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Considerations on the Influence of Micro Urban Heat Islands to the Temperature - Humidity Index During July 2017 in Craiova City Centre

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Abstract

According to the National Administration of Meteorology, July 2017 was the hottest July months in the last decade, with one of the longest period with canicular temperatures in the last decades, too. In many regions of Romania, including Oltenia and Craiova city, too, yellow or orange code warning had to be announced. To determine real thermal discomfort sensation felt by the population of Craiova city, experimental research concerning micrometeorological measurements of the real temperature and relative humidity that contribute to the local Temperature - Humidity Index (THI) value was performed. According to the experimental research results, confirmed by using thermovision too, in Craiova city centre, five micro urban heat islands (MUHI) were identified. For three streets and a public square, despite the small mean value of relative humidity, due to the temperature's high mean value, in these hot spots the THI mean average was 89.97, and for this thermal discomfort sensation, special protection measures would be needed. The same air micrometeorological parameters in these four hot spots were compared with the ones recorded in English Park, where due to vegetation and trees' shadow, the THI average was 84.11, thus the real thermal discomfort sensation would have made necessary adequate protection measures. In order to study the intensity and spatial pattern of the MUHI, thermal infrared remote sensing (thermovision) was used to observe the surface of MUHI as a complementary indicator of the thermal discomfort sensation with in MUHI. The paper presents relevant interdependence relationships between the near surface air temperatures and pavement/ buildings surface temperatures that have been found for MUHI in Craiova's city centre. The paper proposes practical methods that could be used to decrease the pavements' and buildings' walls temperatures, thus contributing to the decrease of THI in the MUHI within Craiova city centre.

Keywords: *micro urban heat islands, hot spots, temperature - humidity index, thermovision*

Rezumat. Consideraţii privind influenţa insulelor de cădură urbane asupra indicelui temperatură - umiditate în luna Iulie 2017 în centrul oraşului Craiova

Conform Administraţiei Naţionale de Meteorologie, luna iulie a anului 2017 a fost cea mai fierbinte lună iulie din ultimul deceniu, cu una dintre cele mai lungi perioade cu temperaturi caniculare din ultimile decade. In Oltenia, precum şi în oraşul Craiova, a trebuit să fie anunţate avertizări de cod galben sau portocaliu. In vederea evidenţierii stării reale de disconfort termic resimţită de populaţia din Craiova, au fost efectuate cercetări experimentale privind măsurători micrometeorologice pentru determinarea temperaturii şi umidităţii reale care contribuie la stabilirea indicelui de confort termic local. În conformitate cu rezultatele cercetărilor experimentale, confirmate şi prin utilizarea termoviziunii, în centrul Craiovei au fost identificate cinci microinsule de căldură local urbane (MUHI). Pentru trei străzi şi o piaţă publică, chiar şi pentru valori reduse ale umidităţii, datorită temperaturilor mari, în aceste zone fierbinţi media indicelui de confort termic a fost 94,93, şi senzaţia de disconfot termic ar fi făcut necesare măsuri speciale de protecţie. Parametrii micrometeorologici determinaţi în aceste patru zone fierbinţi au fost comparaţi cu cei obţinuti în English Park, unde datorită prezenţei vegetaţiei şi a umbrei arborilor, valoarea medie a indicelui de confort termic a fost de 84,87, deci senzaţia de disconfort termic af fi necesitat măsuri de protecţie adecvate. În vederea studiului intensităţii şi distribuţiei spaţiale în MUHI, pentru măsurarea temperaturii suprafeţelor din MUHI fost utilizată termoviziunea, ca metodă complementară de evaluare a disconfortului termic. Lucrarea prezintă relaţii de interdependenţă dintre temperatura aerului deasupra pavimentului, şi temperatura pavimentului şi a pereţilor clădirilor în MUHI din centrul Craiovei. Lucrarea prezintă câteva metode practice care ar putea fi utilizate pentru reducerea temperaturii pavimentului şi a pereţilor clădirilor, care ar contribui la scăderea indicelui de confort termic din MUHI din oraşul Craiova.

Cuvinte-cheie: *insulele de căldură local urbane , zone fierbinţi, indice temperatură – umiditate, termoviziune*

Introduction

Heat wave in Oltenia and in Craiova city

Craiova City, as one of the largest city of the country, with a population of some 300.000, has a built - up gentle relief plain area of approximately 32 km^2, from 92 to 117 m a.s.l., with 9.0 – 9.4 km maximum extension in N – S direction, and 4.8 – 5.2 km minimum extension in E - W direction. Due to continental – temperate climate, during the warm season, but especially in the June – August period, in the last century, Craiova registered the highlest mean monthly temperature (28.5^{o}C) in July, and maximum absolute monthly temperature peaking at 41.5^{o}C (July 1916), respectively (Cocean, 2011; Boengiu, 2008). The term *canicular* characterizes weather condition in which air temperature, measured in standard conditions at meteorological stations reaches or even exceeds the threshold of 35°C on extended areas. During the last 20 years, the drought period in Oltenia Region started in January 2000 lasting until July, 17th 2002, so during the summer of 2000, there was canicular weather for extended periods of time. The drought of 2000 was in general extremely intense and associated with extended periods of canicular weather and heat waves in the intervals: June 6-10, 21-25, July 2-12, 22-27, August 3-7, 17-24. It affected the entire social life, causing the increase of all life prices (Marinică and Marinică, 2014). In the summer of 2007, in Oltenia, weather was extremely changeable. Among the most important weather aspects, there must be mentioned six heat waves in the intervals (June 19-26; July 2-4; 8-10; 15-24; 27-30; August 22-25), two of these had a great intensity (the ones in the interval June 19-26 and in the interval 15-24 July, respectively). The heat wave from July 15^{th} to24^{th}, 2007 was the most intense for this month for the entire period since meteorological observations are carried out and marked the exceeding of the monthly absolute maximum thermal value of July with 0.8°C: 44.3°C registered at Calafat on July 24^{th}, which in that period was the absolute maximum thermal value of July in Romania; the old absolute maximum thermal value of July in Romania was 43.5°C registered at Giurgiu on July 5, 2000 (Marinică and Chimişliu, 2009; Marinică and Marinică, 2014). It must be noticed that in July 2007, for the first time, the air temperature reached and exceeded the climatologically threshold of 44°C. In July 2007, values higher or equal to 44°C were also registered at three meteorological stations in Oltenia: Băileşti 44.0°C, Bechet 44.2°C and Calafat 44.3°C, which means a more extended area of hot air than in the last century. At soil surface, the maximum thermal value registered in Calafat was 69.0°C, and in Băileşti 71.0°C, the diurnal thermal amplitude being of about 45°C (Marinică and Marinică, 2014). In Oltenia Region, September 2012 was excessively warm, when for 14 days, the maximum temperature values were comprised between 30° and 35°C (Marinică and Marinică, 2013).

According to the National Administration of Meteorology (NAM), in the period 2015 – 2017, July months were canicular in Craiova, when the maximum temperatures reaching 36.7°C (July 30, 2015), 34.2°C (July 14, 2016) and 38.4°C (July 1, 2017) (http://www.accu-weather.com/en/ro/craiova/287856/july-weather/287856).

Urban Heat Island

An Urban Heat Island (UHI) describes the characteristic warmth of both the atmosphere and surfaces in urban areas compared to their non-urbanized surroundings. There are three different types of heat islands: Canopy Layer Heat Island (CLHI), Boundary Layer Heat Island (BLHI), Surface Heat Island (SHI). The first two refer to the urban atmosphere warming; the last one refers to the relative warmth of urban surfaces. The urban canopy layer is the layer of air closest to the surface in cities, extending upwards to approximately the mean building height. Heat island types vary in their spatial shape, temporal characteristics, and some of the underlying physical processes that contribute to their development. Meteorologists measure air temperatures for CLHI or BLHI directly using thermometers, whereas the SHI is measured by remote sensors mounted on satellites (as LST method) or aircraft (Voogt, 2002; Voogt, 2004).

Over the last decades, remotely sensed thermal infrared data have contributed to address the UHI through the estimation of land surface temperature, thus originating the study of the surface UHI. Nevertheless, it has been found that atmospheric and surface UHI are coarsely related, and they can exhibit quite different spatial and temporal patterns. Moreover, within the urban atmosphere the heat island may present significant variations between the canopy and boundary layer (www.urbanheatislands.com).

The progressive replacement of natural surfaces (often composed of vegetation and moisture soils) by built surfaces constitutes the main cause of UHI formation (www.urbanheatislands.com).

Therefore, characteristics such as development, growth, intensity, and spatial pattern of the UHI will differ depending on where the measurements are made. The atmospheric UHI usually reaches its highest intensity in summer, under calm air and a cloud-less sky (Sham et. al., 2012).

In order to study the intensity and spatial pattern of the UHI, in the last two decades, world-wide thermal infrared remote sensing was used to observe the surface of urban heat island as a reliable indicator of the atmospheric urban heat island. Therefore, close relationships between the near surface air temperatures and land surface temperatures have been found (Lo, Quattrochi and Luvall, 1997; Pérez Arrau, 2007; Roşca and Roşca, 2015; Voogt and Oke, 2003; Weng, 2009; Nichol, 2009; www.urbanheatislands.com).

Micro urban heat islands (MUHI) refer to urban hot spots as poorly vegetated, parking lots, non-reflective buildings materials, material and color of pavement and asphalt roads. MUHI are strongly affected by micro climate factors, therefore remotely sensed data (as thermovision) are more suitable than atmospheric data for identifying heat spots (Roşca and Roşca, 2015; Synnefa et al., 2006, 2007, 2009; Stathopoulou et. al., 2005, 2009; www.urbanheatislands.com).

As consequence of canicular heat wave on MUHI, the *Temperature-Humidity Index* (THI) has to be considered. THI, also known as *thermal comfort index*, represents the most used index in world-wide mass-media nowadays; it renders an apparent temperature, namely the temperature felt by human body that cools slower at higher values of the relative humidity due to the reduction of the evaporation rate. THI is calculated with the formula which corroborates air temperature and relative humidity, the critical threshold being 80. If THI is smaller than 65, it means comfort state; 66-79 means alert state; higher than 80 means discomfort state (Teodoreanu and Bunescu, 2007).

In the last decade, the Romanian researchers focused their interest for THI effects in Oltenia region. According to statistical data supplied by Craiova Regional Meteorological Center (CRMC), it was observed that 2000, 2001 and 2007 were the years with the highest number of days (51 days in 2000, 47 days in 2001, and 41 days in 2007) with THI values above 80 for the entire Oltenia territory, when, during July and August, the region was affected by numerous heat waves temperatures frequently exceeding 40°C (Burada and Sandu, 2009; Marinică and Marinică, 2008, 2009).

According to NAM, high THI values of 75 – 80 were recorded in 2015 and 2016 in Craiova, too.

According to the weather forecast provided to the media by the NAM, for large regions of Romania, in July 2017 canicular heat wave was settled, with many daily maximum thermal values reaching 35°C. Therefore in all these regions, and in Oltenia and Craiova, too, yellow or orange code warning had to be announced (http://www.accuweather.com/en/ro/craiova/287856/july-weather /287856).

Aims

Few years ago, Craiova benefited of financing funds provided by a European Project, aiming at the rehabilitation of the old down town; thus some streets became pedestrian areas, surrounded by small shops, pubs and restaurants. Rehabilitation took into account the structure and the facade of buildings, pavement and all the infrastructure (electricity, water, sewerage). Buildings' facades of more than 100 years old buildings; about 60 years old ground floor and 4 floor blocks have been rehabilitated (light colours, architectural ornaments), and the old pavement was replaced by a new one made in synthetic granite cubes (gray, dark gray, dark red) and artificial marble tiles (beige, dark white) (Roşca and Roşca, 2015).

For only ten days of July 2015, a previous study presented an overview concerning the influence of micro urban heat islands to the THI. This study was focused on identifying the hot spots that determine MUHI points in three streets, a large public square and in a public park in Craiova's city centre (Roşca and Roşca, 2015).

The present paper presents a similar overview for all the days of July 2017 (excepting colder and rainy days of the 3rd and 16th of July), in the same hot spots studied in 2015.

Thus, the present paper considers Craiova MUHI for five places: three rehabilitated streets (Panait Moşoiu, Lipscani, Theodor Amann Streets), Prefecture Square and English Park, respectively.

The experimental research considered the direction and the geometry of these five places: Panait Moşoiu Street - N – S direction, about 120m long, 15m wide, mean height of the buildings 12m, with no vegetation; Lipscani Street - E – W direction, about 330m long, 12m wide, mean height of the buildings 10m, with no vegetation; Theodor Amann Street - N – S direction, 130m long, 22m wide, mean height of the buildings 18m, with very poor vegetation; Prefecture Square (but without the Unirea Street that starts in the southern part of this Square) - open space 60 x 80m, with the Prefecture Building (30m high) to the East, an open green park with artesian fountains to the West, shops and 4 floors blocks (25m height) to the South, shops and 4 floors blocks (20m height) to the N, with no vegetation; English Park - open public green park 60 x 60m, with the Prefecture Building (30m height) to the West, Theodor Amann Street (shops and 4 floors blocks, 22m height) to the East, shops and 4 floors blocks (15m height) to the South; Craiova City Hall (15m height) to the North (Roşca and Roşca, 2015).

Craiova city is located in the S-W of Romania, with the city centre situated at the intersection between the parallel 44°19'01.70" N lat., with the meridian 23°47'50.99" E long. The NAM's meteorological data are provided by the CRMC's meteorological station (44°18'37.90" N lat.; 23°52'03.32" E long.) placed near the Airport of Craiova. Thus, the linear distance between CRMC's meteorological point and Craiova city centre (English Park) is 12 km.

The aim of this paper is to determine the temperature felt by human body at higher values of the air temperature and the relative humidity, and finally the real THI in the five hot spots that determine MUHI in Craiova city centre.

Material and methods

The micrometeorological measurement method presented in this paper intends to determine the real THI in each MUHI identified in the centre of Craiova city. The daily micro-meteorological experimental measurements carried on for 29 days in July 2017 were represented by five observations (from 60 to 60 min) in the hourly interval 13 – 17 (when maximum temperature was registered), for each MUHI in the five places mentioned above. The air temperature and air relative humidity, streets' pavement temperatures and park's grass and trees canopy temperatures too, were recorded in the middle of each rehabilitated street, in the center of the

Prefecture Square, and two different places in English Park.

Experimental research was focused to measure the real air maximum temperature and air relative humidity in the three streets and Prefecture Square (T_{MAS} and H_{MAS}), and in the park (T_{MAP} and H_{MAP}), respectively. Air temperature and air relative humidity were measured with hygrometer (Lutron HT - 3009: humidity accuracy ± 2% R.H; temperature accuracy 0.5^{0}C). In all the 29 days when the air temperature and air relative humidity measurements were realised, the air velocity was 1...2 m/s (hot wire anemometer (Lutron YK - 2005AK: air velocity accuracy ± 1% full scale; temperature accuracy ± 0.8^{0}C; measured at 1.2...1.4 m height above the ground) and the nebulosity was 0...50%.

Experimental research was focused also on measuring using a thermometer (contact method) the maximum temperatures of the streets pavement (T_{MPS}) and the maximum temperatures of the grass and trees canopy in the park (T_{MGP}), and the streets' buildings and pavement temperatures ($T_{IR.PS}$) and the park's grass and trees canopy temperatures ($T_{IR.GP}$) too, by using thermal infrared camera (thermovision - non contact method).

For each temperature measurement a precision fine wire thermo-couples (Omega 5 SC-GG-K-30-36; accuracy ± 0.5%), and a temperature data - logger recorder (Lutron BTM - 4208 SD) were used.

All the data presented in Table 1 represent the average of the maximum values determined in the five observations / measurements in the three streets, Prefecture Square and English Park. The real maximum air temperature and air relative humidity measured during the experimental research, were compared with the air maximum temperature (T_{NAM}) and air relative humidity (H_{NAM}) provided by NAM (http:// www.accuweather.com/en/ro/craiova/287856/july).

Based on these measured data, the THI was calculated using the formula provided by Teodoreanu and Bunescu, 2007:

$$THI = (1.8 \cdot T + 32) - (0.55 - 0.0055 \cdot H) \cdot [(1.8 \cdot T + 32) - 58)],$$

where T - air temperature (°C), H - air relative humidity (%). According to this relation there were obtained $THI_{NAM} = f(T_{NAM}, H_{NAM})$; $THI_{MAS} = f(T_{MAS}, H_{MAS})$; $THI_{MAP} = f(T_{MAP}, H_{MAP})$, where T_{MAS} represents the average of air maximum temperatures measured on the streets and Prefecture Square and T_{MAP} represents the average of air maximum temperatures measured in English Park, respectively.

Thermal infrared sensing camera FLIR T 200 was used (FPA uncooled microbolometer detector type; 7.5 - 13 μm spectral range; resolution 324 x 256 pixels; NETD < 0.045^{o}C). For each thermal infrared measure-ment, on the thermal infrared camera, 5 parameter (Emissivity, Distance, Refl. temp., Rel. humidity, Atm. Temp.) were necessary to be set. For air relative humidity (Rel. humidity) and air temperature (Atm. temp.) there were used the values measured with the hygrometer (Lutron HT – 3009).

The reflected temperature (Refl. temp.) was determined with aluminium foil, for emissivity ε = 1, distance d = 0 m.

In a thermal image, each material of the buildings' facades and the streets' pavement materials is characterised by certain specific emissivity.

According to the professional emissivity tables, both for buildings' facades and for pavement materials, the mean emissivity ε = 0.92 was selected. According to the same professional tables, the emissivity for grass ε = 0.97, for leaves ε = 0.98, for bark ε = 0.94; therefore, for the vegetal's emissivity, the mean of those mentioned materials, ε = 0.96, was used (www.icess.ucsb.edu/modis/; www.zytemp.com/infrared/application.asp).

In order to verify the thermal infrared temperature correctness in the streets ($T_{IR.PS}$) and in English Park ($T_{IR.GP}$) too, two precision fine wire thermo-couples (Omega 5 SC-GG-K-30-36), and a temperature data - logger recorder (Lutron BTM - 4208 SD) were used: streets - one on the pavement, placed at 1 m from the building wall and one on the building wall at 1 m height from the ground; park - for vegetal material, one on the grass / ground, placed at 1m from the tree trunk, one in the canopy of the tree's crown, respectively. Each thermal infrared measure was considered correct only when the difference between the temperature in the spot of the thermal image, and the measured temperature of the pavement / building (contact method), was less than 2^{o}C.

Results and discussions

Table 1 presents the daily data provided by NAM (T_{NAM} and H_{NAM}), the data obtained during the experimental measurements (T_{MAS} and H_{MAS}; T_{MAP} and H_{MAP}; T_{MPS}; T_{MGP}; $T_{IR.PS}$; $T_{IR.GP}$), the calculated THI (THI_{NAM}; THI_{MAS}; THI_{MAP}) and the monthly average for all those data, too for each MUHI. According to NAM, out of the 29 analysed days of July 2017, there were recoded: 15 days with low / normal temperatures 26.1 - 31.9^{o}C; 14 days with high temperatures 32.1 - 38.4^{o}C.

There were four intervals with successive days when the temperature exceeded 32^{o}C: 1 - 2 July (38.4 - 32.4^{o}C); 9 - 13 July (32.3 - 35.6^{o}C); 21 - 24 July (32.8 - 36.7^{o}C); 29 - 31 July (32.1 - 33.7^{o}C); four canicular days 1, 11, 22, 23 July (38.4°C, 35.6°C, 35.7°C, 35.3°C).

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Table 1: Comparison between the experimentally measured data and the data announced by National Administration of Meteorology

DAY	NAM VALUES		MEASURED PARAMETERS VALUES						INFRARED VALUES		THI_{NAM}	THI_{MAS}	THI_{MAP}
	T_{NAM}	H_{NAM}	T_{MAS}	T_{MAP}	T_{MPS}	T_{MGP}	H_{MAS}	H_{MAP}	$T_{IR.PS}$	$T_{IR.GP}$			
1	38.4	20	46.8	41.9	51.7	45.2	37.2	41.7	53.4	46.7	82.1	96.1	91.6
2	32.4	35	41.5	35.4	45.9	38.3	43.1	47.8	46.5	39.9	78.8	91.4	84.9
4	26.5	45	32.1	28.2	34.4	31.1	50.3	55.5	35.7	32.5	73.1	81.19	76.8
5	29.7	29	39.1	32.9	42.1	36.3	45.5	52.5	43.5	37.6	74.7	89	82.5
6	30.9	30	40.2	34.1	44.4	37.7	45.2	49.5	46.1	39.4	76.2	90.3	83.6
7	29.4	38	38.9	33.4	42.2	36.2	45.6	52.5	43.1	37.1	75.7	88.8	83.2
8	31.9	33	41.8	35	45.5	38.2	44.1	48.6	47.2	40.1	77.8	92.1	84.5
9	33.8	29	42.9	36.2	46.8	39.8	41.3	46.2	48.1	41.5	79.2	92.6	85.6
10	33	36	41.9	36.1	45.6	39.4	41.8	46.9	47.2	41.4	79.6	91.6	85.6
11	35.6	33	44.5	38.9	49.7	42.6	42.6	47.3	51.5	44.3	82.0	95	89.3
12	32.4	39	41.1	35.3	45.7	38.5	43.5	48.1	47.3	40.2	79.5	91	84.8
13	32.3	33	40.8	35.3	45.3	38.1	43.1	48.4	47.1	39.8	78.3	90.5	84.9
14	27.3	39	35.1	31.2	37.1	34.3	48.3	54.3	38.2	35.5	73.4	84.6	80.6
15	27.7	42	35.3	31.7	37.4	34.5	47.9	53.4	38.6	35.9	74.2	84.7	81.1
17	26.1	42	31.3	27.1	33.4	28.9	50.1	55.9	34.8	30.1	72.3	80.1	75.3
18	29.4	35	38.5	33.6	41.9	36.4	45.8	52.2	42.8	37.6	75.3	88.3	83.4
19	31.3	32	40.5	34.8	44.9	38.1	44.4	49.7	46.7	39.9	77.0	90.5	84.5
20	30.9	31	40.2	34.4	44.5	37.9	45.7	51.1	46.6	39.4	76.4	90.5	84.3
21	32.8	30	41.7	35.7	45.4	38.6	42.9	47.2	47.1	40.3	78.3	91.6	85.1
22	36.7	24	45.3	39.6	50.8	43.7	39.4	43.7	52.3	45.2	81.3	95	89.3
23	35.3	29	44.2	38.4	49.3	42.1	43.5	47.6	50.9	44.1	80.9	94.9	88.7
24	34.3	34	43.5	36.8	47.4	40.6	40.9	45.3	48.9	42.2	80.8	93.2	86.1
25	29.9	34	39.4	33.2	42.6	36.9	46.3	52.4	43.9	37.8	75.7	89.6	82.9
26	26.5	39	34.4	30.6	36.5	33.6	49.7	55.2	37.9	34.7	72.4	83.9	79.9
27	29.5	26	38.8	33.1	42.2	36.3	45.8	52.9	43.2	37.4	74.1	88.7	82.9
28	30	32	39.3	32.7	43.2	35.1	47.3	51.9	44.8	37.2	75.5	89.7	82.2
29	32.1	24	40.9	34.9	45.3	38.3	43.2	47.8	46.8	40.1	76.5	90.7	84.2
30	32.7	23	41.2	35.8	45.5	38.7	43.8	48.2	47.1	40.6	76.9	91.2	85.5
31	33.7	26	42.5	36.5	46.2	39.8	42.4	47.1	48.2	41.4	78.6	92.5	86.1
AVG	**31.46**	**32.48**	**40.12**	**34.57**	**43.89**	**37.76**	**44.50**	**49.68**	**45.36**	**39.30**	**77.13**	**89.97**	**84.11**

Craiova's MUHI took into consideration hot spots as very poor vegetated three walking streets and Prefecture Square, determined by non-reflective and high thermal inertia of buildings materials, colour and material of the pavement.

It must be mentioned the important role of the streets and buildings cover types have on the thermal pattern (air temperature and relative humidity values) of each MUHI, and the relationship between the temperature radiated by the streets (and the atmosphere temperature situated immediately above it), and buildings' facades surfaces too, due to the transfer of energy emitted from the former to the latter.

Due to high temperatures of the streets' pavement T_{MPS} = 43.89°C, and of the park's vegetation T_{MGP} = 37.76°C too, the mentions above are confirmed for each MUHI in all the five places (streets, public large square, public park) where the measured air temperature and relative humidity values are significantly higher than the NAM data:

$T_{MAS} - T_{NAM}$ = 8.66°C; $H_{MAS} - H_{NAM}$ = 13.04°C;

$T_{MAP} - T_{NAM}$ = 3.11°C; $H_{MAP} - H_{NAM}$ = 17.2°C.

Consequently, even THI_{NAM} = 77.13 (alert state), the real thermal comfort on the streets and in Prefecture Square THI_{MAS} was 12.84 grater (discomfort state), and even in English Park THI_{MAP} was 6.98 grater (discomfort state), too.

The values for July 2017 presented in Table 1, in the five specific MUFI identified in the Craiova city centre, confirm the general information presented in the literature concerning the influence of micro urban heat islands to the temperature - humidity index (Sham et. al., 2012). Because construction materials exhibit a high thermal inertia (a low response to temperature changes, and consequently, they continue releasing heat slowly after sunset. Meanwhile, light winds are not capable to produce turbulent exchanges of heat, while clear skies enhance rural cooling by allowing radiative heat loss to the relatively cold night sky. The MUHI measured parameters may exhibit high spatial and temporal variation.

Since urban temperature is strongly commanded by the high thermal inertia of the construction materials, the surface MUHI usually reaches its highest intensity in the afternoon, when the urban surface has sufficiently warmed-up, thus maximizing its heat release.

The above considerations are emphasized by thermal infrared remote sensing that was used to observe the urban heat island surface, as a reliable indicator of the atmospheric parameters of each MUHI.

According to Table 1, the difference between the maximum temperatures of the streets' pavement and buildings determined using a contact method / infrared camera ($T_{IR.PS}$) and the maximum temperatures of the streets' pavement measured using contact method / wire thermo - couple (T_{MPS}) is only 1.49°C; similarly, the difference between the maximum temperatures of the grass and trees canopy in the park determined with non-contact method / infrared camera ($T_{IR.GP}$) and the one measured using contact method / wire thermo - couple (T_{MGP}) is only 1.54°C.

Due to thermal infrared remote sensing accuracy, an important relationship between the near surface air measured temperatures and land surface temperatures have been found:

$T_{IR.PS}$ - T_{MAS} = 5.24°C; $T_{IR.GP}$ - T_{MAP} = 4.73°C;

$T_{IR.PS}$ - T_{NAM} = 13.9°C.

Built surfaces (buildings' facades; pavement) are composed of a high percentage of non-reflective and water-resistant construction materials. Consequently, they tend to absorb a significant proportion of the incident radiation, which is released as heat. As a result, the variable thermal properties of the urban construction materials, in combination with the three dimensional geometry of built-up surfaces, modify neighbouring air temperatures.

The narrow arrangement of buildings along the city's streets forms *urban canyons* that inhibit the escape of the reflected radiation from most of the three-dimensional urban surface to space.

This radiation is ultimately absorbed by the building walls, thus enhancing the urban heat release. Moreover, light winds are not capable to produce turbulent exchanges of heat leading to radiative heat losses.

For each MUHI, representative thermal images and temperature graphics in certain hot spots are presented in figures 1-5.

Consequently, within Prefecture Square (open space with a green park to the West; white, light yellow and light orange colours for the buildings' facades; beige color of the synthetic granite tiles) a hot spot was observed. Prefecture Square is the main public square of the city, used especially for social, political and cultural activities. Therefore when it was designed, no high vegetation was possible.

In thermal image and temperature graphics presented in figure 1, it is observed that even if the buildings' facades and pavement's, too, are light coloured, the maximum temperatures of those surfaces were 58.5...62.7°C (Li1 and Li2).

The temperatures on the pavement (light gray color synthetic granite) near the fountain's water sprinkle was 56.5...58.5°C (Li 3 and Li4).

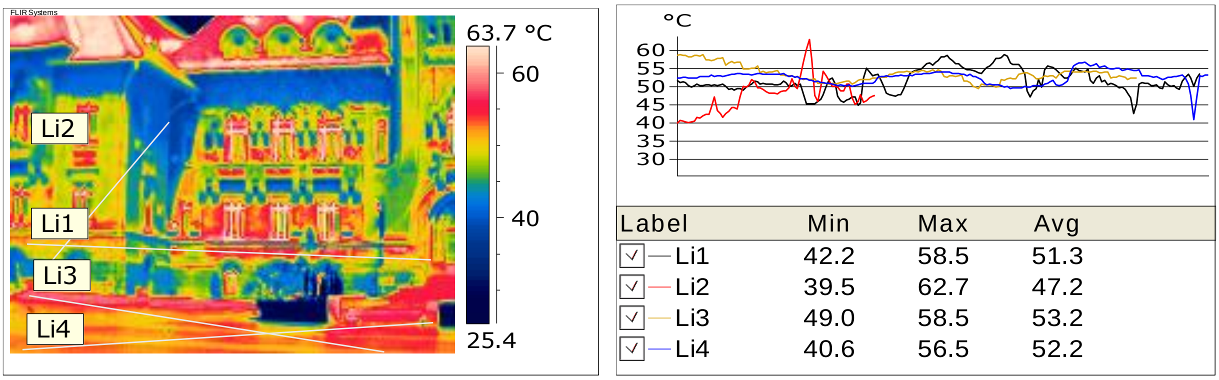


Fig. 1: Thermal images and temperature graphics recorded in Prefecture Square

Thermovision emphasized the same canyon effect for Lipscani Street (no tree; white, light yellow and light orange colours for the buildings' facades; dark white colour for artificial marble tiles of the pavement), too. The thermal image and temperature graphics presented in figure 2 indicates that even if the buildings' facades and pavement's, too, are light coloured, the temperatures of those surfaces were 47.4...48.6°C (Li1 and Li2) and 51.4...55.3 (Li3 and Li 4), respectively.

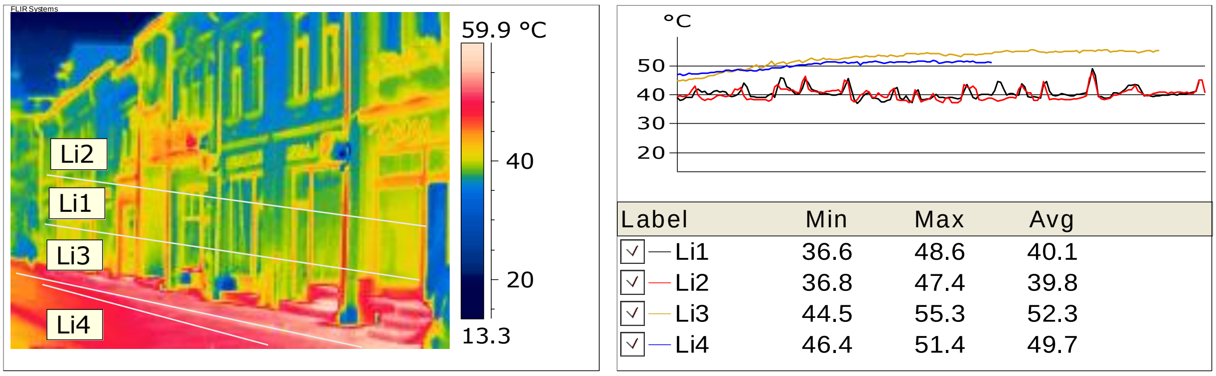
The same canyon effect was identified for Theodor Amann Street as well (very low vegetated; white, light yellow and light orange colours for the buildings' facades; dark white colour for artificial marble tiles and gray granite cubes of the pavement).

Thermal image and temperature graphics presented in figure 3 point that even if the buildings' facades and pavement's, too, are light coloured, the maximum temperatures of those surfaces were 43.4...44.1°C (Li1 and Li2) and 50.6...53.9°C (Li3 and Li4), respectively.

Figure 4 depicts representative thermal images and temperature graphics recorded for Panait Moşoiu Street where canyon effect was observed, too (no trees; white, light yellow and light orange colors for the buildings' facades; dark gray and dark red colours for synthetic granite cubes of the pavement). Even if the buildings' facades are in light colors, the maximum temperature of those surfaces was 45°C (Li1 and Li2). Due to the dark color pavement, the maximum temperature of this surface was 54.1... 54.9°C (Li3 and Li4).

Natural surfaces utilize a relatively large proportion of the absorbed radiation in the evapo-transpiration process and release water vapours, thus cooling the air in their vicinity.

In contrast, built surfaces are composed of non-reflective and water-resistant construction materials and consequently, they tend to absorb a significant proportion of the incident radiation, which is released as heat, and very large values for THI occurred.



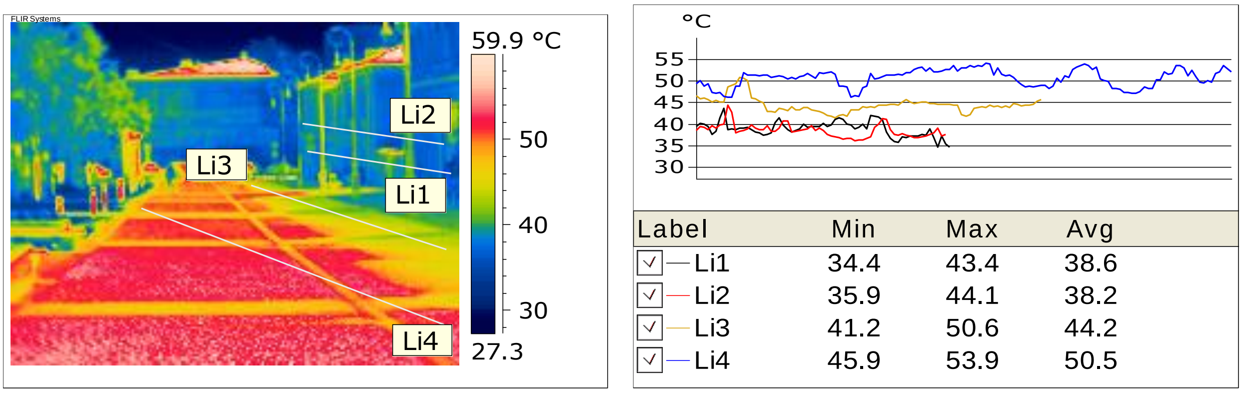
Label	Min	Max	Avg
Li1	36.6	48.6	40.1
Li2	36.8	47.4	39.8
Li3	44.5	55.3	52.3
Li4	46.4	51.4	49.7

Fig. 2: Thermal images and temperature graphics recorded along Lipscani Street

Vegetation intercepts radiation and produces shade that also reduces urban heat release. The decrease of parks and vegetated areas, not only reduces these benefits, but also inhibits atmospheric cooling due to horizontal air circulation generated by the temperature gradient between vegetated and hot spots urban areas.

In comparison with the above presented hot spots, figure 5 presents a representative thermal image and temperature graphics for English Park.

On the trees' crowns (sunny and shady zones) maximum / average temperature was 39.7…40.3°C / 36.6...37.1°C (Li1 and Li2), and the grass / ground (sunny and shady zones) maximum / average temperature was 38.8…45.5 °C / 32.8...38.4 °C (Li3 and Li4).



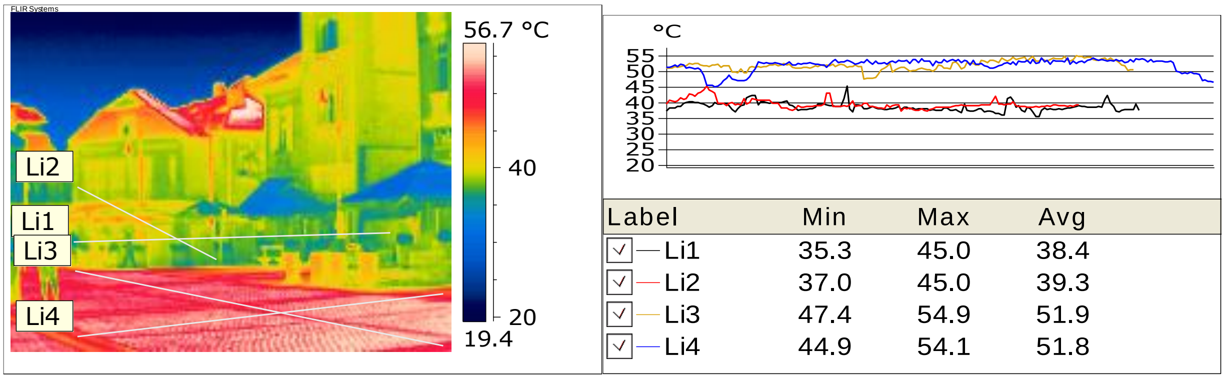
Label	Min	Max	Avg
Li1	34.4	43.4	38.6
Li2	35.9	44.1	38.2
Li3	41.2	50.6	44.2
Li4	45.9	53.9	50.5

Fig. 3: Thermal images and temperature graphics recorded along Theodor Amman Street

Urbanism architects who contributed to this rehabilitation design should have taken into account that in the past 15 years, the summer months in Craiova have become increasingly warmer.

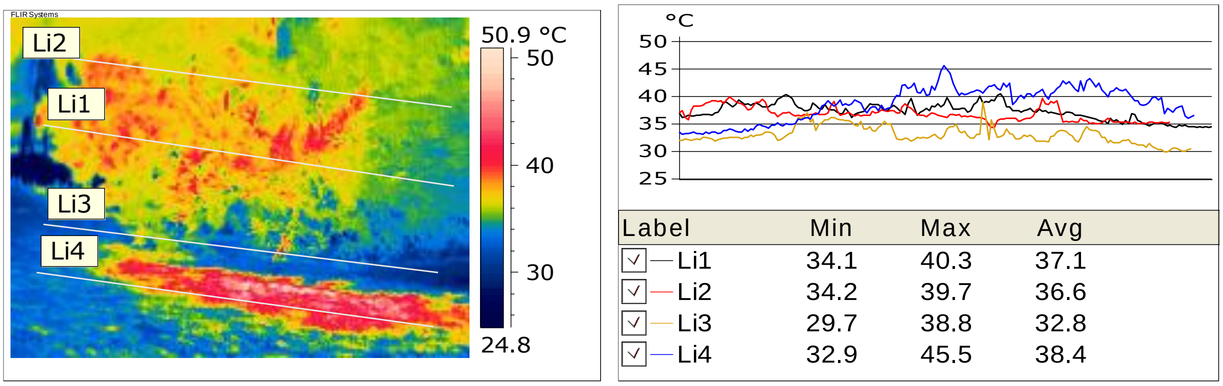
It should be mentioned here for the analysed area covers 9000 m^2 (3 streets and Prefecture Square), there are less than 30 trees. This very poor vegetated area in the hot spots contributes to a large extent to the high temperatures and thermal discomfort sensation that people must deal with.

To reduce the hot spots effects into the micro urban heat islands in Craiova's city centre, a strategically method should be recommended: vegetation increasing that in the same time, will contribute to decrease the urban pollution levels.



Label	Min	Max	Avg
Li1	35.3	45.0	38.4
Li2	37.0	45.0	39.3
Li3	47.4	54.9	51.9
Li4	44.9	54.1	51.8

Fig. 4: Thermal images and temperature graphics recorded along Panait Moşoiu Street



Label	Min	Max	Avg
Li1	34.1	40.3	37.1
Li2	34.2	39.7	36.6
Li3	29.7	38.8	32.8
Li4	32.9	45.5	38.4

Fig. 5: Thermal images and temperature graphics recorded in English Park

To a large extent, the rehabilitation of the streets analyzed in this paper considered the use of the light colours for built surfaces (buildings' facades; pavements). Unfortunately, due to their non-reflective characteristics, all construction materials that have been used for this rehabilitation absorb the incident radiation, that is subsequently released as heat.

In order to decrease the pavements' temperature in the hot spots both in the Prefecture Square and on the rehabilitated streets, an operative, efficient and low cost method should be used: a water sprinkling small car, or temporary water sprinkling system similar with water-fog devices.

Fig. 6: Digital model of modular temporary shady cover for Panait Moşoiu Street

Fig. 7: Digital model of modular temporary shady cover for Theodor Amann Street

In all the hot spots, a simple method that could reduce the reflected radiations' escape from the buildings' walls to neighborhoods consists in permanent or temporary retractable roofs /covers that provide shady zones.

Figure 6 and figure 7 present digital models of modular temporary shady covers proposed for Panait Moşoiu and Theodor Amann Streets.

Conclusions

According to the National Administration of Meteorology (NAM), the month of July 2017 was the hottest July month during the last decade, with one of the longest period with canicular temperatures in the last decades, too. Therefore, in Oltenia and in Craiova city, too, there was a yellow or orange code warning.

In order to determine the real thermal discomfort sensation felt by the population of Craiova, experimental research concerning micrometeorological measurements of real temperature and relative humidity those contribute to the local Temperature – Humidity Index was performed.

According to the experimental research results, confirmed by using thermovision too, four hot spots (three rehabilitated streets and Prefecture Square) were identified in Craiova's city centre.

Despite the low mean value of relative humidity (44.5%), due to the temperature high mean value (40.12^{0}C), in these hot spots the THI average was 89.97, and the thermal discomfort sensation occurred, thus special protection measures were necessary.

The same micrometeorological air parameters in the hot spots were compared with the ones recorded in English Park where due to trees' shadow, temperature and relative humidity averages were 34.57^{0}C, and 49.68%, respectively. Even if the mean temperature was 5.55^{0}C lower and relative humidity 5.18% higher than in the hot spots, the THI average was 84.11 (5.86 lower than in the hot spots), the thermal discomfort sensation occurred, thus special protection measures were necessary.

In order to study the intensity and spatial pattern of the UHI, thermal infrared remote sensing was used to observe the surface of urban heat island as a reliable indicator of the atmospheric microurban heat island. Therefore, close relationships between the near surface air temperatures and land surface temperatures have been found for microurban heat islands in Craiova's city centre.

The experimental results confirm that due to the variable thermal properties of the construction materials (building, pavements) combined with the three - dimensional geometry of built-up surfaces, the neighboring air temperatures increase. In the same time, the narrow arrangement of buildings along the streets leads to urban canyons phenomenon, that inhibit to space the reflected radiation's escape from the three - dimensional buildings' shape and pavements' surfaces. This radiation is absorbed by the building walls and the pavement, thus enhancing heat's release from the micro urban hot spots. On other hand, very light winds are not capable to obtain heat's turbulent exchanges.

Vegetal surfaces utilize a relatively large proportion of the absorbed radiation in the evapo-transpiration process and release water vapours that cool the air.

Vegetation intercepts radiation and produces shade that also contributes to heat's release reducing. The decrease of parks vegetated areas, not only reduces these benefits, but also inhibits atmospheric cooling due to horizontal air circulation generated by the temperature gradient between vegetated and micro urban' areas hot spots.

In contrast, built surfaces are composed of non-reflective and water-resistant construction materials, and as consequence, they absorb a significant proportion of the incident radiation, which is released as heat, and very large values for THI occurred.

According to these considerations, in order to decrease the pavements temperatures in the hot spots, an operative, efficient and low cost method consisting in modular temporary shady cover could be used. A cheaper and shorter term method would be to use permanent or temporary vertical walls and modular roofs made by ornamental green vegetation.

In order to increase the vegetated area in the micro urban hot spots, that will also decrease pollution, in the near future concerted efforts of a consortium of urbanism architects, meteorologists, ornamental plants and trees specialists and environment urban pollution engineers are needed.

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