# USE OF COOL MATERIALS IN OUTDOOR PLACES IN ORDER TO MITIGATE THE URBAN HEAT ISLAND IN A MEDIUM SIZE CITY IN GREECE


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## ABSTRACT

The materials that are used in outdoor spaces are of prime importance as they modulate the air temperature of the lowest layers of the urban canopy layer, they are central to the energy balance of the surface and they form the energy exchanges that affect the comfort conditions of city people. Paved surfaces contribute to sunlight's heating of the air near the surface. Their ability to absorb, store and emit radiant energy has a substantial affect on urban microclimate.
The thermal behaviour of typical construction materials in an urban center of North Greece, at Serres, was investigated. The thermal fluctuation during the day and the surface temperature differences between different materials in a selected area inside the urban centre of the city was monitored.
The replacement of conventional materials with cool materials was evaluated to have significant benefits. CFD simulations showed that materials replacement, accompanied by other mitigation techniques in the area, result at reduction of the mean surface temperature in the streets of the area of 6.5 ºC.
The results of the measurements and the CFD simulations will be presents in the paper.



## KEYWORDS

Cool materials, surface temperature, CFD simulation


## 1 INTRODUCTION

The thermo-physical properties of covered and construction materials in contemporary cities and the urban geometrical characteristics affect the microclimatic conditions inside the urban centers (Lau et al, 2011). The radiant balance of the urban space, the convective heat exchange between the ground and the buildings, the air flowing above the urban area and the heat generation within the city (Mihalakakou et al, 2002), (Santamouris et al, 1999) increase the air temperature in the city.
In order to improve the urban microclimate conditions, various mitigation techniques have been proposed involving the use of highly reflective materials, use of cool sinks and increased plantation (Santamouris, 2007), (Gaitani et al, 2007). Trees and green areas have a large effect at moderating the microclimate and also contribute at cooling the cities (Santamouris, 2001), (Dimoudi, 1996) as evapotranspiration from vegetation foliage reduces air temperature and increases humidity (Dimoudi, Nikolopoulou, 2003). Vegetated areas are known to be comparatively cooler during daytime than most other urban elements (Zoulia et al, 2009).

Mitigating the heat islands effect is therefore a key element to achieving sustainability in a city and it can be done by improving the urban microclimate (Gaitani et al, 2011).
The materials, which are used for the pavements of urban spaces and for the external renderings of vertical (facades) and horizontal (flat roofs) surfaces of the buildings, constitute, the ‘‘skin” of a city. These materials play a decisive role on the heat transfer processes, which take place between the city and the climatic environment. Materials influence the absorption of solar radiation, the emission of thermal radiation, the heat storage, and the evaporation processes that take place in practically every city surface.
The current study investigates the thermal behaviour of construction materials inside the urban centre. The investigation took place in a city at the North Greece, which is assumed as one of the warmest cities during summer in the North Greece.

# 2 MEASUREMENTS METHODOLOGY

## 2.1 Site description

The investigation was conducted in Serres city (Greece), located at 41°05′North and 23°33′E, in North Greece, in an altitude of about 61m above the sea level. The city has intense heat problem during summer and presents thermal episodes of high air temperature that exceed the 40 ºC. The study area is located in the central parts of the city which contains a densely urban structure. The buildings are characterized by four to five floors height and are built in the decade of 1970’s. The streets are covered by asphalt and the pavements are covered mainly by light colour, conventional pavement (concrete) tiles.
In the Table 1 the investigated materials for each measurement point are given and in the Table 2 the photo of materials are included.

Table 1: Investigated materials for each measurement point

| **Material** | **Measurement Point (MP)** |
|---|---|
| Road asphalt | MP1 - MP11, MP14 - MP17 |
| Light gray pavement tiles (both sides of road) | MP 1, MP3 - MP11, MP13 – MP17, MP19 |
| Gray pavement tiles | MP8 |
| Yellow pavement tiles | MP8 |
| Red ground cover pavers | MP8 |
| White pedestrian tiles | MP8 |

Table 2: Photo of investigated materials

| | | | |
|---|---|---|---|
| <br>asphalt | <br>light gray pavement tiles | <br>white pedestrian tiles<br>red ground covers pavers | <br>gray pavement tiles<br>yellow pavement tiles |

## 2.2 Monitoring procedure

A number of monitoring procedures were carried out during hot summer days, in order to investigate the thermal behaviour of construction materials which are used on buildings’

envelope, for covering pavements and open spaces. The thermal fluctuation during the day and the surface temperatures is analyzed.
The present study focuses on measurements of surface temperatures of the roads, the pavements and the vertical surfaces (Stogiannou, 2011). The field surveys involved measuring of surfaces' temperature and microclimatic monitoring of air temperature in 1.8m height. The measurement of surface temperatures took place in 20 different Measurement Points (MP).
A portable station recorded at 1.8m height the air temperature and an infrared thermometer was also employed to measure surfaces temperature at a distance of 1.2-1.3 m.
The experimental procedures were carried out at morning time 8:00am, when the absorbed solar radiation doesn't influence the materials temperature, at 13:30pm and 16:00pm and at 19:30 when the materials emitted the absorbed temperature. The experiments that are presented in this paper were performed on June and July 2011. High temperatures were prevailed during this summer period.

## 3 MEASUREMENTS RESULTS AND DISCUSSION

### 3.1 Asphalt

The surface temperatures of the asphalt road in the study area, during the experimental procedure on hot summer months (June and July) exceeded 45°C during afternoon and they can reach up to 50 and 56°C.
The asphalt's temperature is higher than the $T_{air}$. The temperature difference remains on high levels even during the afternoon, under shadowing conditions, and it is between 1,1°C and 13,2°C.
The mean surface temperature of asphalt of all MPs in each road, at the hottest day of measurement procedure is observed in Fig 1.

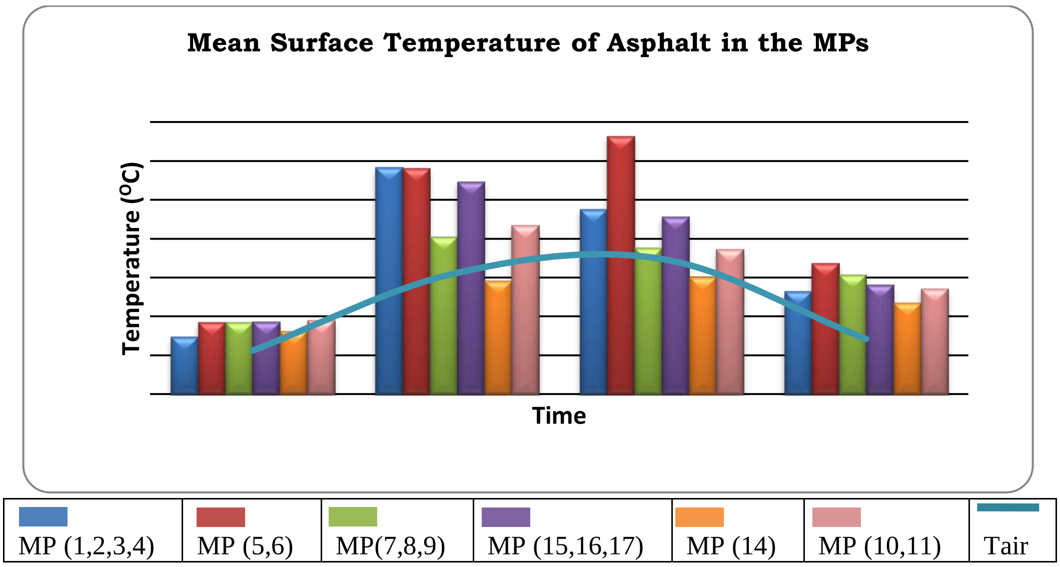
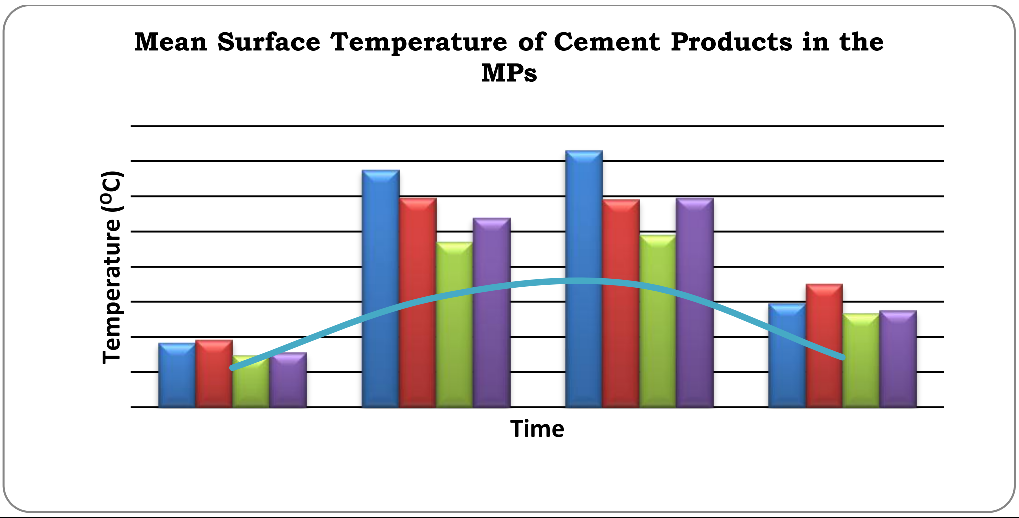



Figure 1: Mean surface temperature of asphalt in different roads of the area (mean value of different MPs in each road, each road is illustrated with a different colour)

### 3.2 Cement products (concrete pavement tiles)

The mainly observed cement products are pavement tiles and ground cover pavers. Their colours are light gray, gray, yellow and red.

In Fig. 2 the surface temperature on the hottest day is presented. The temperatures during the morning and afternoon time are under shadow, while in the noon, the measurement points are exposed in solar radiation. Surface temperatures are higher than air temperature. The surface temperature of gray tiles is always higher than the other colour tiles and may reach temperatures similar to asphalt, up to 56$^{o}$C during afternoon hours.  The surface temperature in the different tiles remains higher than the air even in late afternoon, up to about 5 $^{o}$C.




| | | | | |
|---|---|---|---|---|
| MP (8)<br>gray pavement tiles | MP (8)<br>yellow pavement tiles | MP(13)<br>light gray pavement tiles of both sides of the road | MP (8)<br>red ground covers pavers | Tair |

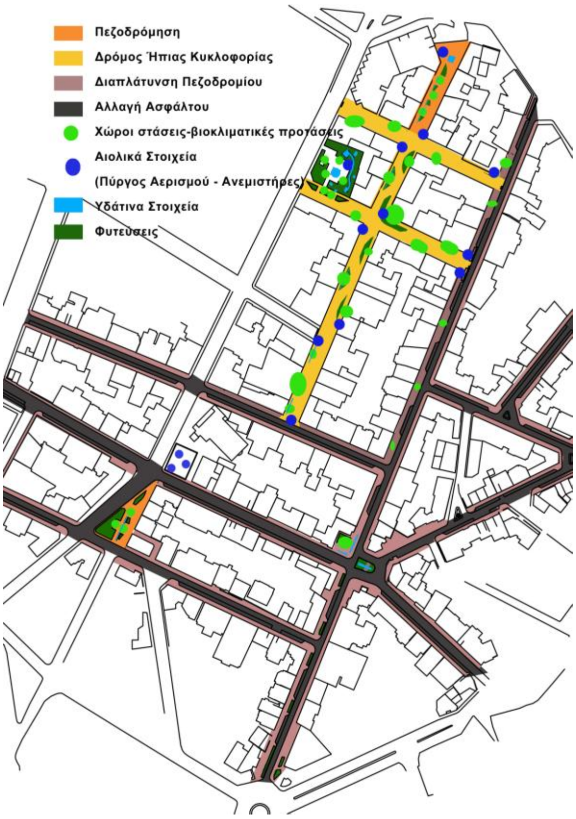
Figure 2: Mean Surface Temperature of cement products in the MPs

## 4 BIOCLIMATIC DESIGN SOLUTIONS

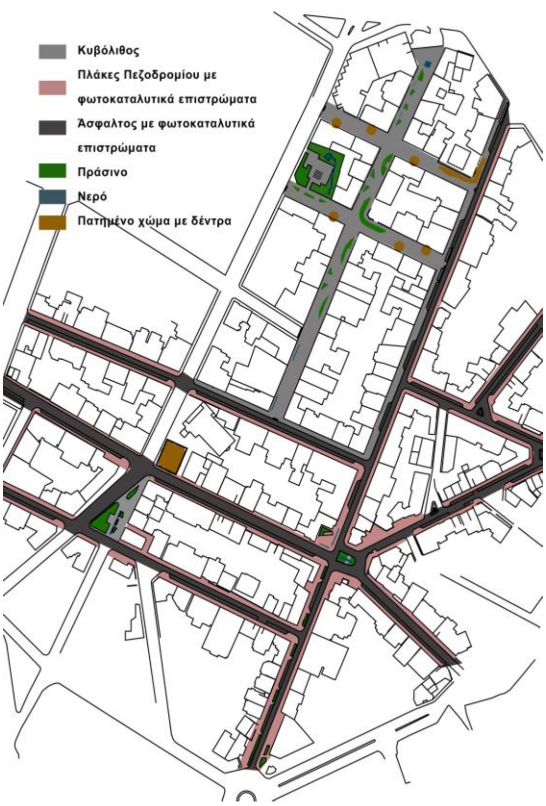
The area is currently characterised by extensive use of conventional materials in outdoor spaces, like asphalt in the streets, pavement tiles in the pavements and reduced green areas. A bioclimatic redevelopment of this part of the city is planned, for improvement of microclimate and outdoor thermal comfort conditions during summer in this area and consequently of improvement of indoor thermal comfort and improved energy performance at the surroundings buildings – lower air temperature of the external environment contributes to reduction of the hours that air-conditioning is used at buildings and at higher efficiency of the A/C units).

In the frame of the general bioclimatic redesign of the area, a total replacement of floor materials is planned with cool materials, together with increase of pavements' width, decrease of streets' width, combined with increase of green surfaces and water elements. The proposed interventions include (Drawing 1, Drawing 2) (Dimoudi et al, 2013):

- Replacement of conventional floor materials with cool materials at pedestrian streets and pavements and replacement of asphalt with cool photocatalytic asphalt at streets. The cool materials will cover the 86% of open areas and the water permeable materials (special pressed soil, low height vegetation, water surfaces) the 7% while in the existing condition the 95,5% was covered with conventional floor materials (e.g. asphalt, pavement tiles) and only the 4,5% was covered with water permeable materials (soil, low height vegetation). The thermal and optical properties of the materials are presented at Table 3.
- Shading of external places with permanent shading elements designed, mainly at sitting places that are created at selected places, but also at open spaces (e.g. park). Extensive vegetation is also used for shading that apart from other cooling benefit it contributes to psychological realm and aesthetic improvement of the area.




**Drawing 1.** Overview of the proposed interventions in the area




**Drawing 2.** Mapping of the use of new materials

**Table 3** Thermal and optical properties of materials (existing condition and proposal)

| | Solar reflectivity coef | Emittance coef. |
|---|---|---|
| **Conventional materials – Floor and facades** | | |
| Street asphalt | 0.10 [1] | 0,85-0,93 (0,89) [2] |
| Light colour roof covering / flat roofs covered with pavement tiles | 0.35 [1] | 0.90 [3] |
| Light colour mortar | 0.60 [1] | |
| Medium colour mortar (beige, grey) | 0.40 [1] | |
| Grey colour | | 0.87 [3] |
| Dark colour mortar | 0.20 [1] | |
| Typical structural material | | 0.80 [1] |
| **Cool material - Floor coverings** [4] | | |
| **Asphalt (**Ecorivestimento grigio photocatalitic concrete based mortar (speciment 1)- Fotofluid | 0.37 | 0.89 |
| **Street blocks** (Street blocks CE, light grey (N$^o$ 5) or beige (N$^o$ 6) ) | 0.67 | 0.89 |
| **Pavement tiles** (White floor tiles (N$^o$ 12)) | 0.68 | 0.92 |

[1] TOTEE 20701-1 (2010)
[2] Incropera De Witt (1990
[3] Santamouris M. (2006)
[4] ABOLIN,

- Extensive use of vegetation with native species – shrubs and trees - along the streets that act as a natural conditioning system through its evapotranspiration phenomena thus, reducing the air temperature in the area.

- Enforcement of air ventilation in the outdoor spaces with outdoor fans located at selective places to increase air circulation through the streets and create comfort sitting places during hot days.
- Several water installations, like fountain - jet, water-curtains, spray-systems in selected locations in the area for introduction of direct evaporation combined with the natural evapotranspiration of vegetation.

# 5 SIMULATION STUDY OF THE AREA

## 5.1 Simulation procedure

The simulation of the thermal conditions in the study area was performed with the detailed 3-dimensional tool ANSYS CFX 13, which is an advanced general code computational fluid dynamics model that solves the Navier-Stokes differential equations and turbulence by the finite elements technique in the 3D space. It handles very detailed 3-dimensional geometry with the ability to solve efficiently heat transfer and fluid flow phenomena. Its accuracy has been widely verified against experimental and theoretical tests (http://www.ansys.com). Advanced CFD models can calculate with a high degree of accuracy microclimatic parameters at every grid point of the meshed space. However, the more complicated is the geometry of the urban open space, the more resources of input data and calculation are needed.

The 3D geometry of the area that was audited and designed by the architects' team, in a .dwg file, was imported in the CFD software. The more detailed is the structural and 3D geometry of buildings, streets, pavements, urban equipment and vegetation the more representative and accurate simulation is. This .dwg file was imported and refined in the Design Modeler module of the simulation tool where solid surfaces (buildings, streets, pavements and trees) and the fluid domain area were defined. The fluid domain area encloses the study area by a dimension of 1,000 m * 800 m * 80 m (height) – this was at least 4 times the max height of structural domains in order to avoid flow reflection at boundaries and fluid returns during simulation.

The simulation domain was meshed (solid surfaces and fluid domain volume) and mesh was created at all area's surfaces (streets, pavements, facades on streets, facades not facing streets, roofs, etc). The surfaces have been meshed by the Advanced Proximity and Curvature Function and the mesh dimensions have been selected by the criterion of the fully developed flow within the fluid domain. The typical element in the mesh had dimension of 5.0 m, with denser mesh close to solid surfaces (facades, vegetation, water elements, etc) from 0.1 to 0.5 m (tetra-, hexa-, octa- surface elements). The final mesh constituted of 2,099,018 nodes and 11,015,546 elements (Figure 3).

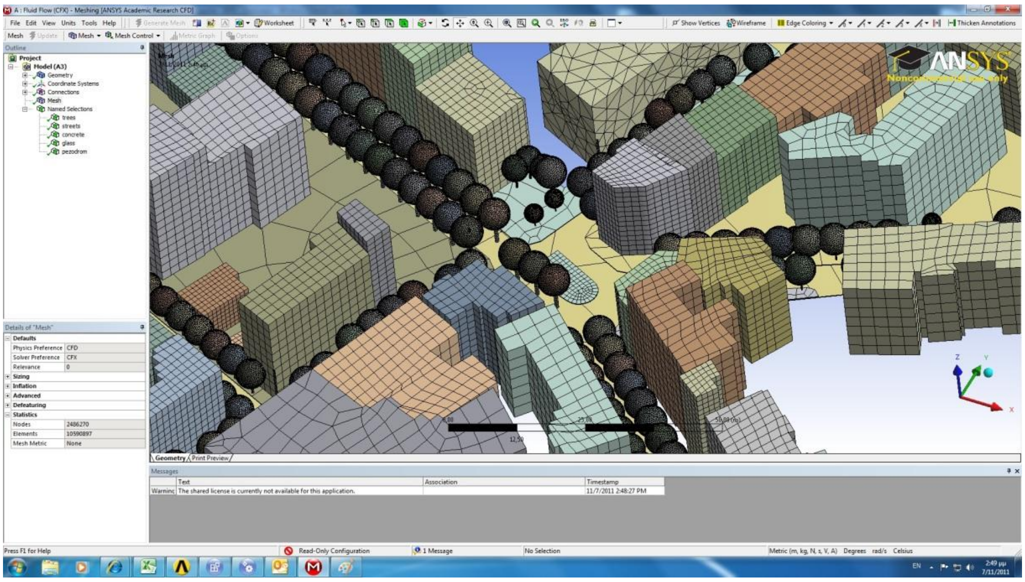



**Figure 3** Mesh details in section of the study area

The meshed geometry was used to define the physical parameters in the area under consideration (CFX-Pre). Surfaces with materials (concrete, glass, pavement, water, trees) and properties (emission and reflection coefficients) have been defined. The Shear Stress Transport model with K-turbulence KE and O-Turbulence frequency was applied to simulate turbulence. Thermal energy was simulated by the discretised model in surface to surface and medium to surface modes. This takes into account opposite surfaces energy exchange that is very important in the heat balance of the open spaces in case of replacing conventional surfaces with cool materials. Solar radiation has been taken into account in slope and deviation through the top boundary. Vegetation has been considered as physical barrier to wind flow with shadowing. Water elements were defined as free surfaces (zero friction) with a constant temperature of 15 ºC.

Boundary conditions were defined by monitored data (air temperature, wind speed and direction, radiation, surface temperatures) that were taken during the summer period 2011. A time step (5 sec) and convergence criteria ($10^{-4}$ RMS of residuals) have defined under steady state of transient calculation.

Finally, the results have been processed in the CFD Post module, provided by the software, for the final presentation.

## 5.2 Model validity

The ANSYS CFD model of the study area was validated against monitored data of the area that were carried out during summer 2011. The warmest day for the monitored period, with complete microclimatic data (i.e. air temperature, air velocity, surface temperature) that were monitored at different locations and heights in the area, was selected the $4^{th}$ August 2011.

The data that were used for validation of the model is the monitored data in different streets and heights within the study area, i.e. the air temperature and wind velocity at heights 1.8 m and about 4.5m, the surface temperature of the facades at 1.8m height and the material surfaces of streets, sidewalks.

The climate data for that period from the Meteorological station in the city were used to simulate the climatic data in the intervention area and in the locations where measurements were carried. The simulation results were compared with the measured values of surface and air temperatures and wind speed. Since, the surface temperature measurements made during midday, the comparisons were made for the same period.

Satisfactory convergence of the values between monitored and simulation data was achieved. The difference between the monitored and simulated values range between 0.670 to -0.624 °C for the air temperature, 0.300 to -0.300 °C for the surface temperature and – 0.030, -0.090 up to -0.192 m/sec for the air velocity. Therefore, the achieved high accuracy proves that the model that was developed for the study area is reliable for assessment of the existing condition and the proposed interventions in the area.

## 5.3 Simulation results

The conventional materials of the streets and pavements in the area were proposed to be replaced with cool materials that are characterised by high solar reflectivity and thermal emittance (Table 1). The existing and the proposed condition of the area were simulated for the noon of the hottest day of the monitored period, thus, for the July 19$^{th}$, 2011.
It was assumed that the mean maximum surface temperatures occur during the hottest day. The monitored results showed that the maximum values in the different streets in the area occur approximately the same time. Thus, the surface temperature for all surfaces in the area was simulated at the same period that is the noon of the hottest day. The mean surface temperature for each street of the area was then calculated and the mean surface temperature for the whole area was derived.
The surface temperature distribution in the area is illustrated in Figures 4 and 5 for the existing condition and the proposed interventions accordingly. The mean surface temperature in the area during noon of the July 19$^{th}$ reached 40.3ºC in the existing condition while the materials change together with the other interventions in the area, reduced the surface temperature to 33.8ºC, thus, obtaining a temperature reduction of 6.5 ºC.

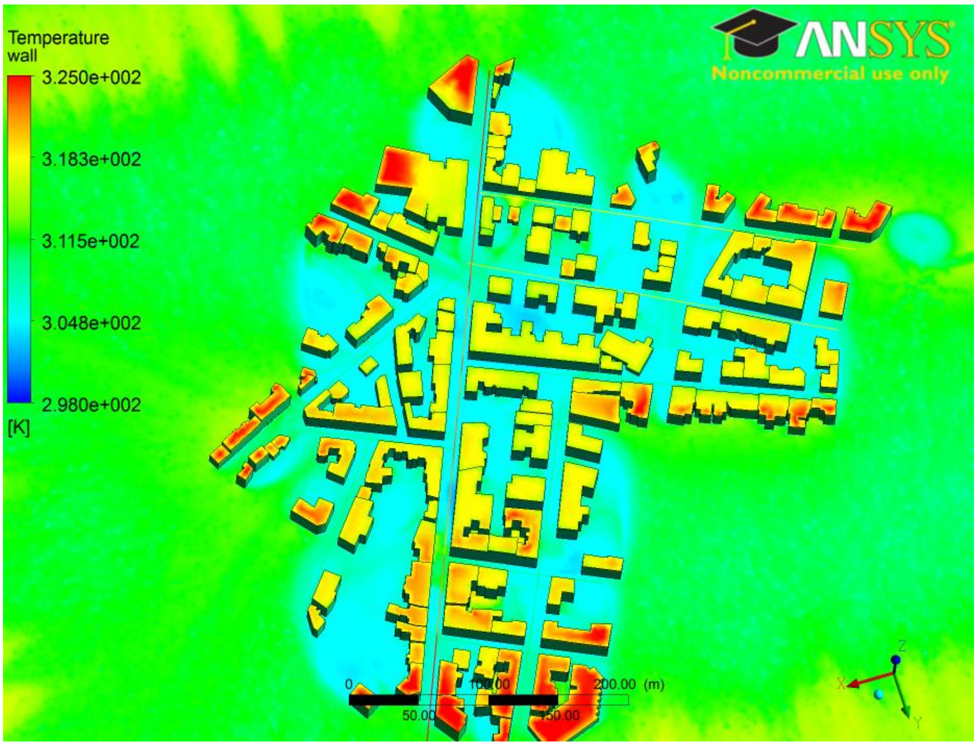



**Figure 4** Surface temperatures in the area - Existing condition

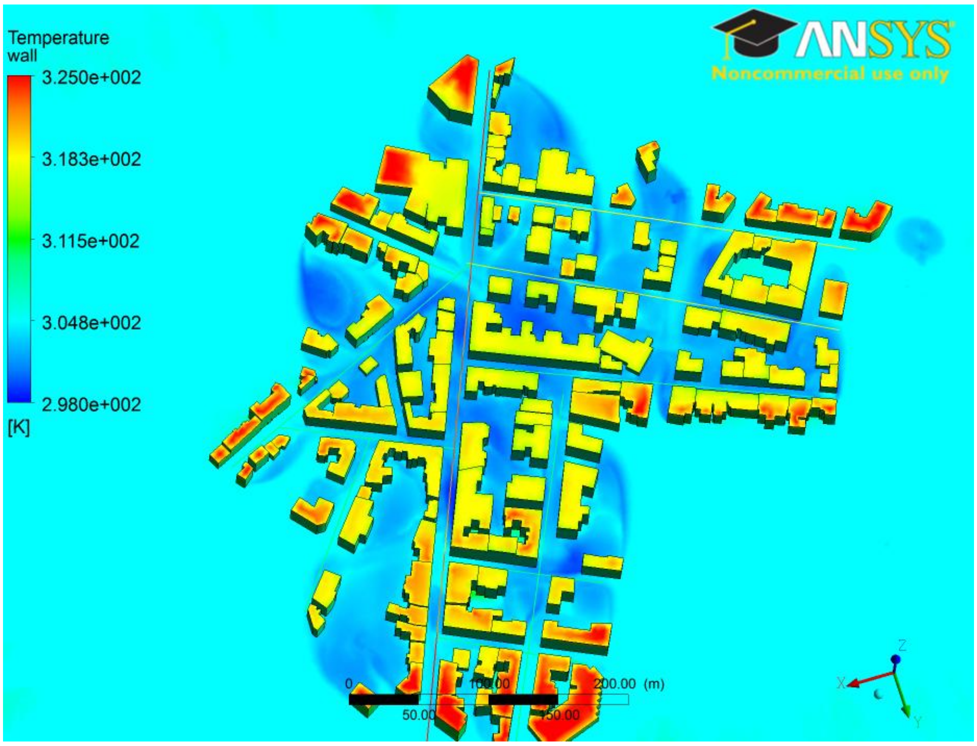


**Figure 5** Surface temperatures in the area - Proposed condition

## 6 CONCLUSIONS

It is evident that the thermo-physical properties of covered and construction materials in contemporary cities and the urban geometrical characteristics affect the microclimatic conditions inside urban centres.

Measurements in conventional materials (asphalt, pavement tiles) in a city centre reported surface temperatures up to 50 -56 ºC during the summer period. Bioclimatic interventions combined with replacement of all conventional street and pavement materials with cool materials reduced surface temperature by 6.5 ºC.

This temperature reduction will have a big influence on the microclimate of the area, the thermal comfort of people in the outdoors spaces but also it will affect indoor conditions and houses' cooling loads.

## 7 ACKNOWLEDGEMENTS

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