NUMERICAL MODELING OF THE URBAN CLIMATE – A PREVIEW ON ENVI-MET 4.0

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Abstract

More than ten years after its first official release and with more than 1500 registered users throughout the world the microclimate model ENVI-met is undergoing a huge overhaul in the upcoming Version 4.0. The major changes include a whole new 3d editor, an upgraded calculation of wall temperatures and radiation as well as the possibility to define the diurnal variation of the meteorological boundary conditions of the model area.

Key words: ENVI-met, microclimate simulation

1 INTRODUCTION

The three-dimensional microclimate model ENVI-met (Bruse and Fleer, 1998) is used in the fields of urban climatology, urban planning, architecture, building design and has attracted more than 1500 registered users since its first public release in 1998.
Version 4.0 of ENVI-met is planned to be released in early 2010 and is going to include a few major improvements from which some of them will be presented in this paper.

2 NEW FEATURES IN ENVI-met 4.0

2.1 Full 3D editor

ENVI-met up to version 3.1 uses an extruded 2.5D format for constructing and saving the model area. Here, 2.5D means, that for each grid cell, only one upper and one lower z boundary value for a building or plant can be set. This format has the advantage that the model area can be saved as a simple text file which can, to some degree, be read and edited in any text editor, but does not allow more complicated buildings to be constructed in the editor. Furthermore this format lacks the possibility to include information about the physical properties of the facades in a specific grid cell. Up to now, these properties can only be defined for the whole area.
The format in which the model area is constructed and saved in ENVI-met 4.0 is the full 3D format. This does not only give the user more freedom when designing buildings, but also allows to specify the physical properties of each façade element individually. The Editor of ENVI-met has been largely rebuilt for this purpose and now features a real 3D mode which is based on OpenGL and allows the user to view and work in his model area from every possible angle.

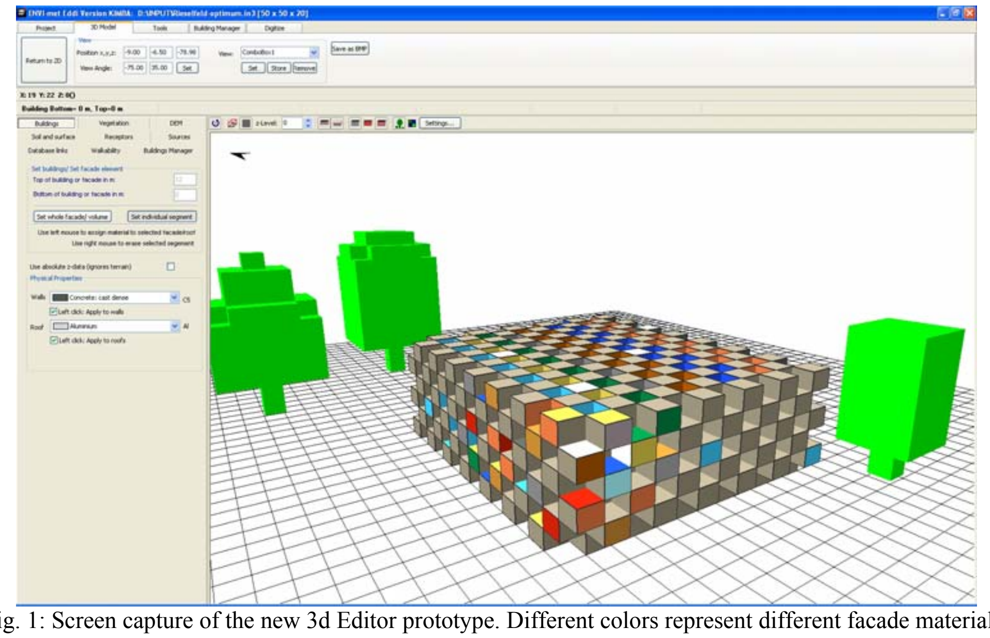

Fig. 1: Screen capture of the new 3d Editor prototype. Different colors represent different facade materials.

2.2 Advanced calculation of façade temperature and wall energy balance

As prior versions do not take into account the heat capacity of facades, the calculation of the surface temperature of facades has been completely rewritten for the 4.0 version of ENVI-met.
The new calculation of façade surface temperature is based on a 3-node transient state model motivated by the work of Terjung, and O' Rourke (1980). The physical properties of the wall and the façade included in the calculation are: reflectivity, absorption, transmission, emissivity, heat transfer coefficient, specific heat capacity and the thickness of the wall.

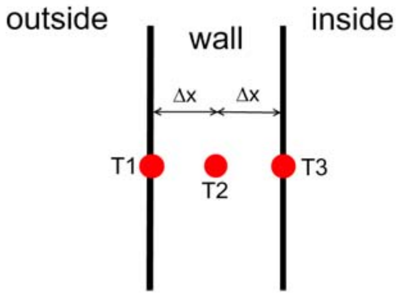

Fig. 2: Schematic of three node model

The energy balance of the outer façade surface can be written as

$$Q_{sw,net}^{abs} + Q_{lw,net}^{abs} - \varepsilon\sigma T_{1,2}^4 + h_{c,o}(T_{air} - T_1^*) + \frac{\lambda}{\Delta x}(T_2^* - T_1^*) = \frac{c_{wall}\rho\Delta x}{2\Delta t}(T_1^* - T_1)$$

with $Q_{sw,net}^{abs}$ and $Q_{lw,net}^{abs}$ being the absorbed incoming short wave and long wave radiation [W], ε the emissivity [%], σ the Stefan-Boltzman constant, $h_{c,o}$ is the convection coefficient for the outside wall [W/(m²K)], λ the heat transfer coefficient [W/(mK)], Δx the distance between two nodes [m], c_{wall} heat capacity of the wall [J/(kgK)], $T_n^{(*)}$ the temperature at node n at present (T_n) or future (T_n^*) time step.

With the Fourier Equation

$$\frac{\delta T}{\delta t} = \frac{\lambda}{c_{wall}\rho}\frac{\delta^2 T}{\delta x^2}$$

the energy fluxes at the node in the center of the wall can be summed up as

$$(P+2)T_2^* - T_3^* = PT_2 + T_1^*$$

with $P = \frac{\Delta x^2 c_{wall}\rho}{\lambda\Delta t}$.

For the node at the inside of the wall the energy balance sums up to

$$-T_2^* + (\frac{P}{2} + \frac{h_c\Delta x}{\lambda} + 1)T_3^* = \frac{P}{2}T_3 + \frac{h_{c,i}\Delta x}{\lambda}T_i$$

with $h_{c,i}$ as the heat convection coefficient at the inside (7.7W/(m²K)).

Heat fluxes parallel to the surface are not taken into account and each façade element can – at the moment - only consist of one material, i.e. it is not possible to explicitly model the thermal behavior of walls consisting of more several layers. As the database can easily be edited it allows the user to freely adjust the walls according to his wishes.

The new calculation method also allows a rough estimation of the energy balance (heating/ cooling load), respectively the development of the temperature within single buildings. For these calculations the buildings are treated as empty volumes of air. Neither the heat capacity of elements within the building nor the internal heat fluxes are regarded for this purpose.

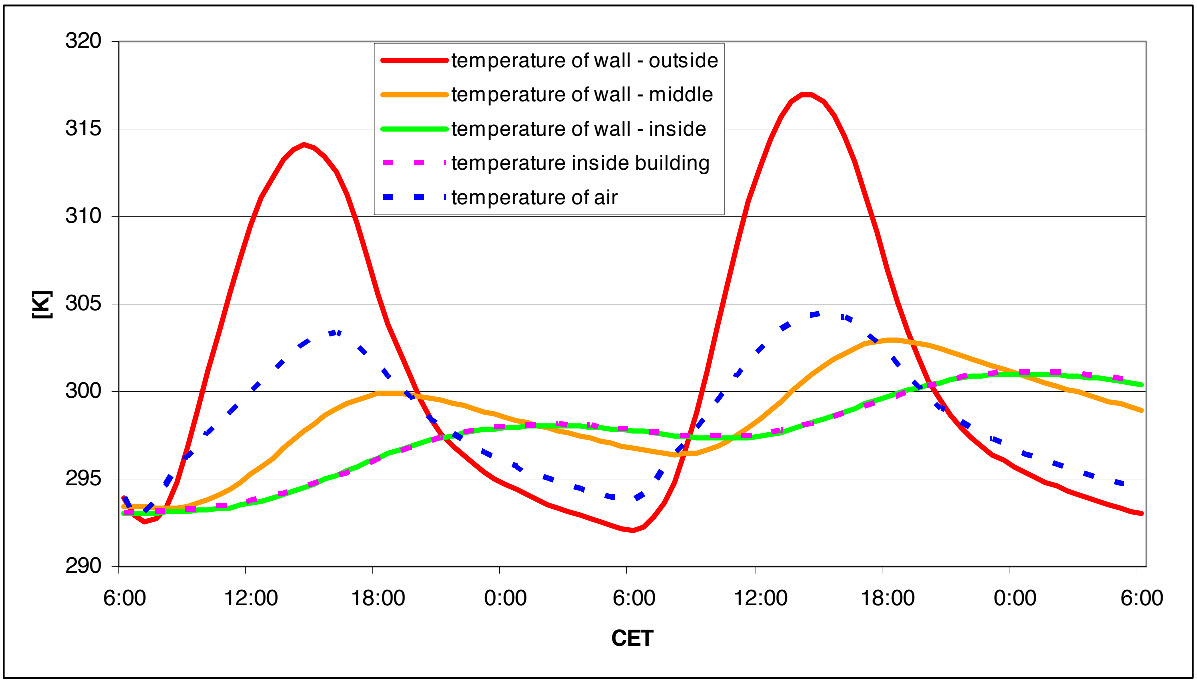

Fig. 3: Development of the temperatures of the three nodes of the facade model and the air temperature inside and in front of the building within 48 hours (summer day in central Europe)

2.3 Forcing

In prior versions of ENVI-met the atmospheric boundary conditions of the simulation could only be adjusted by setting some initialization values from which ENVI-met deduces directly (incoming radiation) or indirectly (wind speed, air temperature, humidity) the diurnal variation of the boundary conditions of the simulation.

This approach facilitates the use of ENVI-met for beginners and non scientists but allows only very limited influence on the development of the boundary conditions, on which the results of a micro scale model strongly depend. As of Version 4.0 of ENVI-met, it is now possible to define the diurnal variation of the atmospheric boundary conditions and the incoming radiation. This allows a much better comparison between measurements and simulations of ENVI-met which were run with the according boundary conditions. It also allows developing much more detailed weather scenarios for testing purposes.

The forcing feature of ENVI-met has been tested within the course of the KLIMES project (www.klimes-bmbf.de) and has been found to produce results that are in good accordance with measurements.

3 CONCLUSIONS

With Version 4.0 the micro climate simulation ENVI-met makes a huge step forward in terms of accuracy and realism of the simulations. Due to the new 3D format there are no longer any limits to the architecturally detailed reproduction of the model area. Each façade element can be attributed with its own physical properties and the new calculation of the wall temperatures allow a much more detailed and realistic simulation of the urban micro climate. The implementation of Forcing, i.e. user defined diurnal variation of the boundary conditions, finally allows a realistic comparison between measurements and simulations and facilitates to simulate specific scenarios, e.g. the impact of climate change on the simulation area.

References

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