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Influence of the Urban Heat Island Effect of a Large City on the Physiological Stability of Tree Plantations

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ABSTRACT

Lviv (Ukraine), a city of about 1 million inhabitants, is classified as a Western Forest-Steppe according to the forestry zonation. The mesoclimatic anomaly in the western forest-steppe with its humid mild climate is composed of the sum of microclimates formed by the thermal regime. As in every large city, Lviv has historically developed a distinctive microclimate influenced by many natural and anthropogenic factors, including global climate change, urban development, population growth, landscape fires, etc. This contributes to the development of a heat island effect, which is characterised primarily by an increase in air temperature and a decrease in air humidity and is a negative factor for the development of vegetation in the city's green zone. It was necessary to investigate the territory of the "dry island" – the lower tier of the "heat island" – to determine the level of vitality of the main woody plants located within these boundaries. As it could be observed, the "dry island" is located in the dense development of the central part of the city, where the temperature of the dead underlying surface (stone, asphalt, concrete) was in the range of 57–62 °C, the air temperature was 28.5–29.1 °C, and the humidity was 50.2–51.2%. Drought conditions affect the growth, development and reproductive capacity of woody plants. It has been established that the heat island should be reduced by urban greening in the horizontal and vertical ranges, and to maintain the physiological stability of tree plantations in the hot season, it is necessary to develop recommendations for the care of vegetation in the green zone of the city, depending on microclimatic indicators, especially air and soil temperatures, air and soil humidity.

Keywords: heat island effect, microclimate, physiological state, trees, environmental safety.

INTRODUCTION

In large cities, the characteristic configuration of the internal buildings contributes to the development of one or more "heat islands". Building materials such as stone, brick, asphalt, concrete, roofing iron, and compacted soil absorb and release solar heat, while high-rise buildings restrain air flows. It is known that the nature of the urban climate is most pronounced in stable anticyclonic weather patterns. During this period, the difference in temperature between urban and rural areas is most clearly defined. The temperature field is revealed in isolines, which outline the boundaries of the "heat island". In recent years, more scientific papers focusing on the primary causes of heat islands and highlighting geophysical factors such as reflected and accumulated solar radiation, albedo and heat capacity studies have been published. It turns out that, both in the historical past and today, hardly anyone tries to delve into these urban root causes in order to provide a rational answer to the question: "what should be done?". Historical analysis of the genesis of the dynamics of anthropogenic changes in the natural underlying surface of large cities and the associated thermal changes makes it possible to identify errors in the morphological structure of urban development and to some extent to minimise the impact of negative thermal phenomena. This approach will help to provide optimal solutions in the general urban planning. It is no coincidence that more and more scientific articles on the problems of green urban infrastructure have recently appeared.

Khan et al. (2022) found that an increase in green infrastructure (GI) significantly reduces the height of the planetary boundary layer (PBL), thus increasing the risk of higher pollution concentrations, while there is a significant impact on sea breeze strength and humidity levels, which increases the risk of thermal discomfort. These results are compared with those of thirty similar projects from other cities to provide a global assessment of the mitigation potential of additional GI in cities. These results contribute significantly to the understanding of the mitigation potential and impacts on urban climate of increasing GI on a seasonal scale.

Paper of Farrell et al. (2022) presents a new framework for plant selection for green infrastructure and uses a case study to demonstrate the approach used to select trees and shrubs for Australian cities. It is shown how plant properties and natural distribution of species can be used to overcome the lack of information on tolerance to both single and multiple stressors; rainwater retention, cooling, biodiversity and air pollution mitigation.

Based on the analysis of eco-hydrological effects caused by urbanisation, a water-soil-plant continuum (WSPC) system for rainfall runoff based on the sponge city concept was proposed (Jiang et al., 2022). The current technical problems of parameter optimisation, continuous operation, and modelling of connections for bioretention facilities are identified and recommendations for overcoming them are given. This new concept indicates the source, form and types of non-point source pollutants (NSPs). In particular, heavy metals, persistent organic pollutants (POPs) and microplastics in wastewater and their risks to bioretention soil media (BSM).

The results of Meili et al. (2021) show that increasing urban vegetation cover can reduce the Universal Thermoclimatic Index (UTCI) in the tropical city of Singapore by less than 3 °C (long-term average) during the midday, all weather conditions considered. Further reductions are hampered by high humidity levels. This increase in humidity not only reduces thermal comfort, but can potentially lead to higher energy consumption for air conditioning and should be carefully analysed in future studies to fully appreciate the benefits of urban vegetation in hot, humid climates.

Moser-Reischl et al. (2019) identified distinct species-specific patterns that highlight the greater drought tolerance and recovery of *R. pseudoacacia* compared to *T. cordata*. These results show that in drier and warmer climates, *T. cordata* can provide more air cooling in a short period of time due to its high transpiration, although this comes at the expense of a high water requirement and subsequent reduced growth in water scarce conditions. On the contrary, *R. pseudoacacia* has proven to be a more suitable and adapted species in areas with less water availability due to its better water use efficiency, even at the cost of low canopy transpiration, despite higher soil moisture and latent heat transfer from the soil.

In Zhang et al. (2021), 1688 large cities around the world were studied and it was shown that 70% (1181) show an increase in vegetation derived from remote sensing (2000–2018). For 68% (1.138) of the studied cities, urban vegetation growth is less strong compared to the vegetation growth found in the surrounding areas of these cities. In general, positive vegetation trends are widely observed in cities in Europe and North America, while negative urban vegetation trends are predominantly observed in Africa, South America and Asia.

Expanding urban areas are continuously replacing vegetation cover (VC), which accelerates carbon emissions (CE), increases land surface temperature (LST) and contributes to global warming. This study aimed to assess the CE dynamics in Penang, Malaysia, as a result of land use and land cover (LULC) changes during 1996–2021, and to determine the impact of CE dynamics on LST changes and urban heat island (UHI) effects. In this regard, remote sensing and geospatial methods were applied to monitor changes in LULC and biomass carbon stock assessment methods were used to quantify carbon storage. The results of the study illustrate a 17% decline in forest cover and an excessive increase in urban areas (22%), mean LST (8 °C) and UHI (38%) over the past 25 years. Carbon stock (CS) concentrations show a 24% decline in high CS zones with more than a 1% annual drop from 1996 to 2021. In addition, due to the significant loss of VC, carbon attracts sunlight, which has led to a decrease in CS in built-up and non-built-up areas (Rahaman et al., 2022). It was found by Kabano et al. (2021) that the length of the growing season increased along the urban-rural gradient ($p < 0.001$) and was the longest in the least built-up LCZ class ($p < 0.001$). The length of the growing season decreased significantly with increasing ground surface temperature ($p < 0.001$). These findings contrast with those for temperate cities, where higher temperatures are often associated with longer growing seasons. Our findings suggest that the elevated surface temperature associated with the urban heat island (UHI) is a limiting factor in the length of the season in the urban tropics.

It has been found by Marando et al. (2022) that urban green infrastructure (UGI) cools European cities by an average of 1.07 °C and up to 2.9 °C, but at least 16% tree cover is required to achieve a 1 °C reduction in urban temperatures. The microclimate regulation by the ecosystem service (ES) mainly depends on the amount of vegetation within the city and on transpiration and evaporation of the canopy. In addition, in almost 40% of countries, more than half of the resident population does not benefit from the microclimate regulation service provided by urban vegetation. The widespread implementation of UGI, particularly in arid regions and cities with insufficient forest cover, is key to ensuring healthy living conditions for citizens in cities.

In Maroni et al. (2021), Landsat satellite images and unpublished data provided by NASA were used, interpolated and classified in QGIS software using bands 4, 5 and 10 converted to grey level (NC). This procedure allowed us to obtain the spectral brightness of the reflectance temperature. The land surface temperature (LST) and normalised difference vegetation index (NDVI) were used, corrected for emissivity and spectral error, to determine the surface temperature of different areas in Villa Rodriguez. The results showed a total variation of 3.86 °C among the sample points, which is increased by the difference in the significance of the heat balance in urban open-air areas with buildings. Green areas and parks with abundant vegetation and the use of new building materials in future construction will help improve the urban climate, and such regulation of local temperature on a global scale is an effective step towards eliminating the negative impacts of climate change.

In ancient cities, like Lviv (Ukraine), with their radial-ring layout, a heat island is usually formed in the historic centre, the most anthropogenised part of the city. In the presence of developed green areas in the inter-ring and inter-radial spaces, the phenomenon of overheating of the underlying surface and the formation of a heat island is rarely observed.

Fires in natural ecosystems have a significant impact on the microclimate of Lviv and its ecological state. In particular, 2 km north of the city limits, there is a peat bog that burns annually in the spring and summer, emitting a significant amount of combustion products into the environment. The burning of the Lviv landfill also has a significant impact on the city's environmental condition, with a huge fire in 2016 that was extinguished even by firefighting aircraft. The fire killed three firefighters and left one person missing. The combustion products of both solid waste and peat bogs are accompanied by significant pollution of urban air with incomplete decay products, heavy metals, and smoke particles. Heavy metals cause serious health consequences, especially the risk of cardiovascular and cancer (Bosak et al., 2020; Nersesyan et al., 2021; Serhiyenko et al., 2022a). Inhalation of combustion products can trigger the emergence of dangerous diseases and exacerbate existing chronic diseases in people of all ages. These phenomena are accompanied by post-traumatic stress disorders and diabetes mellitus (Kobylkin et al., 2020; Popovych et al., 2024; Serhiyenko et al., 2021; Serhiyenko et al., 2022b).

MATERIALS AND METHODS

The aim of the study is to establish the process of heat island formation in a large city and its impact on the physiological development of vegetation. The object of study is the physiological state of vegetation formed as a result of microclimatic changes. The subject of the study is the impact of high temperatures on the development of tree species.

The research programme was designed to determine how the natural underlying surface of the Lviv Basin has changed in the process of urban transformation and how these changes affected its albedo and heat capacity and the formation of a "heat island". At the same time, we studied the urban impacts on the vitality of the city centre's green infrastructure: morphological and physiological changes and adaptations, and suggested ways to neutralise the heat island. The research area is about 100 hectares, including the "city within the walls" (50 hectares) and the southern built-up part of the basin. The dimensions of all the main elements of the existing underlying surface were calculated according to their projections: buildings (roofs), streets, sidewalks, squares, green spaces (plantings of trees and shrubs, lawns, flower beds).

To study the internal and external boundaries of the "heat island", a typical weather type for the city of Lviv (49°50′33″N and 24°01′56″E) with its rather high humidity level was selected. The Marton Aridity Index for Lviv is -38.3 (Kyiv – 32.6, Warsaw – 28.6). For July, this index is 28.1 (Kyiv – 22.6, Warsaw – 24.4). The surface of the city receives 163.3 kcal/cm^2 of total radiation annually, which in the summer months is: June – 23.0, July – 22.5, August – 18.8. However, the actual value associated with weather conditions is as follows: June – 13.4, July – 16.6, August – 12.2 and is due to the level of cloud cover. July has the highest number of sunny, cloudless days. Thermophysical changes at these stages were determined by the value of the albedo index (%) and specific heat capacity (kJ/(kg-K)). The points selected for the microclimatic surveys were located on the east-west transect, which ran in the middle of the probable "heat island" and the transverse north-south transect. The northern boundary is located between the walls of the former "city within the walls" and the "'On the ramparts' park" (1.9 ha), and the southern boundary is between Yu. Slovatskoho Street and Ivan Franko Park (10.5 ha). Data were collected at the time of the highest solstice within two hours (14:00–16:00). Two Kestrel-4000 portable weather stations were used to collect meteorological data, measuring air temperature and humidity, wind speed, and light level. The temperature of the dead underlying surface was measured with a pyrometer, and the soil with soil thermometers. Soil density (kg/cm^2) was measured with a specially designed density meter (MPK G 01 N 9/36). The meteorological survey data formed the basis for the construction of isolines and graphical models of the heat island. Biometric measurements of trees, representatives of families, genera, and species were carried out. Specimens that have been under constant urban impact for 100 years or more were selected. The height of the trees was measured with an altimeter-eclimeter RM-5 (Suunto), and the diameter was measured with a Topex measuring tape. The morphological and physiological state of trees growing in xerophilic conditions of the "heat island" - in the IV ecological and phytocoenotic zone ("EPZ") (street and square plantings), optimal in the II EPZ (park plantings) and I EPZ and in forest plantations - was compared.

According to the forestry zoning, the city of Lviv belongs to the Western Forest-Steppe. The mesoclimatic anomaly in the Western Forest-Steppe with its humid mild climate consists of the sum of microclimates formed by the thermal regime. The microclimatic studies were conducted at nine points located on the north-south and west-east transects that intersect in the centre of the city, representing its territory (Fig. 1).

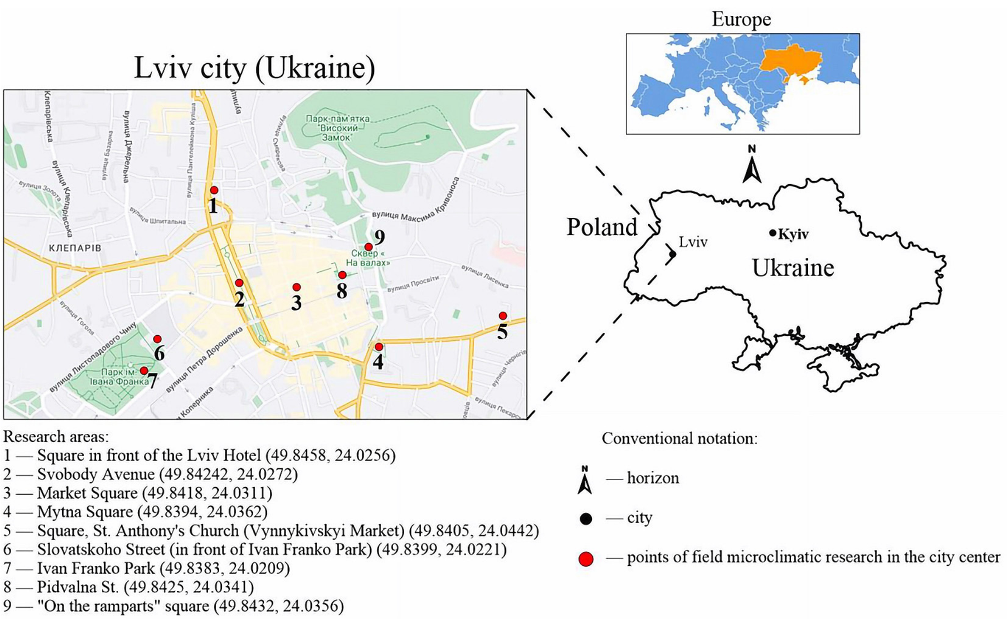

Figure 1. The scheme of the studied microclimate areas within the dry island of a large city (Lviv, Ukraine)

RESULTS AND DISCUSSION

Microclimatic features of the city centre's "heat island"

Microclimatic investigations made it possible to identify overheating of the horizons and soil surface characteristic of the "heat island", which leads to alkalisation of bulk soils, the level of which in most cases reaches pH = 7. Understanding the current thermophysical state of a densely built-up pit comes through comparing the albedo and heat capacity of the surface. The albedo level of the vegetation cover was 30–40% and became the main factor of cooling and humidification of the city environment. The albedo of the water surface (7.1%) accounted for about 3% of the total area, which to some extent affected the microclimate of the area. As is well known, a characteristic property of water is its accumulation of heat (heat capacity C = 4.18 kJ/(kg×K)) and at the same time cooling of air (Fig. 2).

The mesoclimate of the city centre is becoming warmer and drier, but its impact on the climate of the surrounding area was insignificant. The specific gravity of each element of the underlying surface – natural and artificial – was taken into account while determining the thermal characteristics, i.e. albedo and heat capacity of the study area (100 ha) (Fig. 3).

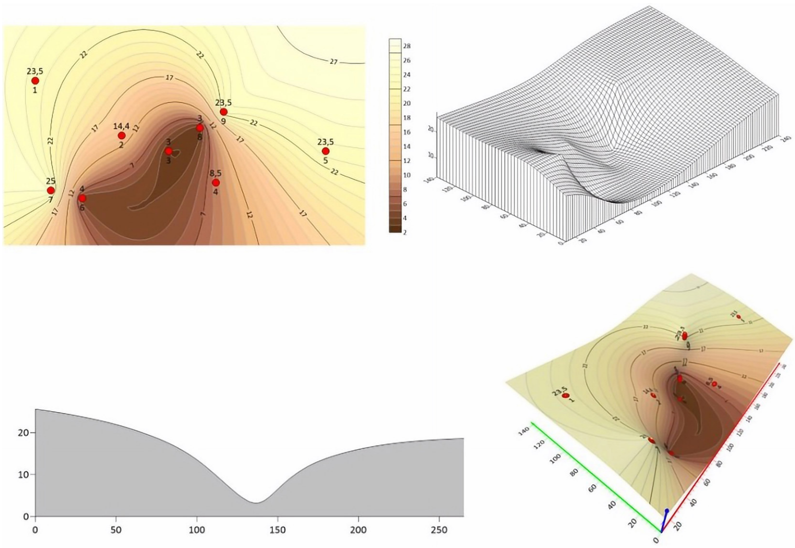

Figure 2. Albedo within the study areas, %

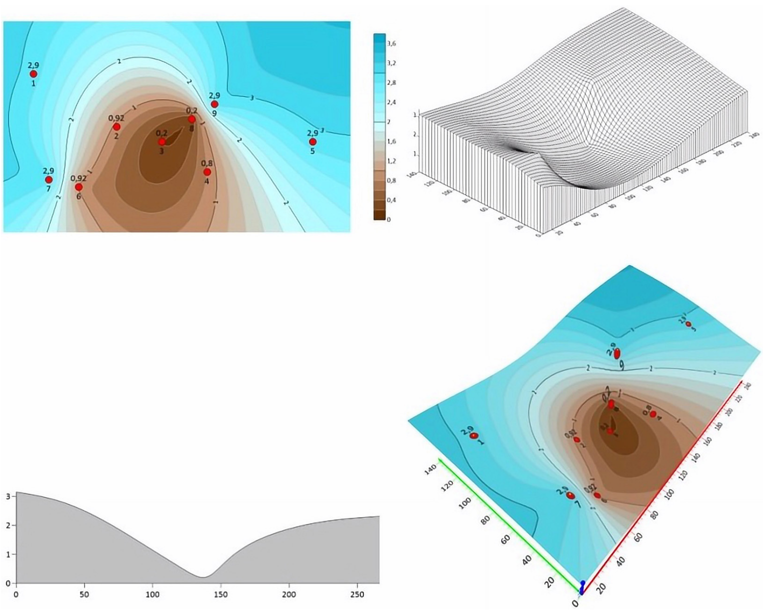

Figure 3. Heat capacity within the studied areas, kJ/(kg×K)

During the microclimate studies, we found a differentiation in microclimate indicators. The highest air temperatures were recorded in Rynok Square – 29.1°C, Mytna Square – 29.0 °C, and Svobody Avenue – 28.5 °C. These areas with their large area of dead underlying surface are in the zone of active influence of urbanisation processes, primarily xerophytic ones. The air temperature was significantly lower in areas with a smaller area of dead surface: squares near the Lviv Hotel – 24.5 °C, Na Valakh – 24.2 °C, and near St. Anthony›s Church – 24.9 °C (Fig. 4).

There is a significant difference in temperature between the areas with natural and dead underlying surface. Dead underlying surface : Mytna Square – 62.0 °C, Rynok Square – 61.0 °C, Pidvalna Street – 54.0 °C, Svobody Avenue – 54.0 °C, Y. Slovatskoho Street – 50.7 °C. Soil cover of green areas: Ivan Franko Park – 19.1 °C, Na Valakh park – 18.9 °C, in front of St. Anthony's Church – 18.2 °C and Lviv Hotel – 17.8 °C (Fig. 5).

The temperature of the soil with the plantings was different: the square in front of the Lviv Hotel – 15.3 °C, Ivan Franko Park – 15.9 °C (II EPZ), the square near the St. Anthony's Church (Lychakivska St.) – 15.1 °C and Na Valakh park – 14.8 °C (III EPZ) (Fig. 6).

Air and soil humidity levels exhibit a correlation with temperature indicators. In regions characterized by a non–permeable underlying surface (tiles, cobblestones, pavement), the humidity levels are as follows: Rynok Square – 46.4%, Svobody Avenue – 50.2%, Mytna Square – 45.9%. Conversely, increased humidity levels

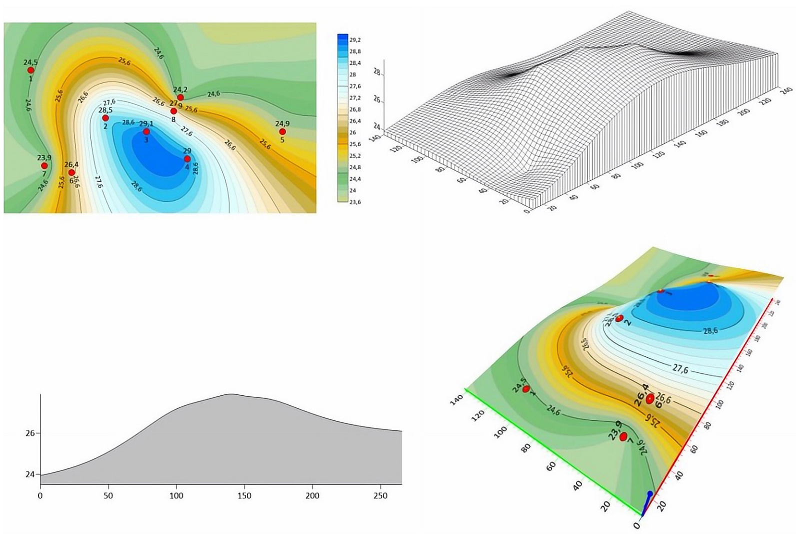

Figure 4. Air temperature above the underlying surface in the middle of the "heat island" within the buffer

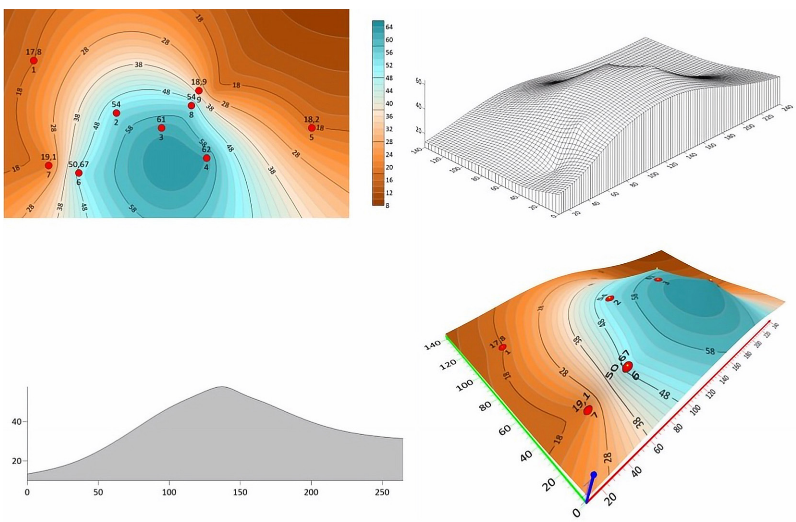

Figure 5. Temperature of the underlying surface in the middle of the "heat island" within the buffer zone, °C

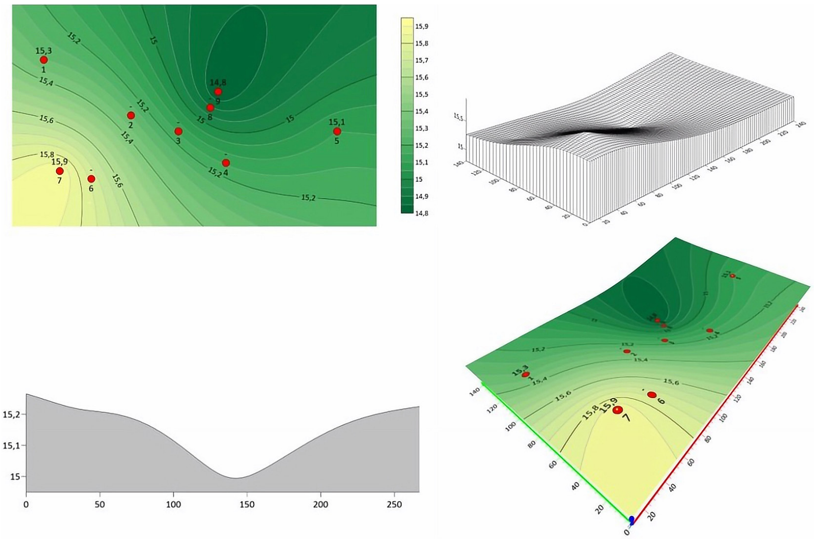

Figure 6. Soil temperature of the natural underlying surface of green spaces located in the center of the "heat island" and within the buffer zone, °C

were recorded in areas with greater exposure to the environment; specifically, the Pidvalna Street – 54.7%, near the Na Valakh park and on Yu. Slovatskoho Street – 57.3%, adjacent to the Ivan Franko Park (Fig. 7).

The highest humidity levels were recorded in the outer zone of the "dry island" – in the park in front of the Lviv Hotel (air – 62.0%, soil – 34.1%), Ivan Franko Park (air – 62.4%, soil – 52.6%), Na Valakh (air – 61.7%, soil – 34.5%) and near St. Anthony's Church (air – 61.2%, soil – 42.2%) (Fig. 8).

The investigation of the territory of the "dry island" – the lower tier of the "heat island" – was required for establishing the level of vitality of the main woody plants located within these boundaries. As it could be observed, the "dry island" is located in the dense development of the central part of the city, where the temperature of the dead underlying surface (stone, asphalt, concrete) was in the range of 57–62 °C, the air temperature was 28.5–29.1 °C, and the humidity was 50.2–51.2%. Drought conditions affect the growth, development and reproductive capacity of woody plants. The most threatening to plant life is soil dehydration caused by high air dryness. If we follow its changes on the north-south transect (Pidvalna Street – Yu. Slovatskoho Street), we will see that the humidity regime of the pit decreases from the outskirts of the "heat island" to the central part of the city center.

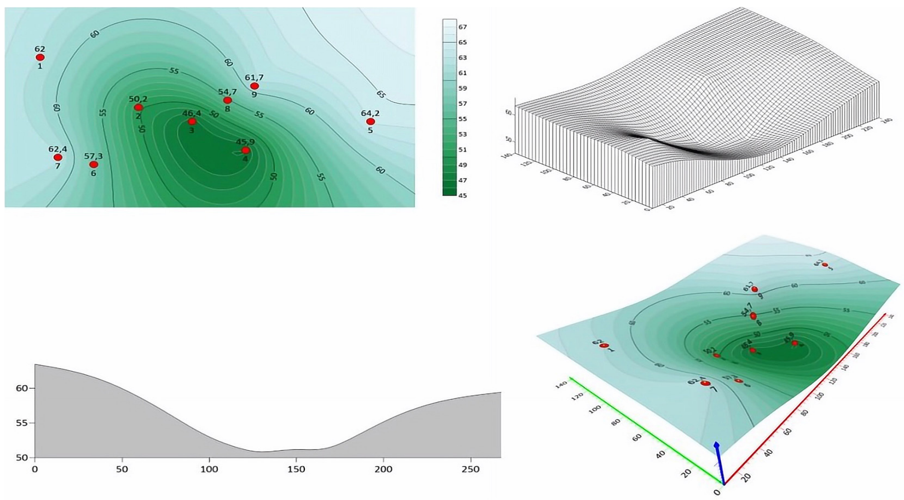

Figure 7. Relative air humidity of the dead underlying surface in the middle "heat islands" and within the buffer zone, %

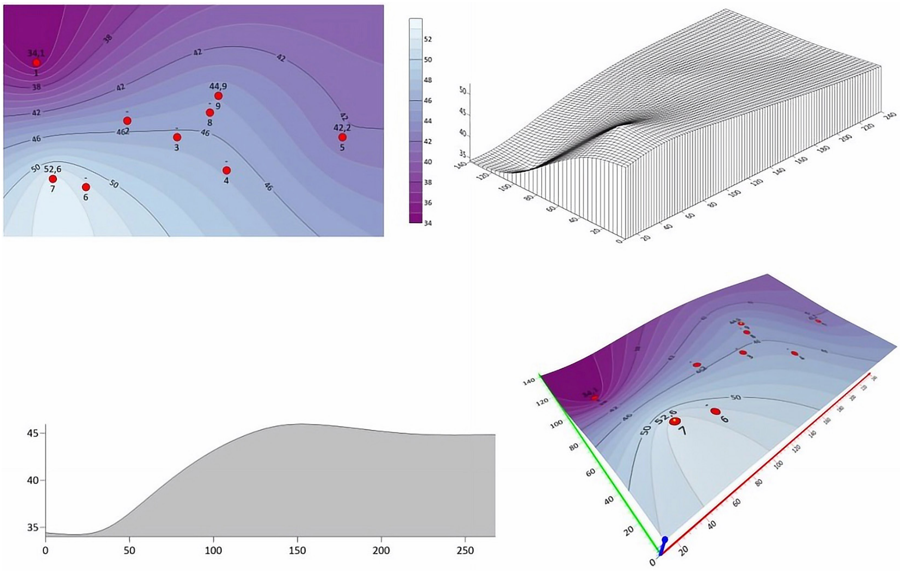

Figure 8. Relative soil humidity of the natural underlying surface of green spaces in the middle of the "heat island" and within the buffer zone, %

Comparative microclimatic studies in areas of sunlit and tree-covered areas have shown that even small projective coverings with crowns of 30–50 m^2 can cool the underlying dead and natural surface with their shade, for example, at the Vynnykivsky Market and Mytna Square. Larger sites, such as Rynok Square and Lviv Hotel, show a greater difference in air temperature. The influence of the rather shaded section of the boulevard on Svobody Avenue (located in the east-west direction), which at noon is covered by its own shadow, is significant. The difference between the illuminated and shaded areas is 8 °C.

Microclimatic indicators of the underlying surface correlate with the intensity of the light flux. The indicators of the level of insolation intensity, temperature and humidity are interrelated, both in areas with paving and ground cover (Fig. 9–11).

The ecological condition of the "green infrastructure" city centre

According to the classification of the Ukrainian ecologist P.S. Pogrebnyak, we have distributed the species composition of trees growing in the "heat island" zone according to the main edaphic factors – soil fertility and acidity. The analysis

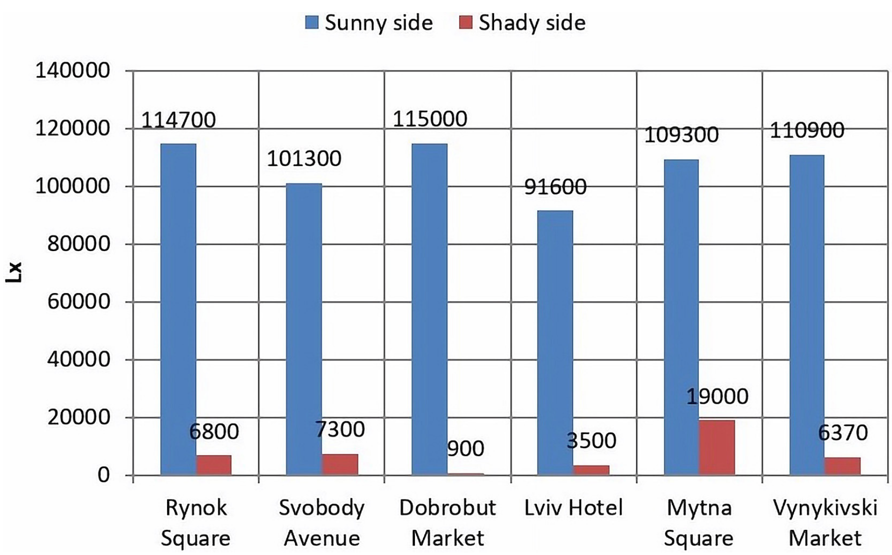

Figure 9. Lighting intensity levels in illuminated and shaded areas, Lx

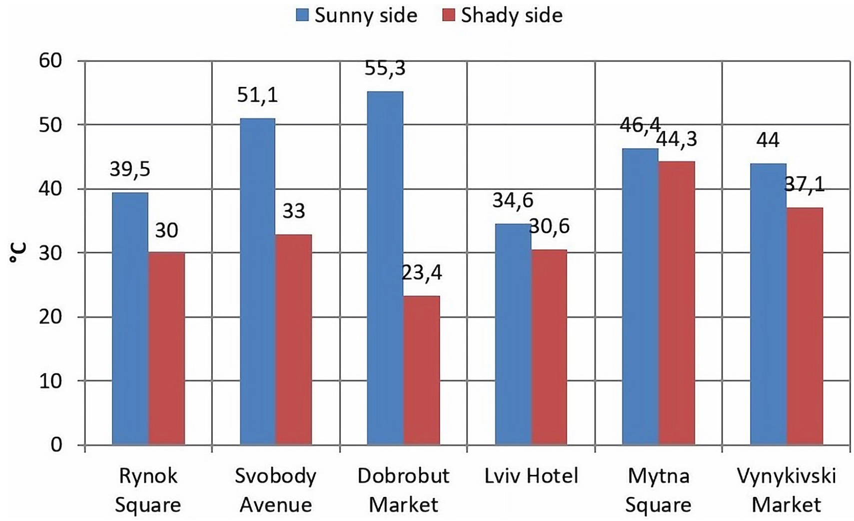

Figure 10. Temperature of the paving surface (stone, tile) of illuminated and shaded areas, °C

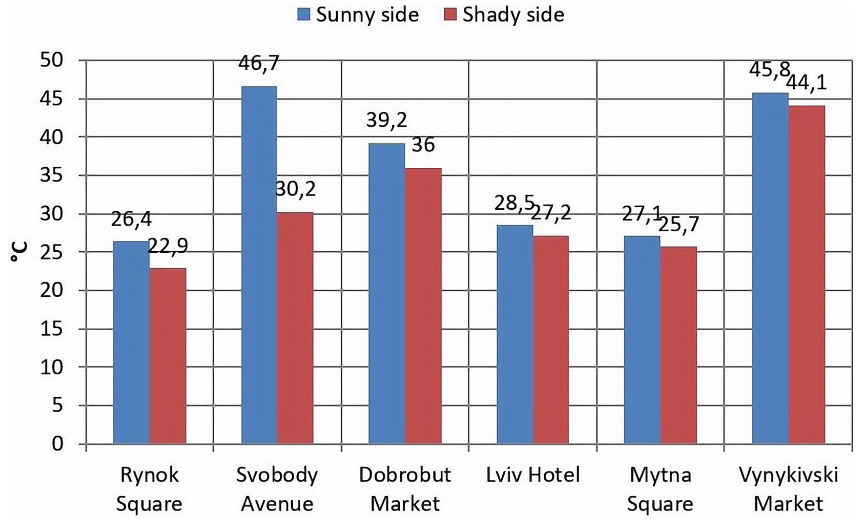

Figure 11. Surface temperature of the soil cover of illuminated and shaded areas, °C

confirms the fact that the plants in the city centre were selected to match the level of soil fertility (Table 1). As we can see, the plantations contain the most mega- and mesotrophs. This can be explained by the fact that species were selected for planting that were suitable for bulk soils with a sufficient amount of humus. Acedophilous plants (northern white-cedar, common juniper) develop poorly in these conditions, where alkaline soils prevail. The main reason for such a low vitality (% of trees) of more than 200 weakened woody plants growing in the "heat island" zone is the thermal xerophytic regime of air and soil, which has been confirmed by research.

The analysis of the genus composition of woody species (Table 2), which are concentrated within the Lviv city centre (Rynok Square, Halytska Square), showed that the range of woody plants is represented mainly by the following species: small-leaved linden (*Tilia cordata* Mill.), spreading elm (*Ulmus laevis* Pall.), horse chestnut (*Aesculus hippocastanum* L.), blue spruce (*Picea pungens* 'Glauca'), Kanzan cherry (*Prunus serrulata* 'Kanzan-Zakura'). Almost all of the plants in this part of the city centre were planted after the end of World War II and are in the age range of 70–90 years old, with single specimens of smooth elm and thorny spruce, for example, reaching 100 years old. Other old-growth trees include 18 specimens of *Tilia cordata* and 1 specimen of *Aesculus hippocastanum* on Rynok Square.

The analysis of the composition of woody species concentrated within the Lviv city centre (Rynok Square, Halytska Square) revealed that the range of woody plants is represented mainly by the following taxa: small-leaved linden (*Tilia*

Table 1. Distribution of woody plants in relation to soil fertility and acidity (according to P.S. Pogrebnyak)

Oligotrophs	Mesotrophs	Megatrophs	Acedophiles	Calciphiles	Nitrophiles	Alkalophiles
Juniperus sabina L.	*Quercus robur* L.	*Acer platanoides* L.	*Prunus cerasifera* Ehrh.	*Ulmus minor* Mill.	*Ulmus minor* Mill.	*Ulmus minor* Mill.
	Quercus rubra L.	*Acer pseudoplaianus* L.	*Juniperus communis* L.	*Ulmus laevis* Pall.		
	Aesculus hippocastanum L.	*Ulmus laevis* Pall.	*Thuja occidentalis* L.			
		Fraxinus excelsior L.				
		Fraxinus pennsylvanica L.				
		Juglans regia L.				
		Tilia cordata L.				
		Tilia europaea L.				
		Tilia platyphyllos Scop.				

Table 2. Distribution of woody plants in Lviv city centre by genus

No.	Genus	Amount, pieces	%
Halytska square			
1.	*Ulmus Pall.*	6	60
2.	*Tilia L.*	4	40
Total		10	100
Rynok square			
1	*Aesculus* L.	7	20
2.	*Tilia L.*	25	71.4
3.	*Prunus*	2	5.7
4.	*Picea*	1	2.9
Total		35	100
Svoboda avenue			
1.	*Acer* L.	70	32.3
2.	*Tilia L.*	12	5.5
3.	*Thuja*	34	15.7
4.	*Ulmus Pall.*	11	5
5.	*Fraxinus* L.	4	1.8
6.	*Picea*	4	1.8
7.	*Quercus* L.	7	3.2
8.	*Prunus*	7	3.2
9.	*Armeniaca*	1	0.5
10.	*Juglans*	4	1.8
11.	*Sorbus*	1	0.5
12.	*Tilia L.*	12	5.5
Total		217	100

cordata Mill.), spreading elm (*Ulmus laevis* Pall.), horse chestnut (*Aesculus hippocastanum* L.), blue spruce (*Picea pungens* 'Glauca'), Kanzan cherry (*Prunus serrulata* 'Kanzan-Zakura'). Almost all of the plants in this part of the city centre were planted in the post-war period and are in the age range of 70–90 years old, with single specimens of spreading elm and blue spruce, for example, reaching 100 years old. Other old-growth trees include 18 specimens of *Tilia cordata* and 1 specimen of *Aesculus hippocastanum* on Rynok Square. The average height of the elms on Halytska Square is 12.3 m, and the height of the small-leaved linden is 4.4 m. All the linden trees are young plants (5–8 years old), which replaced some specimens of spreading elm, which were removed due to their poor quality.

The sanitary condition of all woody plants of *Ulmus laevis* is unsatisfactory: significant damage to skeletal branches due to improper cropping, tissue growth on trunks, excessive compaction of the root zone of trees and insufficient feeding area. The sanitary condition of *Tilia cordata* plants is good, which is explained by the young age of the plants.

The Rynok Square is dominated by old-growth trees of small-leaved linden and horse chestnut and blue spruce (70–90 years old). Among the young trees, 5 specimens of the decorative form of horse chestnut and two Kazan cherries have been planted. The average height of the young trees is 3.5 m, and that of the old trees is 14.5 m.

The sanitary condition of all woody plants on Rynok Square is satisfactory but replacing some specimens with young large trees of the same species would be advisable, in our opinion. Another important part of the green infrastructure of Lviv city centre is Svobody Avenue, the central avenue of Lviv. Lviv's central avenue, along which valuable old-growth plantations are concentrated, as well as young specimens of woody plants planted in recent years. In total, the inventory list includes 217 trees, among which the most numerous are the horse chestnut – 57 plants aged 70–110 years and 5 young trees aged 7 years. Maple (*Acer* L.) is also well represented: the largest number of representatives of Norway maple (*Acer platanoides* L.) – 52 specimens, as well as 3 sycamore maples (*A. pseudoplaianus* L.) (60–80 years old) and 15 young sharp–leaved maples (*A. platanoides* 'Globosa'). The age of the maples ranges from 10 to 120 years, but the vast majority of plants are 60–80 years old. Another taxon represented by 34 plants is *Thuja occidentalis* 'Fastigiata'. Less numerous in the inventory materials is the genus *Tilia* L.: small-leaved linden (*Tilia cordata*) – 10 specimens and one specimen of large–leaved linden (*T. platyphyllos* Scop.) and common linden (*T. europaea* L.). Among elms, plants of Scots elm 'Pendula' (*Ulmus glabra* 'Pendula') – 9 specimens (20 g), Scots elm (*U. glabra* Huds.) – 1 specimen, and field elm (*U. minor*) – 1 specimen were found.

Other plants are represented by a small number of species and cultivars. The genus Ash (*Fraxinus* L.): common ash (*Fraxinus excelsior* L.) – 1 pc, green ash (*F. pennsylvanica* L.) – 3 pc (60–100 years old). European spruce (*Picea abies* L.) – 4 pcs (50 years old). Oak genus (*Quercus* L.): English oak (*Quercus robur* L.) – 2 pcs (110 years old), northern red oak (*Q. rubra* L.) – 4 pcs (7–10 years old) and common oak 'Piramidalis' Q.r. 'Piramidalis') – 1 pc (10 years old).

Three 40-year-old cherry plum (*Prunus cerasifera* Ehrh.), one 15-year-old common apricot (*Armeniaca vulgaris* Lam.), two 10-year-old and two 50-year-old walnut (*Juglans regia* L.), one 25-year-old mountain-ash 'Pendula' (*Sorbus aucuparia* 'Pendula') and four blackthorn (*Prunus spinosa* L.) plants were also recorded, with an average age of 60 years. Many of the trees are in poor sanitary condition, which has led to the replacement of old trees with younger plants by the relevant services. A graphical representation of the range of woody plants in Lviv city centre is shown in (Fig. 12–13).

Impact of the "dry island" on the physiological state of trees

The complexity of the research of the influence of the thermal field includes the study of a number of parameters that reveal the peculiarities of the physiological state of woody plants, in particular, representatives of the Cupressaceae family - cultivars of the genus *Juniperus* L. and *Thuja occidentalis* L. These are conifers that grow in large numbers in the city centre.

The average data for seven months (beginning and end of the growing season) show that the impedance of the weakened *Thuja occidentalis*

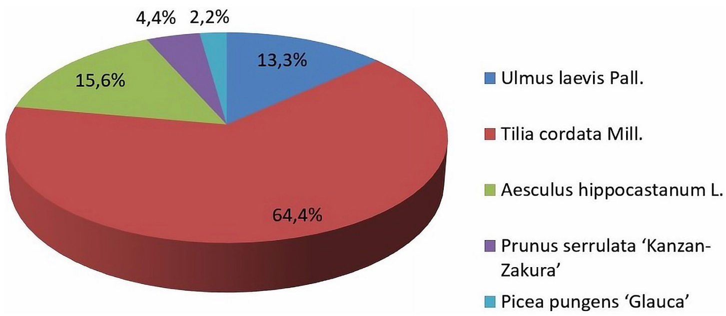

Figure 12. Assortment of woody plants on Rynok Square and Halytska Square (city centre)

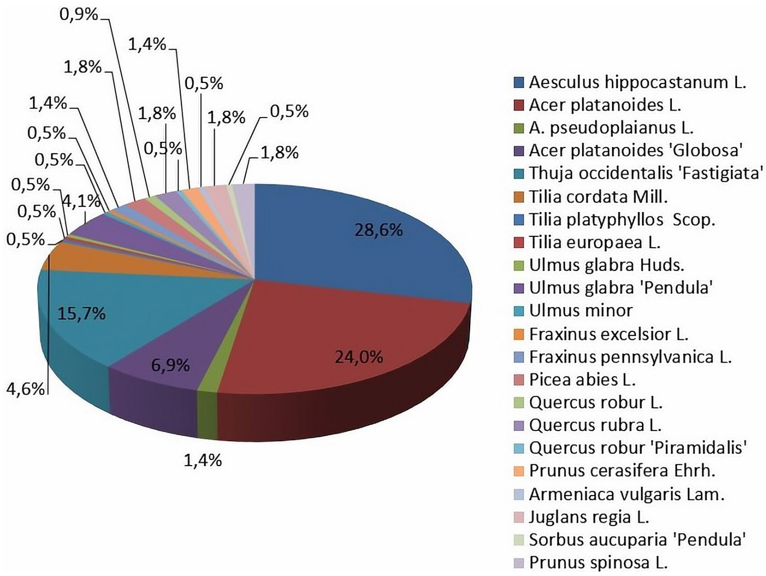

Figure 13. Assortment of woody plants on Svobody Avenue (city centre)

'Fastigiata' trees growing on Ivan Franko Street is almost 70% higher than that of the trees in Stryiskyi Park. As expected, the polarisation capacity of the weakened trees on Ivan Franko Square is 73% lower than in the park (Kucheryavyj et al., 2023a; Petlovanyi et al., 2021).

For a comprehensive assessment of the vitality of the listed ornamental cultivars, the method of chlorophyll fluorescence induction (CFI) was also used. Induction curves were determined using a dynamic single-beam fluorometer. The results obtained show that the cultivar growing in optimal conditions (5 points) in the arboretum of the Botanical Garden of the National Technical University of Ukraine has the highest value of the vitality index (0.63). Worse growth conditions (4 points) and, accordingly, a slightly lower level of vitality (0.52) were found in the specimen growing on I. Gorbachevskoho Street. The most unfavourable growth conditions were recorded for the juniper growing next to the carriageway on Svobody Avenue (3 points), and its vitality level (0.26) (Petlovanyi et al., 2021; Popovych et al., 2022).

The cultivars of Thuja occidentalis L. growing in similar environmental conditions – Svobody Avenue, I. Gorbachevskoho Street and the Botanical Garden of the Lviv National Forestry University of Ukraine – had similar indicators. Svobody Avenue and a number of parks are characterised by phytocoenoses with their characteristic phytoclimate and negative temperature gradient (difference in temperature in the crown and at the level of the root system in the hole), free-standing trees are completely under the influence of a positive temperature gradient, when the soil temperature in the hole (in the zone of root branching) is higher than the air temperature in the crown (Kycheryavyi et al., 2021; Kycheryavyi et al., 2023b).

It was found that the edaphic factor is closely related to the climatic factor and manifests itself differently in the conditions of phytocoenosis (a park near the Lviv Hotel) and street plantings (Halytska Square), which was confirmed by microclimatic observations and studies of tree vitality.

The "dry island" – the lower tier of the "heat island" – is formed by heating the dead underlying surface of the pit, which at midday in summer (July) ranges from 57–62 °C, and corresponds to the heat-intensive characteristics of the main building materials (kJ/kg×K): stone (paving stones) – 1.26, concrete – 1.0, asphalt – 0.92). Since these elements of the dead underlying surface of the pit occupy 92% of the entire study area, they are the main thermophysical factors in the formation of the heat island. The upper tier of the heat island is actively formed by heat transfer from the roofs of buildings covered in the city centre mainly with iron (0.46 kJ/kg×K) and zinc (0.38 kJ/kg×K) tin. The warm air rises upwards (up to 100 metres or more) via convective radiators and dissipates, reducing the humidity level in the upper layer of the "heat island" (roof tier). The study of this tier was not part of our research programme (Popovych et al., 2021a; Popovych et al., 2019b; Skrobala et al., 2022).

The study of the microclimate of park edges as a transitional, ecotone zone from open space with a paved road surface, sidewalks to greenery in the

II ecological and phytocoenotic zone of the belt shows that the vertical design of plantations plays a significant role in changing microclimatic indicators. The multi-component, multi-tiered structure of plantations has a more significant impact on reducing temperature and optimising humidity conditions compared to single-tier plantations. In July, the air temperature in the open space 20 m from the edge of the Ivan Franko Park was 34 °C, and at the edge of the single-tiered open forest 30.5 °C (10.3% lower). Instead, the complex, closed, multi-component four-tiered edge of the green spaces of the Sheptytsky Museum of Folk Architecture and Rural Life (one tree, second tree, undergrowth and grass tiers) reduces the temperature by 18%. The study of relative air humidity found that it was 22% higher in the multicomponent forest edge compared to the open space. Park edges are an important barrier to the movement of lateral flows that carry noise, dust, harmful gases, etc. Even in a leafless state, forest edges can reduce wind speed by 45–64%, and this directly depends on the species composition, exposure and vertical structure.

CONCLUSIONS

During the study of the peculiarities of heat island formation in a large city and its impact on the physiological development of vegetation were established:

1. As a result of urbanisation processes, development of a large city, population growth, heat transfer from roof and street surfaces increases, which leads to the formation of clear boundaries of the dry island as an indicator of the lower tier of the heat island;
2. Modelling the values of microclimatic indicators makes it possible to assess the damage to tree plantations, and can also serve as recommendations for developers on the formation of squares, parks, plantings, hedges, taking into account the most acceptable values of temperature and humidity of the air and soil of the underlying surface;
3. To preserve the physiological stability of tree plantations during the hot season, it is necessary to develop recommendations for the care of vegetation in the green zone of the city, depending on microclimatic indicators, especially air and soil temperatures, air and soil humidity;
4. The heat island should be reduced by greening the city in the horizontal and vertical ranges;
5. The island of dryness is determined by microclimatic indicators, as well as the values of indicators of woody plants' vitality, which requires additional study and further comprehensive research.

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