The influence of bioclimatic urban redevelopment on outdoor thermal comfort

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One of the greatest environmental challenges for the sustainability of future cities is the mitigation of the urban heat island phenomenon and thus, improvement of outdoor comfort conditions for people. The emphasis of this work is to analyze how mitigation techniques in a dense urban environment affect microclimate parameters and outdoor thermal comfort. The quantitative differentiation of outdoor thermal comfort conditions through bioclimatic urban redevelopment for an area in the city of Serres, Greece is investigated. The main bioclimatic interventions concern the application of cool paving materials, the increase of vegetated areas and the creation of water surfaces. The analysis and comparison are performed for a hot summer day with the ENVI-met model. Software simulations regarding microclimatic and outdoor thermal comfort conditions are performed for the daytime period 06.00 to 20.00 (14 hours) at the height of 1.8m from the ground. The examined parameters are air temperature, surface temperature and mean radiant temperature (T_{mrt}). The evaluation of outdoor thermal comfort conditions is conducted using the index PMV (Predicted Mean Vote), adapted for outdoor conditions. The results of simulations are discussed regarding the assessment of bioclimatic interventions.

Keywords: bioclimatic design, CFD simulation, urban microclimate, outdoor thermal comfort

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1. INTRODUCTION

The population of people living in urban areas is estimated at 50% (3.4 billion) of the world population and it is predicted to reach 60% (5 billion) by 2030, according to the Population Reference Bureau (Mirzaei & Haghighat, 2010). As the largest cities of the world are confronted with serious environmental problems (high concentrations of gaseous pollutants, urban centers overheating etc.), it is imperative that environmental conditions of urban areas be improved. According to the Intergovernmental Panel on Climate Change (IPCC, 2014), the greatest threats for urban areas are heat stress, extreme precipitation, inland and coastal flooding, landslides, air pollution, drought and water scarcity.

Climate change has created multiple problems in the urban environment. High temperatures, poor air quality and strong winds can cause heatstroke, dyspnea and injuries, respectively. One of the most important challenges for modern cities and especially for those with dry and tropical climate is the mitigation of the urban heat island phenomenon. Urban heat island refers to the higher temperatures of densely built urban areas compared to the rest urban space and outlying rural surroundings. The United States Environmental Protection Agency (EPA) classifies the phenomenon into two categories: surface and air. Temperature differences of surfaces can reach up to 15 °C and air temperature differences up to 12 °C (EPA, 2008). These high temperatures lead to heat stress of residents and, in some cases, increase energy demand of buildings. Studies have shown that an air temperature increase of 1 °C for an urban area could lead to an electricity consumption increase up to 8.5% (Santamouris et al., 2015).

Thermal sensation of residents can be evaluated by outdoor thermal comfort indices. Thermal comfort is defined as 'that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation' (ASHRAE, 2013). A more analytical approach by Fanger (1982), mentions that thermal comfort is achieved when the rate of metabolic heat generation and the heat loss of the body are balanced. Many indices have been developed to estimate outdoor thermal comfort conditions in the last years. PMV-PPD (Predicted Mean Vote - Predicted Percentage Dissatisfied) model (Fanger, 1972) was developed for indoor spaces and it was adapted for outdoor climate by Jendritzky in 1993 (http://www.model.envi-met.com). PET index (Physiological Equivalent Temperature), developed by Hoppe in 1999, have been used in many outdoor thermal comfort studies and assessment of the urban heat island phenomenon (Ketterer & Matzarakis, 2014). Another important index, developed by the International Society of Biometeorology in 2011, is UTCI (Universal Thermal Climate Index), which has been used to assess urban microclimate and outdoor thermal comfort (Park et al., 2014).

The emphasis of this work is to analyze how mitigation techniques in a dense urban environment affect microclimate parameters and outdoor thermal comfort. The quantitative differentiation of urban microclimate through bioclimatic urban redevelopment is investigated. There are many bioclimatic interventions that could improve microclimatic conditions (e.g. planting trees in an urban area with hot climate). The microclimatic variations caused by bioclimatic interventions should be analyzed quantitatively in order to reach valid scientific results. This quantitative analysis can lead to the computation of thermal comfort indices that combine many microclimatic parameters to estimate the thermal sensation of man. A microclimate simulation tool was employed in this study to analyse the studied area.

2. BIOCLIMATIC DESIGN METHODS

Urban microclimate is greatly affected by bioclimatic urban design. The siting of urban green, water surfaces, artificial constructions and their architectural form directly affect the insolation and wind conditions of an urban space. Plants characteristics (evapotranspiration, leafage density, tree crown width, etc.) and outdoor paving materials attributes (heat capacity, solar reflectance, etc.) also play an important role. Design interventions can also be extended to building shells (e.g. creation of green roofs).

2.1 Cool paving materials

Materials with high solar reflectance[1] and high infrared emissivity[2] are characterized as ‘cool’, because these properties prevent the development of very high temperatures in the urban environment. High solar reflectance leads to the absorption of less solar radiation compared to conventional materials and limits the surface temperature rise in the presence of high solar loads (Carnielo & Zinzi, 2013). The lower surface temperature of the material decreases the ambient air temperature as heat convection intensity from a cooler surface is lower (Doulos et al., 2004). High infrared emissivity of a material means that the absorbed short wave radiation is highly released as long wave radiation to the urban environment, so the stored heat is dissipated and the material is cooler. Many studies have shown the positive impact of cool materials to the mitigation of urban heat island (Santamouris et al., 2011; Santamouris, 2013; Carnielo & Zinzi, 2013; Zoras et al., 2014; Radhi et al., 2014). Approaching the effects on energy consumption of buildings, cool paving materials have an indirect impact on energy demand, affecting outdoor air temperature and radiant environment. Taha (1997) estimated that a change in the albedo for a Los Angeles area could lead to 1.5°C decrease in air temperature and combined albedo and vegetation changes could result in annual savings of 71 million dollars ($) regarding electric power. Due to pavement changes the annual savings were estimated to 15 million dollars ($). However, Yaghoobian & Kleissl (2012) support that increasing ground surface albedo could lead, in some cases, to increased annual cooling demand of

[1] Solar reflectance is the ability of a material’s surface to reflect the incident solar radiation and is calculated on a scale from 0 to 100%.

[2] Infrared emissivity is the ability of a material to release the heat that has absorbed and is calculated on a scale from 0 to 100%.

a building due to increased reflectance of solar radiation to building envelope, while the impact on heating demand is negligible.

2.2 Urban green

Vegetation affects outdoor thermal comfort not only because of the different properties values (solar reflectance, infrared emissivity, heat capacity etc.) compared to other materials of the built environment, but also due to evapotranspiration procedure. Water loss (water vapor) increases air humidity which leads to an increase of latent cooling (Dimoudi & Nikolopoulou, 2003). Additionally, geometric characteristics of plants (height, tree crown width, leafage shape and density, etc.) determine shading in the urban environment and have a great influence on surface temperatures. For hot climates, shading is the basic factor that prevents the development of very high temperatures, because overheating is mainly caused by storage of heat to sun exposed surfaces (Ali Toudert, 2005). It has been observed that in an urban park the air temperature could be 3-4°C lower than the surrounding urban area for the noon hours of a summer day (Bernatzky, 1982). Shashua-Bar & Hoffman (2000) have also investigated the cooling effect of shading in small urban green spaces, courtyards and streets in subtropical climate and detected an air temperature difference of 1°C compared to spaces exposed to solar radiation. This difference could reach 3°C for the hottest hours of the day. Regarding energy savings due to urban green, many studies indicate that the cooling effect of shading on building envelopes could conduce to the reduction of cooling demand (Akbari et al., 1997; McPherson et al., 1997; Donovan & Butry, 2009).

2.3 Water surfaces

The influence of water surfaces on urban microclimate lies on the fact that air temperature and humidity are affected by evaporation. In addition, water is characterized by high heat capacity and low solar reflectance. The low solar reflectance leads to the high absorption of solar radiation. Despite the high absorption, there is not a significant change of water temperature because of thermal inertia and evaporation of a water surface (Sanchez de la Flor & Alvarez Dominguez, 2004). Based on these properties, water bodies have relatively stable temperature conditions and have a positive impact on summer months for hot climates. Saaroni & Siv (2003) examined the effect of a small lake on air temperature and relative humidity for an area of Tel Aviv in Israel and found that air temperature was decreased by 1.6°C, while relative humidity was increased by 6% compared to the surrounding urban area during the hottest hours of the day (field observations for May and June). Robitu et al. (2006) investigated the influence of vegetation and water pond on urban microclimate for a square in Nantes, France through in-situ measurements and software simulations. Based on their study, the existing square (with vegetation and water pond) compared to a same empty square differ for the highest values of PMV index by 2.86. For the existing square, the highest PMV value was calculated at 0.54 (neutral thermal sensation), while the highest PMV value for the empty square was calculated at 3.4 (very hot sensation). Calculations were conducted for the summer period and noon hour (14.00) at the height of 1.5 m.

All new advanced low cost mitigation and adaptation technologies developed during the last years offer a serious potential for energy and environmental improvements and can highly contribute to improve indoor thermal conditions in buildings and especially the quality of life of low income population and protect its health (Santamouris & Kolokotsa, 2015).

3. CASE STUDY

In the case study, the quantitative differentiation of outdoor thermal comfort conditions through bioclimatic urban redevelopment for an area in the city of Serres in Greece is investigated. The Serres city, is located in northern Greece (longitude 23°33′05″, latitude 41°05′14″), at an altitude of 55m. It is one of the warmest cities in northern Greece, characterized by very high ambient temperatures in summer period that may exceed 40°C. In winter, there is a high percentage of relative humidity (mean value 76.9%) and temperature can reach -7°C. The value of incident solar radiation is high throughout the year and it can reach 6.76 kWh/m^2/day in summer period. The mean annual wind speed is 1.5 m/s.

The calculation of outdoor thermal comfort conditions for the summer period of the study area was conducted both for the existing condition and proposed design. The surface temperature, the mean radiant temperature (Tmrt) and the comfort index PMV are calculated and discussed for the existing and the after the interventions condition.

Simulations were performed with the ENVI-met 3.1 model. ENVI-met is a three-dimensional non-hydrostatic microclimate model and is able to calculate and simulate climate in urban areas with a typical grid resolution of 0.5 to 10 meters in space and 10 seconds in time (Ozkeresteci et al., 2008). It uses fundamental laws of fluid dynamics and thermodynamics to calculate microclimatic parameters and thermal comfort indices. Simulation is performed at three main levels. Firstly (Area Input File Editor), the urban environment is designed (building masses, vegetation etc.) and the respective structural materials with their thermophysical properties are defined. Secondly (Configuration File Editor), climatic data is inputted and simulation limitations are defined (wind speed and direction, turbulence model, time steps, etc). Finally (Start ENVI-met), the calculations are conducted based on the two aforesaid data files. Interpretation and visualization of the results are carried out using LEONARDO application.

Output files of the simulation were imported in BIOMET application, in order to calculate the thermal comfort index PMV. Body parameters were defined according to standard human (ISO 7730, 2005). The only change was made in static clothing insulation

(0.5 clo instead of 0.9 clo), because simulation was conducted for a day of July (hot summer conditions). The selected height for the calculations was defined at 1.8m. The visualization of results was carried out with QGIS 2.10.1 software.

3.1 Existing situation

The study area has dimensions 400 x 420 meters and consists of 17 blocks (fig. 1). The main streets of the area are Western Thrakis and Nikou Nikolaou. The width of the streets ranges from 8 to 12 meters. The height of buildings ranges from 8 to 26 meters and most buildings have been built at the decade 1970-1980. The ground floor of the buildings are commercial shops and the rest floors are residences. There is limited urban green and vegetation is mainly located along the streets. The main structural materials of outdoor spaces were asphalt and concrete tiles.

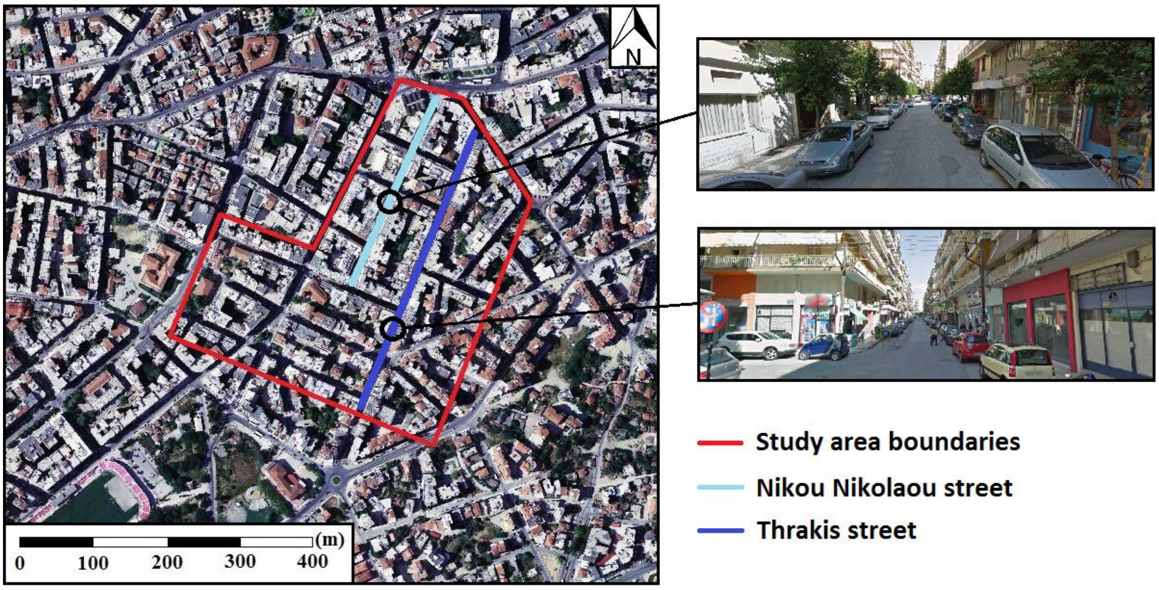

Fig. 1. Study area in Serres, Greece

Grid dimensions were defined at 225 x 225 x 30 cells, while cell dimensions were defined at 2 x 2 x 2 meters (grid dimensions: 450 x 450 x 60 meters). Furthermore, 10 nesting grids were added (20m), around the study area, in order to mitigate the interactions of boundaries with the study area. The urban environment was designed based on a three-dimensional geometry file (Dimoudi et al., 2014) and field observation. Database regarding thermophysical properties of the existing materials was configured according to the Technical Guideline 20701-2 of Technical Chamber of Greece (TOTEE, 2010). Subsequently, conditions and limitations of the simulation were selected. Based on monitored data of the outdoor thermal conditions in the area, the 19th of July was selected as the day of simulation, because it was one of the warmest days of June and July 2011 (Dimoudi et al., 2014). Start time was defined at 06.00 am and time duration at 14 hours in order to follow the atmospheric processes. Output data was regulated to be saved every 2 hours (06.00, 08.00, 10.00 etc.). Wind speed in 10m above the ground was defined at 2 m/s, based on the mean value of July and wind direction was selected west, according to Hellenic National Meteorological Service (www.emy.gr, 2016). All climatic data (initial temperature, specific humidity, etc.) was inputted according to HNMS mean values for July. Aerodynamic roughness length was estimated at 1.5, based on Davenport's roughness classification (Wieringa, 1992). Regarding turbulence settings in the atmospheric boundary layer, E-epsilon model was selected.

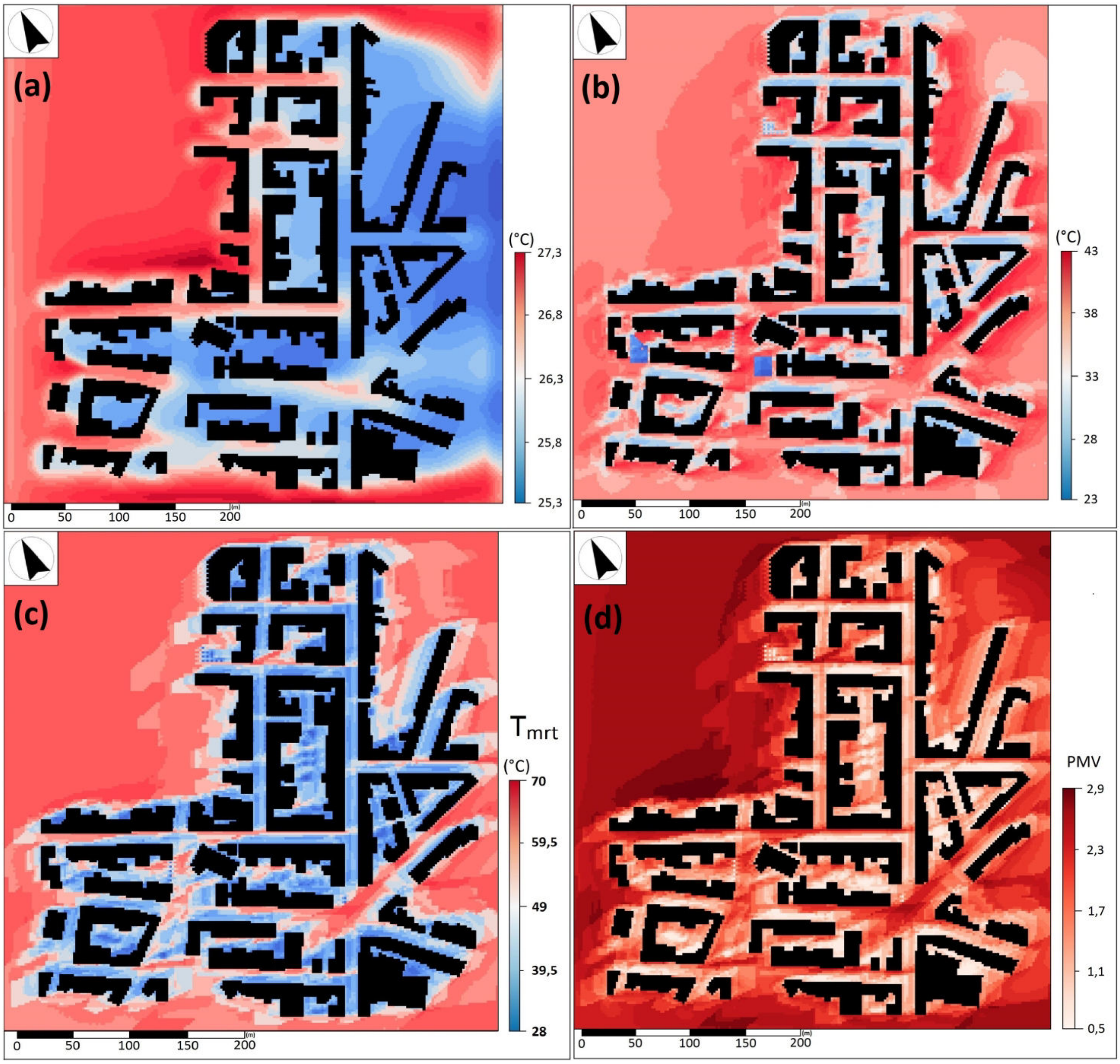

Fig. 2. Existing situation - simulation results for time period 06.00 to 20.00:
(a) Mean values for air temperature at 1.8m, (b) Mean values for surface temperature,
(c) Mean values for T_{mrt} at 1.8m, (d) Mean values for PMV index at 1.8m

Simulation results for the existing condition are presented in figure 2. Mean values for PMV index for the existing urban area range from 0.5 (slightly warm) to 2.9 (quite hot). Simulation is based on the German Guideline VDI 3787 (2008), where PMV is adapted to outdoor situations, at a thermal sensation scale from -4 (very cold) to +4 (very hot). It should be noted that PMV index can exceed +4 value for outdoor spaces in summer heat stress situations and reach values up to +8. Developers mention that while this result is numerically correct, it violates the range of the original PMV system (http://www.model.envi-met.com, 2016).

3.2 Proposed bioclimatic interventions

Replacement of conventional paving materials (asphalt, concrete tiles) with cool materials, increase of vegetation and addition of water surfaces are the main proposals of bioclimatic redevelopment (Dimoudi et al., 2014). Design Interventions include traffic calming streets, sidewalk widening and linear tree planting along the streets (fig. 3). Photocatalytic cool asphalt and cool pavement tiles with high values of solar reflectance are selected as cool materials, which cover the 86% of open areas. Water permeable materials (special pressed soil, low height vegetation, water surfaces) cover the 7% of the open areas. The existing situation is characterized by 95.5% cover of conventional paving materials and 4.5% cover of water permeable materials (Dimoudi et al., 2014).

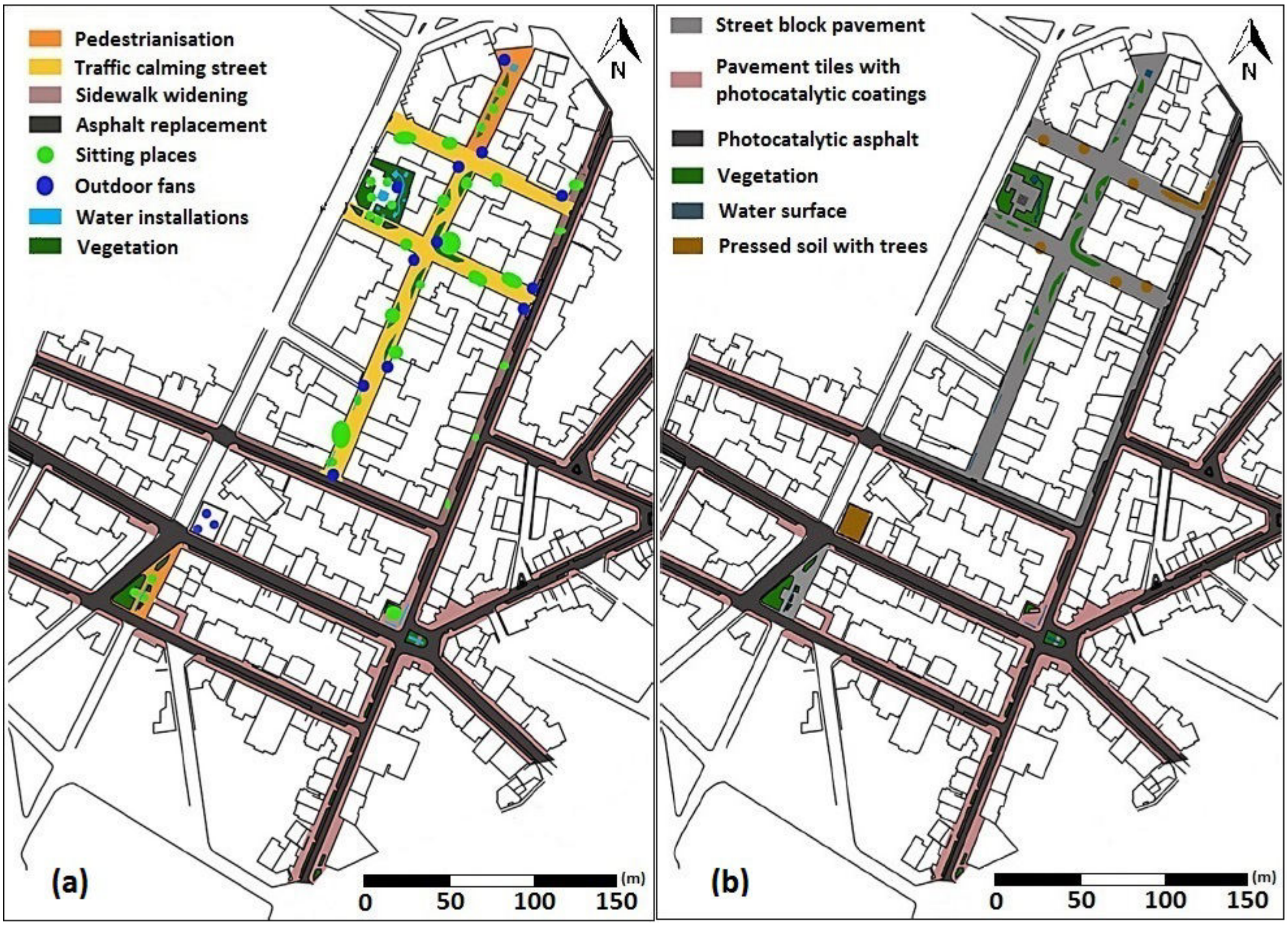

Fig. 3. Proposed bioclimatic design of the study area – interventions (a) and materials (b)

The urban environment (Area Input File) was created in ENVI-met based on the aforesaid interventions. Three new materials (Photocatalytic asphalt, cool pavement tiles, street block pavement) were added to ENVI-met database and their thermophysical properties were defined (Dimoudi et al., 2014). Conditions and limitations of the simulation were defined the same with the existing situation in order to get comparable results.

The main observations regarding simulation results are the slight decrease in air temperature and the considerable decrease in surface temperatures (fig. 4). PMV and T_{mrt} values show spatial fluctuation compared to the existing situation. Further discussing on the comparison of the results is conducted in the following section.

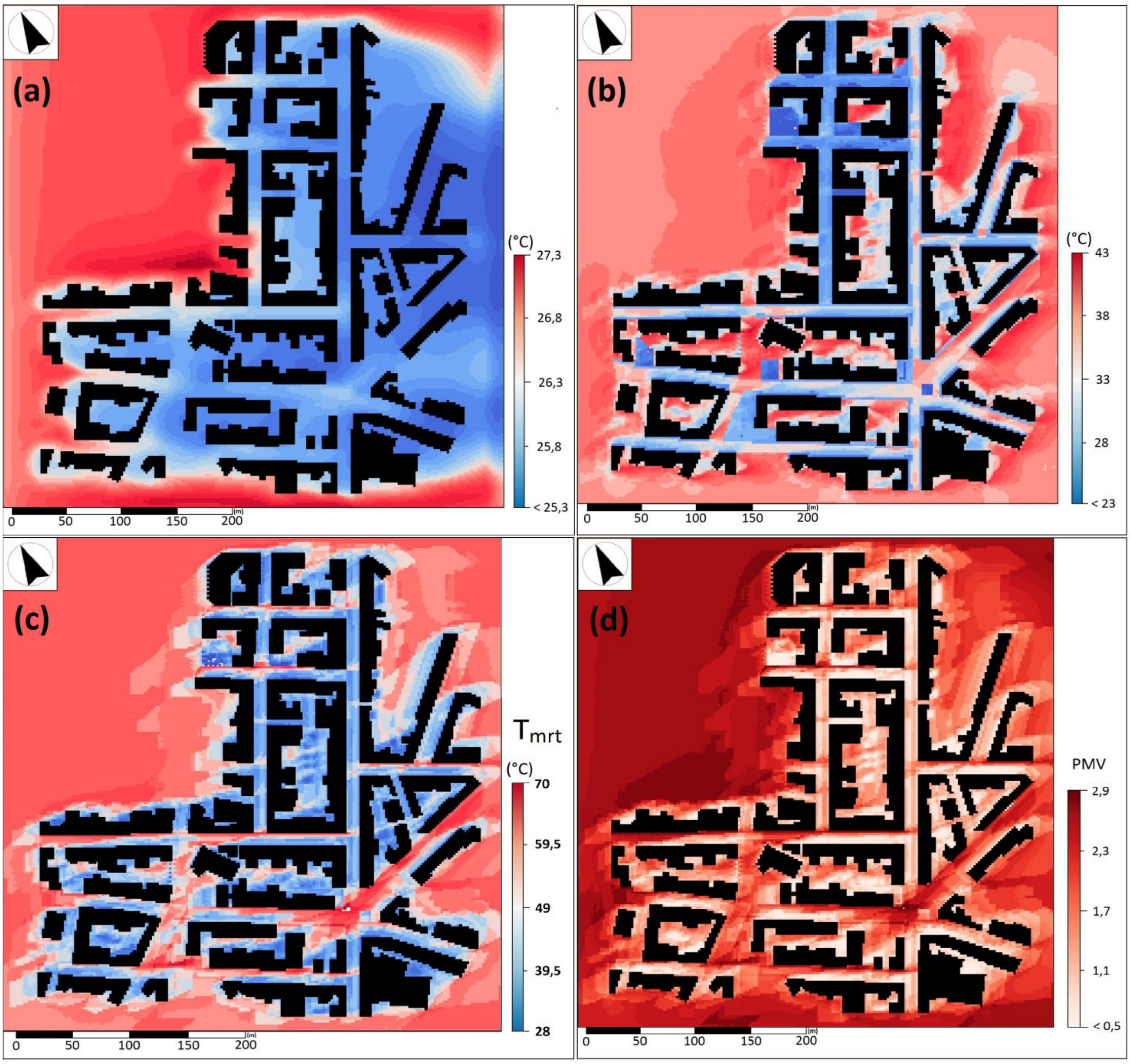

Fig. 4. Proposed bioclimatic design - simulation results for time period 06.00 to 20.00: (a) Mean values for air temperature at 1.8m, (b) Mean values for surface temperature, (c) Mean values for T_{mrt} at 1.8m, (d) Mean values for PMV index at 1.8m

4. RESULTS AND COMPARISON

Based on the simulation results with the microclimate model ENVI-met, many changes regarding microclimatic conditions and outdoor thermal comfort are observed after the proposed bioclimatic interventions.

Air temperature reduction is evident at the largest part of the study area (fig. 5). The greatest reduction is observed at the area where street block pavement of high solar reflectance (0.67), vegetation and water surfaces have been proposed - maximum decrease value 0.9°C. There is also a noticeable reduction at the area where photocatalytic asphalt (solar reflectance 0.37) has been proposed.

Surface temperatures show even greater decrease (fig. 5). The impact of cool materials on surface temperatures is evident. The maximum reduction (16°C) is observed at the area with pressed soil and vegetation. However, there are two places where surface temperature is increased.

Mean Radiant Temperature (T_{mrt}) is characterized by spatial fluctuation of values in the study area (fig. 6). For the most part of cool material areas, a slight increase of T_{mrt} is observed in the current simulations. According to Li (2012), increasing pavement reflectance leads to an increase in the Mean Radiant Temperature, due to the increased reflected radiation and consequently might increase the risk of reducing human thermal comfort during hot periods. It is also detected that in cool material areas with high Sky View Factor (SVF), a considerable increase in T_{mrt} values is observed. On the contrary, at pressed soil areas with vegetation, a significant decrease in T_{mrt} values is shown.

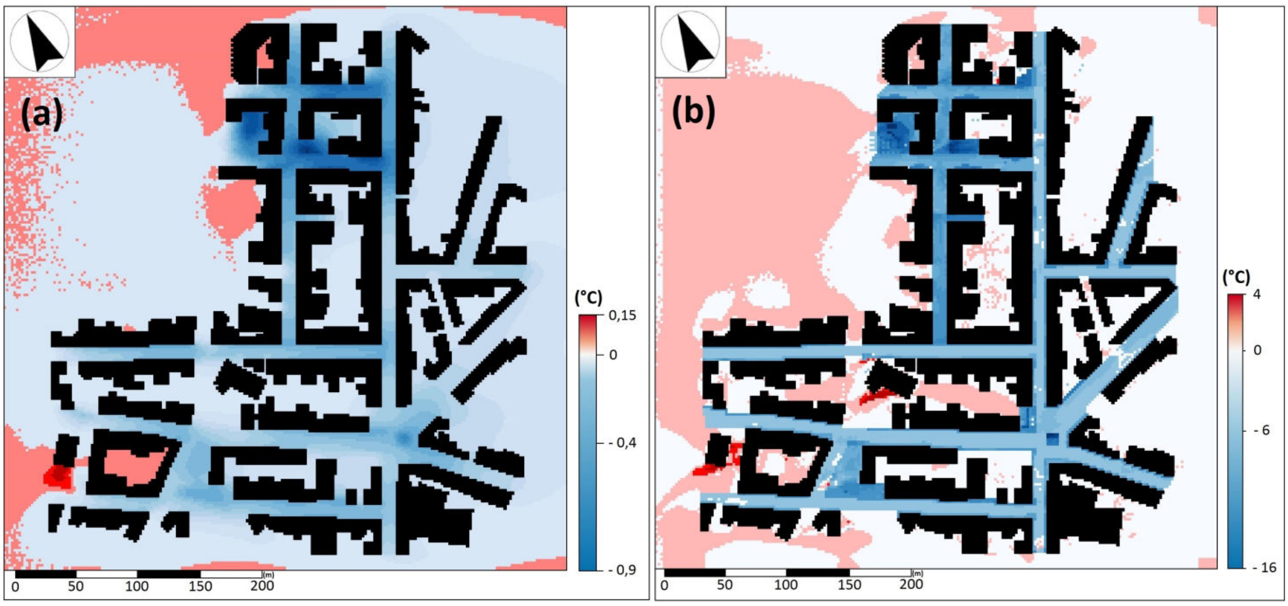

Fig. 5. Simulation results comparison (time period 06.00 – 20.00):
Mean air temperature differences at 1.8m (a) and mean surface temperature differences (b)

PMV index is also characterized by spatial fluctuation of values in the study area (fig. 6). The index is greatly affected by T_{mrt}. Some areas are exposed for great time to solar radiation during the day (SVF index) and their solar reflectance is increased through the bioclimatic redevelopment. In these areas, T_{mrt} values are increased at the height of 1.8m.

Fig. 6 shows that there is a strong spatial correlation between PMV - T_{mrt} - SVF. Erell et al. (2014) mention that the surface temperature reduction that is caused by high reflective materials, which leads to reduced long-wave emission, is counterbalanced by increased reflection of solar radiation and the net effect of increasing the albedo of urban surfaces may thus be an increase in the thermal stress to which pedestrians are exposed.

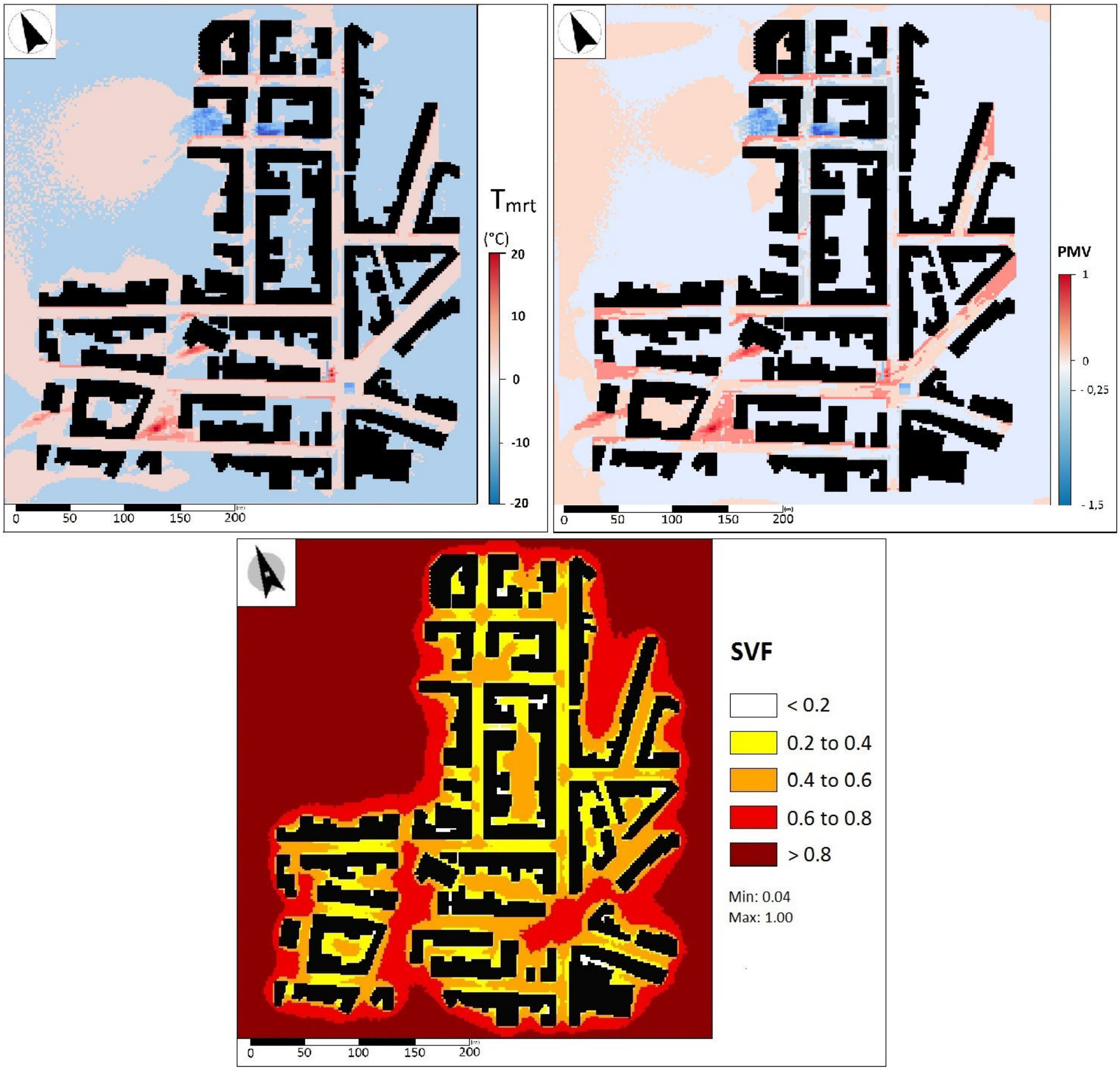

Fig. 6. Simulation results comparison (time period 06.00 – 20.00):
Mean PMV and T_{mrt} differences at 1.8m and SVF index at zero height

Regarding temporal fluctuation of microclimatic conditions and outdoor thermal comfort, four diagrams were created based on the mean values of all grid cells (except buildings) for the reference height (fig. 7). It should be noted that grid cells of the broader study area, which show very low or zero fluctuation of values, are also considered for the calculations. It is observed that the greatest differences are noticed at 14.00 for all diagrams. It is also detected that T_{mrt} mean values are slightly higher at the bioclimatic situation, in contrast to the other parameters. PMV index (mean value of all grid cells) is lower during the hot hours of the day.

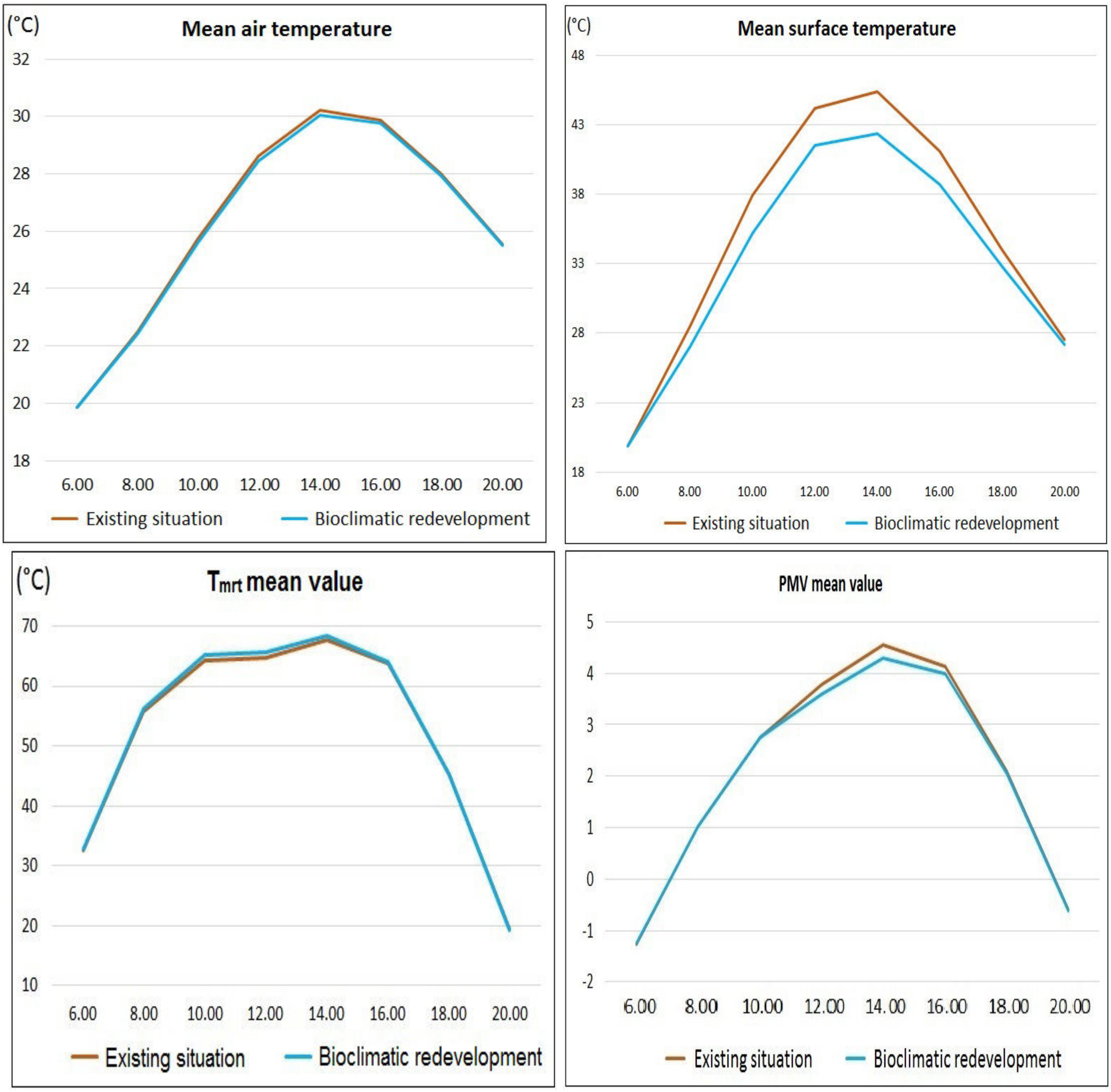

Fig. 7. Temporal fluctuation comparison of microclimatic parameters and PMV

5. DISCUSSION

Results show that air temperature and surface temperatures are considerably affected by the proposed bioclimatic redevelopment. This is mainly due to the fact that cool materials cause a significant reduction on the values of these two parameters under the examined conditions (fig. 5). Similar impact of cool materials on the aforesaid parameters under hot summer conditions is also supported by many other studies (Synnefa et al., 2011; Santamouris et al., 2012; Carnielo & Zinzi, 2013; Georgakis et al., 2014).

Regarding outdoor thermal comfort conditions, spatial fluctuation of values is observed, which is correlated with Mean Radiant Temperature (Tmrt) and Sky View Factor (SVF) (fig. 6). In some areas, where cool materials are applied, an increase in Tmrt is noticed (mean value from 06.00 to 20.00), which is mainly caused by the increase of the material's solar reflectance. This increase of Tmrt may lead to an increase of heat stress despite the air temperature reduction. This has been also deduced by other studies (Lynn et al, 2009, Erell et al., 2014; Yang et al., 2016; Taleghani et al., 2016; Schrijvers et al., 2016) and has been examined through different thermal comfort indices (ITS, PET, UTCI).

Regarding the effect of the bioclimatic redevelopment on the energy consumption of adjacent buildings, outdoor air temperature is decreasing, but Tmrt is increasing in some areas, which means that there might be a radiant load on the facades of the buildings. This might result to a higher cooling demand. As mentioned above (2.1), Yaghoobian & Kleissl (2012) reported that an increase in pavement solar reflectance by 0.4 (from 0.1 to 0.5) in Phoenix, Arizona, led to an increase in annual cooling loads of an office building by 11% and the impact on annual heating loads was small. Li (2012), also mentions that the reflected radiation on building surfaces might have an impact in terms of building energy use. However, Rosenfeld et al. (1998) support that an albedo increase of roofs and pavements by 0.35 and 0.25 respectively, in an area of 1250 km^2 in the city of Los Angeles, could lead to air temperature reduction of 1.5 °C during the peak period and annual peak power reduction up to 0.7 GW (0.6 from roofs and 0.1 from pavements). Qin (2015) mentions that aspect ratio (ratio of building's height to the road's width) is a basic factor for the application of reflective pavements in an urban canyon regarding energy absorption of the building walls and recommends an aspect ratio no greater than 1.0. Additionally, Zoras et al. (2015), studying the same area in Serres with the same parameters, estimated that the cooling load of the buildings could be reduced to by 6.88 %, due to external air temperature improvement of 1 ^{o}C. The reduction was more significant in lower floors, old buildings and in north facing zones of the building blocks.

Despite the progress made in this research field, there are not general conclusions for the influence of reflective pavements on buildings energy consumption and this should always be examined in combination with urban morphology, buildings' materials and climate characteristics.

6. CONCLUSIONS

Improvement of outdoor thermal comfort conditions will be a crucial challenge in the near future, since temperature rise will intensify overheating in cities. In this work, the main interventions of bioclimatic redevelopment were the application of cool paving materials and increase of vegetation and addition of water surfaces. The results showed that vegetation has a considerably positive impact on outdoor thermal comfort under hot summer conditions, mainly because of shading and evapotranspiration. However, the application of cool paving materials should be examined in combination with the urban morphology (SVF) and their thermophysical properties.

Simulation results with the ENVI-met model showed that the application of cool paving materials in areas with high values of SVF may lead to worse thermal comfort conditions in daytime. T_{mrt} should also be analyzed carefully, as high solar reflectance in conjunction with high values of SVF may cause discomfort in daytime, due to high T_{mrt} values. The correlation between SVF, T_{mrt} and PMV is not determined by general rules and it should be examined on a case-by-case basis. More refined theoretical models and measurements in real cases will offer validated data on the correlation of these parameters. On the other hand, the positive impact of cool paving materials in night hours is indisputable, because surface temperatures are lower (lower absorption of solar radiation during daytime) and this leads to a decrease in air temperature at night (less release of heat).

The matters that have been investigated are basic factors for quality of life in cities. By virtue of global climate change, the necessity of internationalization of these matters and finding solutions for many climatic zones has arised. The future of urban areas depends on the research on the characteristics that make cities sustainable.

Acknowledgement

This work was carried in the frame of the Master of Science Program in "Environmental Engineering and Science", at the School of Environmental Engineering, Democritus University of Thrace.

References

Akbari H., Bretz S., Taha H., Kurn D., Hanford J. (1997). Peak power and cooling energy savings of high-albedo roofs. *Energy and Buildings – Special Issue on Urban Heat Islands and Cool Communities*, 25, 117-126

Ali Toudert F. (2005). Dependence of Outdoor Thermal Comfort on Street Design in Hot and Dry Climate. *University of Freiburg: Meteorological Institute*, Dissertation

ANSI/ASHRAE. (2013). Standard 55 - Thermal Environmental Conditions for Human Occupancy. *American Society of Heating*, *Refrigerating and Air-Conditioning Engineers*, Atlanta, USA

Bernatzky A. (1982). The contribution of trees and green spaces to a town climate. *Energy and Buildings*, 5, 1-10

Carnielo E., Zinzi M. (2013). Optical and thermal characterisation of cool asphalts to mitigate urban temperatures and building cooling demand. *Building and Environment*, 60, 56-65

Dimoudi A., Zoras S., Kantzioura A., Stogiannou X., Kosmopoulos P., Pallas C. (2014). Use of cool materials and other bioclimatic interventions in outdoor places in order to mitigate the urban heat island in a medium size city in Greece. *Sustainable Cities and Society*, 13, 89-96

Dimoudi A., Nikolopoulou M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. *Energy and Buildings*, 35, 69-76

Donovan G., Butry D. (2009). The value of shade: Estimating the effect of urban trees on summertime electricity use. *Energy and Buildings*, 41, 662-668

Doulos L., Santamouris M., Livada I. (2004). Passive cooling of outdoor urban spaces. The role of materials. *Solar Energy*, 77, 231-249

Erell E., Pearlmutter D., Boneh D., Kutiel P.B. (2014). Effect of high-albedo materials on pedestrian heat stress in urban street canyons. *Urban Climate*, 10, 367-386

Fanger P.O. (1982). Thermal comfort: analysis and applications in environmental engineering. *Robert E. Krieger Publishing Company*, Malabar, Florida

Georgakis C., Zoras S., Santamouris M. (2014). Studying the effect of “cool” coatings in street urban canyons and its potential as a heat island mitigation technique. *Sustainable Cities and Society*, 13, 20-31

Hoppe P. (1999). The Physiological equivalent temperature - a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, 43, 71-75

Intergovernmental Panel on Climate Change (2014). Climate Change 2014, Impacts, Adaptation and Vulnerability – Summary for policymakers. *Working Group II – Contribution to the Fifth Assessment Report of the IPCC*

ISO 7730. (2005). Ergonomics of the thermal environment. Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. *Geneva: International Organization for Standardization*

Ketterer C., Matzarakis A. (2014). Comparison of different methods for the assessment of the urban heat island in Stuttgart, Germany. *International Journal of Biometeorology*, 43, 76-84

Li H. (2012). Evaluation of Cool Pavement Strategies for Heat Island Mitigation. *University of California*, *Davis: Institute of Transportation Studies*, USA

Lynn B.H, Carlson T.N., Rosenzweig C., Goldberg R., Druyan L., Cox J., et al. (2009). A modification to the NOAHLSM to simulate heat mitigation strategies in the New York City metropolitan area. *J. of Applied Meteorology* and Climatology, 48, 199–216.

McPherson E., Nowak D., Heisler G., Grimmond S., Souch C., Grant R., Rowntree R. (1997). *Quantifying urban forest structure*, *function*, *and value: the Chicago Urban Forest Climate Project*. *Urban Ecosystems*, 1, 49-61

Mirzaei P., Haghighat F. (2010). Approaches to study Urban Heat Island – Abilities and limitations. *Building and Environment*, 45, 2192-2201

Ozkeresteci I., Crewe K., Brazel A.J., Bruse M. (2003). Use and evaluation of the ENVI-met model for environmental design and planning: An experiment on linear parks. *21st International Cartographic Conference (ICC) 'Cartographic Renaissance'*, Durban, South Africa

Qin Y. (2015). Urban canyon albedo and its implication on the use of reflective cool pavements. *Energy and Buildings*, 96, 86-94

Park S., Tuller S., Jo M. (2014). Application of Universal Thermal Climate Index (UTCI) for microclimatic analysis in urban thermal environments. *Landscape and Urban Planning*, 125, 146-155

Radhi H., Assem E., Sharples S. (2014). On the colours and properties of building surface materials to mitigate urban heat islands in highly productive solar regions. *Building and Environment*, 72, 162-172

Robitu M., Musy M., Inard C., Groleau D. (2006). Modeling the influence of vegetation and water pond on urban microclimate. *Solar Energy*, 80, 435-447

Rosenfeld A., Akbari H., Romm J., Pomerantz M. (1998). Cool communities: strategies for heat island mitigation and smog reduction. *Energy and Buildings*, 28, 51-62

Saaroni H., Ziv B. (2003). The impact of a small lake on heat stress in a Mediterranean urban park: the case of Tel Aviv, Israel. *International Journal of Biometeorology*, 47, 156-165

Sánchez de la Flor F., Alvarez Dominguez S. (2004). Modelling microclimate in urban environments and assessing its influence on the performance of surrounding buildings. *Energy and Buildings*, 36, 403-413

Santamouris M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island - A review of the actual developments. Renewable and Sustainable Energy Reviews, 26, 224-240.

Santamouris M., Cartalis C., Synnefa A., Kolokotsa D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings — A review. *Energy and Buildings*, 98, 119-124

Santamouris M., Gaitani N., Spanou A., Saliari M., Giannopoulou K., Vasilakopoulou K., Kardomateas T. (2012). Using cool paving materials to improve microclimate of urban areas - Design realization and results of the flisvos project. *Building and Environment*, 53, 128-136

Santamouris M., Kolokotsa D. (2015). On the impact of urban overheating and extreme climatic conditions on housing, energy, comfort and environmental quality of vulnerable population in Europe. *Energy and Buildings*, 98, 125-133.

Santamouris M., Synnefa A., Karlessi T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Solar Energy*, 85, 3085-3102

Schrijvers P.J.C., Jonker H.J.J. de Roode S.R., Kenjereš S., (2016). The effect of using a high-albedo material on the Universal Temperature Climate Index within a street canyon. *Urban Climate*, 17, 284-303

Shashua-Bar L., Hoffmann M. (2000). Vegetation as a climatic component in the design of an urban street: an empirical model for predicting the cooling effect of urban green areas with trees. *Energy and Buildings*, 31, 221-235

Synnefa A., Karlessi T., Gaitani N., Santamouris M., Assimakopoulos D.N., Papakatsikas C. (2011). Experimental testing of cool colored thin layer asphalt and estimation of its potential to improve the urban microclimate. *Building and Environment*, 46, 38-44

Taha H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and Buildings*, 25, 99-103

Taleghani M., Sailor D., Ban-Weiss G. (2016). Micrometeorological simulations to predict the impacts of heat mitigation strategies on pedestrian thermal comfort in a Los Angeles neighborhood. *Environmental Research Letters*, 11, 1-12

TOTEE. (2010). Technical Guideline 20701-2. Thermophysical properties of structural materials and testing of insulating adequacy of buildings. *Technical Chamber of Greece*, Athens

EPA. (2008). Reducing Urban Heat Islands: Compendium of Strategies, Urban Heat Island Basics. *United States Environmental Protection Agency*

Wieringa J. (1992). Updating the Davenport roughness classification. *Journal of Wind Engineering and Industrial Aerodynamics*, 41, 357-367

Yaghoobian N., Kleissl J. (2012). Effect of reflective pavements on building energy use. *Urban Climate*, 2, 25-42

Yang J., Wang Z., Kaloush K., Dylla E. (2016). Effect of pavement thermal properties on mitigating urban heat islands: A multi-scale modeling case study in Phoenix. *Building and Environment*, 108, 110-121

Zoras S., Tsermentselis A., Kosmopoulos P., Dimoudi A. (2014). Evaluation of the application of cool materials in urban spaces: A case study in the center of Florina. *Sustainable Cities and Society*, 13, 223-229

Zoras S., Veranoudis S., Dimoudi A. (2015). Urban Microclimatic Improvement Effects to Building Blocks Energy Consumption by the Use of Energy Simulation. *The 7th International Conference of SuDBE2015*, Reading, United Kingdom

Internet references

http://www.emy.gr/hnms/english/climatology/climatology_region_diagrams_html?dr_city=Serres (last access 15-09-2016)

http://www.model.envi-met.com/hg2e/doku.php?id=apps:biomet_pmv,
(last access, 15-09-2016)