Performance evaluation of a homemade cylindrical basket heat exchanger, by a multi-sensors monitoring campaign

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ABSTRACT

Very Shallow Geothermal Systems (vSGS) can be economic attractive, even in case they do not present high efficiency, when excavation and realisation costs are significantly lowered by on-site construction and management; a typical case is the rural environment, where necessary equipment is usually already owned by final users and customers.

Up to date, in contrast with the increasing utilisation, a wide scientific literature on the performance of vSGS does not exist, presumably because of their "plug-and-play" nature and relatively low efficiency. In fact, these systems can be object of high improvements, too, firstly by an increased knowledge of thermal interaction among underground, baskets and ambient temperature wave, and the consequent variations following seasonality and building energy demands.

The paper presents the results of an experimental monitoring campaign on a homemade cylindrical geothermal basket, which will be connected to an underground cellar, for improving thermo-hygrometric comfort of wine.

The vSGS and the monitoring system (composed by a set of underground temperature sensors and a dedicated Micro-Thermal Response Test machine M-TRT) have been realised entirely in-house, without accessing to commercial products. Through a 3D displacement of sensors inside and outside the basket, it has been possible to determine the entire thermal behaviour of the geo-exchanger, subjected to different thermal pulses and to changing climate.

Finally, it has been possible to determine a range of costs for such in-house installations, when local conditions allow an easy and efficient on-site realisation.

1. INTRODUCTION

Shallow Geothermal Systems (SGSs) provide thermal energy by exploiting underground heat and transferring it into a building (IGSHPA, 2013). Heat can be extracted from any source, no matter how cold, but a warm source allows higher efficiency. SGSs have the potential to work in reverse mode, to provide cooling, as well (Giambastiani et al., 2014). The benefits of this technology concern the primary energy savings and the local and global CO_2 emissions reduction, when compared to alternative air conditioning systems (EPA, 2015).

In recent years, following the geothermal market increment and the general aim to meet larger sections of population, new needs to decrease installation costs of SGS and requirements for better adaptation to specific building energy loads have emerged. Some very Shallow Geothermal Systems (vSGS) recently appear on the market, such as Geothermal Baskets (Ex.: Betatherm, Uponor), Spiral Heat Exchangers (Ex.: Rehau), and Horizontal Ground Collectors (Ex.: Rehau, Haka Gerodur). These vSGS are buried in underground at a maximum depth of 6 m to contain installation costs, with the drawback that they are therefore affected by climate seasonal influence (Kusuda and Achenback, 1965), with evident exceptions if they are installed below buildings (Mihalakakou et al., 1995).

In this paper, we present a long-term thermal response test specific campaign for geothermal baskets, conducted on a homemade cylindrical basket heat exchanger. Then, we present a specific data analysis of TRT data, useful for the design of a geothermal basket field. Finally, we propose an approach in basket designing, which takes into account all the variability parameters affecting the basket performance: seasonal variation of underground temperature, moisture variation affected by rainfall and irrigation and on/off periods of extracting – injecting energy from/to the basket.

2. OVERVIEW ON GEOTHERMAL BASKETS AND THEIR APPLICATIONS

The most known variant of borehole heat exchangers, valid only for modest power needs, is the installation of horizontal ground collectors. In such case, the achievement of the required power occurs through the lying of collectors on a free area, about 2 m deep from the surface.

In the last years, one of the main research topics has been to extend the thermal exchange surface by maintaining invariant excavations and drilling length (Self et al., 2013). In this way, the thermal exchange is concentrated in a smaller volume, reducing the need of space and, consequently, the installation costs. The objective is to extract more power per meter of drilling or excavation, with respect to traditional configurations. The way to achieve this result is basically the introduction of spirals among existing types of geo-exchangers, both for vertical and horizontal solutions.

A possibility to use spiral method on the very shallow underground is given by geothermal baskets (Machler, 2011). The commercial solutions are designed to reach a depth of 1 – 4 m with a diameter of 2,4 m (upper side) and 1,4 m (lower side). The conic shape is due to the simplicity of transportation on vans and trucks, once the baskets are stacked. The spirals are fixed to the four sides of the baskets. The installation is made by an excavation to reach the required depth. Usually the upper side is buried beneath ground level in order to avoid freezing problems at the surface. Commercial baskets can provide around 0,5 – 2,0 kW (varying depending on the pipe length and the subsoil conditions), so that, for higher power needs, a geothermal basket field should be installed. Appropriate distance among baskets should be taken into account in the design, to avoid thermal depletion of the subsoil.

Similar to the theoretical concept of baskets, helical heat exchangers are designed for vertical drillings (Zarrella and De Carli, 2013; Moch et al., 2014); the return pipe turns around the delivery pipe, along the length of the hole. Thanks to this design, the exploitable power per meter is much higher than the traditional vertical geometry. The drawbacks are the difficulty in transportation and the large borehole diameter (around 400 mm), which imply that, to keep the economic convenience, the spirals cannot be deeper than 6 - 10 m. As for geothermal basket solutions, the massive amount of exploitable energy can lead to a fast thermal depletion of the underground, so the appropriate distance among spirals and the long-term behaviour should be carefully considered in the design.

In both cases of baskets and helical heat exchangers, because of their relatively low depth without interaction with confined aquifers, there is usually no need of cementation with consequent cost and materials reduction. Moreover, the large diameter of the excavation facilitates the embedding of special devices to improve the thermal performance of the system, such as irrigation equipment to increase the moisture content of the soil and then enhance thermal energy recovery (Rabin and Korin, 1996).

In fact, moisture content of the subsoil around the spirals modifies the exploitable heat and/or the heat dissipation potential of the underground. We should take into account this phenomenon when performing a dedicated thermal response test campaign to define the performance of a geothermal basket.

A mixed geometry between conic baskets and helical heat exchanger is the so-called cylindrical basket heat exchanger (Boughanmi et al., 2015). They are currently not a commercial configuration, because of transportation issues, but some cases of installation exist, and they can be economic convenient solutions when the baskets are realised directly on site (Tinti et al., 2016).

3. THE THERMAL RESPONSE TEST CAMPAIGN PERFORMED

The Thermal Response Test (TRT) is the standard well-known production test for SGS (Sanner et al., 2013). It was primarily used to determine three important quantities for Borehole Heat Exchangers (BHE) design: the undisturbed ground temperature, the equivalent ground thermal conductivity of subsoil and the borehole thermal resistance (Eklof and Gehlin, 1996).

The standard TRT procedure consists in providing a constant heat injection for a period of about 3 days, and then measuring the inlet and outlet temperatures of the circulating fluid (Beier, 2008). Focusing on the data analysis procedures, the most common and standardised technique is the Infinite Line Source (ILS) method, which allows to get, by inverse analysis based on logarithm regression on data set, the ground thermal conductivity and the borehole thermal resistance of a BHE (Mogensen, 1983).

Many variations from this scheme (test procedure and analysis), tested and implemented in recent years, exist; the general purpose is to try to take into account the whole variety of thermal phenomena, hydro-geological context and geo-exchangers design configuration, which cannot be entirely tackled by the standard procedure and analysis method (Spitler and Gehlin, 2015).

We performed a TRT campaign analysis on a geothermal basket, different from the standard procedure under different aspects.

In this work the geothermal basket was realised on site and installed in the surface underground in a courtyard of a wine cellar, in Emilia Romagna Region (Italy), at a maximum depth of 2,0 m below ground level (included the 0,5 m soil coverage above the basket).

The subsoil temperature distribution had been deeply analysed in the area of intervention. Four monitoring boreholes, equipped with temperature sensors PCE-

HT71, were installed at different depths and location. Borehole I and II are vertical, and they are both equipped with 3 temperature sensors located at 2, 4 and 6 m depth (Tinti et al., 2014). Borehole III, with a total length of 17 m, is inclined (10° from horizontal plane) and it hosts 3 temperature sensors at 1,8, 2,6 and 3,7 m depth, 2 of them (the deepest ones) located below the building. Borehole IV is vertical and shallower than the others are; it hosts temperature sensors at 0,10, 0,65 and 1,20 m depth (Tinti et al., 2015). The set of sensors was used to calibrate on site some new models for the definition of temperature distribution in the subsoil, useful for the design of underground buildings (Benni et al., 2016). The geology of the examined area, up to 6 meters depth, is basically composed by clay, with different degrees of water content, strongly dependent on the weather conditions. The long-term temperature monitoring campaign allowed us to define an in situ value of thermal diffusivity of the clay, which is around 0,029 m^2/days.

The geothermal basket was installed in this context (Figure 1). It was placed – distance centre to centre – 1,4 m East from Borehole I (WGS84 coordinates 44°24’46,20” N, 11°39’17,11” E); the basket was then connected to a Micro-Thermal Response Test machine (M-TRT) with a maximum heating power of 1,5 kW (Figure 2).

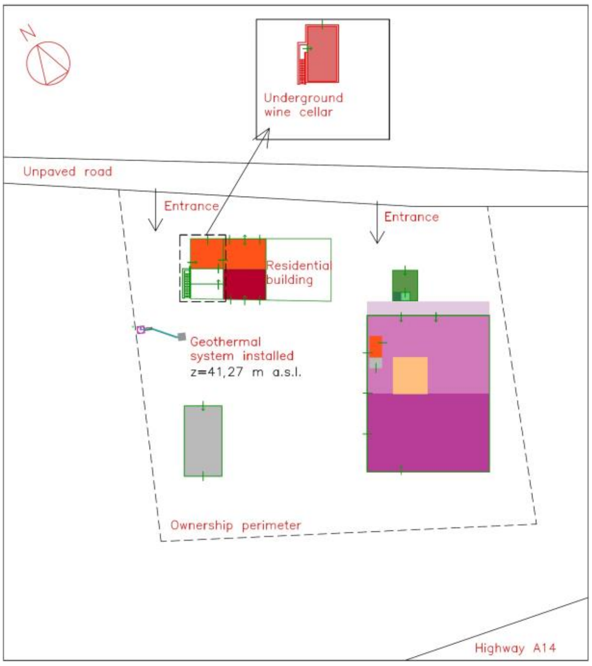

Figure 1: Map of the area highlighting the geothermal system location. z (m) represents the absolute altimetry above the sea level.

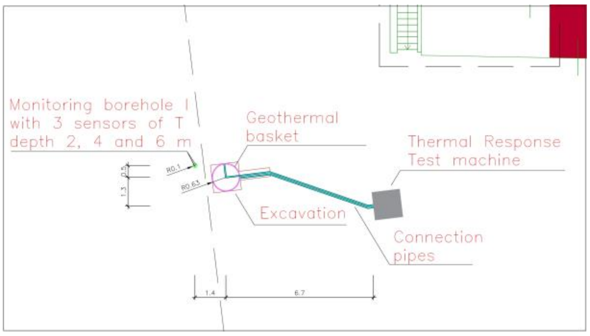

Figure 2: Detail of the system installed to monitor the performance of the very Shallow Geothermal System: monitoring borehole, geothermal basket and Micro-Thermal Response Test machine.

The geothermal basket is composed by a metal support, realised in the laboratories and subsequently brought to the field, and by HDPE pipes, which were coiled around the support directly on site (Figure 3a). The basket was then installed in the ground at the desired depth by a small size excavator, owned by the farm. Inside the excavation, four additional temperature sensors were installed, two at the centre of the basket (0,5 and 2,0 m) and two at its border (0,5 and 1,0 m) (Figure 3b). The central return pipe of the basket and the connections between basket and the TRT machine were properly insulated. Table 1 resumes all the details concerning the geothermal basket.

Figure 3: Geothermal basket during realisation phase (a) and buried in the ground, with the pipes allocating the sensors (b).

Table 1: Details of the geothermal basket.

Width of the basket	1,2 m
Height of the basket	1,5 m
Length of the pipes	60,0 m
Number of coils	13
Pipes material	PE 100 DN 32 PN 16
Ground coverage above the basket	0,5 m
Depth of the basket	2,0 m

According to the commercial technical specification for similar products, this type of basket configuration can exploit, at the maximum, about 700 - 800 W from a clayey subsoil, as it is our test site.

A dedicated M-TRT machine was then built in the University laboratories. The machine can provide up to 1.500 W, almost twice as the estimated exploitable geothermal power from our test site. This power level was chosen since it is the amount strictly necessary to correctly test the working mode of a geothermal closed loop system, according to the International Norm ISO 17628:2015 (ISO, 2015). Anyway, we left room for improvement and for power increment.

The built M-TRT can be illustrated as a Cyber-Physical System (CPS), which consists of a hydraulic part and an electronic part designed to manage the whole machine. The electronic control is schematically described in Figure 4. All the physical data about the status of the machine are recorded and real-time measurements are done from signal conditioning circuits. The information are then converted in digital data thank to an Analog to Digital Converter (ADC). The elaboration is performed by a microcomputer used in industrial environment called “Raspberry Pi 2”, which represents one of the best trade-off between performance and cost, available today on the market. A tailored power management has been designed to supply the electronic control system and the electrical parts, such as the pump.

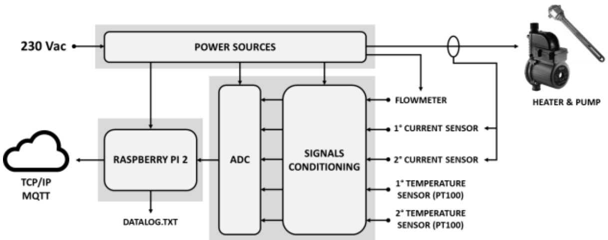

Figure 4: Schematic block of the wireless monitoring system.

The data collected by the system are then sent wirelessly to a cloud server for post-processing and real-time alarming. The communication is based on GSM/3G communication because the environment of the deployment is usually a rural area where alternative wireless connection (e.g. WiFi) are absent.

The set of measurements logged by the system concern the inlet and outlet temperature to/from the basket, the flow rate of the water injected into the circuit and the power consumptions. A circulation pump is used to move the water into the basket and to modulate the flow, which is recorded by a flowmeter connected to the electronic logger. This sensor is the flowmeter FPR204P-PC manufactured by Omega Inc. (Figure 5, and measures the actual amount of water used during the test. This commercial sensor provides an output current proportional to the intensity of the flow.

Figure 5: Model of the flowmeter used.

An electronic interface with amplifiers and filtering is present to each sensor. In particular, temperature measurements are done using PT100 sensors and an appropriate circuit permits to achieve accuracy of 0,01 °C and precision of +/- 0,03 °C.

Three 500 W resistances, which can be switched-on by the user, permit to achieve 3 levels of power, according to the type of test to perform. Electric power meters are necessary to measure the power transferred by the resistances to the water through Joule effect. The measure is performed using low-cost current transformers (CT, split-coil transformers) which can measure the current and the power (since the mains are known). The current transformers are provided with mechanical clamps, which wrap around the isolated power cable. This solution is the most convenient because it does not require the direct connection between the logger (supplied by low voltages) and the electrical equipment (i.e. pump and resistances) which are directly connected to the mains. Therefore, this non-invasive method of measurements provides additional level of safety in comparison to competing systems on the market.

The whole monitoring system is powered by the mains (230 V) and a safety control is implemented to shut down the heater, in case of over-temperature or low level of water in the tank.

Concerning the underground sensors, they are battery operated and organised in 2 tiers, as depicted in Figure 6. The first module is a wireless collector and is deployed at the ground level to permit an easy wireless connectivity. Then, three underground modules are wired connected to it, and deployed at different depths below the ground level (2, 4 and 6 m). An on-board digital temperature sensor is calibrated to achieve accuracy of 0,01 °C and precision of +/- 0,03 °C.

An aggressive power management of the modules permits this stand-alone logger to consume very few energy from the battery. The power consumption of the smart sensors can reach levels of 120 μW. Considering that the rechargeable battery on-board has a capacity of 1000 mAh, the application has an estimated lifetime of 4 years, before the battery replacement (or recharging).

Figure 6: Prototype of the standalone underground sensors.

Here the wireless communication is between the sensors and a gateway located in a more comfortable site with internet connectivity. The radio communication exploits an innovative wireless protocol called LORA (Long Range RAdio) which is capable to achieve some kilometres of radio range with a very few power. It is considered the prominent standard for the forthcoming Internet-of-Things (IoT) revolution.

Data processing and transmission are performed by local logger equipped with a Raspberry Pi 2, a well-known development board for rapid prototyping of monitoring systems, multimedia servers or IoT applications. A stack of two boards has been designed to interface the analog front-end between the sensors and the Raspberry board. A Linux operating system allows installing several software modules, such a Virtual Private Network (VPN), and permits to create secure wireless communications with remote access to the logger.

The software executing on the gateway consists of a *Connection manager*, designed for runtime management of GSM/UMTS connection and data send, and a *Data Acquisition manager*, which samples the sensors, measure the parameters for the test campaign and processes the acquired information in a continuous loop.

The Sampling rate can be controlled remotely. The system is compliant to the most recent communication protocols for the IoT and provide an interface with the Message Queue Telemetry Transport (MQTT), which is a lightweight message protocol developed on top of the well-known TCP/IP protocol. For back-up purposes, acquired data is also stored in the local file system.

The Thermal Response Test was performed by using the step pulse technique (Witte and Van Gelder, 2006), in a multiple analysis experiment, which is proved to be useful to evaluate groundwater movements (in this case, due to the very limited depth, we talk of rainfall contribution) and borehole-machine interaction (Bruno et al., 2013).

In case of vSGS, the natural temperature waves along the basket height change across time, so such long experiment can help to better understand the thermal interaction between basket and underground. The TRT was conducted uninterruptedly for 12 days, with a constant flow of 800 l/h. The time laps was divided in 3 periods equally distributed, with different power levels: 500 W (1st period), 1.000 W (2nd period) and 1.500 W (3rd period). Subsequently, we performed a release period, keeping the circulation pump active lasting additional 12 days.

During the whole TRT time laps (both charging and discharging), we run the monitoring system described above, whose list of sensors is summarised in Table 2.

Table 2: List of monitoring sensors during TRT.

Groups	Sensor	Measurement	Unit
TRT	PT100	T fluid inlet	°C
	PT 100	T fluid outlet	°C
	FPR204P-PC	Fluid flow	l/h
	CT, split-coil transformers	Power heater	W
	CT, split-coil transformers	Power pump	W
Basket	PCE-HT71	T at 0,5 m	°C
	PCE-HT71	T at 1,0 m	°C
	PCE-HT71	T at 0,5 m	°C
	PCE-HT71	T at 2,0 m	°C
Borehole I	PT 100	T at 2 m	°C
	PT 100	T at 4 m	°C
	PT 100	T at 6 m	°C

Figures 7 and 8 report the behaviour of power and fluid temperature during the TRT. The beginning temperature of the circulating water was around 12,7 °C, while the average ground temperature along the basket height was around 8,6 °C.

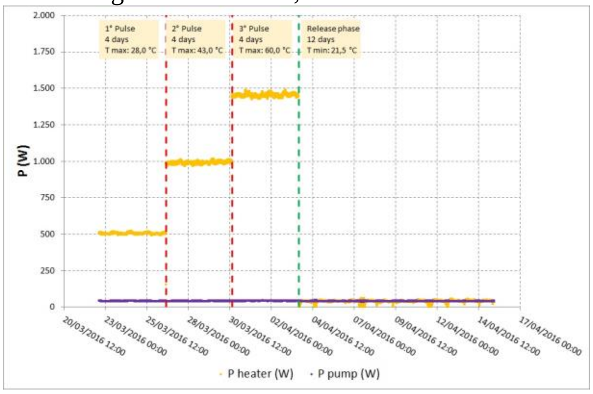

Figure 7: Multi-step power evolution of Thermal Response Test performed.

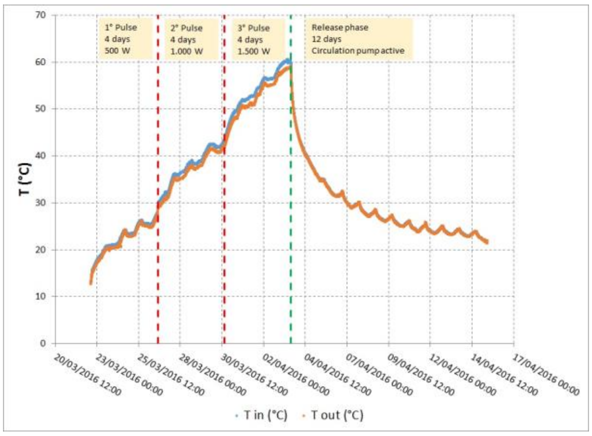

Figure 8: Behaviour of inlet and outlet fluid temperature.

Just looking at the data of the multi-step TRT, some interesting preliminary considerations can be found:

- Although the presence of insulation for M-TRT and the connections above ground, the top of the basket, placed at 0,5 m depth, is strongly affected by weather daily variations, and so the circulating fluid. The fluctuations decrease when injecting additional power, and they tend to disappear at high load levels, which are however not reached in normal operation of the geothermal heat pump system, because of unacceptable efficiency losses;

- The trends of the different step-pulses, excluding fluctuations, follow the semi-logarithmic behaviour, tending to a stabilisation after 4 days of operation, before the next power injection;

- As expected, in the clayey underground, with high heat capacity, the period of heat release is very long, with a semi-logarithmic behaviour.

During all the TRT period, rainfall phenomena did not occur, so that the basket showed its maximum stability, without exceptional temperature falls. We did specific TRT tests for a short time during rainfall events, in order to verify the influence of it on basket performances (Figure 9).

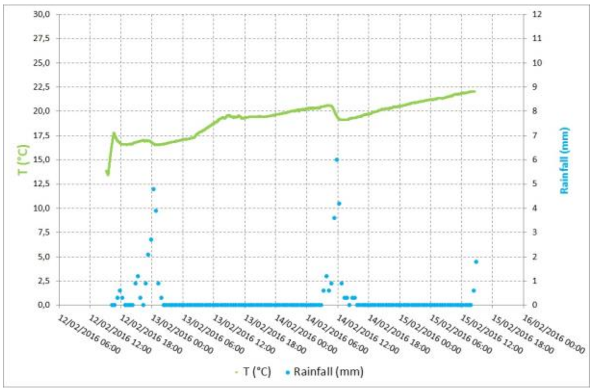

Figure 9: Effect of rainfall on temperatures behaviour in short dedicated TRT. Rainfall data refer to a support of 30 minutes.

Figure 10 reports the behaviour of underground temperature inside Borehole I, at 2, 4 and 6 m depths.

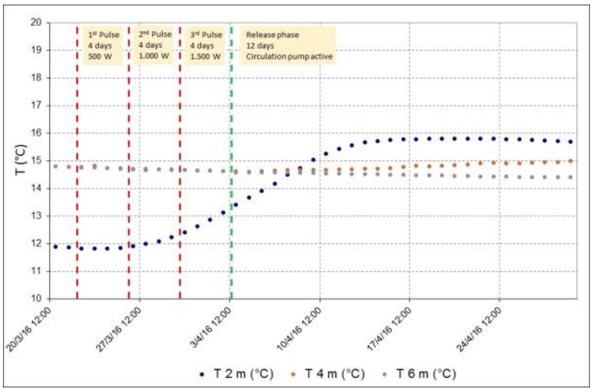

Figure 10: Behaviour of underground temperature inside Borehole I, at 2, 4 and 6 m depths.

From the data, it is again clearly shown the importance of heat capacity of underground, which obstacles the heat transfer: heat wave arrived after 4 days to Borehole I at 2 m depth, after 11 days at 4 m depth and never reached 6 m depth in the considered period. This is an advantage when designing a geothermal basket field, because there is no need of large spacing among baskets. Drawback of this, is that heat release after injection (and also extraction) is particularly low and ground layers around the basket store the injected energy for a large amount of time, decreasing the exploitable geothermal energy quota.

Inside the basket, the temperature waves follow the same behaviour of circulating fluid, with phase shift and specific damping, according to the relative position of each sensor. Again, the high heat capacity makes the ground unable to return to undisturbed conditions in short time.

4. DATA ANALYSIS

The aim of the data analysis in this kind of test was not to find the thermal parameters of underground, neither to define a basket thermal resistance. In fact, the thermal properties of the considered ground layer were already known, while it is not possible to define a unique thermal resistance for the basket, because of the too high influence of external factors influencing the resistance of the basket itself.

Therefore, we opted for a different solution: we used the data set acquired to estimate the trend of inlet / outlet temperatures in many conditions:

- Varying seasonal periods along the year (change of underground temperature along basket depth);

- Varying weather and anthropic conditions along the year (variation of moisture content inside the ground due to rainfall and anthropic causes, such as irrigation);

- Varying working temperature of heat pump (ground side) along the year (heating/cooling at different loads following different needs);

- Varying working hours of the heat pump along the year (on/off periods and consequent charging/discharging of underground).

The procedure began with the definition of a specific time and weather dependent exploitable heating/cooling power from the basket, through interpolation of the behaviour of the 3 load tests and the discharge test. Then, we applied the seasonal waves of underground temperature and the possible working temperature of the heat pump (ground side) along the year. It resulted in a matrix of fluid temperatures and exploitable power, on a daily basis. From the obtained values of power matrix, we obtained regression coefficients identifying the behaviour of the fluid, for each power and temperature combination. Then, it is possible, by inserting a typical set of load profiles, efficiency data of heat pump and a succession of weather conditions and other anthropic factors, to simulate for each day the working mode of the geothermal basket (or geothermal basket field), specific for the geometry and the geology of the site. The complete workflow of the procedure is presented in Figure 11.

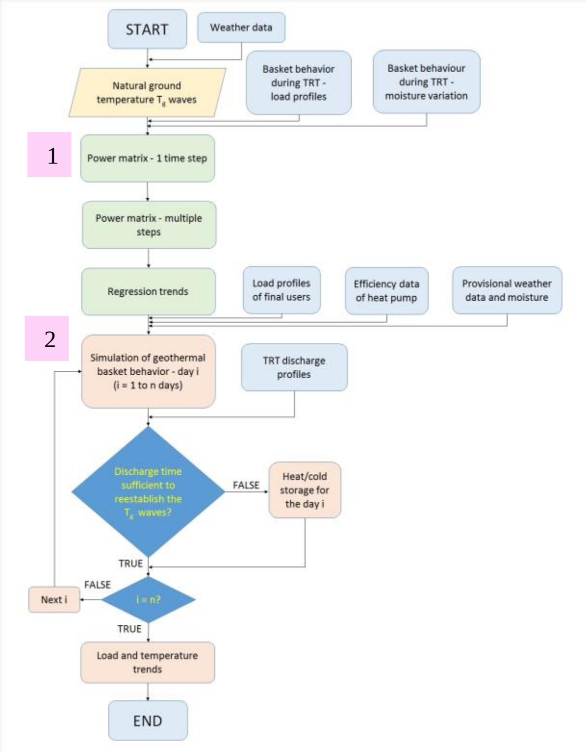

Figure 11: General workflow of the data analysis.

The two main points of the data analysis are the realisation of the power matrix and the simulation of geothermal basket behaviour for each time step of operation.

The realisation of the power matrix is strongly influenced by TRT results, and it is modified according to the information collected on the modification of heat dissipation underground due to weather phenomena or anthropic factors. Two parallel ways should then be taken, for both dry and wet conditions. The procedure implies also the use of coefficients to adapt the first attempt power matrix in to the exact power results during TRT period. The workflow concerning the realisation of the power matrix is presented in Figure 12.

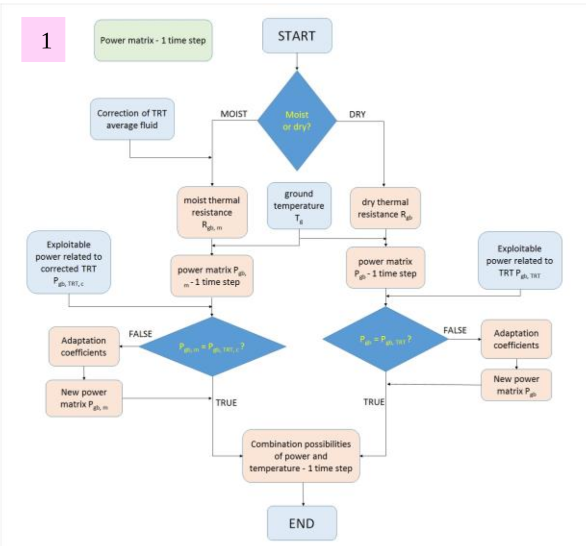

Figure 12: Detail - workflow of point 1. Realisation of power matrix.

The simulation of the geothermal basket behaviour is an iterative procedure starting from the tentative values of inlet temperatures for each time step. By inserting the regression coefficients taken from the power matrix, the program returns an outlet fluid temperature and an exploitable power, strongly dependent by the moisture and temperature conditions of underground at the time step considered. A control function of the power and efficiency requests from the heat pump is then inserted and, if not satisfied the power equality (including tolerable percentage differences), the iteration begins, by automatically changing the efficiency of the heat pump up to the convergence. The procedure is then repeated for each time step during the analysis period. The iterative procedure for the simulation of geothermal basket behaviour is presented in Figure 13.

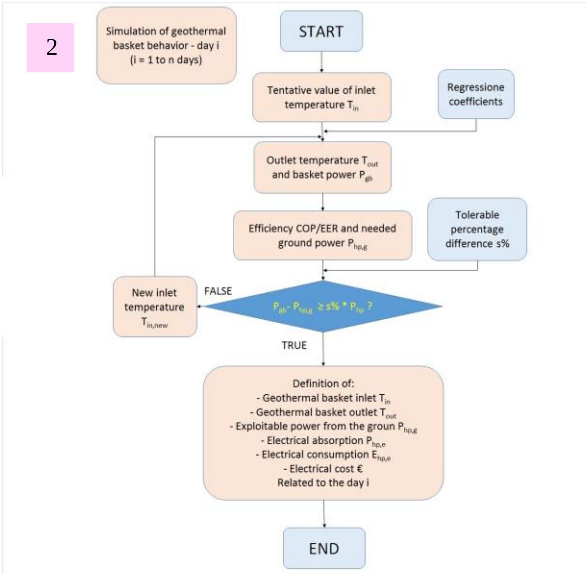

Figure 13: Detail - workflow of point 2. Simulation of geothermal basket behaviour for each time step.

The capacity of the ground to release heat during discharging periods can be quantified by the analysis of underground temperature data during the TRT release period. The results of this analysis should then be added to the general workflow, to take into account the quota of heat/cold stored in the subsoil, different for each time step, at different weather and moisture conditions. The quota will then be used to calculate the unavoidable exploitable energy decrease both at short and long term operations.

The procedure is repeated for all the time steps considered in the analysis and it gives back a realistic load of the basket during the working period.

5. PRELIMINARY RESULTS AND THEIR POTENTIAL IMPACTS ON VERY SHALLOW GEOTHERMAL DESIGN AND MARKET

The analysis performed allows defining the performance of a geothermal basket, subjected to different weather conditions and other external factors. Many different scenarios can be simulated, both for residential and non-residential applications. In this paper, we report the results of the application of the method on a realistic residential energy load. The details of the load considered are stated in Table 3.

Table 3: Synthetic data of the year load simulation.

	Heating	Cooling
Peak power (W)	875	400
T user side (°C)	45 / 40	13 / 18
Daily working hours (h)	14	14
Working months (months)	6	6

The weather condition of Emilia Romagna Region has been considered. Other external factors, such as irrigation, which could increase the performance, were not considered at this stage.

The results of the analysis are shown in Figure 14 and 15.

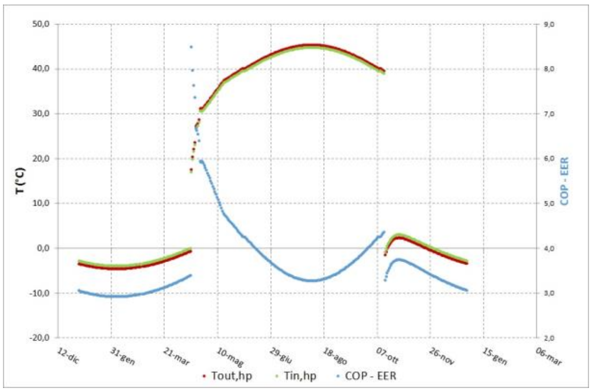

Figure 14: Temperature and efficiency results of the system, varying according to weather conditions influencing the basket behaviour.

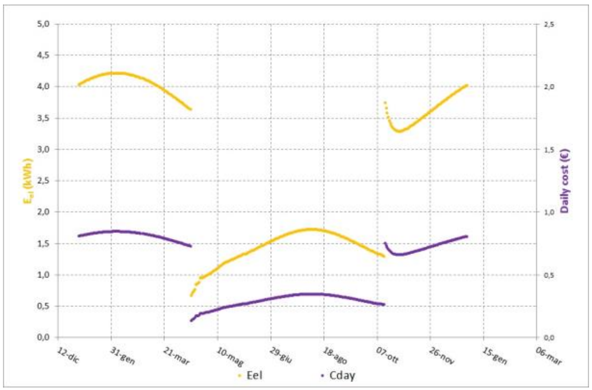

Figure 15: Energy consumptions and cost results of the system, varying according to weather conditions influencing the basket behaviour.

A final resume of the results is reported in Table 4.

The electric energy cost was fixed at the value of 0,2 €/kWh.

Table 4: Resume of the results for the synthetic case.

	Heating	Cooling
Seasonal energy consumptions – circulation (kWh)	76,7	76,7
Seasonal energy consumptions – compression (kWh)	705,2	258,3
Seasonal energy costs (€)	156,4	67,0

6. DISCUSSION

The results show how a single homemade energy basket can be effective, even if the exploitable power is not very high. When dealing with geothermal basket projects, all geological, weather and anthropic conditions should be considered, because the exploitable power is strongly affected by many causes and it varies during the year, which reflects on working temperatures of the fluid and therefore on the seasonal heat pump efficiency.

A detailed analysis on geothermal baskets seems particularly useful in case of non-residential applications, when the energy requests do not necessarily follow seasonality. In such cases, the deep knowledge of transitory periods and the variations of basket load and response during the year due to climatic factors can be fundamental in the decision making process.

The realisation of homemade cylindrical baskets on site can be impactful in all those rural contexts where the necessary excavation machines are already present on site, in order to contain costs. The costs of the homemade geothermal basket installed and used for the experiment are reported in Table 5.

Table 5: Costs of the geothermal baskets, equipped with proper temperature sensors at different depth.

Materials (pipes and metal structure)	103 €
Excavation and installation	113 €
Kit of temperature sensors	98 €
TOTAL	314 €

The continuous cost reduction of electronic devices is an indirect incentive to equip all vSGS with proper sensors, which can help to better define the behaviour of the system, affected by seasonal, weather and moisture variations, both for monitoring and machine learning concepts and procedures.

7. CONCLUSION

In the paper, we presented a new procedure to realise, perform and analyse a Thermal Response Test, which is specific for the assessment of the exploitable energy from very Shallow Geothermal Systems. In particular, we performed the TRT on a homemade cylindrical geothermal basket in a particular well – known geological and hydro-geological context and we used the data to calibrate a model able to define the behaviour of the basket on short and long-term period, with different energy loads and subjected to different external factors.

The complete set of sensors was put in place in order to understand the external factors influencing the behaviour of the basket. Starting from the results of the TRT campaign, the energy response of the geothermal basket subjected to a hypothesised load across one reference year was simulated. The experience done emphasised the importance of knowing and predicting the ambient effects that influence the behaviour of the basket on the short and long term; these effects could cause unexpected variations of efficiency of the heat pump system, which on the contrary should be kept under control in all vSGS projects.

Further analysis are planned, in order to improve the model for the design of an entire geothermal basket field. Moreover, different load profiles related to residential and non-residential buildings will be added. It will be possible then to verify the potential of geothermal basket exploitation for many alternative possibilities, also in conjunction with other heating and cooling systems, mainly air-to-air heat pumps, which are currently the most used technology to satisfy the energy needs in rural environment and off-gas grids houses. The final aim will be to set up a cheap smart monitoring control of the hybrid (vSGS and air) systems for rural application, in order to improve the overall performances and the market potential of the energy baskets and the vSGS in general.

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