A MICRO-SCALE FIELD AND NUMERICAL STUDY FOR ASSESING THE SEASONAL THERMAL EFFECTS OF A VEGETATED COURTYARD ON URBAN CLIMATE

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ABSTRACT

Appropriately designed open and semi-open spaces may function effectively as positive bioclimatic elements in the urban environment that may be integrated in a sustainable urban design context. Courtyards are common architectural solutions; depending on their detailed design (geometry, vegetation presence and materials), they can be positive or negative climatic elements in the urban environment In the present study the microclimatic and thermal comfort conditions of a vegetated courtyard area located in an urban cluster of the city of Athens (Greece) are estimated and evaluated. In the selected courtyard area, continuous measurements of microclimatic parameters (air temperature, relative humidity, wind speed, net radiation and global solar radiation) were carried out during a summer and also a winter time period. In addition, an urban microclimatic model was used to evaluate combined building and vegetation design scenarios that may improve microclimatic and bioclimatic conditions inside the courtyard and also in the surrounding urban cluster area. It was found that the average difference between mean radiant temperature inside the courtyard and the surrounding streets depends on vegetation and may reach values up to 30 ºC. In addition, results revealed the existence of a cool island effect in the daytime during the summer period reaching 3 ºC close to the building and 1ºC in the center of the courtyard in a site without shading either from plants or buildings. In winter, however, a weak heat island effect during night time inside the courtyard was found to create more comfortable thermal conditions than the surrounding urban area. The implications of the study's results on the architectural design for Athens are mainly associated with propositions to have high mass residential buildings with backyard vegetated areas to moderate the extremely high or low air temperature values and to ameliorate, to a certain degree, comfort conditions of occupants.

Keywords: urban microclimate, thermal comfort, simulation, ENVI-Met model, CFD modeling, urban design, sustainable cities

1. Introduction

A microclimate-based design strategy in urban areas is mainly related to control of solar access and air flow inside the various urban clusters. Courtyards are common architectural solutions, traditionally associated with the Mediterranean region. The courtyard as a result of regulations due to the high building density is an irregularly shaped space, usually without plants and trees, designed mainly for daylight and validation to the backroom (Tsianaka, 2006). Researches in arid and semi arid climates showed that the courtyards can be considered as cool reservoirs to improve the microclimate (Attia 2006). Multiple courtyards were also found to improve convective cooling and mitigate additional heat loads (Ernest and Ford 2012). In the Mediterranean climate of Athens an appropriately designed garden is capable of functioning as a positive climatic element in urban design (Tsiros and Hoffman 2014). Tsianaka (2006) concluded that in high building density areas narrow courtyards are more beneficial than wider courtyards, indicating the crucial role of the geometry of space. Outdoor conditions within the courtyard, however, may often be less comfortable than in the open surroundings depending on the orientation (Meir *et al*. 1995). Solar radiation screening and urban structure are the most important factors in determining the courtyard thermal environment (Yang *et al* 2012). The correct orientation of semi-enclosed open spaces can improve their thermal behavior, while orienting them irrespective of solar angles and wind direction may create thermal discomfort in them (Meir *et al*. 1995). Shashua-Bar *et al*. (2011) confirmed that these architectural solutions may have positive or negative climatic elements in urban environment depending on combinations of mature trees, grass, overhead shading mesh and paving.

The present study deals mainly with the potential cooling effect of a vegetated courtyard located in an urban cluster of the city of Athens (Greece). Previous study in Athens focused on the cooling effect of vegetated streets (Shashua-Bar *et al*. 2012; 2010) whereas the cooling effect of street vegetation was also evaluated in terms of energy savings in buildings during hot summer days in the Athens urban environment (Tsiros, 2010). The present work focuses on the thermal effects of courtyards.

2. Study sites and data

For the purpose of the study, an urban block with a courtyard area in downtown Athens was selected. The chosen study area has a dense building morphology with a building of eight stores attached to the NW side of the courtyard. The courtyard has NNE orientation since it is attached to the NNE side of the two-storey building. The garden is a densely wooded area with high coverage of irrigated vegetation (more than 85% of the floor area). In the northern side is a three storey building school with front and back school's courtyard. A detailed monitoring study based on in-situ measurements of air temperature, humidity, wind speed and solar radiation inside the courtyard was carried out during the summer of 2013 and the next winter. The measurements were carried out from 22nd of July to 01st August 2013 for summer period and from 21st February to 12th March 2014 for winter period.

3. Model parameterization and input data

The model simulations have been carried out with the three-dimensional non-hydrostatic climate model ENVI-met Version 3.0 (Bruse and Fleer 1998). This model has been used in a number of studies to predict the thermal comfort in outdoor conditions (e.g., Attia and Duchhart, 2011; Johansson *et al*., 2013).

4. Results

Selected scenarios were examined to evaluate the influence of vegetation, ground surface materials and geometry on the microclimate of the courtyard for summer and winter weather conditions. In order to identify the comfort conditions in the courtyard the mean radiant temperature was used. Figure 1 presents the values of mean radiant temperature (T_{mrt}) and surface temperature (T_{surf}) at 12:00 LST inside the study area and also in the surrounding area at 2m height. In the first scenario all vegetation from the courtyard has been removed and replaced by irrigated grass 50cm height while the vegetation of the surrounding area was replaced by bushes. In the second scenario the buildings of eight and seven storeys attached to the NW side of the courtyard replaced by three and two storey buildings, respectively.

In the summertime, during the hours when the courtyard receives solar radiation (10:00 to 17:00), trees have a great impact by lowering the surface temperature by up to 8 ^{o}C in relation to the grass. The mean radiant temperature is generally characterized by high values almost during the whole daytime and is greatly affected by the vegetation and ground surface materials (Figure 4a and 4b). Inside the courtyard in the current design the mean radiant temperature at 12:00LST varies from 45 to 55^{o}C while in the surrounding area and mostly in the nearby asphalt roads exceed 70^{o}C. The difference of 10^{o}C observed inside the courtyard lies in the diversity of vegetation on the density of foliage. At the same time in the second scenario with the reduced building height the Tmrt in the courtyard has values from 50 to 60 ^{o}C while early in the morning and at late afternoon the Tmrt is up to 23 ^{o}C. The difference at 12:00 LST between the current design and this scenario caused by the shade of tall building in the present design.

The high irrigated vegetation has a huge impact in thermal comfort by lowering the MRT by up to 15 ^{o}C in relation to grass cover. In the case of first scenario in the mean radiant temperature there were not observable changes in relation to the height above the grass; the mean radiant temperature exceed 60 °C while the surface temperature is up to 37° C and this is caused by increasing the solar radiation and decreasing the shade of the tree coverage. At 7:00 LST the Tmrt in the courtyard is up to 18 °C in the current design and the first scenario; while in the afternoon the Tmrt in the current design is up to 26°C and in the scenario with the grass may vary from 34 to 38 °C. At 21:00 LST in the whole simulated area it varies from 17 to 18 °C and from 24 to 26 °C in high and low vegetation coverage respectively.

In addition, the surface temperature showed to be much higher inside the courtyard with the grass coverage rather than the high tree vegetation; there were no differences, however, between the current design and the second scenario. The surface temperature values at 12:00 LST vary from 25 to 34°C and 33 to 36°C in the current and the first scenario respectively. In the nearby asphalt streets the surface temperature is up to 50°C in both cases. In the schoolyard the replacement of high-tree vegetation with bushes increase the surface temperature up to 10 °C. At 7:00LST inside the courtyard the surface temperature is the same in both cases (18 °C) whereas at 17:00 LST the difference between the current and first scenario is up to 9 °C. During the hours where the courtyard receives solar radiation the trees have a huge impact on the surface temperature. The trees lower the temperature by up to 8°C in case of grass coverage. Forming a shallower courtyard by reducing building height the surface temperature during the midday is at the same level as the current design (up to 34°C) while late the afternoon the surface temperature is much higher because of the decreasing of shading by the buildings.

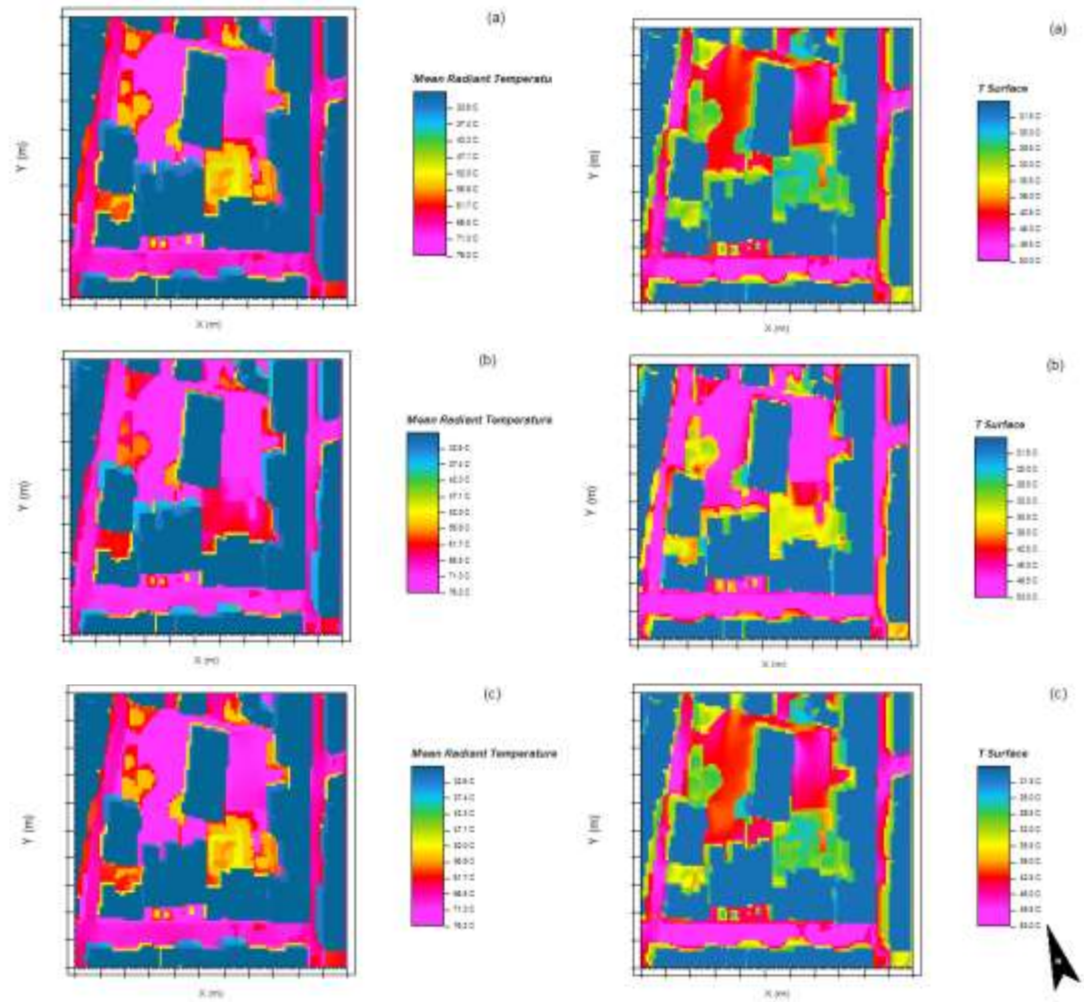

Figure 1: Simulated mean radiant temperature (left) and surface temperature (right) for typical summer day at 12:00LST at 2m height at current situation (a), scenario with grass coverage (b) and change of geometry (c). The range of data is 32.6 (dark blue) to 76.2°C (light red) for Tmrt and 21.5 (dark blue) to 53 °C (light red) for Tsurf.

5. Conclusion

The results obtained in the present study indicate that in the Mediterranean climate insufficient vegetation (such as grass) in courtyards may lead to local overheating conditions in summer mainly due to surface temperature increases. The average difference between mean radiant temperatures (up to 30 ºC) inside the courtyard and the surrounding streets depends on vegetation. The most overheated area was found to be the asphalt streets and paved school courtyard which has limited vegetation. To improve thermal comfort in such cases, additional shading by using shade with large tree canopies is required.

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