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Coupling building energy simulation software with microclimatic simulation for the evaluation of the impact of urban outdoor conditions on the energy consumption and indoor environmental quality

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ABSTRACT

The indoor energy simulation software of buildings, by default do not include the actual meteorological conditions (outside humidity, temperature, etc.) but uses average external weather data obtained by statistical analysis, which do not take into account local outdoor microclimate variations due to the urban landscape. This may lead to miscalculation of the needed energy for cooling and heating if the model is integrated in a real time building control scheme. Another important parameter in the energy simulation is the convection heat transfer coefficient between the outside environment and the building outside walls. The coefficient is calculated, in most energy simulation software, based on equations generated by wind tunnel experiments. In our approach a microclimatic environment simulation coupled with the indoor energy simulation will calculate dynamically the convection heat transfer coefficient between the outside environment and the building outside walls. The use of the meteorological data produced by a microclimatic simulation along with the dynamic calculation of the convection heat transfer coefficient is implemented in this work to achieve a better energy simulation of the building. Finally, the coupling of the two domains can lead to a ±40% difference in heating/cooling needs.

1. Introduction

The significant shifts in climate variables projected for the 21st century, coupled with the observed impacts of on-going extreme weather and climate events, ensure that climate change is set to remain a pressing issue for urban areas over the coming decades [1–3].

Urban thermal deterioration is the combined result of the urban heat island developed mainly in cities with a positive thermal balance and of the global warming which affects the urban climate as well. Significant effort is being put by various researchers on the impact of the urban microclimate to the buildings' energy consumption. Nowadays it is evident that the increase of urban temperatures has a serious impact on the energy demand of buildings by increasing significantly the energy consumption for cooling, while decreasing to some extent the energy consumption for heating. Therefore, the urban landscape creates a climate which affects, human comfort, air quality and energy consumption [4,5].

The tools that support the quantification of the microclimatic impact on the energy consumption of buildings are the Building Energy Simulation (BES) combined with microclimatic models. BES is an absolutely necessary tool in integrated building design and operation [6]. This importance can be illustrated by a large variety of BES software that are in use today [7]. The available BES combine many empirical and first-principle models to describe relevant energy transfer processes in buildings [8].

The modelling of urban thermal conditions is performed in different scales, namely mesoscale or microscale, depending on the area under investigation. For example, the climate of street canyons is primarily controlled by the micro-meteorological effects of urban geometry rather than the mesoscale forces. There are strong microscale variations of surface temperature that arise due to changes in radiant load with surface slope and aspect, shading, and variations in surface thermal and radiative properties [9]. Although there are no clear-cut distinctions between different categories, models might be classified into groups according to their

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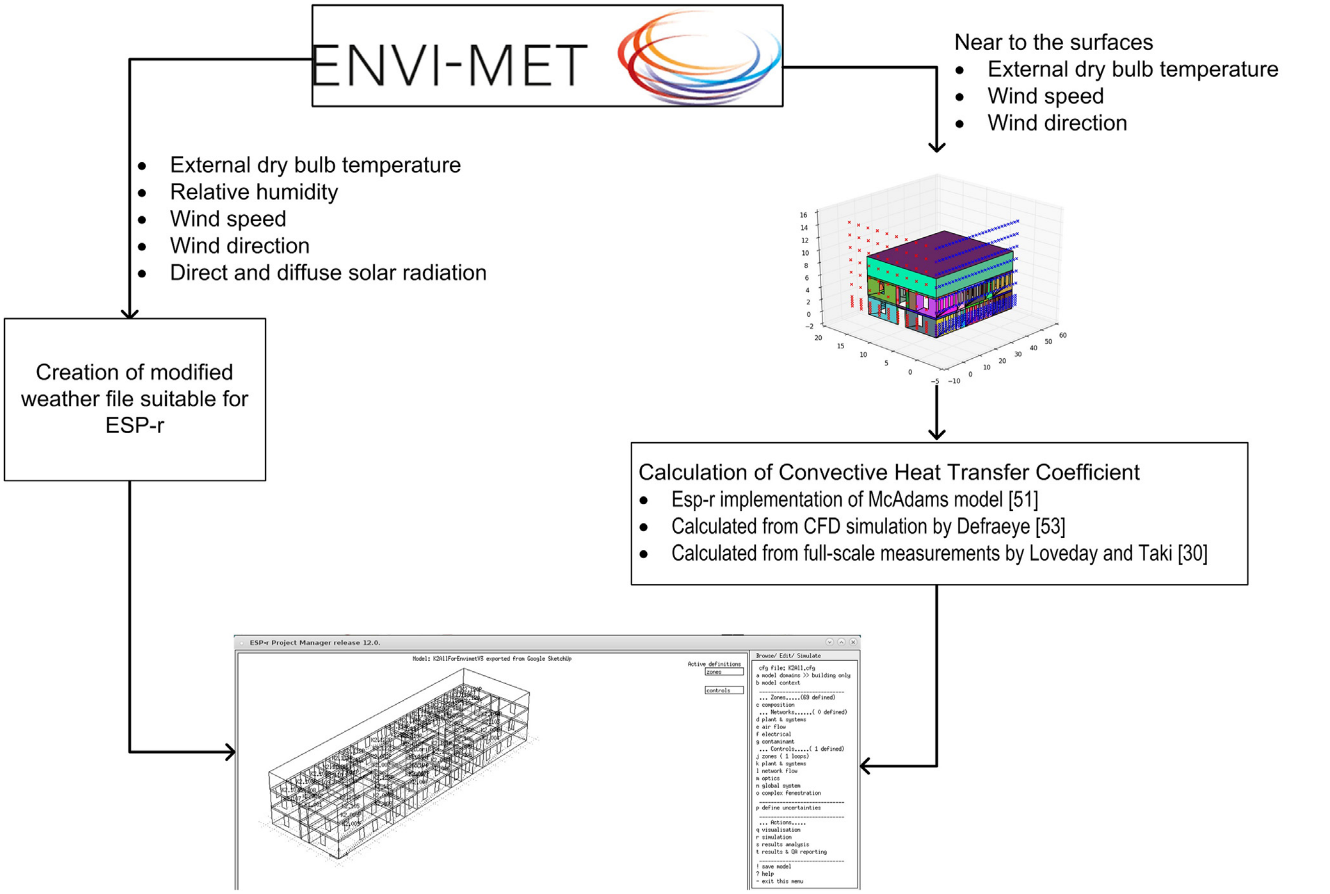

Fig. 1. The coupling methodology.

physical or mathematical principles (e.g. reduced-scale, box, Gaussian, Computational Fluid Dynamics) and their level of complexity (e.g. screening, semi-empirical, numerical) [10].

In order to accurately estimate the impact of urban microclimate on the energy consumption, BES tools should be effectively interconnected to allow more sophisticated and, at the same time, more efficient calculations which take into account the impact of the microclimatic conditions on the energy demand for buildings. Various researchers have performed similar efforts. A simulation tool for the prediction of the effect of outdoor thermal environment on building thermal performance (heating/cooling loads, indoor temperature) in an urban block consisting of several buildings, trees, and other structures is proposed by [11]. External surface temperature and mean radiant temperature are used to estimate the impact of the outdoor environment. As underlined by [12] the evaluation of policy measures in district level requires the effective combination of the building geometry with possible canyon formation, along with local weather conditions and energy load prediction, in order to effectively manage the available resources.

To this end, the aim of the present research is to combine the building simulation tools with microclimatic models targeting to improve the accuracy of the energy requirements' calculations.

Section 2 provides a description of the methodology while Section 3 includes a short description of the case study. Section 4 describes the BES and microclimatic program analysed in the present research. Section 5 provides the necessary information about the methodology used so that the BES and microclimatic model can exchange information. Section 6 compares the convective heat transfer coefficient (CHTC) results obtained using different models, and provides a thorough discussion. Section 7 summarizes the main the conclusions of this paper.

2. Materials and methods

As mentioned in Section 1 the present paper describes a coupling procedure between BES and microclimatic conditions in order to effectively evaluate the impact of outdoor conditions in the buildings' energy consumption. The key parameter for the coupling procedure is considered to be the CHTC between the exterior building surfaces and the external environment since it can be 3–4 times higher than the radiative heat exchange [13,14].

The CHTC is influenced by several factors, such as the orientation of the building envelope, the geometry of the building and building surroundings, the building surface characteristics, wind speed and wind direction, patterns of the local airflow around the building and surface to air temperature differences [15]. The geometry and position of nearby buildings in urban areas change the airflow patterns around the dwellings under study [16,17], which powerfully influence their CHTC.

There are three main methods of obtaining the values for CHTC: (a) analytical, (b) numerical and (c) experimental [8]. Analytical methods are only valid for specific flow patterns and simple geometries, e.g. flat plates and cylinders [18]. Numerical methods, namely Computational Fluid Dynamics (CFD), are powerful tools to calculate CHTC [19,20]. Experimental methods, both in reduced-scale and full-scale tests, are currently still the main source of CHTC data [21–24].

The procedure followed in the specific research is depicted in Fig. 1 and is described below:

1. A building thermal model is developed using ESP-r [25]. The specific tool is selected for the specific study as it uses airflow networks which enable the calculation of the movement of air masses inside or outside buildings, etc.