USING COOL PAVING MATERIALS TO IMPROVE MICROCLIMATE OF URBAN AREAS – DESIGN REALISATION AND RESULTS OF THE FLISVOS PROJECT.

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ABSTRACT

The present paper deals with the application of 4500 square meters of reflective pavements in an urban park in the greater Athens area. The aim was to improve thermal comfort conditions, reduce the strength of heat island and improve the global environmental quality in the considered area. It was estimated that the use of cool pavements contributes to decrease the peak ambient temperature during a typical summer day, up to 1.9 C. In parallel, the surface temperature in the park was reduced up to 12 C while comfort conditions have been improved considerably. It is concluded that the use of reflective pavements is a very efficient mitigation technique to improve thermal conditions in open urban areas.

KEYWORDS

Heat Island, Cool materials and pavements, Heat island mitigation techniques

INTRODUCTION

Urban heat island is the more documented phenomenon of climate change. The phenomenon relies to higher urban temperatures compared to the surrounding areas because of the positive heat balance caused mainly by increased anthropogenic heat, decrease of the air flow, lack of heat sinks and increased absorption of solar radiation by the city structure.

Heat island is very well-studied and documented phenomenon for the city of Athens, Greece. Apart of the global climatic change that increases the ambient temperature and the frequency of heat waves, heat island is an additional reason that contributes to the temperature increase. The impact of heat island on the cooling energy consumption of buildings is quite important. Studies have shown that the cooling energy consumption may be doubled because of the increased ambient temperatures in the affected areas. In parallel, the environmental quality in the overheated zones is worsening as pollution is increasing, and the ecological footprint of the city is growing seriously.

To counterbalance the impact of heat island efficient mitigation techniques have been developed and applied.. This implies the use of advanced materials for the urban environment, able to amortize, dissipate and reflect heat and solar radiation strategic landscaping of cities including appropriate selection and placing of green areas, use of green roofs, solar control systems, and dissipation of the excess heat in low temperature environmental heat sinks like the ground, the water and the ambient air .

Materials presenting a high reflectance to solar radiation together with a high emmisivity factor are known as cool materials. Such materials may be used in pavements, other urban structures and building roofs Important energy benefits are also associated to the use of reflective materials as the cooling load of buildings is seriously reduced.

Although reflective materials have been extensively tested in cool roof applications, existing data on their potential to mitigate heat islands when used in pavements and other urban structures is very limited.

The present paper reports the results of a real project in Athens, Greece, where extensive use of cool colored paving materials has been made aiming to reduce ambient temperatures during summer and improve the environmental quality of a public urban park. In total, 4500 m2 of cool paving materials have been applied to the area, while extensive measurements combined to numerical modeling have been performed before and after the rehabilitation of the area to identify the mitigation potential of the used cool materials and document the thermal performance of the whole project.

DESCRIPTION OF THE SITE AND REFURBISHMENT CHARACTERISTICS

The Flisvos urban park is a coastal area located in the south western part of Athens, Municipality of Paleon Faliron, and covers a total area close to 80000 m2. It is surrounded by a major traffic axis and the sea, Saronic Golf. The park was composed by green and paved areas that given access to the sea. The so called green part was quite sparsely planted with small trees and bushes. Paved areas were made of asphalt, concrete and quite dark paving components. The absorptivity of the used paved surfaces was measured between 0,55 to 0,65, while areas covered with concrete and asphalt presented much higher values, 0,79 and 0,89 respectively.

The local Municipality in collaboration to the Prefecture of Athens has designed and undertaken a major refurbishment plan for the area. The plan was executed in two faces. During the first one almost 2500 trees and bushes are planted while during the latest one almost 4500 m2 of existing pavements have been replaced with new cool materials presenting a high reflectivity to the solar radiation. The overall refurbishment of the park has been started at 2009 and was finalized during the summer of 2010. The first phase was finished during the end of 2009 when all green areas have been planted, while the change of the pavements has been taken place during June and part of the July 2010. The present paper concentrates on the second phase and deals with the evaluation of the thermal advantages rising from the use of the cool pavements.

CHARACTERISTICS OF THE SELECTED COOL MATERIALS

Paving materials have been selected to satisfy the following criteria :

a) To present the higher possible non specular reflectivity to solar radiation.

b) To present the lowest possible decrease of the reflectivity because of the ageing effects.

c) To present the highest possible emissivity factor something common for most of the paving materials

d) To present the highest possible durability and aesthetic value.

Based on the above, small concrete blocks of light yellow color have been designed and selected. The blocks have been colored using infrared reflective pigments mixed in the whole mass of the blocks during their preparation. For aesthetic reasons and in order to avoid a rapid degradation of the material's reflectivity a light yellow color has been selected. The solar reflectivity of the selected materials has been optimized after various tests in relation to the proportion and the characteristics of the used primary materials, (concrete, sand, gravel, etc), and the infrared reflective pigment . The global solar reflectance of the selected material was calculated close to 60 %, while the corresponding reflectivities in the visible and infrared parts are close to 47 and 71 % respectively. The emissivity of the selected concrete blocks was measured close to 0.9

EVALUATION METHODOLOGY

To evaluate the possible thermal impact of the used cool pavements on the environmental quality of the considered area, the following methodology has been designed and used. The methodology involved five distinct steps.

Step 1 :Monitoring of the Initial Situation : Detailed measurements of the main climatic parameters in the area including surface and ambient temperatures, wind speed and concentration of pollutants have been performed in the considered area prior to any intervention.

Step 2. Development of a Computational Model for the Initial Situation: A thermal model of the area has been created using CFD techniques and simulations have been performed using the boundary conditions measured during the previous step. Comparisons of the measured against the predicted values are performed and the model was improved until a very good agreement is achieved.

Step 3. Monitoring of the Final Situation : Given the installation of the cool pavements, new measurements have been carried out. All measurements have been performed according to the same experimental protocol described in step 1.

Step 4. Development of a Computational Model for the Final Situation: A new thermal model considering the installed cool pavements has been created using the same CFD tool. All other parameters and conditions stay similar as in the model described in Step2,. Simulations have been performed for the boundary conditions measured in step 3. The calculated values have been extensively compared against the measured ones and the model improved until the best possible agreement is achieved

Step 5. Theoretical Comparisons for a Typical Summer Day : The boundary conditions corresponding to a typical summer day have been defined in details and simulations have been performed by using both calibrated thermal models. Values of the main climatic parameters in the considered area have been calculated for the initial and the final situation using exactly the same boundary conditions. Both sets of calculated data have been compared and conclusions on the thermal impact of the cool pavements have been drawn.

Such a methodology offers the possibility to identify in a quite good approximation the possible impact of a major intervention in an uncontrolled environment operating under dynamic boundary conditions.

MONITORIN STRATEGY

A complete monitoring plan has been designed and applied for both sets of measurements performed before and after the installation of the cool pavements. Ambient and surface temperatures, relative humidity, wind speed and direction as well as the concentration of suspended particles were recorded during the experiments in most of the areas of the park.

The mobile station went through the whole park following a specific route. Measurements were performed in a continuous basis, Measurements at eight reference points were recorded on an hourly basis. Comparisons between the various experimental and theoretical data sets have been performed for the reference points. In parallel to the above measurements, solar radiation data as well data on the undisturbed wind and temperature have been taken from the meteorological station

THE COMPUTATIONAL THERMAL MODEL

Computerised Flow Dynamic Techniques, CFD, have been used to evaluate the thermal environment in the considered space. For the specific work the PHOENICS CFD package has been used. As it concerns turbulence, the standard k-e model has been used. The values of the surface temperatures were calculated through the TRNSYS, simulation tool and then introduced as a boundary to PHOENICS and simulations of the ambient temperature and wind speed distributions have been performed. At the inflow boundaries, the wind field is specified.

As it concerns the interference coming from the boundaries to the flow, the distance between the object and the boundaries of the domain was set equal to 6 times the characteristic length for the position of the inlet (6H), 8 times to the position of outlet (8H) and 5 times to the lateral boundaries (5H). The top and side boundaries were considered as the symmetry conditions.

DESCRIPTION OF THE INITIAL SITUATION. MONITORING AND SIMULATION RESULTS

Detailed measurements in the park have been performed the 14th and 15th of April just before the start of the works to install the cool pavements. Both days were clear and solar radiation intensity during the noon period was close to 800 W/m2. Daily average surface temperatures in the non-shaded parts of the park varied between 24,5 C for the grass, 26,7 for the pavements, 28,4 C for the asphalt and 28,8 C for the dark bare soil. Corresponding surface temperatures in the shaded parts were 6-9 C lower. Ambient temperatures at 3.5 m height varied for both days between 16.5 C and 19.8 and for the period between 9:00 t0 17:00. The maximum spatial temperature gradient in the park was close to 2,2 C and was recorded in the early afternoon period.

Following the specific evaluation methodology described previously, specific simulations have been carried out to predict the thermal conditions in the considered space during the period of the measurements. In all simulations the undisturbed boundary conditions have been taken by the National Observatory of Athens and are used as inputs to the CFD code. In parallel, the surface temperature of the main materials in the area has been simulated and then used as inputs to the model. The maximum difference between the measured and the predicted surface temperatures never exceeded 0.4 C. Simulations have been performed for many different measured boundary conditions and the model was continuously improved to better fit the existing conditions. The agreement between the theoretical and the measured temperatures is found to be satisfactory. The maximum temperature difference between the two sets of data never exceeded 0.5 C. The spatial distribution of the temperature is also similar for both the measured and the theoretical data. Thus, it may be concluded that the developed theoretical thermal model can predict with sufficient accuracy the climatic conditions in the area prior to the installation of the cool pavements.

APPLICATION OF THE COOL PAVEMENT – MONITORING RESULTS

After the installation of the cool pavements in the park, detailed measurements have been performed using exactly the same experimental protocol as in the first monitoring campaign.

Measurements have been performed for the 27th of July and the 4th of August. Both days were clear and solar radiation intensity during the noon period was 840 and 950 W/m2 for the first and the second day respectively.

The daily surface temperature of the non-shaded cool pavements varied between 31,3 C to 33,8 C during the first day and 37,6 C and 39,9 C during the second one. The corresponding surface temperatures for the conventional pavement varied between 35,9 C and 39,2 C for the first day and 43,4 C and 47,5 C for the second one. The maximum temperature difference between the cool and conventional pavements was 5,4 C and 7,6 C for the first and the second day respectively. As expected, the temporal variation of the ambient temperature at 3.5 m height, presented the lower temperatures next to the sea front, (26 C- 28,2 C), while temperatures in the interior part of the park varied between 26.5 C to 29.5 C. The maximum spatial temperature gradient in the park was close to 1.5 C.

The same evaluation methodology described previously has been followed and CFD simulations have been performed for the 27th of July. The undisturbed climatic conditions given by the National Observatory of Athens have been used as inputs. Surface temperatures for all materials including the cool pavements have been calculated using TRNSYS and then are used as inputs to the CFD model. A very good agreement between the calculated and the measured surface temperatures has been achieved. The maximum difference between the measured and the simulated data never exceeded 0.3 C. Through repetitive runs the model has been improved the maximum possible to represent the new climatic situation in the park. The achieved agreement between the two sets of data is found quite satisfactory and the difference never exceeded 0.4 C. The predicted spatial distribution of the ambient temperature is very close to the measured one.

CALCULATION OF THE MICROCLIMATIC IMPROVEMENTS

As foreseen by the evaluation methodology, comparative simulations of the thermal conditions in the considered space have been performed for the peak period, (14:00), of a typical summer day and with and without the cool pavements. The developed and tested CFD models have been used correspondingly. The undisturbed temperature and wind speed used for the boundary conditions were 32 C and 2 m/sec blowing from northern directions. The solar radiation intensity was taken equal to 940 W/m2. Surface temperatures for all materials have been calculated using the TRNSYS thermal simulation model. The average temperature of the non shaded cool pavement was calculated equal to 36.8 C while the temperature of the conventional pavement equal to 48.1 C.

The calculated ambient temperatures for both scenarios at the eight reference points are given in Figure 1. As expected, for the coastal part of the park, (points 6-8), temperatures are very similar and the impact of cool pavements is fully negligible. On the contrary, in the inner part of the park the impact of cool pavements is important and contributes to a decrease of the maximum ambient temperature up to 1.9 C. This is very close to the results reported in similar projects were cool pavements have been considered to improve the environmental quality of open spaces.

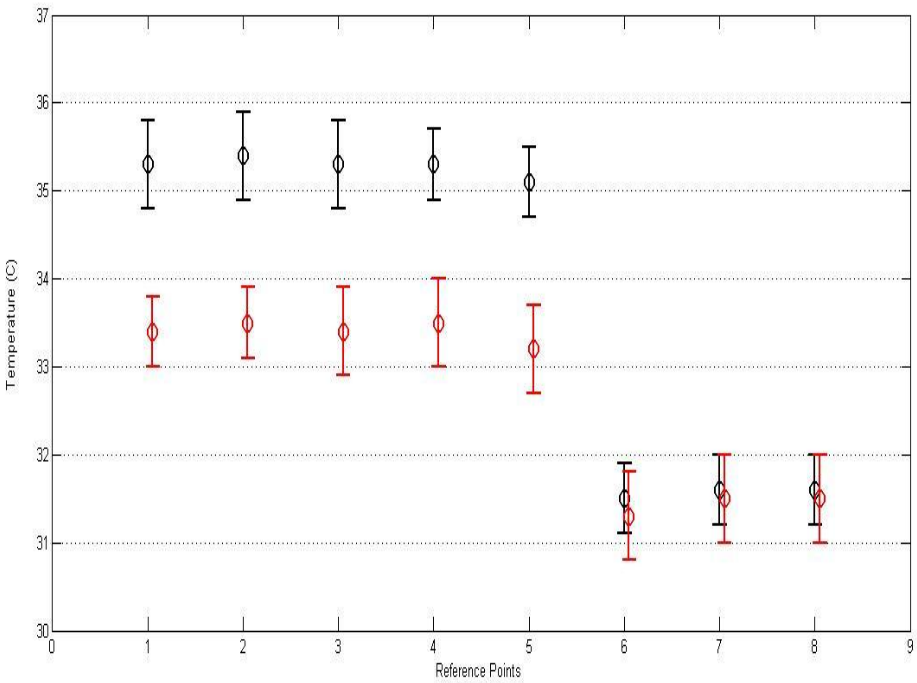

Figure 1 : Comparison of the predicted distribution of the ambient temperature in the park at 1.80 m height for 14:00 of a typical summer day before, (black), and after the installation of the cool pavements, (red)

CONCLUSIONS

Heat island increases temperature in urban areas, increase the energy consumption for cooling purposes and affect the global environmental quality of cities. Use of advanced mitigation techniques contributes highly to decrease temperatures and improve comfort in open urban areas. Cool materials presenting a high solar reflectivity and emissivity have been proposed as an effective mitigation technique when applied to buildings and open spaces.

Almost 4500 m2 of cool pavements have been used to rehabilitate a major urban park in the greater Athens area. In order to evaluate the impact of cool pavements, measurements of the climatic conditions in the considered place have been performed before and after the installation of the cool materials. A specific evaluation methodology has been designed and applied. Computerised fluid dynamic techniques have been used to simulate the specific climatic conditions in the area before and after the installation of the new pavements. After validation against the two sets of the collected experimental data, comparative calculations have been performed with and without the cool pavements under the same climatic boundary conditions. It is found that the extensive application of reflective pavements may reduce the peak daily ambient temperature during a typical summer day up to 1.9 C while surface temperatures are reduced up to 12 C. In parallel, calculations of the thermal comfort conditions in the area have shown that cool pavements improve considerably comfort in outdoor urban spaces.

The overall analysis has shown that use of cool pavements is an efficient mitigation strategy to reduce the strength of heat island in urban areas and improve the global environmental quality of open areas.

REFERENCES

PHOENICS software tool. Available at: : http://www.cham.co.uk/.