STUDY OF THE URBAN HEAT ISLAND IN LECCE (ITALY) BY MEANS OF ADMS AND ENVI-MET

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Abstract: The Urban Heat Island (UHI) phenomenon is associated to a cascade of effects on citizens' health, energy consumptions and air quality. Accurate local scale UHI numerical predictions are particularly relevant for the achievement of a sustainable urban planning. In this paper, we evaluate the performance of two different modelling techniques to predict temperature distribution within the urban environment. The diagnostic integral-semi-Gaussian model ADMS-Temperature and Humidity Model and the prognostic Computational Fluid Dynamics (CFD) based model ENVI-met were used and results were validated against field measurements collected during summer 2012 in four different neighbourhoods of Lecce, an Italian medium size city. Results suggested that even if the entire building morphometry and green areas were carefully reproduced within the CFD-based model and only parameterized within the integral model, the level of complications appeared to be not essential in temperature predictions. As a consequence the integral model resulted to be more effective for a fast and accurate assessment of air temperature distribution within the city.

Key words: *Urban temperature; ENVI-met; ADMS-Temperature and Humidity model; Land use parameters; Morphometry.*

INTRODUCTION

The prediction of the outdoor thermal environment in urban areas has become a matter of great concern because of the ongoing rapid urbanization causing the Urban Heat Island (UHI) phenomenon that is known to display higher air temperature in urban settlements with respect to their rural surroundings. Knowledge of the air temperature distribution within a city is of interest for scientists, engineers and urban planners because of its connection with energy consumption (Konopacki, S. and H. Akbari, 2002), ground level of ozone (Rosenfeld, A. H. *et al*, 1998) and mortality rates (Changnon, S. A. *et al.*, 1996). It is known that air temperature distribution and its evolution in time depend on different concomitant aspects such as meteorological factors (wind speed and direction, humidity, cloud cover) and urban texture parameters.

Modelling techniques have become a powerful tool to investigate the thermal environment within a city and then to help decision makers to establish mitigation strategies. Despite their widespread usage, the fidelity and limits of applicability of most numerical models employed for urban climate assessment have not been thoroughly determined (Memon, R. A. *et al*, 2008). Within this context we evaluate the accuracy and reliability of two different modelling techniques in predicting temperature distribution within the urban environment. The diagnostic integral-semi-Gaussian ADMS-Temperature and Humidity Model (hereafter ADMS-TH) (CERC, 2011) and the prognostic Computational Fluid Dynamics (CFD) based model ENVI-met (Bruse, M. and team, 2011) were validated against field values arising from a measurements campaign that was held during summer 2012 in four different neighbourhoods of Lecce, an Italian medium size city.

MEASUREMENTS CAMPAIGN AND MODELLING SET-UP

Description of the measurement campaign

A measurement campaign was carried out in Lecce (Figure 1a) from July 21 to September 9, 2012 (a total of 51 days). Air temperature (°C) was measured by Standard Thermistor Probes assembled with Tinytag by Gemini Data Loggers in four study sites (Sites 1, 2, 3, 4) located within the city, while two meteorological stations (hereafter Meteo sites 1 and 2) recorded typical meteorological variables (wind speed and direction, relative humidity, solar radiation, rain, atmospheric pressure) (Figure 1b). Sites 1, 2, 3 were chosen as representative of the urban environment, each one having a different morphometry (see Digital Elevation Model (DEM) in Figure 2b). Basic morphometric parameters were calculated for each site using the methodology reported in Di Sabatino, S. *et al.* (2010). From Figure 2 it can be noted that

Sites 1, 2, 3 may be regarded as a compact neighbourhood while Site 4 as a sparse canopy typical of a sub-urban environment. The analysis of collected data from Meteo sites 1 and 2, allowed us to select days August 10-11 as representative of the mid-summer in Lecce.

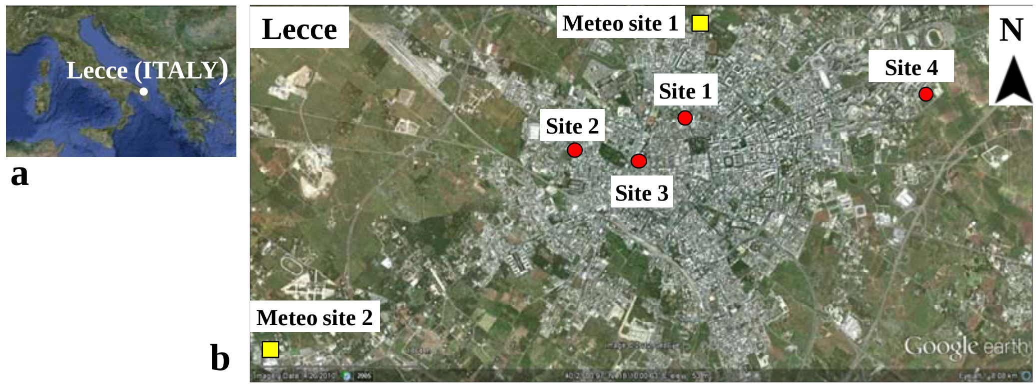


Figure 1. a) Position of the city of Lecce in southern Italy. b) Position of the study sites (red circles) and meteorological stations (yellow squares) (base map from Google Earth).

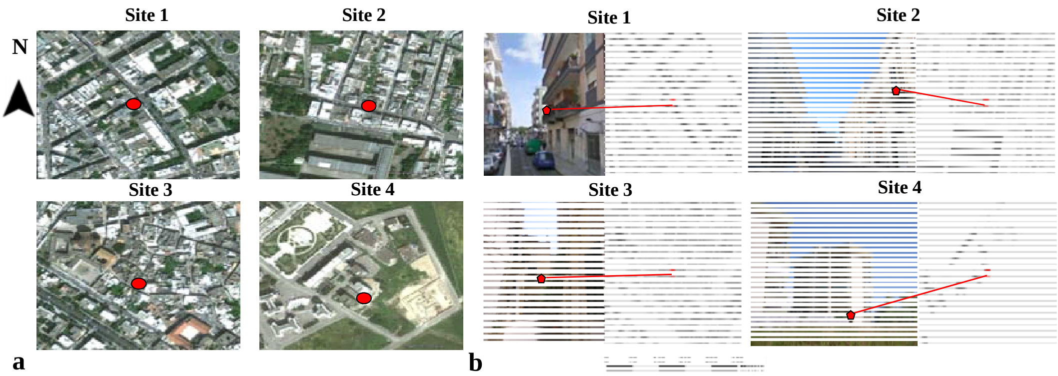


Figure 2. a) Aerial images of the four study sites. b) Sketch of the street canyons (left) and DEMs (right), with indication of the position of temperature sensors (red point).

Modelling set-up

ADMS-TH simulations were performed for the whole measurement campaign period (i.e. 51 days). Both land use (albedo, surface resistance to evaporation, thermal admittance) and morphometric parameters (normalized building volume and roughness length) of the study sites were estimated and used as input for the model. Hourly meteorological data (i.e. temperature, relative humidity, wind speed and direction) were taken from Meteo site 1 while solar radiation and rainfall from Meteo site 2. For the simulation of the study sites, computational domain size was 1.4km x 1.4km, meshed by a 100 x 100 horizontal grid and the study site was nested covering an area of 350m x 350m. For the simulation of the whole city, the computational domain was 10.5km x 13.75km with a grid resolution of 42 x 55 cells. The computational time was about one hour for simulating a single day (per site) on a Intel Centrino Duo (1.73GHz) PC with 1GB RAM.

ENVI-met boundary conditions were parameterized by the reconstruction of building morphometry, surfaces (asphalt, pavement, brick roads, loamy soil) and by explicitly reproducing the vegetation, that is perceived as an active element by the model in terms of both biological and aerodynamics effects. Simulations were initialized at 06:00 of August, 10 (Meteo site 1) with a spin-up time of 3-4 hours. The area input file has an horizontal extension of 350m x 350m with a grid resolution of 2m x 2m x 2m chosen on the basis of a grid convergence test. The computational time was about one week per site on a Intel XEON 3.33GHz Workstation with 2GB RAM.

RESULTS

Validation of numerical simulations

Figure 3a shows the observed and calculated temperature profiles for August 10-11 in the four sites. During the first hours of the day (06:00–11:00) ADMS-TH results are in good agreement with measured data, showing a maximum underestimation of 1.6°C at 11:00 in Site 4 and overestimation of 0.3°C at 08:00 in Site 3. On the other hand, ENVI-met provided good results during the first two hours corresponding to the spin-up phase. Then it systematically underestimated measured data up to 2.6°C at 10:00 in Site 4. From 12:00 to 16:00 both models underestimated measured data up to 2.6°C in Site 2. From 17:00 onwards, ADMS-TH quantitatively captured the temperature decrease, while ENVI-met systematically overestimated measured temperatures, probably due to the predicted low wind speed (always lower than 0.5ms^{-1}). Figure 3b shows the daily profiles of observed and ADMS-TH temperatures averaged over all the measurement period, confirming the good performance of ADMS-TH results. Predictions are within the measurements error bars, especially for Site 1 and Site 3.

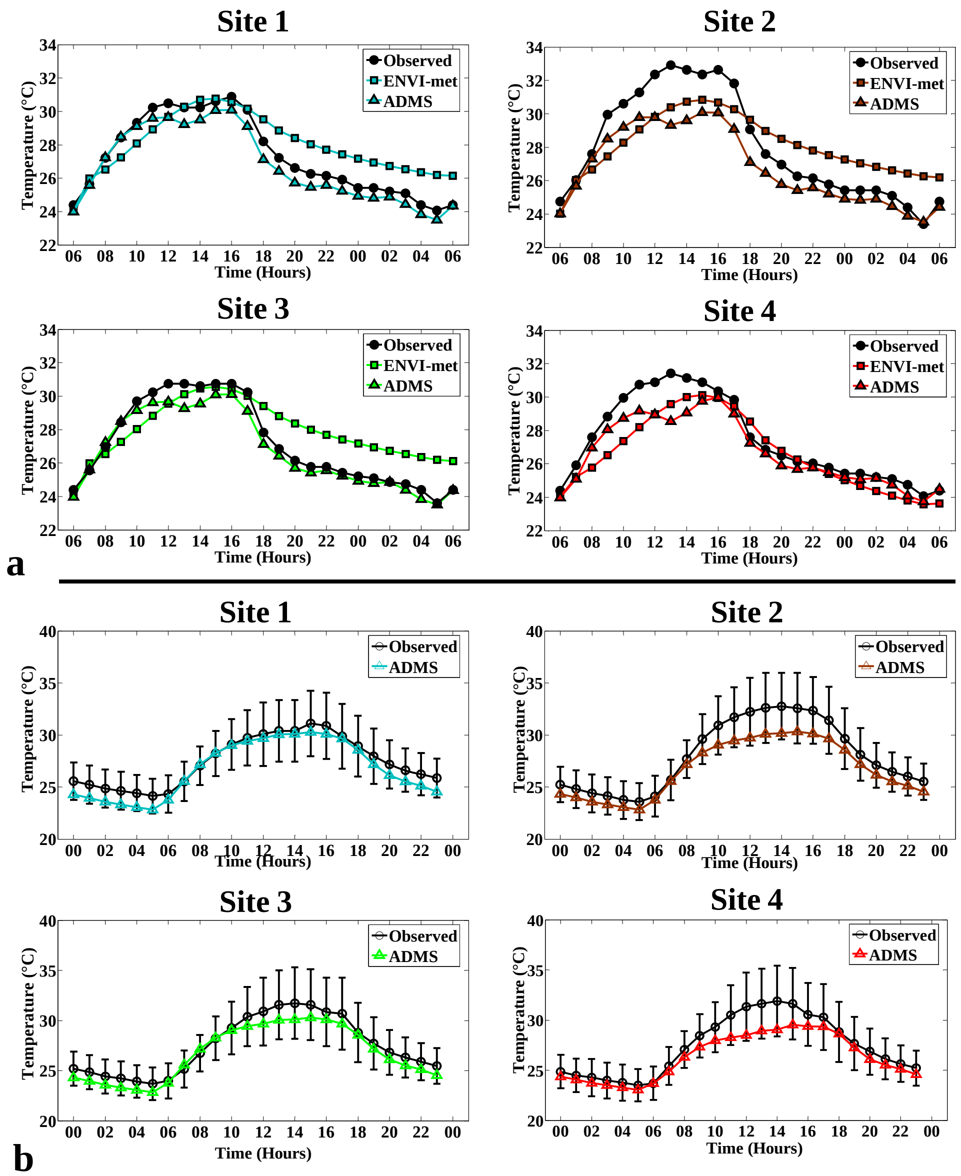


Figure 3. a) Observed and calculated temperature profiles for August 10-11. b) Daily profiles of observed and ADMS-TH temperatures averaged over all the measurement campaign period.

Analysis of thermal environment

In order to analyse the temperature distribution, Figure 4 shows maps of air temperature predicted by the two models on August 10 (at 12:00, 15:00, 20:00 and 23:00) at 2m (pedestrian level) for Site 1 (representative of the urban environment) and Site 4 (representative of the sub-urban environment). At 12:00 ADMS-TH and ENVI-met showed similar temperature distributions, predicting a cooler area in the eastern side (domestic garden) of Site 1 and in the area characterised by agricultural lands in the eastern-southern side of Site 4. On the other hand, the models were not able to well detect the influence of a public gardens in both sites (northern side). At 15:00 both the models showed higher temperatures with respect to 12:00. The street canyon effect on temperature distribution are now more visible in ENVI-met, especially in Site 1. In Site 4 both the models predicted a similar temperature pattern, with ENVI-met showing a less distinct cool zone in the area characterised by the agricultural lands. The public garden present in the northern part of the site (Figure 4) is seen as a cooler zone by ADMS-TH, while in ENVI-met the presence of vegetation is not well distinguished from the built surroundings. At 20:00 ADMS-TH was able to still predict lower temperatures in the presence of the domestic garden in Site 1, while ENVI-met predicted a smooth pattern over the entire area. In Site 4, the cooler zone (due to the presence of agricultural lands) is smaller than that found in the previous hours. At 23:00 both ADMS-TH and ENVI-met maps show the cooler zone in Site 1 domestic garden. In Site 4, ADMS-TH still predicted temperature differences between the built area and the agricultural lands, while a more homogeneous pattern is present in ENVI-met.

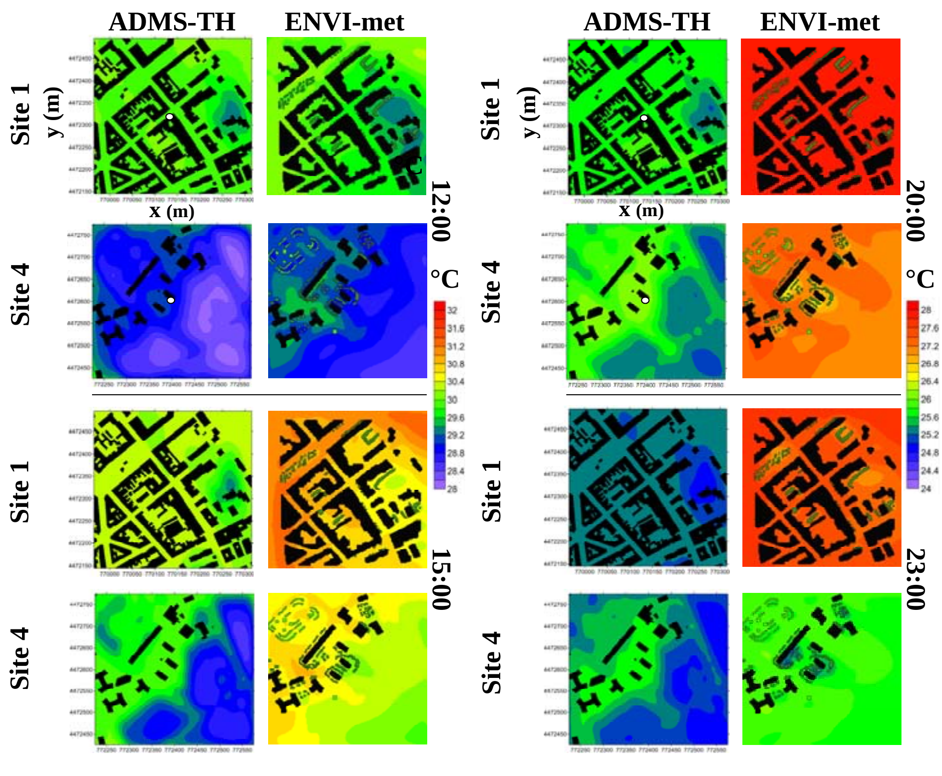
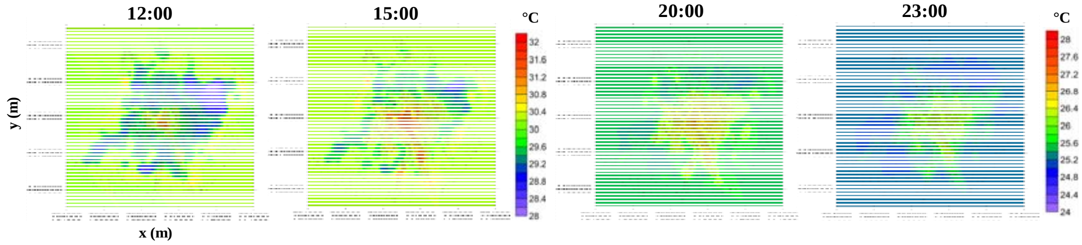


Figure 4. Temperature maps obtained by ADMS-TH and ENVI-met in Site 1 and Site 4 on August 10, 2012 at 12:00, 15:00, 20:00 and 23:00.

Figure 5 shows ADMS-TH maps of the whole city of Lecce. The expected UHI phenomenon is always captured by the model with a warmer area in correspondence of the inner part of the city with temperature weakly decreasing from the city centre towards the suburbs (Oke, T. R, 1987). From 12:00 to 15:00 the warmer inner area size increases and numerous different thermal zones can be distinguished as a consequence of the shadows forming within the canopy. At 20:00 and 23:00 when solar input is absent and only longwave emissivity is important, maps show a clear distinction between temperature in the centre (urban), outskirt (sub-urban) and rural areas.



Temperature maps obtained by ADMS-TH for the whole city of Lecce on August 10, 2012 at 12:00, 15:00, 20:00 and 23:00. x(m) and y(m) are the Gauss-Boaga plane coordinates.

CONCLUSIONS

In this work two modelling techniques, i.e. a CFD-based (ENVI-met) and the integral-semi-Gaussian model (ADMS-Temperature and Humidity Model) approaches, were used to evaluate their accuracy in predicting the temperature distribution in Lecce, a medium size city of southern Italy.

Even though urban morphometry is one of the most crucial factor altering the temperature distribution within the city, both models were not able to quantitatively capture the geometric effects on temperature distribution, even though ENVI-met explicitly reproduced the urban three-dimensional geometry. ENVI-met weakness may be due to the simplified input meteorological profile such as constant wind direction, low wind speed and idealized profiles for air temperature and solar radiation (Yang, X. *et al.*, 2013). The integral model ADMS-TH slightly underestimated the diurnal temperatures probably due to the currently adopted ratio between ground heat flux and net radiation. This hypothesis is supported by the nighttime good accordance with measured values. Even though in ADMS-TH the morphometry was parameterized results were in better agreement with the observations than ENVI-met ones.

The overall good performance of ADMS-TH highlights the importance of correctly reproducing the hourly meteorological conditions. An improvement in ADMS-TH validation could be achieved by using more refined values for land use parameters and by using the correct ratio between ground heat flux and net radiation. A better performance of ENVI-met may be indeed achieved by using the next version (4.0) (Yang, X. *et al.*, 2013) where full meteorological forcing and building thermal inertia will be introduced in the model.

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