THE STUDY OF EFFECTS OF GREENERY ON TEMPERATURE REDUCTION IN URBAN AREAS

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Urban landscape is largely characterized by high degree of built space, high share of artificial surface material and the reduction of green areas, which leads to changes in the microclimate and the deterioration of thermal comfort in outdoor urban space. One of the most important roles of urban greenery is the impact on the reduction of air temperature due to less heating of green space compared to paved surfaces and due to tree shading. The paper analyses the influence of urban greenery on temperature reduction. Aim of the study was to measure the difference in warming up of grassy surfaces and paving materials commonly used for public areas and to evaluate the impact of tree shading on the surface cooling during the day. For this purpose, measuring of surface temperatures was performed during the summer months in 2015 in the central city zone of the city of Niš. The measuring included: grass, asphalt as most commonly used paving material, and concrete tiles commonly used for pedestrian areas. Results show the temperature of grass is significantly lower than the temperature of paved surface at any time of day. In the case of paved surfaces, temperature of shaded or partially shaded material is lower than the temperature of surface exposed to sunlight during the whole day, a temperature difference exists even after nocturnal cooling. The results indicate the importance of green areas for cooling of urban spaces, due to their lower warming and surface shading from tree canopy.

Key words: *urban green areas, surface temperature, urban heat islands, outdoor thermal comfort*

1. Introduction

Urban environment is defined as the physical environment in urban areas, with its complex mix of natural elements (including air, water, land, climate, flora and fauna) and the built environment, ie a physical environment constructed or modified for human habitation and activity encompassing buildings, infrastructure and urban open spaces [1]. The process of urbanization brought about changes in cityscape, reduction of green areas and increase of paved areas, and the changes of city climate and emergence of so called urban heat islands. Urban heat islands (UHI) represent the areas inside cities where the air temperature is higher than the air temperature of the surrounding area. With higher temperatures, energy consumption increases and air quality worsens, affecting directly and indirectly people's health and comfort [2, 3, 4]. The major factors, which affect air temperature, can be categorized in three groups: temporal effect variables - such as land surface temperature wind speed and cloud cover; permanent effect variables (spatial variables), such as land use/land cover urban morphology and building material and albedo; and, cyclic effect variables, such as solar radiation and anthropogenic heat [5]. The research aimed at reduction of negative effects of UHI, are mostly focused on materials and formation of urban area. When the effect of material on climate is concerned, numerous researches were conducted in America [6-9], Asia [10,11] and Europe [12, 13]. The authors agree that the surface temperature considerably affects the temperature of the surrounding air. The surface temperature is of prime importance to the study of urban climatology, because it modulates the air temperature of the lowest layers of the urban atmosphere, is central to the energy balance of the surface, helps to determine the internal climates of buildings and affects the energy exchanges that affect the comfort of city dwellers [14].

Green areas have a considerable impact on the reduction of temperature in cities owing to the higher albedo in comparison with the paving materials and evapotranspiration- combined loss of water to the atmosphere by evaporation and transpiration. Trees are particularly important from the aspect of cooling through evapotranspiration and shading. Evapotranspiration can create oases with 2–8 °C lower air temperatures that their surroundings and a cooling effects that extends out in to the surrounding area [15]. Urban vegetation or green infrastructure is very important because of its key role in mitigating urban heat island and climate change, but also for provision of multiple ecosystem services and aesthetics and improvement of the socio-environmental quality of life in cities [16, 17, 18]. There are numerous studies addressing the impact of green areas on urban microclimate improvement. Rahn et al. [8] compared the summer daytime surface temperatures of nine different pavement surfaces and a grass cover, over a nine week period in the hottest part of summer (2012, 2013) in Alabama. Results of the project indicate that darker pavements were hotter, while more reflective lighter pavements were cooler. Grass was the coolest of all surfaces tested and researchers suggest that grass surfaces might be used as a reference by which to measure all so called "cool pavements" – materials with high solar reflectance to the short wave radiation and a high emissivity (the ability to radiate absorbed, or non-reflected solar energy). Research shows that important energy gains are possible when light color surfaces are used in combination with the plantation of new trees. Use of high-albedo urban surfaces and the planting of urban trees are inexpensive measures that can reduce summertime temperatures [19].

Public open spaces are very important for everyday living because all civic, cultural and social activities occur there. Previous researches showed that outdoor thermal comfort directly affects the intensity of use of public open spaces and outdoor activities [20, 21], and that spatial characteristics as the form, configuration and combination of surface materials influence the urban microclimate [22]. The urban climate and outdoor thermal comfort can be improved by adopting cooling strategies. Vegetation can be very effective as it delivers several mechanisms of cooling simultaneously and in a complementary manner: evaporative cooling and evapotranspiration, reflectance and shading.

2. Scope of the research

The goal of the paper is determining difference in heating of green surfaces and standard carriageway and walkway pavements in order to assess the extent to which the green surfaces (grass lawns and trees) cool the surrounding air and to suggest measures for improvement of thermal comfort of selected main city square in the center of the City of Niš. To this end, temperatures of green areas (grass lawns) and characteristic paved surfaces (asphalt and concrete tiles) were measured. In order to determine the effect of shading on warming or cooling of paved surfaces, temperatures of asphalt paved surfaces with different amount of shading were measured. Measuring of temperatures was performed during the summer months of 2015 in the central city core of Niš.

2.1. Thermal properties of the material

Transfer of heat occurs in three ways: by conduction, by convection and by radiation. The Sun radiates electromagnetic waves which transfer heat. All bodies having temperature higher than the absolute zero radiate heat, but simultaneously absorb energy in the form of electromagnetic waves. The body surface area plays a significant role in that. The total radiation energy falling on a body is partially absorbed, partially reflected and partially let through.

Solar energy enters our atmosphere as shortwave radiation in the form of ultraviolet (UV) rays and visible light, the ground heats up and re-emits energy as long wave radiation in the form of infrared rays. Properties of surface materials such as: albedo, emissivity and absorption capacity affect the surface temperature and consequently the urban temperature. Research shows that albedo and emissivity are the factors with the greatest influence on the surface temperatures of materials [23,24].

Albedo or ability to reflect solar radiation denotes a value in the range 0-1 which presents which part of solar radiation is being reflected. Table 1 presents values of albedo for common paving materials as well as albedo of grass and trees. The value of albedo materials vary in time due to material ageing and pollution. Paving materials used in urban areas generally have a lower albedo than areas with vegetation; they reflect less and absorb more sunlight, which naturally results in higher surface and air temperatures. Emissivity determines the amount of long-wave radiation emitted by the surface, and as such the surface temperature. As for the emissivity, most of building materials (except metals) have high coefficients of emissivity (0.8-0.9) which means that they start to emit heat even at small increase of temperature. Materials which are used for paving have higher capacity for storage of heat than the natural materials which means that emission of heat from these surfaces during night is higher than emission of natural materials (soil, grass etc.). „Cool-materials“ are characterized by a high solar reflectance to the short wave radiation (the ability to reflect the visible, infrared and ultraviolet wavelengths of the sun, reducing heat transfer to the surface), and a high emissivity (the ability to radiate absorbed, or non-reflected solar energy). They are good emitters of long wave radiation and release the energy that has been absorbed as short wave radiation.

Table 1: The values of albedo of standard paving materials

Material	Albedo
Asphalt	0.04-0.15
Concrete	0.10- 0.35
Dark concrete tiles	0.05- 0.35
White concrete tiles	0.70
Grass	0.25-0.30
Trees	0.15-0.18

Source: combined from [13] and [24]

2.2. Impact of greenery on temperature reduction

Vegetation plays an important role in regulation of temperature in cities because it affects the cooling in several ways simultaneously, or via evapotranspiration, reflection of solar radiation and shading. Through evaporation, incoming energy is used to convert water into water vapor. Energy is being used to drive the evaporation process rather than being transferred to the sensible heat that we feel, thus air temperatures are lower. Where the water is within a plant, on its surfaces or in the soil, the process is termed evapotranspiration [25]. In the previous section, the concept of albedo and an impact on warming has been explained – lower albedo increases energy absorption and warming of surrounding air. Therefore, in the urban environments, where albedo is around 0.15 more heat is absorbed and retained than in the rural environment which has albedo of 0.2-0.25. As for the shading, greenery has multiple functions. The tree crowns prevent penetration of sunrays and prevent storage of energy and warming of the surrounding area which is the consequence of radiation of accumulated energy. In addition, shading reduces the direct gain of energy through windows and the resultant internal greenhouse effect, contributes to energy saving and reduce emission of waste heat energy. Eventually, the three crowns protect people from the direct exposure to sun radiation, which is very important because thermal discomfort is more affected by the direct exposure to solar radiation than by increased air temperature [26]. The cooling effect from a tree shade depends upon crown shape and density and tree density. Dense trees block more incoming solar radiation, reducing solar warming, but they also reduce light infiltration [27]. The impact of greenery on cooling depends on the size of the greenspace surface area, but also on the type of greenery and composition of green area. Honjo and Takakura suggested that a 100 m wide greenspace cools to a distance of 300 m and a 400 m wide greenspace cools to a distance of 400 m. They recommended that greenspaces should be no more than 300 m apart for optimum cooling within a neighborhood [28]. In addition to the role of greenspace size, the cooling effect around a greenspace is influenced by the type and composition of vegetation. Hart and Sailor analyzed air temperature data collected across the city of Portland, Oregon, and they reported that the most important urban characteristic separating warmer and cooler regions was tree canopy cover [29]. Noro and Lazzarin also reported that possitive effect of the greenery mitigation action is mainly due to the shadowing effect of trees [30].

3. Method of the research

The measuring of surface temperatures was conducted in the center of the city of Niš, on the main pedestrian surface. The city of Niš is located in the Niš valley, at 43°19′ latitude north and 21°54′ longitude east. The center of the city, near the central monument is at 194m above sea level. Niš has a moderate continental climate with the mean yearly temperature of 11.4 °C. The hottest month is July with the mean temperature of 21.3 °C, and the coldest month is January with the mean temperature of -0.2 °C. The measuring points were chosen because they are exposed to the sun for the most of the day, except those points which were intentionally chosen as shaded in order to determine differences in temperature of shaded and sunlit surfaces. The measurement was performed during the summer months (from 20th June to 20th September 2015) when the air temperatures are the highest and when the duration of insolation is the longest.

The recording was performed using a thermal vision camera E30 (FLIR Systems, Sweden) having thermal sensitivity less than 0,1 °C, accuracy ±2% of the detected temperature and photograph resolution 160×120 pixels. During the daylong measurements of surface temperature, daylong measurement of air temperatures were performed using manual thermometer of the type ODT 0302 (Iskra, Slovenia) sensitivity ± 0,1 °C, accuracy ±0,05 °C.

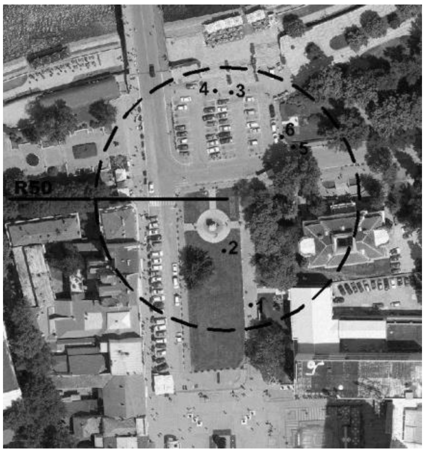
Since all the points are at the small distance, in the circle having radius of 50m, measuring was performed using one device and duration of measuring for all the marked points is in the range 10-20 min, which does not have a considerable impact to temperature variation. Prior to the start of recording temperature, two control measurements of surface temperature were performed using contact thermometer and thermal vision camera. It was found that deviations are small and that they do not exceed 0.1^{o} C. Contact thermometer requires more time for temperature detection, which would increase time span of temperature measuring to more than an hour, and for that reason measurements were continued using thermal vision camera. Measurements were performed only during the clear days, most of them being in the time between 14:30 and 16:00h. This time period was chosen after it was found that the temperatures of measured surfaces were the highest. In addition, “random measurements” at different times of day were performed, as well as two daylong measurements of temperatures with a pause of an hour from 06:00 to 22:00h, one on 08th July and other on 10th August. Measurements were performed on days with clear weather without clouds (max cloudiness 4/10). During the measurement period, there were minimal to no winds (max wind speed 2.4 m/s). Daily insolation ranged from 8.6 to 11.8 h. Since the surface temperatures mostly depends on air temperature, wind speed, solar irradince and albedo of the surface; the albedo values of standard paving materials are shown in Table 1 and the meteorological data for measurment period are shown in Table 2.

Table 2: Meteorological data for measurement period

Date and time	05.07. (16:00h)	06.07. (15:45h)	11.07. (15:30h)	13.07. (15:30h)	15.07. (15:15h)	16.07. (15:30h)	19.07. (15:45h)	20.07. (14:00h)	22.07. (14:50h)	25.07. (15:30h)	27.07. (15:00h)	03.08. (15:00h)	08.08. (16:00h)	14.08. (06:00h)	18.08. (19:30h)	19.08. (06:00h)	19.08. (16:00h)	21.08. (16:10h)	23.08. (07:00h)	04.09. (15:45h)	18.09. (17:40h)	26.08. (13:00h)	28.08. (18:00h)	30.08. (15:30h)	04.09. (15:45h)	18.09. (17:40h)	18.09. (19:00h)
AT (°C)	31	33	27	29	30	32	37	34	36	35	32	36	36	22	28	16	31	22	15	31	23	28	31	35	35	36	34
WS (m/s)	2.4	0.8	2.4	2.4	2.4	0.8	0.8	2.4	2.4	0.8	2.4	0.8	2.4	0.0	0.8	0.8	0.0	0.8	0.0	0.8	0.0	0.8	0.8	2.4	2.4	2.4	2.4
ASI (W/m^2)	565	712	759	676	856	727	703	859	885	716	794	732	685	234	76	166	665	641	15	586	523	830	228	578	558	101	0

AT - air temperature, WS - wind speed, ASI - average solar irradiance; *Source: Republic Hydrometeorological Service of Serbia*

For the needs of analysis of mutual relationship of temperatures measured on pedestrian surfaces and air temperatures, data of the meteorological station Niš were used, from the measuring point closest to the location where surface temperature was measured. The measurement included six measuring points, four of which were exposed to sunlight the whole day: grass area, concrete slabs, lighter and darker asphalt; and two points on the asphalt surfaces which were in partial or full shade during the day. The position and description of measuring points are shown in Fig.1.



Measuring points	Pavement
Point 1	Concrete tiles
Point 2	Grass
Point 3	Dark asphalt - sunlit
Point 4	Light asphalt - sunlit
Point 5	Asphalt - shaded
Point 6	Asphalt - partly shaded

Figure 1: Position and description of measuring points

4. Results and discussion

4.1. Measurements of temperatures of different pavement materials

Temperatures of surfaces during daylong measurements were presented in Tab. 3 and Fig. 2. In Tab. 3 the color was used to indicate dynamics of temperature variation of each of the points, from the lowest (20°C – light grey) to the highest (60°C – dark grey).

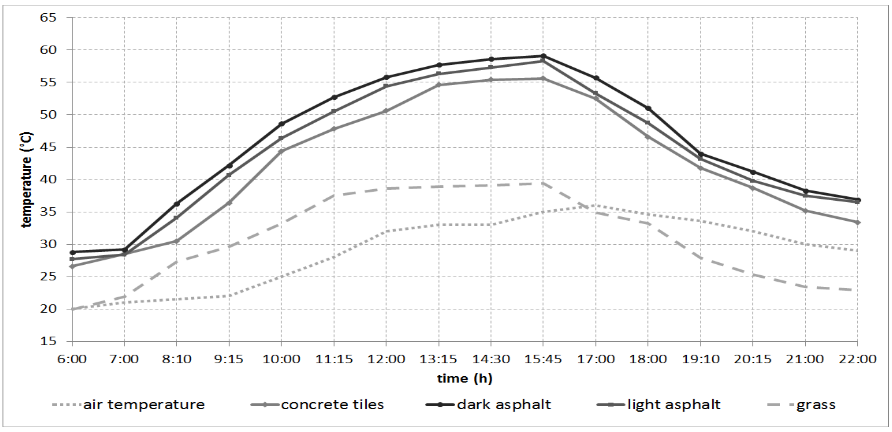


Figure 2: Daylong variation of air and surface temperature

Table 3: Graduated presentation of air and surface temperature variation

TIME/TEMPERATURES	6:00	7:00	8:10	9:15	10:00	11:15	12:00	13:15	14:30	15:45	17:00	18:00	19:10	20:15	21:00	22:00
									20-25	25.1-30	30.1-35	35.1-40	40.1-45	45.1-50	50.1-55	55.1-60
air temperature	20	21	21.5	22	25	28	32	33	33	35	36	34.6	33.6	32	30	29
concrete tiles	26.6	28.5	30.5	36.4	44.4	47.8	50.6	54.6	55.4	55.6	52.5	46.6	41.8	38.7	35.2	33.4
dark asphalt	28.8	29.2	36.3	42.2	48.6	52.7	55.8	57.7	58.6	59.1	55.7	51	44	41.2	38.3	36.9
light asphalt	27.7	28.4	34.1	40.7	46.4	50.5	54.4	56.3	57.3	58.3	53.3	48.7	43.2	39.8	37.5	36.5
grass	19.9	21.9	27.3	29.6	33.2	37.5	38.6	38.9	39.1	39.4	34.9	33.2	27.9	25.3	23.4	22.9

Daylong measurement indicated that all materials reach maximum temperature in the period between 14:30 and 15:30h. The highest measured temperature during the daylong measurement was the temperature of dark asphalt (59.1°C) in the period between 15:00 and 16:00h. The temperature of lighter asphalt during the whole day was lower than the temperature of dark asphalt for 1-2°C. The concrete tile surface reaches the maximum temperature of 55.6°C, which is 3-4°C lower than the temperature of asphalt (59.1°C). The lowest measured temperature of surface is the grass area temperature which in the hottest part of the day would not exceed 40°C, which is for 20°C less than the temperature of the hottest material – asphalt. It is worth noticing that in the afternoon hours the temperature of grass surface starts to decrease, so after 17h the temperature of grass is lower than the air temperature, and from 19h to the last measurement of the day at 22h, this difference is 5-7°C.

The differences in air temperature and the hottest material temperature range from 7-9°C in the morning (first measurement at 06:00 and last at 22:00) to 24°C at the hottest part of the day, which indicates that heat of pedestrian surface during the day considerably contributes to the increase of surrounding air temperature. The difference in temperature between the coolest material (grass) and hottest material (dark asphalt) range between 9°C in the morning and evening (first measurement at 06:00 and the last at 22:00) and 19.7°C at the hottest part of the day.

Figure 3 shows the measurement results of air temperature and temperature of concrete tiles, dark asphalt and grass in the course of the entire measuring period. The air temperature during the measuring period ranged between 15 °C in the morning up to 37 °C in the hottest part of the day. The temperature of the hottest material (dark asphalt) ranged between 25.3 to 61.5 °C, so that the difference of air temperature and the hottest material was between 10 and 24.5 °C. The smallest differences between the air temperature and the hottest surface were found in early morning hours, while the largest differences were found at the hottest time of the day.

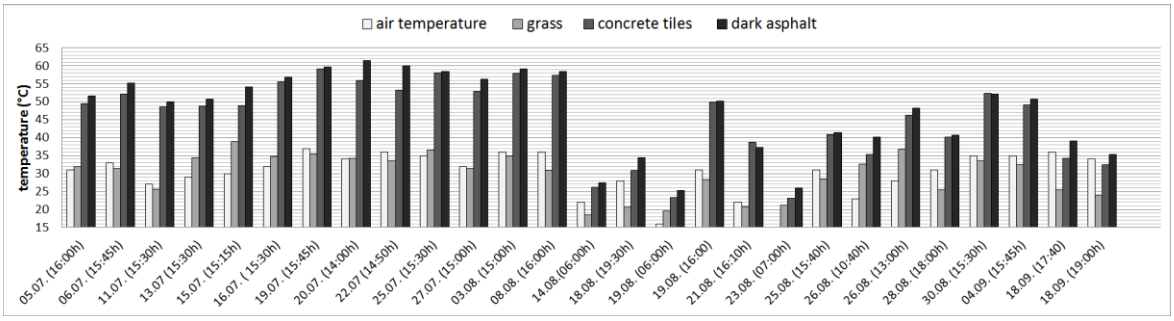


Figure 3: Temperatures of air and the chosen materials in the course of the entire measuring period

After the daylong measuring of temperatures had confirmed that air and surface temperatures were the highest in the period between 14:30-16:00, a large number of measurements were conducted in this part of the day with the goal to determine the maximum surface heating up. In this part of the day, the air temperature varied in the range from 27 °C to the maximum of 37 °C (Δt=10 °C)

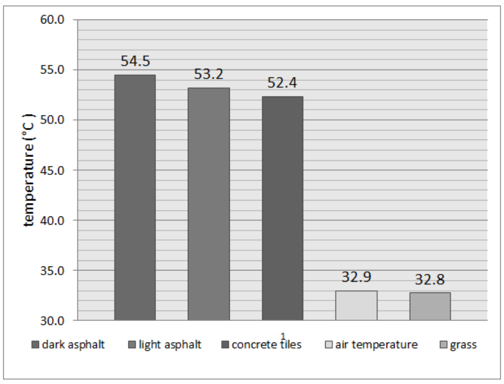


Figure 4a Mean maximum temperatures of surfaces for the entire measuring period (5th July-18th September 2015)

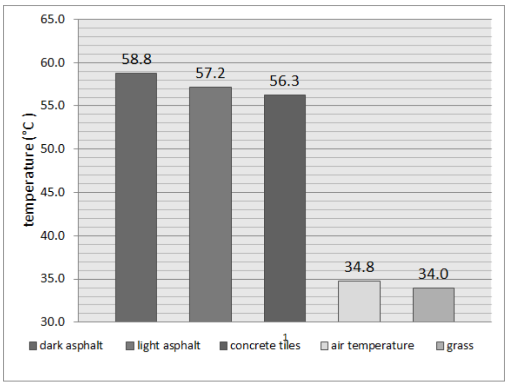


Figure 4b Mean maximum temperatures of surfaces for the hottest period of the year (15th July to 15th August 2015)

The calculation of mean maximum air and surface temperatures was performed during the entire measuring period from 5th July to 18th September (whole period temperatures - WPT) (Fig. 4a) and during the hottest part of the year from 15th July to 15th August (hottest period temperatures - HPT) (Fig. 4b). For calculation of mean maximum temperature only the measurements performed at the hottest part of the day – between 14:30-16:00h were taken. Dark asphalt was assumed as the hottest material (WPT - 54.5 °C, HPT - 58.8 °C), followed by light asphalt (WPT - 53.2 °C, HPT - 57.2 °C) and concrete slabs (WPT - 52.4 °C, HPT - 56.3 °C). The lowest temperatures, as expected, were reached by the grass surface (WPT - 32.8°C and HPT - 34 °C) which was lower than the mean maximum air temperature (WPT - 32.9, HPT - 35 °C).

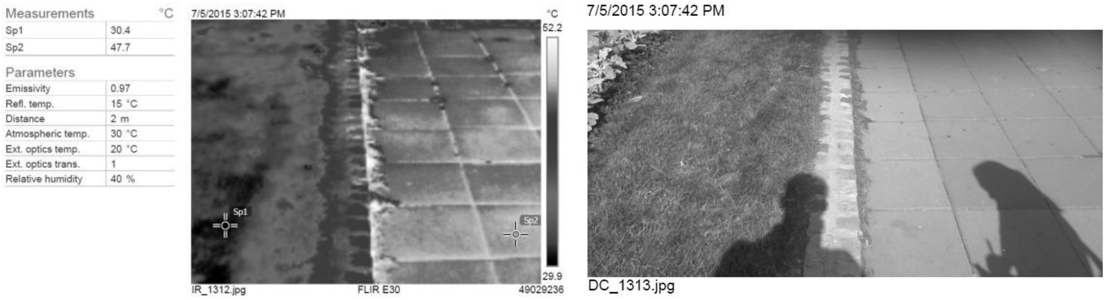


Figure 5: Thermogram (left) and photo (right) of adjacent grassy area and the area paved with concrete slabs

Diagrams (Fig. 4a, 4b) show that the grass temperature during the whole measurement period and during the hottest period is around 20°C lower than the temperature of paved surfaces. Thermogram (Fig. 5) of adjacent grassy area and the area paved with concrete slabs shows the same temperature difference The temperature on thermogram range between 29.9°C (dark grey color on grassy area) and 52.2°C (light grey on concrete slabs joints). The obtained measurement results correspond with the previous research [8, 9] and they indicate the role of the green spaces in cooling of the cities and importance of preservation of green surfaces in cities. Measuring of temperature of light and dark asphalt indicate that the temperature of the light asphalt is 1-2°C lower than the temperature of dark asphalt during the daylong measurement and during the whole measuring period (Fig. 2, Fig. 3), which is in line with the results of other authors [17, 23] who recommend usage of lighter materials in urban environments because of less warming.

4.2. Impact of shading on surface temperature

The effect of tree shading on surface temperature is shown in Fig. 6. Temperature of the points exposed to sunlight the whole day gradually raises during the day (with the constant difference in temperature from 0.8-2.4 °C between dark and light surfaces). Dark asphalt riches the temperature of 55.8 °C at 12h, while partly shaded asphalt reaches the same temperature in the hottest part of day, between 15:00 and 16:00. The temperature of dark asphalt in the hottest part of the day is 59.1 °C. The highest measured temperature of point 5 (almost in daylong shade) is 47.9°C, which means that shaded surface is 11 °C cooler than the surface exposed to sunlight the entire day. The highest temperature of partly shaded asphalt is 55.6°C which is 3.5°C lower than the temperature of the hottest dark asphalt. Shaded or partly asphalt never reaches the maximum temperature of dark asphalt exposed to sunlight. On the other hand dark asphalt exposed to sunlight the entire day never reaches the minimum temperature of shaded asphalt - its temperature remains higher than the temperatures of the shaded or partly shaded surfaces even after nocturnal cooling down. The characteristic of asphalt to heat up quickly by accumulating large amounts of heat energy results in abrupt rise of temperature of partly shaded asphalt when it is exposed to sunlight.

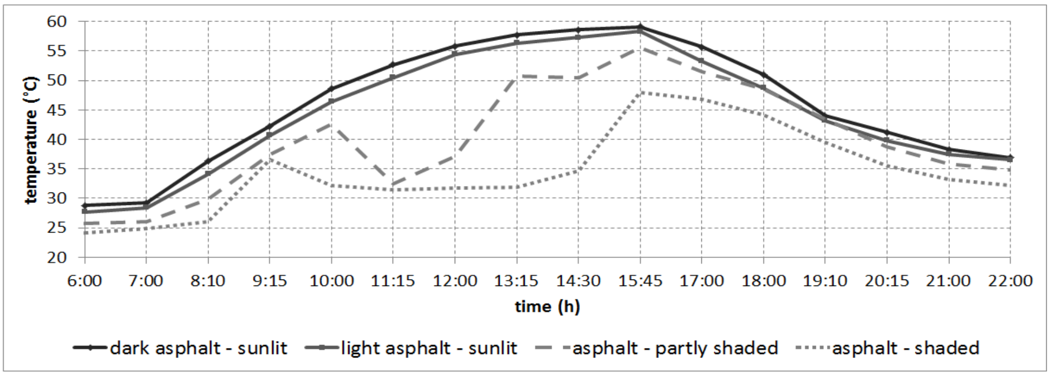


Figure 6: Daylong measuring of temperature of asphalts of different colors and shade

4.3. Mitigation strategies for public open spaces

The results of measurement showed that grass is the coolest material which is in line with other researches [8, 9], but during the measurements it was noticed that most of people were walking through the square, no one was standing in the sun, and few people were standing in the shadow. Even though the temperature of grass is significantly lower than the temperature of paved surface, there were no people near the grassy area except in the shadow. This is in line with other researches reporting that people prefer staying in shaded areas at higher temperatures [29, 30]. Having in mind the purpose of the main city square, number of people and the frequency of use, it is necessary to consider both the function and the users' comfort when designing such space. The comparison of results presented in Fig. 2 and Tab. 3 with results presented in Fig. 6, showed the temperature of shaded asphalt is lower than temperature of grassy areas exsposed to sunlight in the same period of day (10:00 -16:00 h). These results point out the importance of high greenery for urban heat islands mitigation as also proved by other authors [31, 32]. Shading has twofold effect – decreases heating up of paving materials and protects people from direct sunlight. This is particularly important for design of urban public spaces for intensive pedestrian use - squares and pedestrian streets, since grassy areas are not suitable for this kind of spaces. Based on the results of the study, the improvement of microclimate conditions and pedestrians' thermal comfort can be achieved by:

- Replacement of hot pavement materials with cooler materials (for example, replacement of asphalt with concrete tiles);
- Increasing grassy areas (if possible) together with planting trees;
- Increasing the height of buildings edging the square, especially on the western edge, to provide better shading in afternoon hours when the air temperatures and heating of pavement materials are the greatest;
- Planting trees that has both shading and cooling effects and doesn't occupy much of useful surface, when large paved areas are needed (city squares, pedestrian streets, parking lots, etc.) and the usage of grass is not appropriate.

5. Conclusions

The process of urbanization brought to reduction of green areas, increase of paved areas, changes of city climate and emergence of urban heat islands. Optical characteristics of materials which have a very important impact to the urban energy balance are albedo and emissivity of long wave radiation. Use of high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures, and keeps their surfaces cooler. Materials with high emissivity are good emitters of long wave radiation and they readily release the energy that has been absorbed as short wave radiation. Lower surface temperatures contribute to decrease of temperature of the ambient air, as heat convection intensity from a cooler surface is lower. Contrary to the cool roofing materials which have been greatly improved, the cool paving materials are still underdeveloped, since many additional factors, such as: wear and contamination of the surface due to pedestrian and car traffic which alter the properties of the surface layer of the material, heating up due to the reflected radiation in urban canyons, shading caused by people and cars, vegetation and neighboring structures and others, must be taken into consideration in the case of paving materials.

The results show that there are significant differences in temperatures of different paving materials. Asphalt proved to be the hottest material in the course of measuring, while the grass is the coolest material such as expected. Temperature of asphalt, dark and light, is always higher than the temperature of concrete tiles, which means that on the surfaces intended for pedestrians, where different materials (concrete tiles, stamped concrete, marble slabs etc.) can be used, asphalt should be avoided. Surface shading has a significant impact on the reduction of heating up. Measurements indicate that shaded material has a considerably lower temperature than the same material exposed to sunlight the whole day. These results highlight the importance of high greenery in cities as it assist cooling by shading and additionally through evapotranspiration. The results of this study show that improvement of microclimate in the cities can be achieved by use of cooling strategies: use of light-colored surfaces and increase of green areas in cities.

In the further research, it is necessary to analyze in detail various properties of materials, in addition to the thermal ones (safety, durability, wear resistance, water impermeability etc.) in order to determine which of them have the best characteristics to be used in pedestrian or carriageway surfaces. It is also necessary to examine impact of the size and shape of open spaces and surrounding buildings on warming of paved areas. As for the green spaces in cities, further research should be directed to examining potential for compensation of lost green spaces by introducing planted trees and green roofs and facades.

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