GSHP association

Technical Seminar 2013:

Truly Renewable Heating & Cooling

London

December 5, 2013

Modelling and Analysis of Helical Pipe in Ground Heat Exchanger Design

Michele De Carli

Angelo Zarrella

Università degli Studi di Padova

Department of Industrial Engineering

Outline

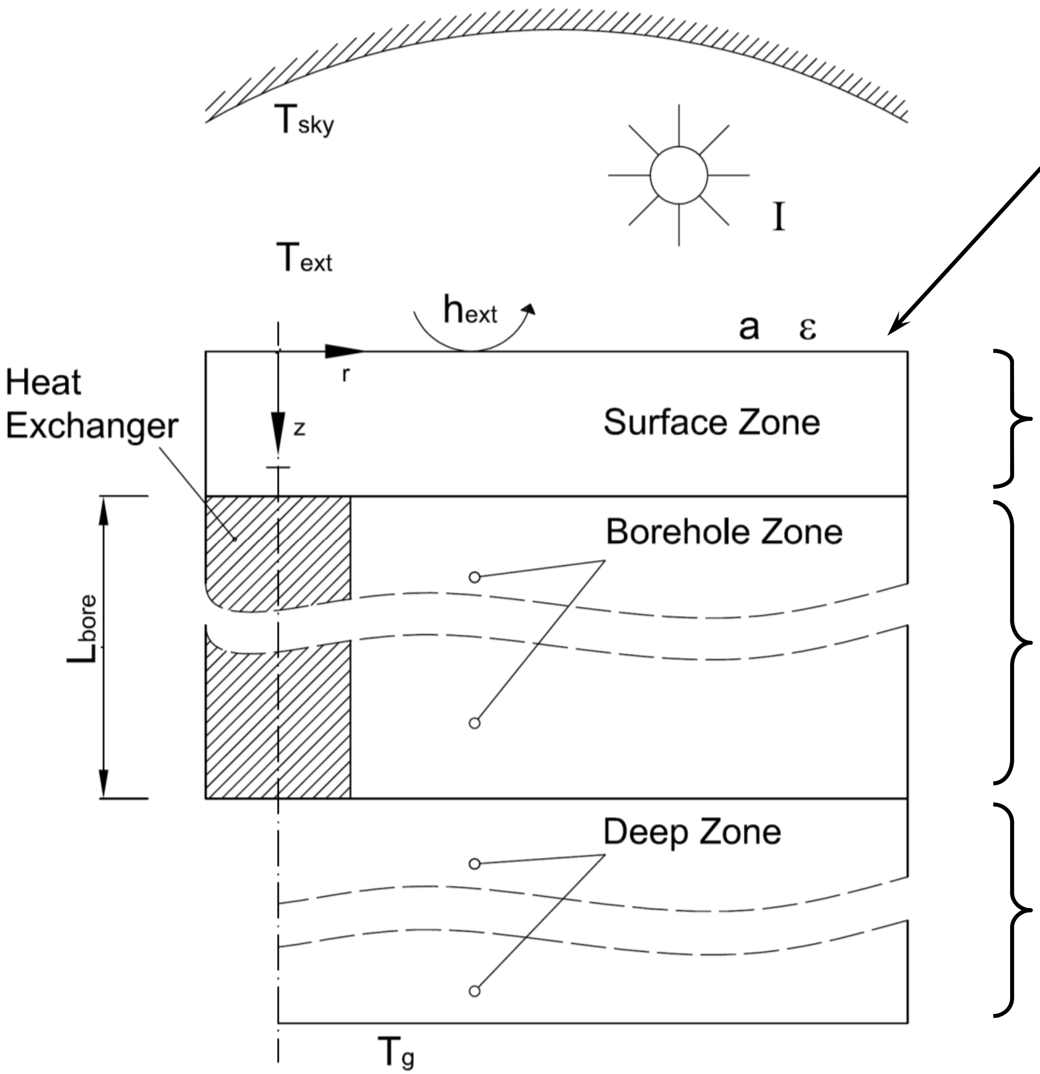
- Some of our Activities about GSHP Systems
- CaRM simulation tool
- Helical Shaped Pipe Ground Heat Exchanger
- Helical Energy Pile

CaRM Simulation Tool

- CaRM: **Ca**pacity **R**esistance **M**odel for vertical ground-coupled heat exchangers:
  - A detailed numerical simulation tool. The problem of heat transfer is solved by means of an equivalent electrical circuit of suitable thermal resistances and capacitances.
  - Developed in Fortran 90 (but we want to re-write).

- Types of vertical ground-coupled heat exchangers:
  - Single U-tube, Double U-tube
  - Coaxial pipes
  - Helical shaped pipe
  - Energy piles (with helical or *n* U-tube circuits)

Approach of the CaRM Model



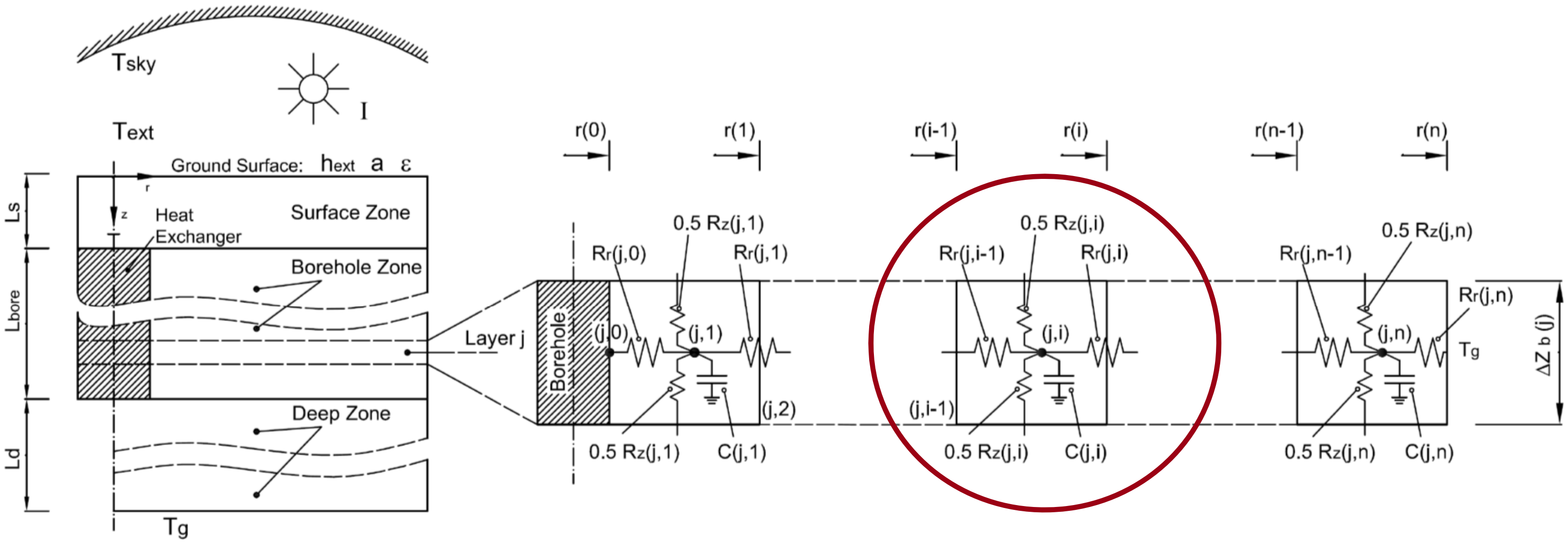
The simulation tool includes the **effects of weather conditions**, i.e. external air temperature, incident solar radiation and radiant heat exchange with the sky.

Heat is only conducted along the depth direction

Two-dimensional heat conduction

Heat is only conducted along the depth direction

Modelling of the Surrounding Ground



General modelling approach

Modelling of the ground surrounding the borehole

Heat balance of the node (j, i):

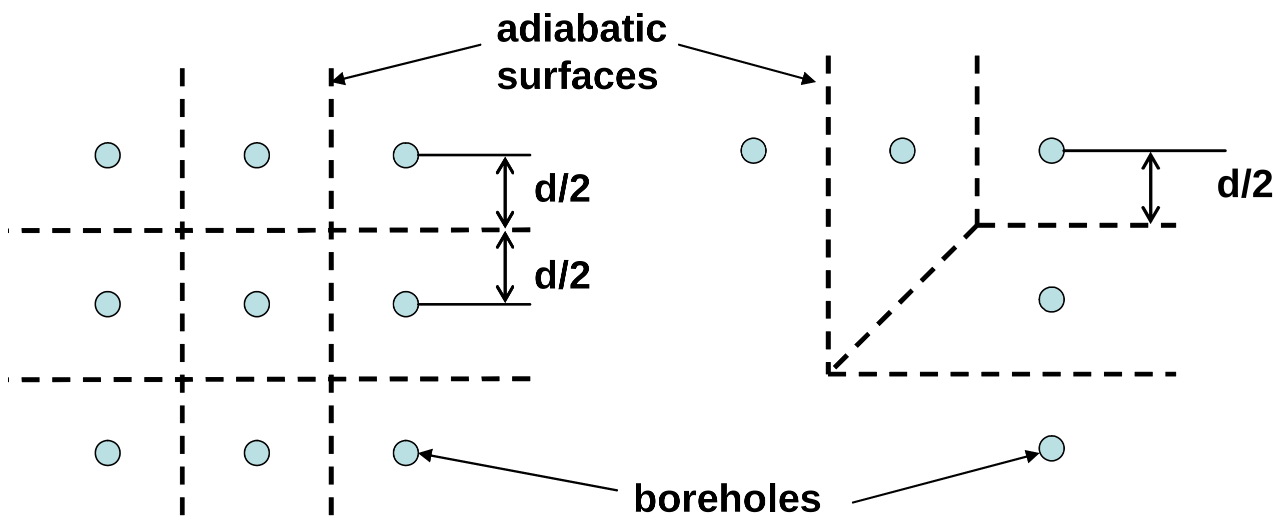
$$C(j,i) = \rho \cdot c \cdot \pi \cdot \left[r^2(i) - r(i-1)^2 \right] \cdot \Delta z(j)$$

$$\frac{T(j,i-1)-T(j,i)}{R_r(j,i-1)} + \frac{T(j,i+1)-T(j,i)}{R_r(j,i)} + \frac{T(j-1,i)-T(j,i)}{0.5\cdot R_z(j-1,i)+0.5\cdot R_z(j,i)} + \frac{T(j+1,i)-T(j,i)}{0.5\cdot R_z(j+1,i)+0.5\cdot R_z(j,i)} = C(j,i)\cdot \frac{T(j,i)-T(j,i)_{-\Delta\tau}}{\Delta\tau}$$

heat transfer along the **radial direction**

heat transfer along the **depth direction**

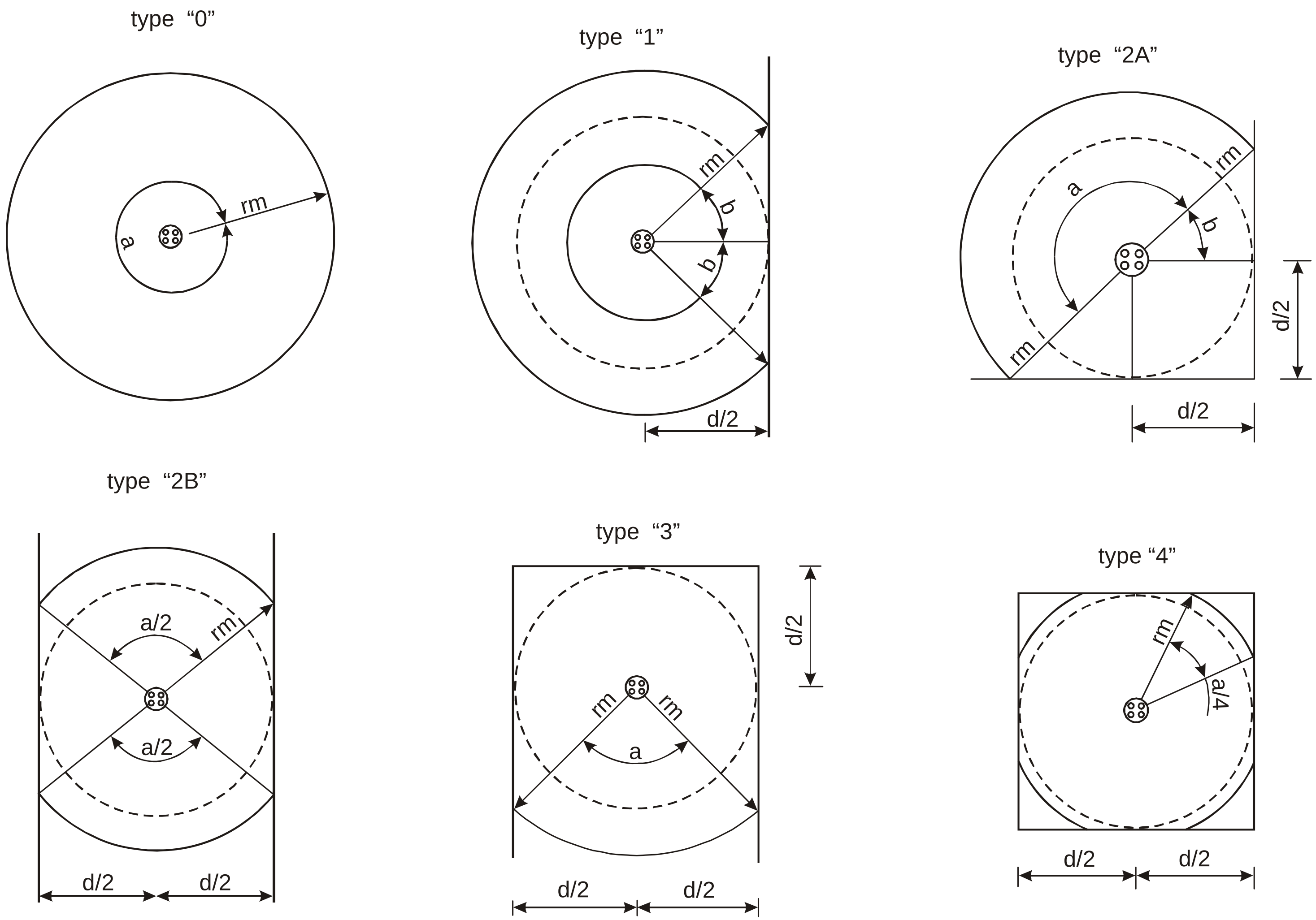
Modelling of the Borehole Field



The model for a borehole field can be implemented, taking into account the influence between adjacent boreholes. If two boreholes are close and at distance *d*, an adiabatic surface at distance *d/2* can be assumed.

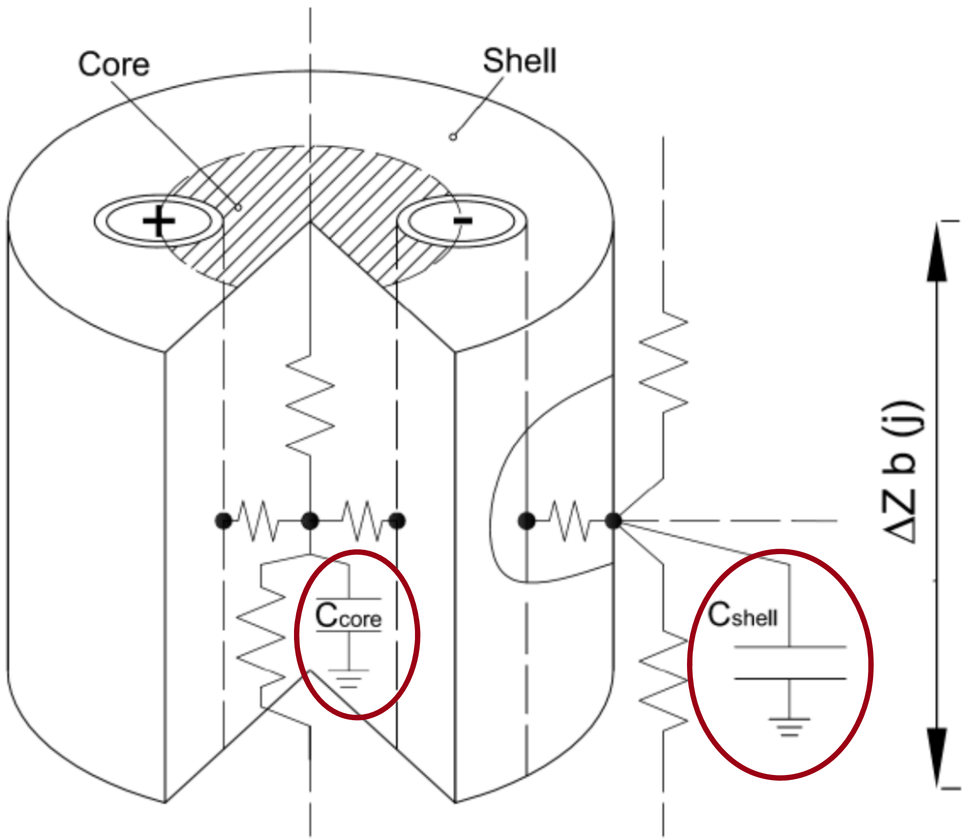
Types of Boreholes

For this purpose, six types of boreholes are considered:



Borehole Thermal Capacitance: Grouting Material and Heat Carrier Fluid (1)

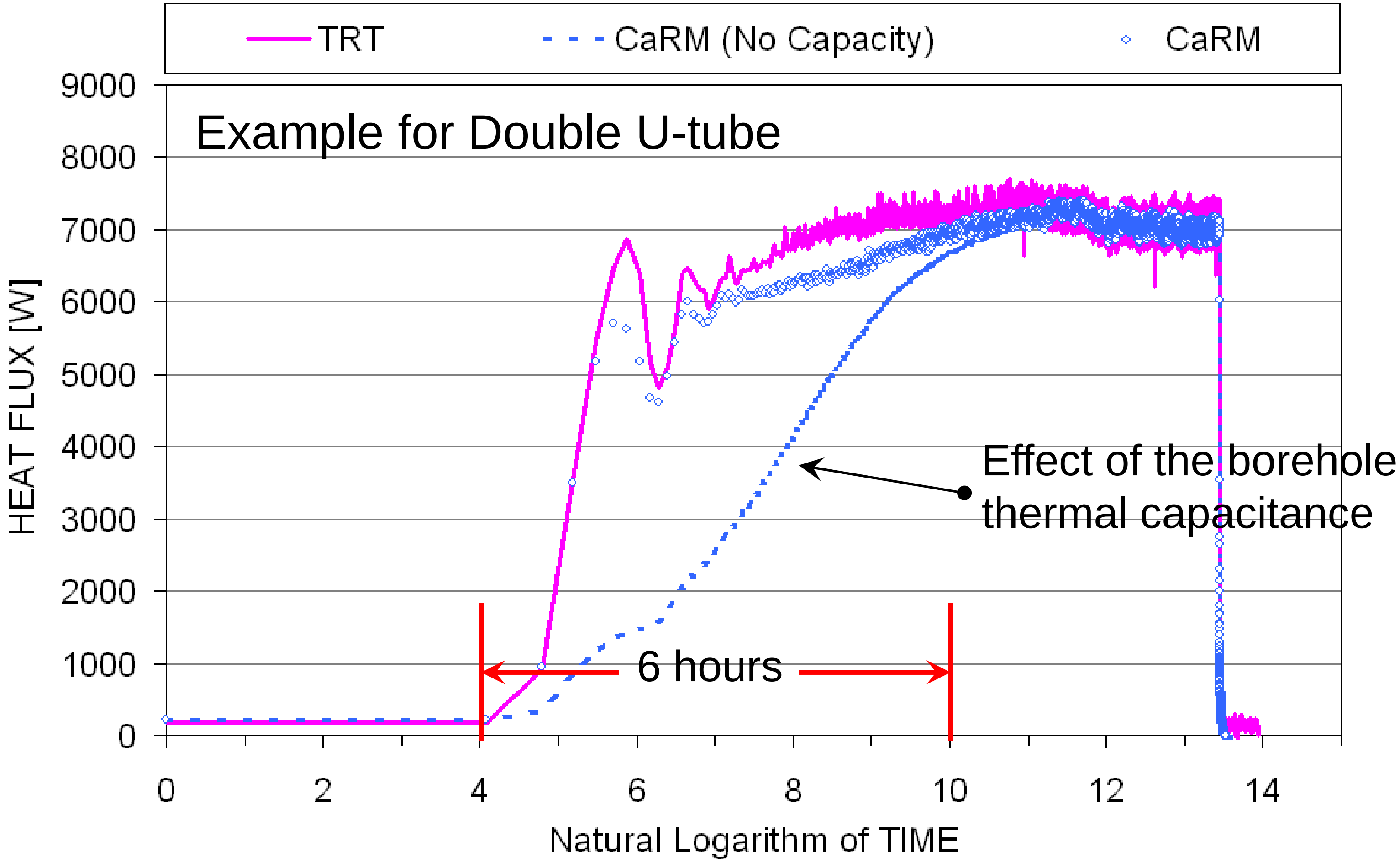
New approach with borehole thermal capacitance, (grouting material and heat carrier fluid)



… this is very important in short time step analyses (e.g. effect of peak loads)…

… but also when the borehole radius increases.

Borehole Thermal Capacitance: Grouting Material and Heat Carrier Fluid (2)

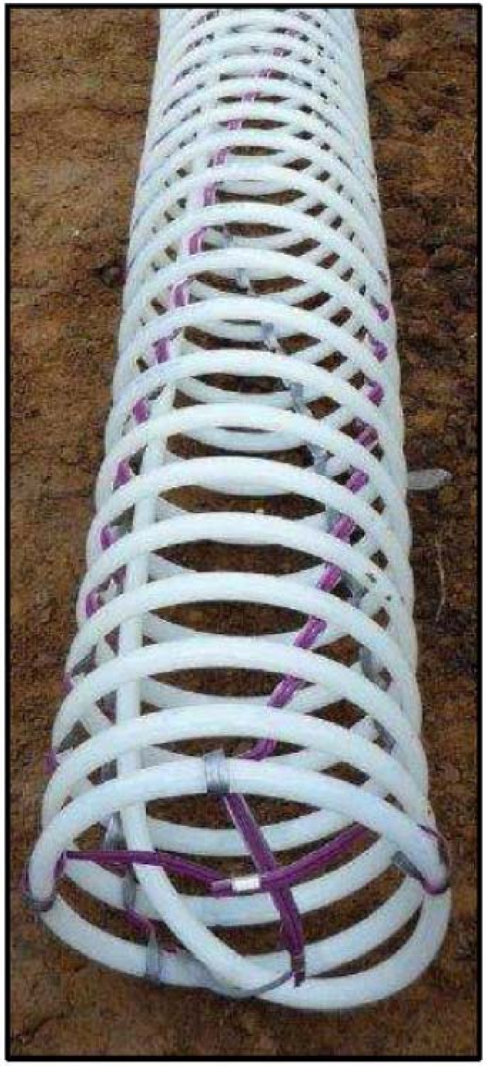


Zarrella A., Scarpa M., De Carli M. Short time step analysis of vertical ground-coupled heat exchangers: the approach of CaRM, RENEWABLE ENERGY (2011), Vol. 36 (2011) n. 9, pages 2357-2367.

Helical Shaped Pipe

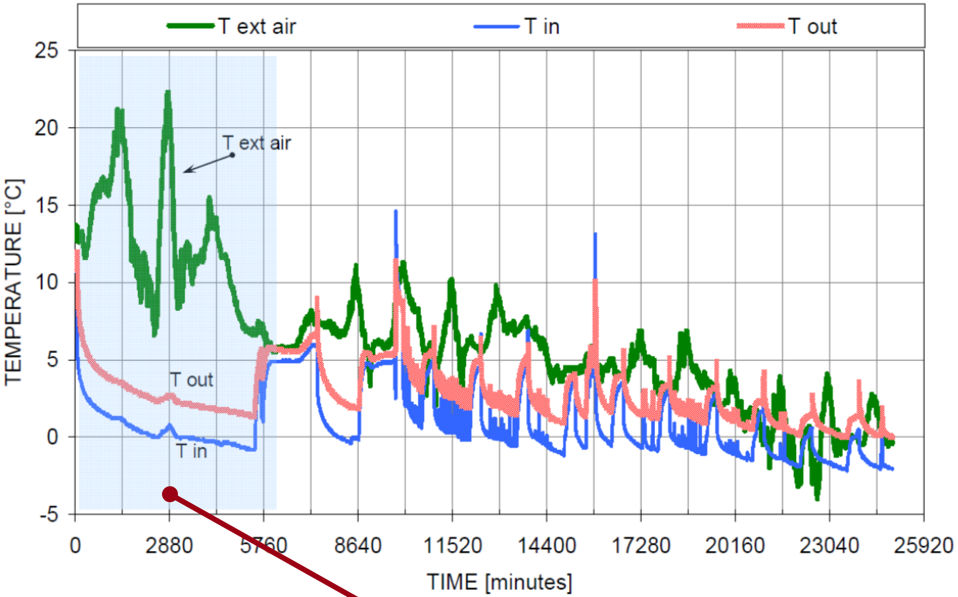
- **CaRM-He** takes into account:
  - Number and pitch of the turns
  - Thermal capacitance of the grout
  - Thermal capacitance of the fluid
  - Different material of pipes (linear and helical pipe)
  - Outdoor climate conditions (temperature, long-short wave radiation)

Outputs: temperatures of the fluid, grout and ground in space and time, heat flow.

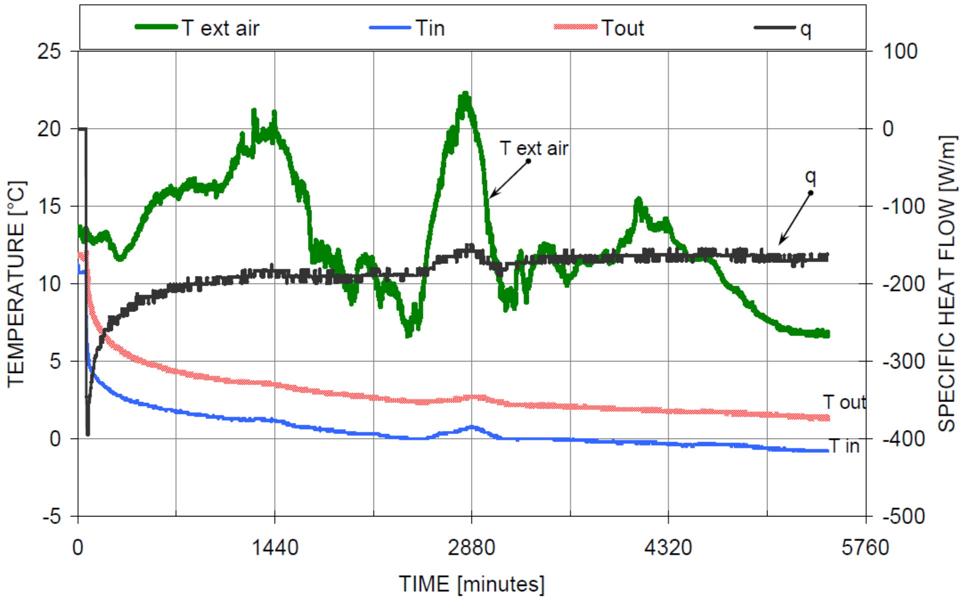


by Rehau

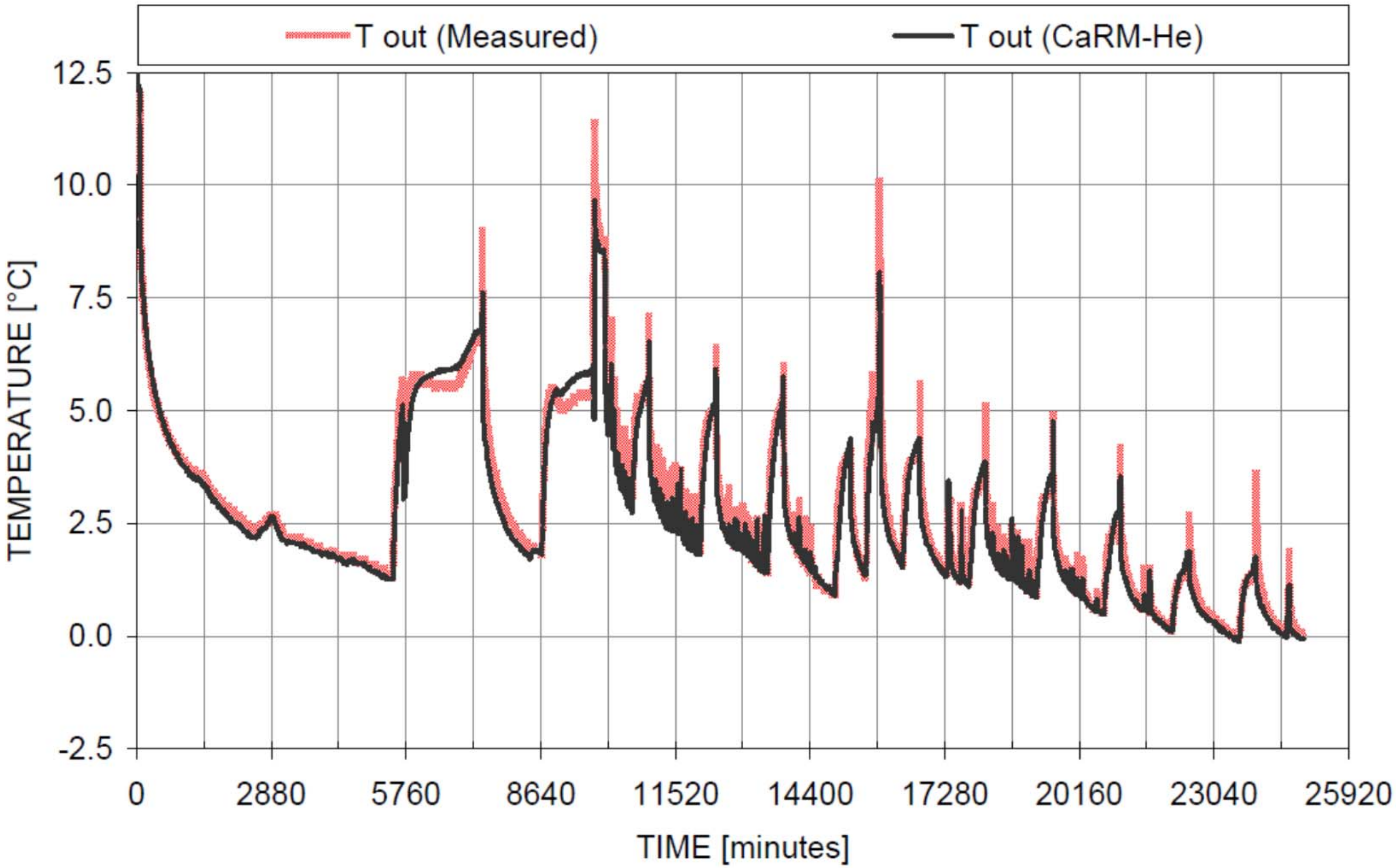
Helical Shaped Pipe: Tuning of the Model



Field measurements carried out in Erlangen, supported by Rehau (Germany)

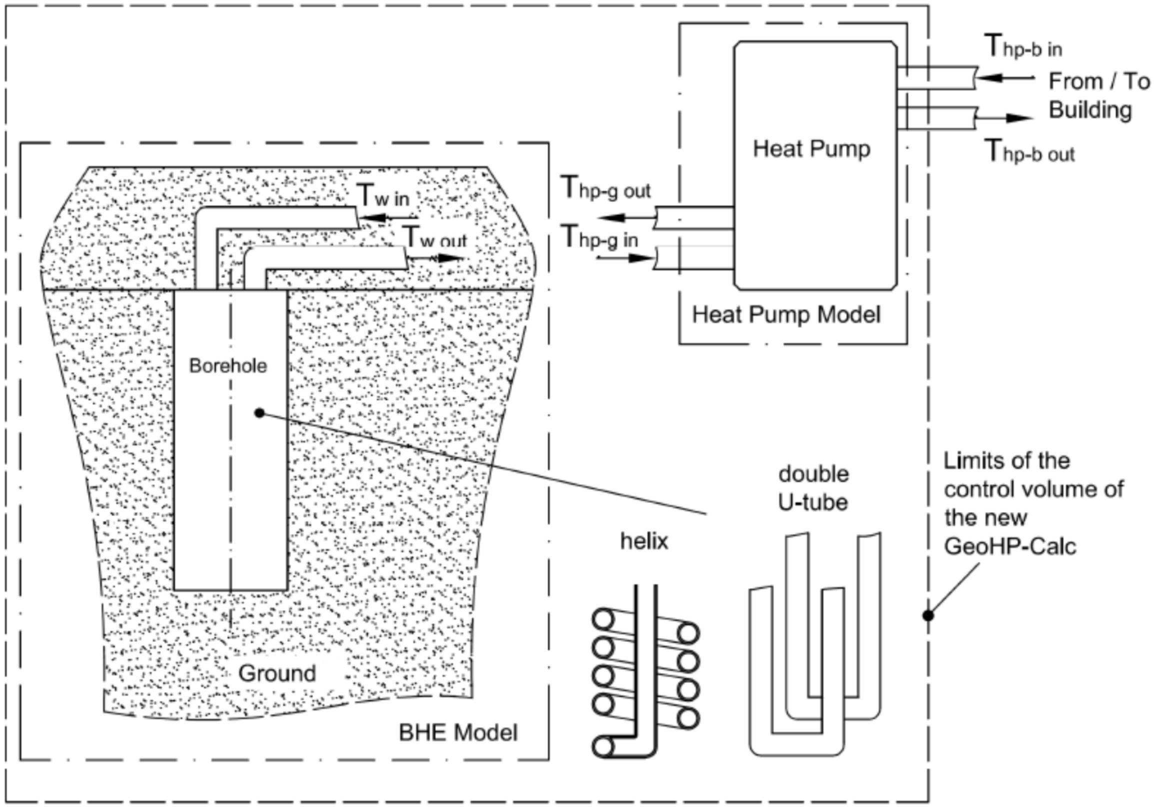


Simulations versus Measurements



Zarrella A., De Carli M. Heat transfer analysis of short helical borehole heat exchangers, APPLIED ENERGY (2013), Vol. 102 (2013) n. 2, pages 1477-1491.

Integrated Model of Borefield and Heat Pump (1)



CaRM + HP model

GeoHP-Calc

Analysis of two types of ground heat exchangers: **helix and double U-tube in two Italian climates (Venice and Naples)**.

Hourly simulations were conducted for six one-year simulation times, and the results of the last simulated year were then compared.

Integrated Model of Borefield and Heat Pump (2)

	Venice	Naples
Heating peak load [kW]	7.6	5.6
Cooling peak load [kW]	-7.7	-8.3
Annual heating energy [kWh]	7582	3513
Annual cooling energy [kWh]	-6234	-7010

Residential Building

$$\frac{\text{Annual Heating Energy}}{\text{Annual Cooling Energy}}$$

	Venice	Naples
Ratio	1.22	0.50
	slightly heating dominant	considerably cooling dominant

How Can We Make the Comparison?

This case study maintained the same energy rate exchanged with the ground (i.e. within a predefined tolerance).

As a consequence, the number of the boreholes was increased or decreased as needed in order to keep the difference between the seasonal electrical consumption of the two heat pumps within a tolerance of around 5%.

Since building loads act as a boundary condition regardless of BHE type, this meant that the seasonal energy rates exchanged with the ground and the seasonal COP values were also identical.

Calculated values of the heat pump during the sixth year.

		Venice		Naples	
		Helix	2U-tube	Helix	2U-tube
Annual electrical consumption	[kWh]	2501	2464	2169	2135
Mean COP during heating time	[-]	5.1	5.2	5.3	5.3
Mean COP during cooling time	[-]	5.3	5.4	4.3	4.4

Results (1)

Considering the low building loads, the boreholes were arranged along a line spaced 7 m apart.

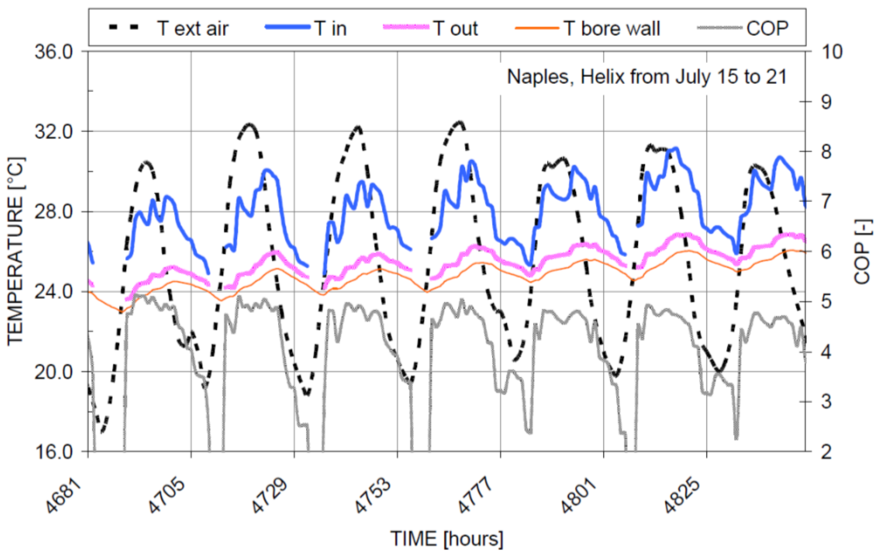
At the end, we found:

Helical Shaped Pipe	Double U-tube
6 boreholes x 15 m	3 boreholes x 60 m
Total borehole length: 90 m	Total borehole length: 180 m

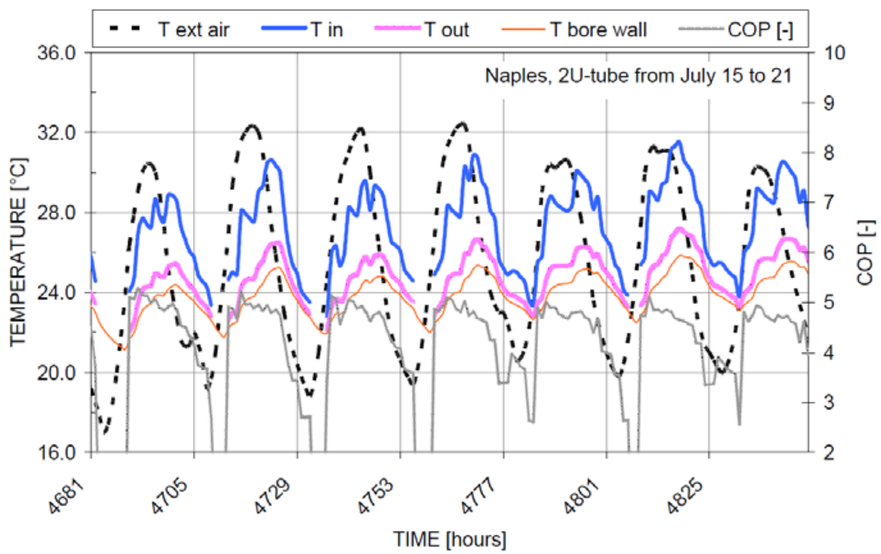
The helical-shaped pipe reduced the total borehole depth by about 50%, regardless of the load profiles (Venice and Naples).

Results (2)

Temperature and COP of helical ground heat exchanger 15 long and 2 U-tube 60 m long in Naples:



Helical Shaped Pipe

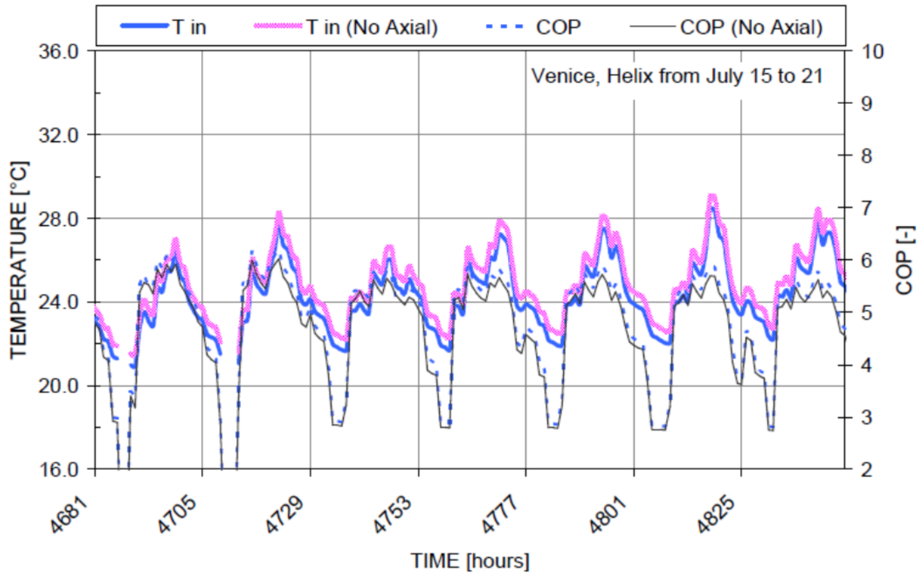


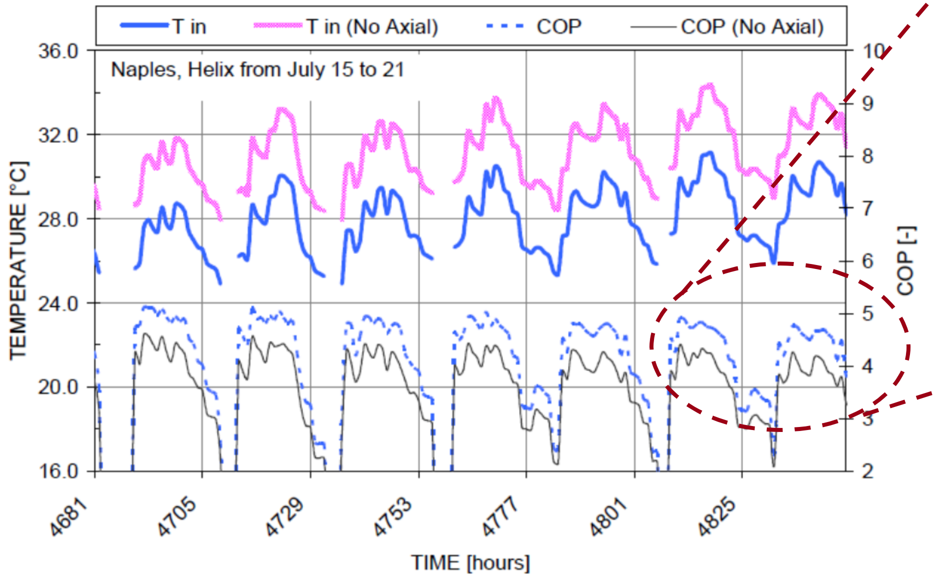
Double U-tube

The borehole wall temperature of the helical shaped pipe was lower than the corresponding value in the double U-tube during the winter and it was higher during the summer:

... this result is due to the influence of the weather (axial effects).

Results (3)

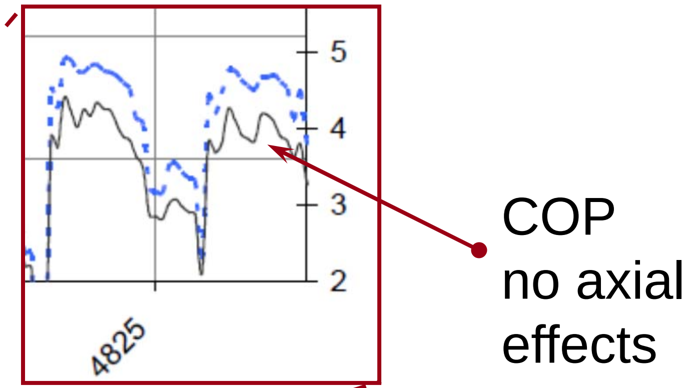




We analyzed the effect of the axial heat conduction on the COP of the heat pump:

For helix 15 m long:

in Venice with an almost balanced case, the influence is negligible.



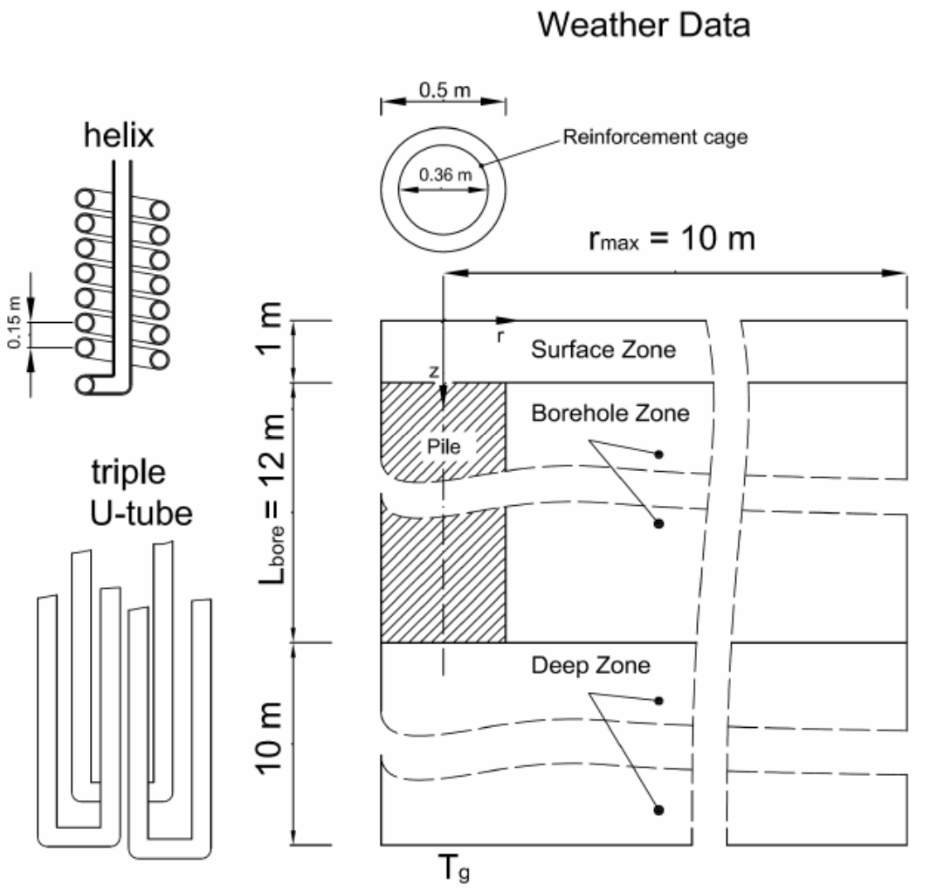
in Naples with a cooling dominant case, the influence is NOT negligible.

Energy Foundation Piles

Helical Shaped Pipe versus Triple U-tube in parallel

Zarrella A., De Carli M., Galgaro A. Thermal performance of two types of energy foundation pile: Helical pipe and triple U-tube, Applied Thermal Engineering (2013), Vol. 61 (2013), pages 301-310.

Case Study



Weather data of Venice

Grout:

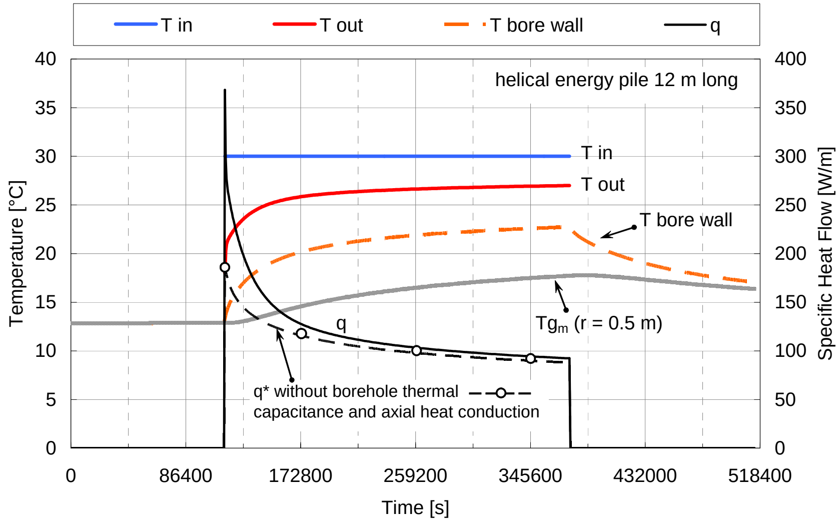
thermal conductivity = 1.2 W/(m K)
thermal diffusivity = 0.75 x 10^{-6} m^2/s.

Ground:

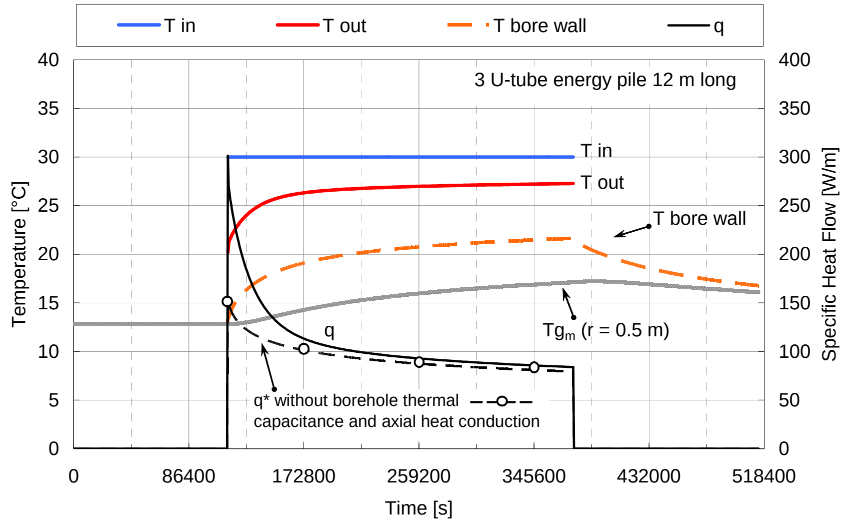
thermal conductivity = 1.8 W/(m K)
volumetric thermal capacity = 2.4 MJ/(m^3 K).

Borehole depth is the same

Case Study: Results (1)



Helical Energy Pile



3 U-tube Energy Pile

We found the heat-carrier fluid temperatures and the specific heat flows q (per unit length of the pile) exchanged with the surrounding ground.

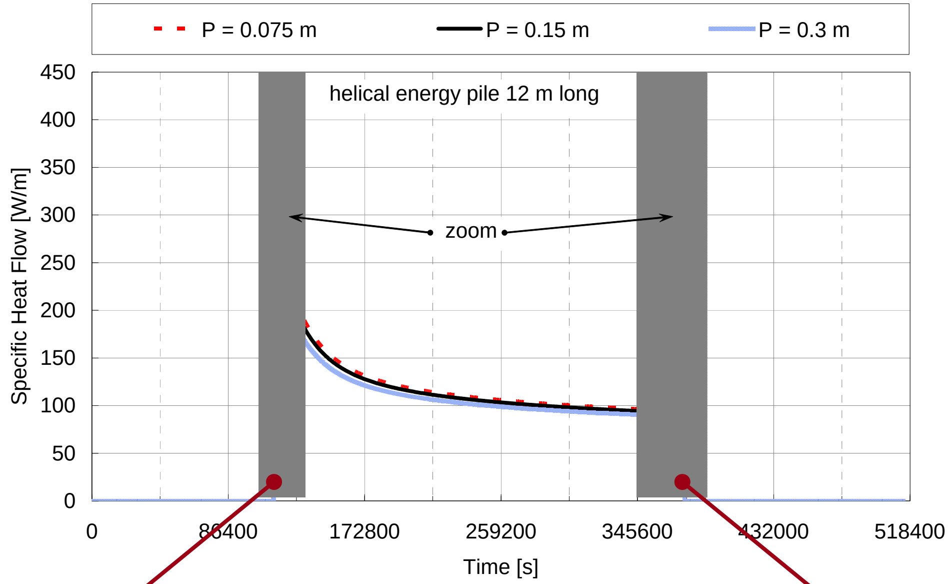
The specific heat flow q* is calculated without the borehole thermal capacitance and the axial heat conduction along the depth.

Compared with the 3 U-tube, with the Helical Energy Pile we found:

- at the peak value, an increase of about 23%
- at regime, an increase of about 9% in terms of specific heat flows

Case Study: Results (2)

Effect of the **pitch P** between the turns.

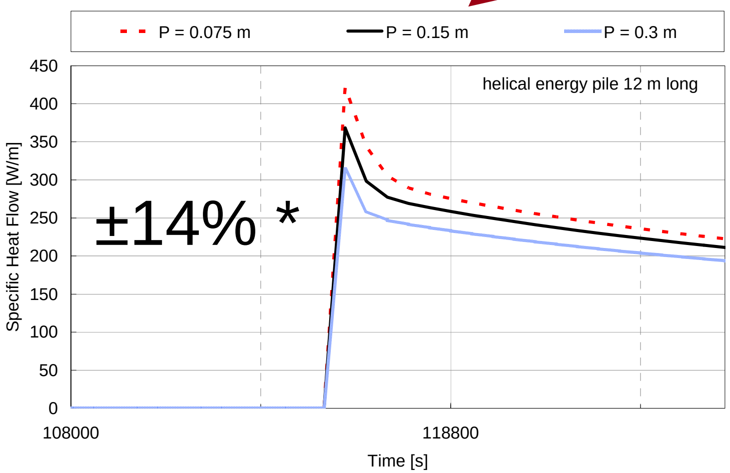


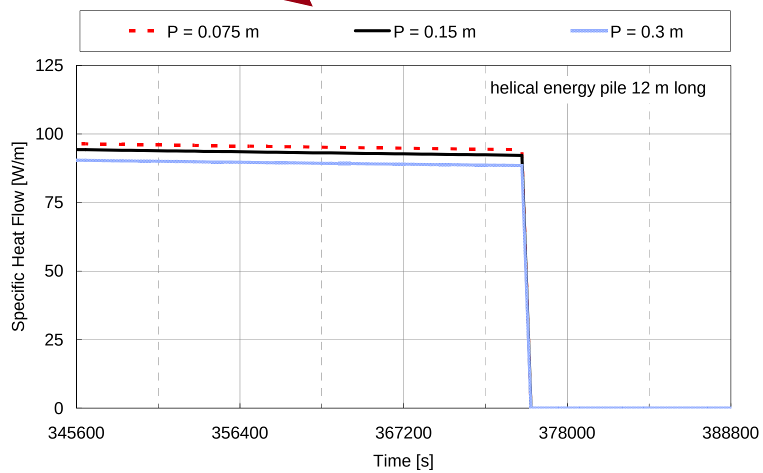
P:

0.075 m

0.15 m

0.3 m





* Reference: 0.15 m

Negligible

Your Question

... Can or can't have the CaRM tool, that is the question…

AZ, MDC: Yes, you can.

Anywhere, Anytime, Anyone

The first freeware complete version will be released in January 2014,

with an interface developed in Microsoft Excel to manage the Input and Output Data.

Please, contact us…

… Thank you for your attention

Michele De Carli (PhD)
michele.decarli@unipd.it

Angelo Zarrella (PhD)
angelo.zarrella@unipd.it