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OBSERVED CHANGES IN AIR TEMPERATURE, URBAN - SUBURBAN TEMPERATURE DIFFERENCE IN THE REGION OF SOFIA (BULGARIA)

SCHIMBĂRI OBSERVATE ALE TEMPERATURII AERULUI, DIFERENȚA DE TEMPERATURĂ URBAN-SUBURBAN ÎN REGIUNEA SOFIA (BULGARIA)

Nina NIKOLOVA[1], Radoslav EVGENIEV[2]

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Abstract: Climate change and the impacts of anthropogenic activity on climate in Europe is documented in many scientific publications but the investigations about climate impact and particularly urban climate are relatively few for Bulgaria. The present paper investigates the variability of seasonal and annual air temperature in Sofia city and surrounding areas (towns Bankya and Bozhurishte) for the period 1961-2015 based on the linear regression method. In order to investigate the urban heat island (UHI) intensity, the air temperature difference between the city and its surroundings is calculated. The study shows increase of air temperature difference between the city and suburban territories during the recent years. The linkages between the observed variability of air temperature difference and atmospheric circulation and urbanization are investigated.

Key-words: *air temperature, city, suburban areas, atmospheric circulation, population.*
Cuvinte cheie: *temperature aerului, oraș, zone suburbane, circulaţie atmosferică, populație.*

1. INTRODUCTION

The relevance of the topic climate – urban areas is emphasized by the creation and the adoption of a number of international documents, among which are 2030 Agenda for Sustainable Development (2015), Paris Agreement (2015), New Urban Agenda (2016).

The extension of the cities and increasing urban population has been a characteristic trend in recent years, both globally and in Bulgaria. Changes in the land cover and in the composition of the atmosphere are most pronounced in cities. As a result of the interaction between the natural components, the elements of the urban environment (buildings, infrastructure) and the anthropogenic activity in

[1] Faculty of Geology and Geography, "St. Kliment Ohridski" University of Sofia, Tsar Osvoboditel Blvd. 15, Sofia 1504, Bulgaria, nina@gea.uni-sofia.bg.
[2] National Institute of Meteorology and Hydrology, Tsarigradsko shose Blvd. 66, Sofia, Bulgaria.

cities, conditions are created for the formation of the so-called urban climate, the main feature of which is the formation of an urban heat island (UHI).

Urban Heat Island (UHI) is the name given to the characteristic warmth of both the atmosphere and the lithosphere in cities (urban areas) compared to their rural (non-urbanized) surroundings (Voogt, 2004). This phenomenon is a research target in a number of scientific publications (Oke, 1982; Quattrochi et al., 2000, Atkinson, 2003; Bai, X., 2003; Feleksy-Bielak et al., 2004). It is established that the annual mean air temperature in a city with 1 million people or more can be 1–3°C warmer than in its surroundings (Akbari, 2005). The heat island is a reflection of the sum of microclimate changes, connected with anthropogenic activity. Approximately around 74 % of Europe’s population is living in cities (United Nations, 2018). More than ¼ of the territory of the European Union is under of the influence of urbanization (EEA, 2006). Adinna et al. (2009) underline the UHI correlated positively with population density and concentration of human activities. During the recent years, the number of scientific publications has increased, emphasizing the importance of knowledge about climate for the urban planning (Eliasson, 2000).

Urban environment influences physical, social and mental state of the people that is way it is of great importance for the quality of life in the cities. On the other side, urbanized territories should play an important role for the activities, connected with the adaptation of climatic changes and the decreasing of emissions of greenhouse gases into the atmosphere. Despite the different space dimensions, urban territories cannot be considered away from regional climate, because urbanized environment changes the climatic factors.

Sofia is the largest urban and industrial center in Bulgaria, in which the anthropogenic impact on the climate is the most pronounced by forming a specific urban climate. In recent decades, the city has been growing, spanning larger territories from the Sofia Valley. Currently, more than 16% of the country's population is concentrated in the capital. The development of the urbanization requires systematic, regional studies of climate fluctuations in the city and its suburban areas, especially in the context of contemporary climate change.

The first studies on the climate of Bulgarian cities have been published in the 1970s followed by a number of publications in the recent decades. Most of the existing publications in the scientific literature in Bulgaria discusses air temperature in Sofia (Hristov & Tanev, 1970; Blaskova, 1983; Velev, 1986; Topliiski, 1992).

Based on 80 years of meteorological observations, Hristov & Tanev (1970) make a detailed analysis of the climatic factors affecting the climate of the city of Sofia. Particular attention is paid to the meteorological elements that have the most direct application in the construction of buildings – strong winds, intense rainfall, frequency of temperatures at different intervals, temperature inversions, depth of soil freezing and others.

Since the 1980s, there has been a growing interest in research on the relationship between climate and anthropogenic activity. Based on the data from the meteorological station in Sofia (Botanical garden) for the period 1887-1980, Velev (1986) analyzes the anthropogenic influence on the climatic parameters (air temperature, precipitation, wind and fog) for the city of Sofia, as well as the future climate change tendency. In the study, the author points out the existing of an urban heat island in the central city part of Sofia, which probably reaches 200-300 m above the earth's surface and is most pronounced in winter and at night.

Topliiski (2007) draws attention to the patterns of climate change through Thornthwaite and Koopen climate indices. In addition, an attempt is made to the establishment of the anthropogenic impact by identifying the differences between the urban climate and that one of the surrounding areas. The initial information is based on air temperature and precipitation data for the city of Sofia (meteorological station at Levski Square, period 1896-1991) and the suburb of the city (station Bozhurishte, period 1924-1991).

The aim of the present study is to contribute to the clarification of contemporary changes in the air temperature in cities and the formation of urban heat island. The results are presented in two subgroups: 1) analysis of annual cycle and observed changes for two investigated periods 1961-1990 and 1986-2015, and 2) evaluation of UHI based on the air temperature differences between the meteorological stations in Sofia and suburban areas Bankya and Bozhurishte and also air temperature differences between various measurement points in the frame of Sofia city.

2. DATA AND METHODS

The subject of the study is the air temperatures in Sofia and its adjoining suburban territories. The selection of meteorological stations is based on the type of underlying surface - a station located in a highly anthropogenic urban environment (Sofia) and two stations located in less anthropogenic sub-urban areas (Bankya and Bozhurishte), as well as on the availability of meteorological data. The three stations are located on territories with similar orthographic features and have slight differences in altitude. The city of Sofia is located in the central part of the Sofia valley and has an average altitude of 550 m. The town of Bankya is located in the Sofia Valley, about 14.5 km west of the capital Sofia, at the foot of Lyulin Mountain, on the bank of the Bankya River and has an average altitude of 640 m. The third measurement point is organized in the town of Bozhurishte, which is located in the western part of Sofia Valley, 13 km west of the city center. The average altitude of this station is 573 m (Fig. 1).

The methodology for UHI investigation is based on historical data and data from short-term observations. The long-term records of climatic elements are used in historical analyses. This allows to detect significant changes in urban climate, but also to examine the contribution of urban development in regional climatic trends. Short-term data is used to detect differences in the degree of manifestation and dynamics of UHI. The analyses are based on two types of data set: 1) monthly data for air temperature from three meteorological stations (Sofia, Bakya and Bozhuroshte) for the period 1961-2015 and 2) daily data from five observation points located in the frame of Sofia city. The monthly data are from the meteorological stations of the National Institute of Meteorology and Hydrology – Bulgaria. The daily data are provided by the Executive Environment Agency, Bulgaria, which organizes the National System for Environmental Monitoring. The geographical location of the stations is presented in Fig. 1. One of the stations "Orlov most" is situated in the centre of Sofia, along the main boulevard "Tzarigradsko shosse", in the area with heavy road transport. The station "Hipodruma" is in the wide centre of the city, while the other three stations (Nadezhda, Pavlovo and Druzhba) are in different districts. The period of the analysed daily data is from January 2006 to December 2015. Based on the daily data monthly values are calculated.

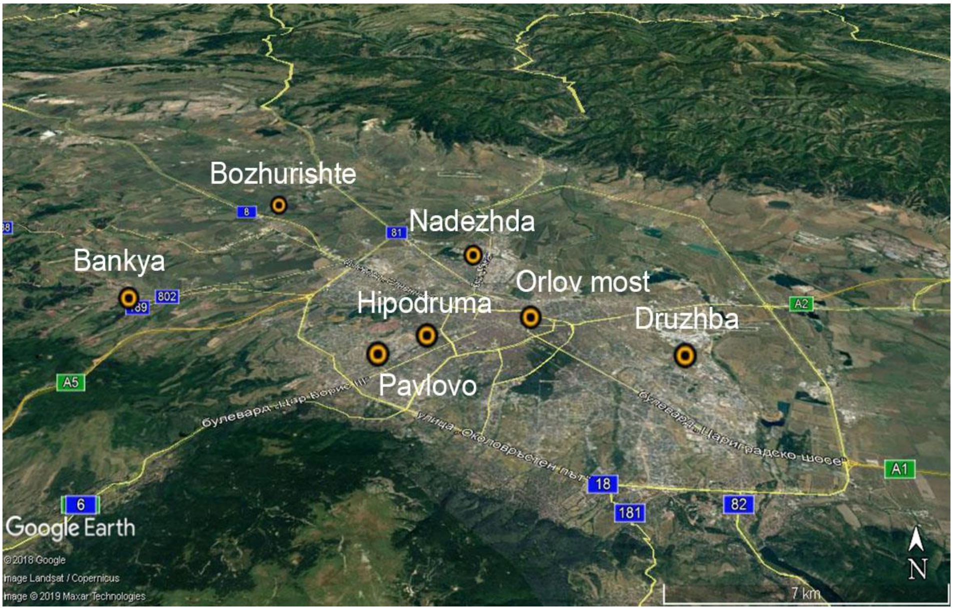


Fig. 1 Geographical location of the meteorological stations (Bankya and Bozhurishte) and stations for automatic measurement of air quality (Orlov most, Nipodruma, Nadezda, Druzhba and Pavlovo)

In order to show the chronological changes on the air temperature in the investigated area, the study period is divided into two sub-periods of 30 years: 1961-1990 (determined by the World Meteorological Organization as a period for calculating the current climate norm) and 1986-2015 (the last 30 years of the study period). The intensity of UHI, which is considered the simplest quantitative indicator of thermal modification induced by urban spaces (Martin-Vide et al., 2015), is investigated by calculation the difference between air temperature in the city and suburban areas and also air temperature difference between various measurement points in the city. The urban – non-urban air temperature differences are evaluated on monthly, seasonal and annual levels.

3. RESULTS AND DISCUSSIONS

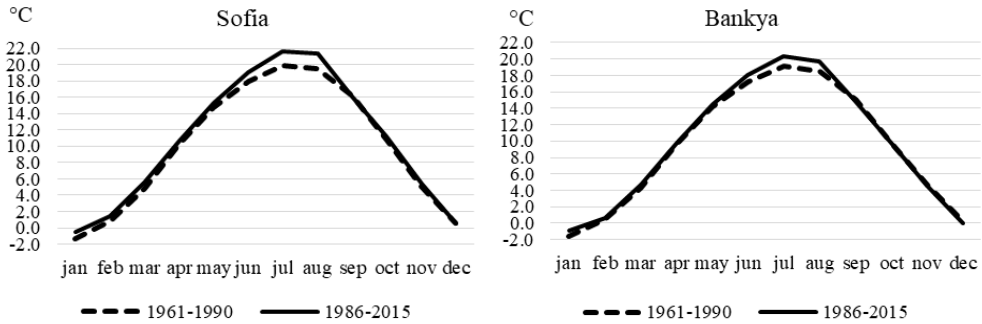
3.1. Annual cycle of air temperature

The annual cycle of air temperature in the investigated stations has a maximum in July and a minimum in January (Table 1). In comparison to the meteorological stations from the sub-urban area, the monthly air temperature in Sofia is higher. The air temperature differences are discussed below.

Table 1 Monthly mean air temperature for the period 1961-1990

Meteorological stations / months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Sofia	-1.0	1.1	5.2	10.4	15.1	18.5	20.7	20.4	16.4	11.0	5.4	0.6
Bankya	-1.3	0.4	4.4	9.6	14.4	17.7	19.7	19.1	15.0	9.8	4.8	0.2
Bozhurishte	-1.4	0.7	4.9	10.1	15.0	18.3	20.3	20.1	16.0	10.5	4.9	0.2

There are no changes in annual cycle of air temperatures for the two 30-years investigated periods: 1961-1990 and 1986-2015 (Fig. 2). The comparison between monthly values for the two 30-years periods shows higher temperatures for the second period (1986-2015).



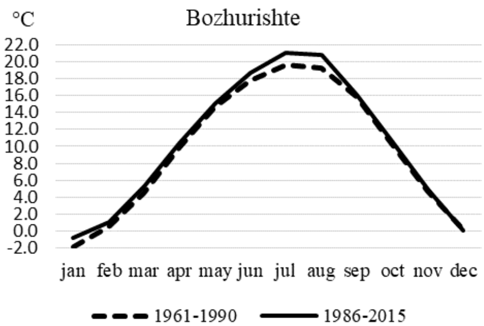


Fig. 2 Annual cycle of air temperature

The air temperature deviations are larger for the summer months and January. The greatest differences are observed in summer months for Sofia station – reaching 1.9°C in August. The difference in the average monthly air temperatures in the station of Bozhurishte is smaller. At that station for the three summer months the difference is in the range of 1.0°C - 1.5°C. The Bankya station has the smallest differences in air temperatures in summer compared to the other stations examined during the studied periods. The difference in the air temperatures for January is the most significant at station Bozhurishte, where it exceeds 1.0°C.

The distribution of the seasonal values of air temperatures corresponds with the global tendencies temperature increase. The warming during summer is most clearly determined. The summer air temperature for the period 1986-2015 is with 1.1 to 1.6 °C higher than in the period 1961-1990 (Table 2). For other seasons, the increase of the temperature is up to 0.6 °C.

Table 2 Seasonal air temperatures for the periods 1961-1990 and 1986-2015, and their differences, Δt °C

Station	**Sofia**			**Bankya**			**Bozhurishte**		
Season/Period	1961-1990	1986-2015	Δt	1961-1990	1986-2015	Δt	1961-1990	1986-2015	Δt
Winter	0.1	0.6	0.5	-0.2	-0.1	0.1	-0.3	0.1	0.4
Spring	9.9	10.5	0.6	9.3	9.6	0.3	9.7	10.2	0.5
Summer	19.1	20.7	1.6	18.3	19.4	1.1	18.9	20.2	1.3
Autumn	10.6	11.1	0.5	9.8	9.8	0.0	10.2	10.6	0.3

The average annual air temperature for the period 1986-2015 has increased in all the investigation stations with values between 0.8°C for Sofia and 0.4°C for Bankya in comparison to 1961-1990 (Fig. 3). The highest value of air temperature increase in the city can be associated to the development of the urbanization. The difference in the air temperature between 1961-2015 and 1961-1990 is from 0.2°C to 0.4°C.

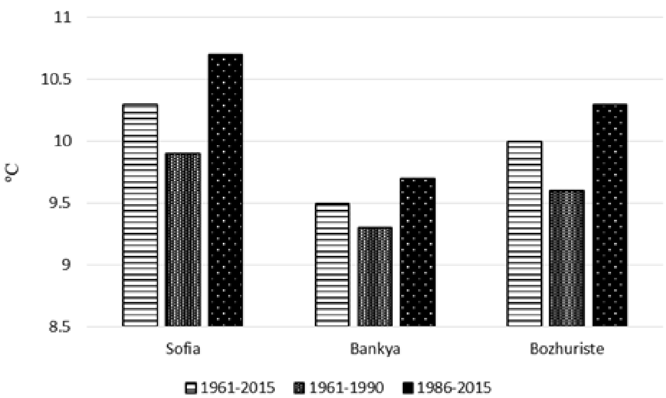


Fig. 3 The annual air temperature for different periods

3.2. The Urban Heat Island (UHI)

An indicator of the presence of an urban heat island is the differences in air temperatures in the city (Sofia) and the suburban territories (Bankya and Bozhurishte), which show a higher thermal level in the city. The differences in the average monthly air temperatures between Sofia and Bozhurishte over the whole studied period (1961-2015) vary from 0.2°C to 0.5°C, being the largest during the cold half of the year. In the last 30 years of the study period, apart from maintaining the differences in winter, there is also an increase in the differences in average monthly air temperatures in summer (July 0.5°C, August 0.6°C and September 0.5°C) (Table 3).

Table 3 Monthly air temperature differences between Sofia and Bozhurishte ($T_{Sofia} – T_{Bozhurishte}$, °C)

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1961-2015	0.4	0.5	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.5	0.5	0.4
1961-1990	0.5	0.3	0.4	0.3	0.1	0.2	0.3	0.2	0.2	0.5	0.5	0.5
1986-2015	0.4	0.6	0.3	0.4	0.3	0.3	0.5	0.6	0.5	0.5	0.6	0.5

The analysis of the differences in air temperatures between Sofia and Bankya (Table 4) shows a significant increase in the average monthly differences for the whole studied period, from 0.4°C in December and January to 1.4°C in September. For the years 1961-1990, the air temperature differences were the smallest (0.3°C) in December and January and the largest in September (1.1°C). In the last 30 years of the survey, the differences in all months have increased, starting from 0.5°C in December and January and reaching 1.8°C in August and September. The biggest differences between Sofia and Bankya are found in the summer months, while between Sofia and Bozhurishte the difference between the various months is very low. The increase of UHI intensity in summer in comparison to winter is pointed out by Martin et al. (2000), Georgescu et al. (2012). From other side Souch & Grimmond (2006) reported that during winter UHI is more pronounced. This shows that UHI is a unique phenomenon for each city, which is determined by local circumstances, i.e. topography, land use, atmospheric circulation, etc.

Table 4 Monthly air temperature differences between Sofia and Bankya ($T_{Sofia} – T_{Bankya}$, °C)

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1961-2015	0.4	0.7	0.7	0.8	0.7	0.8	1.0	1.3	1.4	1.2	0.7	0.4
1961-1990	0.3	0.5	0.6	0.6	0.5	0.6	0.8	1.0	1.1	1.0	0.4	0.3
1986-2015	0.5	1.0	0.9	1.0	0.9	1.0	1.3	1.8	1.8	1.4	0.9	0.5

The largest air temperature differences between Sofia city and suburban areas during summer time can be explain with different land cover in the investigated territories – predominance of the natural green areas in the suburbs and built up and paved areas in the city. The buildings and pavement heat up significantly during the day and radiate the heat throughout the day and night. In winter time, the snow cover and low values of solar radiation and temperatures minimize the effect of the urbanization.

The distribution of air temperature differences established between various measurements points in the frame of environmental monitoring from the Executive Environment Agency, Bulgaria confirms the higher air temperature in the city center (measurement point Orlov most) than in the districts (Pavlovo, Druzhba, Nadezhda). The increase of air temperature in the city center in comparison to the districts is pointed out by Vitanova & Kusaka (2018) and Dimitrova et al. (2019). The highest temperature difference was observed between Orlov most and Pavlovo (Fig. 4). Pavlovo is situated at the district close to Vitosha Mountain with a favorable topographic and meteorological conditions for atmospheric circulation.

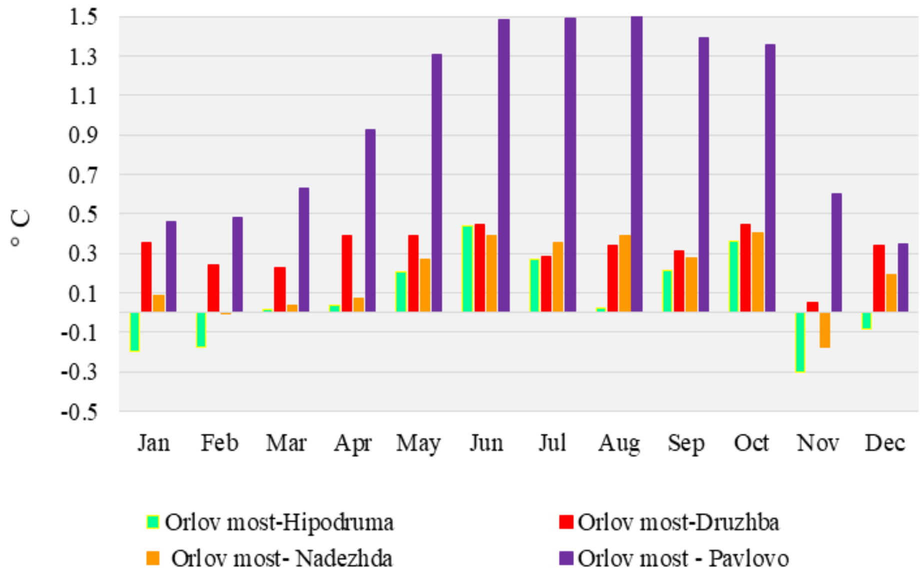


Fig. 4 The air temperature difference between the city center (Orlov most) and districts

The results show well determined annual cycle for air temperature differences between Orlov most and Pavlovo with a maximum in summer months (1.5°C). The higher degree of warming in summer in the city center compared to the suburbs is a characteristic feature of the urban climate.

The measurement points Druzhba and Nadezhda are located at the district which concentrated most part of the industrial sector in the city. The anthropogenic activity, buildings and topographic conditions cause the decrease of the temperature differences in Druzhba and Nadezhda in comparison to Pavlovo. The air temperature difference between city center (Orlov most) and measurement point Hipodruma are the lowest among the investigated areas. Despite the measurement point Hipodruma is located in the residential area, which is not affected by industrial processes, the air temperature differences compared to the city center are the lowest. This is related to the geographical position of the measurement point at the wide center. The negative values of the differences between Orlov most and Hipodruma in winter time can be explained by the location of Orlov most in the area with intensive transport. During winter the air pollutants from the transport in combination with the low altitude determine favorable conditions for temperature inversions which cause very low air temperatures in the city center.

4. CONCLUSIONS

The present study analyzes the variabilities of air temperature in the region of Sofia city for the period 1961-2015. The focus is on the temperature differences between the city and the suburban territories (Bankya and Bozhurishte stations), as well as the temperatures in the city center and residential areas. Based on the survey, the following conclusions can be drawn.

- The average monthly temperatures for the last thirty years of the investigated period (1986-2015) are higher than those for the period 1961-1990, with higher variations during the summer and minimal differences for the other months.
- The differences in average monthly air temperatures between Sofia and the suburban areas (Bankya and Bozhurishte) vary from 0.2 °C to 1.8 °C. The biggest differences are found in the summer. For the period 1986-2015, there is an increase in temperature differences between the city and the suburban areas, which is more pronounced during the warm part of the year.
- The monthly air temperature in the central part of the city is higher than one in the residential areas. The difference increase with the distance from the centre.
- The distribution of air temperature in various parts of the city as well as in suburban areas is influenced by natural factors (topography, synoptic situations and conditions for temperature inversions) and anthropogenic activity and urbanization.

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