Microclimatic Studies of Urban Open Spaces in Northern Greece

Angeliki Chatzidimitriou and Simos Yannas
Environment & Energy Studies Programme
Architectural Association Graduate School
34-36 Bedford Square, London WC1B 3ES, UK
ange1iki@aaschool.ac.uk
simos@aaschool.ac.uk

ABSTRACT: This paper focuses on the microclimatic features of open spaces in the centre of urban blocks and their microclimatic effects on the adjoining buildings and on the parent city at large. The paper reports on air and surface temperature, relative humidity, air velocity and illuminance readings taken in the summer of 2003 in four urban blocks in the city of Thessaloniki, northern Greece. The measurements revealed microclimatic differences, between, as well as within, the four blocks and were used for the calibration of microclimate simulation software ENVI-met. Microclimatic simulations together with solar access studies were performed to investigate possible environmental improvements. The paper summarises the resulting design proposals for microclimatic modifications that can support a variety of uses of the spaces, as well as potential improvements to environmental conditions in the surrounding buildings.

Conference Topic: 3 Comfort and well-being in urban spaces
Keywords: urban microclimates, courtyard geometry, design proposals, simulations

1. INTRODUCTION

Urban development in Greece in the last century has generated a particular type of open space inside urban blocks, characterised by random forms and absence of use. Geometrically, these spaces are the product of building ratios determined by planning regulations. Lack of strategy and appropriate planning has led to fragmented open spaces, which occupy some 30% of the ground area of each block and are defined by the outlines of the surrounding buildings. Administratively, owing to multiple ownership of each building within a block, there is no single individual or authority responsible for their keeping.

Although shapes and sizes vary, typologically, these spaces combine features of courtyards and street canyons, due to their location in the centre of blocks and to the high H/W ratios. According to Oke the climate of the city is a combination of different microclimates, coexisting in the urban canopy and strongly related to urban geometry [1]. It may be assumed that the geometric features of individual open spaces trigger microclimatic variations that may affect environmental conditions in the surrounding area. In previous studies we have reported on observations and design proposals for microclimatic improvements in London, Dhaka and Athens [2, 3]. The present paper summarises the findings of a study that focused on four representative urban blocks in the city of Thessaloniki (latitude 40°33N), in northern Greece, investigating microclimatic differences and possible environmental improvements that could be achieved by design interventions [4].

2. CASE STUDIES

2.1 Four Urban Blocks

![Figure 1: Plans (to same scale), axonometric views and photos of four representative urban blocks in Thessaloniki](image_url)

Views of the four blocks selected for study are shown in Fig. 1. In the first block (area A), the uncovered space, is completely surrounded by buildings, occupies 33.4% of the block, and contains a large amount of vegetation. The H/W ratios, in
different parts of the open space, are relatively low and fluctuate around 1.0, while at the narrowest part the ratio is 2.62. The surrounding buildings are 3 to 7 storeys high and present a variety of typologies and forms.

The uncovered area of the second block (area B) is a typically narrow space, with a long building extending into the centre of the block. The buildings (6-7 storeys) form a deep canyon where solar access is seriously obstructed. The average H/W ratio is approximately 3, but in some parts the ratio rises to over 11. A vacant plot, on the west side of the block provides an opening and access to the street. The open area (29% of the block) is divided by fences and gaps, the ground is covered by concrete pavement, and vegetation consists of a few low trees.

The third block (area C) is located in a dense commercial area, with narrow street canyons, and was developed at a period when legislation permitted full plot coverage at ground level. As a result, in this case, the centre of the block is built. The open area consists of terraces, on the first and second floor, and is completely surrounded by the buildings. Vegetation is totally absent and the terraces are finished with concrete pavement and ceramic tiles. The size of the open space is smaller than the other blocks (18.6% of the block), but the average H/W ratio is below 2, owing to the restricted sky view.

The fourth block (area D), located in the coastal zone of a dense residential district, is adjacent to a park and is thus totally unobstructed from the SE and SW. The buildings (7-8 storeys), are free standing and the open space is permeable and accessible from the streets. The H/W ratios rise to high values (1.7-3.8), but without extreme variations. The open area occupies 32.2% of the block and is evenly distributed between the buildings, forming canyons rather than a courtyard. This is one of the few blocks in which the open space is unified and includes trees and vegetation, fountains, sitting places and entrances to underground parking spaces.

2.2 Air Temperature and Relative Humidity Readings

For the measurements taken from May 26th to June 2nd 2003, data loggers taking hourly readings of air temperature and relative humidity were placed at selected areas. The readings were compared with temperature and humidity measurements for the same period, obtained from a nearby meteorological station located outside the city [5] and referred to as "outdoors" in Fig.2 below. This revealed that the air temperature in the courtyards was generally 6-12K higher than the mean outdoor temperature, which fluctuated between 16°C and 28°C. The higher differences were observed on sunny days suggesting a higher heat island intensity on those days.

In area A temperatures were more stable than "outdoors". The open space was 1-3K cooler during the day and 1-4K warmer at night, probably affected by the presence of trees and vegetation which provided shade during daytime, but reduced the capacity for heat dissipation at night. In areas B and C temperature was steadily above outdoor temperature with slight fluctuations. Area B was 0.5-3K warmer than "outdoors" in daytime and 2-4K warmer at night. Area C was usually 0.5-1K warmer during the day and 3-6K warmer during the night. A steep rise, of 4.5-6K above outdoor temperature peak, observed in the afternoon, during the days with unobstructed sunshine implies an overheating of the space due to direct solar radiation. Temperatures in the courtyards rose faster and dropped more slowly than outdoors. Furthermore, the courtyard of area C cooled slower, compared to area B, while both spaces were equally warm at daytime. In area D daytime temperatures were similar to outdoor temperatures, but at night, they were higher by 1.5-4K. This may be attributed to the high H/W ratios which obstruct solar radiation, reducing daytime peaks, but limit heat dissipation at night, due to restricted sky view.

The levels of relative humidity in areas A, B and C were also compared to the "outdoor" relative humidity, Fig. 3. In area A the fluctuation was mild; maximum values were generally 2-8% lower than the outdoor
ones and minimum levels were 1-18% higher. In area B the fluctuation was more intense during cloudy days, while, on sunny days, humidity levels in the courtyard followed the outdoor ones. In area C humidity levels were steadily lower than outdoors, (except for a few afternoon hours) probably due to the total absence of vegetation and the waterproof finishing of the terraces.

Air temperature readings showed that the ground levels of the courtyards were 0.4-4.8K cooler than the roof terraces during daytime and 0.2-2.4K warmer at night. Similarly, the courtyards were 0.1-5.6K cooler than the surrounding streets during the day, and 0.2-2.4K warmer at night. The roof terraces normally cool to those at roof terrace levels on a cloudy day, and of 6.4-9.9% difference between east and west surfaces in the morning. However, there were large differences between horizontal and vertical surfaces during daytime (max difference 19.9K) and large differences (7.8K-17.4K) were also observed between shaded and exposed parts of the same horizontal surfaces. It is also noteworthy that the highest difference between shaded surfaces of soil and concrete tiles was 15.5K. Table I summarises the measurements.

**Table I. Surface temperatures in four urban blocks (Thessaloniki, June 1st ‘03)**

<table>
<thead>
<tr>
<th>Material</th>
<th>Surface temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>grass</td>
<td>exposed 35.1°C</td>
</tr>
<tr>
<td></td>
<td>shaded 25.8°C</td>
</tr>
<tr>
<td>soil</td>
<td>shaded 20.1°C</td>
</tr>
<tr>
<td>concrete</td>
<td>shaded 22.1°C-32.4°C</td>
</tr>
<tr>
<td>concrete tiles</td>
<td>shaded 28.4°C-36.6°C</td>
</tr>
<tr>
<td>red ceramic tiles</td>
<td>exposed 42.2°C</td>
</tr>
<tr>
<td>dark grey asphal tiles</td>
<td>exposed 45.6°C</td>
</tr>
<tr>
<td>aluminium painted sheets</td>
<td>exposed 46.2°C-46.9°C</td>
</tr>
<tr>
<td>tar (black)</td>
<td>exposed 46.2°C</td>
</tr>
<tr>
<td>grey gravel</td>
<td>exposed 42.2°C</td>
</tr>
<tr>
<td></td>
<td>shaded 25.8°C</td>
</tr>
<tr>
<td>corrugated iron</td>
<td>exposed 31.7°C</td>
</tr>
<tr>
<td>white paint</td>
<td>South 27.6°C</td>
</tr>
<tr>
<td></td>
<td>West 27°C</td>
</tr>
<tr>
<td>yellow paint</td>
<td>South 30.2°C</td>
</tr>
<tr>
<td></td>
<td>West 30°C</td>
</tr>
<tr>
<td>concrete</td>
<td>South 37.3°C</td>
</tr>
<tr>
<td></td>
<td>West 30.4°C</td>
</tr>
</tbody>
</table>

2.4 Solar Access Studies

Simulations of the four areas, produced with ECOTECT v5.2 [6] and RADIANCE v3.1 [7] software, display the effects of the different size, orientation and H/W proportions of the blocks, on solar access to the central courtyards, Figs.4 and 5.

In area A the long axis of the block is directed N-S and thus the N part of the courtyard is accessible to solar rays, around noon, even in winter. The E and W part of the space are shaded in the morning and the afternoon, respectively, during summer, but in winter and spring the whole open space is shaded and only the building elevations have partial access to sunlight. In area B, the long building in the centre of the block, completely obstructs solar access in the courtyard even in the summer, and direct solar radiation reaches only limited spots on the ground level around midday, in June. In December and March sunlight reaches only the highest levels of the buildings. In area C, the ground of the courtyard is continuously

---

**Figure 3:** Relative humidity levels in three urban blocks and a station outside the city (Thessaloniki, May 26th - June 2nd '03)}
shaded, except for a small part on the north side at midday in June. In area D, the SE and SW openings of the block allow partial solar access even in winter, and the open space is never completely shaded, except for the afternoon in June.

Figure 4: Shadows cast in four blocks in December 1st

Figure 5: Shadows cast in four blocks in June 1st

2.5 Microclimate Simulations

The measured data were used to calibrate the microclimate simulation software ENVI-met v3 [8] in order to perform simulations for different seasons to test the possible effects of design interventions aimed at environmental improvements. To this aim the results of simulations of the deep and narrow courtyard of area B, were compared with the measurements with a good agreement. Taking the initial air temperature required by the software at the daily mean temperature for June (24.1°C), the results almost matched the measured data with differences between predicted and measured air temperatures of 0-1.2K (except for a 2K difference on a roof terrace).

3. DESIGN PROPOSALS

3.1 Climatic Context

In the climate of Thessaloniki, a Mediterranean climate, spring and autumn generally provide acceptable conditions for the use of outdoor spaces. However, outdoor air temperatures often rise above 35°C during July and August whilst falling below zero at times in the period from December to March. Strong NW winds prevail in winter with average velocities of 1.6-2.2 m/s. Southerly winds are more frequent between May and August with mean speeds of around 2.0 m/s. Relative humidity levels are high in winter, (79% monthly average in December), and decrease in summer (52% in June). Sunshine availability is high even in winter with incident solar radiation on a horizontal plane varying from 1.42 kWh/m² per day in December to 6.61 kWh/m² per day in July [9]. Design strategies are therefore required, to provide solar access and protect from cold winds in the winter period, whilst controlling solar radiation and providing cooling in summer.

3.2 Microclimatic Improvement Options

The on-site research highlighted the reduced air velocity in the courtyards which according to previous studies causes significant temperature stratification [10]. Openings at the ground level of the blocks, which is relatively warm in the summer, are likely to induce airflow which will contribute to heat dissipation and cooling. As airflow patterns in a canyon depend on the angle of attack of the wind and the direction of approach [11], orientation and position of openings will define the airflow pattern in relation to the direction of the prevailing wind. In summer, openings on the north and south would provide inlets and outlets for the prevailing S winds and the lee vortices in the canyons, promoting cross ventilation. E and W openings would also enhance airflow, inducing spiral vortices in the case of SE winds. N and W openings should be blocked in winter to reduce the effect of cold winds. The addition of a body of water at courtyard ground level will induce evaporative cooling, and combined with improved airflow, may distribute the cooler air within the courtyards in the summer. Light coloured surfaces will reduce solar absorption contributing to lower temperatures in the courtyards. Higher surface albedos will also improve daylight at lower levels in winter. Replacing concrete pavements with soil and grass, and addition of vegetation should also reduce ambient and surface temperatures; addition of trees would reduce air pollutants, provide shade in the summer and lower mean temperatures [12, 13].

Figure 6: Current (a) and alternative building typology (b, c) for increased solar access.

The high urban densities in conjunction with current building geometry present major obstacles to winter solar access for buildings and open spaces, Fig.6a. Variants of the current typology may provide some small improvement, Fig. 6b. However, unobstructed solar access to all levels of the buildings would require the surrounding buildings to be considerably lower Fig.6c. Other studies have suggested that high urban densities can be
maintained, without restricting solar access, by undertaking development within the boundaries of a solar envelope geometry [14]. Reshaping the city's fabric to increase solar access, without altering its density will require height limits to be imposed at some parts of urban blocks whilst concentrating higher rise in other sections.

Public access and extension of the courtyard space at ground and higher levels could promote use of these spaces for a range of activities and occupants. Considering the sheltering effect of canyons and courtyards from extreme weather conditions, the areas inside the blocks may be used all year round, and create a network of connected open spaces in the city, Fig. 7.

Access points through the entrance halls of the apartment buildings, shops with entrances both from the streets and from the interior of the block, cafés and restaurants with extensions in the courtyards and arcades between the ground level activities could be completely open or permeable in the summer, to provide the airflow openings as well. The interiors of the courtyards could be alternative passages through the blocks, or provide gardens for the apartment buildings. Commercial centres, cafés and restaurants, playgrounds, open cinemas, exhibitions, temporary marketplaces are some other possible public functions of these spaces.

3.3 Design Proposals

The courtyard of Area B combined enough common features to be taken as a typical example for the formulation of design proposals aiming at microclimatic improvements to the city's urban blocks, Fig. 8. Five new openings were added at ground level, through entrance halls, commercial spaces and arcades, as airflow inlets and access points to the interior of the block, Fig. 9a. These openings prevent uncontrolled entrance to the courtyard and maintain the potential to close in winter, when protection from cold winds is required. Water pools are added at ground level to induce evaporative cooling. Vegetation and trees are added close to the openings, for the circulation of cool air from the shaded areas.

Gardens are proposed on several spots on the west and south parts of the open space, Fig. 9b, while on the north east parts an extension of the commercial activity to the interior of the block is suggested with shops open towards the courtyard and cafés extending on terraces over the water pools, Fig. 9c. Vertical circulation is proposed on the narrowest part of the open space, leading to terraces on higher levels. The roof terraces with gardens and an open cinema, Fig. 9d, may be used in summer evenings when roofs are cooler than the lower levels of the courtyard and provide sunlit, open spaces in the winter, with evergreen vegetation as wind shield.
4. ASSESSMENT

The proposals described above were assessed using the ENVI-met software by comparing simulation results with those performed for the unmodified block. Arcades, water pools and trees, 10-20m high, were added to the model of the block. Concrete pavements were mostly replaced with soil and grass and the albedo of building surfaces was increased from 0.5 to 0.7 corresponding to lighter coloured surfaces. For the winter simulation, the north and north-west arcades were blocked.

The results of these simulations confirmed that the effects of the proposed interventions would be in the directions expected in both summer and winter. In particular, the summer simulation showed water-pools producing reductions in air temperature of 0.2K and soil and grass by 0.2-0.6K. An intermediate level terrace was predicted to cool ground level by 0.2K during the day but not at night, indicating obstruction of heat dissipation. Areas above trees were predicted to be 0.2K cooler at night. The openings were found to increase airflow across the N-S axis of the courtyard at ground level, from 0.1 to 0.8m/s. In reality increased airflow may correspond occasionally to the EW axis of the courtyard, owing to SE winds which are not included in the software calculations due to simplification of the input data. In the winter simulations, N and W arcades were predicted to be 0.6-1.2K warmer than the original courtyard, but the S and E arcades, which remained open, were predicted to be cooler or unchanged. Areas with soil and grass were predicted to be 0.3-0.6K warmer, areas above water 0.3K warmer, and areas containing trees 0.3-0.6K warmer during daytime.

The addition of vegetation and trees as well as the substitution of concrete pavement with soil and grass proved to have a warming effect in the courtyard in winter and a cooling effect in the summer. Water pools had a similar, but milder, effect on their immediate surroundings. Additional bodies of water, and vegetation extended at more levels (fountains, sprinklers, plants on walls or balconies) are likely to induce these effects. Openings on ground level were found to increase airflow and temperature variation within the courtyard in the summer, but revealed a negative effect in winter. Therefore all openings need to be blocked in winter, even the ones not exposed to wind, to reduce heat loss and prevent incoming airflow. The predicted differences, between the original and the modified area, although small in absolute values, reveal improvement in terms of comfort and of variability of the outdoor environment, and display potential for further development towards desirable conditions in the courtyards.

CONCLUSION

The microclimatic variations in and around urban blocks due to their spatial characteristics has been verified and the issue of improvement of the developing microclimates has been assessed with simulations of a representative area.

REFERENCES