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Study and Analysis of WorldView-2 satellite Imagery for evaluating the energy efficiency of the urban area of Kalamaria, Greece

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Abstract: Energy use is one of the most important issues nowadays due to its serious impacts on the environment, on the decrement of natural resources and finally on the quality of our life. What it is becoming therefore evident, is the importance of a sustainable energy planning for every country and every community. Energy analysts have traditionally focused on energy policy efforts for buildings and equipment to apply demand-side management measures that lower energy consumption or balance demand more efficiently. Today, analysts are closely examining the role of urban infrastructure and urban land uses patterns to better determine energy consumption levels (URL1). The interconnection and interaction of urban forms and land-use with the energy efficiency is the key issue in this study.
The case study concerns the city of Kalamaria, Greece. In 2011 the Greek government has started an effort to compute the status of energy balance of buildings for a number of Greek cities. The goal in this study is to provide useful information that helps and improves this energy planning process with the use of the 8-band multispectral Worldview image. In specific, this study aims at defining the land-uses inside the city (e.g. green areas, build- up, road networks) by classifying the multispectral image with object oriented techniques and subsequently at extracting building information (e.g. roof types) with feature extraction techniques. The further analysis of the results leads to specific grouping of roofing materials with various reflectivity and absorption factors, providing thus information about the buildings' energy behavior.
Keywords: Worldview-2, land-use/land-cover mapping, object-oriented classification, roofing materials, energy efficiency.

1. Introduction

The fast urban expansion and the resulted changes in land-use/land-cover can impose a serious pressure on the environment and consequently can lead to social, economic and environmental changes. It is therefore evident that in order to assess and monitor energy efficiency of an urban environment, it is necessary to evaluate the urban structure and landscape of the region of interest.

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High spatial resolution remotely sensed data, are the primary source for providing detailed imagery of the complex and heterogeneous urban environment. Until recently, satellite-based remote sensing techniques for land-use studies, with the spectral resolution contained in four spectral channels, were sufficient to discriminate between broadly differentiated land cover classes in urban settings. With the launch of WorlView-2, 8-band multispectral imagery is expected to enhance even more the feature extraction and to take the land use/ land cover beyond this level by extracting features like roof types and road conditions (Fig.1).

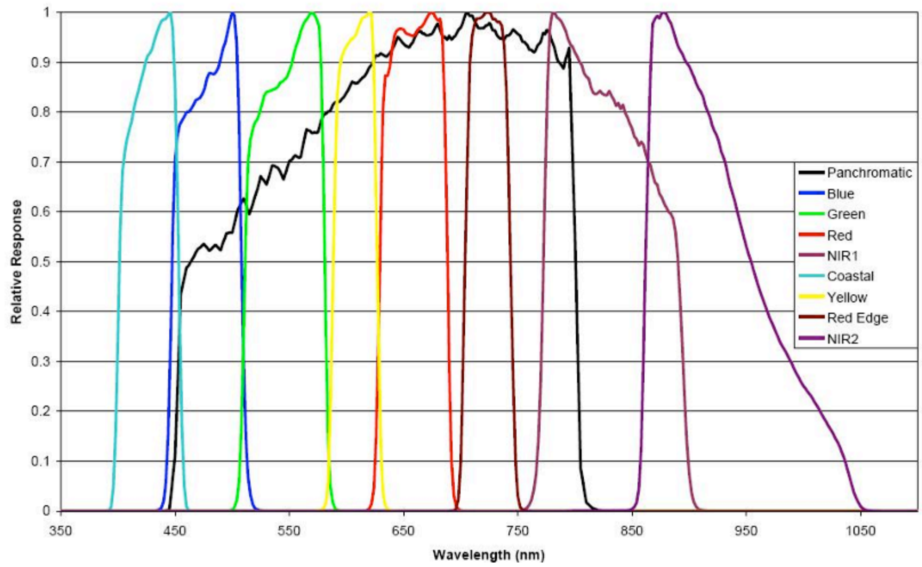

Figure 1: Spectral Response of the WorldView 2 panchromatic and multispectral imager.

The objective of this study is to define land-use (e.g. green areas, build-up, road networks) of the city of Kalamaria, by classifying the multispectral WorldView image and subsequently at extracting building information (e.g. roof types) with feature extraction techniques, in order to provide necessary information for land-use and planning decisions focusing on energy use and energy efficiency.

The further analysis of the results will lead to specific grouping of roofing materials with various reflectivity and absorption factors. At the same time, in-situ measurements of the roofing materials will take place in order to define the exact characteristics of these materials and create a thorough database for building roofs materials. Afterwards, these results will be added in a geodatabase system, providing information about the actual texture of the built-up urban environment, leading to conclusions about the urban heat island effect and buildings' energy behavior.

2. Study Area and Data

The available WorldView-2 images cover the city of Kalamaria in the north part of Greece (Fig.2). The municipality of Kalamaria was chosen as the case study area, since it ideally includes both old and new build-up areas with various roofing shapes, structures and materials. Both panchromatic and multispectral images were acquired on February, 21, 2010 and were orthorectified by DigitalGlobe.

Figure 2: Part of the panchromatic and the 8-band multispectral Worldview images, depicting the city of Kalamaria.

3. Methodology

In order to achieve rooftop extraction and further analyzing the rooftop materials, a series of processes were executed. Initially, the panchromatic and the multispectral images were segmented into administrative boundaries, and the municipality of Kalamaria was extracted. The next step was to pan-sharpen the multispectral image, in order to obtain a high resolution multispectral image, and continue with the classification process. Both pixel-based and object-based techniques were applied in the pan-sharpened image, and finally building information (rooftops) were extracted. The resulted features were introduced into a GIS and the total built-up area for each roofing material and built-up density were calculated. Absorption and reflectance of solar radiance for roofing materials were collected and alongside with in-situ measurements a further analysis of buildings' energy behavior will be executed. The following Figure (Fig. 3) shows the workflow.

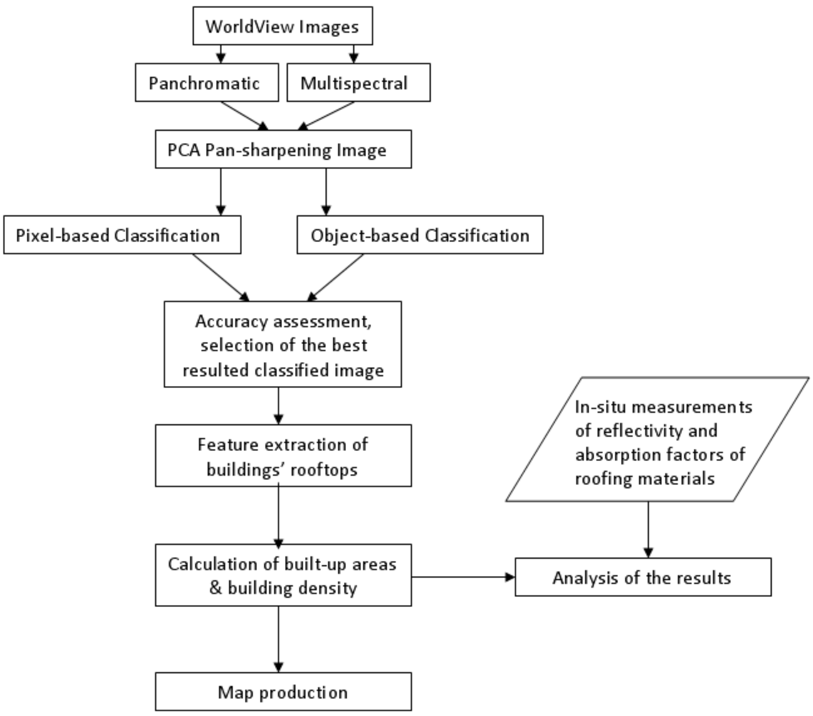

Figure 3: Overall workflow.

3.1. The classification methods

3.1.1. Pixel-Based classification

Image data are often used to create thematic maps through multispectral classification. The first attempt for the case study area was to perform a pixel-based Maximum Likelihood classification on the pan-sharpened image. During this process, specific training sites on the image are located in order to identify the desired classes. The resulting training sites are areas representing each known land cover category that appear fairly homogeneous on the image (as determined by similarity in tone or color). The training sites were chosen carefully in order to achieve the most accurate spectral definition for each class. Based on the visual inspection of the image the following land-cover classes were distinguished: (1) tiled-roofs, (2) cemented-roofs, (3) bright roofs, (4) high and (5) low vegetation, (6) roads, (7) shadow. By locating the proper training sites of each class, the classification is realized according to fuzzy logic, which contributes to optimum results.

3.1.2. Object-Oriented classification

The second classification method that was applied was a rule-based Object-Oriented classification. Object-Oriented classification provides a variety of additional parameters for classifying high resolution remotely sensed imagery in urban areas. According to this method, spatial information such as texture, shape, and context can be used both to increase the discrimination between spectrally similar urban land cover types (Dengsheng et al. 2010, Zhou et al. 2008, Goetz et al. 2003).

Object-Oriented image analysis consists of two steps; (a) segmentation and (b) fuzzy classification of the generated image objects. The segmentation of the multispectral image aims at dividing the image into continuous and homogeneous segments which are meaningful, and moreover should ideally outline the objects in the image that are to be extracted (Aldred et al. 2007, Im et al. 2009). In this study, the multi-resolution segmentation approach is used. All pixels are initialized as single segments that are merged as the algorithm progresses. The algorithm of this clustering process is based on the homogeneity in color and shape of the neighboring image objects. The Figure bellow (Fig. 4) shows three different levels of segmentation with different scale factors; a. 20, b. 30, c. 40. The shape factor was set at 0.8 and compactness at 0.7 for all levels.

a. b. c.

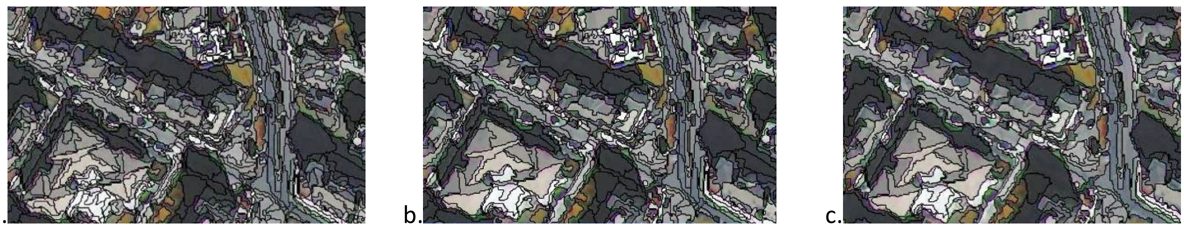

Figure 4: Three different levels of segmentation.

For further processing, the same land-cover classes that were chosen in the Maximum Likelihood classification were distinguished here. Once the pan-sharpened image is segmented, a class hierarchy was developed, were the classification starts from general classes which were further subdivided into more specific classes.

The following Figure (Fig. 5) shows the spectral response of the chosen land-cover classes in the WorldView-2 multispectral image. Based on these values, and with the combination of

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texture and shape characteristics of the image objects, several rules and indices were calculated in order to set rules for the Object-Oriented classification. The Normalized Difference indices were obtained by using the strongest and weakest reflectance bands, respectively, among the 8 multispectral bands for the interested land-cover type to be enhanced. (Hanqiu, 2010)

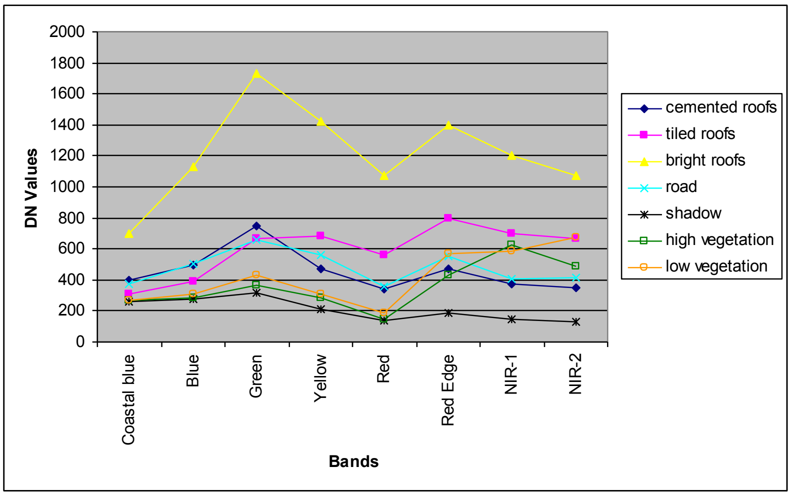


Figure 5: Spectral signatures of the classes

The first classification of the image objects was performed based on Normalized Difference Vegetation Index (NDVI). The NDVI is used widely for the differentiation of vegetation and non vegetation in urban areas. The NDVI is derived using the red and the NIR-1 Band of the image:

$$NDVI=\frac{NIR1-RED}{NIR1+RED} \quad (1)$$

and a first rule for classification was set in order to divide the image objects to Non-Vegetation and Vegetation. Since the new WorldView multispectral image has an additional NIR band, a second attempt for calculating NDVI was executed using the red and the NIR-2 Band:

$$NDVI\_2=\frac{NIR2-RED}{NIR2+RED} \quad (2)$$

The second NDVI was used to set a new rule for further classifying the vegetation into low and high vegetation, since the new NIR band was found to have higher response to healthy low vegetation like shrublands, parks etc.

For the Non-Vegetation objects, a first rule was set based on the mean value of the Brightness, dividing the objects into shadow and non-shadow. Subsequently, a nearest neighbor classification with membership functions was performed only for the non shadow areas using the following classes: tiled-roofs, cemented-roofs, bright roofs and roads. For the class of the tiled roofs the following index with the yellow and green band:

$$NDYG: \frac{Yellow-Green}{Yellow+Green} \quad (3)$$

was found to be very useful for separating the tiled roofs from the rest of the classes, and a membership function was set for this class with an effective threshold of the index. It should be noted that during the maximum likelihood classification, tiled roofs was the class with the maximum error (Fig. 7). For the class of road a threshold of length/width was set as an additional membership function, for the bright roofs the mean brightness value was used, and finally for the cemented roofs the mean value of blue band. The final class hierarchy with associated features and rules is shown in Figure 6.

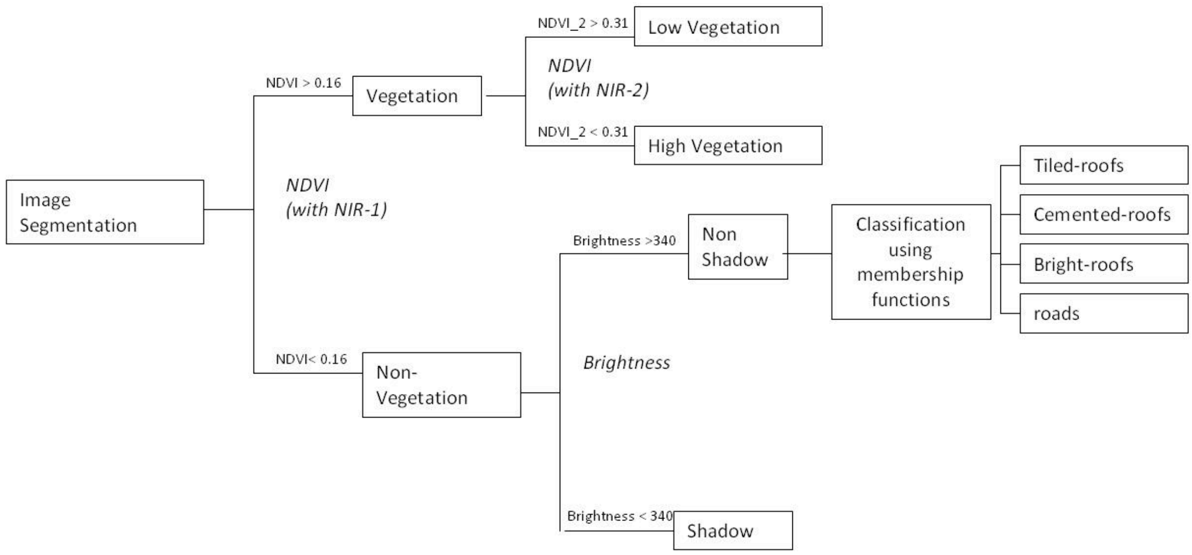


Figure 6: The class hierarchy, with associated features and rules

3.1.3. Accuracy assessment- Comparison of the two methods

With the accuracy assessment, the classified image is compared to geographical data that are assumed to be true. A set of reference pixels, randomly selected, is used to compare the classified data, and the error matrix, the accuracy report and the Kappa coefficient are calculated. Finally, the overall accuracy and the Kappa coefficient, determine the degree of success of the procedure. The results are presented in Tables 1 and 2 (Tab.1 & Tab.2), for the Maximum-Likelihood and the Object-Oriented Classification respectively.

Table 1: Accuracy totals for Maximum Likelihood Classification

Overall Classification Accuracy	83.40%
Overall Kappa Statistics	0.79

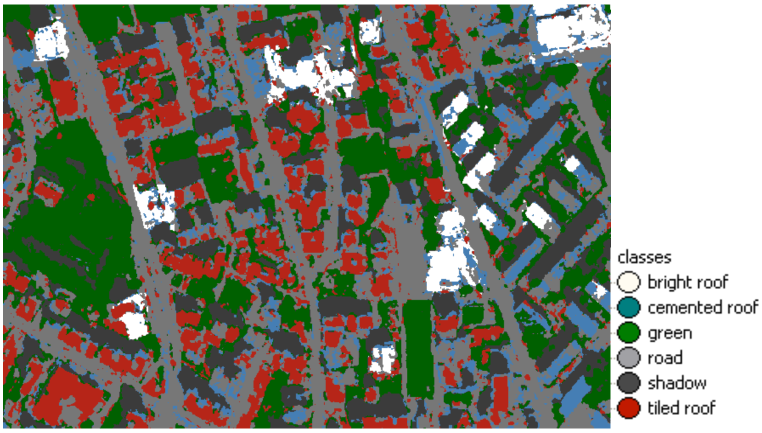
Table 2: Accuracy totals for Object-Oriented Classification

Overall Classification Accuracy	91.43%
Overall Kappa Statistics	0.88

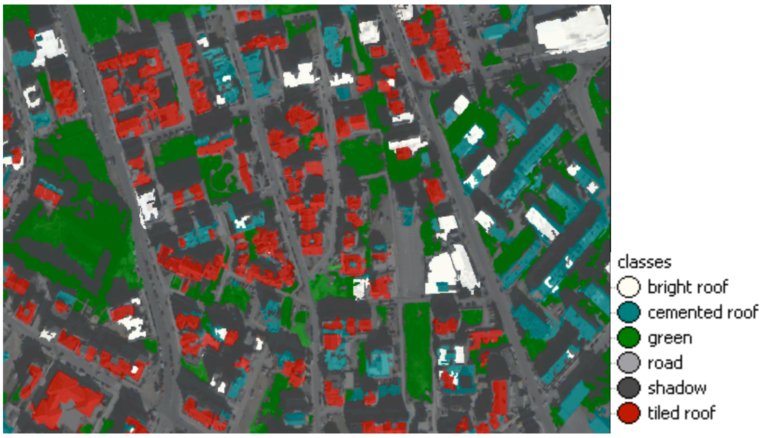
It is obvious that the Object-Oriented approach led to more accurate results according to the accuracy assessment statistics, and also the visual interpretation of the classified images shows that in the Object -Oriented approach, the buildings are discriminated finely, and the salt ‘n’ pepper effect, which is present in the Maximum Likelihood classification, disappears.
Additionally, the class hierarchy developed in this project is more flexible than the Maximum Likelihood approach. This means that more classes can be added either directly or by subdividing the existing ones, or more classification rules can improve the classification if there are new available data (such as vector data for roads, buildings etc). The advantage of having 8 multispectral bands, made the Object-Oriented approach more effective and the characteristics of the new additional bands proved to be very useful for discriminating finely a complex urban environment. In conclusion, the Object-Oriented approach provides a very

useful tool for measuring and analyzing the spatial structures of urban landscape, as it is widely recognized that patterns and processes occur across multiple scales (Forman and Godron 1986, Zhou et al. 2008).

a. Part of the pan sharpened multispectral image.



b. Maximum Likelihood classification



c. Object -Oriented Classification.

Figure 7: Comparison of the Maximum Likelihood and the Object-Oriented classification.

3.2. Delineation of classification results-Feature extraction of buildings' rooftops

In order to extract buildings and calculate the built-up areas, the object-oriented classified image was selected for further processing. The first step was to extract each class to vector shapefile format and introduce these files into a GIS environment. Since the study focusing is building rooftops, the classes of tiled-roofs, cemented-roofs, bright-roofs were extracted and the built-up area for each building category was calculated. The following Table (Tab. 3) shows the results in m^2 and the Figure 8 presents the different types of building rooftops, superimposed on the WorldView image.

Table 3: Area Calculations for the three buildings rooftops

Building Category	**Area (m^2)**
Tiled roofs	197.189
Cemented roofs	717.396
Bright roofs	250.070
Total Built-up area	**1.164.656**

Figure 8: The three different types of building rooftops, in the municipality of Kalamaria

After calculating the areas, the analysis of the density for each building class followed. Density analysis takes known quantities of some phenomena (in our case: the three categories of building rooftops) and spreads it across the landscape based on the quantity that is measured at each location and the spatial relationship of the locations of the measured quantities. The following Figure (Fig. 9) shows the graphical results, where the color intensity increases depicting higher value of concentration and density for the portrayed roof type.

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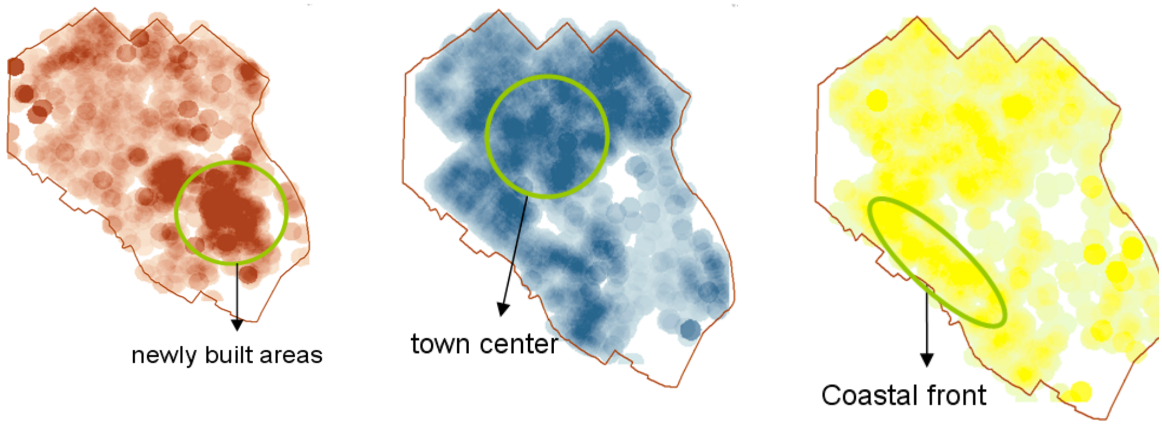

a. Tiled-roofs density b. Cemented-roofs density c. Bright-roofs density

Figure 9: Density for the three roof types, distributed graphically.

As it is obvious from Figure 8 (Fig.8), the majority of buildings have cemented-rooftops. With the density analysis (Fig. 9) it is understood that the highest concentration of cemented-roofs occurs in the north part of the city where the town center is situated, the bright roofs have high concentration in the coastal front of the town of Kalamaria, while the newly built areas in the south-east part of the city, have high concentration of tiled-roofs.

4. Calculations and measurements for reflectivity and absorption

The scope of this study is to present a methodology based on a satellite data processing, in order to evaluate intervention measurements for slopped and flat roofs in hot climates, like in Greece.

Unlike methodologies based on field research, the proposed method is significantly faster and allows access to large building samples. The advantage of the new WorldView-2 imagery, combining high spatial resolution of 0.60m and for the first time 8-band high spectral resolution, makes the feature extraction more accurate and precise. The resulted thematic maps can prove to be a handy tool for the urban planners and specifically for the energy planning decision makers focusing on energy use and energy efficiency.

It is important to link the satellite data analysis both to energy performance of buildings as well as to other parameters affecting indoor air-quality and urban climate conditions. It is a fact that materials of the built-up environment affect the outdoor air temperature and the indoor air conditions, due to solar absorption. There is though an interacting relation; Papadopoulos et al. showed that enhanced urbanization and its impact on the urban climate have a significant impact on the energy behavior of buildings (Papadopoulos et al., 2004). Furthermore, the impact of urban microclimatic conditions on the thermal loads of buildings is a common subject of research, focusing on the modulation of street canyons, which leads to temperature conditions that depart from the climatic data monitored at meteorological stations, affecting the heating balance of buildings, while the building operation affects the present conditions (Papadopoulos, 2001).

Apart from the influence on the buildings' energy behavior, further aspects must be considered, such as the increase of the roofs' external surface temperature, leading to a respective increase of the air-temperature, responsible to great extend for the heat island effect (Oke et al., 1991). Various researches have dealt with this subject; Santamouris et al.

(Santamouris et al., 2011) proposes respective interventions in order to reduce the heat island effect.

Since the climate conditions vary from region to region within Greece, it is necessary to carry out in-situ measurements in the area of interest, for calculating the absorption and reflectance characteristics of roofing materials. The results of the measurements, will lead to conclusions about the average values for absorption and reflectance for the roofing materials.

According to the proposed methodology and the three categories of roofing materials described in the previous chapters, in situ measurements took place for 7 days in the Municipality of Kalamaria. As regards tiled roofs a typical slopping roof construction was measured from 31/03/2011 – 06/04/2011. For the cemented and bright roofs category, a flat roof was chosen, half of it with a white cement layer as coating and the other half covered with black bituminous sheets. The measurements' results are depicted in Figures 10, 11 and 12.

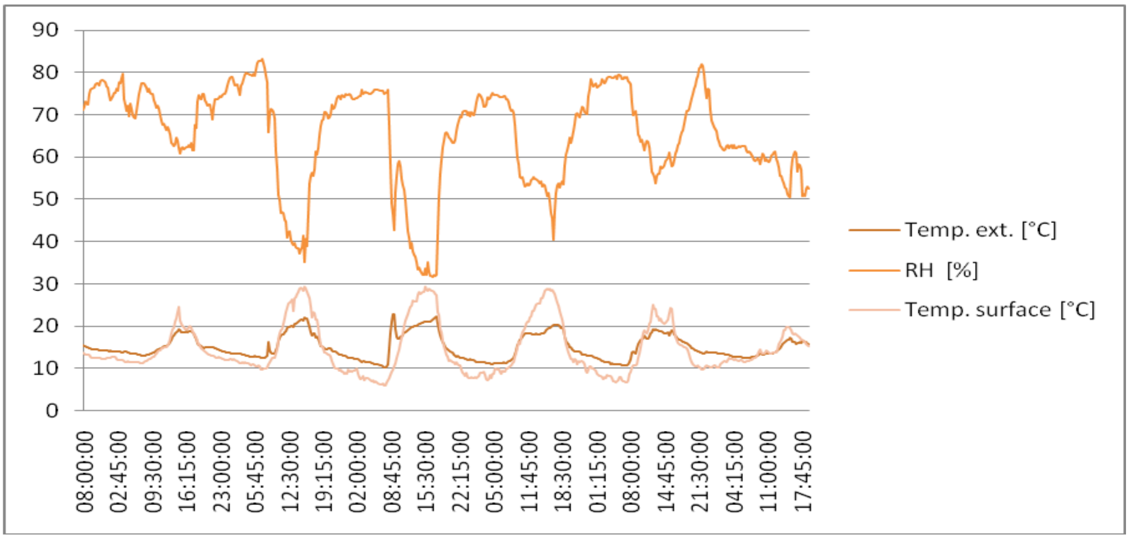

Figure 10: Measurement results for the tiled roof.

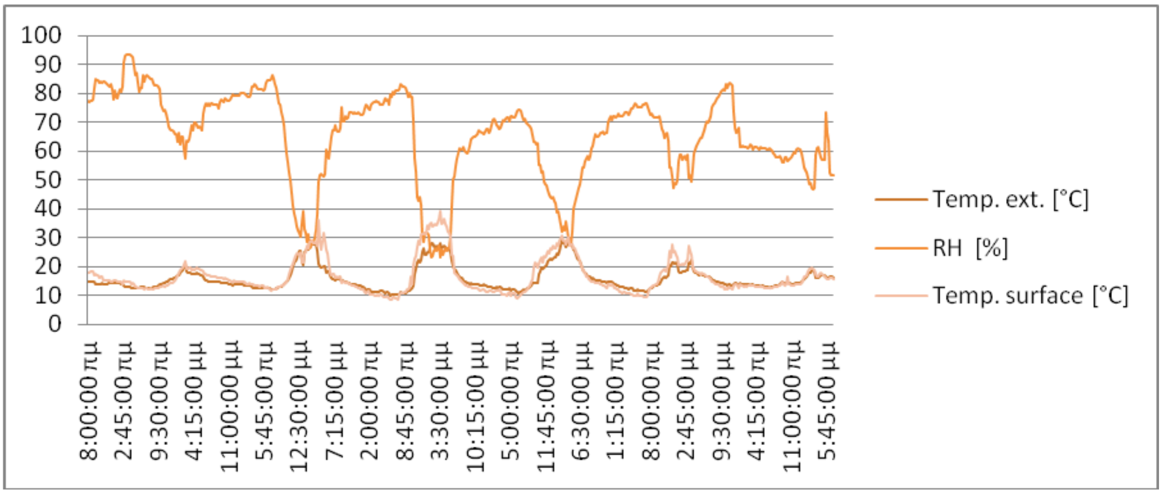

Figure 11: Measurement results for the cemented roof.

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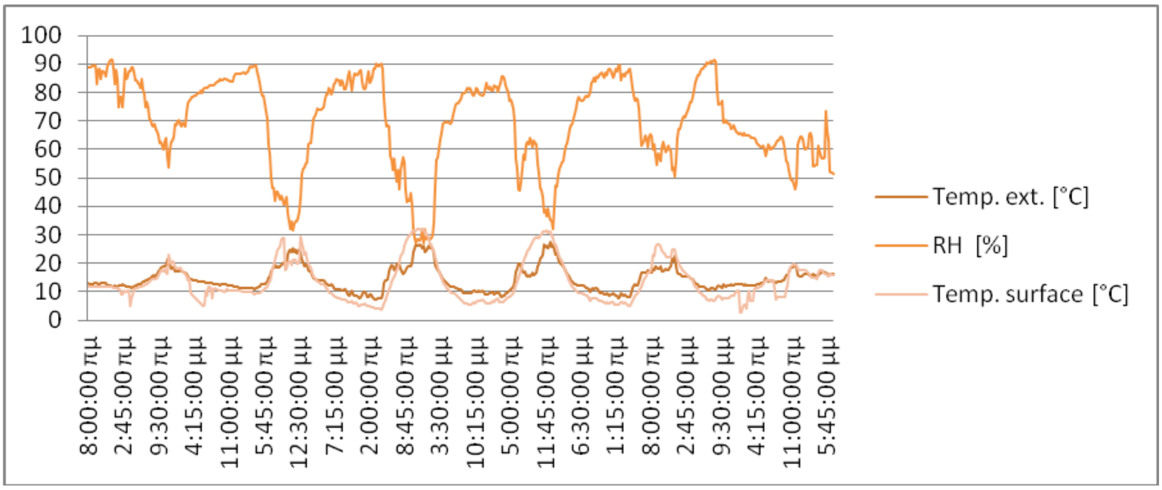

Figure 12: Measurement results for the bright roof.

The mean external surface temperature of the tiled roof reaches 14.75 ^{o}C, of the bright roof 13.49 ^{o}C, whilst the highest of all was measured on the cemented roof, namely 16.71 ^{o}C. The time series follows the external temperature fluctuations. More specifically, during noun, with the maximum solar elevation angle, the surface temperatures are higher than the outdoor air temperature especially in the case of the tiled roof. On the contrary, early in the morning the temperature drops slightly below the air temperature. Again this is even more intense in the case of the tiled roofing.

Furthermore, according to Technical Guidelines (URL2, URL4, URL5) of the implemented EPBD (Energy Performance of Buildings Directive) 2002/91/EC, namely KENAK (URL6), the factor of absorption and reflectance of solar radiance for roofing materials depends mainly on the texture and color of the surface of these materials, and the following general rule stands:

$$\rho + \alpha = 1 \qquad (4)$$

where ρ is the reflectance factor of a surface and α is the absorption factor of a surface.

In general, the reflectance of smooth and polished surfaces tends to be 1 while the absorption factor is respectively very low. On the other hand, dark and rough surfaces have a high absorption factor and low reflectance. These features regarding the physical components of a buildings' envelope, determine the solar gains of roofing materials and play important role on the overall buildings' energy behavior.

The following Table (Tab. 4) gives the typical values for reflectance and absorption of various roofing materials that appear in the topcoat of a building envelope, in Greece (URL3).

Table 4: Typical values of reflectance and absorption factors for roofing materials in Greece

Roofing Materials	Reflectance	Absorption
Tiled roofs (ceramic tiles)	0.40	0.60
Dark roofs(bitumen)	0.20	0.80
Bright roofs (cover with paving plates, bitumen with quartz tile etc.)	0.35	0.65
smooth and polished surfaces (like reflective sheets)	0.80	0.20

According to Technical Guidelines, in-situ measurements and the results of classification, it appears that in Kalamaria, the majority of building rooftops is of dark surfaces (cemented roofs and bitumen), with low reflectance values and high absorption of solar radiance. This affects negatively not only the buildings' energy behavior, as heating and cooling equipment is necessary to work for longer periods, but it also affects the energy environment of the urban tissue. What is therefore evident is the fact that interventions and actions are necessary in order to improve the energy efficiency of the city.

5. Results and discussion

This project studied the potentials of the new 8-band Satellite imagery of WorldView-2, focusing on extracting building information, like rooftops, with feature extraction techniques applied on the multispectral image. Until recently, researchers have traditionally used aerial photos in order to finely discriminate building roof types. Today, with the new generation of high-resolution satellite images, remote sensing techniques tend to be more appealing for these purposes, let alone using the new 8-band Imagery. The introduction of four new bands (Coastal Blue, Yellow, Red Edge, NIR-2) and the combination of spectral and spatial resolution, increases and improves the feature extraction tools and leads to more accurate land-use/land-cover mapping results.

Using the mean values of the new bands and computing various Normalized Difference Indices such as NDVI using both NIR-1&NIR-2 etc. helped to enlarge the contrast between the interested cover type and background noise, and continuously to improve the classification process.

In this project the feature extraction of building types and the further analysis of the results, led to specific groups of roofing materials with various reflectivity and absorption factors. The future work for in-situ measurements of the roofing materials, will define the exact characteristics of these materials and a database for all building materials will be created. This investigation provides information about the actual texture of the built-up urban environment, and leads to thematic maps focusing on building density and rooftop materials. These products could be useful and necessary for developing an energy policy that will promote energy sustainability, including building regulations, urban planning improvements etc.

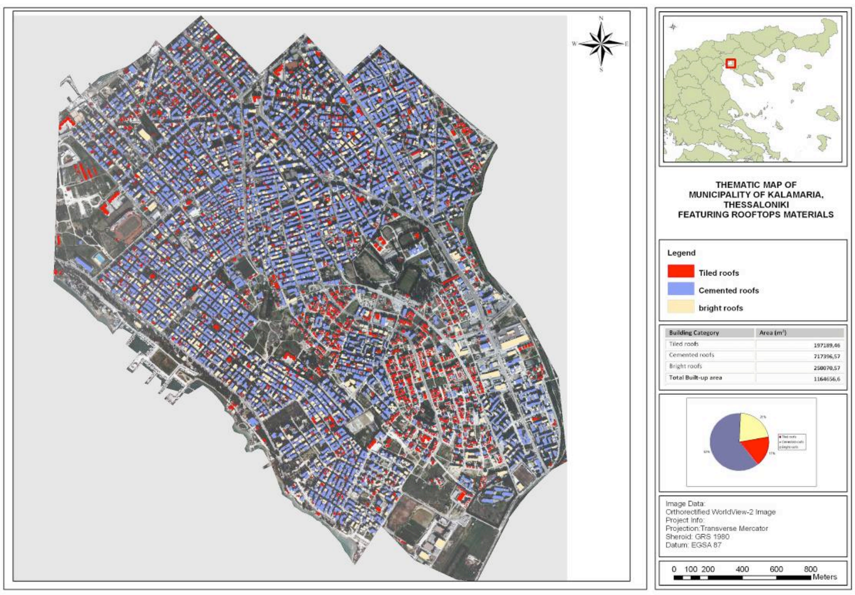

Figure 13: Example of thematic map featuring rooftop materials and resulted area calculations

Moreover, depicting spatially the energy outputs of a city, showing the integration of the physical form of a city with the energy impacts, can contribute to the sustainability of a community by minimizing environmental impacts and reducing energy costs and can serve to examine the potentials of using alternative energy sources.
In conclusion, energy mapping studies based on land-uses/land-cover studies tend to have longer term impacts. The results from these studies together with land use scenarios can provide insights into the actions that need to be taken in order to reduce environmental risks and energy demands.

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