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EU project “Cheap-GSHPs”: the geoexchange field laboratory

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Abstract

The Molinella test site is the open-air laboratory of the EU project entitled “Cheap-GSHPs: Cheap and Efficient Application of Reliable Ground Source Heat Exchangers and Pumps”. Here, innovative helical heat baskets and steel coaxial probes are installed next to the traditional double-U. The tests involve the probes design as well as materials and drilling techniques and machines, therefore the newly developed GSHEs can be directly compared with the traditional ones with respect to technical issues and energetic performances.
The Molinella test site therefore represents a very extraordinary possibility to improve the knowledge of heat transfer processes in shallow geo-exchange systems.

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Keywords: Cheap-GSHPs; GSHE; heat basket; coaxial probe; thermal conductivity.

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1. The Cheap – GSHPs European project

The Cheap – GSHPs Horizon 2020 project (grant agreement No. 657982) focuses on the development of more efficient and safe shallow geothermal systems and on the reduction of their installation costs. For this purpose, the already existing vertical borehole is improved and innovated by developing a new installation technology and the design of a coaxial steel probe. In addition, a new basket type Ground Source Heat Exchanger (GSHP) has been designed and novel installation methodologies have been developed and tested. The project aims at bringing the overall cost of the realization of shallow geothermal systems down, taking into account not only the GSHE itself but also the design costs of the GSHP arrays, the drilling technologies, the implementation of the ground response tests and, finally, the integration of the heat pumps with the heating and cooling systems already existing in the building. Moreover, the project develops a Decision Support System (DSS) and other design tools for the proposed technologies compared to other low enthalpy geothermal systems. In the DSS the local geological aspects as well as the feasibility and economic assessments are evaluated, by considering different plant set-up options, selections, designs, installations, commissioning and operations. These tools will be made publicly available on the web to users (see web site http://cheap-gshp.eu/), including comprehensive training to lower the market entry threshold.

Therefore, the Cheap-GSHPs project addresses the issue to develop drilling machine tools capable of drilling holes with diameters of about 350 mm at various depths and study, simulate and develop materials and production methods for heat basket type GSHE's fitting these boreholes. With a view to improve safety and reduce permitting requirements the improved basket type GSHEs are installed at depths of 15 meters.

In parallel, a series of innovative drilling heads for existing drilling machines has been developed and built. These studies and developments have been performed in order to build an innovative 'Hybrid' drilling machine with the integration of the several techniques considered capable to quickly install coaxial steel GSHEs. In addition, some tests have been performed in order to optimize the design of the coaxial steel GSHE. In order to improve safety and reduce permitting requirements the improved coaxial GSHE's are installed also at depths of 40 – 50 meters.

2. Test site characterization and analysis

2.1. The Molinella test site

In order to carry out the tests, in Molinella (Bologna, Italy) a test site has been planned and completed.
In Molinella, in an area of 300m^2, seven different types of Borehole Heat Exchangers (BHE) have been installed:

- n. 4 coaxial probes made of different materials (PVC and Stainless steel) and with different lengths (96 and 50m) and diameters of internal and external tubes;
- n. 2 helical shaped ground heat exchangers - heat baskets (15m length, different pipe diameters and pitches);
- n. 1 traditional double-U (50 m length), where the borehole was filled with enhanced geothermal grouting in the past.

The monitoring equipment is constituted by a 25m long piezometer for shallow aquifers and a 100m borehole equipped with hybrid fiber optic distributed temperature cable at total depth.
In fig.1 the planimetry of the test site is depicted.

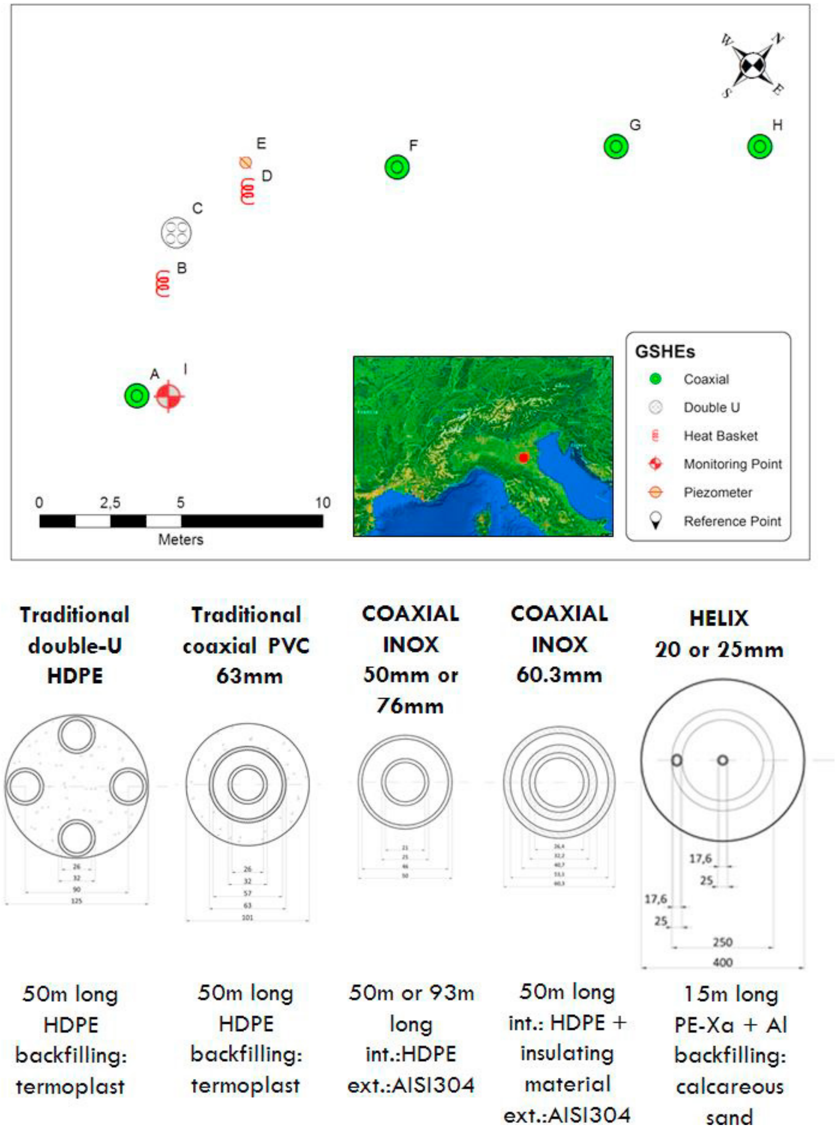

Fig. 1. The Molinella test site planimetry.

The setting up operation of the newly developed GSHEs typologies carried out in the Molinella field test (see fig.2 and fig.3) allowed direct testing of the drilling and installation procedures in terms of timing and practical reliability.

Given a geological setting and thermal load, the heat exchange capacity of a ground heat exchanger depends on the used materials and probe dimensions (length, diameter and thickness). Ground thermal properties have been identified by means of direct, on site measurements on the cores.

In addition, for each probe a Thermal Response Test (TRT) is performed and analyzed by comparing the results obtained by applying numerical analysis based on different modelling approaches. Finally, a hybrid fiber optic cable with distributed temperature sensors is deployed into the 100m borehole. This installation allows measuring directly the temperature along the whole length of the well every meter continuously. Therefore, it will be possible to measure directly the thermal response of the deposition sequence every meter while the TRT is carried out in a nearby GHSE. Moreover, the hybrid optic fiber can simulate a TRT, by the mean of a series of resistance wires coupled with the fiber optic cable.

Fig. 2. Some installation phases of the newly developed Helix GSHP at the Molinella test site.

Fig. 3. Some installation phases of the newly developed Coax GSHP at the Molinella test site.

2.2. Geological setting and direct thermal measurements on the cores

The test site is located in Molinella, between the city of Ferrara and Bologna in the Po Plain. The geological setting of the site is typical of these lowland areas. Unconsolidated sediments come contributed from the Western and Central Alps to the North and from the Northern Apennines in the South to the area of the test site. Limestones, felsic intrusive rocks, and sandstones form the major outcropping units of the Western Alps whereas the Central Alps are characterized by large areas consisting of metamorphic and ophiolitic complexes. The geology of the source region for the Apenninic rivers consists predominantly of Cretaceous to Pliocene sedimentary rocks. In the area of the test site lower and upper delta plain deposits alternate with alluvial plain sediments [1]. The local stratigraphy is known from a 100 m core drilling well, made on purpose. The lithological sequence is typical of a quaternary floodplain deposition environment, dominated by silt and silty clay deposits, alternated with sandy layers. These kinds of sediments are the ones to be more prone to variations of the geotechnical and thermal properties due to temperature variations [2,3]. The water table is 1.5m below the ground level.

For all the main recognized layers, the thermal properties (conductivity and capacity) have been directly measured on the collected core samples by a hand–held instrument *ISOMET 2114-Thermal properties analyzer* [4], which applies transient heat transfer by a probe placed in direct contact with the tested sediment. The measurement is based on the analysis of the temperature response generated by each material to heat impulses induced by electrical heating. As the sample used in the test is bigger than the volume involved in the measurements, the heat-loss in the surroundings are minimized.

In table 1 the main layers of the sedimentary sequence are described and the measured values of thermal conductivity are reported. The measurements were performed on site, soon after the coring, in order to maintain the sediments natural water content.

Table 1. Sedimentary sequence of Molinella test site with the visual description of the deposits and the thermal conductivity directly measured by means of ISOMET.

Depth	Visual description	Thermal conductivity [W/mK]
0.9 – 1.5	Weakly silty clay, black, with scattered root remains	1.04
1.5 – 4.2	Clayey silt with medium-fine sand, hazelnut. From 2.90 m visible gray glazes and ocher oxidation frustules	1.28
4.20 – 7.0	Silt with medium-fine sand, sometimes weakly clayey, gray with ocher oxidation glazes. Between 6.10-6.30 m dark gray/blackish level. At the bottom clayey silt with medium-fine sand	1.24
7.0 – 9.8	Silty clay, gray with slight ocher glazes. Abundant blackish oxidation frustules, particularly concentrated from 9.20 m. Overconsolidated	1.05
9.8 – 12.3	Peaty clay with undecomposed wooden remains and roots. Between 10.0-10.3, 10.5-11.0 and starting from 11.5m more clayey levels.	0.62
12.5 -15.6	Silty clay, gray with ocher and black glazes. millimetric limestone concretions and blackish carbonaceous frustules present. Between 12.8-12.9 level with medium-fine sand starting from 14.0m thin sandy level	1.02
15.6 – 16.9	Weakly silty clay, solid, with blackish organic level between 15.7-15.8 and 15.9-16.0 m. blackish carboneous frustules also present	0.93
18. 4 – 21.1	Weakly silty clay, solid, hazelnut with light gray glazes, passing to hazelnut sandy silt at 19.4 m. Between 20.1-20.5 m silty clay level	1.07
21.1 – 25.5	Silty clay, solid, gray with blackish and hazelnut glazes/stripes, passing to hazelnut from 24.0 m. Thin millimetric sandy levels and millimetric limestone concretions present	1.25
28.6 – 31.2	Silty clay, hazelnut with bluish stripes and ocher oxidation frustules. Thin millimetric sandy levels present	1.12
31.2 – 32.2	Silty clay, gray/hazelnut passing to gray/blackish, with ocher oxidation pitting and thin millimetric sandy levels	1.39
33.5 – 38.1	Sandy silt and/or silty medium-fine sand, hazelnut passing to gray at 34.0 m. Ocher oxidation speckles present	1.38
38.6 – 42.4	Silty clay, gray/bluish, with thin millimetric sandy levels, passing to sandy silt at 39.6 m	1.73
42.4 – 46.8	Medium sand, gray, loose	1.66
46.8 – 50.9	Weakly silty to silty clay, gray/bluish with millimetric limestone concretions. From 49.6 m up to centimetric blackish carboneous frustules and limestone concretions present	1.06
50.9 - 55	Weakly sandy silty clay, gray/bluish with millimetric limestone concretions. From 53.1 m takes blackish glazes with blackish carboneous frustules, even centrimetric	0.87
57.5 - 60	Clay and/or weakly silty clay with light gray-dark gray/blackish spots passing to light gray/bluish from 58.7 m. millimetric limestone concretions and centrimetric organic level present at 59.5 m	0.91
60.0 – 63.9	Plastic silty clay, dark gray/blackish, passing to weakly silty clay, solid, with ocher oxidation patinas. From 61.0 m numerous limestone concretions present both millimetric and centimetric. Between 63.0 and 63.5 gray silty clay level with ocher and gray/blackish patinas and blackish carboneous frustules	1.16
63.9 – 64.5	Sandy silt, gray/dark gray	1.38
70.1 – 72.2	Sandy silt and/or silty medium sand, gray	1.75
72.2 – 72.7	Clay and/or weakly silty clay, blackish with blackish carboneous frustules and undecomposed wooden remains. Solid	1.05
74.2 – 76.9	From weakly sandy to sandy silt, gray, alternated with decimetric gray silty clay levels with ocher patinas. Between 76.2-76.8 m becomes dark gray/blackish	1.47
76.9 – 80.2	clay and/or weakly silty clay, gray/dark gray with light gray stripes and ocher oxidation patinas. At the base blackish pittings. Solid. Between 78.8-79.5 m dark gray/blackish sandy silt level	1.19
81.3 – 82.9	Medium-fine sand with medium gravel, gray. The gravel becomes less recurrent starting from 81.9 m	1.33
82.9 – 87.1	clay and/or weakly silty clay, gray, from solid to hard, sometimes with light gray/blackish spots. Rare millimetric limestone concretions and blackish carboneous frustules present. Between 85.0-854 m organic clay level with some undecomposed wooden remains	1.62
87.1 – 87.7	Sandy silt, gray/dark gray	1.29
90.3 - 100	Medium-fine sand, gray/dark gray, loose, sometimes with thin centimetric from weakly silty to silty levels	1.68

The general aim of this activity is to obtain data of the sediments' thermal properties to be collected in a database which will be populated by thermal properties values obtained from direct measurements performed on samples coming from other test sites planned within the Cheap-GSHPs European project. This database will be useful to improve the definition of the thermal properties of defined granulometric categories of sediments, needed to correctly evaluate the thermal exchange capacity of a given geological setting and, therefore, to correctly design the probes total length in GSHP systems. In literature [5,6], the reference values of thermal properties of sediments categories are quite generic, as reported in table 2. One of the aims of the Cheap-GSHPs European project is to improve the definition of thermal properties of sediment categories.

Table 2. Thermal conductivity reference values extracted from literature (i.e. VDI 4640 [5] and Eskilson [6]). For every category the wet condition is considered, to be more in compliance with the local water table condition.

Sediment category	**ESKILSON**			**VDI 4640**		
	min	max	*recommended value*	min	max	*recommended value*
Clay	0.9	2.22	*1.6*	0.9	2.3	*1.7*
Silt	1	2.3	*1.8*	0.9	2.3	*1.7*
Sand	1.73	5.02	*2.4*	1.7	5	*2.4*
Clay and sand	1.315	3.62	*2*	1.3	3.65	*2.05*
Silty clay	0.95	2.26	*1.7*	0.9	2.3	*1.7*
Silty sand	1.365	3.66	*2.1*	1.3	3.65	*2.05*
topsoil	0.9	2.22	*1.6*	0.9	2.3	*1.7*
Peat	0.2	0.7	*0.4*	0.4	0.4	*0.4*

On the other hand, the measured values can be used to evaluate the thermal exchange capacity for conduction of the whole stratigraphy sequence, in order to compare the global value with the one derived from the TRTs carried out in the tested probes in the Molinella test site. The calculation could be done by means of a weighted mean on the layer thickness. This way provides a rough estimation, as it does not take into account the interferences between contiguous layers and neither the heat transfer capacity of the aquifers through convection processes.

2.3. Ground Response Tests and Modelling analysis of the energetic performances of the new GSHEs

In the test site a double-U (the reference probe), four coaxial and two helical heat exchangers have been placed. The installation of these of ground heat exchangers in the same soil allows the comparison of the thermal behavior between probes with different geometries.

The ground heat exchangers have been tested through the TRTs performed from October 2016 to February 2017. The data collected during the TRTs will be analyzed by means of analytical and numerical models. In particular, the analytical models which will be used are the simplified infinite line source [7], the infinite line source [8] and the cylindrical source [9,10]. In the first two cases the borehole heat flow is represented as an infinite line source or sink inserted into the ground; hence the effects of heat flows along the borehole axis are considered negligible. The last analytical model uses an infinite cylinder as source or sink and the axial heat flux is always neglected as in the previous two cases.

The last approach for the analysis of the TRT data, will use the numerical model CaRM (Capacity Resistance Model) developed at the Department of Industrial Engineering of the University of Padova, In this case, the ground heat exchangers will be modeled considering in detail the geometries and properties of the probes. Unlike the previous approach, this one considers the heat transfer along the depth direction (i.e. axial heat transfer) as well as the radial direction and, in addition, the effect of the weather on the earth's surface in terms of both thermal convection and short-long wave radiation. The simulation tool CaRM is based on electrical analogy and it is used to simulate ground heat exchangers, as described in [11-15]. The model allows considering the fluid flow pattern along the classical vertical ground heat exchangers as an U tube, coaxial pipes or helical heat exchangers. The mean ground temperatures at different distances from borehole are calculated and also the interference between more boreholes is taken into account. Starting from the supply temperature to the heat exchanger, the outlet fluid temperature and the ground temperature in each node are calculated, step by step.

All the tests were performed by setting the same specific power and the same temperature difference on probes of the same length, in order to compare the obtained results. The obtained results will be the subjects of further publications, at the end of the data comparisons.

3. Conclusions

The Molinella test site is particularly remarkable for the possibility to directly compare the energetic efficiency of the tested GSHEs when submitted to representative load conditions, which today has not been done. TRT tests which are primarily designed to determine the thermal conductivity of the soil under steady state conditions and the borehole resistance have been performed on each type of GSHE

Up to now, the first outcomes provided by the Molinella test site show significant performances of the newly developed GSHPs in terms of ease and timing needed for installation. For the coaxial probes, the easy installation is due to the applied piling technique in combination with the drilling tools developed for this purpose. For the helix, a tailor made technique has been developed by building a more powerful drilling machine based on a combination of auger and casing tools to achieve larger diameters.

As for the comparison of the energetic performances, the TRT results will be analyzed by means of several analytical and numerical model outputs, therefore obtaining a comparison between the results provided by the different applied approaches. On the other hand, the overall ground thermal conductivity value obtained from the TRT interpretation shall be compared with the ones derived from the direct thermal measurements performed on the sediments core samples. Finally, the study of the thermal contribution of the different underground layers interested by the heat exchange processes will be deepened by coupling the traditional TRT outputs and the optical fiber temperature recording system.

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