Proceedings of the 2nd ICAUD International Conference in Architecture and Urban Design
Epoka University, Tirana, Albania, 08-10 May 2014
Paper No. 262

Trees and the Microclimate of the Urban Canyon: A Case Study

Blagovesta Dimitrova, Milena Vuckovic, Kristina Kiesel, Ardeshir Mahdavi
Vienna University of Technology
Department of Building Physics and Building Ecology
Vienna, Austria
dimitrova.blagovesta@yahoo.com; milena.vuckovic@tuwien.ac.at;
kristina.kiesel@tuwien.ac.at; bpi@ tuwien.ac.at

ABSTRACT

Urbanization generally influences the microclimate by changes introduced in land cover, the compact spatial structure of the metropolitan areas, the emission of pollutants, the modification of the physical properties of the surfaces, etc. The frequently observed steady increase of urban air temperatures around the world is considered to be a cumulative effect of all of the above mentioned parameters. Higher air temperatures, especially during the summer season, may have major implications for local air quality, heat stress, morbidity, mortality and energy demand. In this context, the present study investigates the capabilities of vegetation to attenuate microclimatic extremes. Specifically, we explored the diversity of microclimatic conditions in two parallel streets (in Vienna, Austria), one with trees, and the other one without. Simultaneously monitored data from two mobile weather stations was obtained for the selected study areas during hot and sunny days in August 2012. Using the collected data, the temporal cooling effects of vegetated areas was systematically studied.

KEYWORDS: trees, microclimate, air temperature, urban canyon

1 INTRODUCTION

Constant urban development brings a radical change in land cover. As cities expand, more natural surfaces are being replaced with impervious cover. The complex urban surface morphology, along with noted increase of sealed surfaces, modifies the total energy balance of the city resulting in higher heat storage in urban areas (Nunez and Oke 1977, Grimmond et al. 1999). It can be argued that loss of vegetation combined with the heat-absorbing properties of sealed structures result in higher outdoor air temperatures, affecting thus negatively the buildings' thermal performance (Taha 1997, Lee and Park 2008). Hence, from a thermal point of view, urban vegetation can be extremely beneficial for a city. The impact of urban trees and parks on a city's energy balance is extensively documented in number of research papers (Akbari et al. 1997; Nowak 2002; Alexandri 2008; Pandit and Laband 2010). Vegetation can mitigate microclimatic extremes directly by shading heat-absorbing surfaces, and indirectly through evapotranspiration cooling (Misni and Allan, 2010). Increasing urban vegetation holds great potential for reducing urban summertime air temperatures and saving cooling energy use in buildings (Huang et al. 1987). In this sense, the necessity to both recover and increase the total amount of green areas is becoming increasingly critical to maintain environmental quality.

In this context, the present study investigates the capabilities of vegetation to attenuate microclimatic extremes. Specifically, we explored the diversity of microclimatic conditions in two parallel streets (in Vienna, Austria), one with trees, and the other one without. Simultaneously monitored data from two mobile weather stations was obtained for the selected study areas during hot and sunny days in August 2012. Using the collected data, the temporal cooling effects of vegetated areas was systematically studied. Additionally, we explored the application of a CFD-based microclimatic model to estimate the microclimatic conditions around envisioned study areas.

2 METHODOLOGY

2.1 Investigated areas

For the purpose of the present contribution, we compared measured data representing specific weather conditions of two parallel street canyons (in Vienna, Austria), one with trees (vegetated canyon), and the other one without (non-vegetated canyon). These streets are similar in terms of orientation, width, and surrounding building properties (Figure 1). The general information regarding the selected study areas is given in Table 1.

Figure 1: Vegetated canyon on the left and non-vegetated canyon on the right

Table 1 Description of selected study areas

Property	Vegetated canyon	Non-vegetated canyon
Orientation	SE - NW	
Street width [m]	18	
Building height [m]	16 - 20	
Building materials	Plastered bricks	
Paving material	Black asphalt, cement concrete	
Vegetation	Trees (12 – 14 m high)	None
Mean SVF [%]	13	45
Traffic level	High	Low

2.2 Data collection and analysis

To systematically address the local variation of the microclimate in an urban canyon, three representative measurement spots were defined for each street (Figure 2). Selected spots were carefully positioned to capture the site-specific microclimatic conditions, in particular, within a street canyon, as well as at the crossroads.

Figure 2: Position of measuring spots within selected streets

Two weather stations (Synotech Onset HOBO data loggers) were mounted on bicycles, at the same height of 1.5 meters (Figure 3). Both bicycles were equipped with temperature and humidity sensors, a low power anemometer for wind speed, and a pyranometer for global solar radiation. Additionally, both bicycles were equipped with CO_2 sensors.

Figure 3: Mobile weather stations

Simultaneously monitored weather data used for this research was collected during some hot and sunny days, between 7th and 22nd of August, 2012. The collection of data was performed twice per day, in the morning from 7:00 to 8:00, and in the evening from 17:30 to 18:30. Thereby 20 minutes could be allocated for measurements at each of the three spots. In order to capture the extent of microclimatic differences resulting from absence of vegetation, the deviation between vegetated and non-vegetated canyon was expressed in terms of mean values.

2.3 Computer simulations

The potential of numeric computational models for the simulation of urban microclimates was also explored. For this purpose, the state of art CFD-based numeric simulation tool ENVI-met (Huttner and Bruse 2009) was employed. A 24-hour simulation with a time step of 10 sec was performed. The simulations were carried out for the 20th August only, as this was found to be the day with the highest temperatures recorded during the whole measurement period. The simulation model was calibrated using the collected empirical data (Dimitrova 2013). Three representative receptors were positioned within each urban canyon, replicating the spots where the empirical data was collected. A number of mitigation actions were defined (Table 2), simulated, and evaluated.

Table 2 Description of selected study areas

SCENARIOS	Vegetated canyon	Non-vegetated canyon
BASE CASE (BC)	Current situation	
SCENARIO 1 (S1)	Black asphalt replaced with white concrete	
SCENARIO 2 (S2)	Increased albedo of building facades	
SCENARIO 3 (S3)	Reducing the number of trees	Addition of trees
SCENARIO 4 (S4)	S1, S2 and S3 combined	

3 RESULTS

3.1 Mobile measurements

Figures 4 to 8 show the temperature difference, global solar radiation, absolute humidity, wind speed, and CO_2 levels respectively, between non-vegetated and vegetated canyon for each sample spot. Every figure is divided into two time periods, morning and evening, thus making the distinctive temporal patterns easier to visualize.

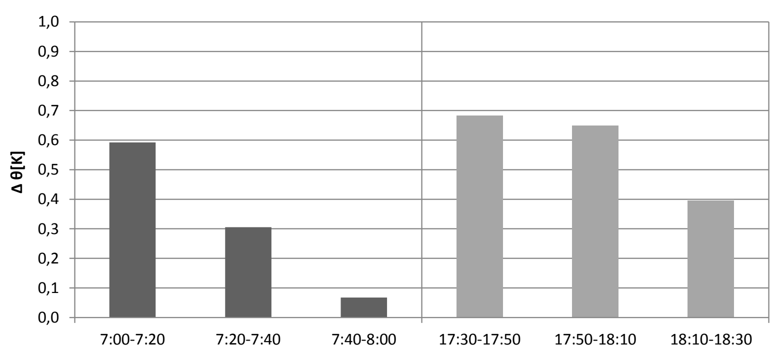

Figure 4: Mean air temperature differences between non-vegetated and vegetated canyon

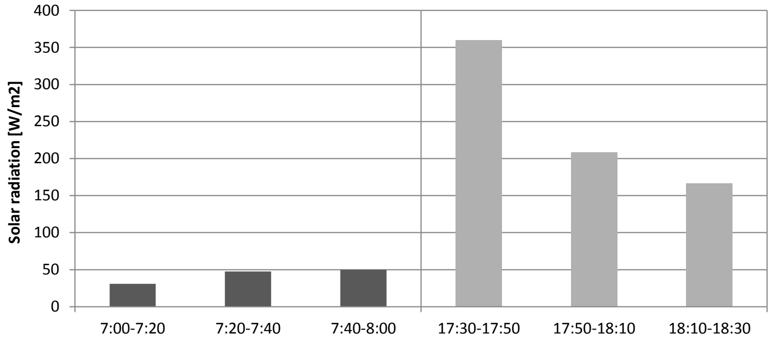

Figure 5: Mean global solar radiation differences between non-vegetated and vegetated canyon

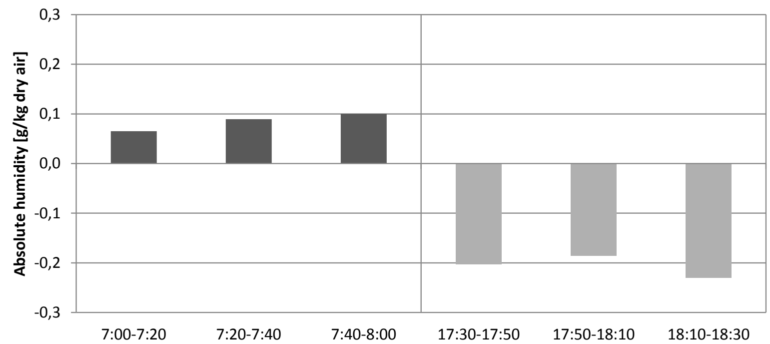

Figure 6: Mean absolute humidity differences between non-vegetated and vegetated canyon

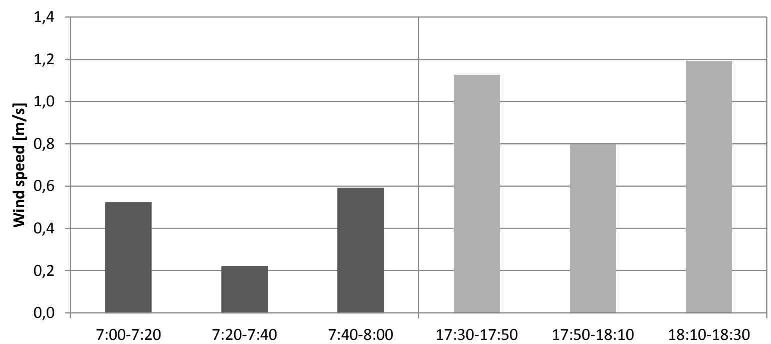

Figure 7: Mean wind speed differences between non-vegetated and vegetated canyon

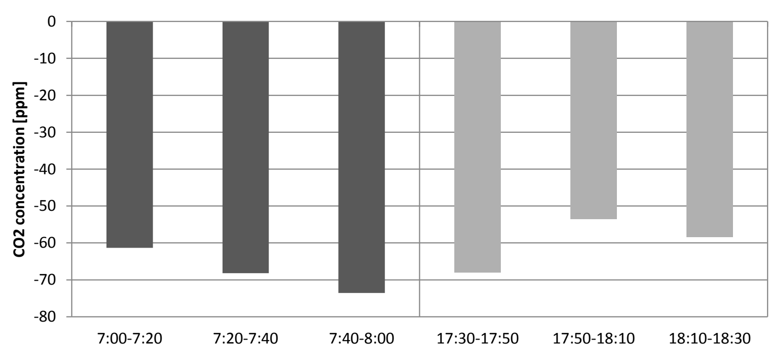

Figure 8: Mean CO_2 differences between non-vegetated and vegetated canyon

3.2 Simulation results

In order to determine the effect of the envisioned mitigation measures, the deviation the simulation scenarios 1 to 4 from the base case was generated (see Figures 9 to 12).

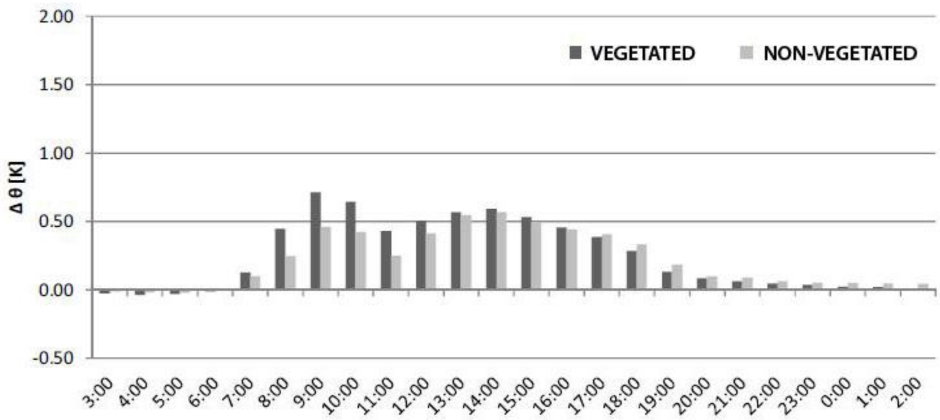

Figure 9: Mean air temperature differences between BC and S1

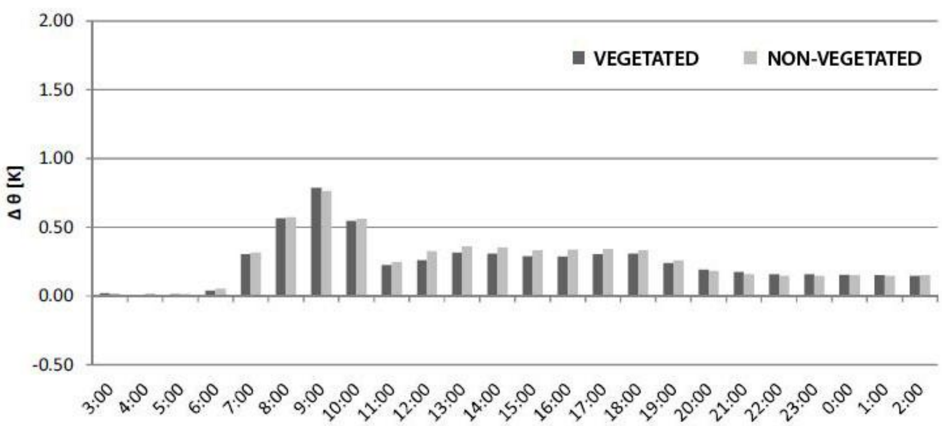

Figure 10: Mean air temperature differences between BC and S2

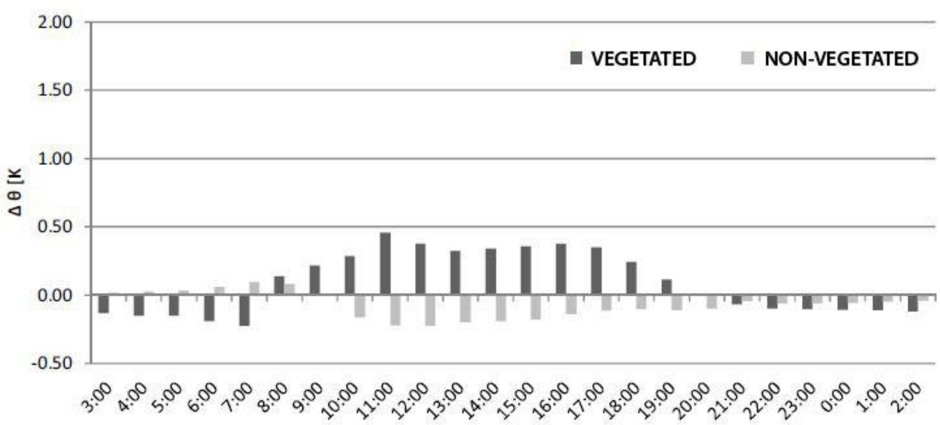

Figure 11: Mean air temperature differences between BC and S3

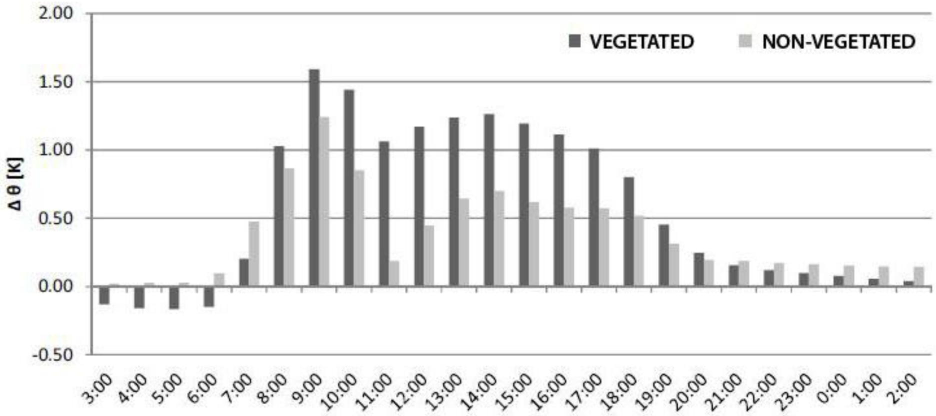

Figure 12: Mean air temperature differences between BC and S4

4 DISCUSSION

4.1 Mobile measurements

The results clearly demonstrate the significant difference between the vegetated and non-vegetated urban canyons in view of the observed climatic parameters. The air temperature difference varies from 0.1 to 0.7 K, depending on the time of the day (Figure 4). Looking at the morning session, the difference was more pronounced during the early morning hours. In the afternoon the air temperature was consistently higher in the non-vegetated canyon. The data further reveals that as the amount of incoming solar radiation increased substantially in the afternoon, the vegetated canyon stayed cooler (Figure 5). This further stresses the important role of tree shading and evapotranspiration, especially during summer months. The process of evapotranspiration may also explain the observed higher absolute humidity in the vegetated canyon during late afternoon (Figure 6). The recorded wind speeds are higher in the non-vegetated urban canyon, confirming that trees can be used as wind breakers (Figure 7).

The recorded CO_2 levels were found to be higher in the vegetated canyon (Figure 8). A number of factors may have contributed to this circumstance. First and foremost the traffic frequency in the vegetated canyon was significantly higher. Moreover, vegetation could have reduced ventilation in the urban canyon, retaining thus air masses with higher CO_2.

4.2 Simulations

Simulated modifications to the base case display significant decreases in the air temperature. The introduction of white concrete resulted in a decrease of up to 0.83 K (Scenario 1). Highest differences are noticed at 9:00 and 10:00 in the morning for non-vegetated canyon, at 13:00 and 14:00 for vegetated canyon, and lowest ones in the hours after sunset. The change in albedo showed an apparent decrease of air temperature in both urban canyons (Scenario 2). Temperature values fell up to 0.8 K at 9:00 in the morning and between 0.3 and 0.4 K during the rest of the day in both urban canyons. Adding trees or reducing the number of existing ones influenced the air temperatures as well (Scenario 3).. The temperature in the non-vegetated canyon slightly decreased after the addition of trees. This is perhaps due to the resulting reduction of the sky view factor. On the other hand, the reduction of the number of trees in the vegetated canyon resulted in a temperature increase. The combined case (Scenario 4) displays substantial alterations of air temperature in both urban canyons. The overall reduction in the air temperature ranged from 1.4 up to 1.7 K.

5 CONCLUSION

We studied numerous climatic parameters to address the presence of trees and vegetation in an urban canyon. The analysis of the local microclimatic conditions shows significant differences between the selected areas. The data shows significant temperature differences between the vegetated and non-vegetated areas, whereby the latter consistently displayed higher temperatures. This can be explained by both shading and evapotranspiration effect of trees (reflected in the smaller SVF values and the higher humidity ratios in the vegetated canyon). We suspect that higher monitored CO_2 values in the vegetated canyon was mainly due to the respective higher traffic frequency. However, urban trees might have contributed to the retention of high CO_2 air masses. Therefore trees should be strategically positioned within an urban canyon in order to mitigate the potential negative impacts.

Our simulation results suggest that a major reduction of summertime extreme temperatures can be achieved via the combination of a number of mitigation measures such as increasing the albedo of canyon surfaces and addition of trees in the urban canyon.

6 ACKNOWLEDGEMENTS

This project was funded in part within the framework of the EU-Project "Development and application of mitigation and adaptation strategies and measures for counteracting the global Urban Heat Island phenomenon" (Central Europe Program, No 3CE292P3).

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