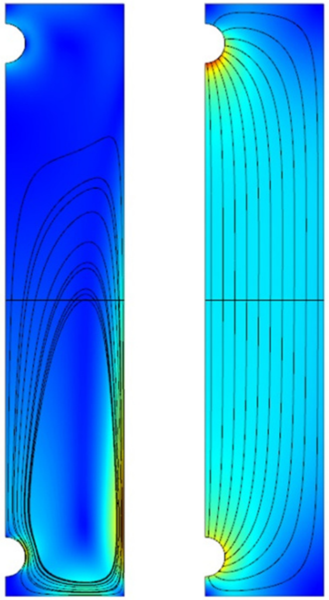
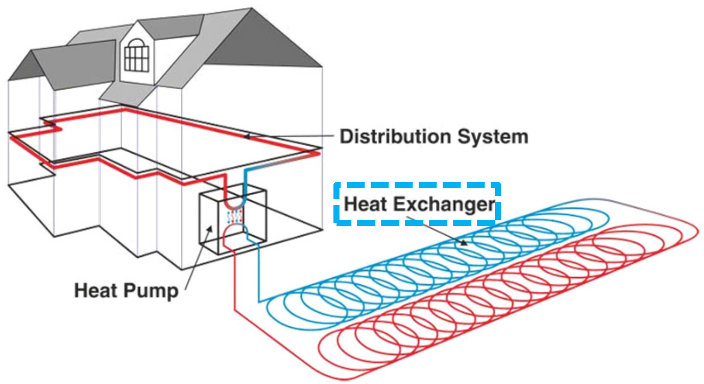
Inclusive Routine of the Soil Surface Energy Balance in COMSOL Multiphysics®



Marco Bortoloni* University of Ferrara, Italy
Michele Bottarelli University of Ferrara, Italy
Yuehong Su The University of Nottingham, UK

Ground source heat pumps



The coupling of a heat pump with the ground is obtained by means of ground heat exchangers (GHEs).

The weakest part in a GSHP is the GHE:

- The heat transfer in the ground is mainly conductive
- The soil thermal diffusivity is low

HGHEs performance are closely linked to the seasonal shallow energy balance

Horizontal GHEs deserves more advantages, but normally lower energy performance.

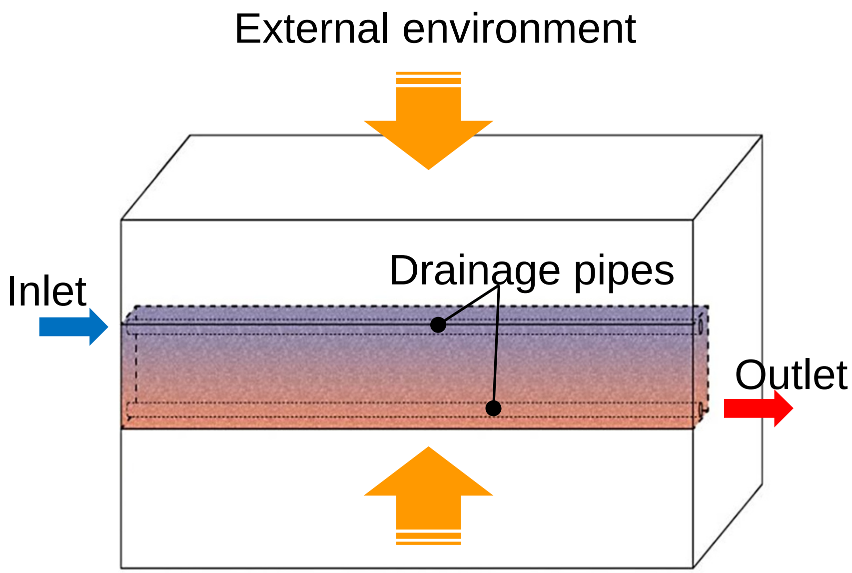
HGHE **_Flat-Panel_**

	HGHE	VGHE
Energy performance	☹	☺
Building cost	☺	😐
Building equipment	☺	😐
Maintenance	☺	☹
Building permission	☺	😐
Soil use restriction	😐	☺
GW contaminant risk	☺	😐
Design	☹	😐
Installations	☹	☺

Drainage trench used as GHE

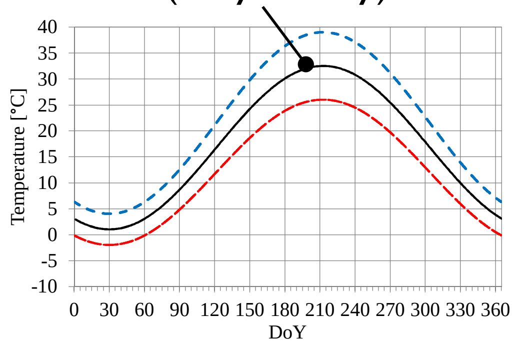
A trench backfilled with coarse matter could:

- maintain the advantages of shallow solutions
- enlarge the thermal inertia
- minimize the hydraulic head loss



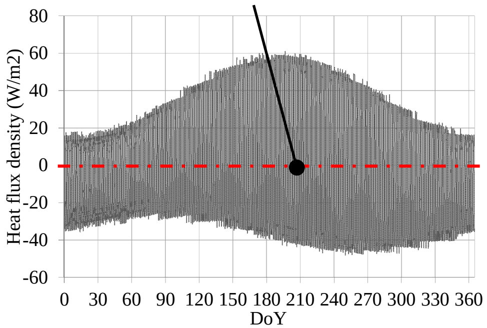
More accurate boundary conditions should be applied at the soil surface:

1st kind condition
Temperature (surface)
(daily/hourly)

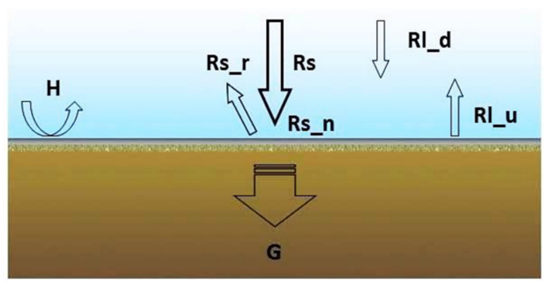


OR

2nd kind condition
Heat flux (surface)
(daily/hourly)



3rd kind condition
Energy balance at the soil surface
(daily/hourly)

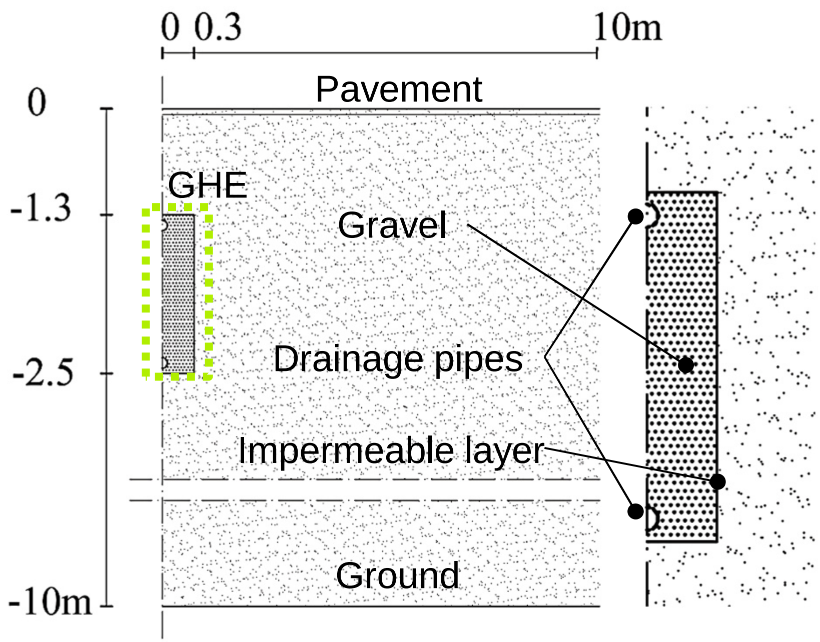


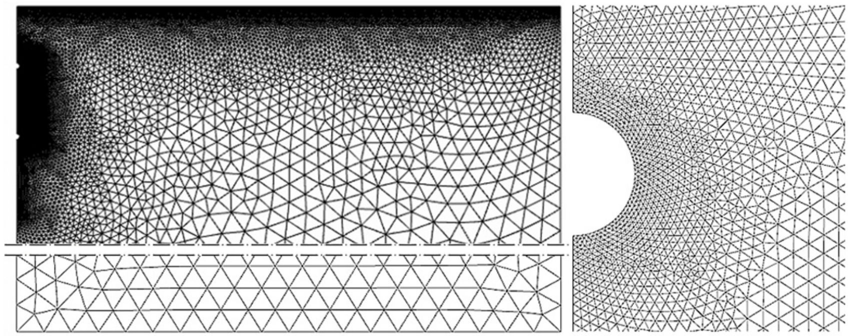
Model domain

Finite Element Modeling of Heat Transfer and Fluid Flow in porous media in a 2D domain

- The GHE is 1.2 x 0.6
- Installation depth from 1.3 m to 2.5 m
- Horizontal pipes (d=10 cm)

Mesh:
- N° elements 26800
- Min element size 0.039 cm^2



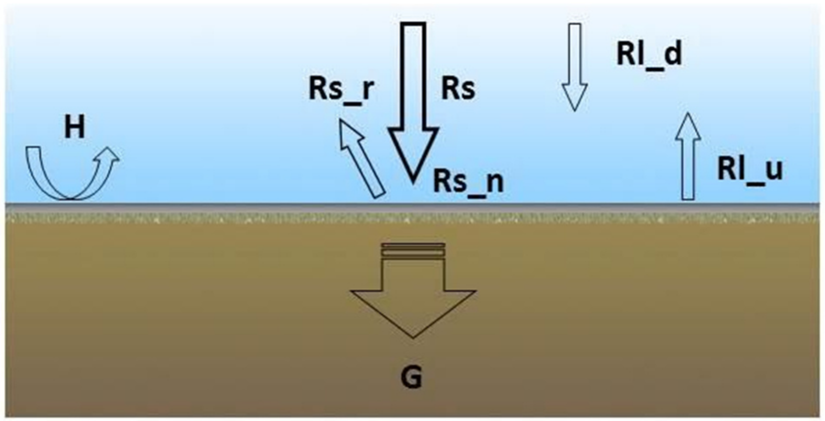


Material properties:

	ρ (kg/m^3)	c (J/kgK)	k (W/mK)
Soil^{domain}	1600	1400	1.2
Pavement	2200	900	1.3
Gravel	2200	840	2.3
Water	1000	4230	0.57

Energy balance at the soil surface

The surface energy balance at the soil-atmosphere interface is:



$$G = Rn - H$$

Where:

- G is the soil heat flux (W/m²)
- Rn is the net radiative flux density (W/m²)
- H is the sensible heat flux (W/m²)

Model variable

$$G = \underbrace{R_s(1-\alpha) + \varepsilon_{sky}\sigma T_a^4 - \varepsilon_s \sigma T_s^4}_{Rn} - \underbrace{h(T_s - T_a)}_{H}$$

Where: $\varepsilon_{sky} = \left(0.787 + 0.764 \cdot ln\left(\frac{T_{dew}}{273.15}\right)\right) \cdot (1 + 0.224N - 0.0035N^2 + 0.00028N^3)$

$$h = \begin{cases} 5.8 + 3.9v & v\ (wind\ speed) < 5\ m/s \\ 7.1v^{0.78} & v\ (wind\ speed) > 5\ m/s \end{cases}$$ (Jürges equation)

Boundary conditions

- Energy balance equation is applied at the soil surface as hourly varying heat flux :

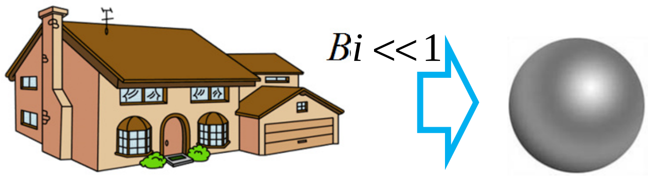
  $G(t,T)$ (W/m^2)

- Constant temperature on the bottom

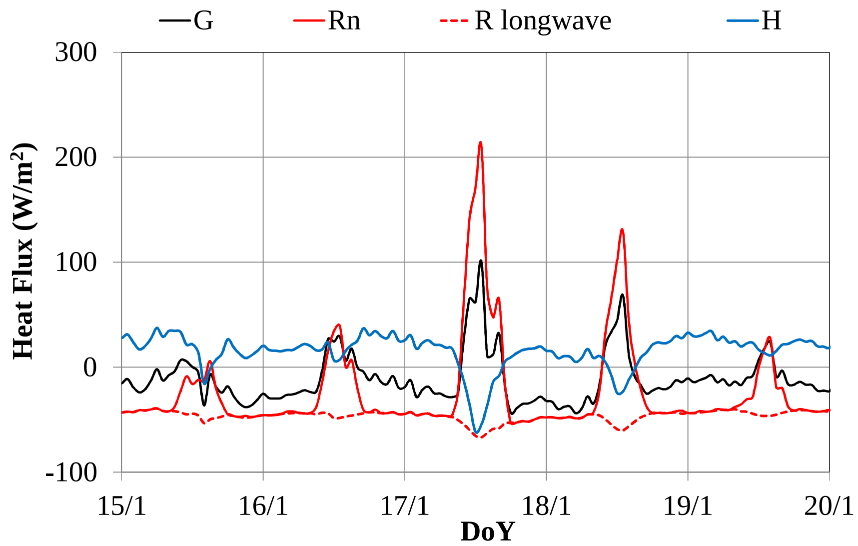
  $(14.4°C)$

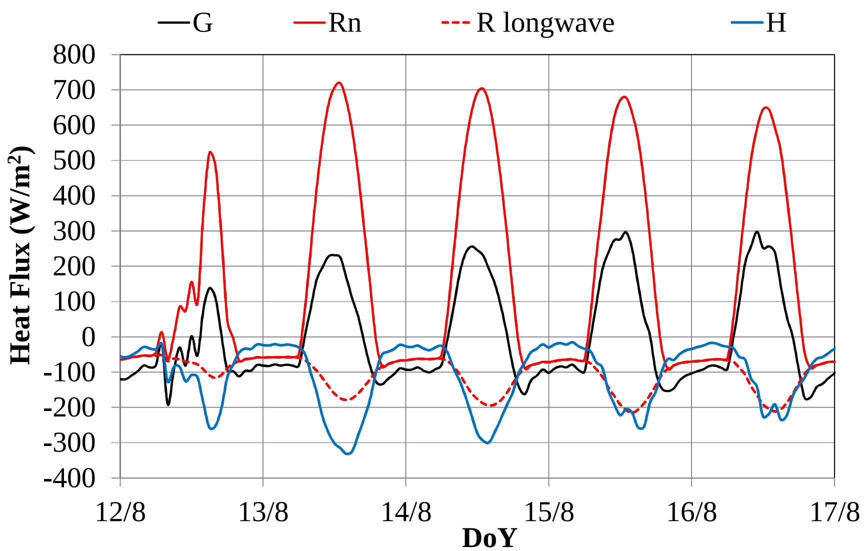
- Adiabatic conditions to other boundaries

- The building energy requirement is related to the outdoor air temperature, assuming the building as a homogenous lumped system



- $$\dot{m}_w(t) = \frac{\dot{Q}(t)}{c_w \Delta T} \qquad \Delta T = 1(K)$$



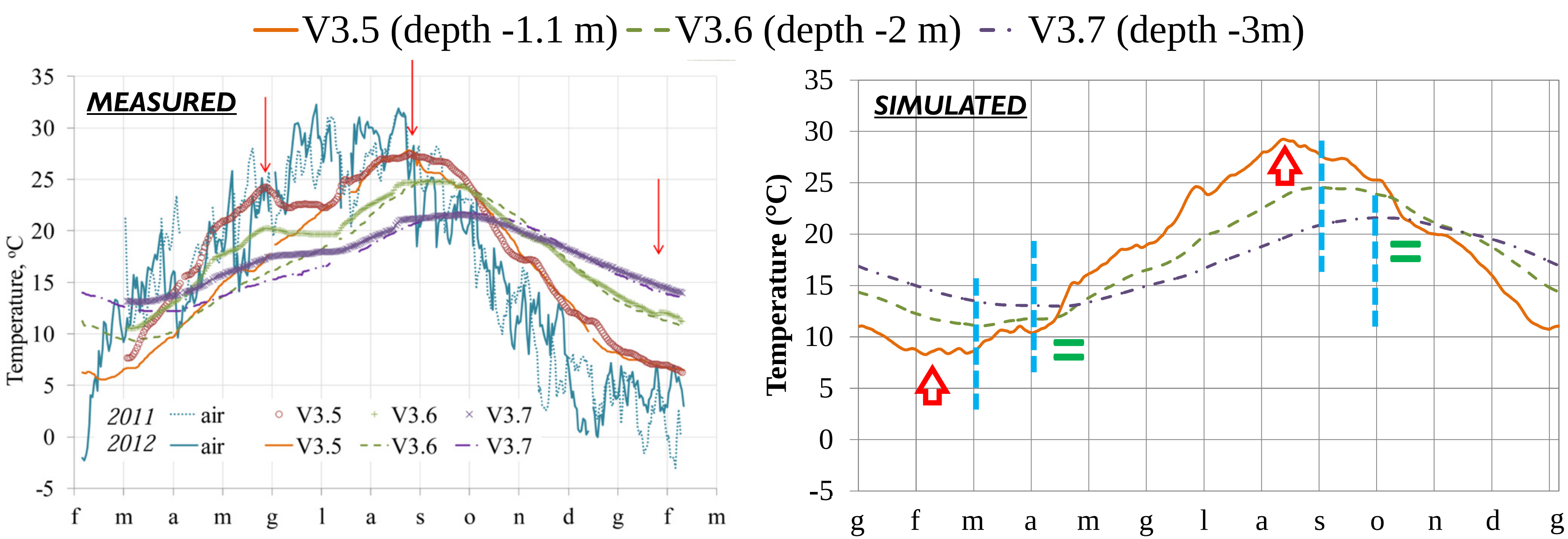


Boundary conditions

The results have been verified with experimental measurements

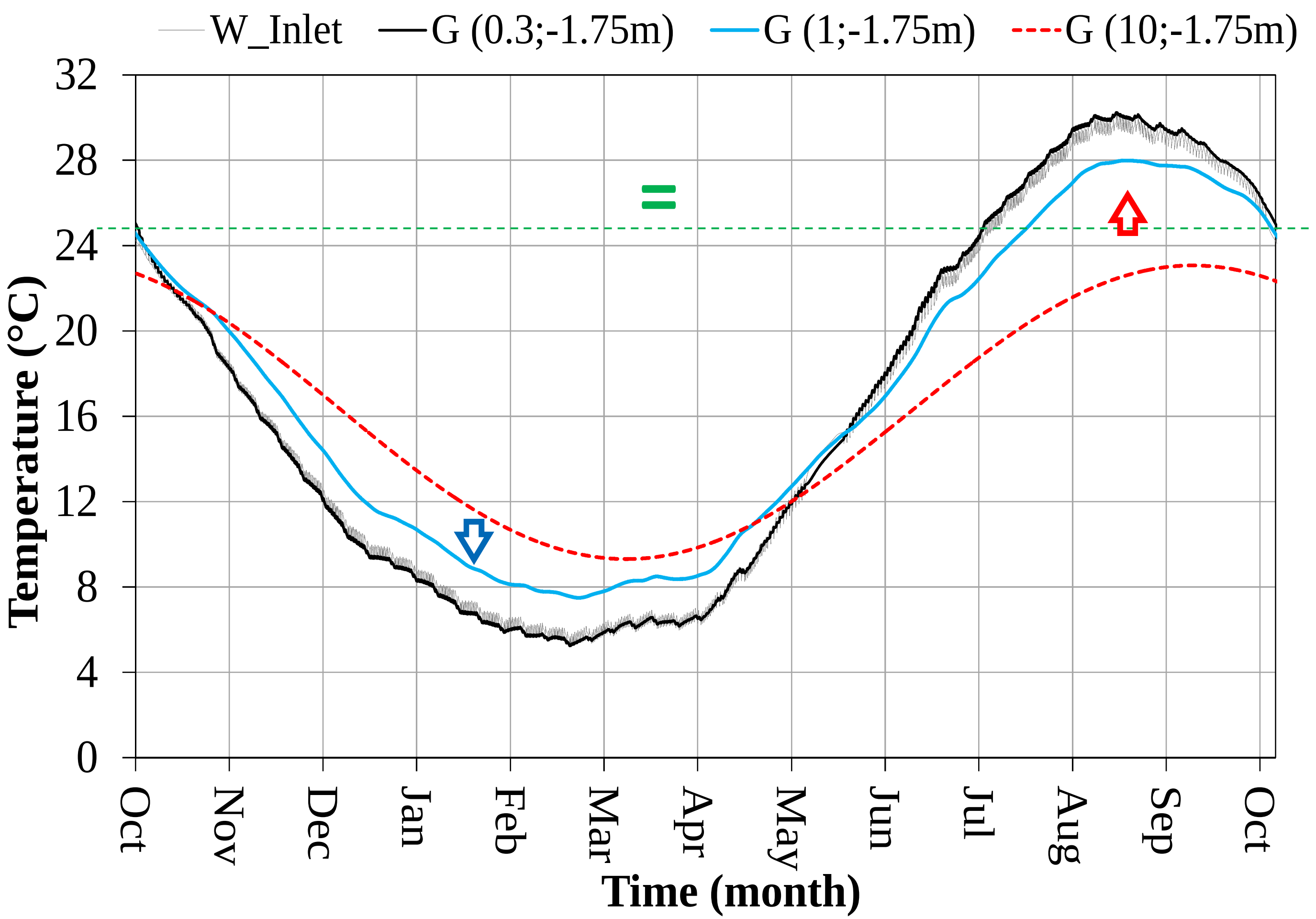
To test the energy performance of a Flat Panel a trial field is working at the Department of Architecture of the University of Ferrara (Italy)

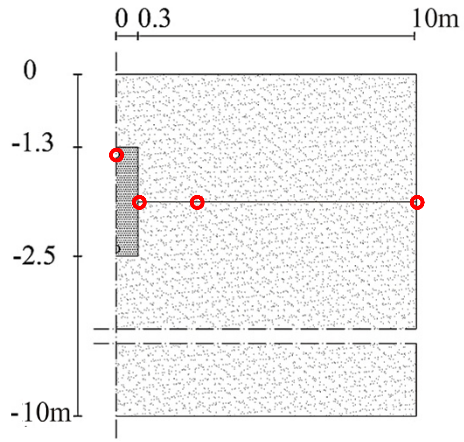
Several digital sensors to monitor the ground temperature



Results: temperature of the working fluid and in the ground

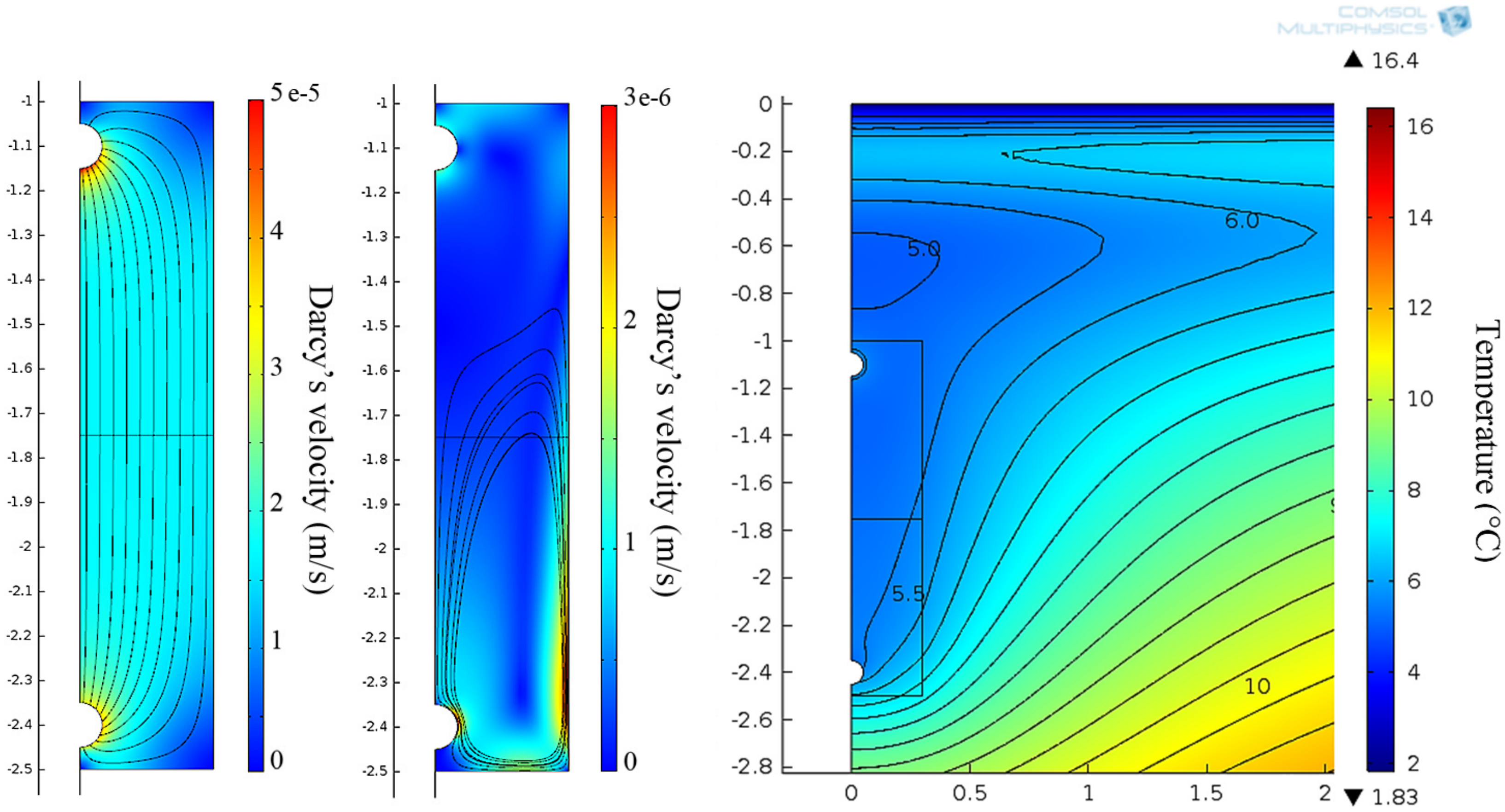
- 2 years time simulation
- No thermal drift





Results

Darcy’s velocity field within the trench, when the system is turned ON and OFF and the thermal field in the soil on 25th of February.



Remarks

A shallow and narrow trench filled with coarse gravel has been analysed as ground heat exchanger (GHE)

The energy balance at the soil surface has been considered in the model as function of surface temperature:

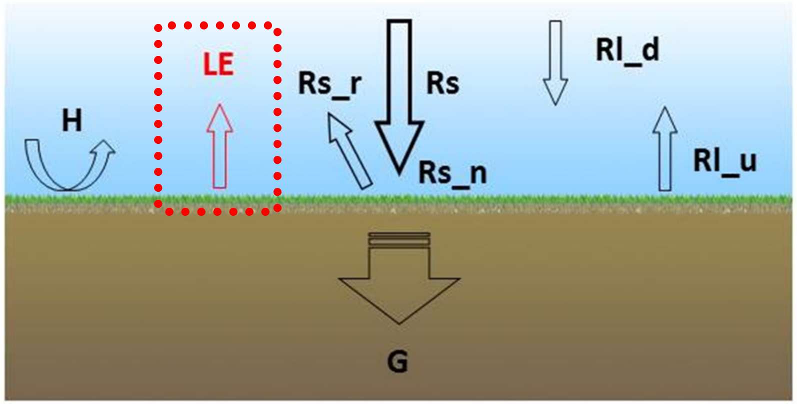
$$G(t,T)\ (W/m^2)$$

The drainage trench as GHE could be an attractive solution:

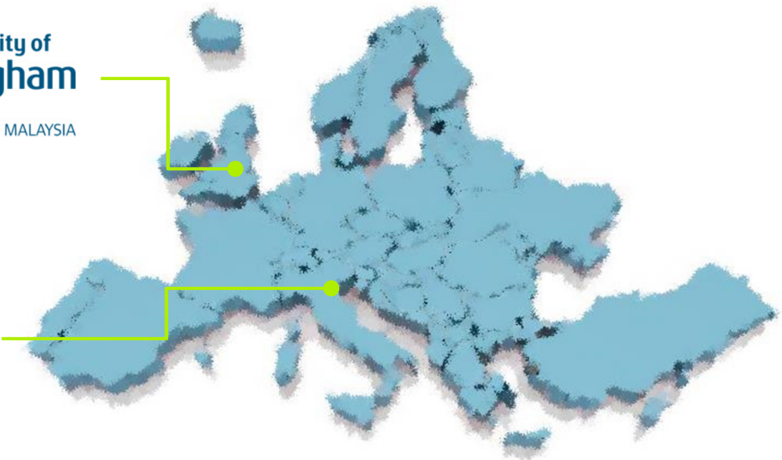
- no thermal drift has been basically highlighted;
- the performance are comparable with widespread horizontal GHEs

Next step:

- Evaporation / Evapotranspiration will be taken into account to consider different surfaces (bare soil / grass)
- More detailed energy building requirements



Thank you for your attention!



Authors:
Marco Bortoloni*
University of Ferrara, Italy

Michele Bottarelli
University of Ferrara, Italy

Yuehong Su
The University of Nottingham, UK

This work has been funded by the University of Ferrara (funds 5x1000, year 2011)