Urban Redevelopment and Microclimate Improvement:
A Design Project in Thessaloniki, Greece

ANGELIKI CHATZIDIMITRIOU[1], PANOS LIVERIS[2], MICHAEL BRUSE[3], LENA TOPLI[4]

[1]Aristiotle University of Thessaloniki, Thessaloniki, Greece,
[2]Bioclimatic Energy Efficient Buildings, Thessaloniki, Greece,
[3]Johannes Gutenberg Universitat, Mainz, Germany
[4]Municipality of Thessaloniki, Thessaloniki, Greece

ABSTRACT: ***A project on the redevelopment of a large urban area, in the historic centre of Thessaloniki in Greece, has been designed and evaluated based on bioclimatic criteria. The proposed interventions included replacement of pavement materials, addition of trees, fountains, sprinklers as well as external fans and their effects on air and surface temperatures and thermal comfort indices in hot summer conditions have been examined with microclimate simulations. An examination of partial application of the proposed interventions (pavement replacement, trees increase and still water spots) with the latest version of microclimate simulation software ENVI-met v3.1betaV has shown mean reduction of 1.5% on ambient temperatures, 16.3% on surface temperatures and 12% on thermal indices at mid summer noon. By integrating water evaporation by fountains and sprinklers in the forthcoming version ENVI-met v4, higher amelioration was observed with ambient and surface temperature reductions of approximately 5% and 17.5% respectively and thermal comfort improvement with PET reduction of 15%. Finally by including the effect of airflow enforcement with external fans, simply as spot wind velocity increase in two squares, pedestrian comfort, calculated with RayMan software was improved by 18% and 41% at noon and up to 35% during the day.***

Keywords: open urban spaces, microclimate, simulation

INTRODUCTION

Dense urban centers frequently endure elevated temperatures in the summer period when high intensity of the heat island effect is observed. The microclimates that develop within the urban streets and open spaces largely depend on the characteristics of their immediate surroundings [1] and highly influence pedestrian comfort. Many studies have presented the influence of urban design, by means of morphology, materials, vegetation and water, in the heat island restriction and the amelioration of open space microclimate and thermal comfort conditions [2-11].

In an effort to enhance the quality of the urban environment through urban design, a project on the redevelopment of a downgraded area in the centre of Thessaloniki, in northern Greece (lat. 40^{o}N), has been proposed by the municipality of Thessaloniki in the framework of a national level plan for urban areas' refurbishment: the "Bioclimatic improvement program for public open spaces". The program, focusing on open space microclimates, pedestrian comfort and building energy savings, called for proposals to redesign open spaces and to meet specific requirements for air and surface temperature reductions and thermal comfort enhancement in the summer period.

The redevelopment project aims in microclimate improvement as well as in spatial renovation and eventually in the revitalization of the whole district. The proposed interventions include replacement of pavement materials, addition of trees and vegetation, ground level fountains, higher level sprinklers and insertion of outdoor fans. This paper presents a preliminary evaluation of the project through simulation results, which indicate the extent of microclimate and comfort improvement that can be achieved by the implementation of the proposed interventions.

THE SITE AND THE PROJECT

The climate of the city is a temperate climate with high seasonal variations, i.e. cold humid winters with strong winds and warm summers with high temperatures, occasionally even above 40^{o}C, and intense solar radiation. Monitoring studies have reported heat island in the city centre, focused particularly in and around the area of the project site [12]. The detected heat island in the study area reveals a seriously downgraded environment regarding the microclimate conditions. Measurements within the project framework in the summer period revealed increased air temperatures (29^{o}C–35^{o}C even in September at midday) and negligible wind velocities even in the evening, when the city is favoured by the local sea breeze, confirming the downgraded microclimate of the examined district.

The study area (Fig. 1) is a large mixed use commercial and residential district located in the historic centre of the city. The area used to be a significant multicultural commercial and financial centre of the city hence contains a large amount of historically noteworthy building stock of the city's last two centuries. However in the present time most of the commercial activity as well as the majority of the old buildings have been abandoned leaving a downgraded area lacking identity and quality regarding the built environment.

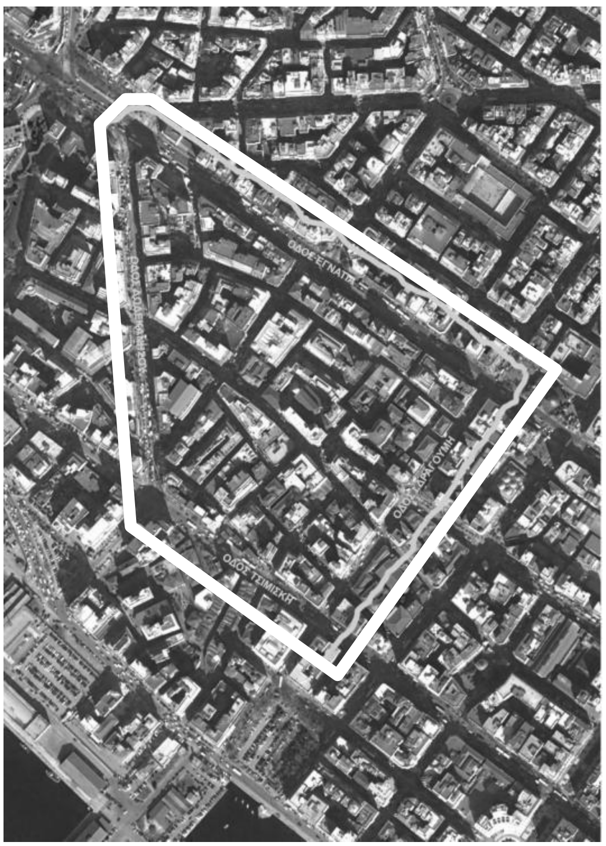

Figure 1: Aerial photo with indication of the study area

Table 1: Climate data for a typically warm summer day and the hottest day of the year in Thessaloniki (source of data : technical guidelines [13])

Thessaloniki climate data	**Typical summer day** e.g. 21/07	**Hottest day of the year** e.g. 25/07
Tair (^{o}C)	26.8	31.6
Tair.max (^{o}C)		42.6
RH (%)	52.8	52.8
Wind velocity	3.3	2.3
Wind direction	NW	NW

The project site extends to several blocks covering approximately 110000m^2 and contains various open spaces such as street canyons, courtyards, arcades parking spaces, and two small urban squares. The majority of the open spaces are narrow canyons between buildings which are insolated for short periods during the day. Two of the major deficiencies of the site are the obstructed airflow even in the evening and the absence of vegetation in most places. Low wind speed in combination with high surface temperatures of hard pavements and building walls induce pedestrian discomfort especially in the narrow canyons where low sky view factor reduces potential for heat dissipation.

Four types of interventions are proposed for the microclimatic improvement of the urban environment in the study area. The first is the complete replacement of the concrete pavements and asphalt streets with similar 'cool' materials i.e. materials with high albedo and high emissivity (Table 2), along with changes in the vehicle circulation network and increase of the pedestrian ways. Also in one of the two squares part of the pavement was replaced by stabilised soil. Cool materials reflect larger amounts of solar radiation and emit larger amounts of absorbed and stored heat therefore keep their surfaces cooler than conventional pavement materials. It should be noted that high albedo materials increase the amount of reflected radiation on pedestrians hence may cause discomfort.

Table 2: Surface properties of conventional and 'cool' pavement materials

material	**albedo**	**emissivity**
asphalt	0.05-0.20	0.94
concrete	0.30-0.40	0.63-0.94
cool asphalt grey	0.37	0.89
cool cobble stones grey	0.67	0.89
cool concrete pavement white or grey	0.68	0.92

The second type of interventions is the increase of the amount of trees and addition of vegetation in the form of shading canopies (Fig.2a). Generally the effect of shading canopies in the narrow canyons is minimal and restricted to few hours in the summer noon, therefore trees and vegetation is preferred to hard shading canopies because of the additional air temperature reductions caused by evapostranspiration.

The third cooling measure is the addition of water in various spots within the site (Fig.2b), mostly as fountains and water curtains at pedestrian level, and also as sprinklers at 15m above ground level. Water elements at ground level are proposed primarily because of their cooling effect but are also considered to add visual and acoustic quality in the open space. The sprinklers are proposed exclusively for cooling by evaporation of small water droplets and their location is set high enough to allow for the evaporation to take place before the droplets reach pedestrian level.

The fourth type of interventions is the insertion of outdoor fans in various sizes and types (Fig.2c): a large suspended horizontal fan, large movable vertical fans, medium size freestanding horizontal fans and small wall mounted vertical or tilted fans. The fans are proposed as a measure to increase the wind velocity and improve pedestrian comfort in summer under very warm conditions at a place where airflow is almost always negligible.

SIMULATION TOOLS

For a preliminary assessment of the effectiveness of the whole project regarding microclimate amelioration, models of the current conditions and the proposed interventions have been examined through simulations for warm summer conditions (a typically warm day and the hottest day of the year, Table 1). Some of the proposed interventions were added successively and examined with different tools.

The effects of the pavement materials replacement, the addition of extra trees, vegetation canopies, and water elements as still water spots on the ground have been examined with microclimate simulation software Envimet version 3.1betaV [14, 15]. The software accuracy has been tested and validated in previous studies based on extensive monitoring data in various open spaces in Thessaloniki [9, 10, 11]. Differences between monitored and simulated values of air and surface temperatures normally do not exceed 15% and are attributed to uncontrolled climatic parameters and urban equipment details i.e. some of the unban environment complexity that cannot be included in the models.

The effect of the running water taken into account as large water droplets in the case of ground level fountains and small ones in the case of high level sprinklers was simulated with the improved version 4 of the same software [16] which is not yet publicly available. The software was specially edited with additional code to include the physical processes and the effects of water droplets evaporation.

Finally, Rayman software [17, 18, 19] was used for calculating the effects of increased wind velocity by fans on thermal comfort indices. Hourly and mean daily values of PET were calculated for specific spots in the two squares of the site, using the microclimate data obtained from the final simulation (all interventions with water evaporation effects) and increasing the wind velocity value by 1m/s to account for the cooling effect of the fans.

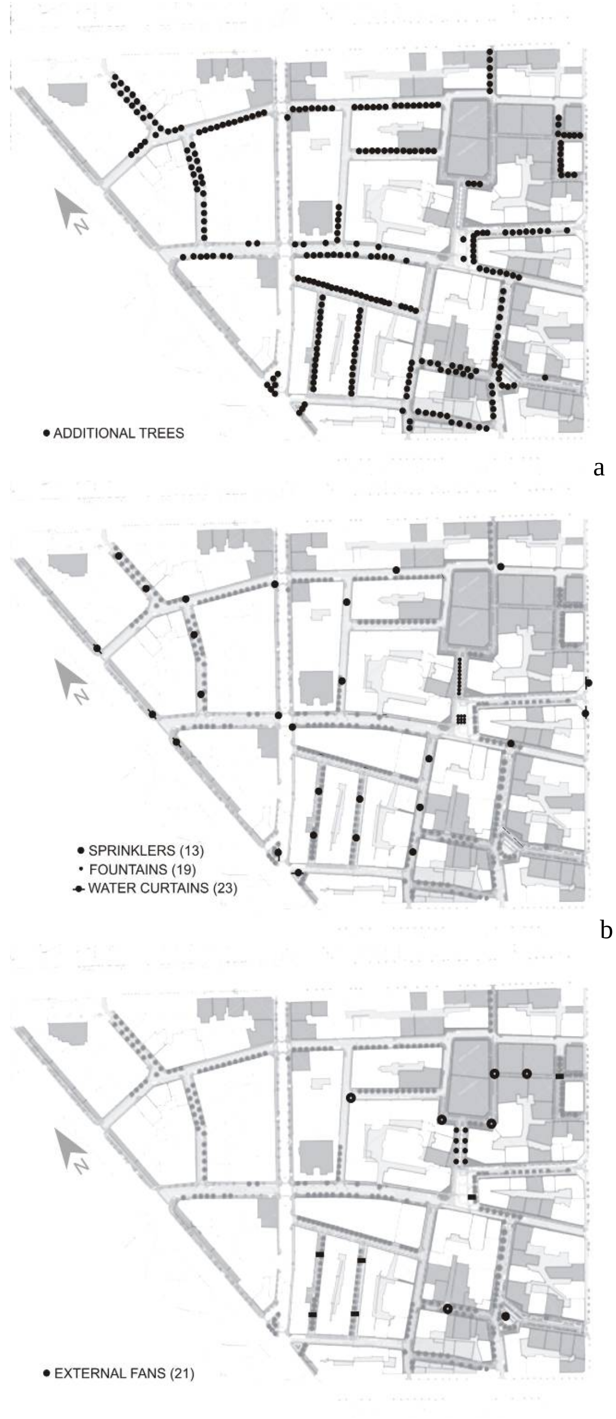

Figure 2: Plan of the study area with indication of the prosposed interventions a.proposed trees and vegetation canopies, b. water elements and c. external fans

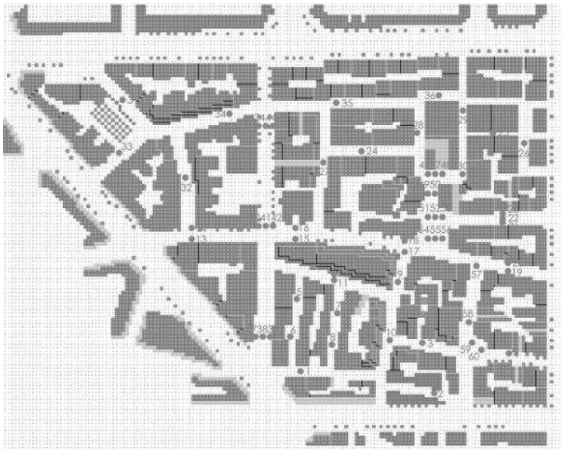

Figure 3: ENVI-met input model of the current conditions with indication of 60 spots for the area average value calculation

Figure 4: ENVI-met result for air temperature at 1.80m above ground level at noon on the warmest summer day: a .current conditions and b proposed interventions with running water elements

RESULTS AND DISCUSSION

Pavement materials, trees and canopies

The comparison between simulation results of the current conditions and the partial application of the proposed interventions (‘cool’ pavement materials, more trees, vegetation shading canopies and still water spots) revealed small effects on air temperature but significant effect on surface temperatures and PMV comfort indices at noon of the hottest summer day (Table 3). The data from 60 spots evenly distributed in the area (Fig. 3) were taken into account to calculate area averaged values for the whole district and compare the microclimate and comfort conditions before and after the implementation of the project proposals. In particular a 1.5% mean ambient temperature reduction was observed, i.e 0.6^{o}C reduction, at 1.80m above ground level and spot reductions fluctuated from 0.3^{o}C to 0.9^{o}C with the higher differences at places where extra trees were added.

The mean surface temperature reduction was 16.3% i.e. average surface temperature in the case of the proposal was 9.1^{o}C lower than the original case because of the pavement material replacement, and shading by the added trees and vegetation canopies. The highest reductions up to 30^{o}C were observed in the small square where besides the additional trees part of the hard pavement was replaced by stabilised soil. The tree shade generally caused surface temperature reductions of approximately 10^{o}C -20^{o}C on most pavements. Smaller reductions of 5^{o}C - 10^{o}C were observed due to the pavement material replacement in most canyons and minimal change up to 3^{o}C in the very narrow canyons where solar radiation is seriously obstructed and airflow has the key the role in summer cooling rather than surface reflectivity.

Thermal comfort indices (PMV) area average reduction was also high 12.2% i.e. 0.9. Thermal comfort improvement may be attributed mostly to shading by the extra trees and vegetated canopies. The highest PMV reductions up to 3.1 were observed at the two squares where additional trees and the absorptive ground surfaces of water or stabilised soil, decrease both incident and reflected solar radiation on pedestrians. Small changes of 0.5 and in some cases even increase of the PMV values (0.1-0.8) were observed at the canyons where only cool pavements were implemented. Despite the lower surface temperatures, ‘cool’ materials exposed to solar radiation, reflect higher amounts of radiation on pedestrians which in some cases may limit the cooling effect in terms of comfort.

Water droplets evaporation

To examine the effect of water evaporation, the current conditions and the proposed interventions, including ground level fountains and higher level sprinklers, were simulated with the improved and specially edited ENVI-met v4. Area averaged values by the data from 60 evenly distributed spots at noon of the hottest summer day, revealed mean ambient temperature reduction of almost 5% or 1.9^{o}C lower temperature in the case of the project proposal, surface temperature reduction of 17.5% or 9.7^{o}C lower temperatures in the proposal case, thermal comfort improvement by 15.3% or 7.7^{o}C lower PET values in the proposal case (Table 3). The highest ambient temperature reductions up to 7.1^{o}C were observed in the case of high level sprinklers particularly in the very narrow canyons, while smaller but also considerable reductions between 2^{o}C and 4^{o}C were observed near the ground level fountains (Fig. 4).

External fans

The effects of external fans on pedestrian comfort were assessed through the thermal indices at two specific spots in the two squares of the district (Fig. 5). The thermal comfort indices PET were calculated with Rayman software, using the previously simulated climatic data with increased values of wind velocity to account for the cooling effect of the fans.

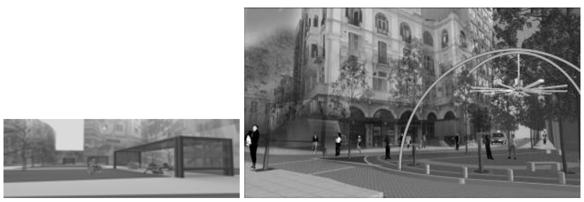

Figure 5: Vertical and suspended fans in the squares

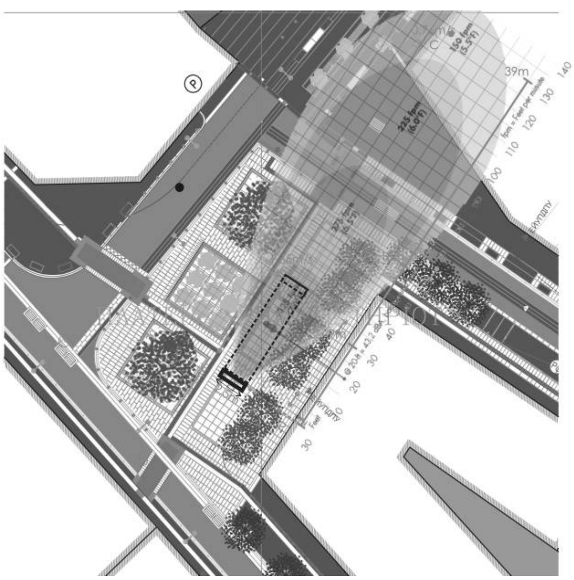

Figure 6: Influence of the vertical fan in the small urban square

In the first square where a large vertical fan is proposed combined with a vegetated shading canopy, additional trees and ground level fountains (Fig. 6), the PET value at noon of a typically warm summer day was found 18.1% or 7.2oC lower in the case of the final proposal compared to the current conditions. The mean daily reduction of PET, taking into account the hourly values from 10:00 to 18:00, was 35% or 19.8oC.

In the second square where a large suspended horizontal fan is proposed along with trees, fountains and stabilised soil instead of hard pavement, the PET value at noon of a typically warm summer day was 41.4% or 24.2^{o}C lower in the case of the final proposal compared to the current conditions, and the mean daily reduction of PET, from 10:00 to 18:00, was 32.3% or 18.5^{o}C.

Table 3: Microclimate simulation results for the current and the proposed conditions at midday in summer conditions

intervention type	**microclimate parameter**	**current conditions**	**project proposal**
pavements trees & canopies	ambient temperature	36.9^{o}C	36.3^{o}C
	surface temperature	53.7^{o}C	44.6^{o}C
	PMV	6.4	5.6
pavements trees canopies & water evaporation	ambient temperature	39.9^{o}C	38^{o}C
	surface temperature	52.6^{o}C	42.9^{o}C
	PET	47.1oC	39.5oC
pavements trees canopies water evaporation & external fans	PET square A	39.8^{o}C	36.2^{o}C
	PET square A *daily average	54.6^{o}C	34.8^{o}C
	PET square B	58.4^{o}C	34.2^{o}C
	PET square B *daily average	52.6^{o}C	34.1^{o}C

CONCLUSION

A redesign project of a large area in the historic centre of Thessaloniki has been prepared in the framework of a national program for the improvement of urban open spaces in terms of microclimate conditions, pedestrian comfort and building energy savings in the summer period. A preliminary evaluation of the proposed interventions with specialised microclimate simulation software has shown the potential improvement in air and surface temperatures and comfort indices. Significant improvement was revealed with the addition trees and vegetation as shading canopies, as well as with replacement of all concrete and asphalt pavements by cool materials. Higher improvement was observed when water evaporation and wind velocity by fans were taken into account. Further evaluation will take place after construction and may reveal in detail the real scale effects of the design proposals on microclimate and comfort within and around the district.

REFERENCES

1. Oke T.R. (1987). Boundary layer climates. second ed. Methuen & Co, London.

2. Yannas, S. (2001). Toward More Sustainable Cities. Solar Energy Journal. 70(3): p. 281-294.

3. Akbari, H., M. Pomerantz and H. Taha (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy Journal, 70(3): p. 295-310.

4. Oke, T.R. (1989). The micrometeorology of the urban forest, J. Phil. R. Sec. Land. B 324: p. 335–349.

5. Doulos, L., M. Santamouris and I. Livada (2004). Passive cooling of outdoor urban spaces. The role of materials. Solar Energy, 77(2): p. 231-249.

6. Cadima, P. (2005). Form and Microclimate: Spatial Confinement and Heat in the Urban Patio. In 22nd PLEA Conference, Beirut, Lebanon, November 2005.

7. Alexandri, E. and P. Jones (2006). Ponds, GreenRoofs, Pergolas and High Albedo Materials; Which cooling technique for urban spaces. In 23rd PLEA Conference, Geneva, Switzerland

8. Nikolopulou, M., N.Chrisomallidou, K. Steemers, R. Compagnon, J. Kang, N. Kofoed,G. Scudo, L. Katzschner (2004). Rediscovering the Urban Realm and Open Spaces (RUROS), 2001-2003. Key Action 4, "City of Tomorrow and Cultural Heritage", from the program "Energy, Environment and Sustainable Development", within the Fifth Framework Program of the EU. ISBN: 960-86907-2-2.

9. Chatzidimitriou, A. and S. Yannas, (2004). Microclimatic Studies of Urban Open Spaces in Northern Greece. In 21st PLEA conference, Eindhoven, The Netherlands.

10. Chatzidimitriou, A., N. Chrissomallidou and S. Yannas, (2006). Ground surface materials and microclimates in urban open spaces. In 23rd PLEA conference, Geneva Switzerland.

11. Chatzidimitriou, A. (2012). Evaluation of the effect of design parameters on urban open spaces' microclimate development and on thermal comfort conditions, during the summer period in the Mediterranean climate. PhD thesis, Department of Civil Engineering, Aristotle University of Thessaloniki (in Greek).

12. Stathopoulou, M., C. Cartalis and I. Keramitsoglou (2004). «Mapping micro-urban heat islands using NOAA/AVHRR images and CORINE Land Cover: an application to coastal cities of Greece», International Journal of Remote Sensing, 25(12): p. 2301–2316

13. Technical Guidelines 20701-3/2010 (2010). Climate data of Greek Regions. Technical Chamber of Greece (in Greek).

14. ENVI-met v.3 Available online: www. envi-met.com

15. Bruse, M (2004). Updated overview over ENVI-met 3.0. In ENVI-met website www. envi-met.com

16. Huttner, S. and M. Bruse (2009): Numerical modelling of the urban climate- A preview on ENVI-met 4.0**.** 7th International Conference on Urban Climate ICUC-7, Yokohama, Japan, 29 June - 3 July 2009.

17. RayMan v1.2 Available online : http://www.mif.uni-freiburg.de/rayman/

18. Matzarakis, A., F. Rutz and H. Mayer (2007). Modelling radiation fluxes in simple and complex environments—application of the RayMan model. International Journal of Biometeorology. 51: p. 323-334

19. Matzarakis, A., F. Rutz and H. Mayer (2000). Estimation and calculation of the mean radiant temperature within urban structures. In Biometeorology and Urban Climatology at the Turn of the Millenium (ed.by R.J. de Dear, J.D. Kalma, T.R. Oke and A. Auliciems): Selected Papers from the Conference ICB-ICUC '99, Sydney, WCASP-50, WMO/TD No 1026, p273-278.