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The impact of green space distribution on the microclimate of idealized urban grids.

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1. Introduction

The positive role of vegetated open spaces in regulating the urban climate and mitigating the Urban Heat Island (UHI) is well documented (Bowler et al., 2010). Urban parks are able to reduce ambient air temperatures and can even generate a ‘cool aura’ that can be felt at small distances usually at their leeward side. The present study attempts to answer the following questions: What is the influence of different spatial distributions of a given fixed area of tree-planted open space on the microclimate of an idealised urban grid? Is there an optimal size and distribution of green spaces that achieves a maximum cooling effect? The study focuses on the city of Thessaloniki which has a typical Mediterranean climate to produce simple green-space distribution guidelines that can be used in the development and regeneration of settlements.

2. Method

One way of answering the aforementioned questions would involve extensive in-situ measurements or simulations of real-world examples. However, a practical issue arises. Ideally a certain degree of consistency of multiple parameters in the examined sample would be required, such as park shape, degree of tree coverage and surrounding urban conditions to deduce a relatively safe result. This implies a rather large sample of cases which may not be available within the geographical limits of an examined city. A parametric simulation is perhaps a more appropriate method as it ensures consistency and is cost and time effective compared to site measurements. However a limitation of this method is that it largely depends on the inherent abilities and limitations of the employed simulation model.

This study focuses on the city of Thessaloniki in Greece. The climate of Thessaloniki (φ = 40° 39’ , λ = 22° 54’) is a typical Mediterranean characterized by mild and wet winters (mean minimum air temperature = 1.3°C) and dry-hot summers (mean maximum air temperature= 31.6°C). The hot period is the least thermally comfortable period. Studies of the UHI in Thessaloniki have recorded air temperature differences of 2°C to 4°C (Giannaros and Melas, 2012). During summer the prevailing winds are Northwestern and Western but several days are windless. The lack of strong winds, combined with high temperatures and relatively high humidity increases the feeling of thermal discomfort.

The simulations are conducted using ENVI-met V3.1 (Bruse, 1999; 2004), a three-dimensional computational fluid dynamics model that simulates micro-scale interactions of air, surfaces and plants. ENVI-met is supplemented by BioMet, from where the Potentially Equivalent Temperature (PET) thermal comfort index can be calculated. For the case study city of Thessaloniki, the accuracy of the model has been validated in previous open space studies and the differences between observations and simulations typically do not exceed 15% (Chatzidimitriou et al., 2013). A limitation of ENVI-met V3.1 is that it does not fully simulate heat storage in buildings and as a result the nocturnal UHI is not accurately represented (Yahia and Johansson, 2013).

The study simulates and compares five cases of green space layouts with a reference case that lacks green spaces (Fig. 1). The model area is 50ha and the underlying urban fabric remains constant through all examined cases. The examined urban form is the dense perimeter urban block with a small internal courtyard. The size of each urban block is 75x75m^2. Inside the block a small courtyard is formed which communicates with the street with small openings, one at each side, approximating the distances often left between buildings for ventilation and access. Regular streets are 15m wide and run perpendicular to each other. Two main streets of a width of 30m meet at the centre of the model. Building height is uniform in the model and corresponds to an average of 4.8 floors according to a residential building stock survey in Thessaloniki (Theodoridou et al., 2011).

The fixed amount of green space is determined using the current Greek Planning Standards (Greek Government Gazette, 2004) which recommend 5.5m^2 of ‘city-wide parks’ and 1.5m^2 of ‘neighbourhood parks’ per capita, totalling to 7m^2 of green space per capita. The same standards suggest that acceptable population densities for urban areas range from 100 to 400 people per hectare. Assuming a mean density of 250 people per hectare the suggested green space for the examined area is 8.75ha. This fixed area is then divided to 1, 2, 4, 8 and 16 square parks which are evenly distributed throughout the model area (Fig. 1). These cases will, from now on, be referred as ‘case 1’, ‘case 2’, ‘case 4’, ‘case 8’ and ‘case 16’ respectively to easily distinguish them. The calculated values of the reference case are extracted from the centre of the model area, which is the least affected by boundary conditions. Similarly the point of data extraction for each examined case is the centre of the park that is closest to the model centre. If several parks exist in equal distance from the centre, then the one located at the leeward side of the model is selected. This is to account for the additional cooling effect of parks located at the windward side of the model.

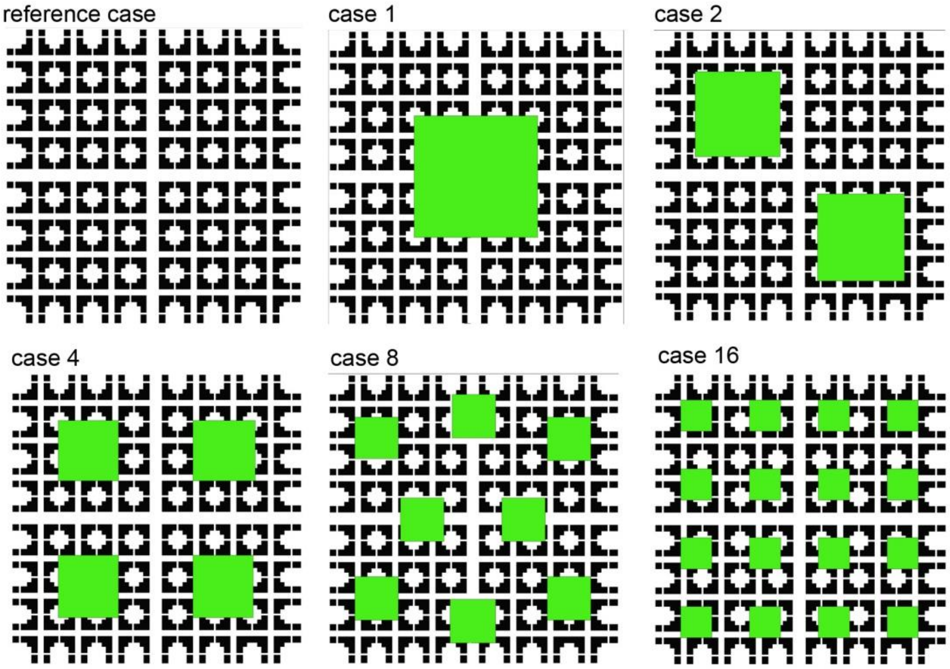

Fig. 1 The examined green space layouts.

Vegetation in ENVI-met is treated as a one-dimensional column of a certain height that is given a Leaf Area Density (LAD) profile. It is assumed that all green spaces are covered by vegetation approximating an average LAD distribution of a forest of Oaks (*Quercus cerris*) which is native in southeastern Europe. The mean tree height is 17m and LAD reaches a maximum of 0.75 at a height of 11m (Čermák et al., 2008). The thermophysical properties of materials and buildings were determined using the relevant guidelines provided by the Technical Chamber of Greece (Shortened in Greek as 'TEE') (TEE, 2012a). The properties of the hard sealed surfaces represent an average situation between asphalt concrete and common sidewalk concrete tiles (Table 1). This material dominates the model space except the green areas which are entirely covered by unsealed soil and whose properties are directly taken from the ENVI-met's database.

Table 1 Calculation of the averaged thermophysical properties of the two dominant materials.

Hard surface materials	Density [ρ, kg/m^3]	Thermal Conductivity [λ, W/(mK)]	Specific heat capacity [c_p, J/(kgK)]	Albedo	Emmisivity ε
Asphalt Concrete	2100	0.7	1000	0.2	0.93
Sidewalk Tiles	2100	1.5	1000	0.46	0.8
Average	2100	1.1	1000	0.33	0.87

A full diurnal cycle of a typical summer day is simulated using climatic data provided by TEE (2012b). To provide more reliable results a model initialisation period of four additional hours is simulated and is later discarded. The initial meteorological parameters are listed in Table 2.

Table 2 Input Parameters used in ENVI-met calculations.

Location:	φ=40° 39', λ=22° 54'		
Simulation Day:	21.07.2014		
Simulation period:	28h (02:00 - 06:00)		
Model and Grid size:	141 x 141 x 20 grids, 5 nesting grids Δx = Δy = 5m Δz = 2m		
Cloud coverage:	0 Octa (clear sky)		
Solar adjustment factor:	0.85		
Initial wind	velocity = 3.3 m/s measured at 10m orientation = 330° (Northwest)		
Potential Air Temperature:	299.95K (26.8°C)		
Specific Humidity (2500m):	5.8 g/kg		
Relative Humidity:	52.8%		
Roughness Length z0:	0.1		
Initial soil conditions:	[0 - 20cm]	[20 - 50cm]	[below 50cm]
Temperature	304.90K	302.22K	300.26K

Relative Humidity	20.0%	30.0%	30.0%
Building properties:			
Indoor temperature	300K		
Thermal conductance	3.05W/m²K (Roofs) , 1.90 W/m²K (Walls)		
Albedo	0.6 (Roof) , 0.5 (Walls)		
Biometeorological Factors:			
Clothing	0.5Clo		
Metabolic Work	110W/m²		
Walking speed	0.3m/s		

3. Analysis of the Results

The analysis focuses on two variables, namely the air temperature and the PET thermal comfort index. PET (Höppe, 1999) is selected as it expresses the complex outdoor conditions affecting the human thermal balance as a uniform indoor air temperature, allowing an easy assessment of thermal comfort. Figures 2 and 4 depict the diurnal changes in air temperature and PET for all examined cases and their differences with the reference case.

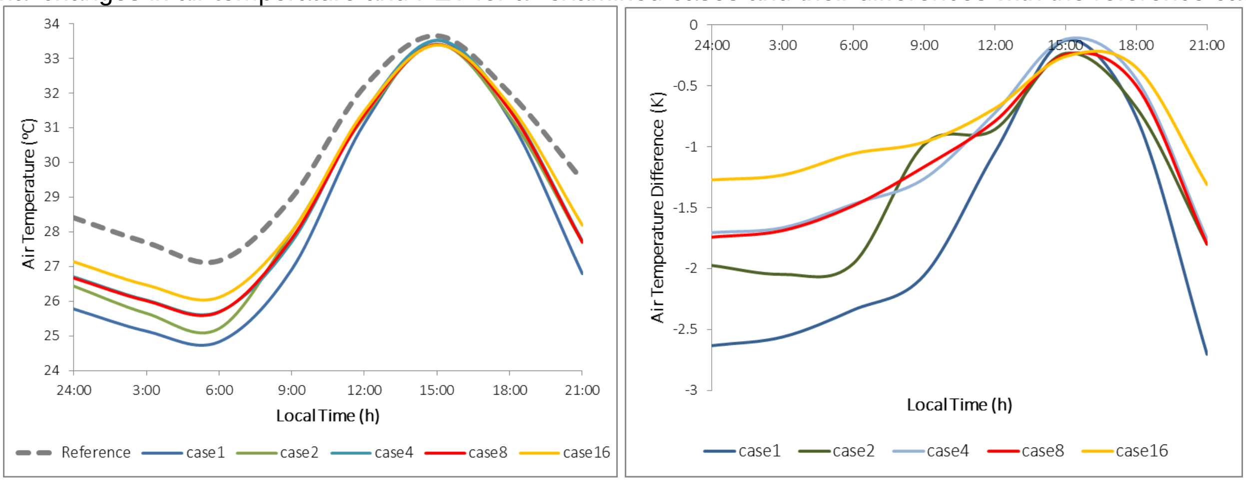

Fig. 2 Diurnal changes in air temperature (°C) in the examined cases (left) and in air temperature differences (K) between the examined cases and the reference case (right).

A noticeable drop in air temperature can be observed in all cases during the nocturnal period. The intensity of this effect is proportional to the size of the park. This effect ranges from 1.3K inside the smaller parks (case 16) to 2.7K inside the largest park (case 1). During the morning and early afternoon this effect is reduced and is almost nullified when maximum air temperatures are observed at 15:00 (local time). This can be partially attributed to the 'cool oasis' phenomenon created by the urban canyons, mostly through shading, which reduces the air temperature differences and the mixing of cool and hot air masses inside the parks as the city heats up after noon. This 'cool oasis' has been observed in early morning and noon in several of the most built-up areas of Thessaloniki, however this trend is reversed after the sunset as the intensity of the nocturnal UHI increases (Giannaros and Melas, 2012). In smaller parks, the enclosure created by neighbouring buildings creates additional shade and traps cool air masses. In contrast, a greater movement of air masses under the canopy of trees is observed in larger parks.

Parks also generate a 'cooling aura' at their leeward side that can reach several tens of meters in length. This effect is mostly observable during the nocturnal period (Fig. 3). On one hand larger parks produce cooler air masses which dissipate over longer distances, but a relatively small area is actually influenced. A reduction of air temperature by 1K is observed on the leeward side of the largest park (case 1) at a distance of approximately 160m and 0.5K at a distance of 300m. On the other hand, very small parks (e.g. case 16) cannot lower the air temperature significantly to create an overlapping of cool auras. When the green area is distributed in medium-sized parks the 'cooling aura' seems to cover larger portions of the model area, as it can be seen, for example in cases 4 and 8. In these cases the 'cooling aura' intensity is approximately 0.5K.

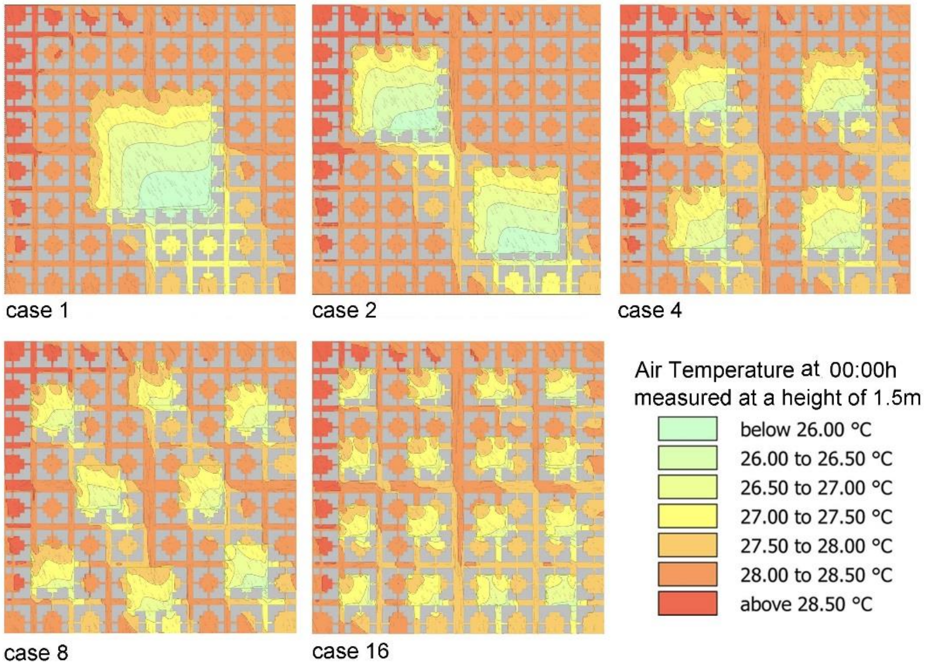

Fig. 3: Distribution of air temperature in the five examined cases at midnight.

Regarding PET, the diurnal differences between the examined cases are relatively small and follow the same trend. This is attributed to the crucial role of radiative heat fluxes, which during daytime and in the afternoon are dominated by the direct solar radiation. Thus thermal comfort mostly depends on the degree of shading and less than the air temperature. The maximum PET difference between the examined cases and the reference case exceeds 18K. Thus, similar daytime thermal comfort conditions can be achieved inside the parks, regardless of size and distribution, as long as they provide the same degree of tree coverage. At night and before dawn thermal comfort mostly depends on the ambient air temperature which has been previously analysed.

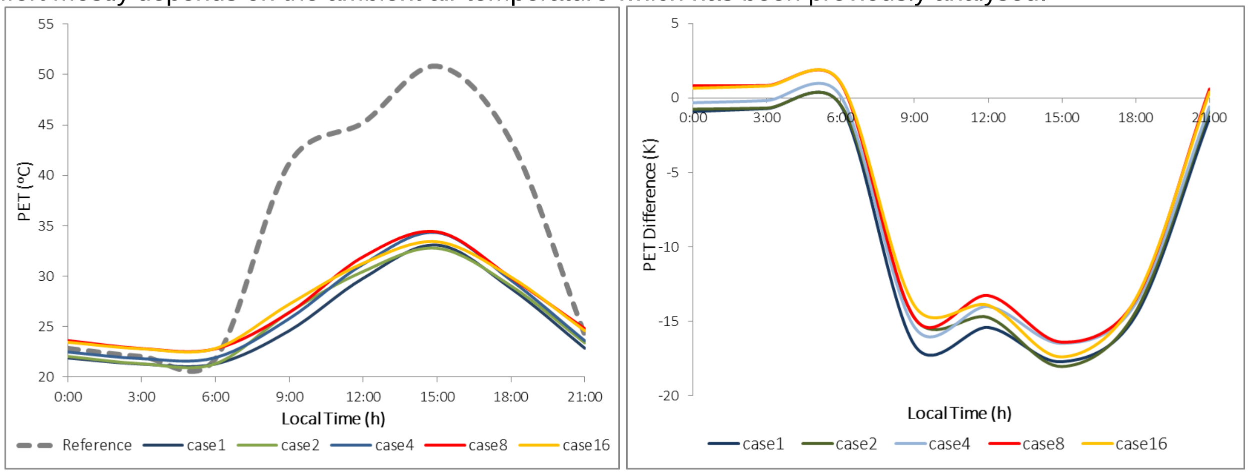

Fig. 4 Diurnal changes in PET values (°C) in the examined cases (left) and PET difference (K) between the examined cases and the reference case (right).

4. Design Implications

According to the analysis medium-sized parks of approximately two to four hectares seem to offer an intermediate solution as they provide significant shade in the morning and generate an overlapping ‘cool aura’ that can mitigate the nocturnal UHI for a large portion of the examined urban model. However, medium parks do not seem as a definite ‘optimal solution’. Smaller parks, although not lowering the air temperatures considerably, can create conditions of daytime thermal comfort equal to that of medium and large parks through shading. Thus small parks, being generally more accessible, can function as cool urban living rooms. The strategy of democratically distributing small parks in the urban tissue has also been suggested by several authors (DeKay and Brown, 2014; Shashua-Bar and Hoffman, 2000). Large parks also have an important role as thermal refuges during heat waves, since their cooling effect inside them is the strongest. Yet, as accessibility becomes important, smaller, centrally located parks should generally be prefered over large green spaces which are often found in the limits of the urban cores.

5. Conclusions

The study has demonstrated a simple method for determining the influence of green space distribution and size on the urban climate through microclimatic modelling. The results of this method are easy to interpret and can inform the urban planning and design processes. A larger sample of green space configurations simulated under different climatic conditions and a validation of findings with in-situ measurements could provide a deeper insight on the underlying microclimatic mechanisms. Future research could focus on these aspects which could not be examined within the limits of this preliminary study.

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