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Low-enthalpy geothermal energy: An opportunity to meet increasing energy needs and reduce CO_2 and atmospheric pollutant emissions in Piemonte, Italy

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ABSTRACT

The scope for diffusion of very low-enthalpy geothermal plants in the Piemonte region of Italy, using groundwater heat pumps (GWHP), was analyzed to check environmental sustainability and the benefits in terms of reducing greenhouse gas emissions from fossil fuels. GWHP implementation seemed particularly suitable to the specific characteristics of the Piemonte plain. An important thick and productive shallow aquifer is present across the entire plain beneath the major energy users and is therefore appropriate for geothermal energy development purposes. The building stock could be adapted to heat pumps in different ways, but objective-oriented policies will be required to reach the best results in terms of environmental benefits.

1. Introduction

The European Union Energy Efficiency Action Plan (EC, 2006) set a target of reducing global primary energy use by 20% by the year 2020 and reversing the trend under current energy and transport policies for CO_2 emissions to increase by about 5% by 2030 (EC, 2007). This, together with the increasing of costs of non-renewable (fossil) energy resources, has stimulated efforts by public administrations and private stakeholders to investigate new technologies by means of research activities and industrial applications. The successful implementation of very low-enthalpy geothermal plants for heating and cooling buildings in several European countries has highlighted one such technology, and this paper reports on an investigation of its potential impact in the Piemonte region of northwest Italy.

There are two basic ground source heat pump systems: an earth-coupled (closed-loop) type and a groundwater (open-loop) type (Rafferty, 2000). In the first type heat exchangers are located underground either horizontally (ground source heat pump, GSHP), vertically (downhole heat exchanger, DHE) or obliquely, and a heat-carrying medium is circulated within the exchanger, transferring the heat from or to the ground via a heat pump. The GSHP configuration is usually the most cost-effective when adequate yard space is available and trenches are easy to dig, especially while a building is under construction. DHEs are widely used when there is a need to install sufficient heat exchange capacity under a confined surface area, such as when the soil is rocky close to the surface or where minimum disruption of the landscape is desired.

Open-loop groundwater heat pumps (GWHP) typically withdraw groundwater to provide heat (PDEP, 1996). In the winter, the GWHP extracts heat from the water to provide space heating. With reversible heat pumps, the heat-transfer process can be reversed in the summer and the groundwater absorbs heat from the living or working space and cools the air (DOE, 1999). GWHPs are suited to regions with extended shallow aquifers, from which it is relatively easy and not very expensive to extract groundwater (Drijver and Willemsen, 2001).

There are three types of commonly used open-loop systems. Direct open-loop heat pumps, where the water is passed directly through the heat exchangers of the heat pump, are largely used for residential and very small commercial applications (Rafferty, 2001). This system is most suitably applied where low-salinity groundwaters are available, because the direct use of high-salinity waters can cause scaling, i.e. the deposition of mineral scales in pipes, valves and/or heat exchangers (PDEP, 1996). Standing column systems (SCW) are used in locations where groundwater wells do not produce sufficient water for a conventional open-loop system and where water quality is also good. In SCW systems, groundwater is re-circulated from one end of the column well (static water level) to the heat pump, and back to the other end (bottom) of the deep bore. Usually, only one well is required for conventional buildings; larger projects may have several wells in parallel. SCW systems

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can be thought of as a cross between closed-loop earth-coupled systems and open-loop groundwater source systems.

The indirect open-loop systems generally involve a heat exchanger between the building loop and the groundwater, which eliminates exposure of any building components to groundwater (Rafferty, 2001). The most important consideration in GWHP design is to obtain a plentiful amount of groundwater with a very stable temperature. Generally, a highly productive, shallow (within 30 m of surface) aquifer would favor successful and efficient functioning of the GWHP.

In practice, all geothermal plants based on GSHP, DHEs or GWHP systems have several advantages over traditional air source heat pumps,

- lower consumption of primary energy to meet the same level of energy end uses;
- good energy performances over the entire heating season, even with very low air temperatures (when the performance of air source heat pump is poor);
- quiet operation, due in particular to the absence of fans;
- most heating elements, such as radiant floors, are almost totally silent;
- when air conditioning is required, the use of GWHPs in standard ventilation and air conditioning (VAC) units yields important savings in terms of primary energy sources;
- high overall energy efficiency;
- reduction of CO_2 and atmospheric pollutants emission (NO_x; particulate matter less than 2.5 μm in diameter) both at global and local levels. If the heat pump is driven by an electric motor, no emissions are produced at the local level;
- the flameless operations simplify fire-prevention procedures.

Against this, uncertainty linked to the long-term environmental effects – especially for DHE and GWHP systems – is currently the main constraint on the wide implementation of GWHP systems in Piemonte. The lack of a regional legal framework for environmental permits creates excessive administrative restrictions by public agencies, a situation that should be resolved as soon as possible. Consequently, several actions have been taken by the regional environmental authority and an intense program of research activities was developed to better characterize the environmental effects due to GWHP installation and operation. These included the characterization of the aquifers in the region, determination of their potential, and the evaluation of what improvement of the building stock might be feasible on the regional scale, the aim being to estimate what reduction of fossil fuel use might be achieved by the installation of DHE and GWHP systems.

In the plain area of Piemonte (roughly the planning areas identified in Fig. 1) the groundwater quality, hydrogeological setting and shallow aquifer characteristics seemed particularly suitable for a wide implementation of GWHP direct open-loop systems.

2. Materials and methodology

2.1. Geothermal energy resources

Piemonte is poor in geothermal energy resources even though its present geologic structure was developed during the recent Alpine orogeny. The central plain area of continental sediments, presenting extensive alluvial fans and moraine deposits, is bounded by the arcuate orogenic belt of the Western Alps (crystalline and carbonate rocks); see Fig. 1. The Western Alps are a thick-skinned thrust belt formed by the subduction of the European Plate beneath the Adriatic Plate that began in the Late Cretaceous. Final collision and nappe staking took place in the Late Eocene (Coward and Dietrich, 1989; Gebauer, 1999; Vezzosi et al., 2004).

The Alpine orogenic wedge was the result of a complex geodynamic process due to plate convergence, characterized by mainly "horizontal displacements" involving lithosphere oceanic subduction followed by continental collision (Polino et al., 1990). The post-collisional, "late-Alpine" (Pliocene to Recent; Hunziker and Martinotti, 1987) history of the chain is mainly dominated by "vertical movements" (either uplift or subsidence), due to both active tectonics and isostatic rebound (Debelmas, 1986; Cadoppi et al., 2007).

In the southern sector of Piemonte the transition from the plain to the Apennines is gradual, being characterized by the intermediate presence of hilly terrigenous sectors (Monferrato and Langhe) belonging to the Piedmontese Tertiary basin. The plain area covers 9349.6 km^2 (36.8% of the total surface area of 25,392 km^2).

The stratigraphic relationships among the various continental units in the region are the results of different exogenous processes linked to Quaternary glacial and alluvial dynamics. Generally, these units are lithologically represented by coarse gravel and sandy sediments (locally cemented) with limited amounts of thick clayey–loamy horizons related to lacustrine facies. An unconfined high-productivity aquifer connected to the surface water drainage network is found across the entire Piemonte plain and in the major valleys in the mountain sector. Confined productive aquifers are also widespread; they represent the main regional source of water for human consumption (Civita et al., 2004).

Thermal (55–70 °C) springs exist only in rare geological circumstances in the southern part of the region (Vinadio, Valdieri, Acqui Terme); they have been used since Roman times, mainly as thermal spas. A few less important hot springs occur in other parts of the Alpine chain, linked to particular local tectonic settings, but energy recovery from these resources could have only local significance. On the other hand, geological bodies and groundwater in the Piemonte plain could represent an important source of clean geothermal energy through the widespread implementation of GWHP technology.

In the Piemonte plain, the vertical separation between the unconfined and deeper confined aquifers varies from a few meters to several tens of meters depending on local hydrogeological conditions. Deep, high-quality groundwater bodies are legally preserved for human consumption. To avoid potential pollution of the deeper aquifer, they should not be intersected by the wells to be used to operate the DHE plant. Moreover, GWHP could be used only with shallow groundwater. Nevertheless, where the local hydrogeological conditions are such that no confined aquifer is present below the water table or the top of the confined aquifer is below 60 m depth, it may be appropriate to consider 60 m as the maximum depth for injecting GWHP discharges or of DHE wells.

To evaluate the hydro-geothermal energy potential that might be exploited by the use of GWHP systems in the shallow aquifer across the entire plain, groundwater temperature data collected by the regional groundwater-monitoring network during the period 2000–2005 were used in combination with the hydraulic parameters from the regional database on pumping tests carried out in productive Piemonte wells since 1990 (Regione Piemonte, 2007). For data clustering and basic statistical analysis the 14 planning areas (Fig. 1) separated by hydrogeological boundaries and defined in the Water Protection Plan (WPP) were considered (Regione Piemonte, 2007). Note that temperature-monitoring network points did not coincide with the wells where the pumping tests were conducted (see Table 1).

Chemical analyses of the waters derived from the shallow aquifer have been performed twice a year since 1990 through the regional groundwater-monitoring network (414 measurement