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FIELD BEHAVIOUR OF A FLAT PANEL GROUND HEAT EXCHANGER

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ABSTRACT: An experimental plant has been devised to investigate the behaviour of a novel type of horizontal ground heat exchanger (GHX), aiming to improve the performance of ground-source heat pumps for space heating and cooling. The GHX system is composed by hollow flat panels, which have been installed edgeways in shallow trenches two meters deep in soil. The hydraulic closed loop and the surrounding soil have been equipped with several digital sensors to monitor the ground temperature distribution and the plant in real-time. The behaviour has been tested for two years in several operating carried out especially in summertime. The specific power of heat transfer for surface-unit achieves considerable values, and no over-heating conditions were measured at the soil surface. Moreover, the GHX showed to be able to involve a large soil volume, and this behaviour enables high energy performance, at least in cooling mode. After few months of inactivity, the natural ground heat transfer erased the memory of the energy exploitation carried out by the GHX. Thus, unlike with the vertical systems, long-term subsurface thermal energy build-up or depletion wouldn't be expecting by shallow GHXs.

Keywords: Ground heat exchanger, flat panel, field behaviour, energy performance.

1 INTRODUCTION

Ground-source heat pumps (GSHPs) have been regarded as a sustainable energy technology for space heating and cooling in commercial, industrial and residential buildings, and a profitable solution when correctly designed. The coupling of heat pump with the ground is obtained by means of ground heat exchangers (GHXs), which can be installed vertically or horizontally. In the horizontal installation, the heat exchangers are placed in shallow trenches few meters deep in soil, as opposed to the vertical solution where the heat exchangers are installed in boreholes drilled down up to hundred meters. Owing to their different installation depth, the vertical solution really exploits a geothermal source, while the horizontal one employs the ground mainly as underground seasonal energy source/sink. However, both solutions are the weakest link in the thermal chain of GSHPs, because the heat transfer in ground is mainly conductive and its thermal diffusivity is low as well. This means that the ground thermal response has to involve the surrounding soil as wide as possible, to perform a profitable exploitation.

For the horizontal technology, several novel shapes of exchangers has been proposed recently in the geothermal sector, such as baskets, radiators and flat panels [1]. These solutions aim to achieve higher energy performance than the widespread installations of straight pipes or slinky coils [2-5]. In the present work, the thermal behaviour of a novel type of the flat panel solution is presented, as resulting from the installation of the first prototype invented at the University of Ferrara (Italy). The idea is an European patent pending.

2 EXPERIMENTAL PLANT

To test the behaviour of the flat panel prototype, a hydraulic closed loop was built in the garden of the Department of Architecture, University of Ferrara (Italy), as shown in Fig. 1. The trial field is 23 m long, 14 m wide, and is equipped with several digital sensors to monitor the ground temperature and the working fluid. The surface of the area is planted with grass, and hosts a young oak-tree. A low portico defines the garden boundaries at western and northern sides, and a high building occupies the eastern side.

The geographical coordinates are (44°49'43.88N; 11°37'20.00E), and the altimetry is 12 meters above sea level. The local climate is continental, with harsh winters (<0°C) and hot, muggy summers (>30°C). The annual rainfall does not exceed 800 mm per year. Historically, this area was an old island of the main river in Italy, the Po River. This explains why the first 4-5 meters of soil are dry and the groundwater table lies in a sandy geological unit, which is 6 meters deep. Moreover, the first human settlement of Ferrara was established in this area around the 4th century. Thus, the first two meters in the ground are frequently mixed with rubble and pottery, and the lithology is very heterogeneous.

Figure 1: Location of the thermal system

2.1 Closed loop

Two prototypes were buried almost two meters deep in the ground, to function as heat exchangers in the closed loop (Fig. 2). The panels were backfilled with sieved soil, originated from diggings; over them, a dedicated irrigation system was laid to irrigate the soil on demand (Fig. 3). Each flat panel is three meters long, one meter high, and made with polypropylene sheets 4 mm thick, spaced out by 20 mm. A labyrinth is formed inside the panel to reduce blind areas and maximize the heat transfer. The hydraulic closed loop is composed of forty meters of insulated DN20 high density polyethylene pipe, a hydraulic pump, a tank with a capacity of 300 l, and three groups of valves. Each flat panel can work alone or in parallel/series mode. An electrical resistance (1.5 kW) controlled by a thermostat, and a chiller installed after February 2012 (1.2 kWt), keep a fixed temperature in the water tank (2-45°C).

2.2 Monitoring system

Several digital sensors are employed in the monitoring system in order to acquire in real time the ground and fluid temperatures. The sensors are installed in horizontal and vertical probe lines (Fig. 3). Each probe line has seven sensors, and is cabled to an electronic concentrator (multiplex). An RS485 wire links the multiplex to a filter, which transforms the signal to USB protocol for connection to a computer. A software controls and stores the data in real time. The system was derived from an industrial application, and modified with the support of experts of the Italian National Council Research, as reported in [6]. Eight probes are installed vertically in the ground up to a depth of 4.5 m. Other two probes are laid horizontally spaced 20 cm and 40 cm from the exchangers, at respective depths of 1.15 m and 1.65 m. A further line probe monitors the temperature of tank water entering/leaving, three valves groups, outdoor air and a point of the ground surface. In Fig. 3 the positions of the vertical (V) and horizontal (H) probes are shown, together with the sensor depth and their distance from the exchangers.

The flow rate is gauged by a flow meter, which is continuously read by a M-Bus device. All data are available via LAN.

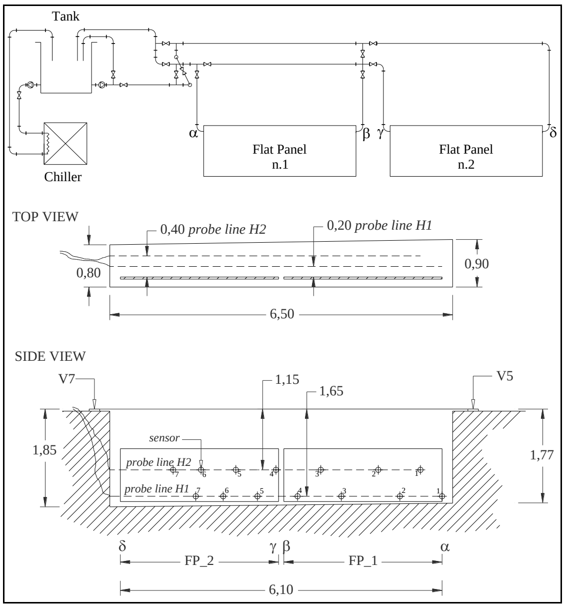


Figure 2: Layout of the closed loop and trench

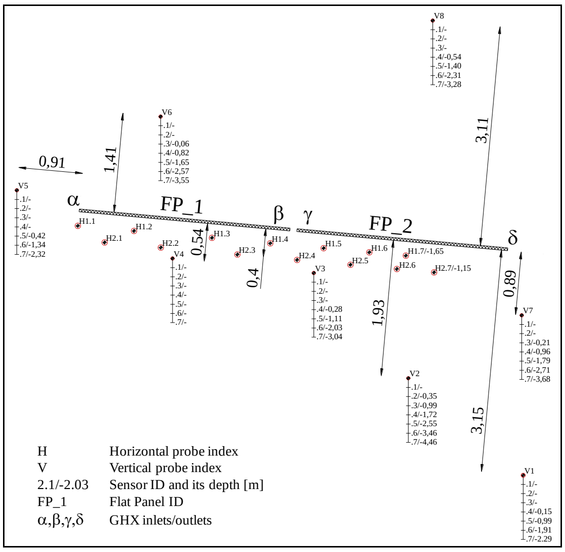


Figure 3: Probes arrangement

2.3 Soil properties

Originally the trench was 40 cm wide, but after the recovery of the heat exchangers for maintenance operations, it was enlarged to 80 cm. That allowed determining directly the presence of several lithologies. Fig. 4 shows the two operating flat panels (*a*), the typical site lithology (*b*), casual masonry debris (*c*), a wall foundation (*d*), and the irrigation system (*e*).

The soil properties are listed in Tab.1 and are typical for sandy loam (Fig. 4.*b*). With exception of the thermal conductivity, all data were assessed in laboratory, by means of direct or indirect methods. The soil thermal conductivity was evaluated indirectly through the use of data provided by the monitoring system. Adopting the analytical solution of the 1D heat transfer problem in a homogeneous semi-infinite solid [7], the heat conductivity was calibrated to obtain the same thermal trend monitored at the nearest sensors.

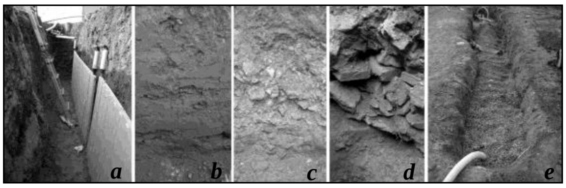


Figure 4: Flat panels (*a*), soil lithologies (*b,c,d*), dedicated irrigation system (*e*)

Table 1: Properties of the lithology (*b*)

Density	1,720 kg/m^3
Porosity	0.36
Specific heat	1.35 kJ/kgK
Thermal conductivity	1.4 W/mK

3 MONITORED DATA

The monitoring system was started up in October 2010, adopting an acquiring time step in accord to the specific operating modes (60-900 s). The closed loop was started up in March 2011.

A summary of the operation modes carried out by the plant is reported in Tab.2. Here, the overall heat transfer, the time period, the working hours and the average operating length of the GHXs are summarized by period. This last one represents the working GHX average length of the specific period. The water temperature kept in the tank was close to 2°C in cooling mode, and approximately 35°C in heating mode. Since the chiller was installed only in February 2012, the operating mode from November 2011 to January 2012 was obtained by means of a natural temperature in the tank, that was varying in time in accord to the air temperature (free mode). Thus, the behaviour does not represent a real controlled cooling mode.

According to the reported data in Tab.2, the GHX specific power in operating time ranged from 45 W/m in wintertime to 80 W/m in summertime. The different energy performance between summer and winter is only related to the higher difference of temperature kept during the first one. In summertime, the leaving water temperature was 10÷15°C higher than the undisturbed temperature in the ground, while in wintertime only 5÷10°C. The former specific powers become respectively 20 W/m and 61 W/m, if the time period is considered.

Table 2: Heat transfer periods

Period	Mode	Energy/Days/Time On/Length *[kWh]/[d]/[h]/[m]*
2011, 03 → 09	Heating	990 / 161 / 2907 / 4.2
2011, 11 → 12	Free	28 / 42 / 351 / 6.0
2012, 01	Free	13 / 31 / 225 / 6.0
2012, 02 → 04	Cooling	225 / 56 / 843 / 6.0
2012, 06 → 09	Heating	264 / 68 / 585 / 6.0
2012, 11 → 12	Cooling	117 / 48 / 364 / 6.0
2013, 01 → 02	Cooling	101 / 41 / 352 / 6.0

The following figures (Figs. 5-7) show the temperature time series of some relevant sensors, that make clear the operation modes of the plant and the variations occurred in the ground owing to the GHX heat transfer.

In Fig. 5, the temperatures of three sensors are presented (V3.5, H1.4, H2.4). Since these sensors are close to the GHXs at different depths, they monitor the operating mode of the GHXs with a short delay. When the plant was turned on in heating mode (March 2011), only the FP_1 was operating firstly. Then, it was closed after two weeks and FP_2 was switched on; this operation is well clear in Fig. 5, where it is also evident when the plant was stopped in May and started up newly in July. Similarly, the pulsed mode in summer and in winter 2012 are evident.

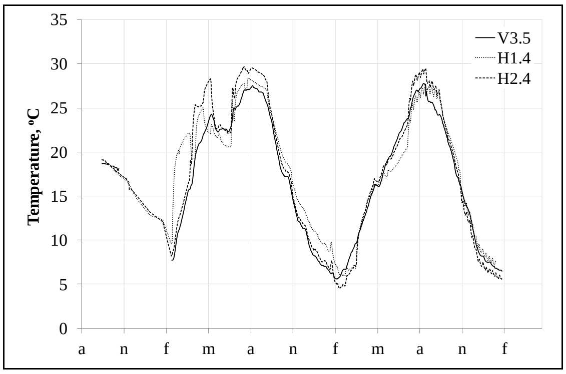


Figure 5: Time series of sensors close to the exchangers

In Fig. 6, the time series for the sensors V3.5, V3.6 and V3.7 are presented together with air temperature. Here, the data are superimposed for the direct evaluation of the monthly temperatures in 2011 and 2012. Even if the system transferred a lot of heat in spring 2011, the maximum temperature were the same in both summers, and only a short delay time is shown at the deepest sensor V3.7.

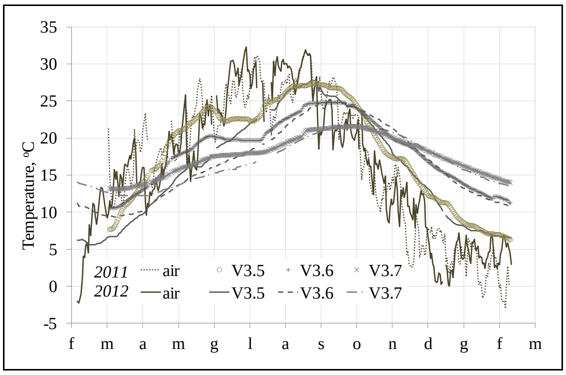


Figure 6: Yearly time series of the probe V3

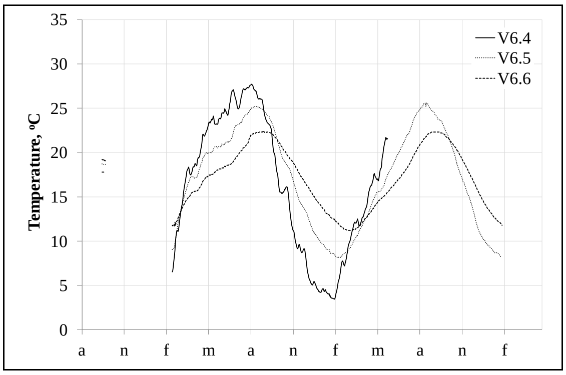
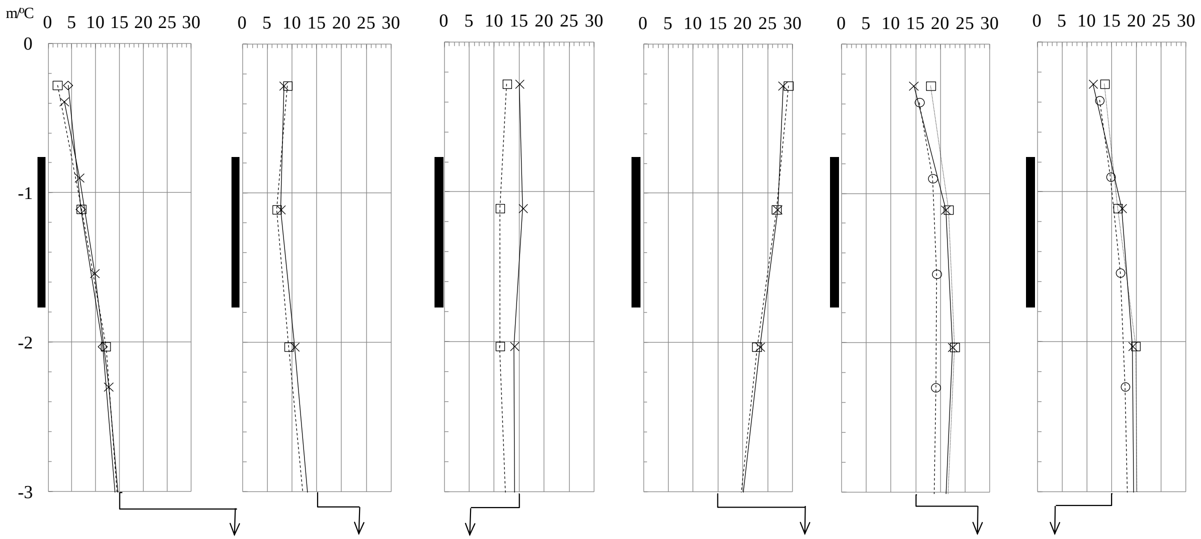


Figure 7: Time series of the probe V6

Moreover, the temperatures in February are fully comparable, even if a cooling mode was operating in winter 2012. So, even if the operations executed by the plant were very different, similar temperatures were naturally achieved after few time of inactivity.

In Fig. 7, the time series of three sensors at the vertical probe V6 are reported, which is 1.41 m far from the GHX. The figure shows that the heat transfer achieved clearly this distance, because the thermal anomaly is still readable. Moreover, the temperatures at the sensors V6.4 and V6.5 did not change in November 2011 and 2012, even if a considerable heat transfer was carried out during the summer 2011.

Finally, in Fig. 8 the full thermal profiles of the probe V3 are shown together with the time schedule of the operations carried out in heating and cooling mode. In the figure, the different markers represents the year considered and the filling colours the plant operation mode. In October, only the undisturbed profile in 2010 diverges from the similar trend in 2011 and 2012. It may be explained as effect of the heating mode operated in 2011 and 2012, while the condition in October 2010 was still unchanged. But, this difference decreases progressively, and in January it is not more present, even if the heat transfer was hard especially in summer 2011. Then, moving from March to April, the difference is well highlighted, due to the operating heating mode in 2011, in opposition to the cooling mode in 2012.



░ *Heating* ▓ *Cooling* ▒ *Free*	Jan.	Feb.	Mar.	Apr.	May	Jun	July	Aug.	Sept.	Oct.	Nov.	Dec.
2010										O	O	O
2011	X	X	░ X	░ X	░ X	X	░ X	░ X	░ X	X	▒ X	▒ X
2012	▒ □	▓ □	▓ □	▓ □	□	□	░ □	░ □	░ □	□	▓ □	▓ □
2013	▓ w	▓ w										

Figure 8: Time series of the vertical profile for the probe V3.

4 CONCLUSION

An experimental plant has been built at the Department of Architecture of the University of Ferrara (Italy) to test the energy performance of a novel shallow horizontal ground heat exchanger, named flat panel. Two flat panel prototypes were installed 1.85 m deep in soil, and linked to a hydraulic closed loop whose working fluid was thermally controlled to simulate the heating or cooling mode of a ground-source heat pump. The plant was tested from March 2011 to February 2013, adopting several different operating modes.

The average specific power for flat panel's unit-length was 45 W/m in wintertime and 80 W/m in summertime. The summer performance was better owing to the higher difference between the working fluid temperature and the unaltered ground temperature, in comparison with the wintertime.

Even if the operations for heating and cooling were very different, similar temperatures were naturally achieved at the same month after few time of plant inactivity. It could be explained owing to the natural energy balance occurring at the soil surface, that is able to delete the memory of the energy exploitation carried out by shallow GHXs.

So, unlike with the vertical exchangers, its behaviour highlights that long-term subsurface thermal energy build-up or depletion wouldn't be expecting by shallow GHXs.

5 REFERENCES

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