THE CASE OF A GEOTHERMAL HEAT PUMP SYSTEM WITH A COMPACT GROUND HEAT EXCHANGER IN DRY SOIL AND SOLAR PANELS RECHARGING

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Abstract: In the near future, in the ground source heat pumps industry compact ground heat exchangers will probably be an answer in case of small gardens, without expensive drilling of boreholes. Solar recharging of ground loops is today a field of research in the geothermal heat pumps industry. This article illustrates the case history of a 10kW geothermal heat pump system installed in 2004 in the north west of Italy, with a soil-water heat pump and compact ground collectors, in the first time connected to a heat recovery from exhaust air unit. One of the main technical bottlenecks was the fact that the soil is locally very dry and low rainfall levels characterize the area during winter. In autumn 2006 the system was connected to solar panels for hot water production and ground loop recharging. Main parameters were recorded and they allow now a first analysis of the possible performances obtained from solar ground loop recharging.

Key Words: c*ompact ground heat exchanger, ground source heat pumps, geothermal heat pumps, ground solar recharging*

1 INTRODUCTION

Geothermal (ground-source) heat pumps (GHP) are one of the fastest growing applications of renewable energy in the world, with annual increases of 10% in about 30 countries over the past 15 years (J. Lund et al. 2004). In Europe, like some other southern countries, Italy has been one of the last to find interest in ground source heat pumps; the reasons should probably be found in some aspects: mild climate, because of the Mediterranean closed sea, different approaches to the heating solutions (cheap natural gas furnaces), a general culture that erroneously identifies electricity for heating with electric resistance, with an immediate callback to high running costs, low interest in renewable energies. Today, the Italian geothermal heat pumps market is still a niche one, that is growing, where people show good interest in this technology but where different technical approaches, competitors and designers introduce a quite wide number of solutions, plugged to the ground, sometimes not standard. Ground source heat pumps can exchange heat with an aquifer (open loops) or through plastic pipes buried in the ground (closed loop); this second approach is definitely considered the more reliable, environmentally friendly and efficient because the system uses always the same liquid, that flows in the pipes. Closed loop can be historically divided into two families: vertical loops and horizontal loops. In Italy for vertical loops we can identify a couple of bottlenecks:

- Legislation limits and grouting: in the Italian market most used grouts are cementitious bentonite grouts but the grouting procedures are not standard; high thermal grouts are not commonly injected in the boreholes. We still have lack of legislation and the actual laws create conflicts each other, so, for example, there is still the open question to consider these boreholes as water wells or not. In Italy the first aquifer (generally in the countryside the static level is from -20 to -60m) is often polluted; this fact creates several law bottlenecks (aquifer is a public property and its control is sometimes managed by the local town council, sometimes by the countries, which Italy is divided in).

- Drilling costs: from our first application in 1998 (Earth Comfort Update, 2000) the cost per meter that usually drillers ask to the customers (drilling and installation, without heat exchanger) has moved from 12€/m up to 45-60€/m, depending of the nature of soil. The main reason, for these high costs, should be that drillers have a very positive business in water wells and the cost is related to this kind of activity, not to the installation of the geothermal probes (heat exchangers)(Maritan and Panizzolo 2008).

Compact ground heat exchangers can be today the “third way”. In the market we can find some exchangers of different shapes (copper or steel spirals, “slinky” ©, “radiator style” modules): all of them have the target to reduce the space needed for a horizontal installation. “Slinky” © systems are very common in the Anglo-Saxon market, USA, Canada, Great Britain; the other two types require definitely less space than the slinky © but they are affected by the problem of the recharging: a certain amount of energy must be re-injected in the ground; in fact without recharging the risk is that the heat pump could run with very low temperatures, less than -3°C, with the effect of low COP (coefficient of performance), in comparison to the common boreholes and trenches design procedures, that consider a limit to 0 or 1°C.

2 THE CASE STUDY

This case study consists in a retrofit heating system with a 10kW Swedish heat pump, connected to an array of 20 compact plastic exchangers modules, called “compact collectors”. We discovered that rain conditions, during winter, make a big influence to the performances of this kind of loop; unlikely, the customer (that became, after, one of our local partners) lives in one of the driest areas in North of Italy: without recharging, during the first winter, temperature of the ground loop cold medium (water and antifreeze) fell below -8°C! The 2006 installed solar panel consists in a small array of 30 vacuum solar pipes, positioned in the roof of the house: this system gives hot water, when requested, but most of the times it recharges the ground loop, with an impressive amount of working hours; in fact it is not needed to wait for high temperature, to start the solar circulating pump. The pipes to the solar collector are both connected to the inlet geothermal line from the ground, in this way the liquid can be heated by the solar tubes, before entering in the heat pump. Winter 2007-2008 was very cold and the minimum entering temperature from the ground loop was -2.5°C.

2.1 Local Climate and soil

The system is located in the hills close to the Viverone lake, near Biella town, in the North West of Italy, 410m above the sea level. The climate of Viverone is mid cold; with 2704 degree days, the lake influence is minimal and during winter season temperatures often fall down -5°C; in Table 1 we can see mean temperatures, min temperatures and rainfall levels over the last 7 years are reported (AVNO Meteo Viverone).

Table 1: Temperatures and rainfall in Viverone lake (Italy)

Year	Mean temp. °C	Min temp. °C	Rain mm
2001	13,3	-9,2	600
2002	13,1	-9,3	1435
2003	13,5	-7,5	744
2004	12,8	-6,3	852
2005	12,2	-9	669
2006	12,4	-8,1	755
2007	12,8	-5,6	671

The surface soil for the first 4 meters is mainly dry silt and clay with some round gravel.

2.2 Heat pump and Ground source compact heat exchanger characteristics

The heat pump installed is a nominal 10kW water-to-water unit with integrated circulation pumps and plate heat exchangers. In Table 2 main technical specifications are reported at heating conditions: -2/-5°C T in/out ground loop and 30/35°C T in/out radiant floor (Eurovent requirements):

Table 2: Technical specifications heat pump

Heating capacity	kW	9,7
Compressor input	kW	2,7
Voltage	V	230
Geothermal flow rate	l/s	0,58
Max water press. drop	kPa	43
Refrigerant type		R407c

Thermal loads of this 160sq m house are fully covered by the heat pump capacity and the heating is provided by a radiant floor low temperature system.
A “compact collector” module consists in a patented compact layout of about 40m 40mm polyethylene PE80 pipe, with an air purging system on the top. Table 3 and Figure 1 illustrate it.

Table 3: Technical specifications ground heat exchanger

Collector module length	1,8m
Collector module height	2.0 m
Hose length per collector module	40 m
Hose type	PE80
Hose dimension	40 mm
Volume per collector module	40 l
Nominal flow	0.2-0.4 l/s
Pressure drop per module @ 0,3 l/s	7Kpa

Figure 1: Compact ground heat exchanger

The producer suggests some basic guidelines for a successful installation: the property must be energy efficient with a maximum heat load normally lower than 50 W/m²; the property must be fitted with mechanical exhaust air ventilation and a heat recovery coil must be installed in the exhaust air duct; the heat pump should offer full coverage with a normal running time of approximately 3000 hours/year; recharging of the compact collector takes place through exhaust air recovery and ground collector being interconnected (IVT Industrier ab, 2005). The collector modules are installed in trenches 3m deep and wide as the soil allows up to 0.3m; they are joined together with weld sleeves or screw couplings. Trenches are filled with sand or soft soil without stones. Twenty “compact collectors” modules were joined and installed in the garden in a 3m deep a 0,3m wide trench (figure 2).

Figure 2: “Compact collectors” installation

2.3 Solar collectors characteristics

In this project the solar collector consists of an array of 30 vacuum tubes, with an absorber plate inside; these products allow thermal diode operation and heat flow only in one direction (tube to manifold). Efficiency characteristic curve can be built at a flow rate of 114l/h, according to SPF Swiss testing laboratory (SPF test C264) with the formula:

Efficiency of Collector = 0.84 - 2.02 (Tm-Ta)/G - 0.0046G[(Tm-Ta)/G]**2

where:
Tm = mean collector temperature, (Toutlet+Tinlet)/2 [°C]
Ta = ambient air temperature [°C]
G = Solar irradiance [W/sq m] (test at 800W/sq m)

2.4 Data analysis

In this section we present a summary of the data collected during two periods: winter 2004-2005 and the last winter 2007-2008. In table 4 monthly climate data are presented: we can see that the two winters are quite similar, with the difference of a colder end of 2007 in comparison to the same period of 2004 and a warmer 2008 in comparison to 2005.
We focus now on the first one: the system was running without ground loop heat recharging; only at the end of the season a heat recovery unit from exhaust air was connected, with low effect on ground liquid temperatures. Rain level in the last three years varies from the minimum of 2005, at 669mm/year, to the maximum of 2004, at 852mm/year. Figure 3 shows three sets of recorded data: Outside temperature (dot line), the temperature of the medium *from* the ground loop (black line) and finally the temperature of the medium *to* the ground loop (gray line). We can see that temperature of the geothermal loop continuously reduced, rapidly during the first winter months and slowly after January. Ground loop inlet temperatures went below 0°C at the end of December 2004 and, in a very cold March, they reached -7,5°C.

Table 4: Viverone lake climate details

Year	Month	Mean temp. °C	Min temp. °C	Rain mm
2004	10	14,3	3,4	93
	11	7,1	-2,6	112
	12	3,1	-5,5	4
	Year	12,8	-6,3	852
2005	1	0,9	-8,6	2
	2	1,7	-6	3
	3	8,2	-9	45
	4	11,8	1,9	120
	Year	12,2	-9	669
2007	10	12	-1,4	31
	11	5,7	-5,5	79
	12	2	-5,6	1
	Year	12,8	-5,6	671
2008	1	3,2	-3,5	79
	2	4,3	-5	25

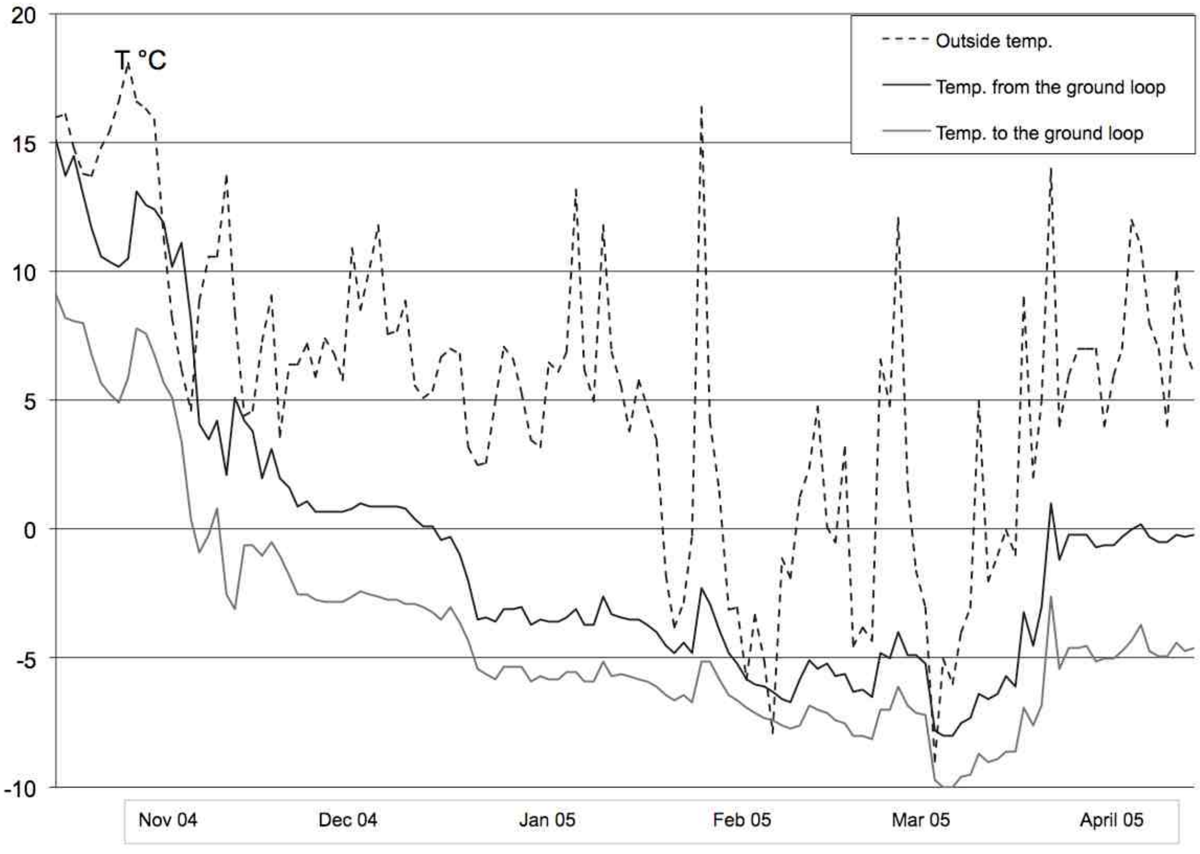

Figure 3: Geothermal loop inlet and outlet temperatures without recharging

During this time we had to change the antifreeze from propylene glycol (20% by volume) to bioethanol (35% by volume), because of the extremely low temperatures of the ground loop. Ethanol has lower viscosity than propylene glycol and it can be used to prevent energy consumption from the cold side circulating pump. Luckily the bad season and the first year of testing were at the end. In Table 5 rain levels and environment temperatures are reported, considering rain days during winter 2004-2005.

Table 5: 2004-2005 wintertime periods with some rainfall or snow

Day (winter 2004-2005)	Mean external temperature	Rain (mm)	Humidity %	Temperature °C liquid from ground
26/11	**5.7**	**0**	**78.0**	**1,7**
27/11	4.8	0	74.9	1,6
28/11	2.7	0	92.3	0,9
29/11	5.1	36	95.0	1,1
30/11	6.7	27	88.9	0,7
01/12	5.5	0	87.3	0,7
02/12	5.1	0	80.8	0,7
05/12	5.4	0	82.0	0,8
06/12	5.6	2	86.5	1,0
07/12	8.1	0	83.1	0,9
17/01	**-1.2**	**0**	**90.4**	**-4,8**
18/01	-1.4	0	96.4	-4,8
19/01	1.1	2	75.9	-4,4
20 /01	1.7	0	58.1	-4,8
21/01	12.9	0	31.8	-4,8
08/03	**4.7**	**0**	**64.5**	**-6,6**
09/03	6.5	0	53.0	-6,4
10/03	3.4	6	69.7	-5,7
11/03	3.7	4	81.0	-6,1
12/03	6.3	0	70.4	-6,0
07/04	**11.9**	**0**	**62.9**	**-0,2**
08/04	10.1	20	81.4	-0,2
09/04	8.3	24	85.1	-0,7
10/04	9.9	0	55.9	-0,6
11/04	10.2	2	75.6	-0,6

The four sets consider some days before and after rain or snow falls: higher temperatures of the cold medium from the ground can only partially be a consequence of the probable higher outside air temperature, because of the clouds: in fact we see that only in the first and

second period air temperature increased; this effect can be related to the presence of a higher level of moisture of the ground, that becomes damper during and immediately after rainfalls. This effect is more visible, lower the temperature of the medium is: we see temperature increases from +0,4°C to +0,7°C during the two coldest periods; in the other hand during the first and the last set of data they vary from +0,2°C to +0,5°C, considering the days that precede. Moisture of the ground had an immediate impact on the temperatures of the medium, because the thermal conductivity of the surrounding soil increased.
We can analyze now the plot of the data related to the last winter 2007-2008: curves are different (figure 4) from the 2004-2005 period.

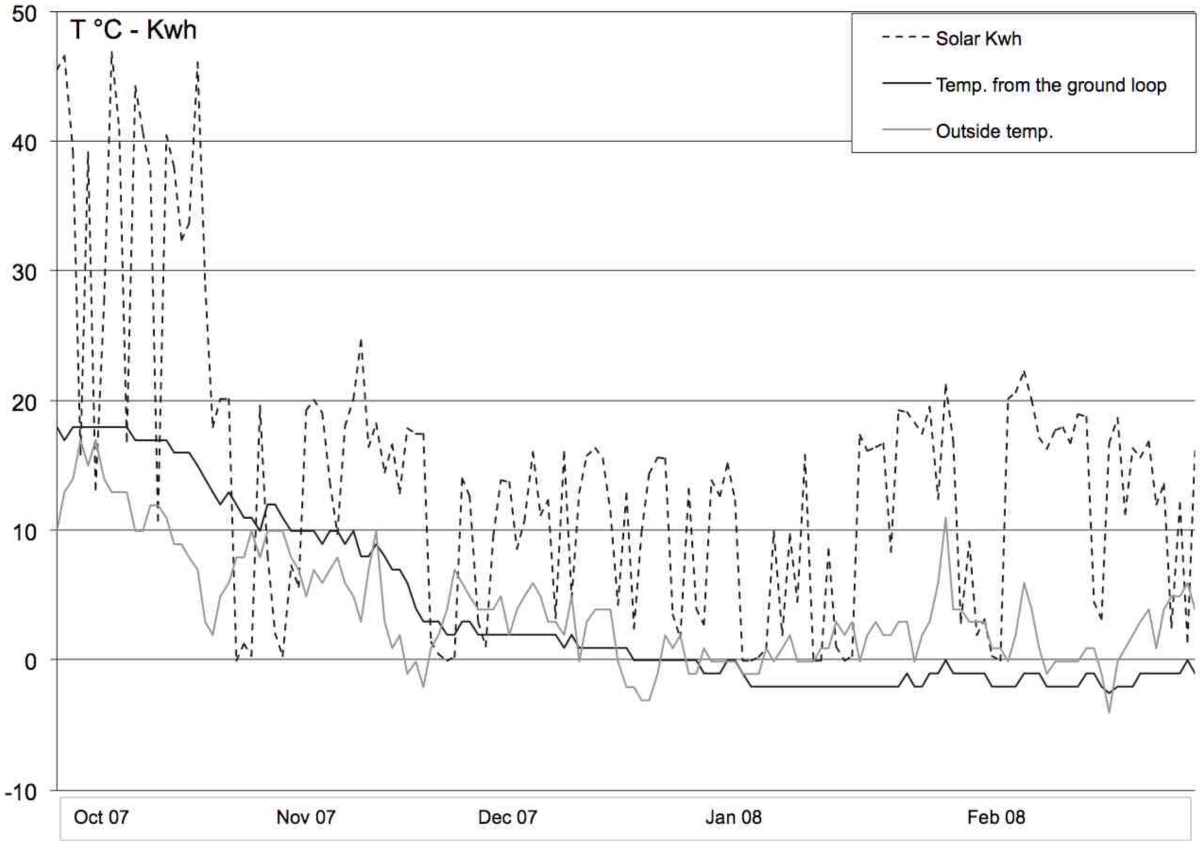

Figure 4: Geothermal loop inlet temperatures with solar recharging

Solar energy production from the roof panels varied from 40-45 kWh/day in case of sunny weather conditions, during first autumn to 15-20 kWh/day during winter months. Temperatures of the air outside followed a trend similar to 2004-2005. Good results came from the inlet geothermal flow temperature: after an initial decrease during October and November months, the curve stabilized at temperatures of +1°C or 0°C in December and -1°C or -2°C in the last two months, January and February 2008. Considering winter 2004-2005, the average increase in temperature is almost +5°C.

3 CONCLUSIONS AND FUTURE RESEARCH

Some lessons can be learned from this project:
- Moisture of the ground had an immediate impact on the temperatures of the medium and, in consequence, local average rainfalls must be considered carefully during design of compact ground exchangers layouts. Rain and moisture of the soil should be critical for compact collectors.

- Recharging of compact collectors must be done; solar recharging is now a good option to integrate hot water production and all seasons' ground loop energy storage. We can have in this case the sum of two effects:
  a) in dry and sunny days, solar panels inject solar energy into the ground,
  b) in cloudy and wet days solar panels produce a low number of kWh but humidity in the soil increases its thermal conductivity.

-Sizing of the solar collectors array is an open question: how many panels or vacuum pipes have to be installed according to the thermal energy extraction from the ground, in other words, what is the relationship between:
  a) rain levels
  b) type of soil
  c) solar energy production
  d) thermal output and extraction of the heat pump?

In autumn 2007 another project started up in a country with water-saturated soil; we will verify these variables, to understand what is the weight of ground moisture in comparison to the others. In the next couple of years data analysis from this system will be important to verify how the system works long term and to try to define some kind of equation that could be used to size properly this kind of compact collectors.

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