

ENVI-MET

principi fisici della modellazione del comfort outdoor

Kristian Fabbri - 13 Novembre 2015



Homepage del software



Headquarter

Accesso veloce alla homepage del software e cabina di pilotaggio della modellazione



Leonardo 2014

Analizza I tuoi risultati e crea una mappa 2D e 3D



Spaces

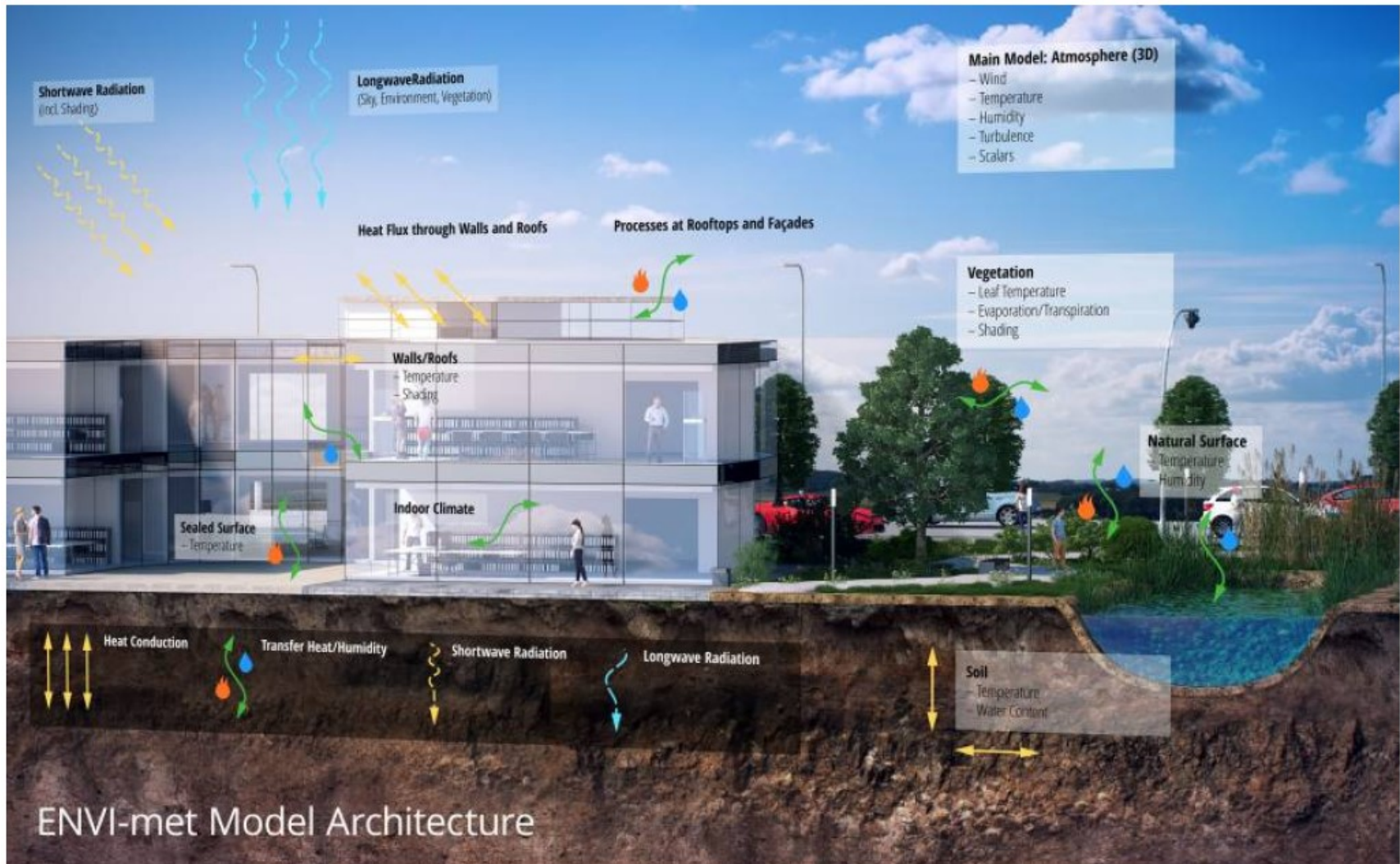
Disegna il tuo progetto e l'ambiente



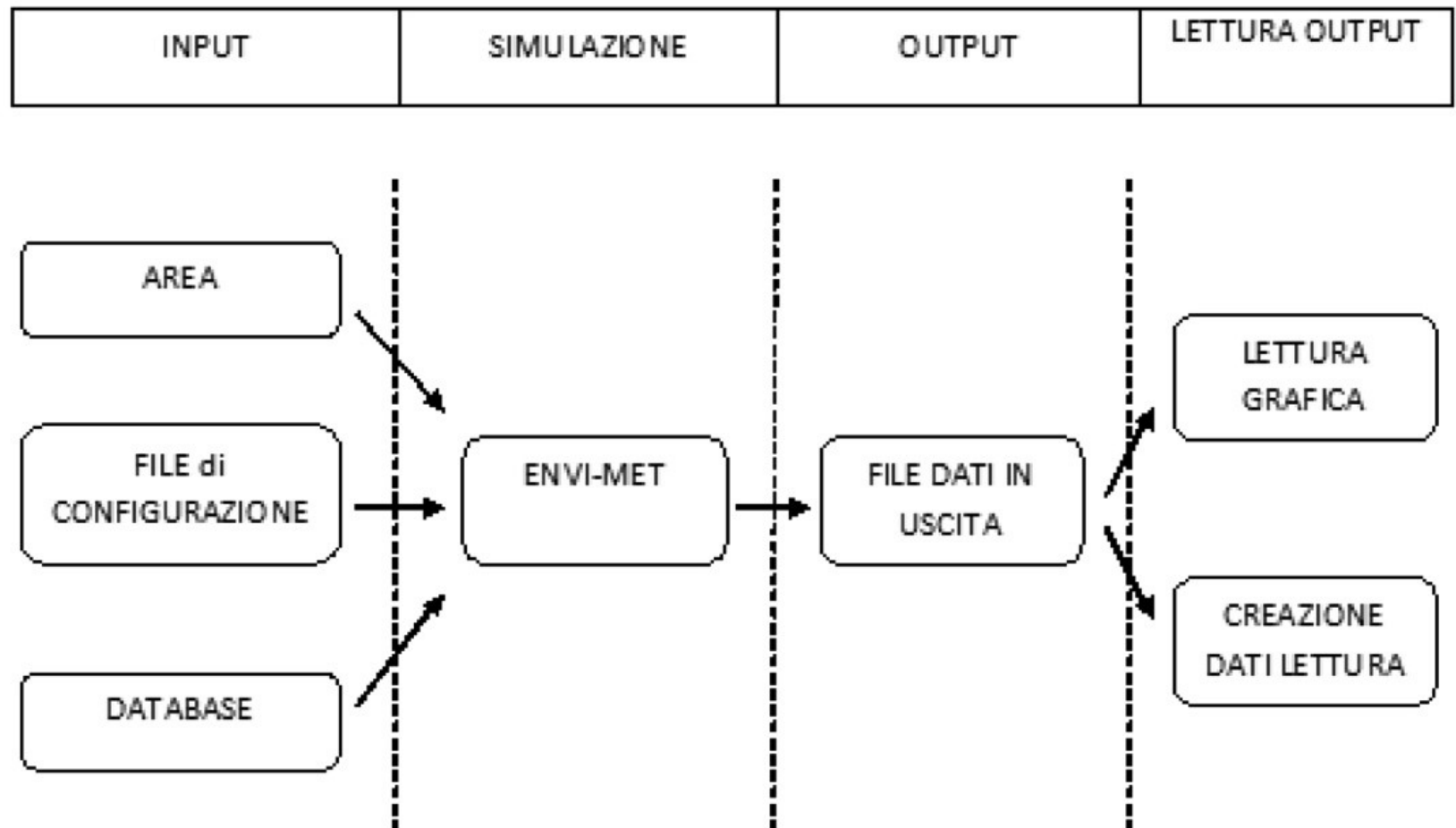
BioMet

Sistema di processo per i file di out put per calcolare PMV/PPD, PET o UTCI

Comfort: Modellazione e progetto architettonico-urbanistico



Struttura del software



Equazioni

Boundary conditions: A *no-slip* condition is used for all solid surfaces. The inflow profile is obtained from the one-dimensional reference model and a zero-gradient Neumann condition is used at the outflow and lateral boundaries. At the top boundary all vertical motions are assumed to be zero. Special boundary conditions are used for the pressure perturbation on all outflow boundaries to keep the model mass conserving.

Temperature and Humidity

The distribution of the air temperature θ and specific humidity q is given by the combined advection diffusion equation with internal source/sinks

Atmospheric turbulence

Turbulence is produced when the air flow is sheared at building walls or vegetation elements. Under windy conditions, the magnitude of local turbulence production normally surpasses its dissipation, so that turbulent eddies are transported by the mean air flow. Depending on the structure of the flow, this leads to an increased turbulence away from the original source of disturbance. *To simulate this effect, a so-called 1.5 order turbulence closure model is used in ENVI-met. Based on the work of Mellor and Yamada (1975) two additional prognostic variables, the local turbulence (E) and its dissipation rate (Σ) are added to the model.*

$$\frac{\partial u}{\partial t} + u_i \frac{\partial u}{\partial x_i} = -\frac{\partial p}{\partial x} + K_m \left(\frac{\partial^2 u}{\partial x_i^2} \right) + f(v - v_g) - S_u$$

$$\frac{\partial v}{\partial t} + u_i \frac{\partial v}{\partial x_i} = -\frac{\partial p}{\partial y} + K_m \left(\frac{\partial^2 v}{\partial x_i^2} \right) - f(u - u_g) - S_v$$

$$\frac{\partial w}{\partial t} + u_i \frac{\partial w}{\partial x_i} = -\frac{\partial p}{\partial z} + K_m \left(\frac{\partial^2 w}{\partial x_i^2} \right) + g \frac{\theta(z)}{\theta_{ref}(z)} - S_w$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial \theta}{\partial t} + u_i \frac{\partial \theta}{\partial x_i} = K_h \left(\frac{\partial^2 \theta}{\partial x_i^2} \right) + \frac{1}{c_p \rho} \frac{\partial R_{n,lw}}{\partial z} + Q_h$$

$$\frac{\partial q}{\partial t} + u_i \frac{\partial q}{\partial x_i} = K_q \left(\frac{\partial^2 q}{\partial x_i^2} \right) + Q_q$$

La modellazione della vegetazione

La vegetazione viene trattata come una colonna mono dimensionale con altezza Z_p nella La vegetazione è trattata come una colonna monodimensionale di altezza z_p in cui il profilo della densità d'area delle foglie (LAD) è usato per descrivere la densità e la distribuzione delle foglie.

Lo stesso concetto è usato, all'interno del suolo, fino ad una profondità $-z_r$, per descrivere la distribuzione delle radici, attraverso il RAD (Root Area Density).

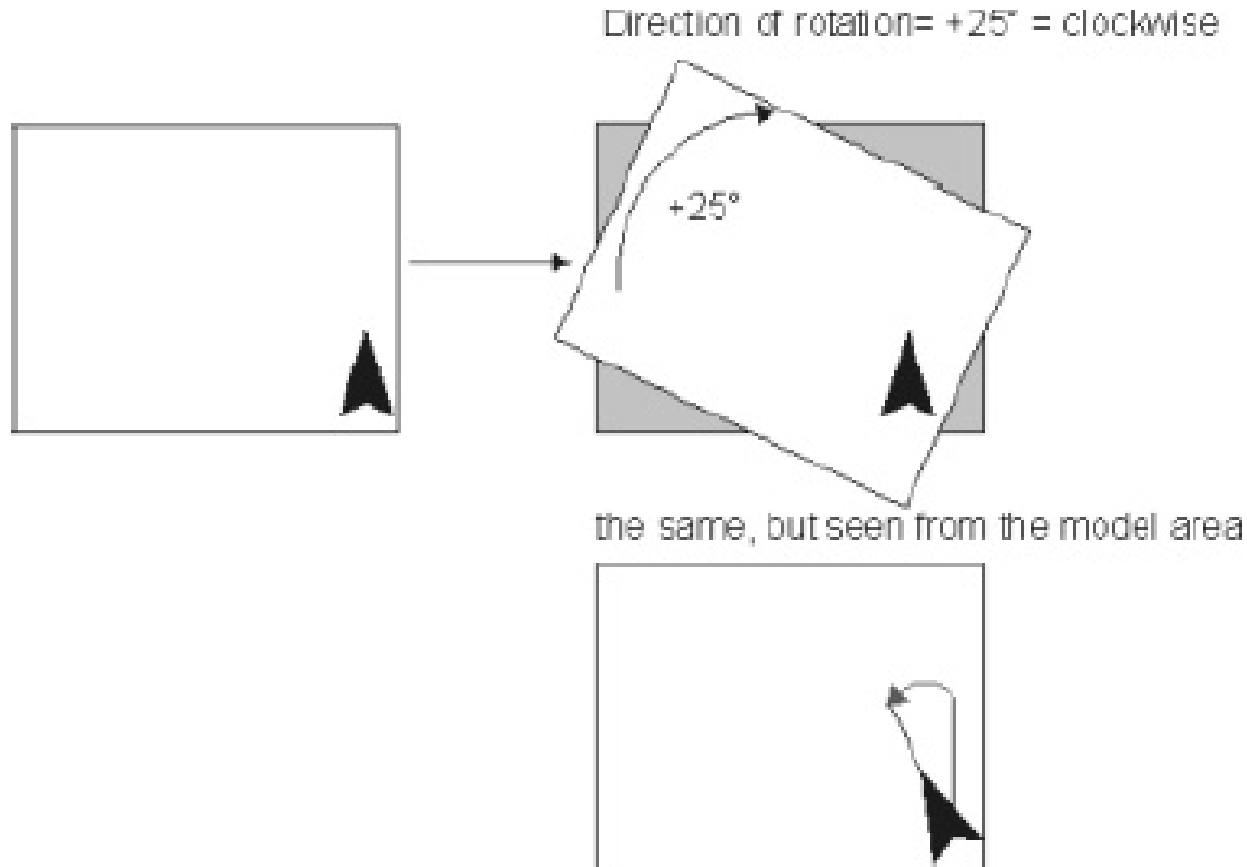
Questo schema universale può essere applicato sia alle piante ad alto fusto, sia ai cespugli, sia all'erba, semplicemente associando ad ogni tipo di pianta i proprio valori di z_p e z_r .

Dominio computazionale e la struttura della griglia

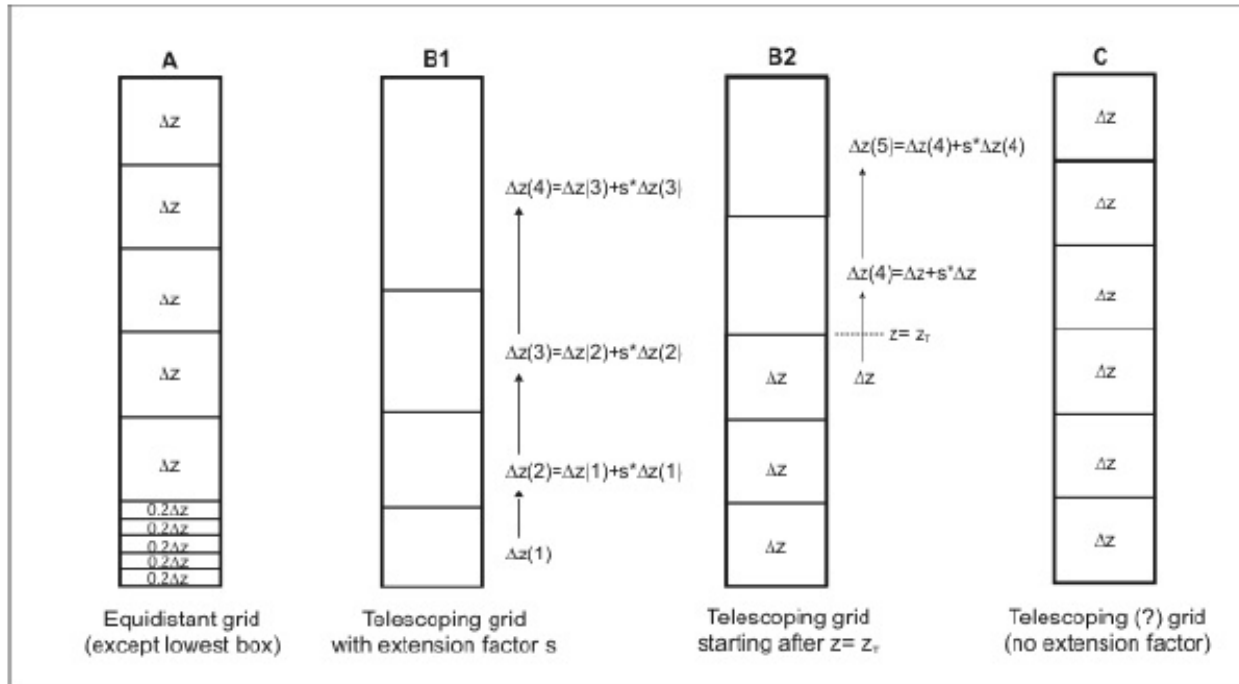
A seconda del problema, la dimensione totale del modello tridimensionale X, Y e Z, nonché la risoluzione della griglia può essere selezionata entro un ampio intervallo. Per impostazione predefinita, la spaziatura Δx , Δy e Δz è equidistante in ogni direzione (solo la cella più bassa al di sopra del suolo è normalmente suddivisa in 5 sotto-cellule con il formato $\Delta z_g = 0.2\Delta z$ per aumentare la precisione nel processo di calcolo della superficie).

Il modello tridimensionale è annidato in un modello unidimensionale che si estende fino a 2500 m altezza. I valori di un modello tridimensionale sono utilizzati come valori di riferimento come anche i profili di afflusso e le condizioni al contorno per il modello tridimensionale.

Rotazione del modello



Griglia verticale



Different concepts for organizing the vertical grid layout: (A): Equidistant Grid, (B): Telescoping grid and (C): Telescoping grid with no extension factor

Nei modelli 3D completi la griglia verticale è fissata una volta creato il modello. L'unico modo per cambiarla è di convertire il modello verso il basso per un modello 2.5D (e perdere tutte le informazioni del 3D), modificare le impostazioni di rete e poi ri-convertirlo in 3D. In breve, quando si crea un modello 3D si dovrebbe pensare alla messa a punto della griglia verticale in dettaglio PRIMA di iniziare a modificare il modello.

La modellazione della turbolenza

Si basa su due variabili: la turbolenza locale (E) e il suo tasso di dissipazione (ϵ).

L'energia cinetica in questo caso rappresenta una misura dell'intensità delle turbolenze dell'aria; essa risulta direttamente legata al trasporto locale di calore e umidità.

Il sistema implementato è di due equazioni di cui la prima descrive la distribuzione di energia cinetica nell'aria in funzione della produzione dei moti convettivi e la seconda esprime la dissipazione dell'energia stessa.

$$\begin{aligned} \frac{\partial E}{\partial t} + u \frac{\partial E}{\partial x} + v \frac{\partial E}{\partial y} + w \frac{\partial E}{\partial z} = & \\ & \frac{\partial}{\partial x} \left(K_E \frac{\partial E}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_E \frac{\partial E}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_E \frac{\partial E}{\partial z} \right) \\ & + K_m \left\{ 2 \left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right)^2 + 2 \left(\frac{\partial v}{\partial y} \right)^2 \right. \\ & \left. + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right)^2 + 2 \left(\frac{\partial w}{\partial z} \right)^2 \right\} - \frac{g}{\theta} K_h \frac{\partial \theta}{\partial z} + Q_E(x, y, z) - \epsilon \end{aligned}$$

on is similar but describes the Dissipation Rate of TKE (ϵ or eps):

$$\begin{aligned} \frac{\partial \epsilon}{\partial t} + u \frac{\partial \epsilon}{\partial x} + v \frac{\partial \epsilon}{\partial y} + w \frac{\partial \epsilon}{\partial z} = & \frac{\partial}{\partial x} \left(K_\epsilon \frac{\partial \epsilon}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_\epsilon \frac{\partial \epsilon}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_\epsilon \frac{\partial \epsilon}{\partial z} \right) \\ & + c_{1\epsilon} \frac{\epsilon}{E} K_m \left\{ 2 \left(\frac{\partial u}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right)^2 + 2 \left(\frac{\partial v}{\partial y} \right)^2 \right. \\ & \left. + 2 \left(\frac{\partial v}{\partial y} \right)^2 + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} \right)^2 + 2 \left(\frac{\partial w}{\partial z} \right)^2 \right\} \\ & - c_{3\epsilon} \frac{\epsilon}{E} \cdot \frac{g}{\theta} K_h \frac{\partial \theta}{\partial z} - c_{2\epsilon} \frac{\epsilon^2}{E} + Q_\epsilon(x, y, z) \end{aligned}$$

La nesting grid

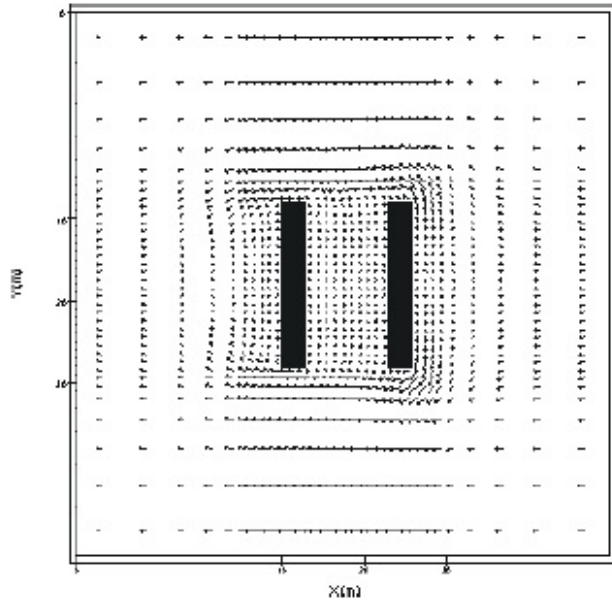


Figure B: (Better) Flow around two Buildings with 5 Nesting Grids

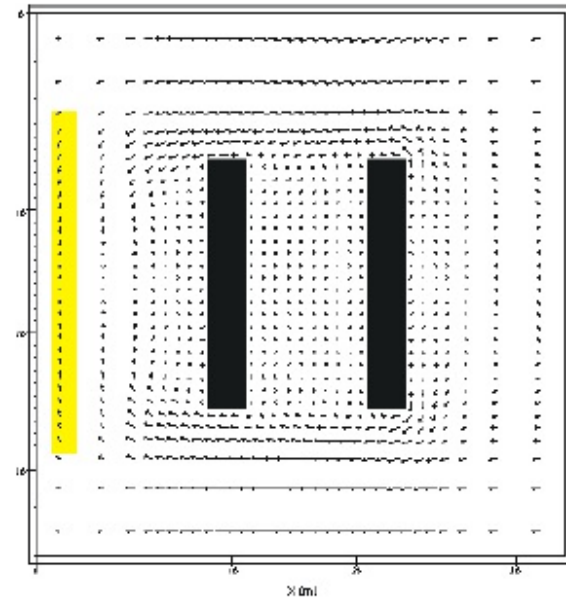


Figure A - Flow around two Buildings with 3 Nesting Grids

The Role of Nesting Grids

The only difference between example A and B is that in (A) we have used only 3 nesting grid cells around the core domain whereas in (B) 5 of them are used. As the grid size of the nesting grids is increasing with each grid, the area is extending very fast with each extra Nesting Grid. The Remember: The Gesting Grids are not included in the Output Files by default, so you will not be able to see troubles there. To see the complete model area, you must include the nesting grids in the Output Files

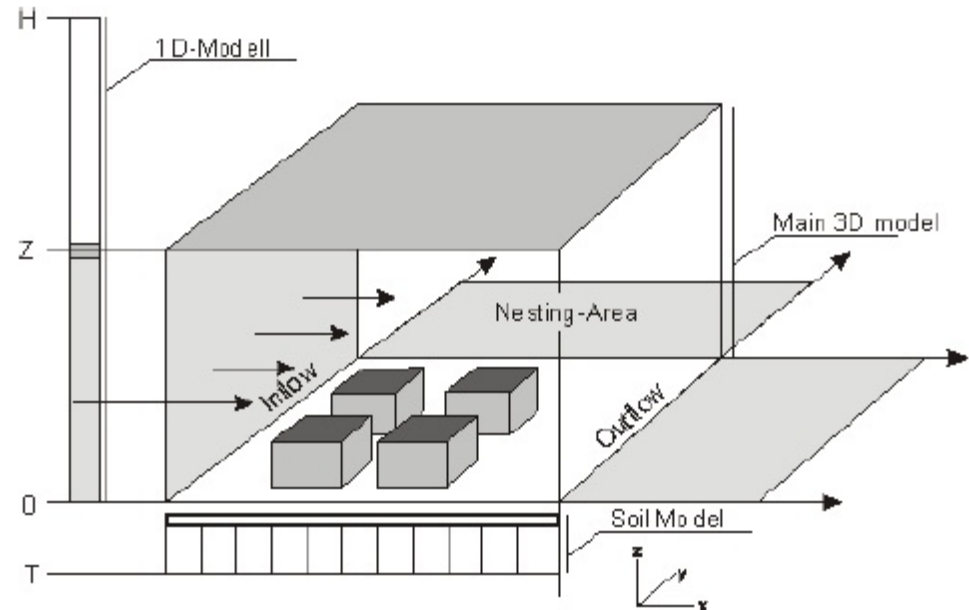
Layout di Envi - met

Basic Layout of ENVI-met

The sketch above aims to give you an impression over the very basic structure of a microclimate model like ENVI-met.

The general design is not only specific to ENVI-met but is used by almost all 3D numerical models.

The Main Model is designed in 3D with 2 horizontal dimensions (x and y) and one vertical dimension (z). Inside this main model, the typical elements that represent the area of interest are placed: buildings, vegetation, different types of surfaces. To use a numerical model, the area of interest must be reduced into grid cells. The smaller one single grid cell is, the finer the resolution of the model is. On the other hand, making the grid cells small means that more cells are needed to cover a certain area.



For example, a 100 x 100 m area can be organised in 100 x 100 grid cells of 1 x 1 m each or it can be organised in 20 x 20 grid cells with 5 x 5 m each. For each simulation, a compromise has to be found between the accuracy and resolution of the model and the number of treatable grid cells. As a rule of thumb, reaching 250 x 250 x 30 grid cells (or any other combination such as 120 x 80 x 30,...) can be considered as a large model needing a good amount of CPU time.

L'altezza del modello

Total Model Height

What is the Minimum Model Height?

Selecting the correct size of the model domain is a central aspect in successful numerical modelling.

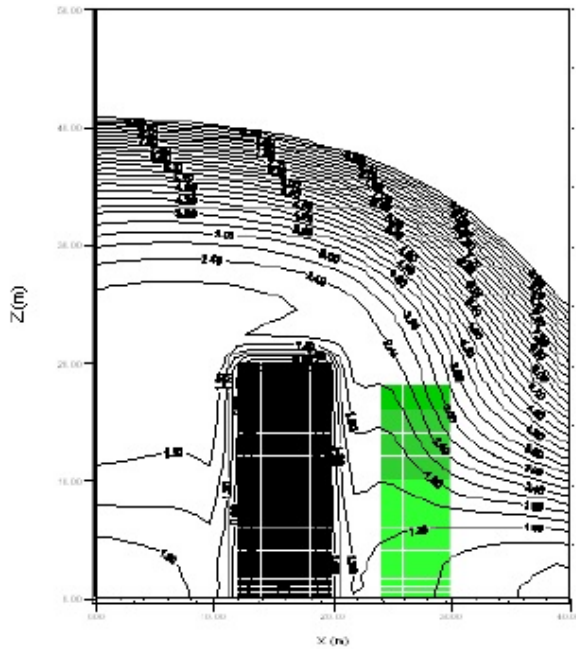
Whereas the horizontal dimension is more or less given by the dimension of your subject of interest, the vertical height of the model is less obvious and can - if not selected properly - cause major problems.

The height of the 3D model is a result of the number of vertical grid points used as defined in the Area Input File and grid size plus the method of grid creation (see also Model Layout).

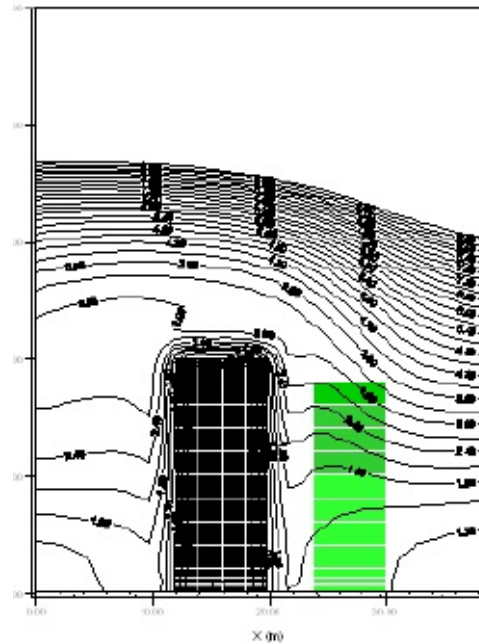
A simple Example: If you have a 30 m building in your model and you choose to have 10 grids with a grid size of 2 m each, the total model height will be 20 m, or, in other words, your building will look 10 m out of the model domain. This is, of course, not acceptable.

Boundary layer

Lateral boundary conditions (LBC) define the way, the model behaves at its lateral boundaries. This is a very specific setting and you normally do not need to change these settings.

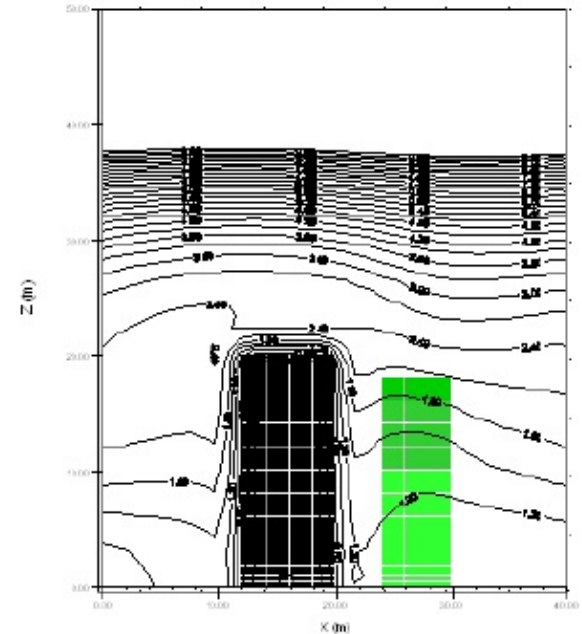


Km distribution for forced/closed LBC



Km distribution for open LBC

low boundary is now more similar to the



Km distribution for cyclic LBC

From Version 4 on, it is recommended to use at least the “Simple Forcing” option for temperature and humidity. This overcomes almost all problems that have been observed with the lateral boundaries in the former versions.

Instabilità – errori numerici

The problem...

In complex Model Areas (and sometimes even in configurations you consider as being “simple”) you might experience numerical instabilities from time to time. *These instabilities appear as “PANICDumps”*

(if ENVI-met has detected that something went wrong) or simply as error messages or crashes of the model. The most frequent error message are “Division by Zero” or “Floating Point Error”.

These messages do not contain any useful information except of the general message, that something went wrong. In fact, *“Division by Zero” is most of the times only the end point of a long chain of problems producing very high or very low (and very wrong) numbers.*

Why is it like that...

First of all, remember that you are working with a very complex numerical model.

There is a conceptual difference between error messages you might get from, say, a text-processing program, and those you get from ENVI-met. Error messages (and the numerical problems which cause these messages) are inseparably connected with the whole process of numerical modelling.

If it would be possible to construct any Model Area and get guaranteed results, numerical modelling would no longer be an advanced technology ;). In other words: *When you decide to use non-linear models like ENVI-met, you must be prepared that things are not always running as you would like them to run.* Sometimes models run on the edge of numerical stability and a complex configuration might cause that they fall over this edge and send you an error message.

Running

Running ENVI-met

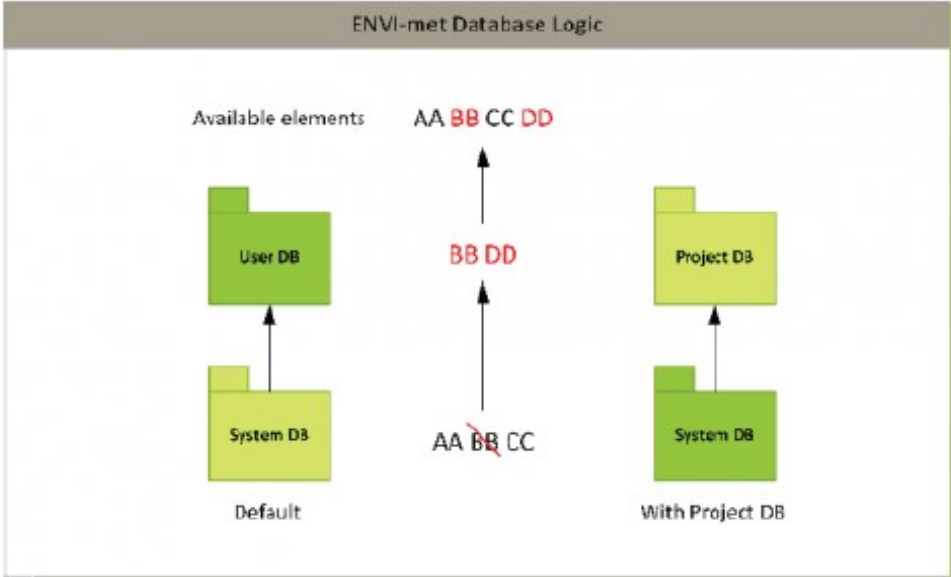
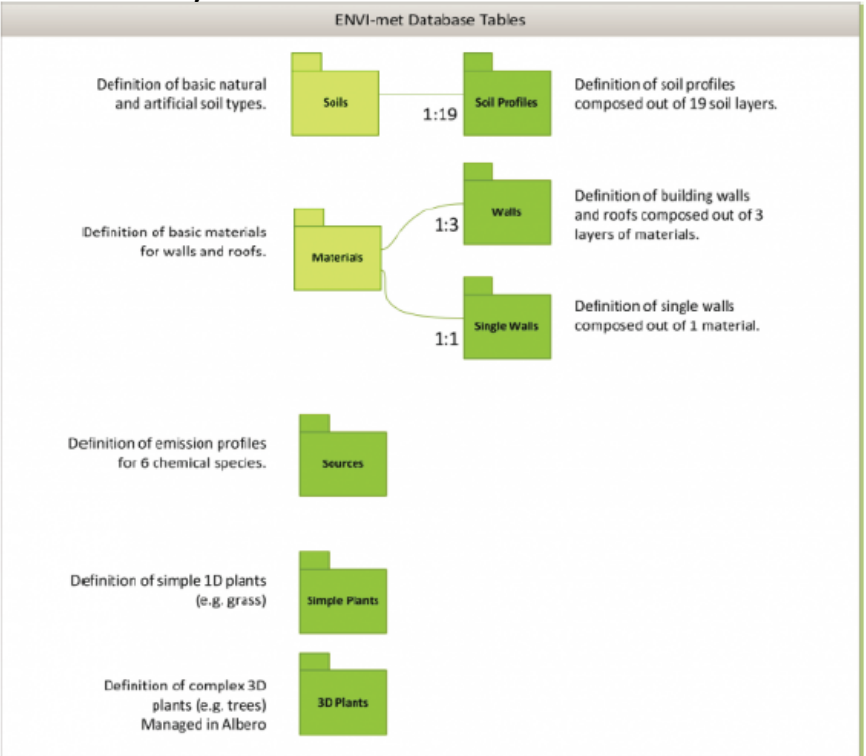
The user friendly interface of ENVI-met sometimes makes people forget that they work with a sophisticated climate simulation system. Normally, these kind of numerical models can only be run on complex and extremely expensive supercomputers.

In more than 20 years of ENVI-met development, we have invented various technologies to bring the scientific power of physical climate simulation models to your desktop. ENVI-met uses a complex system of optimized algorithms and intelligent troubleshooting allowing you to run dynamical 3D microclimate simulations on an arbitrary standard PC bought anywhere on the world running MS WINDOWS.

However, installing the software on your PC is the smallest step in using ENVI-met for microclimate analysis...

Database

Besides the two basic files needed for each simulation, the Area Input File .INX and the Simulation file .SIMX, ENVI-met needs to know a lot of additional information about different items used in your model such as surfaces types, soils, plants or emission sources in the model. These data are not stored in the Area Input file itself (exception: Packages), but in a database system.



Logic of merging database items

Each database entry is defined by a unique key, which has to be a two-sign alphanumeric ID in ENVI-met (e.g. "a0"). Any reference to a database entry, may it be in an Area Input file or some other table of the database is given by using this ID.

Il modello numerico 3D

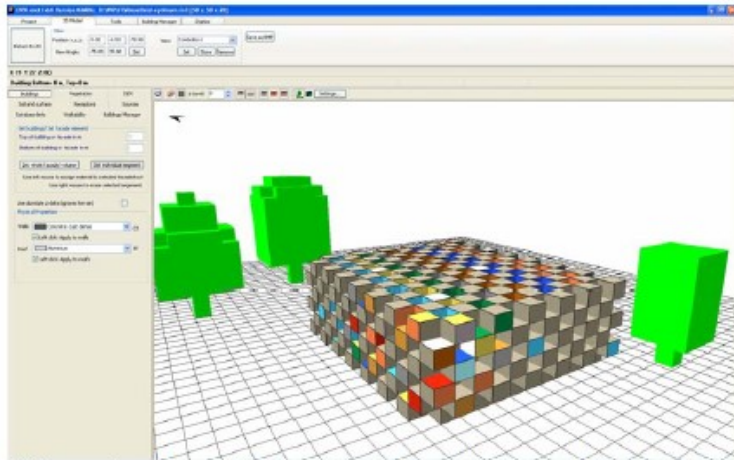


Fig. 1: Screen capture of the new 3d Editor prototype. Different colors represent different façade materials.

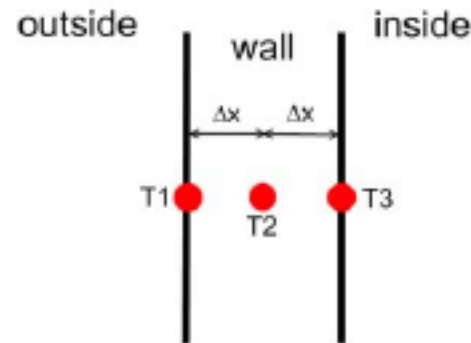


Fig. 2: Schematic of three node model

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.

Il modello numerico 3D

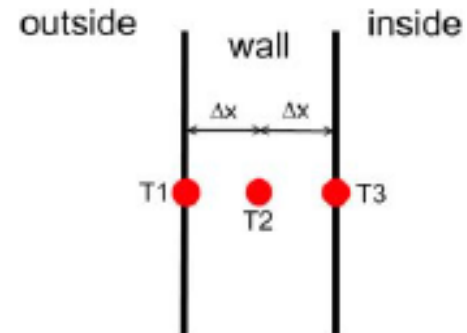


Fig. 2: Schematic of three node model

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

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

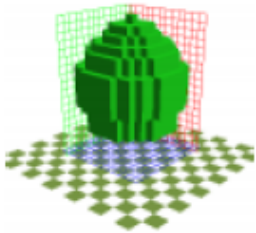
with $P = \frac{\Delta x^2 c_{wall} \rho}{\lambda \Delta t}$.

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

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

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

Cosa si può modellare con ENVI-MET – Vegetazione e Alberature



3D Plant Geometry

ENVI-met supports simple vertical plants such as grass or corn, but also allows complex 3D vegetation geometries like large trees. All plants are treated as individual species with an

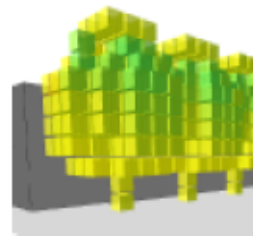
integrated water balance control and heat and water stress reaction concept.



Vegetation water supply

Plants are living organisms and will only contribute in positive way to the local microclimate, if enough water is available in the soil within the root zone. Together with the simulation of the soil

water content and the new sophisticated 3D root model, the dynamic water supply of the plant and the resulting water extraction from the soil can be calculated.



Foliage temperature

The temperature of the leafs is calculated by solving the energy balance of the leaf surface with respect to the actual meteorological and plant physiological conditions for each grid box of the plant

canopy. The health status of the plant and the water supply by the soil regulate, beside other factors, the plants transpiration rate and thereby the leaf temperature. ENVI-met uses a sophisticated model to simulate the stomata behaviour of the vegetation in response to microclimate, CO₂ availability and water stress level.

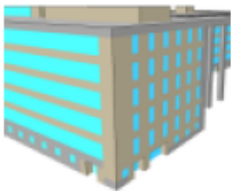
Cosa si può modellare con ENVI-MET – Edificio e involucro



Surface and soil temperature

The surface temperature and the distribution of soil temperature is calculated for natural soils and for artificial seal materials down to a depth of -4m. For each

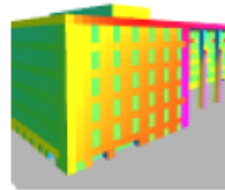
vertical grid layer a different soil or sealing material can be chosen in order to simulate different soils structures. The heat conductivity of natural soils is calculated with respect to the actual soil water content.



Detailed building materials

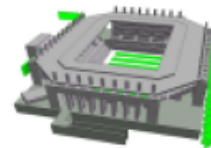
In Detailed Design Mode, ENVI-met allows to assign individual wall types to each wall and roof surface. The wall types can be composed out of 3 layers of different materials with individual

physical properties such as solar radiation transmission, heat capacity or heat conductivity. The different wall and roof materials can be designed graphically using the Database Manager.



Each wall and roof segment in ENVI-met is represented by its own thermodynamical model consisting of 7 prognostic calculation nodes. The temperature of the outside node is updated continuously with respect to the meteorological variables

at the facade and the thermal state of the buildings and other objects within the view range of the facade/roof element considered. The thermal state of the inner wall nodes is calculated from the physical properties assigned to the wall/roof based on Fourier's law of heat conduction

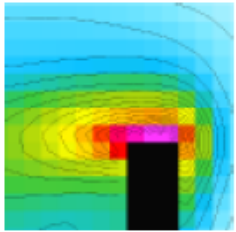


Full 3D building geometry & Single walls

Complex buildings and other structures can be constructed in full 3D with no limitations in complexity as far as the cubic base structure

allows. This allows the simulation of semi-open spaces such as the soccer stadium shown in the icon and in this example. Moreover, ENVI-met Professional allows the usage of single thin walls that can be applied to any grid which can be used to represent spaces which are enclosed by walls but do not behave like a building e.g. bus stop shelters, shading structures...

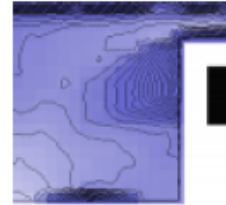
Cosa si può modellare con ENVI-MET – Situazioni specifiche



Turbulence

Turbulence is calculated using the E-epsilon 1.5 order closure ("E-epsilon" or "k-epsilon" model). Two prognostic equations for turbulent energy production (E) and its dissipation (ϵ) are used to

simulate the distribution of turbulent energy. Exchange coefficients (K_x) in the air are calculated using the Prandtl-Kolmogorov relation. For low wind situations, the 1st order mixing length model can be used instead of the E-epsilon model (which often fails in this situations).



Soil water content

Simulating the water balance of the surface and the soil is a crucial aspect in urban microclimatology. While humid soils can act as cooling devices, dry soils are often hotter than asphalt. In

addition, the cooling effect, and -on a longer time perspective- the vitality of vegetation depends on available soil water. ENVI-met dynamically solves the soil hydraulic state of the soil based on Darcy's



Water bodies and ponds

Water bodies are represented as a special type of soil. The calculated processes inside the water include the transmission and absorption of shortwave radiation inside the water. No second energy

balance is used for the ground surface of the water pool, so that heating of shallow systems is lower than under real conditions where the main source of energy is the convection from the water ground surface rather than the absorption of radiation. In addition, no turbulent mixing is included in the model so that the use is restricted to still waters (e.g. lakes).



