Monitoring of GCHP pilot systems in Valle D'Aosta Region: assessment of performance

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***Abstract*—Here are summarized the results of an extended monitoring campaign on three pilot sites in Valle d'Aosta region, located in the northwestern alps, to evaluate energy performance referred to heat extracted and temperature at different depths and with different systems. Experimentation results led to prepare a guide lines aimed for designing properly geothermal plants in a mountainous region, thus focusing on probes spacing, minimum depth of boreholes related to altitude, occurrence/absence of groundwater, morphological factors, practical sizing and indication about operation modes as a function of the hydrogeological conditions.**

***Index Terms*-- geothermal system, temperature and energy performance monitoring, GCHPs impact on soil, operation related to hydro geological conditions**

I. Nomenclature

GCHP	Ground Coupled Heat Pump
TRT	Thermal Response Test
GCB	Ground Coupled Borehole
AHU	Air Handling Unit
EER	Energy Efficiency Ratio
ESEER	European Seasonal Energy Efficient Ratio

II. Introduction

As an implementation of the Resolution of the Valle d'Aosta Regional Council n. 1900/09 [1], concerning the 'Approval of actions aimed at the protection of water resources for human consumption and its implementing rules', the Valle d'Aosta Environmental Protection Agency (ARPA) has been committed to run any action to protect groundwater resource and therefore to understand the potential for underground low enthalpy energy exploitation with no likely environmental consequences. On this base it was decided first to model and forecast the groundwater flow in the porous aquifer of a part of Aosta plain [2] and, as reported in this paper, to identify environmental protection issues related to the exploitation of low-enthalpy geothermal resource by means of heat pumps systems [3].

III. Methodology

The aim of this study was to understand how to use the low-temperature geothermal resources in the Valle d'Aosta Region without generating adverse environmental effects, which essentially may consist of:

- ground and/or groundwater temperature uncontrolled changes;
- risk for hydraulic connection among different aquifers due to drilling;
- risk for release of potential pollutants into the soil in case of borehole collapsing.

With regard to first item the analysis was conducted with an experimental approach on three pilot sites specifically built for experimentations. The three sites were chosen according to elevation, water saturation soil conditions, geomorphologic and climatic conditions such as steepness and exposure and eventually logistics: the first was identified in the Aosta plain at around 620 m a.s.l., the second not far from a creek at around 780 m a.s.l. and the third in a secondary valley at 1.300 m a.s.l..

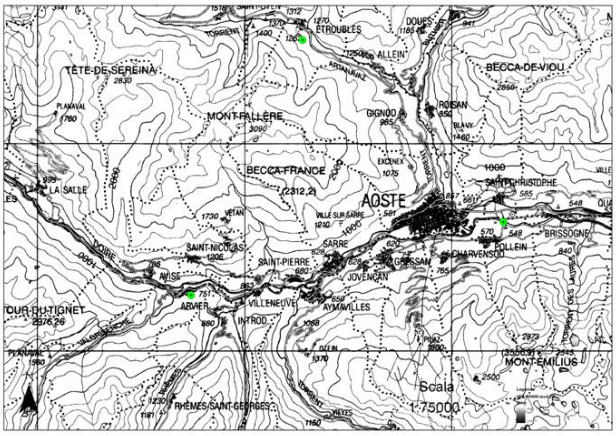

Fig. 1. Localization of the three pilot sites.

The data collected allowed understanding the environmental consequences generated by closed loop systems (GCHP) working.

GCHPs are based on the exploitation of the constant temperature soil feature through the circulation of a heat transfer fluid [4,5], with no groundwater extraction [6]. The boreholes are usually ranging over 50 m up to 200 m depths [7], and, in Valle d'Aosta, ground temperature can vary broadly between less than 5 to more than 12°C, depending on altitude and season conditions.

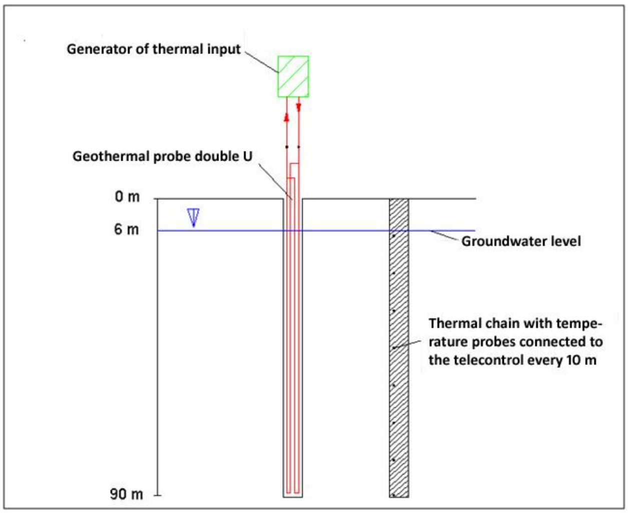

Fig. 2. Ground coupled borehole (GCB) and monitoring borehole scheme.

Fig. 3. View of the pilot site during drilling phase.

In each of the three pilot sites, Arvier (776 m .a.s.l.), Etroubles (1,270 m .a.s.l.), Saint-Christophe (619 m .a.s.l.), the experimental activities were carried out as follows:

- installation of the geothermal piping in an exchange borehole from 50 to 90 m deep;
- installation of a sensor chain to measure temperature changes in the soil every 10 m in a second borehole drilled 2 m away from the first borehole;
- running a TRT [8] in the GCB to measure soil thermal conductivity and average undisturbed temperature;
- installation of a chiller coupled to the borehole and installation of a remote control system to collate data from the borehole and the temperature sensors chain;
- installation of a remote control system to measure and keep track of parameters at exchange borehole, monitoring borehole and chiller;
- heat extraction from the ground, interrupted by shutdowns and restarted according to time intervals, to understand the response of the reservoir in different conditions.

IV. Pilot Sites Setting

In an early phase of the project it was decided to install and operate heat pumps to run temperature change of 3°C between intake and outtake by extracting heat at a maximum of 4.5 kW_{th}. When it was realized there was no chance to transfer the heat produced by water-to-water heat pump in a defined closed environment in all of the three pilot sites, it was decided to install an air-to-water refrigeration unit with a power of 4.11 kW_{th} and an energy efficiency ratio EER of 3.06 (that means ESEER 3.54).

The chiller used is designed to produce water at 7°C going to an AHU or fan coils. For this reason, the extraction of heat had to be performed in indirect mode by reducing the value of output fluid temperature of the machine as much as possible. The minimum values found were: -8.4°C at Arvier, -5°C at Etroubles, and 0°C at Saint-Christophe where, differently from other two sites, the temperature never fell below zero.

Therefore, the typical running mode was definitely set as following:

a) maximum power extracted ranging between 3.5 and 3.9 kW_{th} even if in Saint-Christophe the maximum power was unreachable;
b) setting of minimum temperature (T_{min}) coming from the probe to 0°C (entry into the chiller).

Table 1 summarizes the setting values of the chiller in the three different pilot sites. The parameters are listed below:

- Chiller output fluid temperature (T_{out});
- Chiller input fluid temperature (T_{in});
- Temperature difference (ΔT);
- Minimum temperature (T_{min}).

TABLE I
Running Mode Values for the Experimental Sites and Plants.

Values	Units	Saint-Christophe		Etroubles		Arvier	
		min	max	min	max	min	max
Tout	°C	1	3	-4	0,5	-8,4	12
Tin	°C	5	7	-0,5	2	-1,1	13
ΔT	°C	4		4		4	
Tmin	°C	0		0		0	

The cooling of the soil was obtained by circulating water added with glycol coming from the geothermal probe in the chiller and, after having cooled, re-injecting into the probe to extract the possible maximum amount of energy i.e. until the limit capacity of the machine.

V. Objectives of the Experimental Phases

Running modes were separated in two main phases.

The objectives of the experimentation defined at the beginning of the project were as follows:

- assessing soil saturation condition influence on heat extraction;
- assessing temperature influence;
- defining the volume of soil affected by heat exchange in different operating conditions;

- estimating the energy and environmental sustainability extraction/heat transfer in different reservoirs concerned.

The first three objectives were achieved in the first phase in the sites of Saint-Christophe and Etroubles while the latter was also evaluated in the second phase of systems monitoring.

VI. Experimental Phases

The first phase (Phase 1) started 21st November 2010 and stopped at the end of February 2011. After a pause lasting at least five months during which all early ground temperature were recovered, the second phase (Phase 2) started at the end of July and finished at the end of August, when the plants where restarted in a new operating setting.

According to the pilot sites climatic conditions and to the kind of engine available (that is, as mentioned above, not allowing to transfer heat to the soil), rather than cooling needs in summer [9,10,11] it was decided to simulate heating conditions such as heat consumption related to hot water production, because this condition is fairly more common in mountainous regions.

Therefore it was decided to simulate the disposal of heat for the production of domestic hot water extended to a fifth of the energy entered continuously during 2.5 hours per day.

VII. Results

The outcome of the experimental phases, from the energy point of view, pointed out the following results in the three pilot sites:

c) at Saint-Christophe it was extracted an amount of energy equal to around 16,000 kWh over a little bit less than a year in a scattered running mode, which was estimated to equal to 2,500 hours of operation of the plant;

d) In Etroubles the system, even if being slightly affected by external temperature changes likely due to specific geomorphologic conditions, tolerated positively the heat extraction cycles applied in Phase 2, with a fairly elastic response to stress. In particular there was a poor warming trend along the vertical with homogenization of the temperature at different depths;

e) In Arvier the system was continuously affected by external temperature changes likely due to specific geomorphological conditions, demonstrated to bear a low heat exchange even if applied periodically in Phase 2, with a clear inertia to stress as highlighted by a low and significant reduction of the return temperature. There was even a cooling trend along the vertical and diversification of the temperature distribution with depth.

The suspension of the operation of the thermal forcing after 3 months has had the goal of understanding the capabilities and recovery times of the thermal reservoir compared to the initial values.

In figures 5,6 (Saint-Christophe site), 7,8 (Etroubles site) and 9,10 (Arvier site) data of extracted energy and temperature for the three pilot plants are plotted.

Observing the figures it seems clear that, especially in Arvier and Etroubles, has been reached a critical state to the fact that the machines have operated at rather low temperatures and, in the case of Arvier, even below their limits of operation. This would indicate that the geothermal reservoir has limited ability to dissipate high heat specific loads.

Consequently, the results showed below are the expression of this condition i.e. that in relation to the characteristics of the subsoil and to the depth of the probe, it is possible to reach the maximum power extractable in a relatively short time.

In Saint-Christophe, but especially in Arvier thermal forcing has stopped at different times due to technical problems. The irregularity of the operation of the pilot field of Arvier unfortunately made problematic the interpretation of the data collected.

Conversely, the data collected in the sites of Etroubles and Saint-Christophe results are immediately useful to perform the analyses provided.

Especially for Saint-Christophe it is possible to observe that the time/temperature curve plotted (Fig. 6) has assumed an appearance similar to that suggested in Fig. 4, whose values are are explicative illustrative of the system.

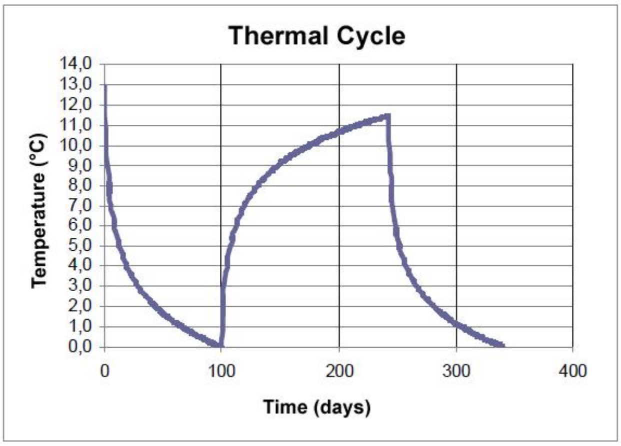

Fig. 4. Diagram of expected thermal cycle (load/unload).

The operation mode of the system can be summarized as: the thermal stress acts on the geothermal probe making circulate water/glycol with the purpose of acting on the probe itself to cool the soil. In other words, to simulate the heating operation of a geothermal heat pump, the cooling unit has been set so that constrain a cold flow in the probe (Table 1).

The dispersing element of the extracted heat is air, while the medium used is the cooled water/glycol in the probe.

In all three sites the stress is set to reach a certain temperature in the borehole and stop only if the return in the chiller you could read the set minimum temperature (0 ° C): as mentioned, the result was different according to specific characteristics of geothermal reservoirs and probes.

Monitored data of the three pilot sites are shown in paragraph A,B,C.

A. *Saint-Christophe testing site*

At Saint-Christophe during Phase 1 from a 90 m deep GCB were extracted around 5,520 kWh of energy during around 1,370 hours, using a power of 4.03 kW with an average specific power of 44.8 W/m.

This provision would allow covering the thermal need of at least a 100 m^2 energy efficient building. The preservation of efficiency of the exchange is made clear by constant slope of the energy-time curve along all the duration of the plant operation. The recovery of the initial temperature is virtually complete in all cases shown in the graph.

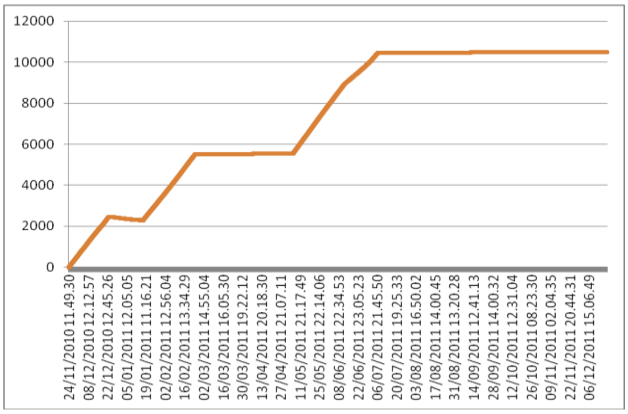

Fig. 5. Extracted energy in Saint-Christophe (November 2010/December 2011).

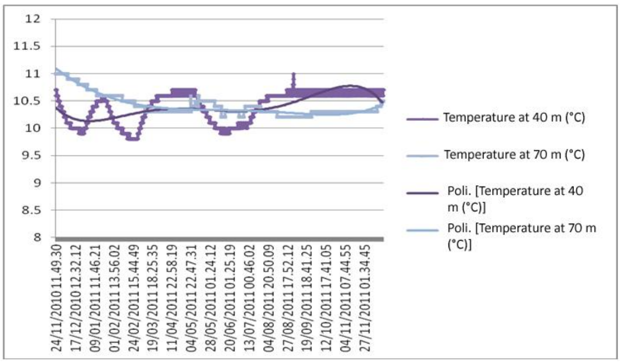

Fig. 6. Temperature values monitored at - 40 m and -70 m in Saint-Christophe (November 2010/December 2011).

The temperature changes in depth seem ruled by the applied cycle more clearly at 40 m depth and the soil inertia is very low, showing a strong correspondence with energy extraction curve, moreover during last cycle applied. In fact initial temperature is reached very early after stopping the extraction system. At 70 m depth the initial temperature shows a decrease by less than 0.5 °C after one year and the change stabilizes at the end of the stress. Differences among 40 and 70 m depths are likely due to inhomogeneous lithology and groundwater flow conditions, likely more favorable at 40 m depth, which are hardly recognizable during drilling operations.

B. *Etroubles testing site*

At Etroubles in the second part of Phase 1 were extracted from a 50 m deep GCB about 5,600 kWh of energy during around 2,780 hours, using a power of 2.01 kW with an average specific power of 40.2 W/m.

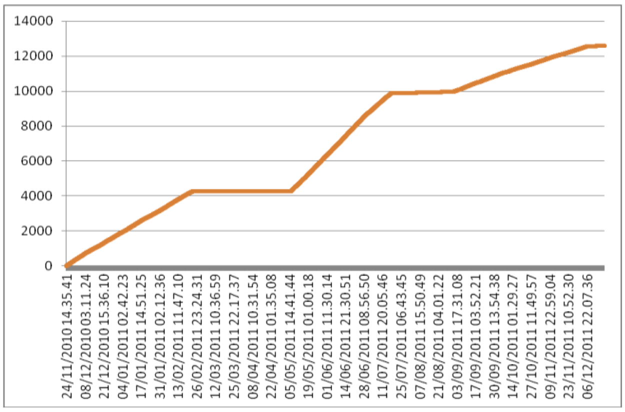

Fig. 7. Extracted energy in Etroubles (November 2010/December 2011).

The heat exchange efficiency changed over time as shown by the slope of the curve energy-time. The temperature curves detected in the monitoring borehole pointed out that the responses to thermal stress are reduced with increasing depth but remain in phase each other both at the beginning and at the end of the thermal stress. The response to thermal stress is slightly unelastic because the reduction in temperature between start and end of stress is around 0.7°C.

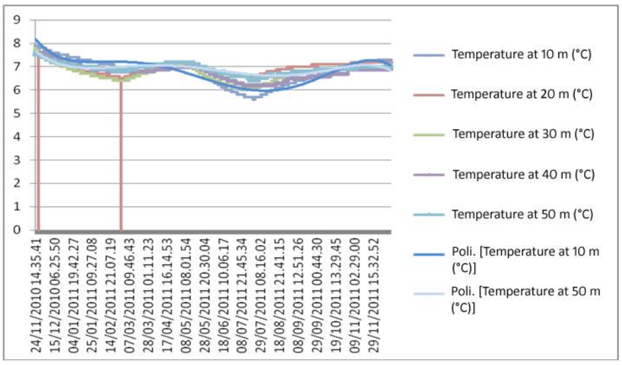

Fig. 8. Temperature values monitored at - 40 m and -70 m in Etroubles (November 2010/December 2011).

C. *Arvier testing site*

In Arvier, during the second part of Phase 1 (from 570 to 1530 hours) were extracted from a 50 m deep GCB around 1,950 kWh of energy during 960 hours using a power of 2.03 kW, with an average specific power of

40.6 W/m.

The loss of efficiency of exchange is clearly demonstrated by the decrease in slope of the curve energy-time between the first two phases of activity of plant.

The temperature detected in the monitoring borehole out that the responses to thermal stress are muffled with increasing depth but remain in phase each other both at the beginning and at the end of the thermal stress. The response to thermal stress is slightly unelastic because the reduction in temperature between start and end of stress is around 1°C.

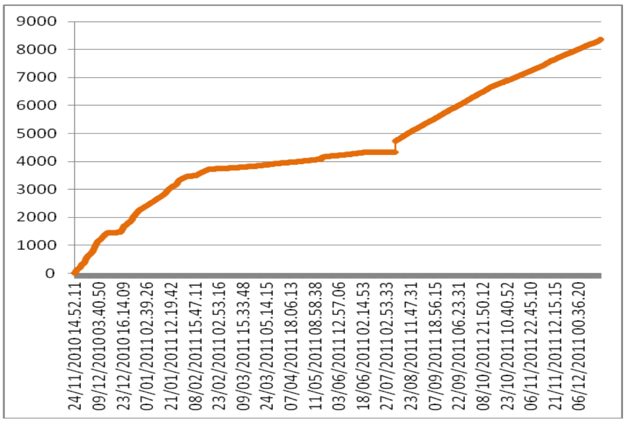

Fig. 9. Extracted energy in Arvier (November 2010/December 2011).

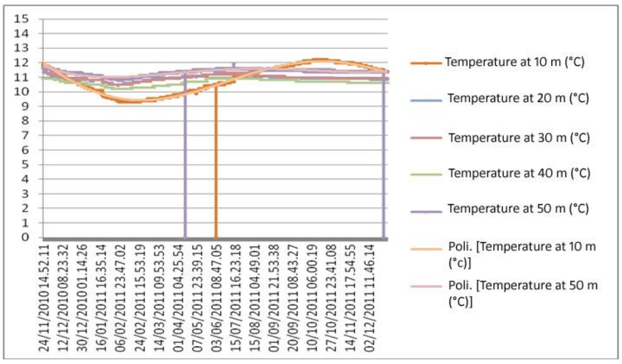

Fig. 10. Temperature values monitored at - 40 m and -70 m in Arvier (November 2010/December 2011).

VIII. Conclusion

Experimentation run in pilot sites led to give some practical inputs for writing the guide lines for ARPA with regard to environmental cautions to be observed in geothermal plants designing, such as:

- depth of a borehole as a function of altitude, presence of water, geomorphological factors;
- spacing among boreholes according to the amplitude and lasting of thermal alteration;
- practical criterion of sizing, i.e. Peclet number [12], as a function of the mechanism of heat exchange (convective or conductive) in the volume of the concerned tank;
- indications on operating mode as a function of the hydrogeological conditions (e.g. summer heat storage in fully unsaturated soil);
- principles for the calibration of numerical models of heat transport in the ground, to be used in case of large plants or special operating mode.

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