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THE ROLE OF TERRAIN RELIEF, BUILDINGS, AND GREEN SPACES IN THE DIVERSIFICATION OF LVIV'S LOCAL CLIMATE

Abstract: This paper outlines the results of a study of Lviv's specific thermal characteristics. The study relied on a series of measurements taken over a 15-month period (from February 2007, through April 2008) at 6 automatic meteorological stations, representing a variety of physiogeographic conditions and land use. The study reveals substantial variations of temperature levels (annual [1-3°C], seasonal [2-4°C], and daily [2-12°C] averages), indicating the presence of an urban heat island. The result of the study is a map of the distribution of average annual air temperatures on the territory of Lviv.

Keywords: air temperature, temperature variation, urban heat island, vertical temperature gradient, temperature distribution map, Lviv.

INTRODUCTION

Lviv's climate is characterised by a temperate climate, exhibiting transitional maritime and continental features, and marked by variable weather conditions. The diversity of weather types results from the presence of various air masses (arctic, polar, or tropical) and of circulation types presenting anticyclonic (during 236 days in the year, on average) and cyclonic (during 129 days, on average) characteristics (Martyn, 1992).

The main features of Lviv's climate are evident in the pronounced annual course of basic climate elements, the solar privilege (1800 hours of sunshine during the year), occurrence of the seasons, temperature fluctuation (during the coldest month the average is lower than -4°C, while during the

warmest, it is above 17°C), changes in air humidity and cloud cover (highest values during fall and winter) and precipitation (740 mm during the year, with highest totals during the summer) (CLINO, 1996). The history of meteorological measurements in Lviv reaches back nearly 200 years. Historical meteorological information may be found in the Cracow Meteorological Cooperative's bulletins, as well as the "Kosmos" publication series, among other sources.

Monitoring measurements were also carried out by the State Meteorological Service, in selected locations in downtown Lviv and in other parts of the city. Short series of measurements were taken also by Lviv University geography students during field assignments, although they provide only general information on topoclimatic conditions in the city. A significant contribution to climate studies in western Ukraine and Lviv was made by M. S. Adrianov (1951). A more recent publication, "Lviv's Climate", attempted to explain temperature variations among Lviv neighbourhoods, with a particular emphasis on the effects of urban green spaces (Babičenko, Zuzuk, 1998).

THERMAL CHARACTERISTICS OF LVIV'S LOCAL CLIMATE

The factors that drive the development of the specific conditions of the local urban climate include: the variety of building structures, large proportions of artificial surfaces, at the expense of natural surfaces, intensive emission of various pollutants (from industry, in particular the energy sector, transport vehicles, communal enterprises and the release of artificial heat.

The goal of the present study is to describe the specific thermal characteristics of Lviv's climate by delineating the spatial variation of thermal conditions within the city. The degree of change in thermal conditions is a function of natural and anthropogenic transformations of the geographic environment and is expressed as a rise in the air temperature relative to the periphery. This phenomenon has been designated in the literature as the urban heat island (Oke, 1987; Landsberg, 1981). A heat island is not a static phenomenon, but exhibits fluctuations during the daily and annual cycles. Urban heat island characteristics (in particular its intensity) are conditioned by the seasons, the time of day, and weather conditions. In European cities, generally, it occurs mainly during hot periods of the year, and during the evening and night periods of the day. It has been clearly demonstrated that anticyclonic weather cloudless, windless weather is favourable to heat island formation and increased intensity.

In order to assess the spatial variations in air temperature (urban heat island) we relied on a 15-month series of topoclimatic measurements (from the period 1.02.2007–1.05.2008), made using electronic recorders (Tinytag Ultra TGU-1500). The same type of equipment had been used previously (beginning in 2002) in topoclimatic studies of the Carpathians, Sub-Carpathia,

and Podolia, producing convincing results that confirmed the equipment's universality and superiority over traditional methods (high degree of precision, high measurement frequency) (Boryczka et al., 2006; Mucha, 2001; Mucha et al., 2008).

Recorders were installed in 6 locations in Lviv, within a variety of landscape structures. Five distinct landscape units converge at Lviv: Pobuzhe Pasmove – in the northern part, Roztoche – in the north-western and south-eastern parts, the Lviv plateau – in the southern part, and the Grodecko-Shchezhecka plain – in the south-western part of the city. Automatic stations were placed on second-floor balconies, on the northern sides of buildings, in order to eliminate the influence of direct sunlight. The stations were programmed to register the measurement parameters at 30-minute intervals.

Recorder no. 1 was located in the centre of Lviv, near the National Opera house. Lviv's downtown is located inside a basin, formed by the Poltva River's tributaries. The basin is bordered by Roztoche and the Lviv plateau. Elevations in the downtown sector reach 280-290 m asl, and slowly descend into the Poltva valley towards the Zboyska neighbourhood, situated in Pasmove Pobuzhe, where recorder no. 6 was placed among low-rise buildings. The highest-lying residential neighbourhood (370 m asl) is Mayorivka (Pasichna street, recorder no. 2) situated in proximity to wooded parks. Towards the south, recorder no. 3 collected data among the dense, high buildings of Sykhiv. Measurement location no. 4 was situated among low, one-family houses with gardens in Kulparkiv, in the undulating terrain of the Lviv plateau. Recorder no. 5 was placed in the Levandivka neighbourhood among buildings of varying height, in relative proximity to the wooded area of Roztoche and Bilogorshcho-Malchycka valley wetlands (landscape unit: Grodecko-Shchezhecka plain).

Based on the collected data (approximately 22 thousand units), we calculated the monthly, seasonal, and annual temperature values (Table 1). Results of previous studies show that, in the second half of the 20th century, the marked warming of the climate has been particularly evident in Lviv; annual average values for recent years clearly deviate from long-term values by as much as 3–4°C, as was the case during our field research (Boryczka et al., 2006).

The 15-month measurement series revealed important variations of thermal conditions in Lviv. The measurements show that:

- the annual average air temperature ranges from 9,6-9,8°C on the outskirts of the city to 11,4°C downtown. The Kulparkiv and Zboyska measurement locations recorded temperatures that were approximately 1°C lower than temperatures measured in the city centre (Kulparkiv and Zboyska are situated lower than Lviv's downtown and are in close proximity to agricultural terrains). Mayorivka (the highest measurement point, at 370 m asl), Sykhiv (lying slightly lower), and Levandivka (situated low, close to wetlands) were notable for

Table 1. Annual averages and extreme air temperature values in Lviv 2007–2008

Observation period	Lviv neighbourhoods where measurements were carried-out					
Measurement period	City centre	Mayorivka	Sykhiv	Kulparkiv	Levandivka	Zboyska
1.02.07–1.02.08	11,46	9,50	9,74	10,23	9,63	10,01
1.03.07–1.03.08	11,60	9,71	9,93	10,40	9,88	10,19
1.04.07–1.04.08	11,34	9,53	9,74	10,18	9,75	9,96
1.05.07–1.05.08	11,31	9,55	9,82	10,18	9,88	9,99
Average values for the research period	11,4	9,6	9,8	10,2	9,8	10,0
Absolute temperature maximum	37,50	33,90	37,10	38,00	34,80	35,70
Absolute temperature minimum	-13,90	-16,50	-14,80	-16,50	-14,20	-15,60
Standard deviation	0,11	0,0	0,08	0,09	0,10	0,09

producing the lowest values. These points are situated near the Roztoche forest complexes;

- the absolute maximum air temperature at each measurement point varied between 33,9 and 38,0°C, but the maximum values were not noted simultaneously, which points to local causes; the highest values were recorded in the city centre and in the Kulparkiv neighbourhood;
- the absolute minimum air temperature in Lviv varied between -13,9 downtown, to -16,5°C in Kulparkiv (a distance of 4 km).

Figure 1 presents the profiles of temperature averages for the year, for the months of January and July, as well as the maximum and minimum temperatures for various Lviv neighbourhoods. It is notable, as well as symptomatic, that the average minimum temperature in July, the average

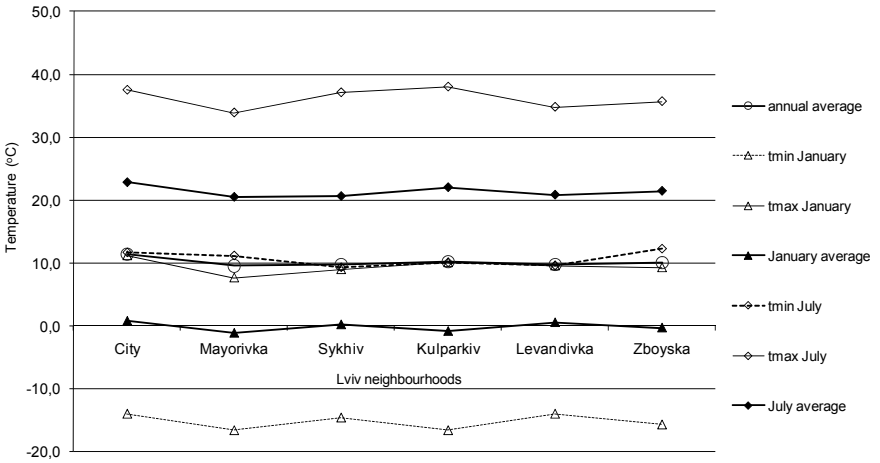

Fig. 1. Air temperature in Lviv neighbourhoods during the measurement period

maximum temperature in January, and the annual average temperature were similar at all the measurement points.

The average air temperature in July 2007 was relatively high and registered values above 20°C (compared to the long-term average of 18,3°C). The average temperature in January presented an even larger deviation from the long-term average (–4,0°C), since it oscillated around zero degrees. These data correlate with the general tendency of climate warming, especially during the winter (Boryczka et al., 2006).

Seasonal average air temperatures measured in the various neighbourhoods of Lviv also revealed significant differences, however similar as in the average annual temperature, between monthly and extreme characteristics. During the summer, the hottest neighbourhoods were downtown and Kulparkiv, but during the winter, it was downtown and Sykhiv – because of high building density, as well as artificial heat. The coldest neighbourhood in winter was Mayorivka (where the influence of altitude is notable) and Kulparkiv (open terrain allowing for the unhindered movement of air).

The spring was warmer than fall (Fig. 2), although both seasons are transitional and the rise in temperature from winter to summer should not be greater than the drop from summer to winter. Certain differences result from variations of the beginning and end-of-season dates in different years. The "geophysical"[1] method of defining the seasons proved to be the most reliable.

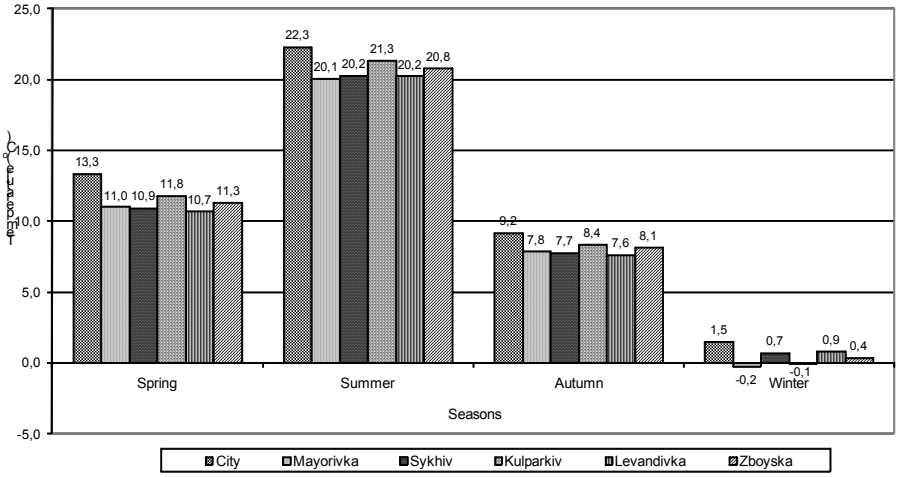

Fig. 2. Average seasonal air temperature in Lviv neighbourhoods during the period of study

[1] Analyses of the beginning and end of the seasons according to astronomical, meteorological, geophysical, and calendar criteria, based on materials from the Lviv University geophysical-landscape reasearch station in Roztoche, revealed that the most reliable were the "geophysical" criteria – that is, the character of the tendencies and dynamics of changes in meteorological elements, particularly air temperature. The final result proved to closely follow calendar seasons (3 months each) with 1-3 days of devaiation.

The variations of average monthly temperatures within Lviv are not great (from 0,5 to 3,5°C), but they are greater than the differences in annual average temperatures. The average temperature is always higher in the city centre than in other neighbourhoods, but fig. 3 shows just how substantial the variations were over the 15-month period of study. The amplitude of the differences between monthly average air temperatures in the city centre and in the other neighbourhoods is temporally and spatially variable. The neighbourhoods most frequently registering the largest differences, compared to the city centre, were Levandivka, Sykhiv, and Mayorivka – the farthest-removed, highest-elevated, and coldest neighbourhoods. The smallest differences were between the city centre and Kulparkiv.

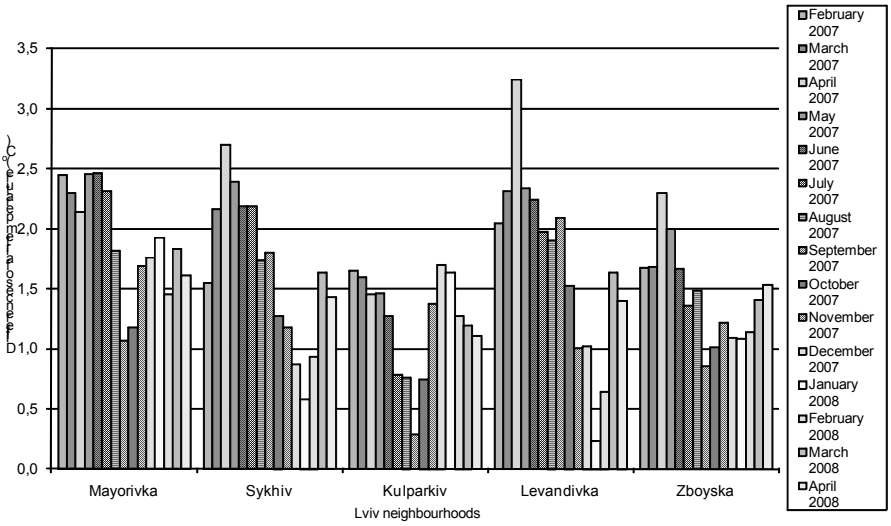

Fig. 3. Differences of monthly average air temperatures measured in the city centre and other Lviv neighbourhoods

Over the course of the year, the largest differences between neighbourhoods were recorded in spring (particularly in April) and during the summer. The smallest differences were noted during the winter. The most substantial difference was recorded in April between Levandivka and the city centre (3,3°C). Slightly lower values (2,3-2,7°C) differentiated Sykhiv and Zboyska from the city centre. Neighbourhoods on the outskirts of the city are colder and their thermal conditions resemble those of the periphery.

DEPENDENCE OF THE URBAN HEAT ISLAND ON WEATHER CONDITIONS

The analysis of thermal variations between Lviv neighbourhoods in various weather conditions (types) outlines local factors in additional detail.

Temperature courses change according to the degree of cloud cover, especially on days with varying cloud cover. They are more pronounced during anticyclonic, cloudless, and windless weather. It is then that variations most pronounced. The smallest thermal variations within the city occur in cyclonic windy weather. In 2008, during the coldest periods, with a daily amplitude of 10–16°C, daily differences fluctuated between 2 and 3°C. On colder nights, the differences reached even 4°C, with the warmest temperatures recorded at Levandivka and the city centre, while Mayorivka and Kulparkiv were the coldest.

Hot, anticyclonic weather produced observations of the highest temperature amplitudes and the most significant spatial variations. The city centre proved warmest during both day and night, while Mayorivka was coolest. During afternoon hours, the temperature difference between these two parts of the city, reached 9-10°C, momentarily going as high as 12-13°C. This substantial difference, which results from differences in warming and cooling speeds between the city centre and outlying areas, is testament to the strengthening of the urban heat island and its increasing intensity.

An analysis of the course of temperature in changing weather conditions (change of air masses) revealed an asynchrony and variations in change intensity, as well as the specificity of thermal condition formation (such as occurrences of inversion) in Lviv. It is conditioned by modifications to the temperature field within the city and on its periphery, as well as the movement of air masses and the reaction of urbanized areas to changes in weather.

In order to characterise Lviv's air temperature field an attempt has been made to represent the urban heat island on a map (Fig. 4), using the MapInfo[2] program. In creating the digital map we used the average annual air temperature values from the automatic recording stations, but also from the Roztoche geophysical-landscape research station, as well as the national meteorological station located at the Lviv airport, Sknyliv (immediately adjacent to the city). The cartographic basis for the localisation of points was a topographic map of Lviv, on a scale of 1:100 000, published in 2007. On this basis, we first produced a graphic outline of temperature distribution, using interpolation, but without taking account of terrain relief and height asl. Even on this preliminary sketch of the air temperature field, the heat island was clearly visible in the city centre with decreasing intensity towards the neighbourhoods of Kulparkiv, Sknyliv, and Zboyska. In the direction of Sykhiv, there was a markedly rapid drop in temperature towards the colder sections of the city: Mayorivka (to the north-east) and Levandivka (to the west of downtown). In both these neighbourhoods the influence of the Roztoche wooded highland is clearly visible.

In order to obtain a realistic temperature distribution for the Lviv area, taking terrain relief into account, we calculated the vertical gradients of air temperature between the low-lying city centre and the surrounding elevations

[2] The digitized portion of the map was prepared by Yu.M.Karpets

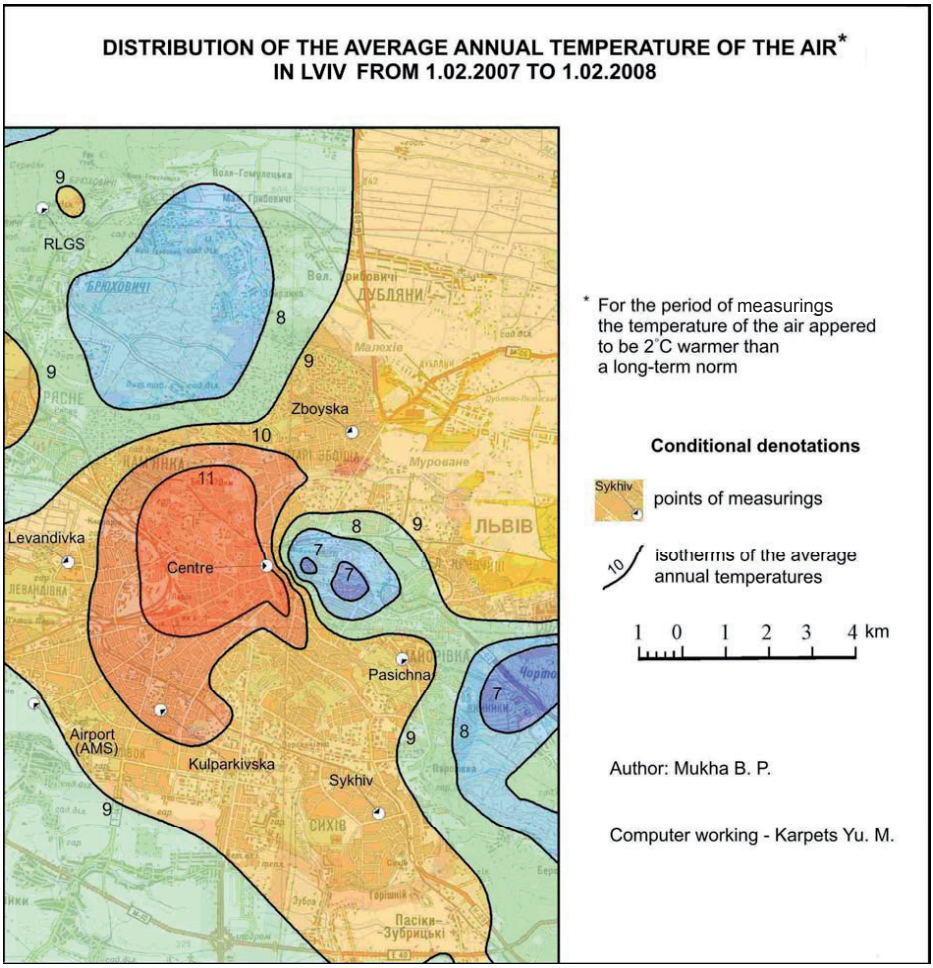

Fig. 4. Average annual air temperature distribution in Lviv (for the period 1.02.2007-1.02.2008)

and depressions. The resulting average gradients were greater than the standard vertical temperature gradient in unsaturated air, reaching 2°C/100 m. Such magnitudes of vertical gradients can occur in the sphere of influence of such geographical factors as: basin localisation of the city centre, release of artificial heat from the city, reduced ventilation, and high building density. Applying the calculated local temperature gradients to relief elements within the city and its immediate surroundings allowed us to complete the network of highest culmination points and simultaneously to obtain new virtual points for the construction of a map of the spatial distribution of annual average air temperatures. The resulting map variant was used to locate new points of automatic measurement. Recorders have been registering data since 1 January 2009 in Lviv's city centre and in surrounding

villages (Pidbrici, Sokolniki, Rudno and Dubliany), which we hope will result in an improved map of the air temperature field in Lviv and its periphery.

SUMMARY

We consider that the study described in the present article, based on a 15-month series of synchronised, 24 hours/day, short interval, automated measurements of air temperature, constitutes an initial contribution towards further research. A valuable result was the determination of the range of changes in air temperature, both daily and annual, in various weather conditions. The proportion of differences in air temperature for annual average values varied between 1 and 3°C, seasonal average differences ranged from 2 to 4°C, while for daily averages the range was 2 to 12°C. In the great majority of measurements, Lviv's city centre proved warmer than surrounding areas by 2–3°C, confirming the stable and frequent occurrence of an urban heat island. During the summer, the Kulparkiv neighbourhood also registered elevated temperatures, but the similarities were not present during winter. The Zboyska neighbourhood, adjacent to Male (Small) Polesie, also registered relatively high temperatures. In the majority of measurements, the Mayorivka neighbourhood proved to be the coldest, followed closely by the Sykhiv and Levandivka neighbourhoods.

The development of thermal differences within Lviv is predominantly conditioned by especially densely built-up areas, artificial heat released from various sources, absolute height of observation points, urban green space complexes, and the proximity of forest complexes and agricultural terrains.

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