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Measurement of subsoil parameters in geothermal heat pump plants

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***Abstract* –This paper explores the measurements of subsoil parameters in geothermal heat pump systems located in historical centers. A closed loop geothermal system serves the heating and cooling requirements of a wing of the Grand Duke historic Palace in the old town district of Pisa. The subsoil temperatures are measured at different depths and positions around the closed loop probes to investigate the thermal diffusion in the subsoil. Water flows, electrical power, flow and return temperatures and other plant data are analyzed to study the geothermal plant energy behavior during the operation.**

I. INTRODUCTION

The use of geothermal energy is a well-known useful application for heating and cooling residential and commercial buildings [1], [2]. Several works present in the literature provide results relevant to the heating and cooling behavior of geothermal heat pump and distribution systems [3].

However, the knowledge of the temperature distribution in the subsoil and a deep analysis of the impact of these systems on subsoil environment is specifically required for applications in historical city centers. A correct estimation of subsurface geothermal parameters is at the basis of an effective design of low temperature geothermal plants. Experimental data are useful to develop and validate numerical models of low temperature geothermal systems [4]. In this paper, we present the measurement of subsoil parameters in a closed loop geothermal heat pump system that serves the heating and cooling requirements of a wing of the Grand Duke Historic Palace in the city center of Pisa.

The paper is organized as follows: in Sec. II we present the geothermal heat pump (GHP) system, in Sec. III we report the description of the adopted measurement system architecture, and Sec. IV presents our measurement results. Finally, in Sec. V we discuss our conclusions.

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II. GEOTHERMAL HEAT PUMP SYSTEM

The Geoheat project consists in the realization of a geothermal heat exchanger plant composed of 8 vertical closed-loop probes, 8 monitoring wells, a GHP plant and a measuring system to finally collect all the quantities of interest. The whole system is located in the city center of Pisa, as reported in Fig. 1.

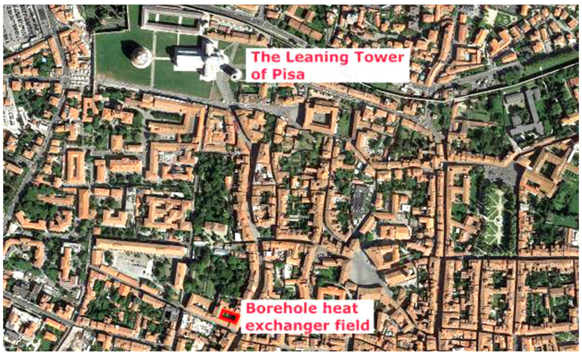

Fig. 1. Location of geothermal field probes inside the medieval old town of Pisa.

The system is realized for air conditioning part of the Grand Duke Palace in Pisa (head office of Earth Science Department of Pisa University) and geothermal probes are installed in the courtyard of the same palace as reported in Fig. 2.

The geothermal closed loop plant is composed of the eight field probes, horizontal pipes, collectors, geothermal heat pump, a tank for technical water of 200 l, one circulation pump for the geothermal side and one for the distribution side.

The air-conditioned building consists of a server room, offices of the University staff and a library room with a total surface of about 250 m^2. All the rooms are located on the third floor of the building and heat/cold distribution inside the building is provided by water fan coils.

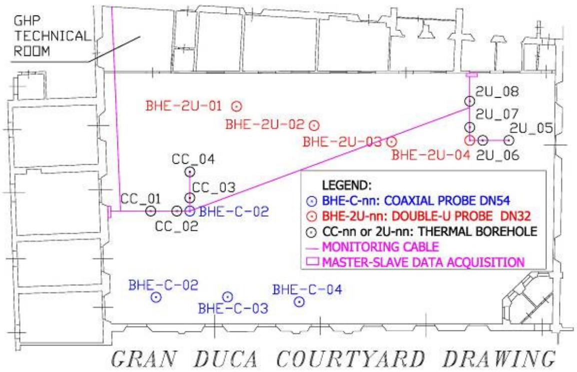

Fig. 2. Location of geothermal probes

The geothermal system consists of 8 boreholes of 45 m depth distributed along a horseshoe path. The distance between two consecutive probes is 7 m. The space between the probe and the borehole walls is filled with conductive grout having 2 W/(m K) thermal conductivity, from the bottom to the top of the well. The probes are filled with water. The eight monitoring wells are positioned along a L path around one coaxial probe (four wells) and one 2U probe (four wells) as shown in Fig. 2. The closer wells are 1 m far from the probe, while the farer wells are at 3 m distance. The heat pump is internally reversible with a nominal heat capacity of 24.7 kW and a declared manufacturer coefficient of performance (COP) of 5.13.

The main components of the thermal power plant and some measurement devices are visible in Fig. 3. A better description of the resistance temperature detectors (RTDs) and flowmeters is reported in the next section.

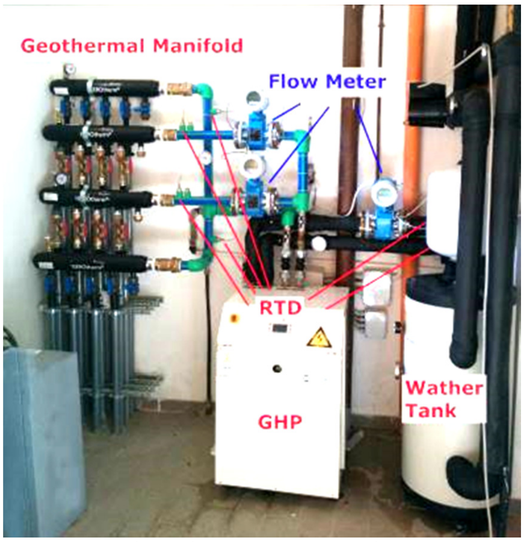

Fig. 3. Technical compartment and positioning of temperature and flow sensors.

A possible critical aspect to be taken into account is due to logistic constraints typical of an old town district. In our case, the perforations were made in the court with a machine of relatively small size and power, because of the available narrow passages to reach the area. The low power at disposal allowed a maximum depth of 45m. This is clearly reported in Fig. 4. A photograph of the adopted machine for the perforation phase in the courtyard is shown in Fig. 5.

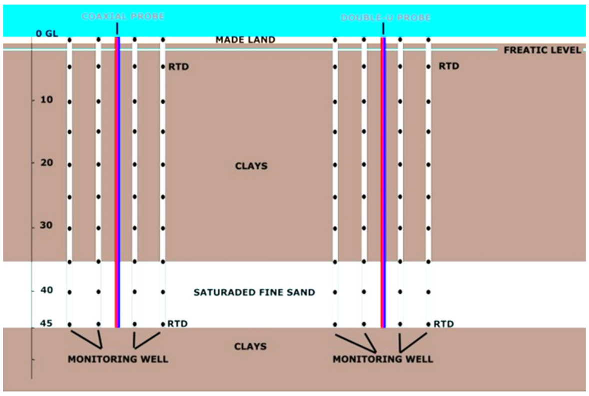

Fig. 4. Stratigraphy of the area and position of temperature sensors.

Fig. 5. Drill rig MTD 40K during the perforation.

III. MEASUREMENT SYSTEM

A schematic of the adopted measurement system architecture is reported in Fig. 6.

The measurement system is based on a 667 MHz Dual-Core Real Time controller (National Instruments CRio-9067) that acts as a server (CRio Master system in Fig. 6) connected to a 8-slot RIO Expansion chassis (National

Instruments cRIO-9067) (CRio Slave system in Fig. 6).

The master controller features are 512 MB of DDR3 memory for embedded operation and 1 GB of nonvolatile memory for data logging.

Measurement data are both locally stored on the nonvolatile memory of the master device and simultaneously sent to a server computer.

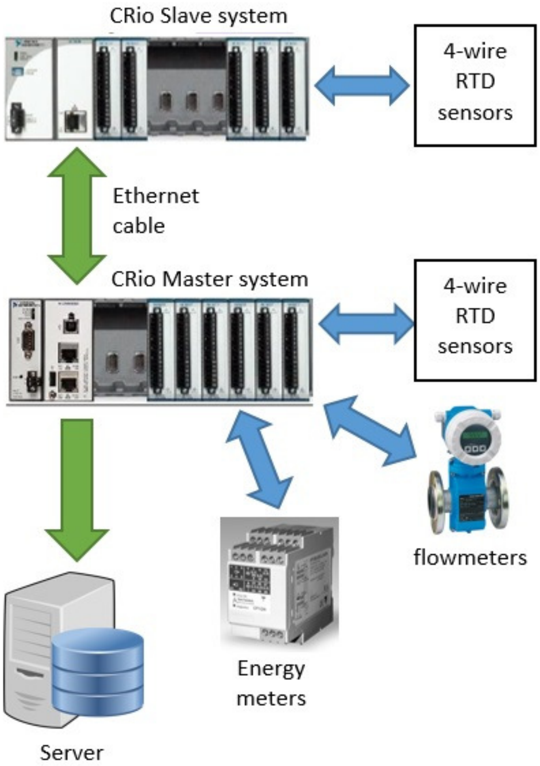

Fig. 6. Schematic of the adopted measurement system architecture.

The slave RIO chassis expansion acts as remote expansion I/O on the Real-Time systems and is connected through Ethernet to the master controller to instantaneously obtain access to analog C series modules. To reduce the length of the in-field sensor cables, the master system is located in the courtyard near the geothermal 2U pipes, while the slave system is located near the geothermal coaxial pipes as reported in Fig. 2. For such reasons, the systems are endowed with a wide temperature range (-40 °C to 70 °C), and severe industrial specifications (50 g shock, 5 g vibration).

The master and slave systems are both equipped with five RTD analog input modules (NI 9217), 4 channels each one, 24 bit resolution and a built-in 50/60 Hz noise rejection. Forty custom-built 4-wire Class A RTD are connected to the two systems allowing the measurement of underground temperature one time per second at five depths and for eight positions as reported in the previous section.

A 16 channels 24-bit resolution ± 21.5 mA current analog input module (NI 9208) is connected to the master controller to measure the environmental and thermal power plant parameters as reported in Fig. 6.

The thermal energy obtained from the coaxial geothermal probes, from the 2U geothermal probes and provided to the building by the heat pump are in particular analysed to investigate the subsurface geothermal heat exchange as well as verify the correct operating of the heating/cooling system.

Thermal energies are calculated by measuring the water volume flow V and the temperature difference between the flow and return of the heat exchange circuit ΔT as

$$E = V \cdot \Delta T \cdot k \qquad (1)$$

where E is the quantity of heat given up or absorbed and k is the water heat coefficient at the relevant temperatures and pressure.

Temperatures are measured by precise 4-wires RTD sensors, class 1/10 DIN connected to a NI 9217 module on the master controller. The water volume flows are measured by three electromagnetic flowmeters. The electromagnetic measuring principle is reported in Fig. 7.

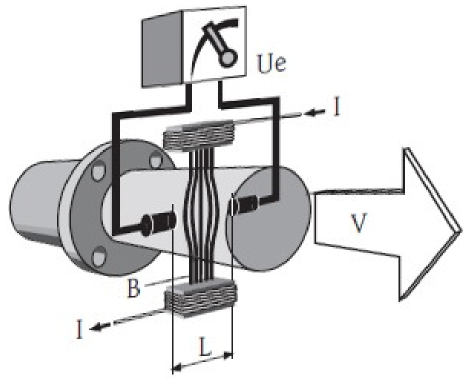

Fig. 7. Electromagnetic measuring principle of adopted flowmeters.

A magnetic field is created through a switched direct current of alternating polarity and the flow velocity is obtained by the Faraday's law principle. The volume flow is then obtained by multiplying the flow velocity by the pipe cross-sectional area. The signal is then converted in a 4-20 mA current and connected to the NI 9208 module.

Heat pump and auxiliary devices (e.g. circulation pumps) electrical absorbed powers are measured by means of 3-phase compact power transducers with 3 programmable analogue outputs 0-20 mA.

A website (www.progettogeoheat.com) has been realized to visualize the monitored data in real time.

Values are updated every 15 sec.

A screenshot of the project website is shown in Fig. 8.

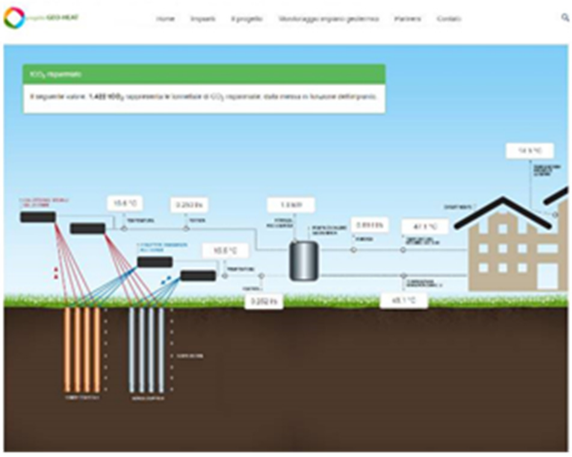

Fig. 8. Screenshot of the real time website

IV. MEASUREMENT RESULTS

The ground temperature variations during the heat pump exercise are carefully monitored. A total of 40 temperature sensors (5 for each well, 9 m spaced) were installed and relevant signals are continuously acquired.

In Fig. 9, the 27 m depth temperatures of each monitor well are reported. Black (blue) lines refer to monitoring wells near to the 2U (coaxial) probe.

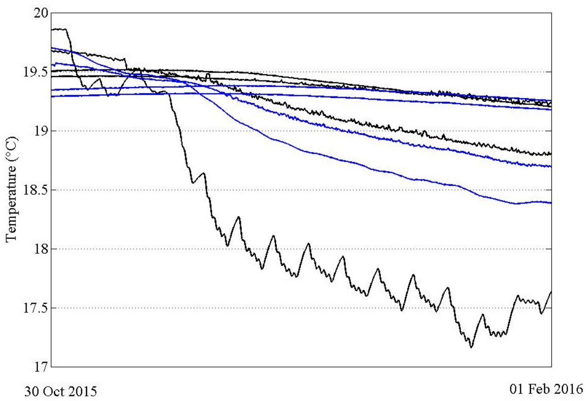

Fig. 9. Temperatures at 27 m depth from ground level for a time ranging from 30/10/2015 to 01/02/2016.

The influence of the geothermal heat pump in the subsoil temperatures is clearly visible in Fig. 10. In more detail, the temperature in the 2U probe (red line in Fig. 10), 36 m depth temperature (blue line) and 45 m depth temperature (black line) are reported.

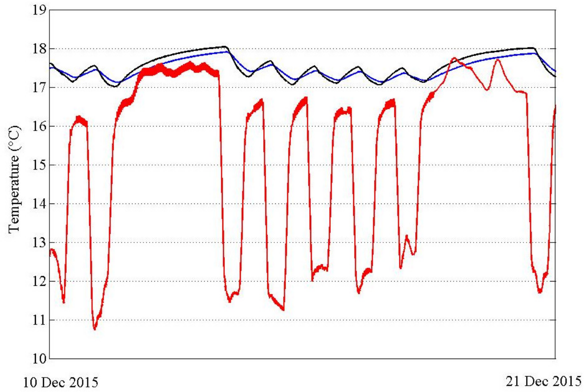

Fig. 10. Subsoil temperatures. Red is the temperature in the 2U probe, blue is the temperature at 36 m depth and black is the temperature at 45 m depth.

Before the power plant start up, the monitoring system registered the underground temperatures along the well at 1 m from the probe without the influence of the GHP. In Fig. 11, the visible increase in the subsoil temperature in is caused by the start of the machine cooling operation. The 45 m depth temperature (cyan line in Fig. 11) increases from 19.8 °C to 22 °C.

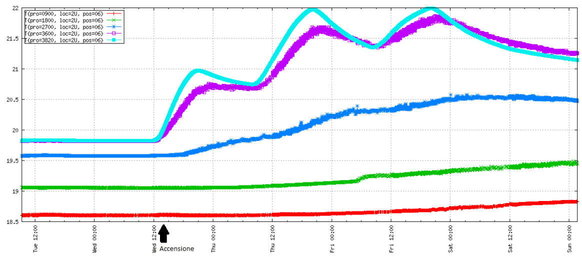

Fig. 11. Undisturbed temperature of subsoil and start of the heat pump in cooling mode.

V. CONCLUSION

We presented the measurement results of subsoil parameters in a geothermal heat pump system located in the Grand Duke Historic Palace in the old town of Pisa.

Subsoil temperatures at different depths around the closed loop probes and several plant data were measured to investigate the thermal diffusion and energy behaviour of the heat pump system during its operation. Results can be useful for the development and validation of numerical models as well as for design of low temperature geothermal plants.

VI. ACKNOWLEDGEMENT

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