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The impact of residential development and municipal greenery on the thermal conditions of the city gullies in Lublin

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Abstract. Urbanization is a serious threat to the soil cover. It entails the process of soil sealing thereby limiting soil functions. The local climate is also affected – sealed areas absorb heat, therefore temperature above them is increasing. It contributes to the formation of an urban heat island, which negatively affects the quality of human life. In the two surveyed gullies in Lublin, 35 measurement points were located, in which two temperature sensors were placed: one at a height of 1.5 m and the other in the soil at a depth of 0.15 m. The measurement points were located at different distances from the buildings (from 10 to 236 m in a straight line) and in the areas with different types of vegetation – trees, shrubs and grass. Research carried out in two gullies in Lublin revealed that the differences in air temperature at various locations were even 10 degrees Celsius depending on the distance from the buildings, the type of plant cover and soil characteristics. Large temperature variability could be observed even within a small area. The negative impact of buildings on the air temperature in the city is eliminated by proper distribution of green areas, reducing the temperature by up to 7 degrees Celsius. The process of soil sealing cannot be avoided. Therefore, land intended for urbanisation should be used rationally. The spatial planning process should take into account not only land for infrastructure but also for green areas to reduce negative impact of soil sealing on the quality of life of the residents.

Keywords: urbanisation, soil, soil functions, temperature, soil sealing, green areas

INTRODUCTION

Soil in the natural environment performs many functions. Through its retention properties it temporarily retains rainwater, carbon compounds and pollutants. The water retention function is also related to the contribution of soils to temperature regulation, which directly affects human living conditions, especially in summer (Smreczak et. al., 2017).

A number of different processes are likely to lead to soil degradation. The urbanisation, associated with the migration of people from the countryside to cities and suburban areas, and a steady increase in the number of city dwellers in relations to the entire population, as well as the urban sprawl through the intensification of land development are a major threat to the soil cover (Łuczyszczyn, Łuczyszczyn, 2018). As a rule, the first human settlements were formed on fertile soils, in river valleys or near mineral deposits. Plain areas favourable for cultivation were for preferred for habitation and, as a consequence, it is the soils of high agricultural utility that were and still are most often degraded as a result of the increase in build-up areas (roads, railway lines, car parks, residential and industrial buildings) (Famielec et al., 2007).

The urbanisation results in soil sealing, i.e. destruction of the top soil layer or its entire profile or covering the soil with buildings, structures and layers of completely or partially impermeable artificial materials (Stolte et al., 2016).

According to the Central Statistical Office's data for 2017, the share of built-up and urbanised areas accounts for 5.4% of our country's area. The state of soil sealing in Poland is not as large as in other countries. however, the more attention should be paid to the appropriate use of land to preserve the soils fulfilling the most important production and environmental functions for future generations.

Sealing poses many risks to the function of soil cover. The most important is the reduction of retention features, which contributes to an increase in surface runoff and thus to an increase in flood risk and increased erosion processes. In urbanised areas, infiltration of water is falling, which results in a decrease in groundwater level, which makes drinking water scarce in cities and makes access difficult for plants. The above mentioned phenomenon causes deterioration of development conditions and quality of green areas, which are essential for air quality, absorbing pollutants and dusts on the surface of leaves (Stolte et al., 2016).

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The sealing also contributes to a decrease in field evaporation (Gruszczyński, 2014).

Soil sealing cannot be entirely avoided or stopped as it is associated with the continuous development of civilization. Instead, detailed knowledge is needed on the impact of land use on the capacity of the soil to retain and mitigate microclimate extremes in order to support more sustainable soil management in urban and suburban areas in the near future. Soil sealing can be counteracted by introduction appropriate spatial planning rules, such as land occupancy limits for administrative units, clear rules for the protection of cultivated soils and the introduction of soil valuation in spatial planning. In addition, various technical measures can be implemented, such as the dissemination of permeable materials for the construction of communication infrastructure and the development of rainwater collection systems (Gruszczyński, 2014).

The aim of the research was to analyse the impact of soil sealing on the ability of the soil cover to perform ecosystem services and on the impact of buildings and urban greenery on local temperature differences that directly affect human living conditions and health in cities.

MATERIALS AND METHODS

Two gullies located in Lublin, the district of Czuby, was the area of study where daily air and soil temperatures were measured. The first gully (gully no. 1) was situated

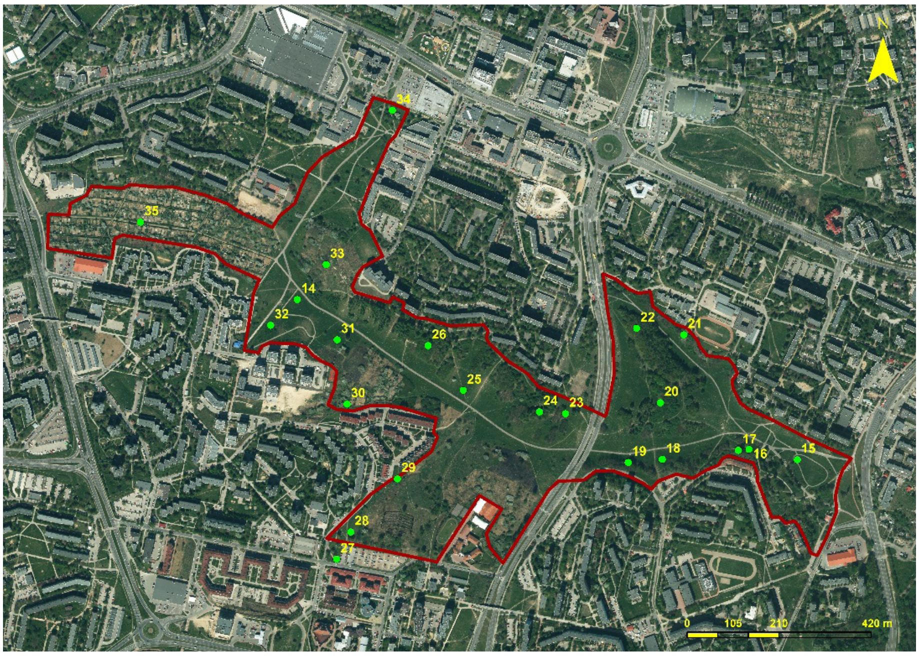

Figure 1. The location of the measuring points in gully no. 1.

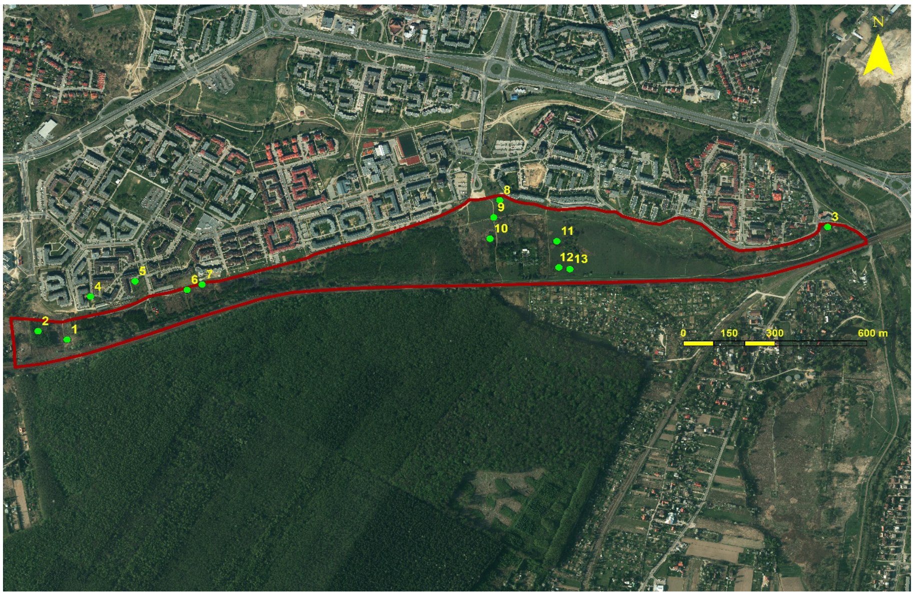

Figure 2. The location of the measuring points in gully no. 2.

in the northern part of the district, between Tomasza Zana, Armii Krajowej, Jutrzenki and Nadbystrzycka streets. The second (gully no. 2) was located between the Lublin-Warsaw railway line and Węglinek and Nadbystrzycka streets. The first gully is located in the part of the district where multifamily buildings (tall blocks of flats and skyscrapers) and commercial facilities (larger retail establishments) prevail. The second one is located closer to the city border, in the vicinity of a forest and a relatively new housing estate of low blocks. Both gullies are situated on high quality soils – very good wheat and good wheat complexes. The greater part of the area is occupied by brown soils and leached soils developed from loess. Both gullies are characterized by varied vegetation (grass, shrubs and trees). Both gullies serve the residents of Lublin as a place of recreation and leisure.

In the gullies under study, 35 measurement points were determined, at each of which two temperature sensors were placed: one at a height of 1.5 m from the ground Surface, the other in the soil at a depth of 0.15 m. The measurement points were determined at different distances from the building (from 10 to 236 m in a straight line) and in areas with different types of vegetation – trees, bushes and grass (Fig. 1, Fig. 2) and were at different heights: in gully no. 1 from 212 to 238 meters AMSL, in gully no. 2 from 201 to 222 meters AMSL. Temperature was detected by means of the iButton technology recorders from MERA-PROJEKT. These sensors record the measurement results in the memory of the device in specific, user-defined (10 minutes) time intervals (meraprojekt.com.pl). Temperature measurements were taken from 7–8.08.2018 from 18:00 to 15:00. The results of the field measurements were averaged for each point, and then interpolated in the ArcGis program, showing the distribution of temperatures and amplitudes for the tested gullies.

For the area under study, the potential insolation, i.e. the amount of incoming solar radiation, was also determined. The values were generated in the SAGAGIS program on the basis of the entered parameters: three-dimensional model of the studied area, date of measurements and latitude of the studied area. The insolation in the analysed gullies was divided into three levels – low, medium and high (Fig. 3). The brighter the colour on the map, the higher the level of potential insolation. The first gully is dominated by medium and high radiation, while the second one by low and medium solar energy radiation.

In the investigated gullies, a buffer of 200 m radius was determined for each measuring point. In each buffer the share of the sealed area was counted. The size of the sealed area was determined on the basis of the Urban Atlas database layers. Subsequently, the percentage of the buffer area covered by the sealed area was determined. For the field collected data, statistical analysis was performed in Statistica.

RESULTS AND DISCUSSION

In urbanised areas, especially in large cities, a specific microclimate is created, characterised by a large temperature range in a relatively small area. This is mainly due to the varied warming of the ground and the emission of anthropogenic heat into the urban atmosphere. Urbanised areas are distinguished by increased air temperature, reduced air humidity, changes in wind conditions and the formation of

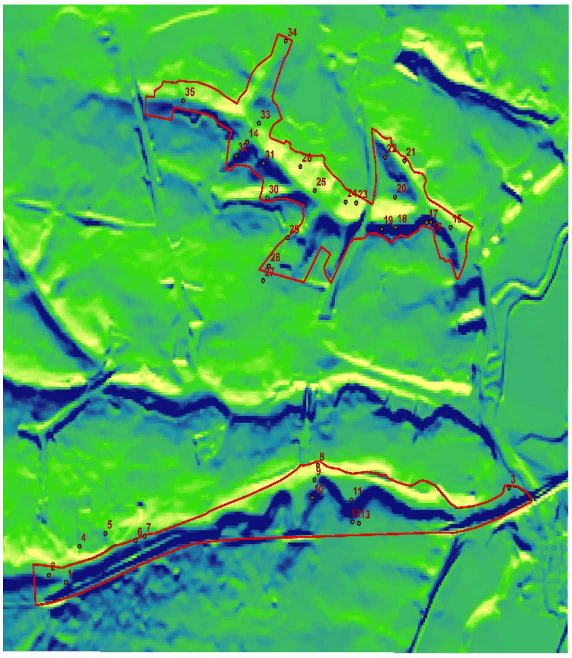

Figure 3. The potential insolation in the studied areas.

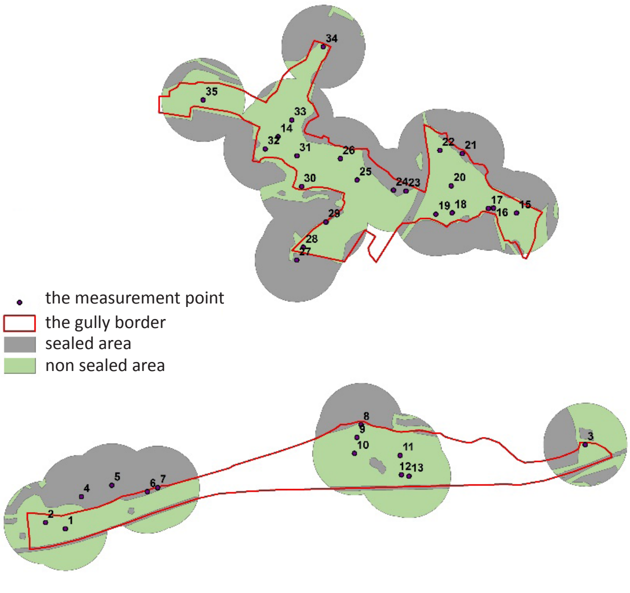

Figure 4. Occurrence of the sealed surface at a distance of 200 m from the measuring point.

a specific urban aerosol and uneven inflow of solar radiation. This has a negative impact on the quality of human life (Osińska-Skotak, 2002).

The studied gullies were diversified in terms of the share of built-up area in the vicinity of individual measurement points (Fig. 4). Gully no. 1 had a larger average sealed surface area around the points – nearly 40%, in gully no. 2 this value did not exceed 33%. The highest value was reached in point 34 (gully no. 1), around which the build-up area took 65.5%. The lowest share of the area sealed off in the given buffer was recorded in points 12 and 13 (gully no. 2) – 8.6%.

The type of buildings and compactness of building pattern play an important role in shaping the urban climate. Thermal and wind conditions in loose and high density build-up areas are different from those in compact build-up areas. The developed areas with a loose pattern of high-rise buildings are characterised by climatic conditions similar to those in undeveloped areas. In such areas there is a higher incidence of cold in winter, while in summer comfort climatic conditions prevail. This is due to the free movement of air masses in these territories. On the other hand, in closed-circuit areas frequent overheating in summer may occur (Osińska-Skotak, 2002). High constructions cause disturbances in air circulation (Gerst et al., 2011).

Urban sprawl reduces evaporation, which is an important element of the climate. Evaporation requires energy, which is taken from the environment in the form of heat. The result is a cooled air layer close to the ground. The high evaporation potential in summer means that the soil can make a significant contribution to the cooling of the air layer near the surface soil and thus to reducing the perception of the so-called hot island phenomena. Soil sealing leads to a significant reduction in evaporation. German researchers conducted a study for the city of Stuttgart, estimating the amount of energy absorbed. Evaporation absorbs about 2500 MJ per 1 m^3 of evaporated water. There are grey-brown podsolic soils in the Stuttgart area with an evaporation rate of 12075 GJ per hectare per year, while the evaporation capacity from 1 ha of the sealed area per year amounts to 2975 GJ. A hectare of sealed land causes an annual energy surplus of about 9100 GJ at the ground surface, triggered by the loss of the cooling function normally ensured by lessive soils under vegetation. The value of 9100 GJ is equivalent to an annual cooling effectiveness of approximately 9100 freezers with 270 l capacity and energy efficiency class A or roughly to the energy required to air-condition 20000 m^2 of office space during one summer (Höke et al., 2011).

Average results of temperature measurements at the detection points have shown that even in a small area the building has a significant impact on the temperature. In gully no. 1, temperatures ranged from 24 to 32 degrees Celsius (thermometer at a height of 1.5 m) (Fig. 5) and from 19 to 24 degrees Celsius (thermometer in the soil at a depth of 0.15 m) (Fig. 6). In gully no. 2 the temperature ranged from

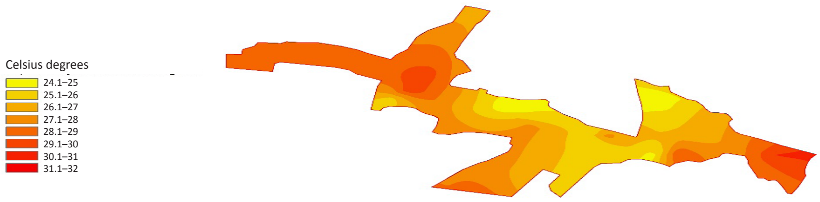

Figure 5. The distribution of air temperature at 1.5 m in gully no. 1 (authors' own study).

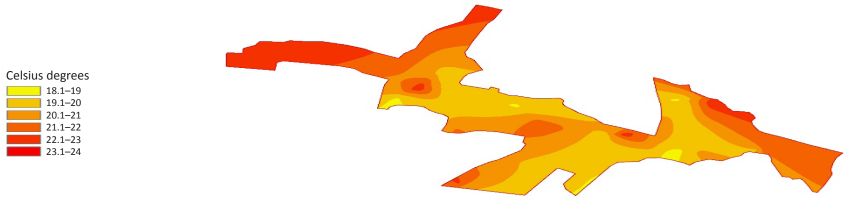

Figure 6. The temperature distribution in gully no. 1 – sensor in soil (authors' own study).

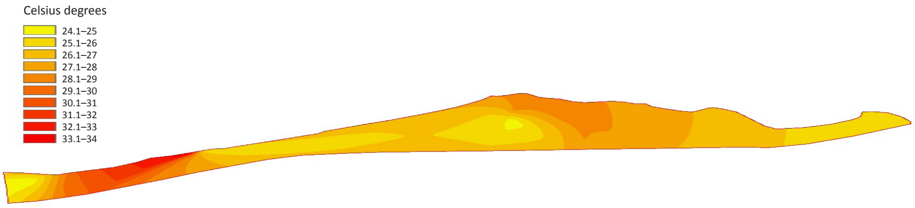

Figure 7. The distribution of air temperature at 1.5 m in gully no. 2 (authors' own study).

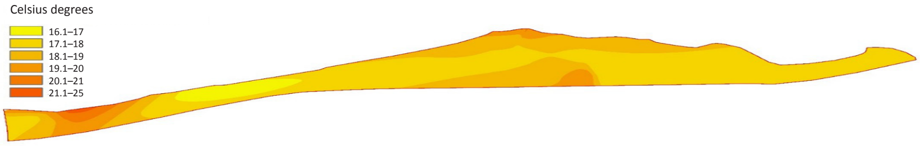

Figure 8. The temperature distribution in gully no. 2 – sensor in soil (authors' own study).

Figure 9. The air temperature amplitude at 1.5 m in gully no. 1 (authors' own study).

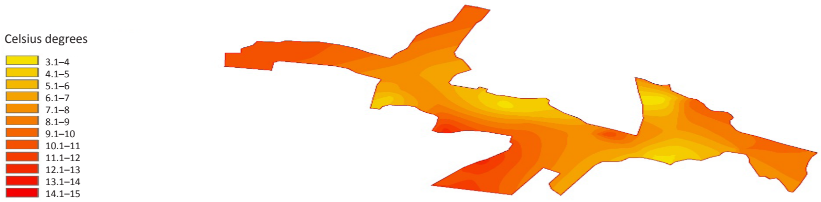

Figure 10. The temperature amplitude in gully no. 1 – sensor in soil (authors' own study).

24 to 34 degrees Celsius (thermometer at a height of 1.5 m) (Fig. 7) and the temperature recorded in the soil from 16 to 25 degrees (Fig. 8). In both cases, higher temperatures occurred near buildings and in areas with grass and low shrubs. A similar correlation was shown by studies conducted in Warsaw (Adamczyk et al., 2008).

Similarly, high variability was observed in the case of daily temperature amplitudes. In both cases, greater daily variability could be observed in the vicinity of buildings, while in areas where there were plantations and bushes the differences were very small. In gully no. 1, the amplitudes ranged from 5 to 17 degrees Celsius (thermometer at a high of 1.5 m) (Fig. 9) and from 3 to 15 degrees Celsius (thermometer in soil) (Fig. 10). In the second gully, on the other hand, the amplitude ranged from 10 to 21 degrees Celsius (thermometer at a height of 1.5 m) (Fig. 11) and from 2 to 13 degrees Celsius (thermometer in soil) (Fig. 12).

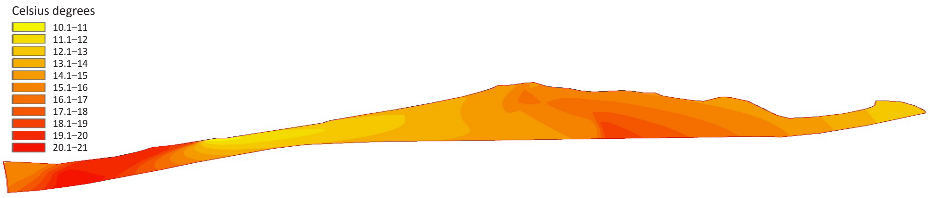

Figure 11. The air temperature amplitude at 1.5 m in gully no. 2 (authors' own study).

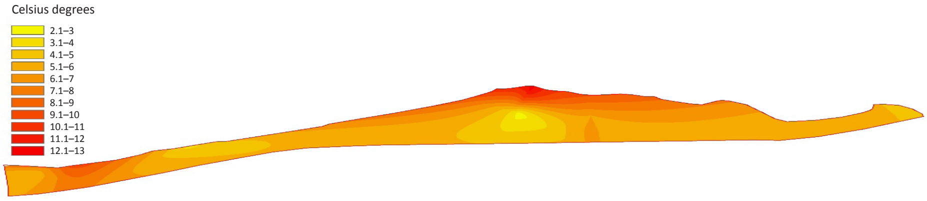

Figure 12. The temperature amplitude in gully no. 2 – sensor in soil (authors' own study).

The measurements taken in gullies have revealed that tall greenery in the form of trees and high shrubs has a greater capacity to limit temperature extremes than low greenery (low bushes and grass). At the same level of insolation and the contribution of the sealed area, temperature differences in areas with low vegetation were up to 7 degrees Celsius higher than in areas with tall vegetation, while the differences in daily amplitudes reached 12 degrees Celsius (Fig. 13). The research conducted by Kaszewski (2014) in Lublin in the Botanik gully (located in the northern part of the city) also demonstrated the cooling effect of high vegetation on air temperature.

Properly designed housing estate greenery and spatial distribution of different types of land use can improve climate conditions in built-up areas. Biologically active areas improve the thermal conditions of surrounding surfaces, even with a high proportion of sealed surfaces (Kuchcik, Baranowski, 2011). Vegetation contributes greatly to the formation of a microclimate, affecting air temperature and humidity, wind direction and speed, and air exchange conditions. Urban greenery also reduces traffic noise and retains pollution (Osińska-Skotak, 2002). Trees play a particularly important role in the modification of the urban climate, as they shade in summer (with dense foliage they can reduce the solar radiation inflow by up to 90%) and cool the air through evaporation. In turn, in winter they reduce the wind, thus contributing to reducing the loss of warm air from buildings, cutting the costs of heating and cooling. The amount of energy benefits obtained depends on the location of the tree and the structure and density of the crown. For instance, a large silvery maple is able to evaporate 265 l of water per hour on a hot summer afternoon. This volume of transpiration has a cooling effect comparable to that of five average size air conditioners (Szczepanowska, 2007).

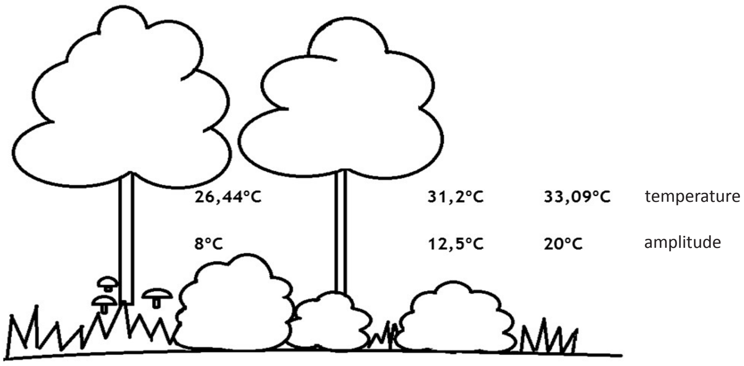

Figure 13. The variation in temperature and temperature amplitude depending on the height of vegetation on the areas of high degree of urbanization and average level of potential insolation (authors' own study).

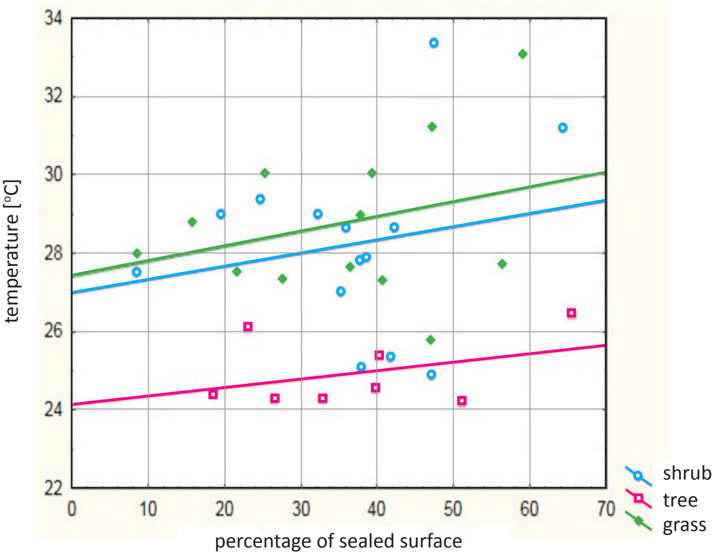

Figure 14. The relationship between the mean air temperature and the percentage of sealed surface around a given measurement point for various types of vegetation (authors' own study).

Statistical analyses showed a trend in the relationship between the share of sealed area in the vicinity of the measuring point, type of vegetation and air temperature (Fig. 14). In the literature, it is rare to find studies taking into account the simultaneous influence of both above mentioned factors on air temperature. In terms of land cover in the studied area, two groups can be distinguished – high vegetation (trees) and low vegetation (shrubs and grass). In locations with high flora, the temperature remained lower than in locations with low vegetation, regardless of the size of the sealed area. In points with a similar proportion of the sealed area, trees cool the air even by several degrees.

The presented measurement and analytical data document the influence of the proximity and size of the sealed area as well as the type of vegetation cover on the temperature and its daily variation in summer. In points with lower housing densities, temperatures are much lower and their amplitudes are narrower. The thermal conditions in the city are strongly influenced by the tree cover. The conducted research showed that the effect of buildings and green areas on thermal conditions in the city is very significant and even on small surfaces there may reach large differences in temperature (even up to several degrees).

CONCLUSIONS

1. The buildings affect the thermal conditions of neighbouring areas. Developed areas are up to 10 degrees Celsius warmer than undeveloped ones. In built-up areas, there is also greater daily temperature variation, with amplitudes up to 21 degrees Celsius. Elevated temperature and its high variability in built-up areas may adversely affect the quality of life of the inhabitants.
2. Vegetation has a positive effect on temperature in built-up areas. High vegetation has greater cooling properties than low plant cover. Tree-covered areas are 7 degrees Celsius cooler than areas covered with shrubs or grass. Moreover, the temperature amplitudes in these areas are considerably lower.
3. High vegetation improves thermal conditions near buildings. In locations with a similar percentage of the sealed area, the temperature was lower in the places with growing trees. It is important to introduce green areas with a predominance of trees in addition to built-up areas when urban spatial planning, which will have a positive impact on the quality of lives of city residents.

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