Third Int. Conf. on Countermeasures to Urban Heat Island: Integration of Microclimate-Responsive Design in the Planning of Urban Outdoor Spaces – a Case Study in Athens, Greece

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ABSTRACT

In the design of outdoor urban spaces microclimate consideration are often relegated in the background compared to other functional, aesthetic and economic design purposes. Even though the necessity of mitigating urban heat and improving thermal comfort is evident, urban microclimate is hardly addressed as design criteria in planning and design processes yet. However, as a consequence of urban expansion and densification and climate change, urban heat and thermal discomfort in urban environments are likely to increase. Therefore, climate-responsive designs should be integrated in on-going urban developments to ensure comfortable living conditions for cities' inhabitants now and in the future. The landscape architecture and urban planning project "One-step beyond. Re-Think Athens, towards a new city centre" represents such an integrative approach. The study exemplarily describes the process of re-designing urban outdoor spaces in Athens by means of climate-responsive greenery.

Introduction

Athens' Mediterranean climate in summer-time is determined by urban heat, caused by high radiation and anthropogenic heat in large urban areas of paved, asphalted materials with a shortage of greenery, shading devices and ventilation. (Santamouris 2012a). Additional low wind speeds in summertime contribute significantly to increased intensity of the heat island in Athens (Santamouris 2012b).

As urban heat comprehensively affects the quality of life of citizens there is a need to create thermally comfortable spaces Climate-responsive designs need to anticipate on local climatic conditions, e.g. by generating shade of tree canopy covers and green surfaces on open spaces with high radiation or generating underground water storage in places where additional irrigation for urban greenery is needed during drought periods.

In 2012 the Greek Onassis foundation announced the international architectural competition 'Re-Think Athens, towards a new city center'. The competition aimed at re-designing and regenerating the city center of Athens, enabling a social, cultural and economic activation of the surroundings[5]. The assignment included the transformation of the Panepistimiou Street from

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busy traffic lanes into a wide pedestrian zone with a tram line. Additionally, present-day problems such as vacant buildings, negative image of the area and poor microclimate conditions had to be solved within the competition entries. Concerning the microclimate conditions, the Onassis Foundation set a series of bioclimatic criteria as design specifications to ensure the effectiveness of the proposed design in the competition entries. Designers were encouraged to use greenery and other technical interventions in the public space to advance climatic conditions. The formulated criteria concerning microclimate were included in the documentation manual of the competition[6]:

1. Reduction by 1,5°C in the maximum summer temperature, measured at a 1,8m height;
2. Improvement by 20% of the thermal comfort index during a typical summer day
3. Reduction by 5% of the maximum surface temperature.

In 2013 the Dutch consortium of OKRA Landscape Architects, MIXST urbanism and Wageningen University won the multi-stage competition with their entry "One-step beyond". Their design proposal integrated public transport and pedestrian zone in the Panepistimiou Street and at the same time aimed at generating a resilient, accessible and livable city. The green boulevard of the Panepistimiou Street formed the hart in a green city network.

Microclimatic aspects were included in the design process from the very beginning in the competition stage. When the consortium received the assignment for the detailed design an international team consisting of WSGreenTechnologies and Studio 75, LDK, NAMA en Atelier Roland Jeol joined the team of designers. By the end of 2013 the detailed plan was finished; the implementation of the project should be finished in 2016.

This paper focuses on the planning and design process of the project 'One step beyond' which met the bioclimatic criteria required within the Onassis Foundation.. Besides the description of the scientific and numerical results, this paper demonstrates the benefits of a multi-disciplinary approach of architects, landscape architects, scientist und engineers and the advantages of integrating microclimate measures and simulations in the planning process.

The following paragraphs describe the competition stage and the stage of the detailed design. In the competition stage, a heat mitigation toolbox was developed and preliminary simulations were conducted. In the stage of the detailed design an iterative process of designing, simulating/ testing and adjusting took place to improve the design and achieve the bioclimatic criteria's.

Competition Phase: Heat mitigation toolbox

The instrument 'heat mitigation toolbox' was developed to gain an overall picture of possible measures to improve the urban microclimate, energy consumption and thermal comfort of citizens. The toolbox was based upon recent scientific literatures on improving microclimatic conditions in specific case study areas in Mediterranean climates, e.g. in Athens. Therefore,

[6] Re-Think Athens – Towards a new city center. Documentation manual for the launching of the European architectural competition. Onassis Foundation. 2012. page 87.

measures and design principles included in the heat mitigation toolbox were expected suitable and scientifically proven for the city of Athens.

The heat mitigation toolbox provided appropriate urban design principles related to (1) greenery, (2) cool materials and (3) water measures which reduce the urban heat island effect (Giannopoulou 2011) and energy consumption in Athens. As confirmed by recent microclimatic measurement and simulation studies in Athens (Giatani 2011), implementation of greenery, cool material or water measures contribute to comfortable climatic conditions for citizens living or moving through the city. In "One step beyond" those design principles were implemented in outdoor spaces and on surfaces of buildings as described in the following sections.

1. Greenery

   Urban green, such as grass, hedges, climbing plants and especially trees mitigate heat through evapotranspiration and more substantially through shading. Leafs of plants reduce solar radiation that reaches hard surfaces, such as paved streets and squares or facades of buildings. The reduction of solar radiation has a twofold effect: the surface and air temperatures as well as the nocturnal Urban Heat Island effect are lower.

   Trees with dense canopies, therefore, are planted on streets (in a row) and on squares (sprawl). Within narrow streets with a lack of space for two rows, triangular planting of trees will provide shade. If there is no space for trees at all, pergolas, shelters or constructions on facades with climbing plants will provide shade.

   Position and density of new street trees are chosen with caution depending on the amount of traffic and the wind speed and –orientation in winter. In streets with high traffic, tree canopies are less dense to assure that car pollution will not stuck under the canopy and this way disturb comfort for pedestrians. In wintertime, sunlight and absence of cool wind are highly appreciated and increase the use of outdoor spaces by Athens inhabitants (Nikolopoulou 2007). Tree positioning, therefore, assures comfortable use of open spaces year-round.

   Another measure from the toolbox is greening the tram lines with grass. It reduces paved surfaces within streets, reduces surface temperatures and enables natural infiltration in storm water events.

2. Cool materials

   The benefit of using cool materials such as light asphalt, light concrete or light natural stones, is their high reflectivity and albedo. Cool materials guarantee less absorption of radiation and lower surface temperatures compared to other conventional materials. Through this reduction of heat storage in urban materials, the process of cooling down the ambient air temperature at night accelerates which moreover implies a reduction of the energy demand by air-conditioning at night.

   Surfaces in and around Panepistimou are 'cool' and also 'permeable' materials, providing a natural water infiltration and this way discharge the sewer system. In adjacent streets, such as Akadimias and Stadiou it will be interesting to think about application of light coloured concrete (for bus lanes) and/or photocatalytic asphalt.

3. Water measures

   Water elements used above and beyond surfaces facilitate a resilient way to manage seasonal abundance and shortage of rainwater, to improve the urban microclimate and to create attractive outdoor spaces. Open or glass covered water gutters integrated in the street design operate as storm water drainage. The overrun of rainwater after a heavy storm event will partly be stored in underground water storage systems to be re-used for irrigations of greenery during drought periods. In drought periods, stored rainwater will furthermore be sprayed on road surfaces for cooling purposes. Moving or sprinkling water is also accommodated in public spaces where people stay and sojourn. Water elements, such as basins with running water or mist, water squares and fountains, improve air humidity and thermal comfort on hot summer days.

The large amounts of flat roofs in Athens offer additional possibilities to improve thermal comfort inside buildings and reduce the energy demand. If the structure of buildings allows, roofs could be equipped as green roofs, roof for water storage or photovoltaic panels, which all cover the roof and reduce heat absorption into the building. Especially in the upper floors, often used for housing or hotel rooms, thermal comfort is improved and less energy for air-conditioning is needed. Green roofs might be combined with vertical gardens or green walls which also effect the lower floors of buildings and - if low enough - even the street canyons.

As warm air is transported in between neighbouring areas, the choice is to not limit the toolbox measures to Panepistimou. Instead the cooling measures are spread over Panepistimou and its surrounding, so that improvement of thermal comfort is achieved on larger scale.

In the first step of the design process, the measures from the heat mitigation toolbox were generally linked with specific parts of the site (Fig. 1). When working out the preliminary design the landscape architect analyzed the specific microclimate conditions and decided for every situation which of the measures from the toolbox suited the most to create optimal microclimate conditions (Fig. 2).

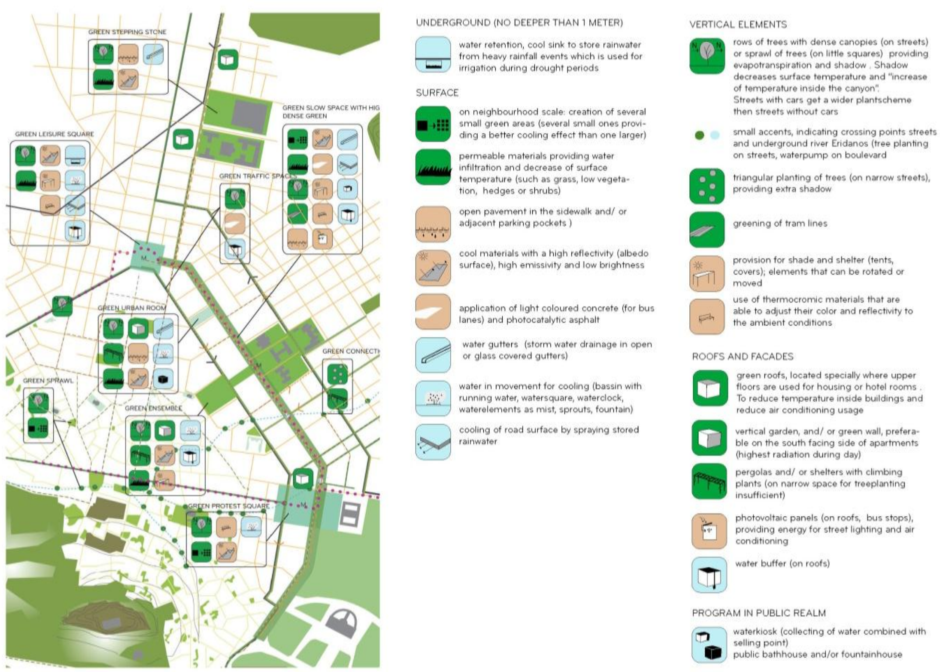

Figure 1: Heat mitigation toolbox – measures and spatial distribution

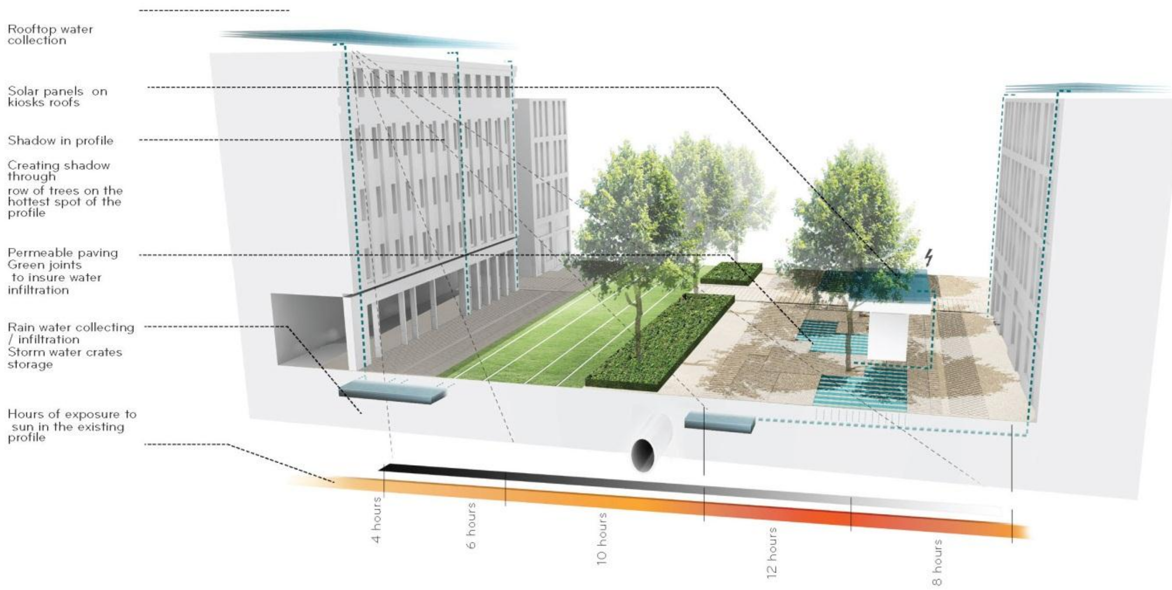

Figure 2 – Analysis microclimate conditions (e.g. sun exposure) and implementation of suitable measures from the heat mitigation toolbox

Preliminary microclimate simulation

To test the effect of the implemented measures from the toolbox a preliminary microclimatic simulation was conducted. As one of the hottest spots in Athens city center, the Omonia Square was chosen as a case to compare thermal conditions of the existing and the newly designed situation for a typical hot summer day.

Human thermal comfort on an extreme hot summer day, exemplarily on the 16th of July 2012, has been simulated with the with RayMan (Matzarakis 2008), a software to simulate radiation fluxes. The human thermal comfort was calculated for the existing situation and for the future design (Fig. 3 and 4).

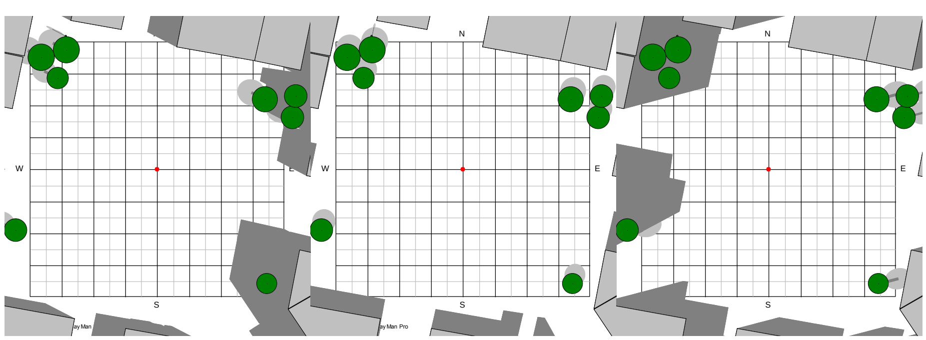

Figure 3: Shading patterns of the existing situation for the Omonia Square (16th of July, left to right at 3 moments during the day: 10, 13 and 16 h local time); Rayman (Matzarakis 2008).

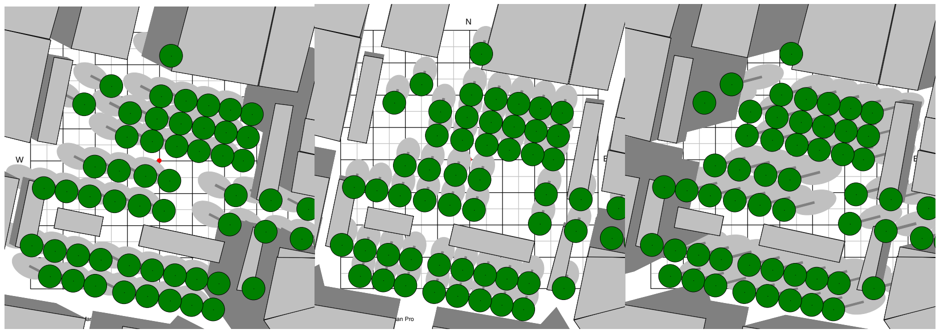

Figure 4: Shading patterns of the future design for the Omonia Square (16th of July, left to right at 3 moments during the day: 10, 13 and 16 h local time); Rayman (Matzarakis 2008).

The thermal comfort index PMV ranges from very cool (-4), neutral (0) to very hot (4). On this very hot day the daytime thermal stress levels reached “extreme heat stress” values. For sunny weather with low wind speeds but lower temperatures a similar reduction in PMV can be expected. The preliminary simulations indicated the positive effect of the design proposal on outdoor thermal comfort (Fig. 5).

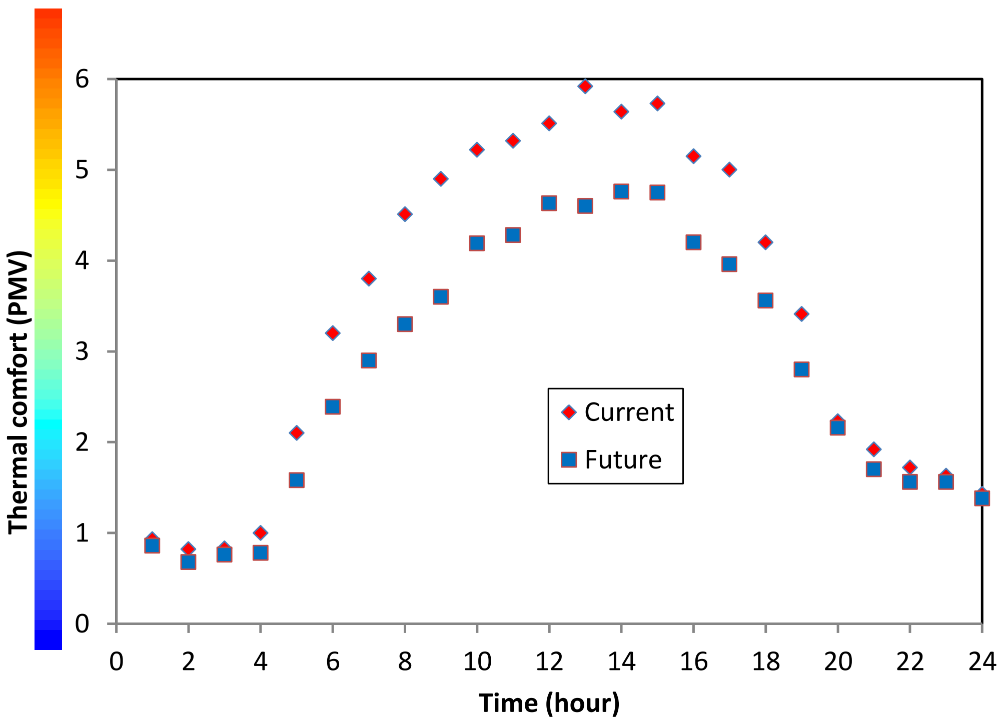

Figure 5: Omonia square average thermal comfort expressed as predicted mean vote (PMV, Fanger, 1972), simulated with Rayman (Matzarakis et al., 2008)

Second Stage: microclimate simulations

In the second stage WSGreenTechnologies conducted two sets of microclimate simulation. The design was simulated using the microclimate simulation model ENVI-met[7], Bruse, and Dostal 2008; Bruse 1999a) in order to investigate the differences in thermal comfort conditions between the actual and the expected situation and suggest re-design measures to improve the microclimate conditions (Bruse 1999b). In the second design phase, results of the ENVI-met simulations were used to adjust and improve the preliminary design in terms of thermal comfort. Finally the newly developed final design was investigated with high resolution models to quantify the achievement of the goals.

First Set of Simulations

In the first set two significant locations of the study area were analysed. The two areas were digitalized into an ENVI-met model with a horizontal and vertical resolution of 2 m and analysed in the actual and the proposed situation. To build a realistic model of the actual situation the local architects pre-processed the current data and information about the buildings, streets and species and sizes of existing vegetation. Further the models of the situation as it is today were supported with aerial and bird-eye pictures taken from Google Earth and Microsoft BING maps. The planned situation based on the plans by the landscape architects, while buildings were modelled identical in actual situation and proposed design.

The results for the area of Omonia Square showed a distinct improvement in thermal comfort. The square and surrounding were a local hotspot because of the large area of hard surfaces (especially asphalt and the reddish tiles in the pedestrian zone), absence of shade, e.g. of trees and high anthropogenic heat load. Due the massive amount of trees in the design, which shaded most part of the place the outdoor comfort condition was definitely enhanced. As re-design measures was proposed also to add some narrow vegetation at the outer parts of the square to break the wind axis.

For the areas of Justice Square the improvement was rather small, mainly due to that a number of dense existing trees have been removed and replaced by smaller and lighter trees. Generally it could be noted, that there was a large spatial variance in terms of thermal comfort in the whole study area due differences in orientation of the street canyon towards the sun, differences in the aspect ratio (height to width ratio) and differences in the existing design, especially materials and presence of trees.

Final Set of Simulations

For the final detailed analysis four characteristic areas of the centre of Athens, two squares and two streets, were selected and digitalized (the complete area of re-design the inner city is too large to be represented as whole in a high-resolution microscale model). The models of the situation as it is today based on the provided plans and tables and on on-site-inspections

[7] www.envi-met.com

(Fig. 6). The models for the future situation based on the plans for the final design as it had been frozen by OKRA mid of July 2013 (Fig. 7).

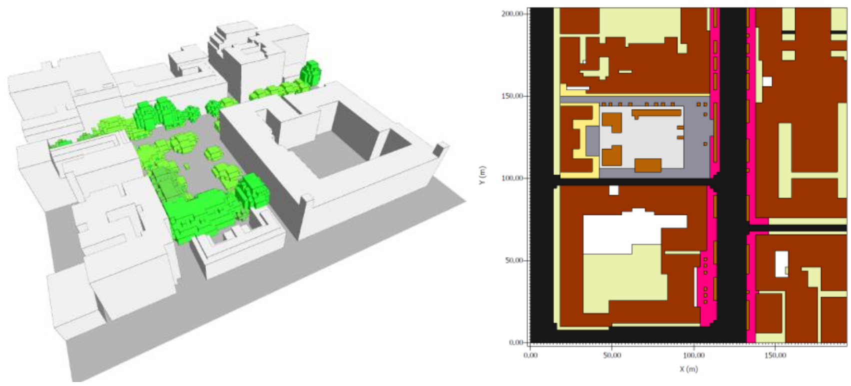

Figure 6. Vegetation and buildings today.

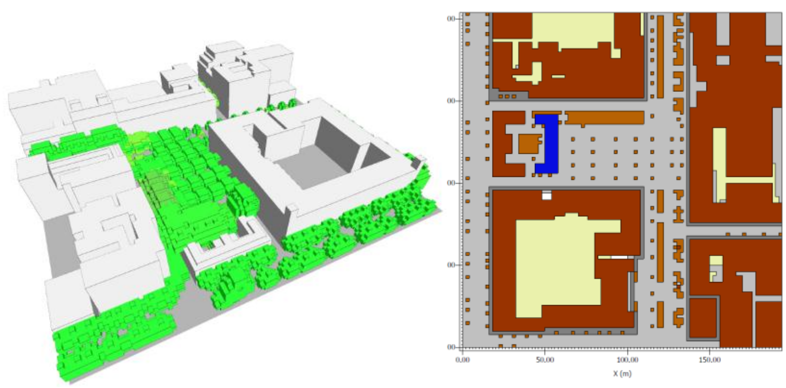

Figure 7. Vegetation and buildings in the design proposal

For more precise input data and results a pre-validation measurement campaign was conducted by the University of Athens in May 2013 and coordinated by Prof. M. Santamouris. In this campaign, the surface temperature amplitude of different materials inside the city centre of Athens was analysed. These measurements were used to adjust the main thermal properties of the soil materials (albedo and thermal conductance) in the ENVI-met database (Final Report on the Thermal and Wind Measurements 2013). With the optimized database, a good fit between simulated and measured temperature amplitude could be achieved.

The four simulation areas are considered as example areas of the re-design and were simulated independently from each other. The same climate inflow profile was used for the situation today and for the re-designed case, namely an idealized (theoretical) summer day with a typical land wind conditions. In reality the temperature reduction taking place in one model area will also have an impact on the model areas downstream of the model. For example, in the case of northern winds, a temperature reduction taking place at Omonia Square and Patission will also lower the incoming temperature at Justice Square and Panepistimiou. Hence, the total effects in air temperature reduction are actually lager than calculated in this model. For each model area daylight access / Sky View Factor, solar access, wind comfort and ventilation, air and surface temperature and thermal comfort indicator PET (Höppe 1999) has been analysed. The following pictures (Fig. 8 and 9) are presented as example of the study results.

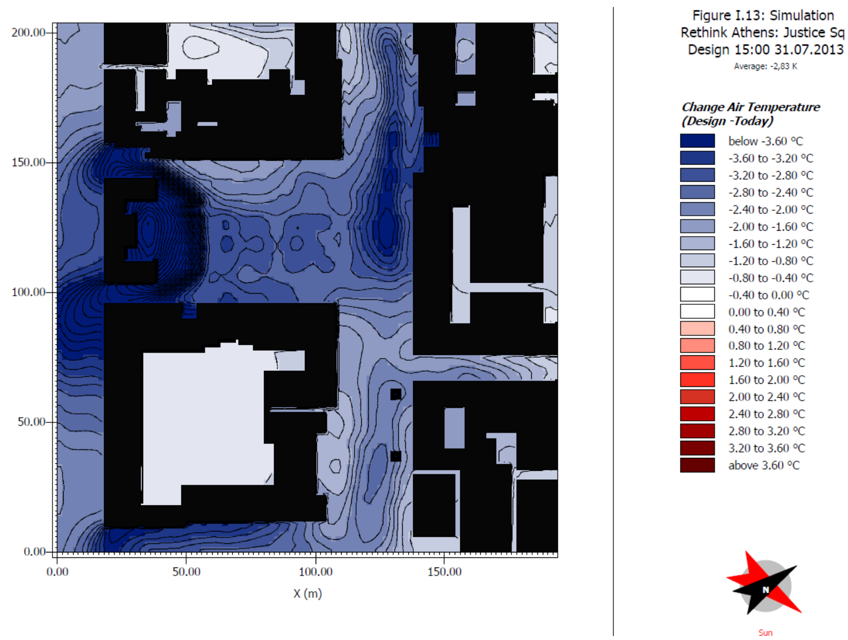

Figure 8. Comparison of the air temperature between the actual and the design situation.

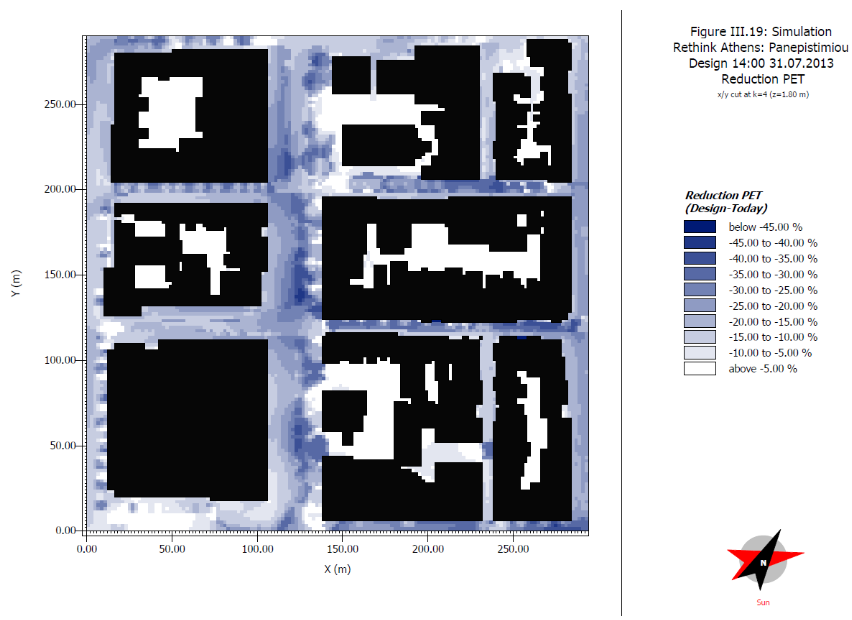

Figure 9. PET of Panepeistimou Street in Design phase in comparison to actual situation

Table 1 summarises the results of the test against the bioclimate criteria. It should be noted, that the calculations for all criteria were limited to the areas of the model, where a re-design has taken place and the backyards of buildings were excluded from the calculation. As shown all the bioclimatic criteria mentioned in the summary description above are met. The re-design showed a significant improvement of the microclimatic condition, even better than the given limit values. The re-designed area will increase the comfort of the users, of the pedestrians walking through it and the energy consumption of the adjacent buildings.

Table 1. Summary of bioclimatic criteria

Bioclimate Criteria	Air Temp	Surface Temp	PET
Target	- 1.50 K	-5%	-20%
Justice Square (Land)	-2.83 K	-29%	-28%
Justice Square (Sea)	-3.00 K	n.a.	-29%
Omonia Square (Land)	-1.80 K	-27%	-21%
Omonia Square (Sea)	-1.94 K	n.a.	-21%
Panepistimiou (Land)	-1.60 K	-23%	-20%
Panepistimiou (Sea)	-1.85 K	n.a.	-19%
Patisson (Land)	-2.11 K	-25%	-23%
Patisson (Sea)	-2,16 K	n.a.	-24%

Conclusion

The case study “One step beyond” describes the re-design-planning process in which besides spatial functional, social, economic and security demands the focus was put on microclimate improvement. It shows how encouraging the integration of urban climate aspects from the very beginning of the design process can (theoretically) lead to significant improvement of the outdoor thermal conditions. Measurements after the realisation of the project in 2016 will have to definitely show the real improvements though the re-design. The monitoring would also confirm if the expected effects on the local economy, like the economical pull through the increment of visitors and tourist in these areas, are actually achieved.

Next to the high-quality of the conceptual design, one major reason for the success of the design proposal was the multi-disciplinary and cooperation of the team. Also the physical distance and the language barriers between the team members (The Netherlands, Greece and Germany) never was an obstacle to a fruitful collaboration. The cooperativeness and a well-organised schedule allowed an in time deliverable of the simulation results and the re-design proposal could be integrated in the design and effectively influence the shaping of a microclimate-optimised neighbourhood. Only by starting in an early stage the mitigation and the re-design measures developed in close collaboration with microclimate consultants, could be integrated in the design, realised and actually give a positive contribution to the reduction of the Urban Heat Island effect. This approach was crucial as a priority for the client was the achievement of microclimate goals.

Although the achievement of the bioclimatic goals represents the success of “One step beyond”, the planning process pointed out some difficulties. One of the main obstacles was capturing the actual situation. As a detailed mapping of the status quo was not available, each existing tree with species, height and diameter of the trunk was captured in the planning area and in the bordering area. Buildings shapes had to be checked as existing data by the municipalities had only limited value.

Promoting through the client a similar multidisciplinary approach and the integration of heat mitigation criteria in early stage should be adopted in all urban planning development and competitions as, like shown in this case study, major modification in the design arose from microclimate consideration.

Acknowledgments

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References

Bruse, M. 1999 a. *The influences of local environmental design on microclimate (...),* Ph.D Thesis University of Bochum, Bochum

Bruse, M. 1999 b: *Modelling and strategies for improved urban climates.* Invited Paper in: Proceedings International Conference on Urban Climatology & International Congress of Biometeorology 1999, Sydney, Australia

Gaitani, N. et al. 2011 *Improving the microclimate in urban areas: A case study in the centre of Athens.* Building Services Engineering Research and Technology [S.I.], v. 32, n. 1, p. 53-71.

Giannopoulou, K et al. 2011 *On the characteristics of the summer urban heat island in Athens, Greece.* Sustainable Cities and Society [S.I.], v. 1, n. 1, p. 16-28.

Höppe, P. 1999: *The physiological equivalent temperature PET – A universal index for the biometeorological assessment of the thermal environment.* Int. Biomet., 43(2)

Huttner S., Bruse M., Dostal P. 2008. *Using ENVI-met to simulate the impact of global warming on the microclimate in central European cities.* Berichte des Meteorologischen Instituts der Albert-Ludwigs-Universität Freiburg Nr. 18 (2008):Helmut Mayer and Andreas Matzarakis (eds.): 5th Japanese-German Meeting on Urban Climatology, October 2008, pp. 307-312

Matzarakis A., Rutz, F., Mayer, H., 2008 *Modelling radiation fluxes in simple and complex environments: basics of the RayMan model*. Int J Biometeorol (2010) 54:131–139, DOI 10.1007/s00484-009-0261-0.

Nikolopoulou, M.: Lykoudis, S. 2007 *Use of outdoor spaces and microclimate in a Mediterranean urban area.* Building and Environment [S.I.], v. 42, n. 10, p. 3691-3707.

Santamouris, M. et al. 2012a *Using cool paving materials to improve microclimate of urban areas - Design realization and results of the flisvos project. Building and Environment* [S.I.], v. 53, p. 128-136.

Santamouris, M. et al. 2012b. *Improving the microclimate in a dense urban area using experimental and theoretical techniques - The case of Marousi, Athens.* International Journal of Ventilation [S.I.], v. 11, n. 1, p. 1-16.

Shashua-Bar, L. et al. 2012 *Passive cooling design options to ameliorate thermal comfort in urban streets of a Mediterranean climate (Athens) under hot summer conditions.* Building and Environment [S.I.], v. 57, p. 110-119.

2013 *Final Report on the Thermal and Wind Measurements Performed in the Panepistimioy Street in the City of Athens.* Physics Department, Group Building Environmental Research, Athens University, 28th of June 2013.