Testing and validation of ENVI-met simulation based on in-situ micrometeorological measurements: the case of Syntagma Square, Athens, Greece

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Abstract

The present paper focuses on the development of a methodology that simulates micrometeorological thermal conditions in an urban context based on weather station data. The micrometeorological conditions at Syntagma square, the central square of Athens, Greece were simulated by ENVI-met software in order to evaluate the thermal conditions experienced by its users. Located in the heart of city’s commercial activity, the square attracts many visitors, especially during summer months, when extreme thermal conditions could be encountered. ENVI-met can simulate the necessary factors for the estimation of thermal sensation through thermal indices, i.e. air temperature, mean radiant temperature, relative humidity, and wind speed. The meteorological data needed as input were obtained from the nearest weather station. In-situ micrometeorological measurements recorded at the height of 1.1m, were used to validate the simulated results. ENVI-met simulations were performed at a high spatial and temporal resolution. The appropriate adjustments were made to the modeling procedure to achieve a successful and resource-effective simulation.

Keywords: micrometeorological measurements; thermal sensation; field surveys; ENVI-met

1. Introduction

The city of Athens, Greece is a popular tourist destination especially in summer months, when extreme thermal conditions are encountered. Syntagma square is the heart of the city and a popular gathering and commuting place. Studies focusing on thermal conditions across urban areas, examine the influence of urban greening on outdoor thermal comfort (Lee et al., 2016; Chatzinikolaou 2018) while numerical simulations are commonly performed with ENVI-met software.

ENVI-met is a three-dimensional microclimate model, based on the fundamental laws of fluid dynamics and thermodynamics and designed to simulate complex surface-vegetation-air interactions in the urban environment (Bruse and Fleer, 1998). The latest version of ENVI-met 4.4.2 (2019), allows the user to specify several soil types, building materials, 3D vegetation and tree types, considering also the month of the year.

The aim of the present study is to test and validate the ENVI-met simulation results based on micrometeorological data measured in-situ and covering a variety of weather conditions.

2. Data and Methodology

Syntagma square (37° 58' 31.95" N, 23° 44' 05.54" E; ~120x120m^2) is surrounded by high traffic avenues, it includes green areas to the north and south and two water fountains, in the centre and in the western part of the square (Fig. 1a).

The micrometeorological conditions of Syntagma square were simulated by ENVI-met. For the simulation, the grid was set to 100x100x30cells, with cell size 1.5x1.5x2.0m resulting to a total area size of 150x150x60m and covering the study area (Fig. 1b). Surface materials, plants, trees and built infrastructure were included in order to give an accurate modelling description of the study area. The simulation ran for 24 hours (00:00-23:00), for each day of in-situ measurements, providing enough time between the simulation onset and the time of the validation data; also avoiding any spin up issues. The time step of the output was 1 hour. Simple Force method for model initial conditions was applied, using hourly dry bulb air temperature and relative humidity records from the nearest meteorological station of National Observatory of Athens at Thission. The ENVI-met default values for specific humidity at 2,500 meters and roughness length were adopted.

ENVI-met results were validated by in-situ micrometeorological measurements. A 7-day campaign was carried out in Syntagma square (July 2010-February 2011), covering summer, winter, and a transitional season. A mobile weather station was used to monitor air temperature (T_{air}), relative humidity (RH), wind speed (WS) and grey globe temperature (T_{gl}) at the height of

1.1m (Fig. 1a). Mean radiant temperature (T_{mrt}) was calculated using T_{air}, T_{gl}, and WS (ISO 7726, 2001).

Figure 1. (a) Satellite view of Syntagma square (red dot represents the mobile weather station location) and **(b)** 2-D area input file for ENVI-met (green dots: trees, grey objects: buildings, white rectangles: water fountains, multicolor rectangles: terrain levels relative to the lowest height for 1m height step).

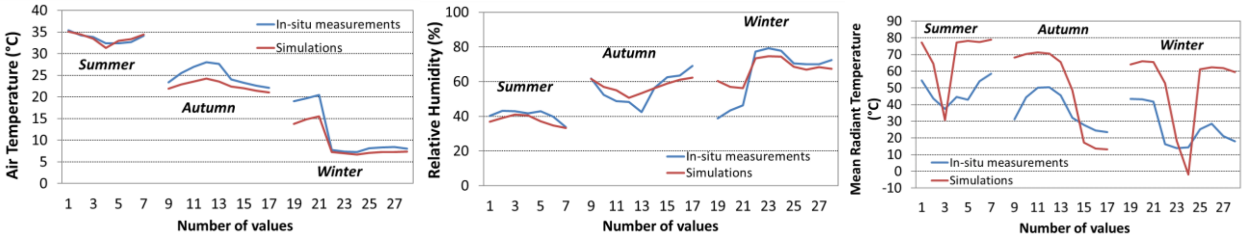
3. Results

A dataset of about thirty values were examined in order to validate the model output for T_{air}, RH and T_{mrt} at the exact location of the mobile meteo station (red dot in Fig. 1a).

The comparison of in-situ and simulated data at the same height above the ground, shows that the model provided quite successful results for T_{air} and RH; while for T_{mrt} there were significant deviations (Fig. 2). To quantify the differences between in-situ and simulated data, the Root Mean Square Error (*RMSE*), the Mean Absolute Error (*MAE*) and the Agreement Index (*d*) (Willmott, 1981), were calculated. A value of 1 for *d* corresponds to a perfect match, and 0 indicates no agreement at all. Table 1 shows that the agreement for T_{air} and RH are excellent with *d* values greater than 0.90. On the contrary, the *d* values for T_{mrt} were about 0.60. Moreover, the results presented a seasonal variation with the best scores being achieved during the summer months.

Table 1. Quantitative comparison of ENVI-met results with the data obtained by in-situ micrometeorological measurements.

Variable	RMSE	MAE	d
Temperature	2.24°C	1.70°C	0.99
Relative Humidity	6%	5%	0.93
Mean Radiant Temperature	25°C	24°C	0.57



(a) **(b)** **(c)**

Figure 2. Comparison between the recorded and the modeled values for (a) air temperature, (b) relative humidity and (c) mean radiant temperature.

4. Conclusions

The results show that proper model set-up, material specifications as well as that the initial conditions using the simple force method, can give very good validation scores for T_{air} and RH. On the other hand, the validation scores for T_{mrt} were significantly lower which means that the forcing of solar radiation is also essential. The results can be improved by importing more accurate terrain characteristics in ENVI-met via the recently released MONDE editor. Furthermore, the full forcing mode -all variables including wind and solar radition can be "forced"- will be used to increase the model's prediction accuracy, to the level required to achieve the goals of this project.

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References

Bruse M. and Fleer H. (1998), Simulating surface-plant-air interactions inside urban environments with a three-dimensional numerical model, *Environmental Modelling and Software*, **13**, 373–384.

Chatzinikolaou E., Chalkias C. and Dimopoulou E. (2018), Urban Microclimate improvement using Envi-Met Climate Model. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-4.

Envi_met 4.2.2. (2019), Manual contents, http://www.envi-met.info/doku.php (accessed 19 January 2019).

ISO 7726 (2001), Ergonomics of the thermal environment-Instruments for measuring physical quantities, International Organization for Standardization, Geneva.

Lee H., Mayer H., and Chen L. (2016), Contribution of trees and grasslands to the mitigation of human heat stress in a residential district of Freiburg, Southwest Germany, *Landscape and Urban Planning*, **148**, 37–50.

Willmott C.J. (1981), On the validation of models, *Physical Geography* **2,** 184-194.