Micro-climatology
Introduction to ENVI-Met

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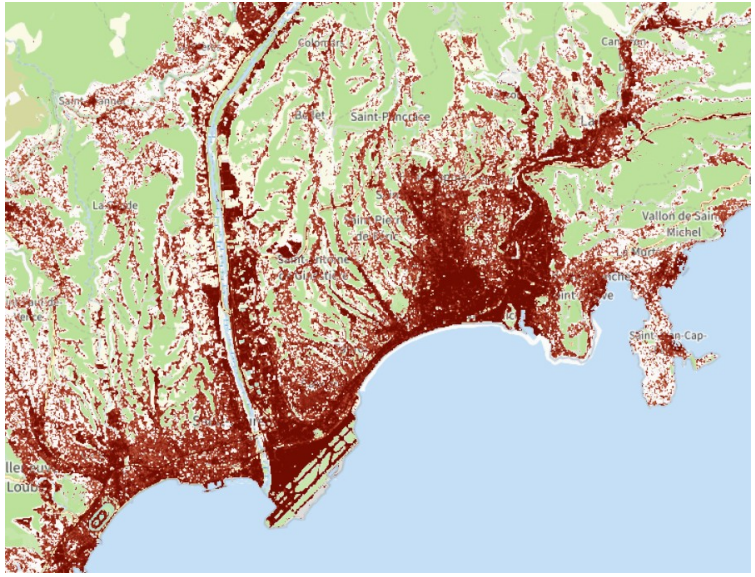
Summary

- Introduction
- Heat Transfer Review
- ENVI-Met

Introduction

- An urban heat island, UHI, occurs when a city experiences much warmer temperatures than nearby rural areas.
- The difference in temperature between urban and less-developed rural areas has to do with how well the surfaces in each environment absorb, hold and release heat.
- So, heat transfer is at the heart of the UHI physics.
- Soil imperviousness also plays a key role.

ENVI-MET



Imperviousness Density 2021
(from Copernicus)

See also for flood impact:

Vallon de la Roquebillière à Cannes

Introduction – Thermal comfort

- Too hot? How is define the thermal comfort?
- Many definitions:
  - NF EN7730 (France)
  - EN ISO7730 (Europe)
  - EN 16798 (Europe) (with buildings performance)
  - EN 15251 (Europe) (with air quality)
  - ASHRAE 55 (North America)
  - GB/T 50785-2012 (China)

Introduction – Thermal comfort

- NF EN7730 (France) & EN ISO7730 (Europe) are similar and based on the Predicted Mean Vote (PVM) model.
- PVM is an index that predicts the average thermal sensation over a large group of people based on:
  - Air temperature
  - Relative humidity
  - Air velocity
  - Mean radiant temperature
  - Clothing insulation level
  - Metabolic rate

COMFORT SCALE ISO-7730	
< -3	Very cold
-3 a - 2	Cold
-2 a -1	Slightly cold
-1 a -0.5	Comfortable cold
-0.5 a 0.5	Comfort
0.5 - 1	Comfortable warm
1 a 2	Slightly warm
2 a 3	Hot
> 3	Very hot

Introduction – Thermal comfort

- PVM is computed by solving the energy balance equation for a human body in a given environment.

$$PMV = \left(0.303\, e^{-0.036 . M} + 0.028\right) . L$$

where M is the metabolic rate (W.m^{-2}) and L the thermal load in (W.m^{-2})

- $L = M - W - \left(C + R + E + K\right)$

with W the mechanical work, C the convective heat loss, R the radiative one, E the evaporative one and K the conductive one.

Center for the Built Environment
CBE Thermal Comfort Tool

Introduction – Thermal comfort

Metabolic rate
(from EN ISO 7730)

For an adult S~1.8m^2 seated:

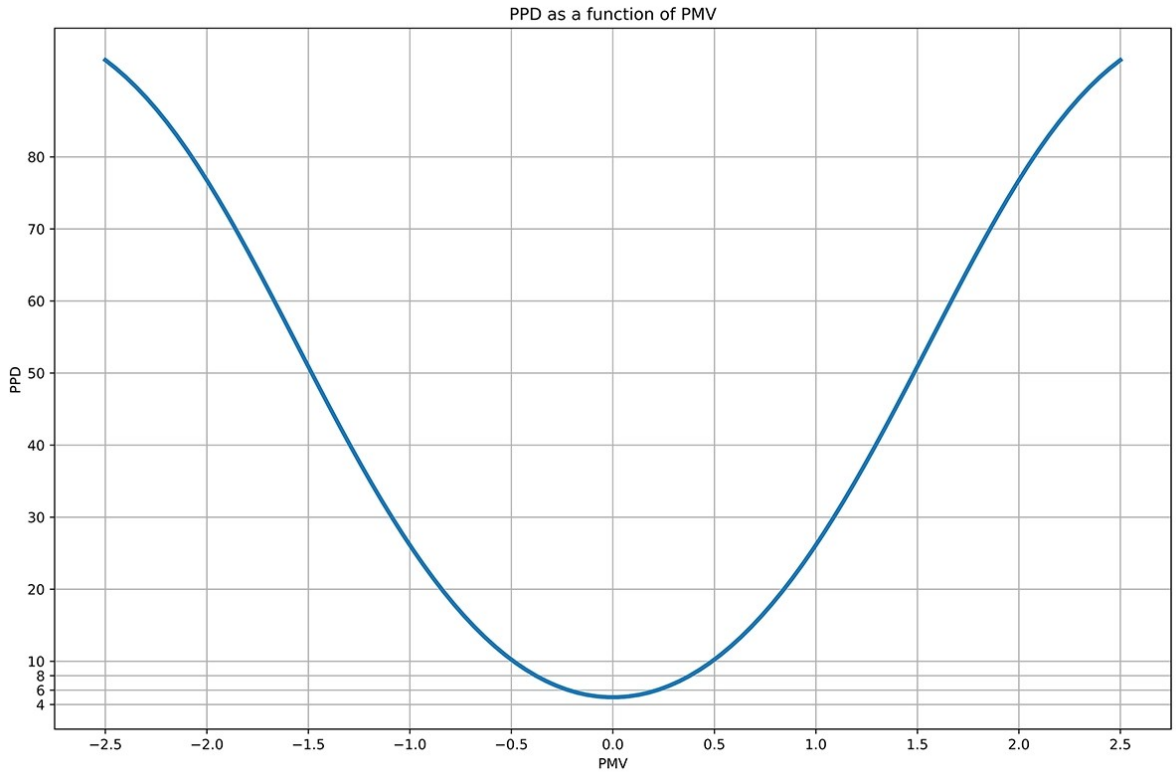
Q=58x1.8 = 104.4 W

Activity	met	W/m^2
Sleeping	0.7	41
Seated, relaxed	1	58
Office work (seated)	1.2	70
Standing, light manual work	1.6	93
Walking slowly (3 km/h)	2	116
Moderate physical work	2.4	140
Intense physical work	3.0+	175+

Introduction – Thermal comfort

- PVM is associated with PPD: Predicted Percentage of Dissatisfied

$$PPD = 100 - 95.e^{-0.03353.PMV^4 - 0.2179.PMV^2}$$



Introduction – Thermal comfort

- Several tools to compute PMV and PPD

Center for the Built Environment
CBE Thermal Comfort Tool

Energy plus
Energy+

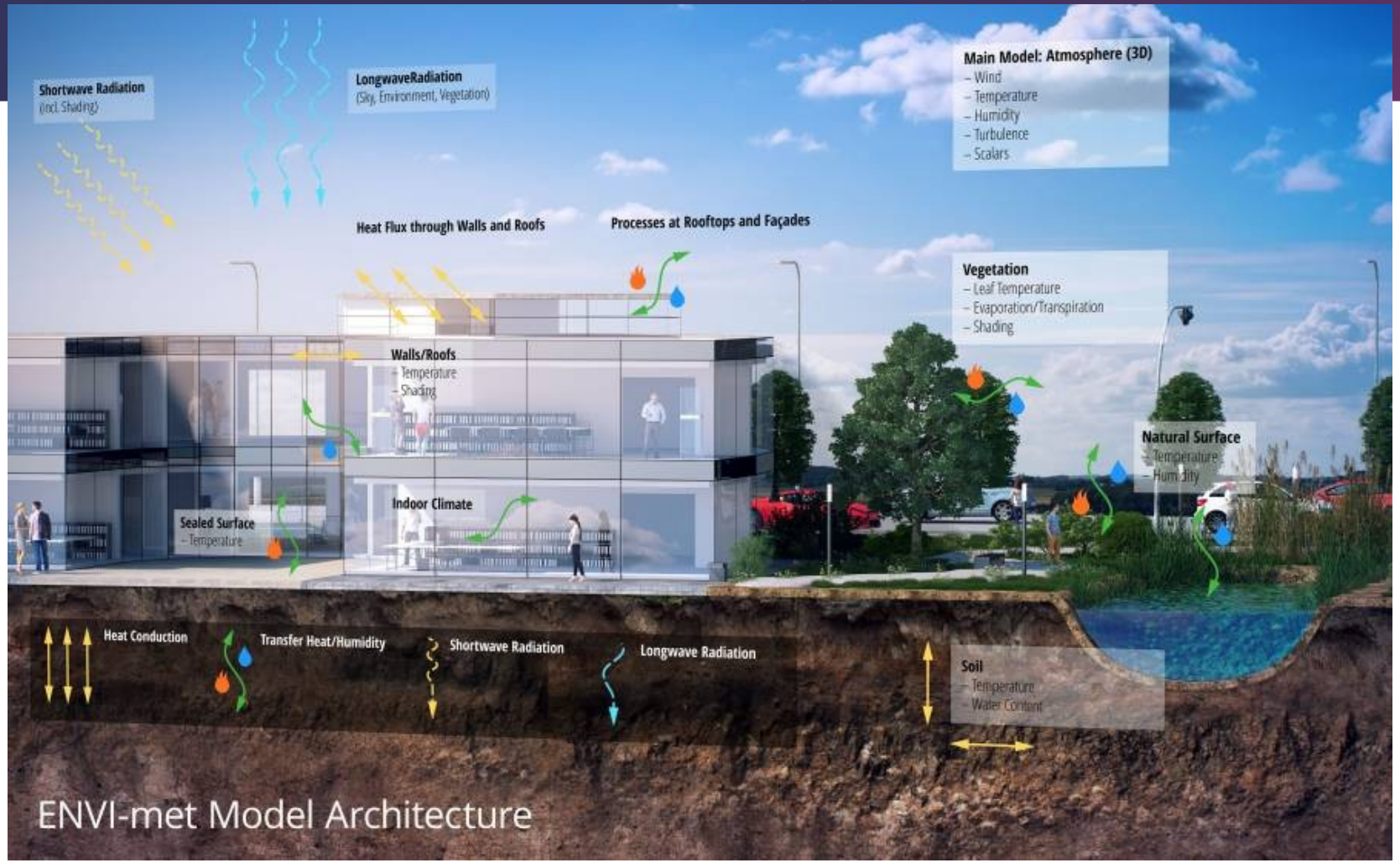
Pythermalcomfort
PyTC

Introduction

- So knowing for given conditions what are the optimal comfort

  the idea is now to ensure that these comfort conditions are met for a given building under given outdoor conditions and to also determine the associated energy cost!
- In order to compute this we need to compute the energy balance for the building.

Introduction – Energy balance



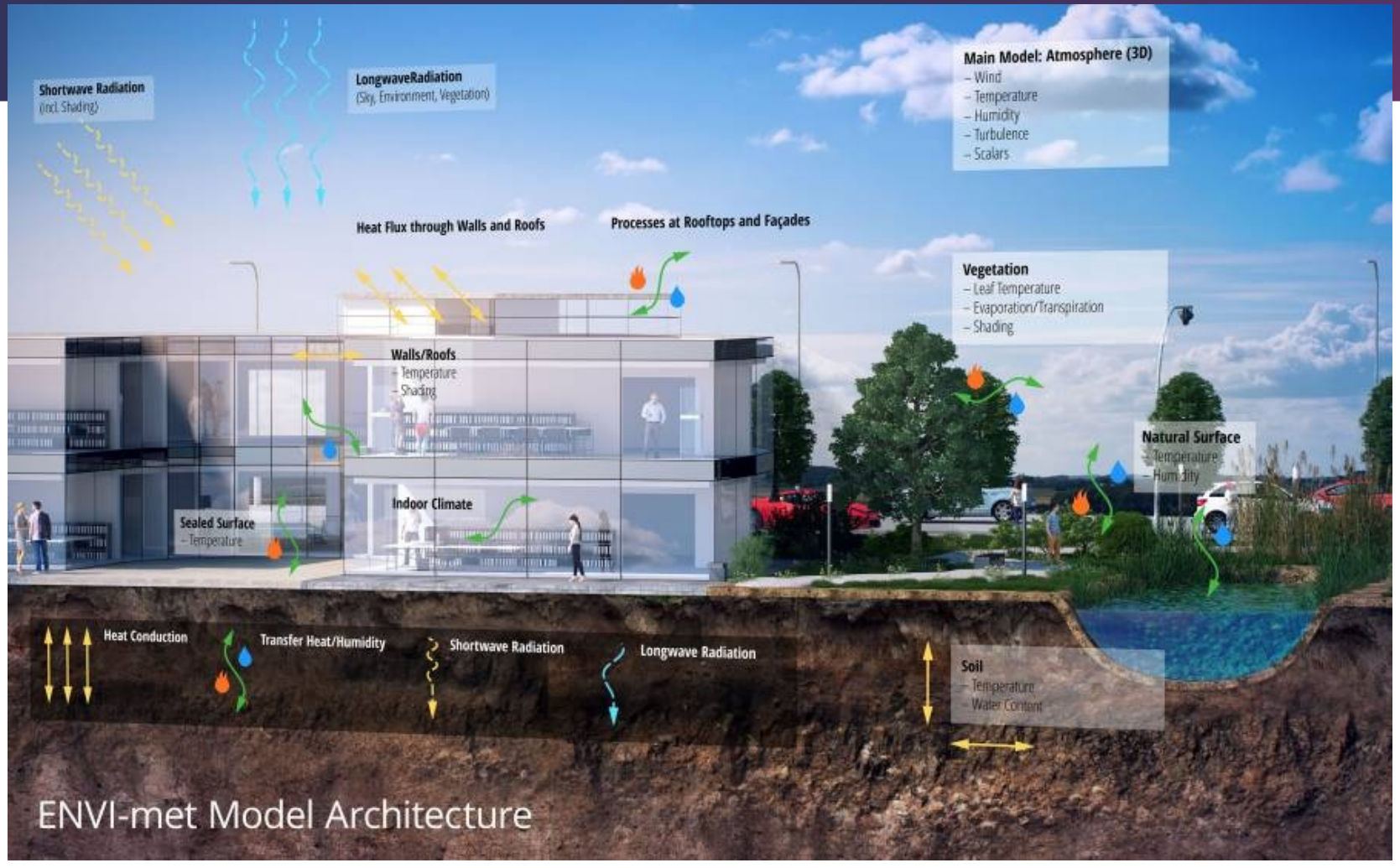
Heat Transfer Review

- Heat is related to energy: it is a form of energy transfer
- What is energy??? Energy is a scalar variable that defines/measures the state of a body (a physical system).
- If the body changes its state, its energy changes!!!
- Energy is stored in different ways:
  - Internal energy: related to the heat capacity of a body
  - Kinetic energy: related to the motion of the body in a given referential
  - Potential energy: related to the position of the body in a conservative force field (gravity or electromagnetic forces)

Heat Transfer Review

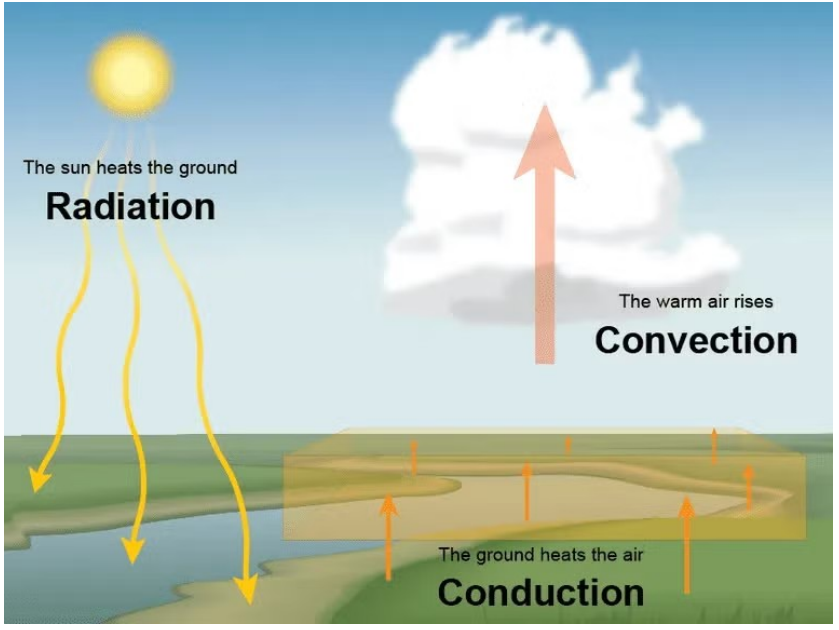
- In thermodynamics the first important concept if the concept of system.
- A thermodynamical system is a material system.
- Its state is described by variables: energy, speed, temperature, ..
- The system is said:
  - Isolated if it does not exchange mass neither energy with its surroundings
  - Closed if it exchanges only energy.
  - Open if it exchanges energy and mass.

Heat Transfer Review



Heat Transfer Review

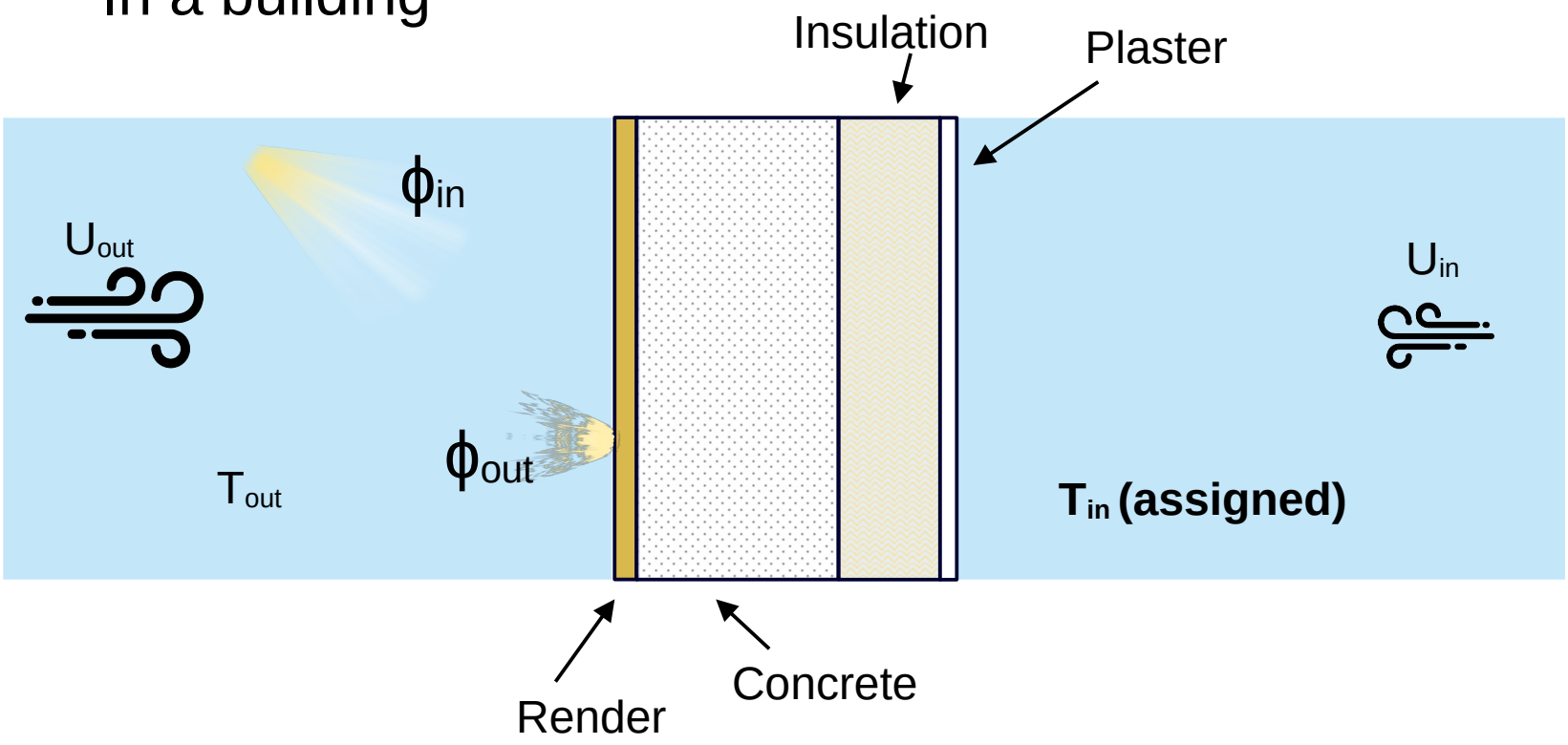
- Heat is a way of energy transfer between a system an its surroundings.
- Heat can be exchanged by 3 ways:
  - Conduction
  - Convection
  - Radiation



From UCAR – Center for Sc education

Heat Transfer Review

- In a building



Heat Transfer Review: Conduction

- Conduction occures :
  - Between external/internal air and the walls.
  - Inside the walls, between the different materials

- The material property involved in conduction is the thermal conductivity, **k ($W.m^{-1}.K^{-1}$)**

- For a **<u>1D homogeneous</u>** wall of width e (m) the amount of heat exchanged in **steady state** with the surroundings is:

$$\Phi_{cond} = k \frac{\Delta T}{e} \left(W . m^{-2} \right)$$

- ΔT is the difference of temperature between the two faces of the wall.

- ϕ_{cond} is a flux (per unit of area). Its a quantity of heat passing through a surface.

- In steady state the flux is the same in the entire wall.

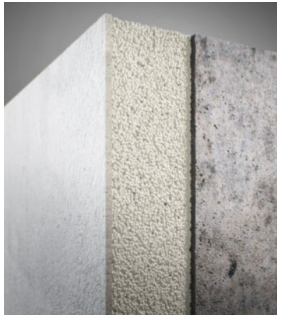
Heat Transfer Review: Conduction

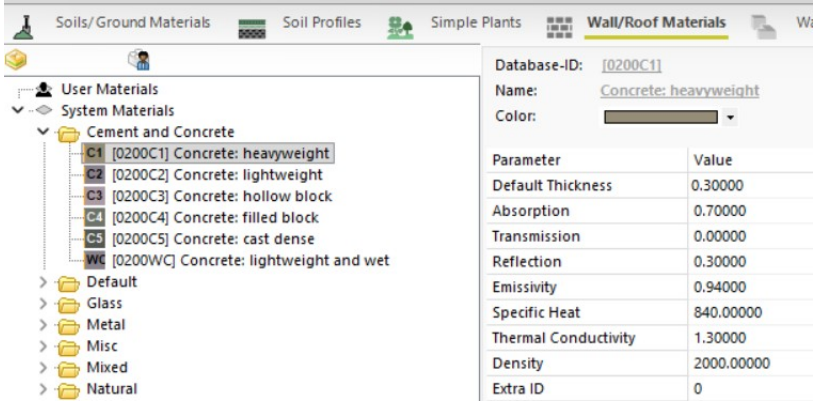
- For simplicity it is preferable to use the thermal resistance of the material:

$$R_{wall} = \frac{e}{k.S} \quad \left(K.W^{-1}\right)$$

- where S is the surface exchange area.
- The flux is now simply: $\Phi_{cond} = \frac{\Delta T}{R} \quad (W)$
- In case of composite walls:

$$R_{Total} = \sum R_i \quad \left(K.W^{-1}\right)$$





Heat Transfer Review - Convection

- Convection involves the heat transfer between a fluid and a surface.
- Here the flux is defined as: $\Phi_{conv} = h_{conv} S \Delta T \quad (W)$
- h_{conv} is the convective exchange coefficient ($Wm^{-2}K^{-2}$).
- It depends of many parameter and of course of the fluid velocity.
- Many formulas depending of the state of the flow (laminar/turbulent), the shape of the surface, of its rugosity….

Heat Transfer Review - Convection

- For instance regarding the heat exchange of the human body with air, EN7730 defines for the PVM equation:

$$h_{conv} = \begin{cases} 2.38 \left| T_{cl} - T_{air} \right|^{0.25} & for\ natural\ convection \\ 12.1 \sqrt{U_{air}} & otherwise \end{cases}$$

where T_{cl} is the clothing surface temperature.

Heat Transfer Review - Radiation

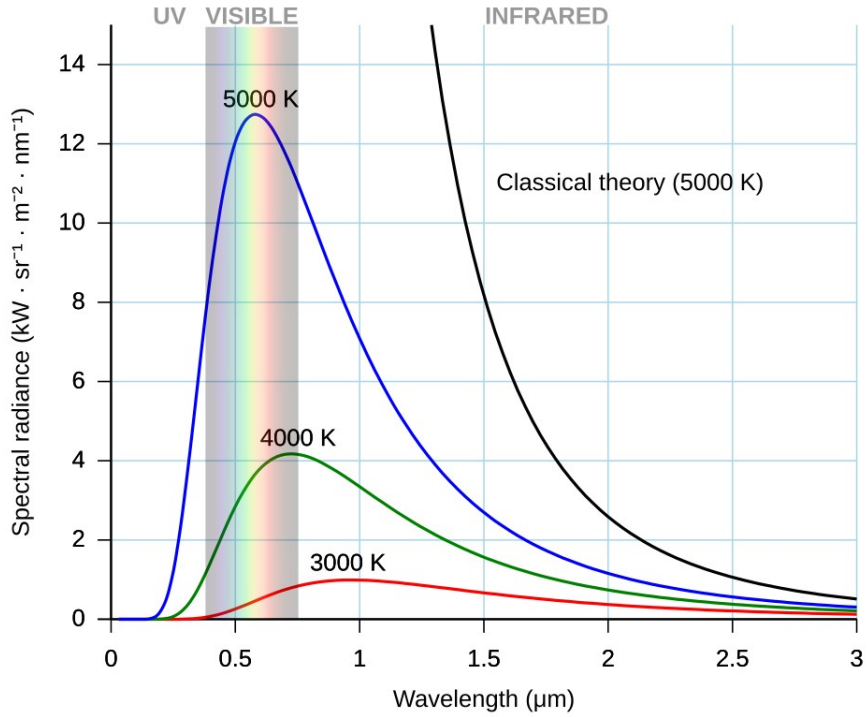
- All bodies radiate energy.
- The amount of energy radiated **by unit of area** is related to the body temperature by the Stefan-Boltzmann law:

$$\Phi_{RAD} = \epsilon \sigma T^4 \quad \left(W.m^{-2}\right)$$

- ε (1) is the body emissivity. (for a blackbody ε=1)
- σ=5.670374 10-8 ($W.m^{-2}.K^{-4}$) is the Stefan-Boltzmann constant.
- This energy is radiated in the form of electromagnetic waves of various wavelengths.

Heat Transfer Review - Radiation

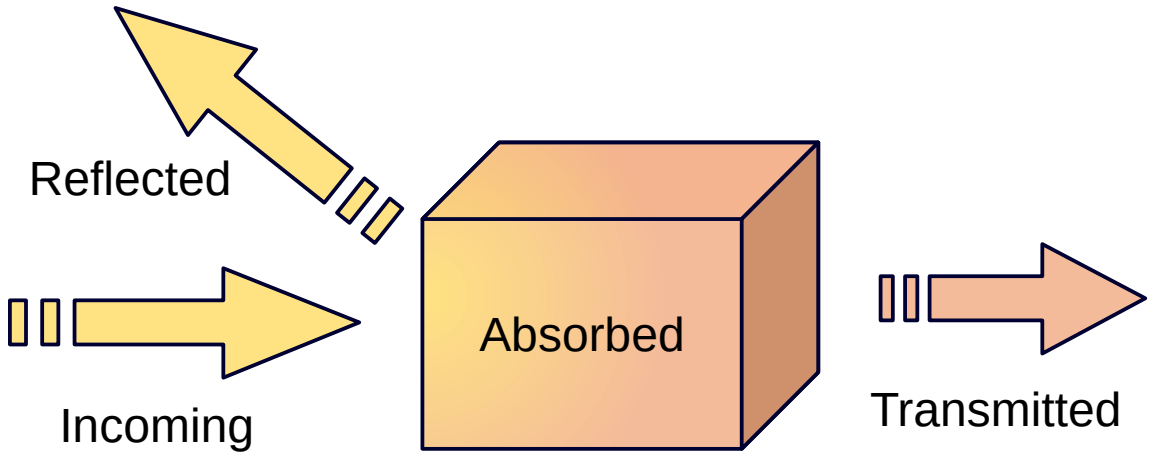
- Plank's law defines the distribution of energy by wavelengths.



- The Sun's temperature is ~5700K so it radiates mainly in the visible range.
- The Earth's temperature is ~300K it radiates mainly in the infrared range.

Heat Transfer Review - Radiation

- When a body is irradiated three phenomena occur:



Heat Transfer Review - Radiation

- When a body is irradiated three phenomena occur:

$$E_{incoming} = E_{reflected} + E_{absorbed} + E_{transmitted}$$

$E_{reflected} = \alpha E_{incoming}$ α is the albedo

$E_{transmitted} = \tau E_{incoming}$ τ is the transmittivity

$E_{absorbed} = \rho E_{incoming}$ ρ is the absorption

$$\alpha + \rho + \tau = 1$$

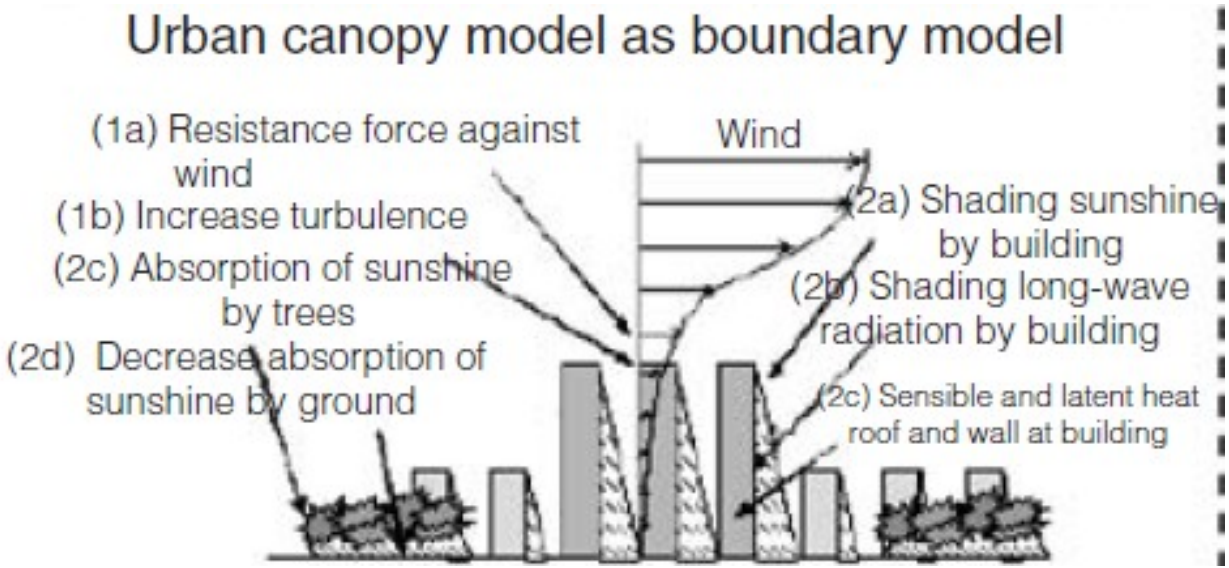
- α,τ and ρ are functions of the wavelength, direction of the incoming beam....

Heat Transfer Review – Source/sink terms

- Source/sink terms represent the release or the absorption of heat by surfaces or volumes.
- For exemple chemical reactions can release heat ($J.kg^{-1}.s^{-1}.m^{-2}$) in a given ground area.
- HVACs can also release or absorb heat close to buildings.
- Latent heat exchange is the heat relased or absorbed during a phase change of water such evaporation or condensation.
- The presence of vegetation (grass, plants, trees) modifies the atmospheric humidity by evapotranspiration.

Heat Transfer Review – Urban Canopy Model

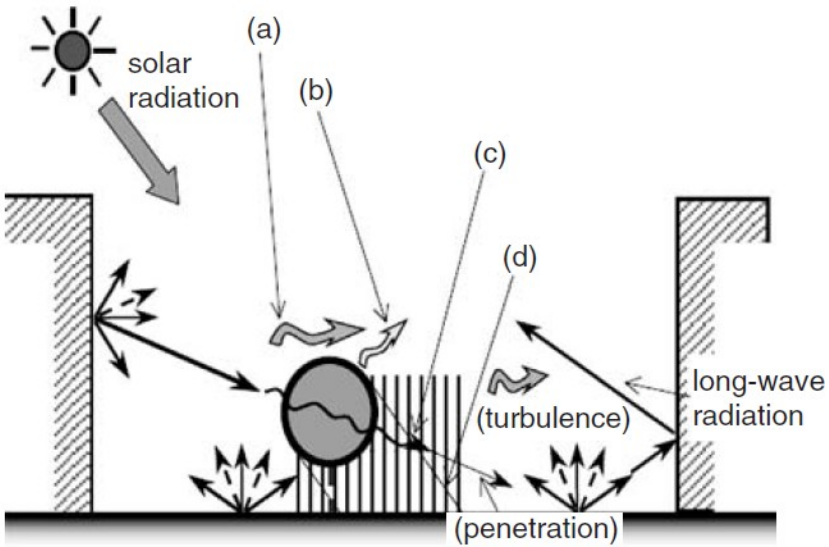
- Urban canopy models are used to simulate how the interaction between the atmosphere and the ground is altered by the presence of urban areas.



From Lun (2009)

Heat Transfer Review – Urban Canopy Model

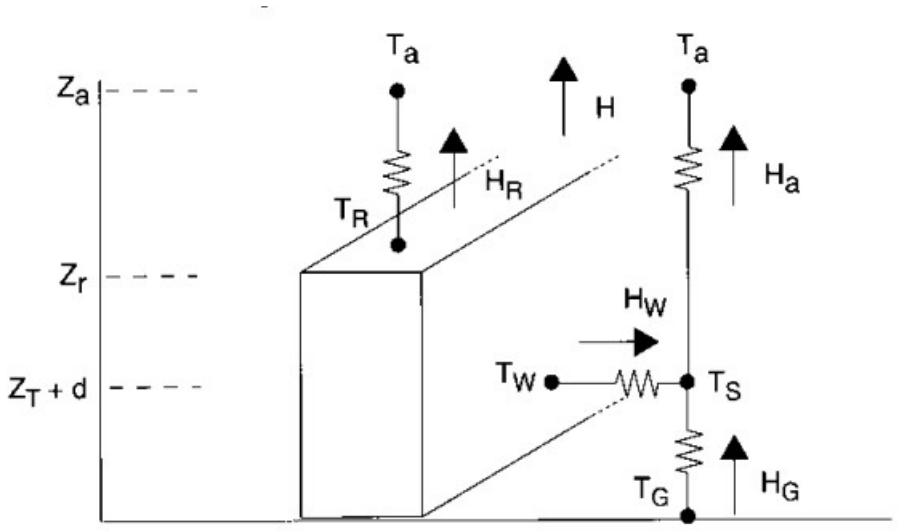
- The presence of vegetation (grass, plants, trees) is also to be considered.



From Yoshida (2006)

(a) aerodynamic effects
(b) latent heat from the tree canopy
(c) shading effect on long-wave radiation
(d) shading effect on short-wave radiation

Heat Transfer Review – Urban Canopy Model



From Kusaka 2001

- T_a air temperature at z_a
- T_R building roof temperature at z_r
- T_w building wall temperature
- T_G the road temperature
- T_G the ground temperature
- T_S the temperature defined at z_T+d

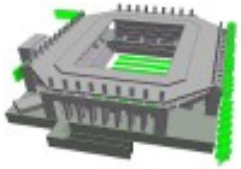
- H is the sensible (convective) heat exchange at reference height
- H_a is the sensible heat flux from the canyon to the atmosphere
- H_w is the sensible heat flux from wall to the canyon
- H_R from the roof to the atmosphere

ENVI-MET

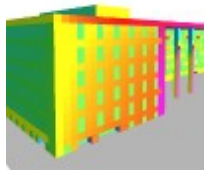
- ENVI-MET is a Computational Fluid Dynamics (CFD) model for studying at the **micro-scale length** (~1 m) the interactions between the atmosphere and the urban or natural surface.

- It incorporates various modules that enable the simulation of interactions between vegetation, soil, buildings, pollutants and the atmosphere.

Atmospheric model 



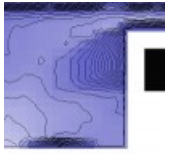
Full 3D building geometry



Building physics

Radiative model

Soil & surface Temperature

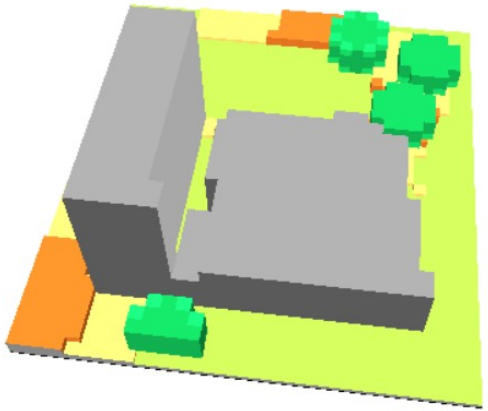


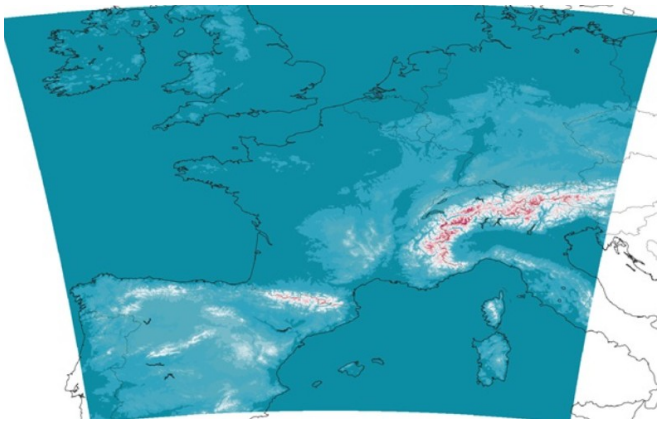
Soil Water content

Soil Water content

ENVI-MET

- Meteorological scales?
  - Global scale – entire planet ~40 000km https://classic.nullschool.net/
  - Regional/synoptic scale – 100km - 5000km
  - Meso scale – 1km - 100km
  - Micro scale - <1m-1km





AROME model MeteoFrance

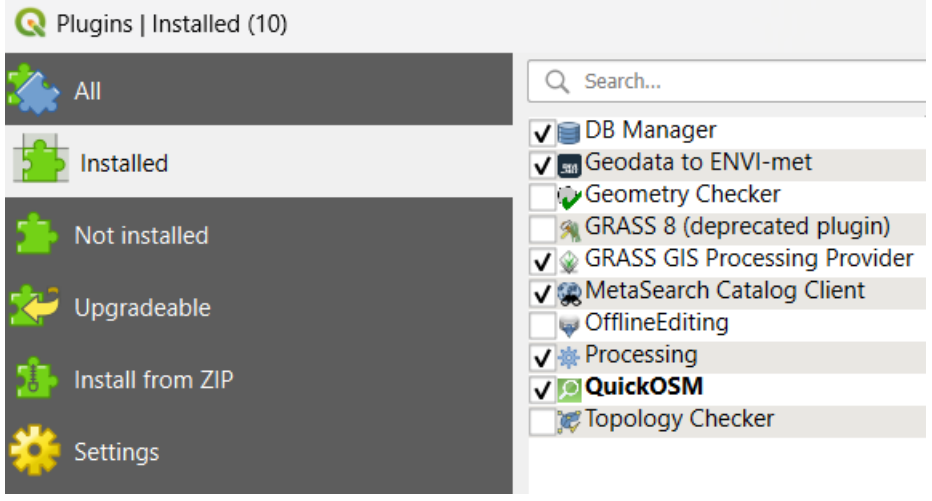
ENVI-MET

- **ENVI-MET** requires a large amount of data to perform a realistic simulation:
  - 3D building model (geometry, materials, ...)
  - Digital Elevation Model
  - Characterization of vegetation (density, height, species, etc.)
  - Characterization of soil (type, temperature and moisture profiles, etc.)
  - Meteo (Wind, Temperature, Relative Humidity, Solar irradiation, etc.)

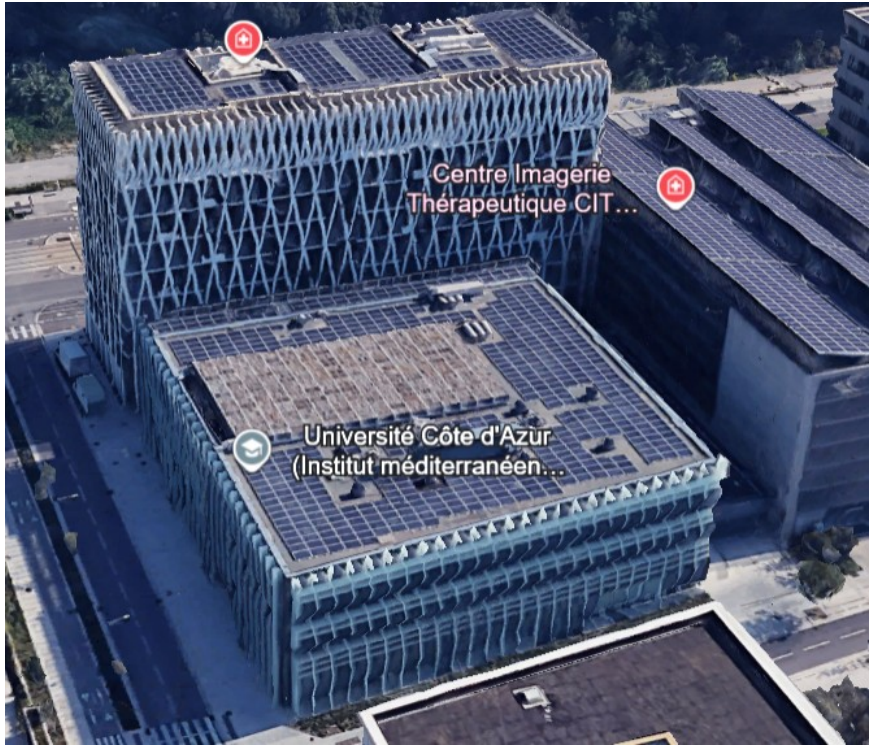
Open datasets are extremely valuable for this purpose!
And GIS too !!!

ENVI-MET & QGIS

- **Geodata to ENVI-MET** is plugin to export ENVI-met model areas from geodata, run microclimate simulations from QGIS and also enables you to visualize climate model results in QGIS.
- It works with QGIS



The domain !!!


Centre Imagerie
Thérapeutique CIT…
Université Côte d'Azur
(Institut méditerranéen…

The domain

- Many possibilies to import geom models …

- BDTOPO from IGN
- Alpes-Maritimes – 06
- Projection LAMBERT 93

Link

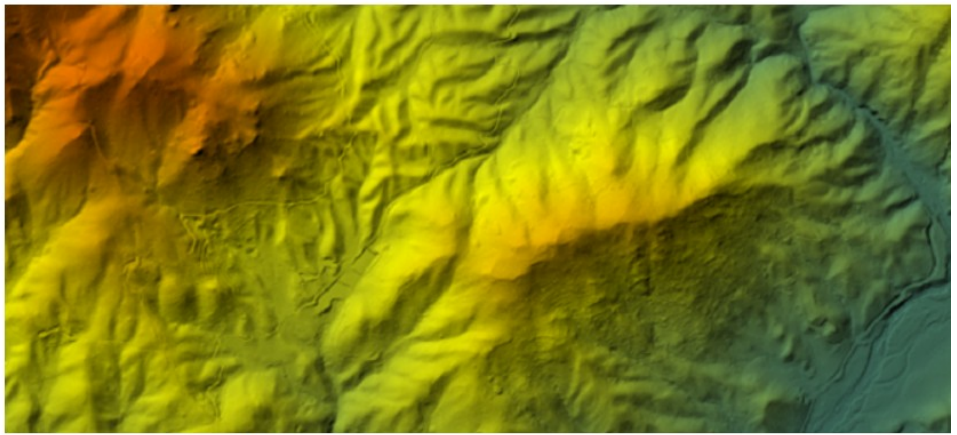
- ADMINISTRATIF
- ADRESSES
- BATI
- HYDROGRAPHIE
- LIEUX_NOMMES
- OCCUPATION_DU_SOL
- SERVICES_ET_ACTIVITES
- TRANSPORT
- ZONES_REGLEMENTEES

The DEM

- Many possibilies to import DEM models …

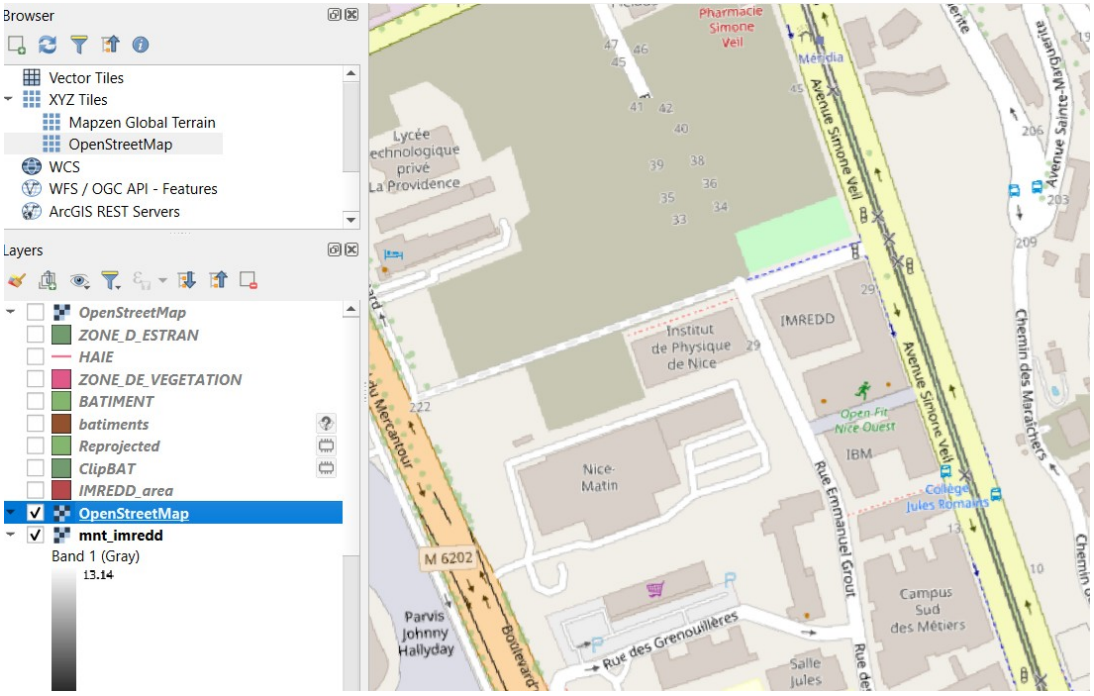
- RGE ALTI from IGN (1m & 5m)
- BD ALTI from IGN (25m)
- Alpes-Maritimes – 06
- Projection LAMBERT 93
- Ellipsoid IAG GRS 1980

Link 1m
Link 5m
Link 25m



Where is IMREDD?

- We find our way with OSM...



Geodata to ENVIMET

- Geodata to ENVIMET plugin allow us to prepare the geometric input file for ENVIMET: **FILE.INX**

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ENVIMET Launcher

Organize your ENVI-met system into Workspaces and projects and define the individual settings for your simulation projects.

Create new simulations files (.SIMX) or edit existing ones on an interactive

Analyse your model results and create 2D and 3D maps.

Green your world! With this tree library, you can design functional 3D and QSM vegetation ready to run in your ENVI-met model

Bringing your designs and environments into the computer. Transform your plans and ideas into Area Input Files

This is the central calculation module, the “ENVI-met Model” itself.

A post processing tool for ENVI-met output files to calculate dynamic and static Thermal Comfort (dPET, PET, UTCI etc)

With this library you can edit, add or modify all kind of materials, soils or other physical settings used in ENVI-met.

ENVIMET

Ressources

- ENVIMET website
- ENVIMET 5.9 download
- ENVIMET Technical website
- ENVIMET 3.1 Manual

- Biblio (password: 1MREDD@06200)