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Urban microclimate and outdoor thermal comfort. A proper procedure to fit ENVI-met simulation outputs to experimental data

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ABSTRACT

This paper, while referring to a case study, focuses on the assessment of the input parameters based on the equations solved by ENVI-met. The output data of different micrometeorological variables and Predicted Mean Vote (PMV) were compared to the experimental values measured on the field in different points and for several days. The results provided by the software were examined while taking into consideration a different cell size of the mesh as well. However significant differences were not recognized and the $2 \times 2\,m^2$ cell-sized model was chosen; it represents a good compromise for what concerns results' accuracy and computation time. This gave the possibility to determine a deviation of 0.6% for air temperature, 0.9% for mean radiant temperature, about 2.0% for relative humidity and about 10% for global radiation. The predictive ability of the software was also testified, for air temperature and mean radiant temperature, by the analysis of the coefficient of determination, Root Mean Square Error and Willmott's index of agreement. Then the PMV values were compared with those measured during a field survey with an average deviation of 0.76 units and it was possible to determine how, among the different Lateral Boundary Conditions (LBC), the open type leads to more reliable results. Finally the latest version of the software was tested and in the conclusions a general procedure to perform simulations in ENVI-met is suggested.

1. Introduction

More than half of the world population lives in urban areas reaching a 75% in the most industrialized countries (PRB, 2012). These percentages are constantly increasing, in the developing countries (PRB, 2001a) in particular, which are located mainly in the tropical area (PRB, 2001b; UN, 2001). In these countries it is possible to have an increase in the urban population of 10^6 per year (NBSC, 2011).

This constant development of cities and a lack of attention towards the planning of open spaces affect deeply the urban microclimate (Dugord, Lauf, Schuster, & Kleinschmit, 2014): the heat island effect, determined by an excessive environment anthropization, leads to an increase in the air temperature affecting comfort and health condition of people (Buchin, Hoelscher, Meier, Nehls, & Ziegler, 2016; Horikoshi, Tsuchikawa, & Kobayashi, 1990; Xiong, Lian, Zhou, You, & Lin, 2016). Those attending open spaces need an environment guaranteeing thermal comfort to perform their activities (Mazhar, Brown, Kenny, & Lenzholzer, 2016; Patz, Campbell-Lendrum, Holloway, & Foley, 2005); conditions which are not ideal affect human and social activities and the economic aspects of these areas as well (Hajat, Kovats, & Lachowycz, 2007). For these reasons, overheating phenomena in urban areas, related to the design of urban spaces and the materials used, must be reduced (Tan et al., 2010). One of the solutions is the implementation of different mitigation strategies: some of them are mutually connected and tend to use surfaces with a high albedo coefficient (Akbari, Pomerantz, & Taha, 2001; Asaeda, Ca, & Wake, 1996), surfaces characterized by evapotranspiration phenomena (Saneinejad, Moonen, & Carmeliet, 2014), vegetation (Alexandri & Jones, 2008) and trees (Klemm, Heusinkveld, Lenzholzer, Jacobs, & van Hove, 2015; Mahmoud, 2011; Park, Hagishima, Tanimoto, & Narita, 2012; Rosenfeld, Akbari, Romm, & Pomerantz, 1998; Shahidan, Shariff, Jones, Salleh, & Abdullah, 2010).

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Nomenclature

b	Clapp and Homberger constant
C_f	Skin friction
CP	Volumetric heat capacity
c_p	Specific heat of the air
d	Willmott's index of agreement
dxy_{main}	Resolution of the main model
dxy_n	Dimension of the cell forming the n-th "Nesting grid"
dxy_{n+1}	Dimension of the cell forming the n + 1-th "Nesting Grid"
D	Diameter of the globothermometer
HCN	Thermal conductivity of the material
$K_{\mu s}$	Hydraulic conductivity
k_r	Thermal transmittance of the roofs
k_w	Thermal transmittance of the walls
$L_{boundarylayer}$	Characteristic linear dimension related to the boundary layer
LAD_m	Maximum value of the leaf area density at the height z_m
LAD(z)	Leaf area density of the plant in height z
LAI	One-dimensional vertical leaf area index of the plant from level z to the top of the plant
MatPot	Potential matrix
n	Coefficient which is 6 for z values included between 0 and z_m, and 0.5 for those z values included between z_m and z_p
p_1	Pressure whose value is used to determine T_A
R	Gas constant
RAD	Root area density
Re	Reynolds number
RMSE	Root Mean Square Error
R^2	Coefficient of determination
$r_{s,\,min}$	Minimum stomatal resistance
s	Extension factor
T_A	Air temperature
T_{GLOBE}	Globe temperature
T_{MR}	Mean radiant temperature
$T_{a,i}$	Air temperature inside the building
$U_{freestream}$	Speed of the freestream
u_*	Friction velocity at the nearest wall
V	Symbol which indicates the type of soil
V_A	Wind speed
y	Distance to the nearest wall
y^+	Non-dimensional distance able to characterize the influences in the wall-adjacent cells
pinz	Height
z_m	Height where there is the maximum value of LAD
z_p	Total height of the plant
z_p	Depth of the roots
z_0	Microscale roughness length of the surface

Greek letter

α_f	Albedo coefficient of the foliage
α_r	Albedo coefficient of the roof
α_w	Albedo coefficient of the walls
α_s	Albedo coefficient of the surface
δ	Distance from the wall
ε	Emissivity of the globothermometer
ε_s	Emissivity of the radiative fluxes with low frequency
η_{fc}	Volumetric soil water content at field capacity
η_s	Soil moisture at saturation
η_{wilt}	Volumetric water content according to the wilting point
θ	Potential air temperature at level z
μ	Dynamic viscosity
ρ	Density
τ_W	Wall shear stress
$\Delta z(k)$	Height of the k-th cell
$\Delta z(k\text{-}1)$	Height of the k-1-th cell

Planning open spaces, from a microclimatic point of view, needs an approach able to ensure thermal comfort conditions (Blocken, Janssen, & van Hooff, 2012; Nikolopoulou & Steemers, 2003). It has the main goal to verify if the strategies adopted are effective to control the effects of the thermophysical properties characterizing the surfaces materials on microclimate and requires sophisticated instruments and software able to evaluate the microclimatic variables of a specific site. Only in the past few years city planners, architects and engineers started to use this approach, even though the problem is well known as some old studies concerning urban climatology (Oke, 1979) report.

Such delay in the field of studies concerning microclimate is due to the complexity of the physics modeling of outdoor urban environments leading to a high number of variables involved affecting each other. Performing a series of experimental measurements on the field is too expensive for what concerns both time and resources. This is why 3D numerical simulations are considered most appropriate, if we want to obtain the prediction of environmental performance characterizing an urban space and improve outdoor microclimate (Arnfield, 2003; Bruse & Fleer, 1998; Neuenschwander, Wissen Hayek, & Grêt-Regamey, 2014).

The necessity to study the microclimate is also determined by the effects of the thermal environment on energy requirements (De La Flor & Domínguez, 2004). A study (Shen, Chow, & Darkwa, 2014) showed that during summer the cooling load of a building characterized by the presence of offices and placed in the metropolitan area of Hangzhou (China), would increase of 10.8% due to a 0.5 K increase of the air temperature. Other studies showed that an increase of 1 K of the air temperature leads to a growth of the electrical energy consumption in the United States (2–4%) and that 5–10% of the electrical energy in urban areas is used to cool buildings and compensate for an air temperature growth of 0.5 ÷ 3.0 K (Asaeda et al., 1996). A further study (Kapsomenakis, Kolokotsa, Nikolaou, Santamouris, & Zerefos, 2013), carried out in Greece, revealed that over the past 40 years, in a typical building with offices, every ten years the heat load and the cooling load had a 1 kWh/m^2 decrease and a 5 kWh/m^2 increase respectively.

So, both due to energy saving reasons and thermal comfort (La Roche & Berardi, 2014), investigating the urban environment through numerical simulations of microclimate can be very useful. Examining and evaluating how people consider the environment from a thermal point of view can be exploited to improve the thermal living environment through a proper urban planning (Salata, Golasi, de Lieto Vollaro, & de Lieto Vollaro, 2016) and to choose accurately the materials for the construction of outdoor spaces (Salata, Golasi, de Lieto Vollaro, Bisegna et al., 2015; Santamouris et al., 2012). Outdoor spaces which were properly planned reduce the possible thermal stress and this encourages people to participate in a higher number of outdoor activities (Nikolopoulou, Kleissl, Linden, & Lykoudis, 2011). This will lead to better living conditions through the reduction of pollutant emissions, of the air-condition energy consumption and of the so-called urban heat island effect.

To be more specific, this paper examines the software ENVI-met (ENVI-met, 2015). It can be considered one of the most com-