Thermo-graphic analyses for monitoring urban areas in Rome to study Heat Islands

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ABSTRACT

Urban settlements bring about variations of the local meteorological characteristics. One of the most important effects is the increase of the temperature in urban areas in comparison with the neighbouring rural environment. This phenomenon is known as urban heat island.

This work presents the results of a research activity carried out by researchers of the CNR LARA (Laboratorio Aereo Ricerche Ambientali – Airborne Laboratory for Environmental Research).

This work presents the results of a research aimed at the study of the territory of Rome and its neighbouring areas by means of remote sensing techniques and analysis method in the thermal infrared. Landstat TM remotely sensed data will be analyzed in the first phase and MIVIS (Multispectral Infrared Visible Imaging Spectrometer) data in the second phase, while in the third phase the results obtained from investigations on covering materials will be described.

Finally, this paper reports some comments on the thermal behaviour of materials, with particular reference to the study of the thermal anomalies highlighted by visualizing the distribution of temperatures at ground; it is then shown that these anomalies correspond to wide areas made impermeable due to the presence of asphalt and cement.

Knowing the thermal response of building materials to sun radiation and studying the interactions with the atmosphere will help in finding solutions to improve their thermal efficiency and consequently to mitigate partially at least the phenomenon of heat islands.

1. INTRODUCTION

The phenomenon of the heat islands is a combination of different factors at different scale, and one of its consequences is the increase of the air temperature. It is generally more remarkable in urban areas than in rural areas: The formation process of the UHI (Urban Heat Island) is actually connected to the characteristics of the local climate, to the morphology of the area and to the superficial thermal-physical characteristics (emissivity, conductivity, density, etc.) of covering materials.

The excessive increase of temperatures in urban areas gives rise to the need to cool interiors and the ensuing higher consumption of electricity brings about the increase of the atmospheric pollution; due to higher emissions of sulphur dioxide, carbon oxide and nitrogen protoxides, suspended particles and carbon dioxide (Rosenfeld et al., 1996).

The negative effects of heat islands can be then summed up from the economic point of view in the increase of energetic costs, from the point of view of air quality in the increase of pollution, and, finally, from the thermal.-hygrometric point of view in conditions of environmental discomfort.

The main strategies, discussed in literature to mitigate the negative effects of the urban heat island, are chiefly directed towards:

- the use of covering materials with high coefficients of albedo (the ratio between the reflected radiation and the incident radiation);
- the extension of green areas, at different scales: regional scale (mesoscale) and local scale (microscale).

2. TIR DATA AND MEASUREMENT OF SURFACE TEMPERATURES IN LADSCAPE AND IN LABORATORY

2.1 First Phase

In the first phase of this preliminary study data remotely sensed by the Landsat TM sensor with a ground resolution of 120 m for the thermal channel (band 6), acquired on a wide area of the town of Rome also including the coast of the Tyrrhenian Sea, the lake of Bracciano, the Castelli Roma and the Tiber Valley, have been analyzed.

The processing of the band 6 (10.4 -12 μm) (Fig. 1) has enabled the different distributions of surface temperatures to be analyzed (Malaret et al., 1985; Abbate et al., 2003). The image visualized in the thermal channel shows the coldest temperatures indicated by darker shades, while the highest temperatures are represented by lighter shades. The urbanized area of Rome is actually affected by a strong heating as if buildings and roads act as “*heat trap*”.

It is interesting to observe in the Figure 1 that high temperatures are present also along the coastline, in the area from Fiumicino towards North.

This effect is due to the impermeability of soils, and in fact the corresponding portion of the image shows the geometry of the landing strips and the buildings of the airport of Fiumicino. The presidential estate of Castel Porziano also appears clearly in the image, close to the coastline towards South. Low temperatures are there determined by the presence of arboreal forest trees (ilex quercus, pinus pinea, pinus pinaster).

2.2 Second Phase

The MIVIS (Multispectral Infrared Visibile Imaging Spectrometer) data, collected over Rome on 19th June, 2004, at 11.30 am, at the altitude of 1500 m with a corresponding pixel of 3 x 3 m, have been analyzed in the second phase.

As measurements of reflectance values at ground and information about the characterization of the air column between the sensor and the earth’s surface were not available, the calibration method, known as IARR (International Average Relative Reflectance), (Kruse, 1988), has been therefore applied.

The visualization of the channel 93 of the MIVIS sensor (8.2 a 8.6 μm) has enabled the thermal behaviour of surfaces present in an area of Rome (Fig. 2) to be stressed.

The map produced by visualizing the irradiation of surfaces shows that natural elements, like water and green areas, present low temperature values and are well discriminated from the surrounding urban context.

On the contrary, the built-up surfaces present higher temperature ranges; some of these surfaces, such as roads, squares and some roofing of industrial buildings, even reach temperature higher then 40°C.

High thermal level have been recorded near road crossings and main roads, and are due to different factors: the wider extension of these surfaces involving a higher exposition to the sun radiation, the dark colour of materials, and the presence of high percentage of bitumen in asphalts.

Another important aspect resulting from the analysis of statistical files is that, in some areas of the town, impermeable surfaces exceed 90% of the total extension and in some cases they even reach values near 100%, so creating the optimal condition for heat islands (Atturo et al., 2003).

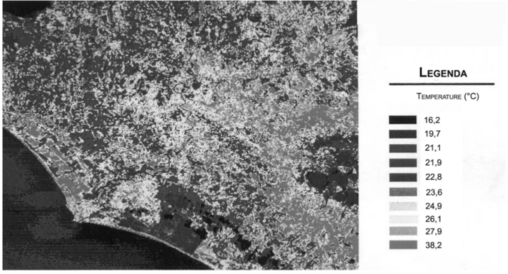

Figure 1: Landsat TM, (ch. 6) the surfaces temperature value at ground.

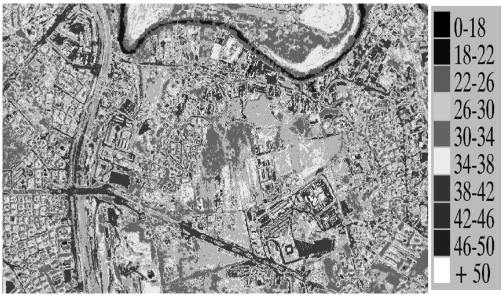

Figure 2: MIVIS, (ch. 93) the surfaces temperature value at ground.

Actually, as already known, one of the main causes of the heat island phenomenon is the low evapotranspiration of urban soil. On the contrary, in rural areas the evapotranspiration of plants, together with a higher porosity of soil, carries out a mitigation action on heat produced by the strong summer sun radiation (Oke, 1987).

The role of building materials is therefore decisive for the superheating of urbanized areas.

The thermal performances of building materials are mainly determined by their optical and thermal characteristics, the albedo and the emissivity are the most significant factors.

2.3 Third Phase

In this phase of the work, the thermal behaviour of some materials, distinguished by means of airborne remotely sensed data, is compared with analyses carried out in the laboratory.

A particular attention of the research group is directed to find a correct methodology for the study of the thermal characteristics of materials under different meteorological conditions.

The materials examined are those more distinguished by analysing remotely sensed data and more used to externally cover urban structures. The main materials used as covering surfaces have been then taken into considerations: grits, basalt, travertine, cement tiles, bricks, eternit, gravel, asphalt and metallic surfaces (Fig. 3).

The experimental investigations have been conducted in Pomezia at the LARA laboratory using the following instrument:

- Thermopint RAYTEK, series MX4 with a spectral range of 4-8 microns, and an optical resolution of 60:1 and a thermal resolution of 0.1°C.

By means of this instrument the research group carried out 3 measurement sessions on 24th June 2004, on 4th August 2004 and on 9th September 2004, in the time interval comprised from 9:00 am to 3:00 pm, as in this interval the highest sun radiation actually occurs.

As known, the sun radiation recorded does not depend only on the surface temperature of the object taken into consideration, but it is also function both of the object’s emissivity and its neighbouring conditions. The emissivity values used in this work are those found in the literature (Avery and Berlin, 2003), while the values of the climatic parameters have been collected by the measurement station at the airport of Pratica di Mare.

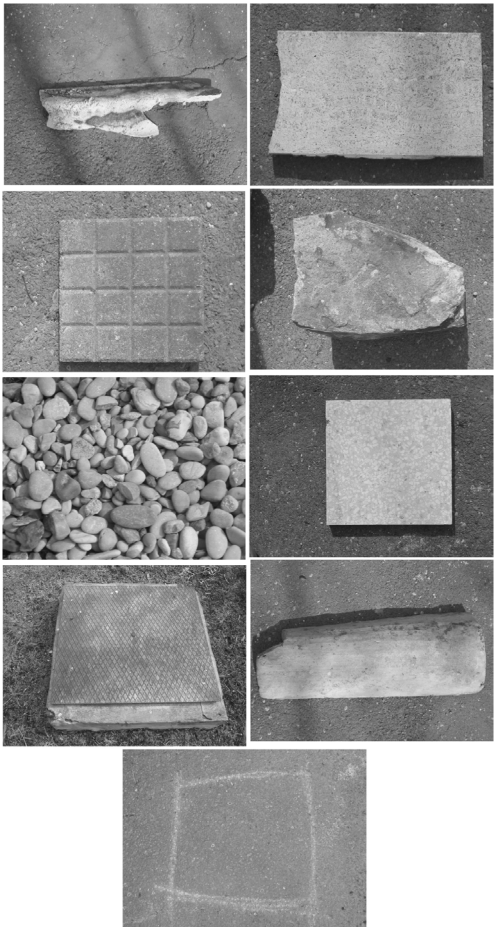

Figure 3: The different types of materials examined.

Figure 4 shows the graph on the temperature trend of every single material according to the measurements carried out by the Thermopoint on 26th June, 2004, on 4th August, 2004 and on 9th September, 2004; all three days were characterized by clear sky. The air temperature trend and the relative humidity trend are reported in Figure 5.

Some first observations emerge clearly from a preliminary analysis of the recorded temperature trend:

- In all measurement sessions the daily air temperature records an increase of maximun 2°C.

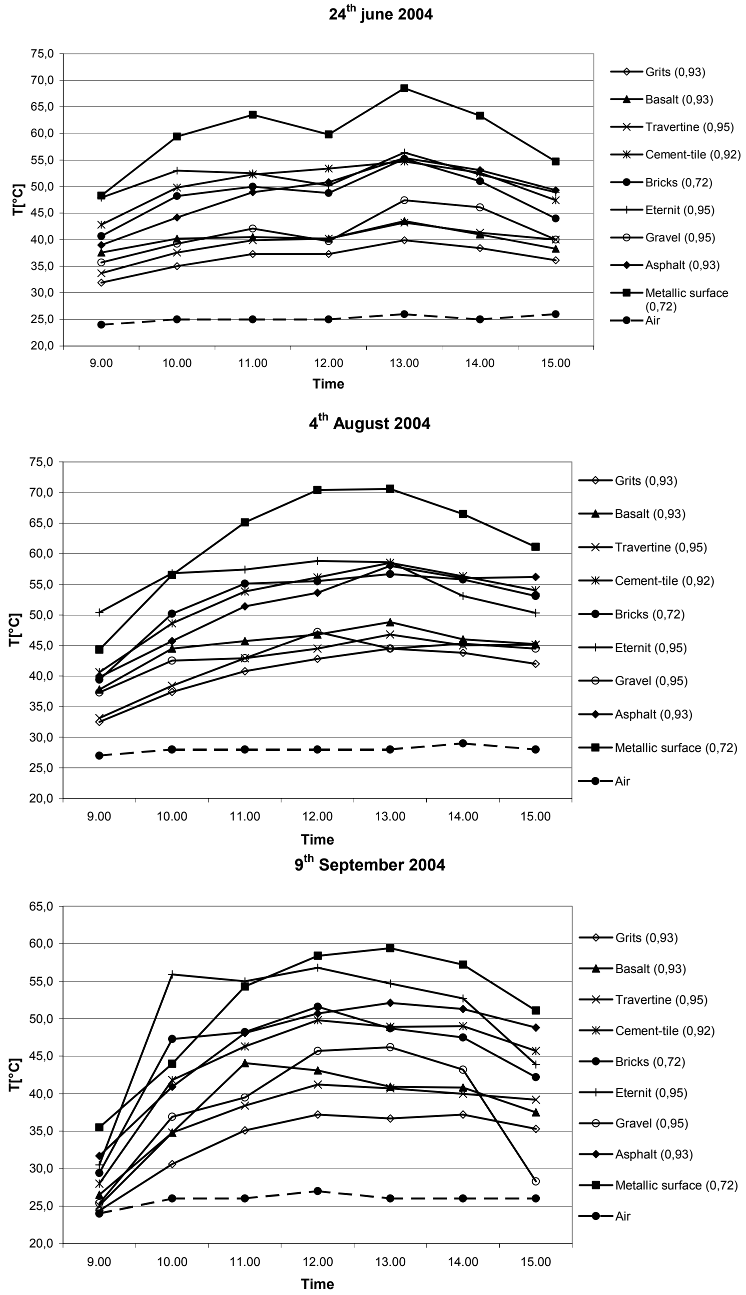

Figure 4: Surface temperature trend of materials.

- In the sessions of 24th June (mean air temperature of 24.5°C) and 4th August (mean air temperature 27.5°C), from 9:00 am to 11:00 am the temperature of travertine, cement tiles, bricks, asphalt and metallic surfaces records an increase of about 9°C. On the contrary, in the session of 9th September, with a man air temperature of 25.3°C, the increase

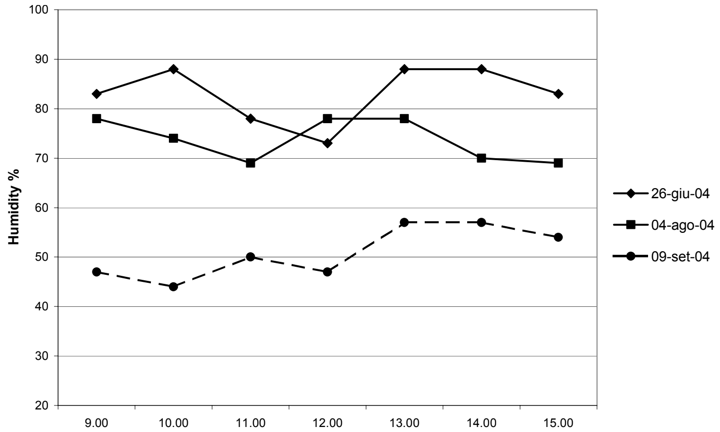

Figure 5: Relative humidity trend.

of the temperature of these materials is higher than 16°C. This certainly depends on the low air humidity (47%) recorded in this session.

- In the session of 24th June, at 12:00 (air temperature of 25°C and humidity of 73%) the temperature of grits and basalt remains constant, while that of the other materials slightly decreases. On the contrary in the session of 4th August (air temperature of 28°C and humidity of 78%) and the session of 9th September a temperature increase of all analyzed materials occurs, with the exception of basalt.
- In the session of 24th June and 4th August at 1:00 pm, with steady air temperature and humidity, the maximum peak of the daily temperature of all materials is recorded. In the session of 9th September, with the air temperature lower 1°C than the above two sessions at the same time, the temperature of materials decreases from a minimum of 0,5°C as to grits to a maximum of 2.9°C as regards bricks, with the exception of gravel, asphalt and metallic surfaces whose temperature slightly increases.
- In all 3 measurement sessions, from 1:00 pm to 3:00 pm, a progressive and slow temperature diminution of all materials is recorded.

From these first results obtained from the research activity still in progress it follows that materials like asphalt, metallic surfaces and eternity, keep a bigger quantity of heat than the other materials taken into consideration.

3. CONCLUSIONS

The results achieved in the first research phase of this preliminary study show that the Landsat TM satellite data enable the characterization of temperatures at territorial scale also in consideration of morphological aspects. In the second phase of the study, the MIVIS data have been proved to be able by means of the analysis of the thermal spectral region to characterize the distribution of temperatures, in particular at a detail scale, and besides they have enabled precise and original analyses to be carried out, otherwise realizable with difficulty.

Both types of data, MIVIS and Landsat TM have given information on the temperature distribution also in consideration of the spectral and spatial heterogeneity of the study area. In particular the two different data analyzed have stressed the actual possibility to verify at different scales that high thermal levels correspond to wide surfaces made impermeable by the presence of asphalt and cement

The comparison between processed MIVIS data and *in situ* analysis in the third phase of the research has confirmed the validity of this image analysis method of remotely sensed data in the examination of temperature values extracted from the MIVIS scenes of single materials.

In conclusion, the validation of remotely sensed data in thermal analyses shows even more the potential of this type of information, enabling analyses hardly realizable in another way so far.

The *in situ* research activity, still in progress, regarding the space-temporal analysis of single materials has enabled the assessment of daily temperature trends in different months of the year, giving further confirmations on the thermal response of single materials and their performances in response to the sun radiation.

These first results, if put into *a space-temporal* system, though encouraging, however need further investigations such as:

- Collection and analysis of more accurate environmental parameters in specific conditions of the study area, like humidity, ventilation, temperatures, etc.
- More detailed analyses of response values of single materials to the sun radiation during the 24 hours of the day and for all months of the year;
- More detailed analyses of physical-chemical quantities to quantify the energetic exchange between single materials (flux measurements, albedo, etc.).
- Validation with other analysis methodologies.

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