POSSIBLE LOCATIONS FOR COOL PAVEMENT USE IN CITY OF RIJEKA

Marijana Cuculic
Faculty of Civil Engineering, University of Rijeka
Radmile Matejcic 3, Rijeka, Croatia
marijana.cuculic@gradri.hr

Sanja Surdonja
Faculty of Civil Engineering, University of Rijeka
Radmile Matejcic 3, Rijeka, Croatia
sanja.surdonja@gradri.hr

Sergije Babic
Faculty of Civil Engineering, University of Rijeka
Radmile Matejcic 3, Rijeka, Croatia
sergije.babic@gradri.hr

Aleksandra Deluka Tibljas
Faculty of civil engineering, University of Rijeka
Radmile Matejcic 3, Rijeka, Croatia
deluka@gradri.hr

ABSTRACT

Heating pavement or the accumulation of heat in the pavement contributes significantly to the average temperature increase in modern urban environments. Because the portion of traffic areas in city centres is significant, application of pavement structures that reduce the effect of warming is one of the strategies that can help mitigate the urban heat island effect.

A large part of central city areas is covered with asphalt pavements. A significant problem of the City is the absence of green areas. The City centre has large parking areas which are constructed as standard asphalt pavements without greening. These areas greatly contribute to the average temperature increase in the City. In addition to reducing the urban heat island effect, cool pavements which can replace the standard pavement construction in the City of Rijeka may contribute to a better storm water management, night-time illumination, noise reduction and pavement deformation prevention which are typical for large longitudinal grades (rutting, shoving ...). A large part of pedestrian areas is suitable for reconstruction by using cool paving materials and, due to their sufficient wideness, can certainly be enriched by planting urban trees.

The aim of this paper is to present temperature trends of the covering surfaces in the centre of the City compared to the same surfaces of the surrounding area and the measured air temperatures during the summer. The paper will show results of temperature measurements on surfaces of different types of pavements (such as asphalt, concrete, stone ...) in several different locations. The result of the paper is a review of possible locations where the use of cool pavements is a solution to reduce urban heat island effect and improve the quality of life in the city.

Key words: cool pavements, urban heat island effect, temperature

1 INTRODUCTION

Modern urban cities have typically more built areas, darker surfaces and less vegetation than their surroundings. These differences affect the climate, energy use and habitability of the cities. Since the built environment absorbs and stores solar energy, the temperature in cities can be several degrees higher than in the surrounding suburban and rural areas. This is known as the urban heat island effect (UHI) and has been researched widely in the last decade (Akbari H., Pomerantz M., and Taha H., 2001).

Pavements typically comprise 30 to 45 percent of the land area in major cities and contribute significantly to the UHI through low reflection of solar radiation and high levels of thermal storage. Pavement surface temperatures exceed 60°C on some days in summer and does not evapotranspire water, unlike soil and other forms of natural land cover (Akbari H., Pomerantz M., and Taha H., 2001).

The causes of the urban heat island can lead to the approaches that could reduce the intensity of the urban heat island effect. In this sense, albedo is a very important material characteristic. Albedo or reflection coefficient is the diffuse reflectivity or reflecting power of a surface. It is defined as the ratio of reflected radiation from the surface to incident radiation upon it. Being a dimensionless fraction it may also be expressed as percentage and is measured on a scale from 0 for no reflecting power of perfectly black surfaces to 1 for perfect reflection of a white surface. If the albedo and/or vegetative cover can be increased in urban areas, there is a prospect for reducing urban air temperatures with the associated benefits in terms of air quality and energy consumption (Syneffa A., Dandou A., Santamouris M., and Tombrou M., Soulakellis N., 2008).

Use of high-albedo urban surfaces and planting of urban trees are inexpensive measures that can reduce summertime temperatures. A large part of pedestrian areas is suitable for reconstruction by using cool paving materials and, due to their sufficient wideness, can certainly be enriched by planting urban trees. Akbari et al. differentiate the “direct” and the “indirect” effects of planting trees around buildings. The direct effect is to alter the energy balance and cooling requirements of that particular building. However, when trees are planted and albedo is modified throughout an entire city, the energy balance of the whole city is modified, producing city-wide changes in climate. Phenomena associated with city-wide changes in climate are referred to as indirect effects (Akbari H., Pomerantz M., and Taha H., 2001).

The temperature analysis on different surface types on a public parking space in centre of the town Kobe has shown that grass-covered parking lots not only improve the visual picture of the city centre but also significantly reduce the heat radiation during the night (Takebayashi H., Moriyama M., 2009).

One of the measures for reducing urban heat island effect is use of cool pavements. Cool pavements include a range of established and emerging technologies that communities have been exploring as part of their heat island reduction efforts. The term currently refers to paving materials that reflect more solar energy, enhance water evaporation or have been otherwise modified to remain cooler than conventional pavements. Cool pavements can be created with existing paving technologies (such as asphalt and concrete) as well as newer approaches such as the use of coatings or grass paving and also do not necessarily require new materials. Cool pavement technologies are not as advanced as other heat island mitigation strategies and there is no official standard or labelling program to designate cool paving materials (EPA, 2008). Cool pavements are defined as paving materials that tend to reflect, provide cooler surfaces and increase water evaporation ratio. Possible mechanisms for creating a cool pavement that have been studied to date are:

a) increased surface reflectance which reduces the solar radiation absorbed by the pavement (conventional concrete, roller-compacted concrete, white-topping and ultra-thin white-topping, asphalt concrete and asphalt chip seals with light-coloured aggregate, asphalt pavements with modified colour);

b) increased permeability, which cools the pavement through evaporation of water (porous pavements);

c) a composite structure for noise reduction which has also been found to emit lower levels of heat at night (a rubber asphalt surfacing) (EPA, 2005).

Cool pavement costs will depend on many factors including, but not limited to: region, local climate, time of year, accessibility of the site, underlying soils, project size, expected traffic, the desired life of the pavement. Besides the benefits and costs listed above, the benefits and cost considerations should include environmental social, and economic aspects, rather than just the economic one. The general initial construction cost for a cool pavement might be higher than that for a regular conventional pavement. However, life-cycle cost analysis can help in evaluating whether long-term benefits can outweigh initial costs. (EPA, 2008).

Rijeka is the largest Croatian port and a typical Mediterranean city. According to Köppen climate classification, Rijeka has a moderately warm and humid climate (type CF). The average air temperature in the city is 13.8°C, the mean temperature in January is 5.6°C, while the mean temperature in July is 23.3°C. It rarely snows in winter and temperatures can reach even 40°C in summer (June, July and August).

Area of the City of Rijeka is about 44.000.000 m^2 and the area of the city centre, which is the subject of this work, is approximately 600.000 m^2 (Figure 1). The city developed in the foothills of the mountains which prevented its expansion into the interior and caused its spreading in the direction NW-SE, by the sea. Due to the nearness of the mountains the altitude varies from 0-500 m above sea level. Also, due to differences in altitude, there is a difference in air temperature between the city centre, which is at around 0 meters above the see level, and the suburban and rural areas, which are at 250-500 meters above sea level. The difference is present in all seasons.

Figure 1: Centre of the City of Rijeka

The aim of this paper is to analyze the surfaces used within the centre of the city and to analyze their behaviour during summer months when the surfaces heat up and release heat energy that is directly related to quality of life in the centre. The paper will also suggest potential areas in the city centre where it is possible to apply the cool pavements in order to reduce the urban heat island effect.

The centre was chosen for analysis because of the large number of people who daily live in it or pass through it, either for residential, business or tourist purposes. A large part of the central city area is covered with asphalt pavements. A significant problem of the City is the absence of green areas which reduce the urban heat island effect and contribute to a better quality of life. Centre of Rijeka has many large parking areas which are constructed as standard asphalt pavements without greening. These areas greatly contribute to increasing the average temperature in the city.

2 DESCRIPTION OF THE PILOT-STUDY CARRIED OUT DURING THE SUMMER OF 2011 IN THE CENTRE OF RIJEKA

In order to establish the behaviour of materials commonly used as the final layers of road pavements in the city, the pilot-study of pavement surface temperatures was carried out at several locations in the city centre. The study was carried out during the summer period of 2011 when the maximum pavement surface temperatures and maximum air temperatures were expected. 40 test points were selected for the study. The selected test points were located on asphalt surfaces, on different types of stone, on concrete surfaces and on green areas. Test points were located in pedestrian areas or exposed to vehicle traffic (streets and parking lots). In order to establish the conditions of insolation of the points, 2 all-day measurements (first on 12.07.2011 from 6.00 till 22.00 and the second on 15.09.2011 from 7.00 till 19.00) were carried out. A total number of 80 measurements at each test point (more than 3000 measurements) were carried out, 35 of which during the all-day measurements of temperature. The remaining measurements were carried out during the daily maximum air temperature values. Test points were located on two busy city streets (Riva street and Riva Boduli street) and on the pedestrian zones (Jelacic Square, Uzarska street, Zrtava fasizma street, Janeza Trdine street and Korzo street). All locations are shown in Figure 2.

Figure 2: Location of test points around the city centre.

At the Location 1 (Riva Street), 12 test points were marked, 6 of which on the asphalt surfaces and 6 on the stone surfaces. Test points are shown and described in Figure 3.

Num. of test point	Type of surface and colour	Type of traffic load	Period of insolation
R1.	Stone, darker	Pedestrians	7.00-20.00
R2.	Stone, lighter	Pedestrians	7.00-20.00
R3.	Stone, darker	Pedestrians	8.00-20.00
R4.	Granite cubes, darker	Vehicles	8.00-20.00
R5.	Asphalt, darker	Vehicles	8.00-20.00
R6.	Asphalt, lighter	Pedestrians	11.00-19.30
R7.	Asphalt, white strip on pedestrian crossing	Vehicles	8.30-19.15
R8.	Asphalt, darker	Vehicles	8.30-19.15
R9.	Asphalt, lighter	Pedestrians	shade
R10.	Asphalt, darker	Pedestrians	10.00-15.30
R11.	Stone, lighter	Pedestrians	11.00-16.30
R12.	Stone, darker	Pedestrians	11.00-16.40

Figure 3: Test points at the Location 1.

At the Location 2 (Riva Boduli street), 12 test points were marked, 4 of which on the asphalt surfaces, 3 on the concrete surfaces, 4 on the stone surfaces and 1 test point on the green surface. Test points are shown and described in Figure 4.

Num. of test point	Type of surface and colour	Type of traffic load	Period of insolation
B1.	Stone, lighter	Pedestrians	8.15-20.25
B2.	Stone, darker	Pedestrians	8.15-20.25
B3.	Concrete, darker	Pedestrians	9.00-20.20
B4.	Concrete, lighter	Pedestrians	9.00-20.20
B5.	Concrete, lighter	Vehicles	10.30-20.20
B6.	Green surface	/	shade
B7.	Asphalt, lighter	Vehicles	11.00-17.30
B8.	Asphalt, darker	Vehicles	11.00-17.30
B9.	Asphalt, white strip on pedestrian crossing	Vehicles	10.00-19.00
B10.	Asphalt, darker	Vehicles	10.00-19.00
B11.	Stone, lighter	Pedestrians	11.30-19.00
B12.	Stone, darker	Pedestrians	11.30-19.00

Figure 4: Test points at the Location 2.

At the Location 3 (Jelacic Square), 8 test points were marked, 3 of which on the asphalt surfaces, 1 on the concrete surface and 4 on the stone surfaces. Test points are shown and described in Figure 5.

Num. of test point	Type of surface and colour	Type of traffic load	Period of insolation
J1.	Asphalt, darker	Vehicles	7.00-17.15
J2.	Concrete, lighter	Pedestrians	7.00-17.15
J3.	Stone, darker	Pedestrians	7.00-17.15
J4.	Stone, lighter	Pedestrians	7.00-17.15
J5.	Stone, darker	Pedestrians	7.30-17.15
J6.	Stone, darker	Pedestrians	8.30-13.45
J7.	Asphalt, lighter	Pedestrians	11.00-12.30
J8.	Asphalt, lighter	Pedestrians	9.30-12.30

Figure 5: Test points at the Location 3.

Locations 4, 5 and 6 were selected in the pedestrian zone, with a smaller number of the test points because the "offer" of pavement surfaces is reduced only to stone surfaces (which are commonly used in most pedestrian zones in the city centre) and concrete surfaces (Location 4). Concrete surfaces at the Location 4 were selected because of the different colours of the concrete; a test point at Location 5 was chosen because it is in the shade the whole day long and two test points at the Location 6 were selected because they are placed on stone surfaces contrary exposed to the sun during the day (Table 1).

Table 1: Test points at Location 4, 5 and 6.

	Num. of test point	Type of surface and colour	Type of traffic load	Period of insolation
Location 4	N1.	Concrete, red	Pedestrians	7.00-17.00
	N2.	Concrete, green	Pedestrians	7.00-17.00
	N3.	Concrete, blue	Pedestrians	7.00-17.00
	N4.	Concrete, yellow	Pedestrians	7.00-17.00
	N5.	Concrete, natural grey	Pedestrians	7.00-17.00
Location 5	T1.	Stone, darker	Pedestrians	shade
Location 6	K1.	Stone, lighter	Pedestrians	10.45-17.30
	K2.	Stone, darker	Pedestrians	8.00-10.40

3 ANALYSIS OF PILOT-STUDY RESULTS

A large number of test points at different locations enabled temperature change analysis of different materials under various conditions. This paper presents the results of all day measurements on test points R5, R9 (Location 1), B6 (Location 2) J1, J2 and J3 (Location 3). Air temperature was recorded at the measuring station “Nikole Tesle” (NT) in the city centre. During all-day observations, weather conditions were stable for past few days, meaning, without any rain, clouds and wind.

The mean daily air temperature measured on 12.07. was 32.0˚C and on 15.09. 28.5˚C. The difference between the minimum and the maximum air temperature was 10.9˚ C (on 12.07.) and 8.0˚ C (on 15.09.2011.). The maximum air temperature was recorded in the afternoon at 16:00 on 12.07.2011 (35.1˚ C) and at 13:00 on 15.09.2011 (31.9˚ C). High air temperature was retained until the evening hours and significantly decreased after 20:30 (Fig. 7).

Diagram of temperature changes of the surfaces exposed to sunlight (Fig.7) shows a different daily change. The maximum surface temperature for different materials was recorded at 15:30 when the accumulation stopped and the heat release and transfer in the environment started rapidly, which resulted in maintaining high air temperature. After 18:00 the cooling of the surface was slower and continual until next exposure to the sunlight.

Different materials behave very similarly under the same conditions. A common feature of all test points is a significant increase in surface temperature under the influence of solar radiation.

All-day measurements showed the periods, the size and direction of heat transfer between the pavement surface and the environment. The similarities in the behaviour of different materials and the influence of different environmental conditions were noted.

Figure 6 shows the test points J1, J2 and J3 on Location 3. Concrete curb (J2) separates the asphalt surface (J1) from the stone surface (J3). All three points are located at a distance of about 0.4 m and under the same external conditions. Infrared picture of these points clearly shows the different surface materials.

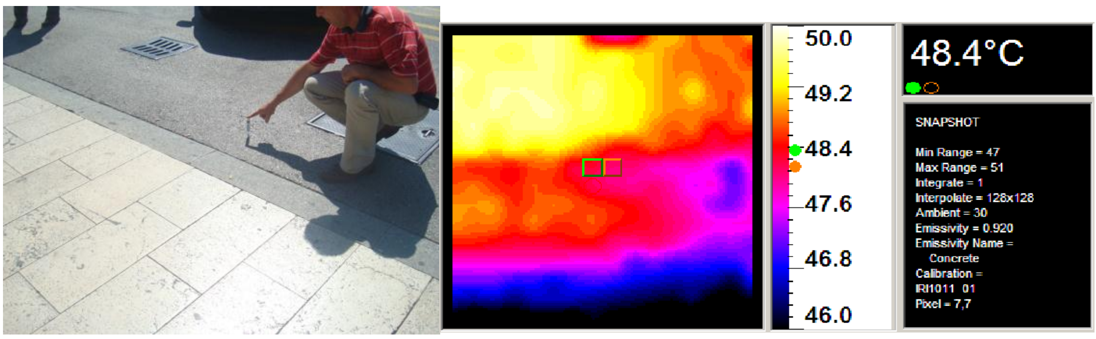

Figure 6: Test points J1, J2 and J3 at the Location 3.

Figure 7 shows a daily change of surface and air temperature at the same test points on 12.07.2011. Asphalt surface (J1) has the highest measured temperature of 60.9˚C, which is 3.6˚C higher than the one of the concrete surface (J2), 8.1˚C higher than the stone surface (J3) and even 26.7˚C higher than the air temperature. Mean temperatures are more even (Fig. 7) and temperature differences are significantly lesser; 0.9˚C between the asphalt and the concrete surface and 2.9˚C between the asphalt and the stone surface.

	6:02	6:30	7:00	7:32	8:00	8:33	9:02	9:32	10:02	10:34	11:05	11:31	12:00	12:31	13:13	13:45
J1.	26,7	27,5	29,0	31,4	33,3	36,3	38,4	39,3	44,4	47,4	48,6	52,4	55,3	56,3	58,8	59,6
J2.	27,7	27,8	29,9	31,9	33,4	36,1	38,1	39,0	43,3	45,9	47,1	51,4	53,1	54,1	55,5	56,9
J3.	27,6	27,6	29,2	30,9	32,5	34,3	36,4	37,1	40,6	43,1	44,5	46,3	48,1	49,7	51,3	51,5
NT	27,5	27,5	27,6	27,6	29,4	29,3	29,2	29,2	30,9	30,9	33,1	33,1	33,0	33,0	32,8	32,8

	14:13	15:00	15:31	16:07	16:36	16:58	17:21	17:46	18:12	18:51	19:15	19:39	20:14	20:39	22:12	av.
J1.	57,4	58,7	60,9	50,2	52,4	49,6	46,9	43,2	40,8	39,8	38,8	37,2	36,2	35,3	32,6	**44,0**
J2.	54,9	56,1	57,3	49,5	50,3	47,5	45,8	43,0	40,4	39,7	38,9	37,8	36,6	35,6	32,8	**43,1**
J3.	51,2	52,7	52,8	48,4	48,8	46,3	44,7	41,9	40,2	39,3	38,6	37,8	36,6	35,3	33,5	**41,3**
NT	33,7	34,2	34,2	35,1	35,1	35,0	35,0	35,0	33,5	33,5	33,3	33,3	32,5	32,5	29,6	**32,0**

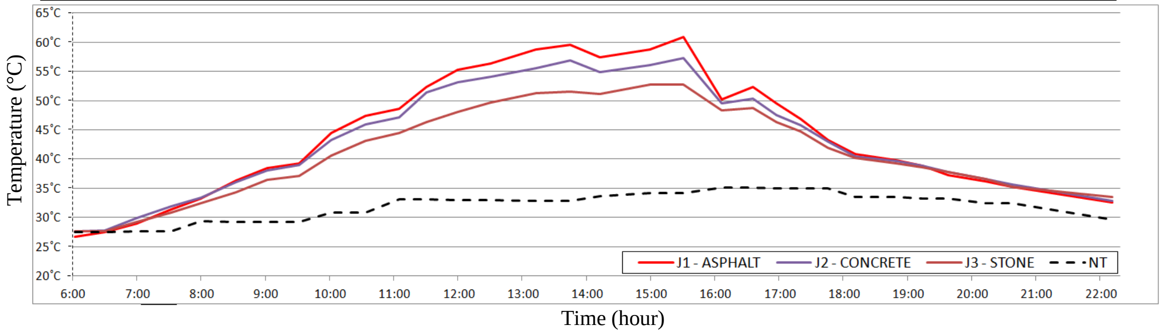

Figure 7: Daily change of surface and air temperature at test points J1, J2 and J3, on 12.07.2011.

In the early morning surface temperature is the same as the air temperature because during the night heat transfer between the surface and the air ended. From around 6:30 am until the end of measurements pavement temperatures are higher than air temperature. Also, from 18:00 the difference of temperature of different materials is minimal. With the appearance of insolation materials behave similarly: from 12:00 till 15:30 the achieved difference in temperature is maintained and at 18:00 the temperatures equalize.

Figure 8 shows the temperature changes at the same test points in the autumn period (15.09.2011). The average air temperature is 3.5˚C lower and the maximum temperature of the asphalt surface is 13.9˚C lower than the same temperatures measured in the summer (12.07.2011). The temperature difference between the asphalt and the stone surface is still significant (6.0˚C). Insolation period is shorter and lasts for 8 hours (on 12.07.2011 it lasted for 9.5 hours). The maximum surface temperature is reached approximately at the same time.

	7:16	8:05	9:02	10:09	10:55	12:00	13:05	14:01	15:10	16:10	17:00	18:03	19:00	av.
J1.	22,1	24,6	28,8	33,4	39,3	39,4	46,3	46,7	47,0	39,8	35,3	32,8	30,1	**35,8**
J2.	22,4	25,3	29,8	34,2	39,3	39,6	45,2	45,7	45,4	38,8	35,1	32,6	30,6	**35,7**
J3.	22,6	24,4	27,8	31,1	34,2	36,1	40,3	41,1	41,3	37,0	34,3	31,7	30,0	**33,2**
NT	22,3	22,8	24,8	25,8	28,3	30,4	31,9	30,3	30,4	31,1	31,4	30,8	29,8	**28,5**

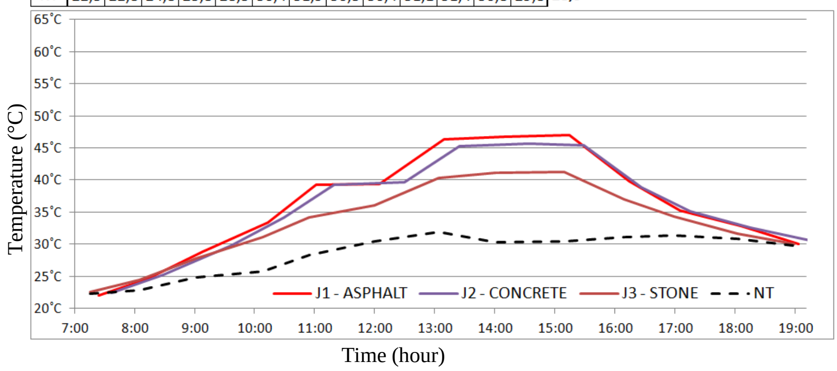

Figure 8: Daily change of surface and air temperature at test points J1, J2 and J3 on 15.09.2011

The analysis determined locations (different conditions) and periods when the surface temperature is lower than air temperature (Fig. 9). This phenomenon is not characteristic for the materials but for the circumstances of the test point: the shadow for B6 and R9 (Fig. 9) or the night period for the point J1 (Fig. 7).

	6:02	6:30	7:00	7:32	8:00	8:33	9:02	9:32	10:02	10:34	11:05	11:31	12:00	12:31	13:13	13:45
R5.	28,4	28,6	28,9	29,5	31,8	34,9	37,7	40,5	43,7	45,6	48,6	49,3	51,1	53,6	55,8	57,1
B6.	25,4	25,9	25,9	25,9	26,1	26,8	26,9	27,6	28,4	41,3	30,6	31,4	30,9	30,8	30,6	30,8
R9.	25,8	26,4	26,3	26,4	26,7	26,9	27,1	27,6	28,4	28,6	29,2	29,1	29,3	29,3	30,0	30,3

	14:13	15:00	15:31	16:07	16:36	16:58	17:21	17:46	18:12	18:51	19:15	19:39	20:14	20:39	22:12	
R5.	57,7	58,4	58,9	57,9	56,4	53,4	54,3	52,6	50,2	47,2	45,6	43,1	40,8	39,4	36,5	**45,7**
B6.	31,6	31,3	33,2	31,4	32,1	34,1	35,0	33,1	32,1	32,3	35,6	30,5	30,1	29,4	28,7	**30,5**
R9.	30,1	31,1	31,9	31,4	31,7	31,4	31,4	30,6	30,9	30,1	30,5	29,8	29,4	29,0	28,7	**29,2**

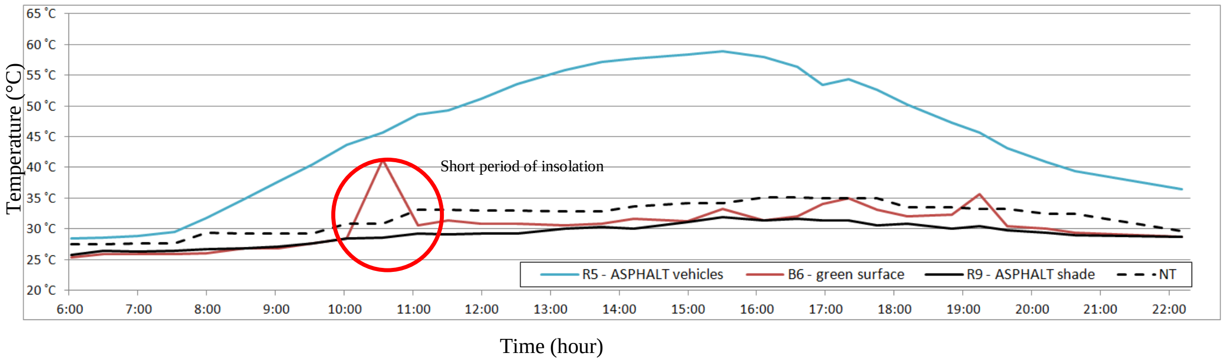

Figure 9: Daily change of surface and air temperature at test points R5, B6 and R9 on 12.07.2011

At test point B6 (Fig. 9) Δt = +12.9˚C was recorded for a shorter period of insolation (from 10.00 till 11.00) as well as a very quick release of temperature Δt = -10.7˚C. At the other test points no such quick release of temperature was recorded after sun insolation which is a result of heat accumulated over a longer period of insolation. Heat accumulation obviously occurs under the surface, in pavement layers.

The temperature change curve for the points in the shade (R9) shows the same features as the curve of the air temperature, only 4.0˚C lower. Surfaces in the shade constantly absorb the heat from the environment and try to cool it. Some test points subjected to sunlight (J2 and J3) succeeded to equalize their temperature with air temperature overnight (Fig. 1) while some test points (R5) heat up environment even during the night (Fig. 9).

Differences in surface temperature indicate the appropriateness of applying concrete and stone materials in public areas. Surface protection from direct sunlight prevents the occurrence of very high temperatures but can also create surfaces that absorb heat from the environment (air).

4 TREE PLANTING AND GREEN-COVERED PARKING AREAS AS A PART OF GREEN INFRASTRUCTURE PRACTICE

Green infrastructure is a term used to describe forested or vegetated open space as well as storm water management practices that mimic natural hydrologic processes at the local level. Green infrastructure practices are engineered structures like green roofs, bio retention, vegetated swales, permeable pavements, rain barrels and cisterns as well as natural practices like planting trees and native landscaping (Clark, 2010).

Trees and vegetation help cool urban climates through shading and evapotranspiration. The shading reduces surface temperatures below the tree canopy because leaves and branches reduce the amount of solar radiation that reaches the area below the canopy. Evapotranspiration is the conversion of water from liquid to a gas. It occurs in the soil around vegetation and from trees and vegetation as they intercept rainfall on leaves and other surfaces. Evapotranspiration cools the air by using heat from the air to evaporate water

(United States Environmental Protection Agency, 2008). Evapotranspiration, in combination with shading, can help reduce peak summer air temperatures.

Two different studies (Huang J., Akbari H. and Taha H., 1990 and Kurn D., Bretz S., Huang B. and Akbari H., 1994) have measured the following reductions:

- peak air temperatures in tree groves 5°C cooler than over open terrain,
- air temperatures over irrigated agricultural fields 3°C cooler than air over bare ground,
- suburban areas with mature trees 2 to 3°C cooler than new suburbs without trees and
- temperatures over grass sports fields 1 to 2°C cooler than over bordering areas.

Scott et al. 1999 (Scott K., Simpson J.R. and McPherson E.G., 1999) performed a pilot-study to measure the difference in a parking lot microclimate resulting from the presence or absence of a tree cover shade. The study was performed in Davis, California during August 1997. Among many other data, the difference in surface temperature between shaded and unshaded pavement was measured. The difference was larger than the measured air-temperature differences. For example, in the afternoon of August 6, the infrared surface temperatures of asphalt at the unshaded site exceeded 60°C while the temperatures at the shaded site were slightly less than 40°C. The observed reductions in solar radiation at the shaded parking lot site and air-temperature reductions near the paved surface suggest that air-temperature reduction is largely due to irradiance attenuation attributable to tree shade. Overall, temperature differences during the hottest days suggest that at this very modest level of shading trees exerted an air-temperature reduction of approximately 1°C to 2°C, compared to unshaded lots.

Another study on the urban heat island mitigation effect, achieved by converting asphalt-covered parking areas to grass-covered ones, was performed in the central ward of Kobe City. Thermocouples were installed at various depths to record the temperature of different material layers including the soil and surface layers. Solar radiation, infrared radiation, air temperature, relative humidity and wind speed and direction were recorded nearby. The surface and air temperatures were used to estimate the sensible heat flux. The estimated reduction in sensible heat flux of an asphalt parking lot converted to a grass covered lot was 100–150 W/m2 during the day and approximately 50 W/m2 at night. The estimated air temperature reduction for the central ward area, if all parking lots were converted to grass-covered parking lots (about 6% of the total land area in the ward), was 0.1◦C (Takebayashi H., Moriyama M., 2009).

Many local landscape ordinances (in U.S.) include requirements for landscape development internal to parking lots. Standards for interior landscaping usually includes some combination of the following options: a) minimum size of parking lot to which regulations apply, b) planting area per parking space, c) minimum percentage of lot devoted to landscape development, d) relationship between the number of trees and the parking spaces, e) maximum distance from any parking space to the nearest tree and f) protecting vegetation from vehicular damage. Cities in the warm climate areas of the south-eastern states and California have taken the lead in adopting cover recommendations. Examples are Agoura Hills, Sacramento, Woodland, Sacramento County, Modesto and Los Angeles, all in California, USA. Sacramento’s ordinance, adopted in 1983, requires 50% shading coverage of total paved area within 15 years. In Sacramento County, trees in parking lots of 5 to 24 spaces must provide 30% lot shading; lots having 25 to 49 spaces must have 40% shading; 50% shading must be attained in lots of 50 spaces or more. Woodland specifies that shade trees must be distributed so that 40 percent of the parking stalls are shaded at high noon when trees are in full foliage. Also, many local communities suggest using permeable materials for parking lots since these materials permit water to enter the ground because they are porous or have void spaces. An important consideration is whether the choice of paving material is consistent with the use intensity and traffic load of the vehicular use area (Wolf K.L., 2004).

To increase the reflectivity of the surface and to make urban areas more attractive, coloured asphalt and coloured concrete are recently more and more used (Fig. 10) (United States Environmental Protection Agency, 2008).

Figure 10: Coloured pavements: left – asphalt (http://www.raedlinger-bau.com) and right – concrete (http://www.bayferrox.us)

Also, non-vegetated permeable pavements, such as porous asphalt, pervious concrete, brick or block pavers (available in a variety of colours and finishes), easily fit into the city centre. For parking lots, it is possible to use vegetated permeable pavements such as grass pavers and concrete grid pavers which use plastic, metal or concrete lattices for support and allow grass or other vegetation to grow in the interstices (Fig. 11) (United States Environmental Protection Agency, 2008).

Figure 7: Grassgrid block pavers [http://www.archiexpo.com]

5 POSSIBLE HEAT ISLAND REDUCTION STRATEGY IN THE CITY OF RIJEKA

Analyzing the inner city centre of Rijeka, certain areas where it would be possible to use cool pavements and other forms of green infrastructures have been selected. Those areas are shown in Figure 8. Possibilities for making those areas more comfortable for citizens during a hot season and reducing overall city temperature during summer are discussed.

Areas marked in blue colour are pedestrian zones. Most of these areas are paved with stone, which is considered as a one type of cool pavements. Those areas are suitable for application of other types of green infrastructures. Pedestrian areas that are not paved with the stone are suitable for tree planting and for use of cool pavements. Possible cool pavements for these areas are coloured asphalt or coloured concrete, or porous asphalt and pervious concrete. These pedestrian zones are not negligible, since their size is about 7% of the total area of the city centre.

Areas marked in yellow are parking areas, mostly paved with asphalt. Those areas are suitable for use of vegetated permeable pavements, especially concrete grid pavers. Also, those areas are suitable for tree planting. The total size of these parking areas is also about 8% of total area of the city centre.

Analysis of the actual effects of these measures on the specific location of the city centre could be direction for future research.

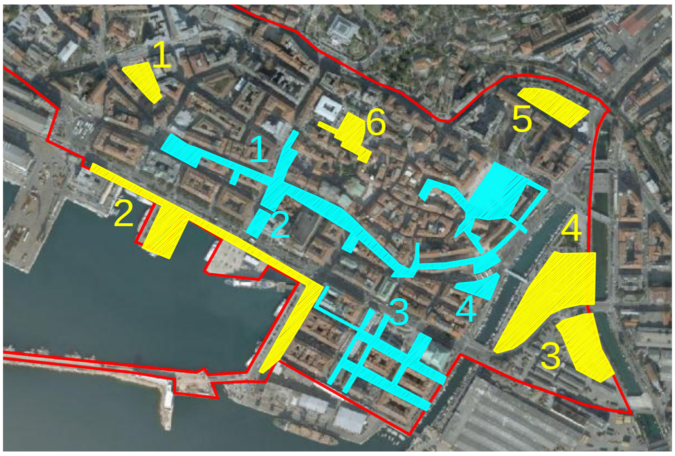

Figure 8: Centre of the city with possible locations for use of cool pavements and green infrastructures

6 CONCLUSION

Heat islands are recognised as one of the most severe ecological problems in the modern cities. The effect of a heat island can be minimised by designing and using surfaces that have good reflection characteristics (e.g. albedo) and those that allow evapotranspiration (e.g. porous materials). Greening and urban forests are also suitable strategies to reduce heat island effect.

Since cool pavements do not necessarily require new materials and new technologies, maintenance costs are the same as those for conventional pavements. Reduction of pavement temperature extends pavement life, which may directly affect the maintenance costs.

City of Rijeka is situated in the zone of moderately warm and humid climate with usually very hot summer months, July and August, with air temperatures higher than 30 degrees. The pilot-study was conducted in the city centre to establish temperatures of different types of pavement surfaces used in central area of the city (asphalt which is dominant, concrete, different types of stones) and suggests possible scenarios for reduction of pavement and air temperatures. The results of the study pointed out asphalt as a less convenient type of pavement which tends to absorb temperature and has a significantly higher temperature than other types of pavement and air above pavement. Possible solutions, suggested in this paper, consider pedestrian and parking areas which are around 15% of total city centre area. Pavements in this area can relatively easily be replaced with permeable pavements such as porous asphalt, pervious concrete, brick or block pavers (available in a variety of colours and finishes) and vegetated permeable pavements such as grass pavers and concrete grid pavers (suitable for parking lots). The suggested solutions would certainly have a positive effect on the microclimate situation in the city centre of Rijeka during summer period.

It may be difficult to change historic appearance of city streets but it should not be the reason not to set norms and standards that can be achieved by timely planning. Increasing the number of parks, playgrounds, streets with a higher percentage of alleys, parking lots constructed of grass or concrete grid pavers, with natural shade from trees are all measures that significantly reduce the effect of the urban heat island and contribute to the fight against global warming. This is why this strategy should be considered for reduction urban heat island effect.

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