-0.19, because of weathering, soiling and abrasion [23]. According to studies [24] there is a reduction in the cool coatings reflectance after weathering exposure.

The albedo was measured for a set of different materials and the averaged values are given at Table 3 together with the corresponding values of NDVI, NIR and RGB.

Table 3 Values from close-up images at the study area

Material	NDVI [-]	NIR [%]	RGB [%]	Albedo
POINT 4 'new' conventional asphalt	0.05	0.32	0.35	0.12
POINT 7 cool asphalt	-0.13	0.20	0.33	0.12
POINT 8 conventional asphalt	-0.03	0.24	0.38	0.17
Marble	0.014	0.53	0.49	0.38
Tactile paving tile for blind	0.23	0.58	0.47	0.30
Vegetation	0.56	0.63	0.26	0.21

The surface temperature maps were then constructed using the corrected emissivity for IR images from four flights at corresponding different hours, during the same day (12.04.16 / 07:30 (at sunrise), 10:30, 14:30 and 20:00 (just after sunset)). The flights were performed in a predetermined pattern at an altitude of 100 meters. A total of 80 partly overlapping images were recorded in each flight. The spatial distributions of surface temperatures are shown in Figure 7-10. In order to look at the temperature variations during the day, one may take the difference between pairs of temperature maps. A more general approach however, is to perform a Principal Component Analysis (PCA) of the stack of temperature maps. PCA is a common method within multivariate statistics for reducing the dimensionality of large data sets [25]. The aim of PCA is to extract statistical relevant information from the data set by reducing large number of correlated variables to a limited number of linearly uncorrelated principal components, using an orthogonal transformation. Each principal component is composed of a scores matrix, which describes how the different variables relate to each other, and a loading matrix, which can be looked upon as the weight or influence of each variable on the scores. In the present study, with the stack of temperature maps, the first PC score image yields a map of the temperature variations for the different areas (Fig.11).

During the survey the air temperature was between 14.0°C and 28.2°C and the relative humidity from 31% to 80%.

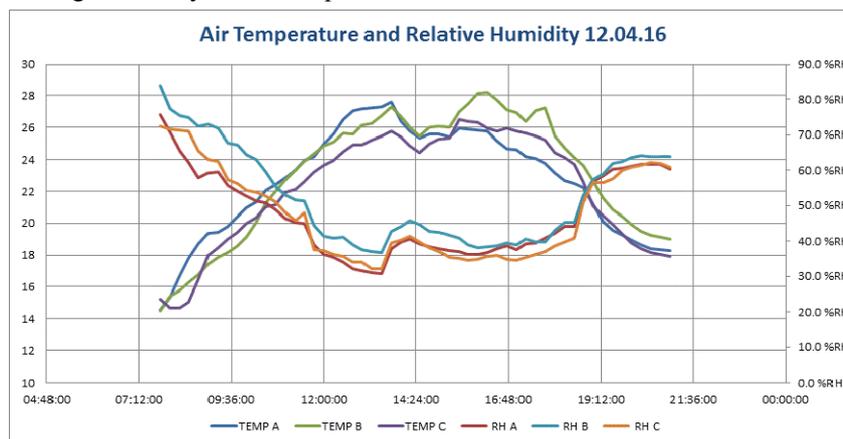


Fig. 6 The diurnal variation of air temperature and relative humidity at the study area on 12.04.16

Simple weather stations were placed at three points of the square with different surface features (A. concrete paving tile, B: asphalt and C: marble).

## 5. Results and discussion

### 5.1 Reflectance properties of materials

The application of NIR images at urban scale analysis accumulated further radiometric info on the thermal properties of the materials. The reflectance properties of the different materials in the close-up frames of indicative points are listed in Table 3. The asphalt with the cool coating has a slightly darker color (RGB-value) and lower NIR reflection than the conventional old asphalt; hence the NDVI for the asphalt with cool coating is lower than for the conventional one. The marble has an NDVI value similar to the asphalt, however the visible color (RGB) for the marble is bright and the marble has different thermal properties than the asphalt. The tactile paving tile for the blind has a bright color and also a high reflectance value in NIR, and thus a high NDVI value. In addition, the high measured albedo values of the asphalts indicate the aggregative exposure. The old asphalt's albedo was measured 0.17 while the more recent (two years old) asphalts conventional and the one with cool coating, both have values of 0.12. These values point out the weathering effects and degradation of the streets due to the high traffic at the area. As noted in literature previously, conventional asphalt initially has a very low albedo, but with ageing and exposure, it eventually increases significantly. On the contrary, the cool coating with high initial reflectance presents a decreased albedo due to surface accumulations and material degradation.

### 5.2 Thermal properties of materials

Thermal scanning of Ymittos area, allowed the collection of information as to the elements, characteristics of materials, and state of decay due to weathering or man-made alterations. According to the surface temperature distributions, the lowest temperature was measured at the green areas with average value close to air temperature. The marble was the coolest material at the square with mean value at noon 34°C. The asphalt with the innovative cool coating had lower surface temperature compare to the conventional one, of the same age, about 4°C. However, the comparison of old conventional asphalt to the new analogous cool, showed lower differences, due to the increase of old asphalt's albedo with time and the degradation of cool coating due to weathering and ageing. The paving tiles had lower temperature of 3°C compared to the asphalt, due to color, geometry, texture and the higher reflectance of cement.

Table 4 Values for 11 points of interest

Point	Type	Emissivity	Surface Temperature 1 7:30	Surface Temperature 2 10:30	Surface Temperature 3 14:30	Surface Temperature 4 20:00
1	Street-Conv. Asphalt	0.95	11.6	30.1	44.7	17.9
2	Trees-Park	0.97	14.1	24.7	34.3	17.5
3	Street-Conv. Asphalt	0.95	11.5	28.3	41.2	17.5
4	Street-Asphalt	0.95	12.0	30.2	44.5	19.0
5	Street-Conv. Asphalt	0.95	12.0	27.5	40.2	17.1
6	Street-Conv. Asphalt	0.95	11.7	29.6	44.2	18.4
7	Street-Cool Asphalt	0.95	12.7	33.0	43.5	17.5
8	Street-Conv. Asphalt	0.95	13.0	32.2	45.8	19.3
9	Square-Marble	0.95	10.8	25.1	35.5	15.3
10	Square-Marble	0.95	11.8	25.9	34.3	17.6
11	Tactile Tiles	0.95	12.7	28.6	41.0	18.4

The surface temperature maps were calibrated for the correct emissivity according to the material properties. The surface temperature distribution at the study area on 12.04.16, are shown in Figures 7-10 (please note the differences in the color scale of the various figures). The first recording of temperatures (taken at sunrise), shows that the various surfaces cool off differently during the night. Generally at dawn, surface temperatures in the vegetated areas are higher than the paved surfaces which again are higher than most of the building roofs. The map changes during the course of the day, and at noon, the roof temperatures are generally higher than the ones of paved surfaces, which again are higher compared to the ones of the vegetated areas.

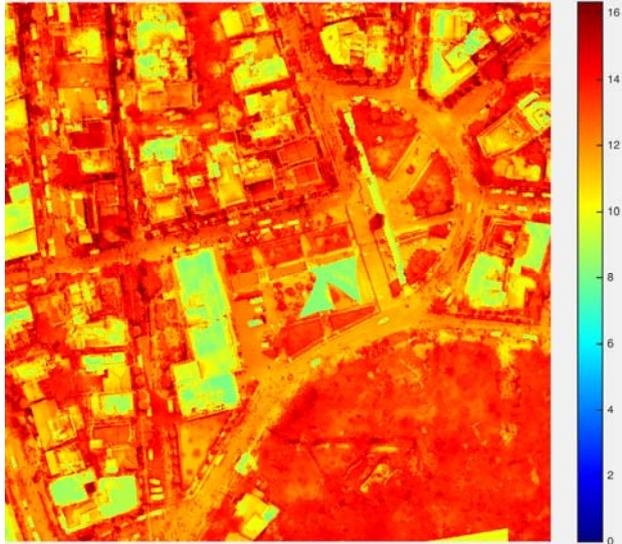


Fig. 7 Map of the surface temperature (°C) distribution, 7:40

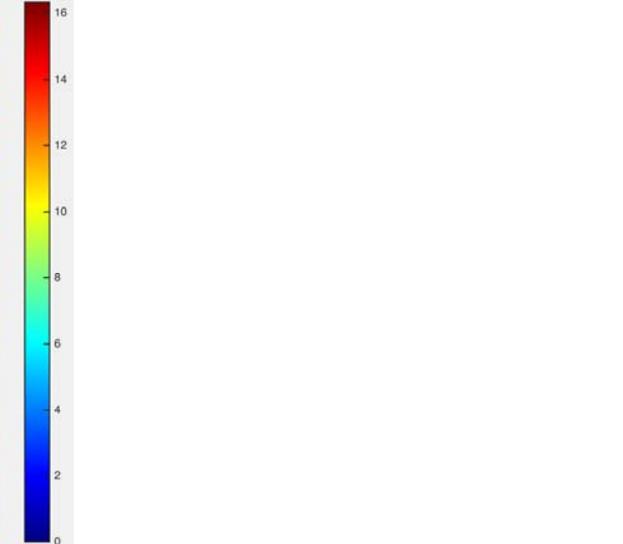


Fig. 8 Map of the surface temperature (°C) distribution, 10:15

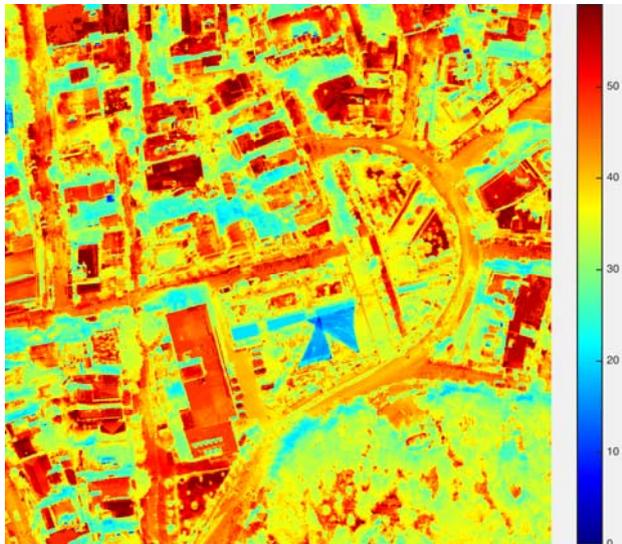


Fig. 9 Map of the surface temperature (°C) distribution, 13:30

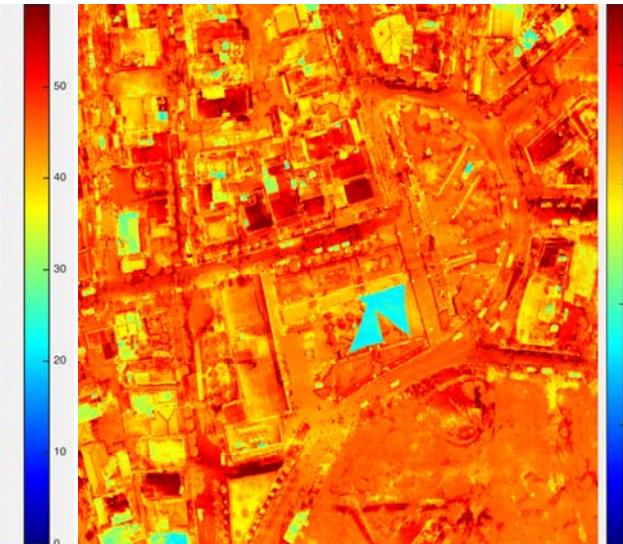


Fig. 10 Map of the surface temperature (°C) distribution, 20:20

The maps obtained at various times of the day have shades at different locations. With many recordings during the

day the effect of the shades can be eliminated by combining the non-shaded parts of the stack of maps. This is an advantage of the methodology of using UAVs where several recordings can easily be carried out, compared to satellite imaging. Some observations drawn by the temperature maps could be summarized:

- NDVI can be used to classify materials with different emissivity values
- Reflectance properties of materials are closely related to the surface temperature;
- Aging of asphalt increases its reflectance values and albedo, and thus its surface temperature decreases;
- The changes in surface temperatures during a diurnal heating cycle varies with the materials involved;
- The focus on a small number of points (i.e. 11points) is indicative but fragmented, due to rapid and continuous variance of surface temperature in space and time;
- The maps ease the understanding of relations between different physical properties and features of the materials

The PCA score image of the stack of the four calibrated surface temperature maps shown in Fig. 11 reveals the dominant patterns of the surface temperature variations during the day across the area.

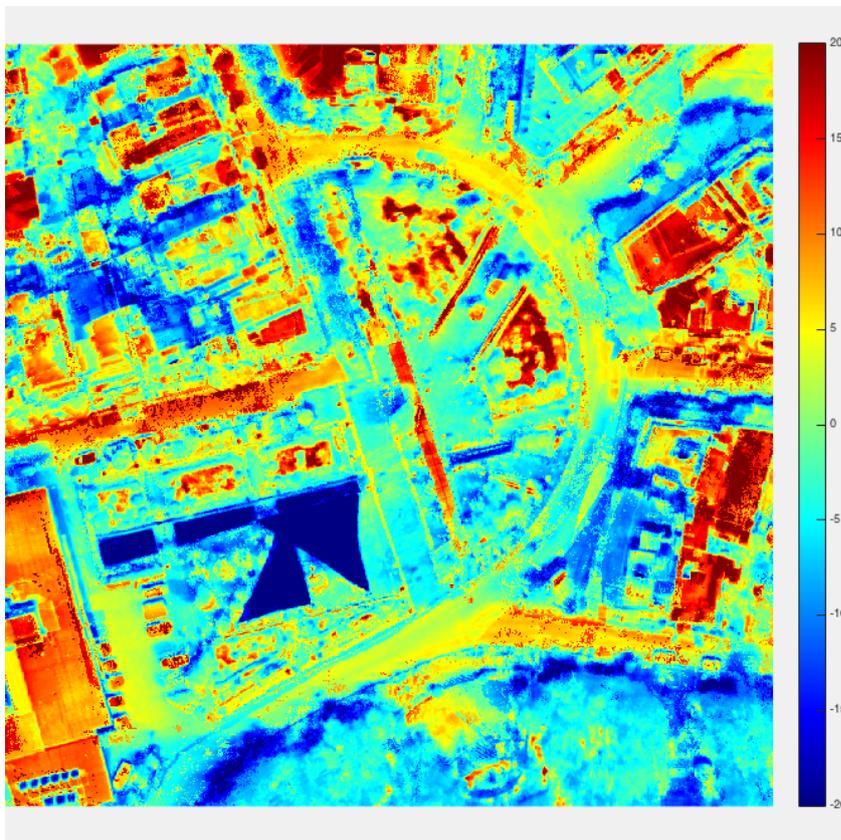


Fig. 11 PCA of four calibrated surface temperature maps

The high scores represent large variance (streets and buildings), while low scores indicate low variance (vegetation and water). The marble at the square presents low score and small temperature difference during the day accordingly.

## 6. Concluding remarks

The integration of sensors on UAVs provided an enhanced and flexible measured survey solution with highly accurate data captured on site. The calibrated VIS/NIR/IR images obtained by aerial sensing confirm works carried out at ground level. By covering a wider spectral range with high spatial resolution up to centimeters, the new measurement capabilities with the integrated methodology will advance the:

- a) Development of classified maps with physical properties of the materials at neighborhood scale;
- b) 3D modeling, validation and computation of surface parameters for urban planning;
- c) Evaluation of the implementation phases of rehabilitation projects;
- d) Exploration of the man-made alterations;
- e) Study of the weathering effect on the degradation of the surfaces;
- f) Decision making of micro-climatic design

The findings are applicable and fundamental in the process of bio-climatic urban planning.

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