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Research paper



Urban "Heat-Island Effect" and its Connection with Architectural and Climatic Features on the Example of Poltava

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Abstract

The concept of "heat-island effect", its structure and features of formation over the city are given. The climatic and other features of the city that influence the formation of this phenomenon are mentioned. The data on functioning in the city of the municipal production enterprise of the heat economy is indicated. The traditional method for determining the formation of the urban "heat-island effect" is described. The data and comparative graphs on the temperature regimes of the city and region are presented. The possibility of influencing architectural features of the city on the formation of the "heat-island-effect" is determined. According to the obtained results, further integrated researches are proposed for obtaining reliable results of the given question.

Keywords: *air temperature, city architecture, climate, heat-island effect, meteorological stations.*

1. Introduction

"Heat-island effect" is a zone of elevated temperatures over cities and industrial areas resulting from the increased release of heat energy. As a rule, it is observed in large cities, where the temperature of air throughout the year is higher in several degrees than in the surrounding territories. Urban "heat-island effect" is the area in the internal part of the big city, characterized by elevated air temperatures compared to the countryside. The center of the urban "heat-island effect" is usually shifted from the city center to the other side, where the prevailing winds are directed [1].

According to the United Nations, until 2050, the proportion of people living in urban areas will grow and reaches approximately 70% of the world's population (54% already in 2014). This growth will be caused by several reasons:

- ✓ migration from countryside to urban areas due to growing opportunities in urban areas;
- ✓ an increase in the number of cities with improved infrastructure in developing countries;
- ✓ the development of a number of countryside areas to urban areas.

The big city affects all components of the natural environment: atmosphere, vegetation, soil, relief, hydrographic network, the regime and chemical composition of groundwater, soils and even climate. Differences in temperature, relative humidity, and solar radiation between cities and their countryside are sometimes commensurate with movement in natural conditions at latitude 20. Moreover, the change of some natural factors, as a rule, has an effect on others. As a result, the heat, electrical, magnetic and other physical fields of the Earth are changed in 83 cities. Naturally, the impact on the environment is greater, the larger the city [2].

Modern big cities are not only exposed to weather conditions, but they themselves exert a great influence on them, as well as on the ecological situation. Here are some of the features of the big cities:

- ✓ Aerosol Hat
- ✓ Heat-island effect
- ✓ "Motley" albedo
- ✓ Features of visibility range
- ✓ Wind conditions
- ✓ Features of the cloud cover
- ✓ Features of precipitation
- ✓ Radiation conditions
- ✓ Flow characteristics
- ✓ Features of evaporation.

One of the most significant features of the urban climate is the emergence of the so-called "heat-island effect" in the city, which is characterized by higher air temperatures than in the countryside (Fig. 1). This phenomenon occurs simultaneously as a result of several reasons.

Firstly, the albedo of the underlying surface in cities is reduced due to the appearance on it of buildings, structures, artificial coverings. Reduction of the albedo as a result of the development of the areas leads to a more intensive absorption of solar radiation in comparison with unoccupied areas and accumulation of the heat absorbed by the day in the construction of buildings and structures, and its release into the atmosphere in the evening and night hours. In addition, in urbanized areas, the heat consumption for evaporation is sharply reduced by reducing areas with open soil cover and occupied by green plantations, and the rapid removal of atmospheric precipitation by rainwater systems does not allow the creation of a reserve of moisture in soils and surface

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water bodies. Urban development also leads to the formation of zones of air stagnation, at low wind speeds, prevents turbulent mixing of the surface layer of the atmosphere and the transfer of heat to its overlying layers. Consequently, the heat transfers of the building due to the deterioration of the conditions of turbulent mixing in the surface layer decreases in comparison with the undeveloped territories, the heat builds up inside the building, causing it to overheat.

Secondly, the formation of the "heat-island effect" in the city's area is facilitated by a change in the transparency of the atmosphere. Coming into the atmosphere, various impurities from enterprises and transport lead to a significant decrease in the total solar radiation. But, to an even greater degree, they reduce the counter infrared radiation of the earth's surface, which, combined with the heat transfer of buildings and industrial objects, leads to the appearance of a local "greenhouse effect" and the development of temperature anomalies in the city's area; the city is "covered with a blanket" of greenhouse gases and aerosol particles.

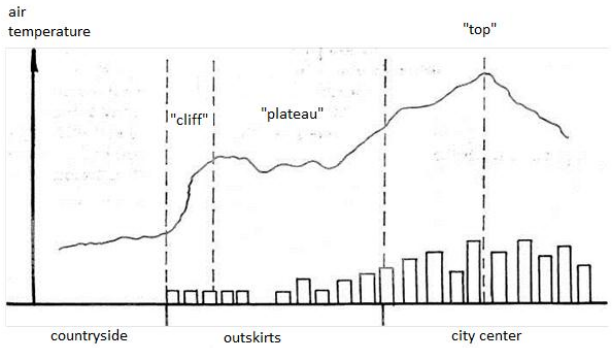


Fig. 1: Section of the "heat-island effect" over the city

Most strikingly, the contrast of the city-countryside temperature manifests itself in clear, windless weather and disappears in windy, cloudy weather. In the evening and the first hours after sunset, due to the peculiarities of the formation of the "heat-island effect", the temperature contrast is sharper than at noon, and in the summer it appears better than in winter with similar synoptic situations.

The average air temperature in a big city is usually higher than the temperature of the surrounding areas on 1 - 2 °C, but at night with a small wind, the temperature difference can reach 6 - 8 °C. Over the centers of big cities, the "heat-island effect" rises by 100 - 150 m, and in smaller cities by 30 - 40 m. The patterns of air temperature change during the transition from the countryside to the central part of the city are shown in Fig.1. A significant horizontal temperature gradient appears at the "city-countryside" boundary, corresponding to "heat-island cliffs", sometimes reaching 4 °C/km. Most of the city represents a "plateau" of warm air with a rise in temperature towards the city center. The heat homogeneity of the "plateau" is disturbed by "discontinuities" of the general nature of the surface in the form of cold areas - parks, water bodies, meadows and heat regions - industrial enterprises, dense buildings.

Over the central part of big cities is the "top of the heat-island effect", where the air temperature is maximum. There may be several such "tops" in large agglomerations due to the presence of industrial enterprises.

The formation of the "heat-island effect" in the built-up areas has a number of direct or indirect environmental and bioclimatic effects and consequences, both positive and negative. Here are some examples. The direct negative bioclimatic effect of the "heat-island effect" is a decrease in the comfort of the conditions of the population's staying in the city during the summer as a result of an increase in air temperature combined with a decrease in wind speed. In the cold season, the bioclimatic effect is positive. Due to the same factors, and also due to the increase in absolute minimum temperature, the discomfort of the conditions of the population's staying in open spaces decreases.

Environmental consequences of "heat-island effect":

- "the displacement of the city" by its climatic characteristics in the southern direction: the frost-free and snowless periods in the city are increasing, the earlier onset of the growing season,
- increase in the number of days with thaws. In the cold half-year, the transition of air temperature through 0 °C creates problems not only for economic, road maintenance services of the city, but also for the state of the components of its natural environment, primarily green vegetation [3].

2. Physiographic and Climatic Characteristics of Poltava

Poltava is the center of the eponymous region. Coordinates of centroid: 49° 00` 36`` N; 34° 00` 33`` W. The city area is about 105 km^2.

The picturesque city is located in the eastern part of Poltava Region on both banks of the Vorskla River and is one of the largest industrial and cultural centers of the Left Bank of the Dnieper. Poltava lies within the great East European plain, on the plain Poltava plateau and its steep slope.

The geographical location of Poltava within the temperate climatic zone determines its features of temperate continental climate type: the average temperature of July air (+ 20.5 °C); average January temperature (-7.0 °C); annual rainfall is 525 mm; coefficient of humidification of 0.7; the duration of the frostless period is 174 days. The distribution of winds in cold and warm periods of the year is shown in Table 1.

Table 1: Repeatability (%) and speed (m/s) of winds in Poltava

Month of the year	Repeatability of winds, % / Speed of winds, m/s								
	N	NE	E	SE	S	SW	W	NW	Calm
January	9,0 3,1	10,0 2,9	11,9 3,5	8,7 2,8	14,7 3,2	14,9 3,4	20,2 3,6	10,6 3,6	2,5
July	19,5 2,4	12,3 2,3	11,0 2,2	5,3 2,0	7,5 2,1	8,3 2,5	20,4 2,7	15,7 2,5	7,4

In the western outskirts of the city are dominated by dark gray forest soils and black earth and in the east - turf, and meadow. Green plantations occupy more than 1/5 of the city's area. The city has 32 objects of the nature reserve fund.

Natural resource potential, convenient economic and geographical location of Poltava determined the specialization of its enterprises in the fuel, machine-building, food, light industry. The city gives 1/4 of industrial production of all region.

There are two railway stations in the city - "Kyivskyi" and "Pivdennyi". Bus connections are provided by the bus terminal (inner regional and interregional passages) and two bus stations (suburban routes).

Poltava belongs to cities with a population density of more than 3000 people/sq.km. Its population is 291,963 people in 2017. About 87% of the city's population is Ukrainians. 44.0% of the able-bodied population is employed in industry, more than 16.0% is in the service sector, 6.0% in science, culture and education.

3. Heat Supply of the City

Poltava Regional Utility Production Enterprise "Poltavateploenergo" is the largest enterprise in the region by its capacity and number of service consumers, which provides a complete cycle of heat supply (the continuity of the production process, transmission, and distribution of heat energy) in Poltava and 4 district centers of the region.

The enterprise is based on the property of the joint (communal) ownership of territorial communities of villages, settlements and cities of the Poltava region and transferred to the operational management of the Department of Housing and Communal Services of the Poltava Regional State Administration. The enterprise is accountable and controlled by the Poltava Regional Council.

Today, the company carries out licensed economic activity for the production, transportation and supply of heat energy and is the provider of services for centralized heating and hot water supply, providing more than 200 thousand inhabitants of the city with a central heating service, almost 150 thousand of which receive a centralized service supply of hot water. The total number of consumers of the enterprise is from among budget institutions, other consumers and religious organizations are 1,445.

The company operates heating networks and hot water supply networks with a total length of 210.7 km (in a 2-pipe dimension) for the heat energy transportation.

On the balance sheet of the regional production enterprise "Poltavateploenergo" there are 92 boiler-houses and heat generators, with a capacity of 881.9 Gcal/h, located in the cities of Poltava, Karlivka, settlements Mashivka, Reshetilivka, Kotelva. 90 boiler-houses and heat generators operate on natural gas, and another 2 boiler-houses - on solid fuels (rivets and wood pickles). The location of the overwhelming majority of the objects of the enterprise is a zone of dense housing development of cities and settlements. For a year, the company produces from 0.885 to 1.0 million Gcal of heat energy. At the same time, the average annual consumption of natural gas over the past four years is almost 130 million m^3. 119.6 million m3 of blue fuel is consumed in 2014 [4].

4. Traditional Research Methods of "Heat-Island Effect"

The traditional method for discovering the urban "heat-island effect" is based on comparing the measurements inside the city and in the nearest countryside. The intensity of the "heat-island effect" is estimated from the difference between the air temperature at a meteorological station in the city and the air temperature at a meteorological station located outside the city. A positive sign of the difference, as a rule, is interpreted as a manifestation of the urban "heat-island effect".

However, such an approach can hardly be considered justified. The urban "heat-island effect" is a consequence of the process of the territory urbanization and is considered as one of the most visible examples of mesoscale climate change as a result of human activities.

There is a problem of isolating from the set of factors that determine the spatial changes in air temperature, the impact of the urban environment. Its solution is a difficult but necessary task. Otherwise, the scale of anthropogenic impact on the heat regime of the surface air layer in the city will be distorted, and another phenomenon will be issued for the anthropogenic "heat-island effect" [5].

The main feature of the urban "heat-island effect" [6] is its intensity ΔT_L, defined as the difference between the maximum (or minimum in the case of the "cold-island effect") values of the air temperature in the city T_U and the average air temperature outside the city $\overline{T_L}$:

$$\Delta T_L = T_U - \overline{T_L} \quad (1)$$

The urban "heat-island effect" is manifested in the form of closed areas of isotherms over the city. Over big cities, the "heat-island effect", with some approximation, is homogeneous across the horizon. This allows to identify the so-called "plateau" covering most of the city, the value of which is approximately equal to the average temperature over the city, as well as its "top" in the center (the area of extreme temperature values) and "cliffs" along the edges (areas of elevated horizontal gradients temperature at the borders of the city) [8].

The characteristic of the "plateau" of the urban "heat-island effect" $\overline{T_L}$ is the difference in the average values of the air temperature in the city $\overline{T_U}$ and outside the city $\overline{T_L}$:

$$\Delta \overline{T}_L = \overline{T}_U - \overline{T_L} \quad (2)$$

In some sources, for example [3], possible climate differences in big cities were compared to the surrounding countryside in the middle latitudes:

- General radiation - 15 - 20% lower;
- Ultraviolet radiation in winter - 30% lower;
- Ultraviolet radiation in summer - 5% lower;
- The duration of sunshine - 5-15% lower;
- The average annual temperature - 0.5 - 1.0 ºC higher,
  the average winter temperature - 1 -2 ºC higher;
- The duration of the heating season - 10% less;
- Impurities:
  condensation nucleus and particle in 10 times more,
  gas impurities in 5 - 25 times more;
- Average wind speed - 20 - 30% lower,
  storm - 10 - 20% lower,
  calm - 5 - 20% more;
- Total precipitation - 5 - 10% more,
  in the form of snow - 5% less;
- Number of days with precipitation less than 5 mm - 10% more;
- The number of clouds - 5-10% higher;
- Repeatability of fogs in winter - 100% more,
  in summer - 30% more;
- Relative humidity in summer - 8% less,
  sometimes - 11 - 20% less;
- Thunderstorms (frequency) in 1,5 - 2 times less.

5. Meteorological Stations of Poltava and Region: Research Data

Meteorological conditions are one of the most important factors for assessing climate change. Observation of the temperature regime and precipitation in the region is carried out by the meteorological stations (MS) of the Poltava Regional Center for Hydrometeorology, which are located in small cities as Gadiach, Lubny, Kobeliaky, and countryside lake Veselyi Podil, and big city Poltava (Fig. 2).



Fig. 2: The location of the meteorological stations of the Poltava Regional Center for Hydrometeorology

A brief meteorological survey (data from the Poltava Regional Center for Hydrometeorology for 2015) was as follows [7]:

MS Gadiach.

The average annual air temperature was + 9.5 °C, which was + 0.5 °C higher than last year and + 2.5 °C higher than normal. The coldest was the second decade of February with a temperature of (- 6.3) °C, the minimum in the air in the first decade of January declined to (- 20.7) °C. The warmest was the third decade of July with an average decade temperature of + 22.7 °C, in the first decade of September the maximum in the air was + 35.4 °C.

Annual precipitation was 585 mm, which is 92% norm, for the warm period it amounted to 296 mm, for the cold period 289 mm.

MS Lubny.

Average annual air temperature, according to the data of MS Lubny, amounted to 9.8 °C, which is + 0.5 °C higher than last year and + 2.4 °C above the norm. The warmest was the third decade of July, in the average decade the air temperature was + 22.6 °C, the maximum air temperature in the first decade of September rose to + 35 °C. The coldest was the first decade of January with an average decade temperature of (- 5.7) °C, the minimum temperature in the first decade of January declined to (- 19.6) °C.

The annual amount of precipitation was 543 mm, which is 87% of the norm. During the warm period fell 273 mm, during the cold period 270 mm of precipitation.

MS Veselyi Podil.

The average annual air temperature was + 9.9 °C, which is + 0.5 °C higher than last year and + 2.2 °C higher than normal. The coldest was the second decade of February with an average decade temperature of (- 6.2) °C, the minimum temperature in the first decade of January decreased to (- 21.8) °C. The warmest was the third decade of July with a temperature of + 23.1 °C, the maximum air temperature in the second decade of August increased to +34.7 °C.

The annual amount of precipitation was 491 mm, which is 96% of the norm by the data from MS. During the warm season, its sum was 271 mm, while the cold - 220 mm of precipitation.

MS Kobeliaky.

The average annual air temperature was + 10.2 °C, which is + 0.4 °C higher than last year and + 2.1 °C of norm. The coldest was the first decade of January with a temperature of (- 7.0) °C, the minimum temperature in the first decade of January decreased to (- 23.7) °C. The warmest was the third decade of July with a temperature of + 23.4 °C. The maximum in the air was noted in the second decade of August +35.7 °C.

The annual amount of precipitation for MS Kobeliaky was 518 mm, which is 99% of the norm. During the warm period (IV-X) the amount of precipitation was 275 mm, during the cold period - 243 mm of precipitation.

MS Poltava.

Average annual air temperature according to the data of the MS Poltava was + 9.8 °C, which is + 0.6 °C higher than last year and + 2.2 °C above the norm. The coldest was the first decade of January with an average decade temperature of (- 6.7) °C, in the first decade of January there was a decrease in the minimum air temperature to (- 21.9) °C. The warmest was the first decade of August with an average decade temperature of + 23.0 °C, the maximum air temperature was noted in the second decade of August and was +35.8 °C.

Annual precipitation was 542 mm, which is 95% of the norm. During the cold period, 263 mm of precipitation was falling, during the warm period - 279 mm of precipitation.

In 2015, the average annual air temperature in the Poltava region was + 9.8 °C. Compared to the norm of 1961-1990, the last year's average annual air temperature was higher by + 2.2 °C, and compared with average air temperatures for the period 1981-2010 by + 1.6 °C.

According to the above data, it is possible to construct a schedule for comparing the temperatures of the city and countryside (Fig. 3).

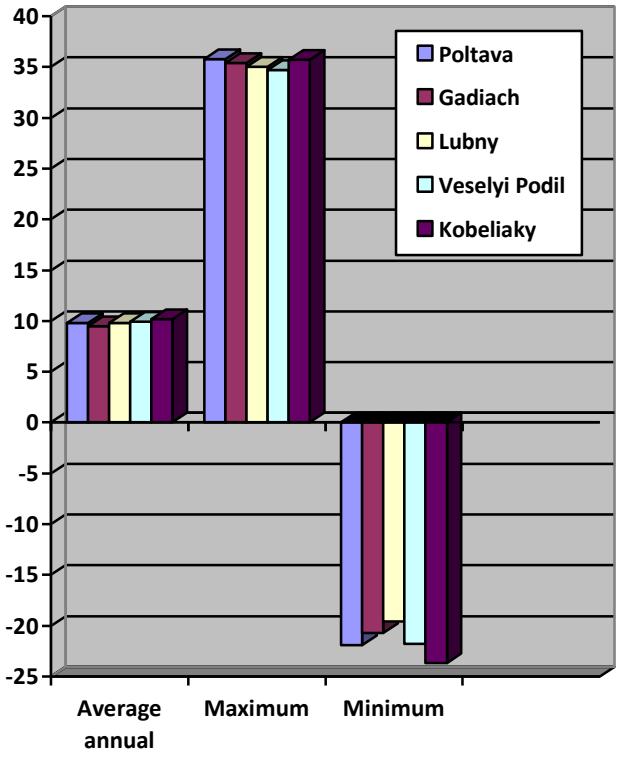


Fig. 3: Schedule for comparing the temperatures of the Poltava and surrounding cities and countryside

It is clear from the chart that in comparison with smallest cities in the region Poltava has higher rates both temperature: average annual and maximum. However, Kobeliaky has higher rates, which may be due to the location of the city in the northern part of the region. This situation requires further detailed studies.

6. The Architectural Part of yhe City

The above situation is possible due to the impact on the climatic features of the type of architectural and urban landscape, which depends on the planning and urban planning organization of the city [8]. Thus, the Poltava refers to the "city-plain", characterized by a homogeneous height building.

High-rise buildings, in this case, are the nature of accent objects, their inclusion in the urban structure is homogeneous. This type of building is common in modern and late medieval cities, which are located on a relatively calm relief and have significant areas of historically developed buildings or valuable natural landscapes that are protected at the legislative level. These cities include most of the capitals of European countries: Paris, St. Petersburg, and others.

There are also such types as "city-bowl" and "city-hill".

"City-bowl" is characterized by an increase in the height of buildings from the central to the outskirt's part of the city. This type of building is typical for modern cities, located on a relatively calm relief, and has developed around low-rise, historically-formed development of the central part of the city. In this case, high-rise buildings are located outside the city's central area. These cities include Dushanbe, Jerusalem, and others.

"City-hill" is characterized by the placement of high-rise objects in the central part of the city and a gradual decrease in the height of buildings to the outskirt's part. This type of building is typical for modern big cities of post-industrial countries, in which there is no historical part: the USA, Canada, New Zealand, etc.

7. Conclusion

The obtained result, of course, cannot be regarded as a denial of the possibility of the "heat-island effect" existence in Poltava. One can confidently say only about the insignificant influence of the city on the heat regime in its surroundings. This may be due to the local features of the city (a small repetition of the combination of conducive weather conditions that contribute to the appearance of the "heat-island effect"), and its general weak intensity. However, the method used in the work does not answer the question of the absence of "heat-island effect" in other areas of the region. For this reason, one cannot speak of the urban nature of the detected results of the city temperature. The question of the existence of the "heat-island effect" in other areas of the Poltava region should be considered open until a large-scale complex of microclimatic measurements in the city and in landscape-like background areas will be conducted.

References

[1] Yasin Toparlar, Bert Bloken, Adelya Khayrullina, "The phenomenon of urban heat-island effect", *Sustainable building technologies*, (2015), pp:72-79

[2] A.O. Panskiy, G.I. Mazurov, "Analysis of heat-island effect over some cities of the Russian Federation", *Journal* "Meteorologicheskiy vestnik", V.3, (2010), pp: 80-122.

[3] Litvinkova I.A. *"Microclimate of the urban environment. Formation of "heat-island effect""*, YO "BGY P.M.Masherova», (2005), available online: http://ekolog.org/books/42/3_2.htm

[4] Golik Yu.S., Kalinichenko V.M., Volik V.P., Shyianov M.Ye., Maksiuta N.S., "*The Plan of sustainable energy development of the city of Poltava by 2020, approved by the decision of the ninth session of the Poltava City Council of the seventh convocation of January 31, 2017"*, pp: 18–27

[5] Stewart I.D., "A systematic review and scientific critique of methodology in modern urban heat island literature", *International journal of climatology*, Vol.32, No.2, (2011), pp: 200-217, https://doi.org/10.1002/joc.2141

[6] I.L. Marinin, O.R. Dranicher, "Some estimates of the characteristics of the heat-island effect in Odessa", *Ukrainian Hydrometeorological Journal*, No.12, (2013), pp: 54-61.

[7] "*Regional report on the state of the environment in the Poltava region in 2015*", Poltava Regional State Administration, Department of Ecology and Natural Resources, (2016), available online:
http://old.menr.gov.ua/index.php/dopovidi/regionalni

[8] Klyuzko V.M., "Town-planning tasks of placing high-rise multifunctional buildings, connected with improvement of wind regime of territories", *Urban planning and territorial planning*, Vol.55, (2015), pp: 188-193, available online: http://nbuv.gov.ua/UJRN/MTP_2015_55_27