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SEASONAL OCCURRENCE OF HEAT ISLAND PHENOMENON IN THE URBAN BUILT ENVIRONMENT

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Abstract

Latest analysis regarding the climate change phenomenon arises issues related to air quality, human comfort within urban environments and an increased energy demand attributed to the building sector. The Urban Heat Island (UHI) phenomenon is directly responsible for the poor quality of life in cities and for increased energy consumption. Characteristic features pertaining to a specific urban environment, such as local microclimatic conditions, urban morphology and anthropogenic heat release respectively, generate this phenomenon. Therefore, local studies must be conducted for a specific urban settlement, being very relevant for adopting suitable strategies that aim to counteract the harmful effects of UHI phenomenon. In this respect, the paper presents results of a study case comprising an investigation of the UHI occurrence and intensity for the city of Iasi, Romania. Analysed data is based on information regarding temperature values for the summer of 2013, gathered through an experimental ground-based sensor network comprising 7 observation points within the metropolitan area of Iasi city.

Keywords: climate change, heat island, urban built environment, UHI intensity

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1. Introduction

In the current context of global warming issues, the increasing UHI phenomenon present worldwide draws attention towards the need to adapt cities for future climate change conditions in order to reduce energy consumption demand attributed to the construction industry. Climate change caused by greenhouse gases, massive deforestation, changing watercourses, and also other type of destructive anthropogenic activities that impact the environment have become a certainty.

These negative effects are felt by the natural, human and social-economical systems, therefore the associated risks claim a variety of policies and strategies at local, regional and global level. The European Union Agenda reflects the impacts of climate change on the natural environment and the nature of political instruments available to mitigate the resulting adverse effects represents an important aspect according to *European Environment Agency* (2012) and *EC* (2008).

Research studies pertaining to this matter emphasize that more than a third of the European Union population, 170 million people currently live in regions affected by climate change (European Union Report 2020, 2009). According to *European Union Report 2020*, the greatest risk is observed along the coast of Spain, in Italy, Greece, Bulgaria, Cyprus, Malta, Hungary, on a large area of Romania and, respectively in southern France. The extent to which different regions of Europe are likely to be affected by climate change was quantified by an index of vulnerability to these changes (Fig. 1).

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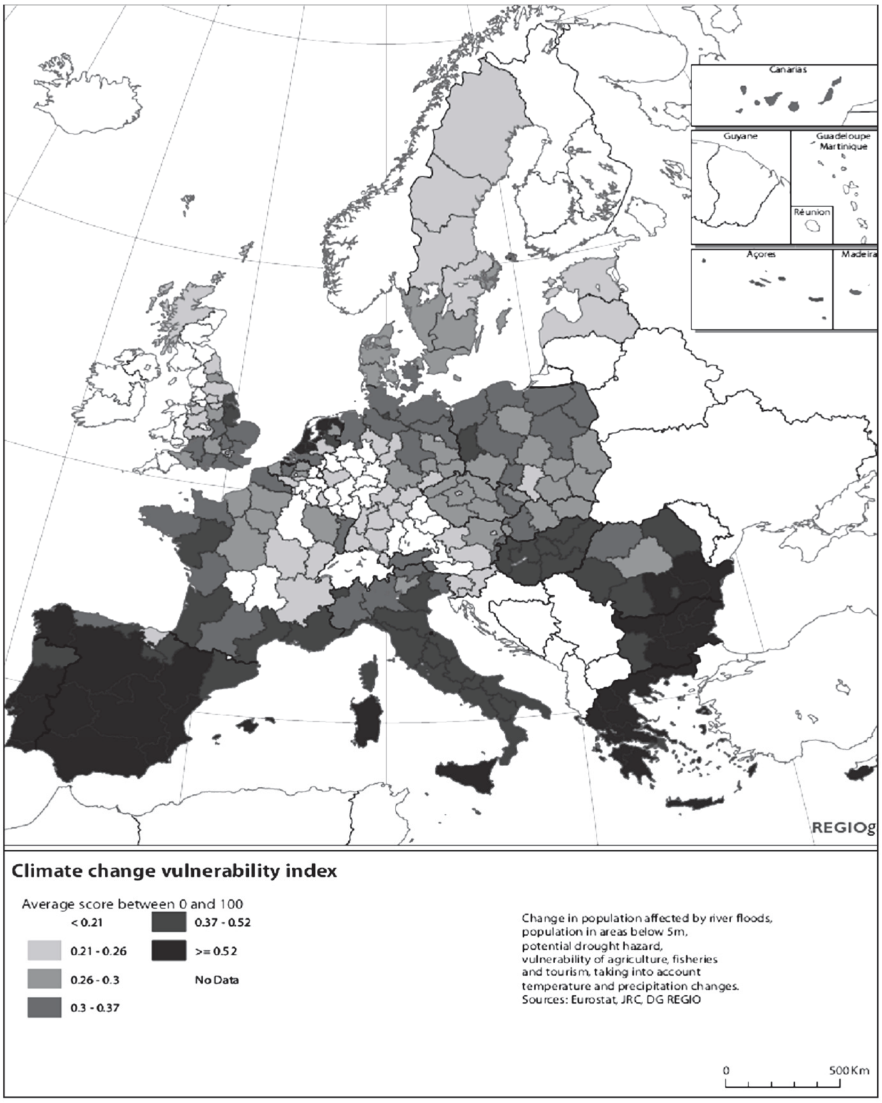

Fig. 1. Index of vulnerability to climate change, according to (EU 2020 Report, 2009)

Conclusions of *European Union Report 2020* (2009) highlight the importance of cities adapted to future environmental conditions, the severity of this impact is dependent on physical vulnerability, levels of economic development, natural and human adaptive capacity, health services and regulatory mechanisms. In the same context - United Nations Framework Convention on Climate Change, 2009; Kyoto Protocol, (International treaty, 1994; 2005), two directions are drawn that include fundamental strategies: mitigation and adaptation strategies for environmental climate change. The two directions, mitigation and adaptation, fall in line with the concept known as "*smart cities*" which target the creation of resilient cities, hence resilient urban built environment being capable of coping with the future conditions regarding climate change.

Regarding the relationship between climate change and classes of buildings, this is complex, with a pronounced synergy nature, considering the following aspects:

- Buildings intervene with an important share in the production of greenhouse gases, 40% in European environment, thus contributing to climate change;
- The impact of environment on existing buildings cannot be ignored because it occurs at structural level and is closely related to user behaviour to the extent that adequate indoor environmental quality can be ensured (air quality, thermal and visual comfort, etc.);
- Impact of climate change on buildings behaviour is manifested particularly by increasing summer temperatures, therefore comfort conditions without additional energy consumption becomes difficult;
- The measures to reduce energy consumption, properly managed, contribute positively in most cases, to the way in which the buildings respond to environmental climate change.

Impact of climate change on buildings is manifested through increased indoor temperature values (Bullen, 2004; Gupta and Gregg, 2013; Kadhim-Abid et al., 2014c), which during hot season exceed comfort levels and are accountable for mortality and morbidity rates observed in urban environments (Matzarakis, 2011). Key opportunities to increase the adaptability of buildings to environmental climate change target the design phase, optimized ventilation and user behaviour. Due to the fact that climate change affects buildings and urban settlements withal, mitigation strategies and adaptation measures should be considered by stakeholders and building industry responsible (Kadhim-Abid, 2014a; Wamsler et al., 2013).

Another factor that impacts the UHI phenomenon, implicitly with repercussions on the quality of life within the built urban environment, is the urbanization phenomenon. With the expansion and development of urban centres, an increase of total artificial surface is registered, which along other anthropogenic activities are responsible for the high temperatures recorded in cities during hot seasons. The link between the urban surface alteration and its conduct in terms of thermal behaviour, including adaptation and mitigation measures to alleviate the negative effects of the urbanization phenomenon, require a systematic monitoring. Urbanization, as a phenomenon, demands an analysis from two perspectives: first locally, by monitoring and analysing the UHI phenomenon and second, in the context of global warming. Urbanization influences the UHI phenomenon's presence within urban centres through increased areas of the built environment, measured by diminished natural surfaces in favour of artificial ones. Artificial surfaces absorb incoming solar radiation during the day, which is stored by the built mass of the urban settlements and then released back in the environment during the night. These artificial impervious surfaces alongside factors such as city morphology, local climate and other anthropogenic activities specific to urban environments generate the UHI phenomenon. Amongst the mitigation strategies adopted for alleviating the UHI phenomenon, most efficient proved to be green surface integration within the urban environment as follows: at urban level through vegetated permeable surfaces (Gupta and Gregg, 2013; Kleerekoper et al., 2012, Scherba et al., 2011) or at building level through green roofs or green facades included in the building's envelope (Kadhim-Abid et al., 2014d; Niall, 2010; Xu et al., 2011). Green roofs are also suitable for lowering the energy demand attributed to energy consumption for cooling the buildings during warm seasons (Ascione et al., 2013; Berardi et al., 2014).

The processes caused by UHI have consequences of economic and social nature. Especially, they affect human health through increased pollution levels manifested in elevated mortality and morbidity rates. Accountable for this occurrence are *heat waves* within the urban environments, a phenomenon with increased frequency in recent years that present a direct impact on human health (Amengual et al., 2014). UHI phenomenon also influences considerably the high temperature range recorded during summer, which furthermore leads to overheating processes of the exterior environment, thus requiring greater energy consumption demand for cooling the buildings.

The negative effects UHI generates in the urban environment are a certainty, as well as, the fact that they engage increased energy consumption levels. In order to alleviate these effects, as mentioned above, implies issues related to reduced greenhouse gas emissions, indoor environmental quality, matters of energy supply and human health. Regarding the energy issue strategies, these are solutions of sustainable nature, which differentiate themselves by aiming to improve building and built urban environment behaviour. The study and evaluation of systems that could potentially reduce energy demand, therefore improving local microclimate conditions are required in order to establish mitigation strategies aimed to tackle negative UHI effects. Each urban settlement presents unique features related to different city morphology, various microclimate conditions and pollution level.

A demand for investigation at local level thus arises, regarding the implementation of suitable measures specific for an urban environment. Hence, UHI phenomenon must be analysed from case to case through temperature differences between rural and urban areas and spatial distribution manifestation. Typically, regarding the European region, a city with 1 million inhabitants registers an UHI intensity with a value of approximately 8°C (Shahmohamadi et al., 2010). From a climatic perspective, an air temperature value of 1°C corresponds to a distance of 200 km in latitude and to an altitude difference of 150 – 200 m, therefore such a difference of 1°C registered between the urban and rural environment becomes considerable (Alexe, 2012). In this regard, the paper presents results of an investigation regarding UHI occurrence within the metropolitan area of Iasi, Romania.

2. Case study

2.1. The Urban Heat Island phenomenon

Heat island phenomenon is characterized by different intensity and spatial distribution from one city to another (Oke, 1982) and depends on the city's morphology. Increased temperatures caused by the UHI phenomenon can be explained through the amount of heat absorbed by the built mass during day-time, which is then further on released in the environment after sunset, therefore creating a temperature difference between an urban zone and a rural one. This is called the magnitude or intensity of the UHI and it can be described as the positive difference between air temperature values registered within the city and those registered on the outskirts or rural areas. For UHI intensity calculation, Eq. (1) (Oke, 1987) is used:

$$\Delta T_{u-r} = T_{u} - T_{r} \ [°C], \quad (1)$$

where: T_u is the air temperature registered at an urban station, [°C]; T_r is the air temperature registered in the rural environment, considered as the reference temperature, [°C].

According to Oke (1982), a heat island is generated by a combination of factors, which he grouped in five categories:

- reduced evapotranspiration by replacement of natural surfaces with artificial, impermeable ones;
- anthropogenic heat release, which stagnates within the dense built environment;
- air pollution;
- albedo and thermal properties of urban surfaces;
- surface geometry.

2.2. Environmental specificity for Iasi municipality, Romania

Looking to identify the UHI occurrence within Iasi municipality, the environmental context of the city is relevant as local microclimatic conditions, city morphology and population density (Zoran, 2011) affects the phenomenon's behavior. Iasi city is located in the northeast part of Romania, being geographically positioned on seven hills, which influence the city's microclimatic wind conditions. Area morphology presents altitudes between 300 and 350 meters in the west and south and a lower altitudinal class in the north and northeast, between 100 and 150 meters. The 2002 census population registered 320,888 inhabitants with a density of 2173,8 inhab/km^2, (http://www.primaria-iasi.ro/). The total area of Iasi sums up to 95,3 km^2. Regarding the built area within the city, a 13.6% increase from 2005 since 2012 is registered (Kadhim-Abid, 2014b).

Results regarding daily variations of the global solar radiation, with respect to the radiation factors in Iasi Metropolitan Area (IMA), recorded in 2000 along with multiannual variation of global solar radiation recorded between 1963 and 2007, are presented in Fig. 2 and Fig. 3, respectively. Results were processed with data courtesy of National Institute of Meteorology from Iasi. Data regarding multiannual global solar radiation present an increasing tendency towards the radiation values recorded since 1963 until nowadays, emphasizing the current environmental climate change phenomenon.

The temperature parameter, in terms of microclimatic conditions is generally influenced by the following environmental factors: land use, artificial surfaces, anthropogenic heat release, demography and, in a broader manner, the economic development of a city. These factors imprint considerable changes to the thermal regime, inducing changes in air temperature values within the urban area. Although the built mass of Iasi city is more horizontally extended rather than vertically developed, the temperature regime is nevertheless influenced by its specific urban agglomeration. A study regarding the temperature regime characteristic for Iasi (Alexe, 2012) presenting increased multiannual average temperature values since 1961 until 2009, is depicted in Fig. 4. Assumptions of the study, as illustrated in Fig. 4, reveal an increase of temperature values, related to the urbanization level, implicitly, having as effects the presence of UHI phenomenon within the IMA. Furthermore, this fact emphasizes the thermal inertia of the active surface and an increase in solar radiation withal.

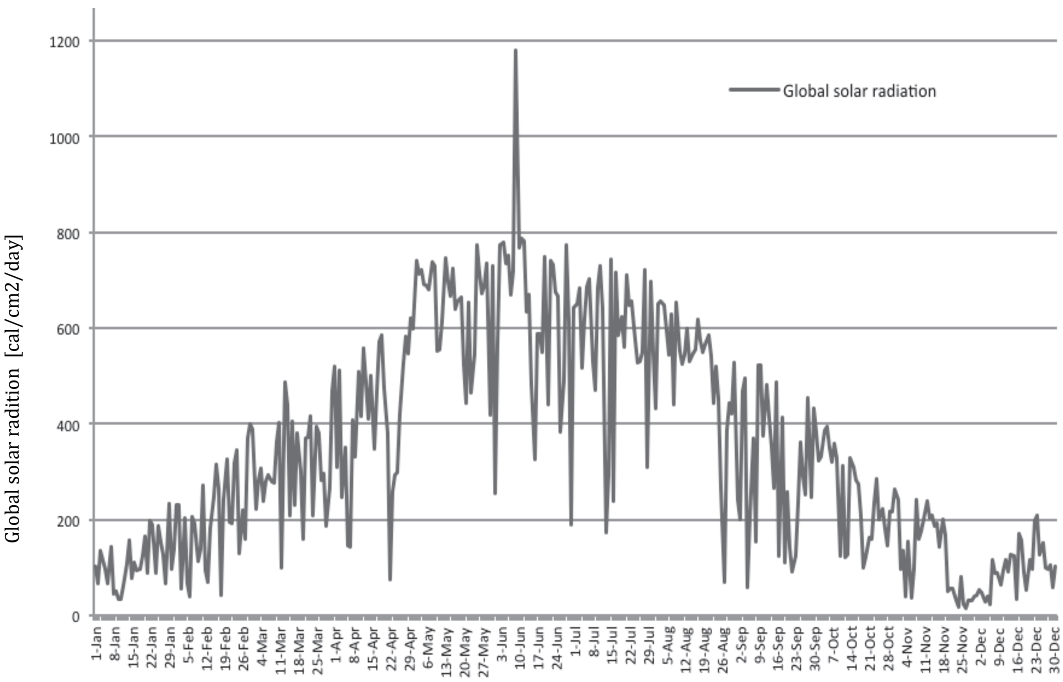

Fig. 2. Values for daily variations of global solar radiation recorded in IMA, 2000

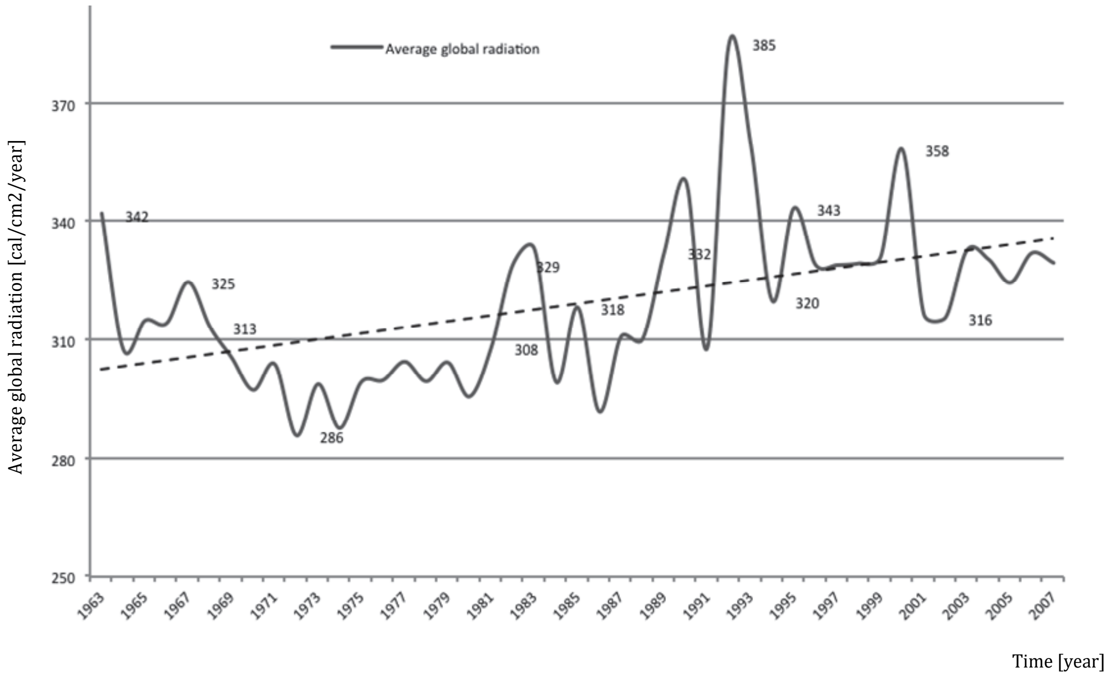

Fig. 3. Values for multiannual variation of global solar radiation recorded in IMA, 1963-2007

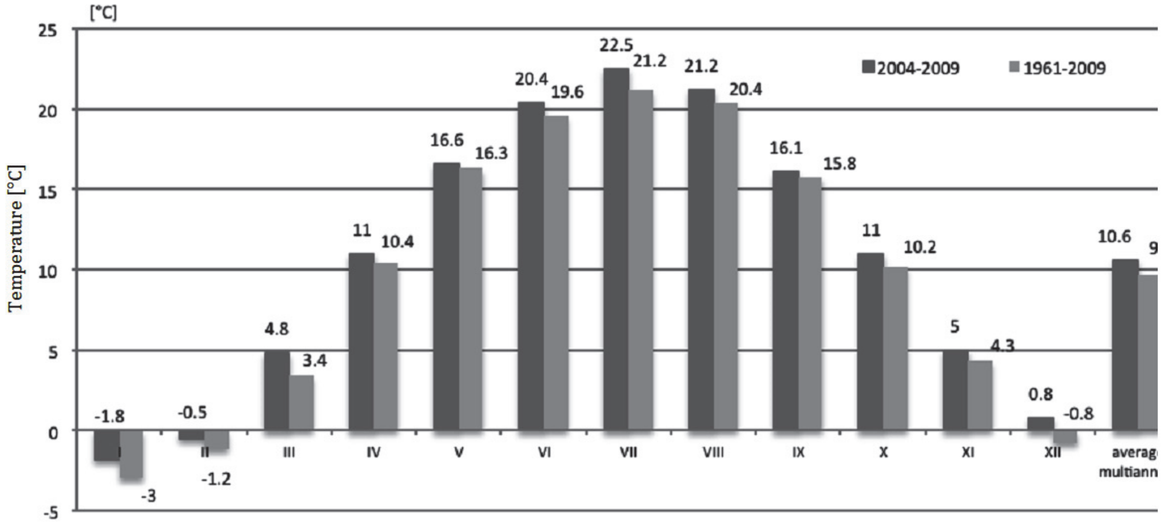

Fig. 4. Multiannual average temperature for IMA during 1961-2009, adapted from Alexe (2012)

2.3. Research methodology

In order to study the UHI occurrence, a research methodology has been developed based on data gathered through an experimental ground surveillance network, compiling information acquired throughout the year 2013. The experimental surveillance network considered a number of 7 observation points. In order to assess isotherms, air temperature difference and UHI magnitude, 5 observation points (U1, U2, U3, U4 and U5) have been mounted across the city and 2 (R1, R2) installed in the rural area of IMA, as presented in Fig. 5. The observation points imply data-logger sensors responsible with acquisition of temperature and humidity values. The sensors were mounted in standard meteorological shelters, similar to those used in conventional weather stations. In order to identify UHI intensity, numerical data was determined using Oke's formula, illustrated in Eq. 1. This numerical data presented in this study has been processed courtesy of *Department of Geography, Faculty of Geography and Geology*, Iasi.

3. Results and discussion

The analysis of the case study results followed mean hourly distribution values for summer at all the urban and rural stations. The season was divided according to exact solstice characteristic for the year 2013 and all values were averaged based on hourly readings. Furthermore, a reference day was chosen for the summer season under analysis.

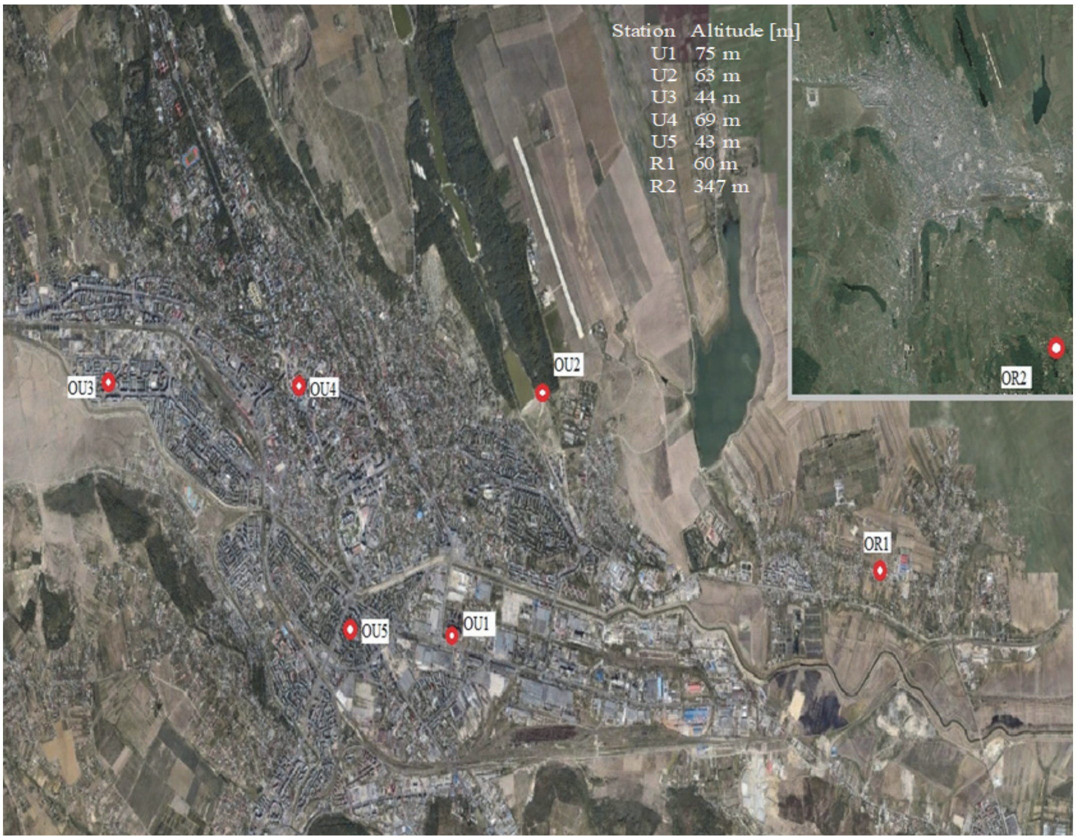

Fig. 5. Urban and rural observation points of the experimental surveillance network, IMA

The diagram depicted in Fig. 6 presents the temperature regime of summer 2013. UHI intensity is always positive with maximum and minimum values registered at 20:00 in the evening with a value of 3.7 °C and at 08:00 during morning, respectively, with a value of 1.5 °C. Averaged values registered at rural stations are lower than those registered at the urban ones, yet rural station R2 presents values close to U2, U3 and U4, within the interval 09:00 to 17:00.

After the seasonal and monthly data inspection, a week with highest registered values was chosen in order to further examine the UHI behaviour in extreme conditions. Thus, highest values were identified from 5th to 11th of August. When comparing temperatures recorded at all stations during the hottest week, considerable differences were observed between the U4 station and the other ones, except U1, which presents similar values.

The station U1 is mounted in the industrial area of the city, which is characterized by increased artificial surfaces with high albedo values and increased anthropogenic heat release, whereas U4 station is situated in an area with low building density. The similarities regarding the temperature values recorded at station U1 and U4 respectively, could be explained through the altitudinal difference between stations and air currents present in the city, which induce movement of heated air from one zone to another.

Due to the fact that the values registered at rural station R2 were lowest compared to results from other stations, this was chosen as reference station when considering UHI intensity, according to Eq. (1).

The temperature distribution observed in Fig. 7, based on mean hourly air temperature values registered from 5th to 11th of August, highlights the characteristic of UHI phenomenon's night expression regarding temperatures accounted in the city centre, station U4. This station presents values higher than those recorded at other stations, in the interval between 20:00 and 06:00.

Cumulative frequency presented in Fig. 8 regarding air temperatures values for each station, during 5th -11th of August, depicts that curves pertaining to urban station U4 and U1 profile occupy the lowest position within the graph. Therefore, it can be stated that 50% of the time, temperatures recorded within the city centre are equal or exceeding 24.8°C. The rural station R2 whose profile positions its median crossing the profile at 22.5°C, determines therefore a difference of 2.25 °C when compared to results obtained at the U4 location. Also, the U5 station reveals high temperatures when compared with results from other locations.

4. Conclusions

The investigation pertaining to the urban environment of Iasi city, in the context of UHI occurrence during summer of the year 2013 reveals that the intensity of this phenomenon is always positive.

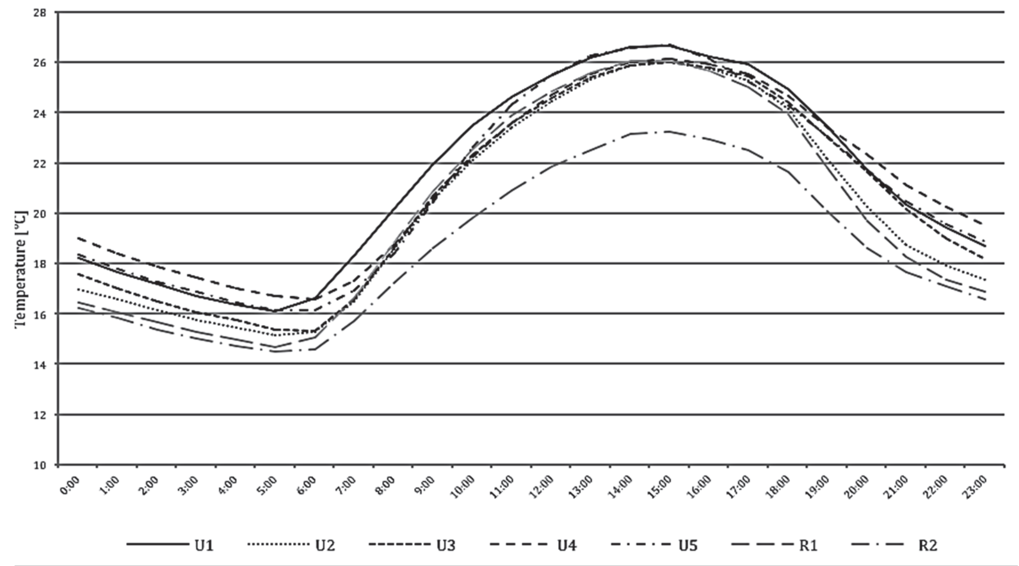

Fig. 6. Results on mean hourly distribution of temperature regime, reference day of summer 2013

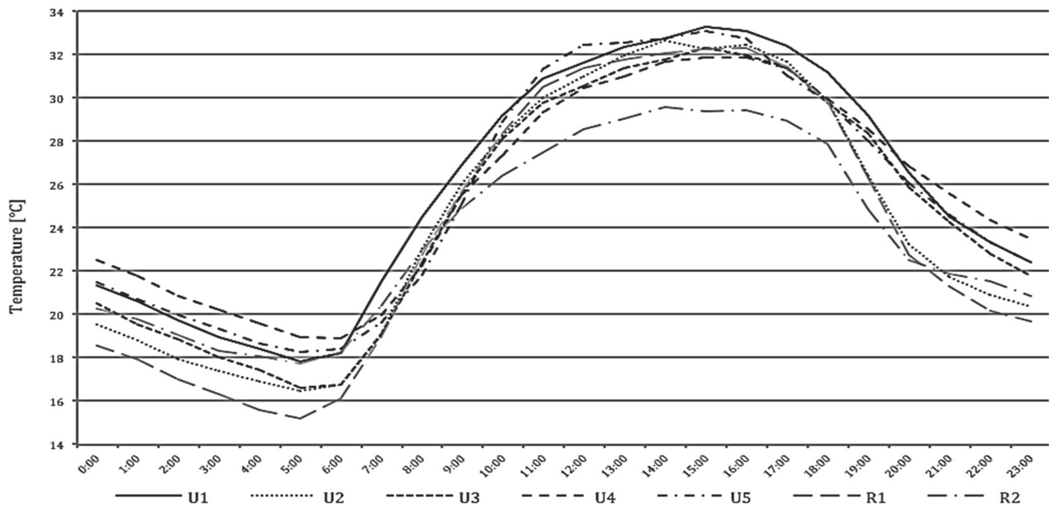

Fig. 7. Results of mean hourly air temperature values registered in Iasi, 5th -11th of August 2013

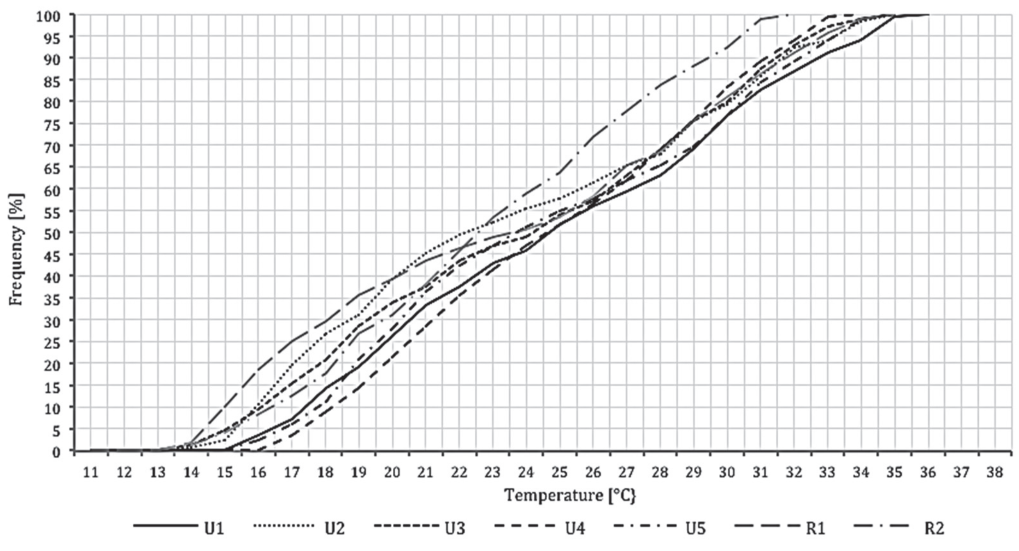

Fig. 8. UHI frequency distribution in the IMA, during 5th -11th of August 2013

Maximum UHI values were recorded around 20:00 with an intensity of 3.7 °C, the recorded temperature difference between urban and rural environment. During the hottest week accounted, the period starting from 5th to 11th of August for the year 2013, it can be stated that 50% of the time, air temperature values were equal or exceeding 24.8°C, with an UHI intensity of 2.25 °C. The study regarding the UHI in Iasi city reveals a considerable intensity of the phenomenon, which can be explained, aside the environmental climate change implications, through increased anthropogenic heat release and a decrease in natural or pervious surfaces within the urban environment. These changes related to increased artificial surface of the urban environment are emphasized by the fact that within Iasi city, the built area registered an increase of 13.6% from 2005 since 2012.

This paper investigates the presence and intensity of the UHI phenomenon within the Iasi Metropolitan Area, Romania. Results of the temperature regime analysis confirms UHI occurrence in Iasi city. This conclusion leads to the need of adopting mitigation strategies alongside adaptation measures for buildings against climate change since the impact of climate change on buildings manifest mostly by increased indoor air temperatures values, which further on, during hot season lead to increased anthropogenic heat release and greater energy demand.

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