Wide use of sustainable energy from aquifers in Italy: pilot plant design and implementation

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Abstract: Storing thermal energy in aquifers and acquiring heat and/or cold from extracted groundwater has been proven to be a popular sustainable energy technology, especially in the Netherlands, because of its cost-efficiency, delivering on average approximately 60% less CO_2-emissions and substantial savings compared to sole use of fossil energy. Nevertheless, in the rest of Europe socio-economic, legislative and technological barriers prevent widespread application so far. The “*Europe-wide Use of Sustainable Energy from aquifers*” (E-USE(aq)) project, started in June 2015 and financed by the Climate KIC, aims to pave the way for a Europe-wide use of this new cost-efficient form of collecting and using renewable thermal energy and thus the creation of new business strategies and new jobs. The Department of Industrial Engineering of the University of Bologna is involved in the realization of one pilot plant in Italy, which will act as flywheels that enhance wide application of the technology in Italy. The paper shows the site identification and the design phase of the pilot plant, including monitoring and control systems. Moreover, the paper shows which barriers have been faced during the development of the project and how they can be overcome.

Keywords: Aquifer thermal energy storage, renewable energy, heating and cooling, pilot plant design, monitoring and control systems.

1. Introduction

The European energy bill is highly influenced (up to 50%) by costs related to buildings’ heating and cooling, which are mostly realized by fossil fuel consumption. The reduction of the fossil fuel consumption as well as of the related environmental impacts can be reached only if renewable and also sustainable alternatives can be found. The search for renewably energy is usually a search for renewable electricity, but there is also the possibility of using renewable heat, in particular geothermal energy. Shallow geothermal systems are very interesting since they are applicable in both small and large installations, via ground-coupled heat pump systems, and including also energy storage.

Shallow geothermal energy systems are typically limited to depths of 200 m below ground level (BGL), and can be subdivided into two mayor classes, that are i) vertical or horizontal closed looped piping (closed systems, Fig. 1a) and ii) groundwater open systems with re-injection (Fig. 1b).

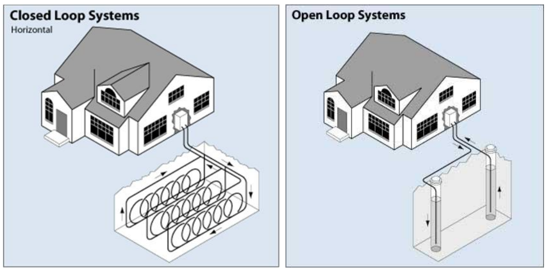

Figure 1: a) closed loop system (horizontal) and b) open loop system.

The first type of systems utilizes the natural, constant temperature of the subsoil for above-ground heating/cooling applications, while the second type of systems utilizes groundwater as temperature steady heat source. In that second case, also energy storage can be done. In fact, the concept of aquifer thermal energy storage (ATES) is that in summer, groundwater is extracted to provide cooling. The heated groundwater is injected back into the aquifer to create a heat storage. In winter, the flow direction in the system is reversed such that the heated groundwater is extracted to provide heating and create a cold storage. However, presence of soil and groundwater contaminants in many urban environments may limit applicability of ATES and hampers redevelopment of these sites. Combination of ATES and remediation is therefore considered a promising new concept to achieve both energy savings and improvement of the groundwater quality (Sommer et al., 2013; Possemiers et al., 2014; Ni et al., 2015).

ATES is applied worldwide and application overviews generally show a constant but slow growth in the last decades. Several applications can be found, among others, in Belgium (Possemiers et al., 2014, Vanhoud et al., 2011), China (Zhou et al., 2015), Sweden (Andersson et al., 2003, Gehlin et al., 2015) and Germany (Sanner et al., 2005). The Netherlands are the exception, since here the growth has been exponential: in fact, ATES system has grown from around 200 installations in 2000 to more than 2,000 in 2012 (Bonte et al., 2013). Growth rate of ATES systems is locally driven by several factors (Bloemendal et al., 2015), like energy saving targets, competition by fossil fuels, economic growth rate, lack of knowledge, legislative issues.

The “*Europe-wide Use of Sustainable Energy from aquifers*” (E-USE(aq)) project, started in June 2015 and financed by the Climate KIC, aims to pave the way for a Europe-wide use of this new cost-efficient form of collecting and using renewable thermal energy and thus the creation of new business strategies and new jobs. The project involves several European partners and foresees the realization of at least 5 pilot plants in Europe. The Department of Industrial Engineering of the University of Bologna (UniBo) is involved in the realization of the Italian pilot, which will act as flywheels that enhance wide application of the technology in Italy. The paper shows how the selection of the potential site for pilot installation has been carried on by UniBo, including the techno-economic evaluation of the integration of an open loop heat in district heating, anaerobic digestion and tertiary heating/cooling plants. The paper also shows the design phase of the pilot plant, including monitoring and control systems. Moreover, the paper shows which barriers have been faced during the development of the project and how they can be overcome.

2. Italian pilot sites assessment

2.1 Methodology of preliminary pilot sites assessment

Five potential sites have been compared by UniBo to verify the opportunity of integration of an open loop heat pump system. The sites were identified also to verify the opportunity of a combination of aquifer energy valorization and remediation. All the sites were preliminary analyzed to evaluate techno-economic sustainability, as well as to identify potential barriers to the realization of the plant, environmental concerns in particular. Three different sites (Modena, Bologna and Forlì, see data in Table 1) involve district heating (DH) networks. One site regards the opportunity of integrating an aquifer heat pump with an anaerobic digestion (AD) plant under revamping near Bologna, while the last site is about the application of a reversible aquifer heat pump for tertiary buildings heating and cooling in an electric station near Bologna. Both sites characteristics are summarized in Table 2. Heat pump size has been defined for each site accordingly to on-going project forecasts, while energy saving was computed on the basis of projects’ forecasts (if available) or through estimation made by UniBo. In particular, the evaluation of the Coefficient of Performance (COP) of heat pumps as well as Energy Efficiency Rate (EER) of chiller were made with the hypothesis of R134A refrigerant machine application and through the hypothesis of a temperature difference of 5°C between outlet water temperature and refrigerant temperature (condensing or evaporating), while refrigerant condensing and evaporating temperatures were set, respectively, at 9°C and 30°C in heating and cooling mode. The energy saving in heat pump mode has been computed by considering a seasonal methane boiler efficiency of 75%, while the EER of existing air-liquid chiller has been estimated in about 3.1 (refrigerant condensing temperature of about 50°C). Finally, yearly operating time has been estimated on the basis of users’ energy consumption data.

2.2 Aquifer heat pump integration with district heating/cooling and aquifer remediation

The redevelopment of the “*ex-Mercato Bestiame*” area in Modena was a part of a general revamping plan of the district heating of the whole city. The project foresaw the realization of a 33,4 km district heating network, able to supply hot water at 90°C to 9,900 equivalent apartments of 300 m^3, with a nominal heating power of 58 MW th per year. The project foresaw the up-grading of an existing thermal power plant, made by two methane boilers (total installed power of 1.5 MW th), thus allowing the connection of new users to the existing district heating network. The new heating plant was supposed to provide hot water to these users by the following sources: i) heat recovery from a new 800 kW th cogeneration plant for the simultaneous production of electric energy (700 kW el), ii) heat from a 600 kW th open loop heat pump (fed by a portion of the electric energy produced by the cogeneration plant), iii) thermal energy produced by a 100 kW th solar thermal plant and iv) two extra methane boilers (2.5 MW th and 4.0 MW th), functioning as integration and emergency heat source for peak demands. In Modena application the open loop heat pump should have work as a preheater of the return water at 60°C for the gas boilers and/or cogeneration unit, thus being in series.

Starting from the ‘80s, district heating networks were developed in different areas of Bologna, thus contributing to build up a distributed system of thermal energy power plants. In the last years, the system has been up-graded through the installation of cogeneration plants as substitute of old boilers plant, especially the ones fed by oil. In particular, in Via San Giacomo (Fig. 2) there is a thermal power plant fed by methane that produces superheated water at 120°C, that is used to heat mainly buildings of different Departments of the University of Bologna. In Via Berti Pichat there is a new trigenerative plant (installed in 2007), which is made by two cogeneration plants, two methane boilers, two absorption chillers and two refrigerant compressors. The cogeneration plants produce hot water at 120°C, that can be sent to the Via San Giacomo thermal power plant as integration and back-up; while the two methane boilers produce hot water at 90°C for Hera S.p.A. headquarters buildings as well as for buildings of different departments of the University of Bologna. The district cooling network serves only the area of Berti Pichat: so, a 600 kW th open loop reversible heat pump should be placed in Hera headquarters, near the trigeneration plant. The heat pump can work as a preheater of the return water at 70°C for the gas boilers and/or cogeneration plants in the cold season. On the other hand, the reversible heat pump can work as integration unit for absorption chillers instead of refrigerant compressors in the warm season, with an estimated EER considerably higher than value that can be reached by existing air-condensing chillers. After a procedure of soil remediation was started, various investigations were carried out on Hera headquarters site. The analysis revealed that a significant state of soil contamination is present. The contamination is determined, in particular, by the presence of heavy metals, such as cadmium, chromium, lead, thallium and cyanide, in addition to aromatic hydrocarbons. Soil contamination is due to the industrial distillation of coal, which was washed from naphthalene, and purification of the syngas, which was purified by cyanides, thiocyanates and oxides of nitrogen, which was carried out in the area since 1850. The first aquifer underlying the area, which is between about 14 m and 20 m deep, is thus in part contaminated by these elements.

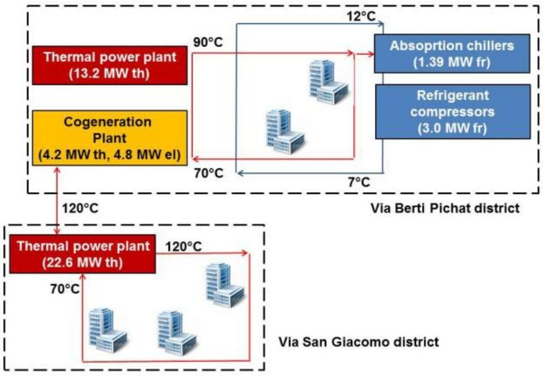

Figure 2: schematization of Via San Giacomo heating/cooling district in Bologna.

In 2006 the Municipality of Forlì planned the development of district heating and cooling network in the city area. The aim was to design a distributed system of thermal energy power plants which may include existing facilities (i.e. the municipal Waste-to-Energy power plant) and new cogeneration and trigeneration plants, with particular attention to renewable energies as power source. The final aim was to complete by 2016 the primary district networks of 28.5 km length, the secondary district network of 90 km length as well as all the power plants integration, thus making possible to reach 86 MW th of peak production and 131,000 MWh th/year of thermal energy production, able to serve 14,600 equivalent apartments of 300 m^3. In this general framework a potential site of interest for the application of an open loop heat pump system were identified by UniBo at the "*ex-Ospedale Morgagni*" area, where the University Campus is under development. The district heating would be fed by a cogeneration plant of about 0.8 MW th and 0.7 MW el, plus two methane boilers for a total thermal power installed of 1.5 MW th, working as back-up and integration units. The network would work in the temperature range 60-90°C. A 300 kW th open loop heat pump would be integrated in the under construction district heating of the University Campus, working as a preheater for the cogeneration system.

Table 1: DH pilot sites assessment.

Item	DH pilot sites		
	Modena	**Bologna**	**Forlì**
Heat pump (kW)	600	600	300
Outlet temperature (°C)	67	75	70
COP	3.0	2.6	2.8
Working hours (h/y)	2,500	2,500	2,500
Chiller (kW)	-	600	-
Outlet temperature (°C)	-	7	-
EER	-	6.2	-
Working hours (h/y)	-	1,500	-
Aquifer contamination	Nitrates	Heavy metals, Hydrocarbons	Nitrates

Table 2: AD and H&C pilot sites assessment.

Item	AD pilot site	H&C pilot site
	Bologna	**Bologna**
Heat pump (kW)	500	160
Outlet temperature (°C)	50	65
COP	4.4	3.1
Working hours (h/y)	4,500	2,500
Chiller (kW)	-	160
Outlet temperature (°C)	-	7
EER	-	6.2
Working hours (h/y)	-	1,500
Aquifer contamination	Ferrous, Manganese, Arsenic	Manganese

2.2 Aquifer heat pump integration with anaerobic digestion and aquifer remediation

The AD plant under revamping will have to operate the treatment of the organic fractions from the separate collection separation of municipal solid waste (MSW), for a maximum quantity of waste of 135,000 tons/year, of which 100,000 tons/year maximum coming from the separate collection of food waste and similar, and the remaining 35,000 tons/year coming from the separate collection of lignocellulosic waste (green waste). The introduction of an anaerobic digestion section (semi-dry process) allows, in addition to the production of high quality compost (mixed soil improver) the production of biogas. The anaerobic digestion process takes place inside watertight reactors and is based on a continuous semi-dry process of degradation. The anaerobic digester works in the temperature filed 40-55°C, that covers both mesophyll and thermophile microorganisms. The biogas is then sent to which is sent to a system of "upgrading" for refining it up to biomethane, which if finally stored in the same area to be used for automotive applications, or, if the evolution of the Italian regulatory framework would allow it, to be put into the methane grid. In case of overproduction of biogas, it will be sent to the existing cogeneration power units in the service of the nearby landfill. Moreover, the aquifer is characterized by a high content of Ferrous, Manganese and Arsenic, the latter being probably produced by the nearby landfill. The revamping project foresees to cover the heat demand coming from the anaerobic digestion process through a 500 kW th boiler. UniBo proposal was to substitute the methane boiler with an open loop heat pump.

2.3 Aquifer heat pump/chiller for tertiary buildings heating/cooling

Another potential site was identified in the Martignone electric station, placed near Bologna, owned by Terna, which is the Italian operator in electricity transmission grids. The electric station is a transformation station 380 kV/132 kV. Moreover, the station includes two buildings, one hosting the emergency teams that cover the ordinary and extraordinary maintenance of 2,800 km of electric lines and the other one hosting offices and remote control station. The "changing room building" is a single floor building which includes conditioned rooms with a volume of about 1,600 m^3 which are currently heated and cooled by a complex series of plants, including electric and methane boilers, air-liquid heat pumps and chillers. The "office building" is a two floors building which includes several offices, bathrooms, data centers, battery room and a remote control station. The conditioned rooms have a volume of about 3,800 m^3 and are currently heated and cooled by electric and methane boilers and by an air-liquid chiller.

UniBo started at the same time a mapping of existing plants and an energy audit of the two buildings. The energy audit was carried on by two different approaches: i) estimation of buildings energy consumptions (through UNI EN 12831 and UNI TS 11300) and ii) computation of past energy consumption (methane and electric energy). A whole peak thermal power demand of about 150 kW th and a peak cooling power demand of about 160 kW fr have been estimated, while a yearly energy demand of about 170,000 kWh for heating and of about 49,000 kWh for cooling have been computed. The computation of past energy consumption found different technical obstacles. First of all, there is no separated computation of electric energy consumption, since Terna has a special contract for energy consumption. Moreover, the larger quantity of electricity is consumed by the electric station, and not by the buildings' facilities, so there is no chance to make a seasonal analysis of the whole electric consumption to identify summertime consumption increasing due to air conditioners impact. Nevertheless, by analyzing methane consumption it is possible to have a rough comparison between estimation and real consumption. The methane bills correspond to a methane consumption of 24,160 Sm^3, 20,020 Sm^3 and 21,830 Sm^3, respectively, for the years 2013, 2014 and 2015. If the seasonal efficiency of the methane boilers is taken into consideration (due to the oversizing of the boilers), a consumption of about 23,100 Sm^3 of methane can be predicted, which is coherent with the real consumptions. So, through the installation of a 160 kW th reversible heat pump it is possible to verify the application of an open loop heat pump/chiller in the heating and cooling (H&C) of tertiary buildings. Hot water can be produced at a mean temperature of 65°C, while cool water should be produced at 7°C.

3. Techno-economic evaluation of different sites

A preliminary economic analysis was carried out through the application of the Net Present Value (NPV) method to evaluate investment profitability for each potential site. The formula of NPV can be expressed as in Eq. 1.

$$\text{NPV} = \sum_{t=0}^{n} \frac{F_t}{(1+i)^t} \qquad (1)$$

where t (years) is time, n (number of years) is the time period considered for the investment evaluation (which will be assumed equal to technical life time of the heat pump for treatment simplicity purpose), i (%) is the discount rate, F_t (€) is the net cash flow at year t. Moreover, both costs and revenues are computed taking into account a constant yearly inflation rate e. The net cash flow F_0 at t=0 corresponds to the starting investment: the simplifying hypotheses of full investment payment and plant operation start in the same year (t=0) are also assumed. The net cash flow for period t>0 was computed taking into account the main costs and revenues components.

Table 3: Main assumptions about pilot sites economic assessment.

Item	Symbol	Value
Evaluation period	n	20 years
Discount rate	i	5.0%
Initial investment	F_0	360,000€ DH Modena-Bologna 195,000€ DH Forlì 300,000€ AD Bologna 112,000€ H&C Bologna
O&M yearly cost	$C_0^{O\&M}$	1.0% of F_0
Yearly O&M costs escalation rate	$r_{O\&M}$	1.0%
Yearly electricity cost escalation rate	r_{Energy}	2.5%
Yearly methane cost escalation rate	r_{Fuel}	2.5%
Natural gas price in Italy	R_0^{Fuel}	37.8 €/MWh
Electricity cost	C_0^{Energy}	115 €/MWh (cogeneration) 170 €/MWh (grid)

The initial investment was estimated by site owners in the range 600-700 €/kW th, depending on plant size, coherently with literature data (Lee, 2013; Subias et al., 2011). A cost to be considered is the operating and maintenance (O&M) cost. $C_0^{O\&M}$ is the O&M cost, which is evaluated as a percentage of initial investment. An escalation rate $r_{O\&M}$ is considered to evaluate the increasing costs of O&M due to plant component wear and tear over the years. Another cost to be considered is the electric energy cost C_0^{Energy}, which is computed on the basis of heat pump/chiller COP and EER and estimated operation time (see Tables 1 and 2).

An escalation rate r_{Energy} is considered taking into account the electric energy cost increase over the years. In DH and DA case studies the electric energy is produced by a cogeneration plant: so, the cost to be considered is not the commodity price cost (about 170 €/MWh el for an industrial user), but the production cost referred to the cogeneration plant. The cost has been estimated in 115 €/MWh el on the basis of preliminary project assumptions. Profits depend firstly on natural gas price. Natural gas price varies considerably, depending also upon the country of installation. In this paper, since the heat pump will be realized in Italy, averaged figures are used, being representative for the Italian energy market. So, heat pump saves natural gas from being burned in methane boilers, thus producing the fuel saving profit R_0^{Fuel}. An escalation rate r_{Fuel} is considered taking into account the natural gas cost increase over the years. The previous formula of NPV can thus be rewritten as Eq. 2. Table 3 summarizes the main assumptions about economic assessment.

$$\text{NPV} = -F_0 + \sum_{t=1}^{n} \frac{[R_0^{Fuel} \cdot (1+r_{Fuel})^t - C_0^{O\&M} \cdot (1+r_{O\&M})^t - C_0^{Energy} \cdot (1+r_{Energy})^t]}{(1+i)^t} \qquad (2)$$

The results of NPV evaluation for the five pilot sites are shown in Fig. 3: all DH sites have a negative NPV after 20 years, meaning that the technological solutions taken into consideration are not sustainable. The first reason is in the relatively high temperatures requested by DH application (over 60°C for Modena and Forlì and over 70°C for Bologna), which reduce the COP of the heat pump. Secondary, in two cases there is no district cooling (Modena and Forlì), further lowering the profitability of the plant. Despite the potential interesting techno-economic profile (7 years of pay-back time without considering incentives), the AD revamping project was not finalized due to two potential environmental related problems. The first one is connected to the contamination of the aquifer, which may be a critical point in the authorization process of the plant revamping. The second one is that the continuous extraction of heat from the aquifer all over the years can produce a temperature profile displacement within the aquifer. In fact, with this plant configuration there is no compensation during the summer time, since the plant always works in heating mode. The solution is to limit working hours per year, but this reduces plant profitability. Another possible solution is to use the heat pump as a chiller in summer time for cooling, but the estimated cooling demand, both from offices buildings and from biomethane up-grade process results as low. Finally, as expected, the H&C application has a sustainable economic profile, since it combines relatively low temperature in heating mode and it also includes cooling mode.

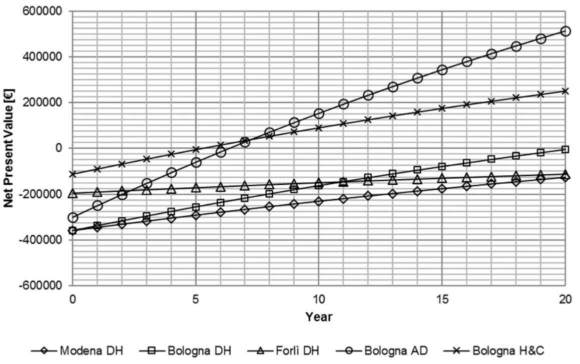

Figure 3: comparison of different potential sites for open loop heat pump pilot plant realization in Italy.

In the economic evaluation of the H&C application Italian mean energy costs for methane and electricity have been considered (see Table 1) to give more replicability to the results. Nevertheless, it should be noted that the real application has lower pay-back time than the computed 5 years (see Fig. 3), since the electricity costs is much lower than 170 €/MWh for Terna (due to particular favorable conditions of the energy supply contract) and that through the substitution of existing methane boilers with heat pumps the electric station can become "methane free", thus further reducing energy costs (i.e. methane grid connection costs). So, the pilot site was identified in Bologna electric station on the basis of a preliminary techno-economic assessment, including also environmental concerns (impact on aquifer contamination and thermal equilibrium).

4. Preliminary design of the pilot plant

4.1 Pumping test

A series of pumping test has been conducted at the electric station to verify aquifer characteristics. The realization of pumping test does not require any kind of authorization from Emilia-Romagna region. A first well has been realized starting from 27th of July 2016. The well was dug up to 50 meters, taking samples for each meter. The soil resulted as mainly composed of silts and clays, except for the aquifer layer, that was identified at a depth of 20-28 meters, where sand and stones were also identified. The same well was then dug up to 100 meters, but without taking samples. No further aquifers were found, and the soil was characterized again by the high presence of silts and clays. So, the only available aquifer was identified at a depth of about 25 meters. Then, two further wells were completed at 40 meters’ depth for monitoring purposes. Wells realization was completed by 12th August 2016. Preliminary pumping test started on 19th September 2016 and was concluded on 31st October 2016: test was carried on the 100 meters’ depth and 4” diameter well through i) a submersible centrifugal pump with vertical axis (Fig.4a), ii) a water volumetric flowrate meter (Fig.4b), and iii) a phreatimeter, used to measure water level variation in the pumping well.

The preliminary pumping test was done accordingly to ISO 22282-4. So, a variable rate test was firstly performed: the starting flowrate was fixed at 0.3 l/s. This type of test involves pumping the test well in a step-wide increasing up to the maximum capacity of the pump. The variable rate test is fundamental to determine the optimal discharge rate for the realization of the constant rate test, which requires a long duration (up to 72 h) and includes also the monitoring of other wells. Moreover, variable rate test is important to monitor drawdown and recovery of water levels in the well test as a function of time, and to verify how water discharge rate varies during the test as a function of time.

Figure 4: a) picture of the water pump and b) of the water volumetric flowrate meter.

Test results are shown in Fig. 5: the limit of water flowrate can be fixed at 1.7-1.8 l/s, since over this limit the level variation slightly increase. A constant rate pumping test was carried on with a value of 1.8 l/s. The test was carried on for 72 hours and the level in three wells, including two monitoring wells. Water levels in the monitoring wells kept constant during the test. So, the maximum water flowrate that can be extracted from one well has been experimentally verified and it is equal to 1.8 l/s.

4.2 Water sample analysis

Two water samples were taken (one in July and one in November 2016) and analyzed to measure the physical-chemical characteristics of the aquifer. The water is characterized by a very high concentration of manganese (1,200-1,300 μg/l) and also very high total hardness (560-590 mg/l $CaCO_3$). The high level of manganese concentration is quite common in the area and it is probably not due to anthropic activities (ARPA, 2006). Water temperature was measured at 18-19°C.

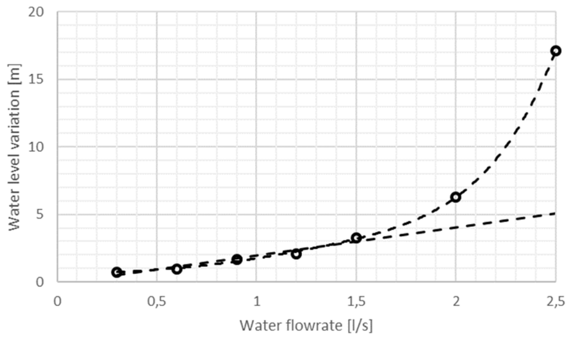

Figure 5: pumping test results.

4.3 Pilot plant preliminary design

The combination of pumping test results and buildings energy audit allows to define the optimal size of the heat pump/chiller as well as the number of wells needed to feed the machines. Thermal and cooling peak power request was fractioned by buildings. A heat pump working with R-134A refrigerant, with water at 14°C out of the evaporator and with water at 65°C out of the condenser has a COP of 3.1, meaning that about 27 kW th are taken from the aquifer to produce 40 kW th. A maximum temperature difference of 5°C can be fixed for the aquifer injection: so, a peak groundwater flowrate of about 5.2 l/s can be estimated. At least three extraction wells should be realized, since with a smaller number the risk is that the well is not able to guarantee the flowrate (see Fig. 5). Three injection wells have been identified as the right number to guarantee a simpler balancing of the water circuit.

The pilot plant has been developed through an innovative concept, called "*cold district heating*", so named for its peculiarities of distributing technical water directly pumped from underground, at an average temperature of 12-20°C. In traditional district heating thermal energy from available sources is transported to areas where it is needed: district heating networks usually use pressurized hot water as heat carrier with a supply temperature of about 90°C. Whereas lower supply temperatures are sufficient to gain comfortable room temperatures in buildings with suitable heating systems (i.e. floor heating), low temperature district heating was developed (Kofinger et al., 2016; Ommen et al., 2016; Yang et al., 2016). In this case, a major challenge is the hygienic preparation of domestic hot water (DHW) if supply temperatures drop below a certain value: to avoid the origin and the proliferation of legionella, minimum temperatures must be guaranteed, i.e. over 50-60°C. Unlike the traditional district heating, the cold district heating achieves a simpler infrastructure equipped with polyethylene pipes that are bare cutlery so as to facilitate the thermal exchange with the ground, thus allowing for containment of typical energy distribution losses of a conventional district heating network. The groundwater is brought to the users served by the network, named “*cold ring*”, where heat pumps and/or chillers ensure the supply of heating and/or cooling. So, users can indifferently need heat or cold: even better, the higher is the balancing of heat and cold request by the users, the lower is the impact on groundwater temperature. Moreover, under certain conditions, groundwater can be used for direct cooling (Ampofo et al., 2006). In the case of ”*free cooling*“ EER can reach two or three digit values, since the electric energy consumption is due only to groundwater pumping. The peculiarity of the pilot site system is that in the office building there are some rooms that need cold all year long since they host data centers and electric panels. So, in wintertime, there are heat pump and chiller that work with same cold ring, from which they, respectively, take or bring heat.

Clogging is one of the most common operation and maintenance issue related to groundwater exploitation. Both manganese and very high hardness are potential causes of clogging. Water hardness seems to be more severe at high temperatures (>80°C), while the problem with the precipitation of manganese (and iron) is critical at relatively low temperature, i.e. under 40°C. Manganese precipitation occurs with increments of the redox potential or pH. These conditions can be reached if i) oxygen enters into the groundwater, ii) water with different characteristics is mixed with the groundwater and iii) groundwater loses CO_2. So, it is very important that the circuit is watertight. Two different solutions have been implemented to limit the risk of clogging: the first one, which is an option still under investigation, concerns the realization of an inertial separator between the extraction wells and the cold ring. The separator may be necessary since turbidity (probably due to lime and sand transport) has been observed during the pumping test in the discharge water, especially during the pump restart. The second one is the realization of a secondary circuit with two flat plate heat exchangers in parallel. In fact, due to the high content of manganese and the very high total hardness, the groundwater cannot be used directly with the heat pumps/chillers. Moreover, the use of two heat exchangers limits the risk of plant stop due to heat exchanger clogging.

To prevent the entry of oxygen from the outside and in the aquifer it is also important that the heated or cooled water is fed back to the groundwater below its level to avoid contact between the air and the groundwater. The maintenance of a good overpressure (to avoid also the release of air bubbles) should be guaranteed. The use of automatic valves has been foreseen to control the pressure in the injection wells. So, inverter pumps have been chosen to ensure the groundwater flowrate can be kept constant even if circuit pressure may vary due to the action of the automatic valves.

5. Preliminary design of the monitoring and control system

ATES plant monitoring is a fundamental aspect in the plant design (Desmedt and Hoes, 2007; Vanhoudt et al., 2011). The monitoring system of the plant includes two different monitoring sections. The first one concerns the monitoring of the aquifer, the second one the performance of the ATES heat pump system. The monitoring of aquifer status is implemented through the realization of two monitoring wells near extraction and injection areas (one per area) and a third monitoring well, to be placed far away from both areas, to evaluate long term influence of the plant on the aquifer. The three monitoring wells have been already realized to complete the pumping tests. Aquifer monitoring system will include i) extracted water temperature and flowrate, groundwater level (measured in the extraction wells), ii) injection water temperature and flowrate, groundwater level (measured in the injection wells), iii) aquifer temperature and level (measured in three different points by the three monitoring wells). Moreover, every 18 months one sample of water will be analyzed to evaluate (if any) the impact of the pilot plant operation on water chemical-physical characteristics. The monitoring of the groundwater will also allow to verify the thermal plume of the plant on the compare it with the theoretical plume forecast made by geologists.

Heat pumps and chillers performances will be monitored through heat pumps/chillers electric consumption, ii) flowrate and temperatures of the hot/cold water produced by heat pumps/chillers, iii) electric consumption of back-up units (electric boilers, heat pumps, chillers). These data are fundamental to assess pilot plant efficiency and effectiveness in energy production. Furthermore, a local meteorological station will be installed, thus measuring local air temperature and humidity. These data are fundamental to compare ATES heat pump performance with an air-liquid heat pump. A database will be implemented, wherein measured data are stored, including the opportunity to access data remotely.

Finally, a control system software will be developed to automatically manage the plant. In particular, groundwater flowrate will be regulated on the basis of users' energy demand, while cold ring circuit pressure and discharge temperature will be regulated to maintain groundwater temperature variation within 5°C.

6. Obstacles and barriers in the realization of an ATES heat pump plant in Italy

Overcoming of present day barriers for wide-scale market introduction of ATES system in Italy is one of the main objectives of the E-USE(aq) project. These barriers can be mainly technical, geological, socio-economic and legislative, and can be generally summarized as: a) disappointing quality levels and hampering robustness of the installations, b) knowledge and skills divided between consulting and contracting companies and maintenance staff, c) unpredictability's because of unfamiliarity with the underground and its characteristics, d) lack of knowledge and experience, e) lack of adequate regulations, f) presumed relatively large initial investments with unclear savings during operation.

The realization of the innovation project, and of the pilot in particular, allows UniBo to face some of the above mentioned barriers, and so stimulates the development and implementation of solutions and strategies to overcome these barriers. A first barrier in the realization of an ATES system is of legislative kind. The installation of an open loop system required the following authorizations: i) the use of public water resources (Emilia-Romagna Regional Regulation 41/2001), which can occur against the payment of an annual fee, assimilated to either industrial or domestic water use (Emilia-Romagna Regional Law 3/1999); ii) the authorization to install a well; iii) the authorization for discharging groundwater in the aquifer, released by the Province. In particular, the authorization to discharge groundwater has to comply with the national regulation Dlgs. 152/06 which states that groundwater has to be re-injected in the same aquifer where the withdrawal occurred and that the water has to maintain identical chemical characteristics. A preliminary project must be presented to obtain these authorizations. But if the project is not aligned with authority expectations, it may ask for project improvements and modifications, thus causing delays in the project realization. One aspect which stays in "grey zone" is the open loop system monitoring, i.e. the realization of monitoring wells. In fact, the realization of a monitoring wells system is not mandatory, but it is recommended by regional authorities. So, it would be good to approach regional authorities in the preliminary phase of plant design to evaluate which are the main critical aspects and/or possible implementations that should be added to the project. This approach may help in minimizing authorization process impact.

Another important barrier is of economic kind. The realization of a pilot in Italy has been hampered by the negative combination of a prolonged recession and of relatively high investment required for the realization of the ATES system. The recession has caused a generalized review of investment plans, with subsequent cancellation or put on standby of the investments less profitable or more uncertain. This is the case of most of the sites that have been evaluated. The investment in the realization of an ATES system is perceived as low profitable and uncertain. So, it is necessary to give more robustness to ATES system business plans, and one way to do this is through the realization of pilot plants. Another approach is to establish incentives on capital account for this kind of application, thus making the investment more attractive.

Relevant barriers are also present from a technical perspective. First of all, to properly design the ATES system reliable data about aquifer characteristics should be known. In the case of Terna's plant, no data were available, so the company has to organize on field test (i.e. pumping test). These tests were carried on with own financing, and with no certainty of the results. In other words, after preliminary on field test Terna may obtain as a result that the aquifer hasn't the requested characteristics. Two possible solutions can be suggested: the first one is the realization of a regional database about aquifer characteristics. The access to this database should be free, thus helping engineers and geologists in the design of this kind of plants. Furthermore, some incentives should be introduced for the realization of pumping test. In fact, the realization of pumping test does not require any kind of authorization. On the other hand, the region may not be informed about test results. So, there is the possibility that a large amount of relevant data is not shared. The region may contribute to the realization of pumping test, with the only constraint to data sharing after test realization.

Finally, the design of an ATES system requires several skills, i.e. engineering, geology, economy, legislative, … For a proper design, realization and operation of the ATES system different actors should be involved, with multidisciplinary and integrated knowledge. It might be useful to establish professional courses and/or certifications directed to the technicians involved in the design of ATES systems.

7. Conclusions

The paper shows the preliminary techno-economic analysis carried on to identify the best site for the realization of an ATES heat pump pilot plant in Italy. The paper also shows the design phase of the pilot plant, introducing the innovative concept of cold district heating, which will be applied at a relatively small scale in the application described in the paper.

Once the pilot plant will be commissioned and running (switch on is foreseen for October-November 2017), data will be acquired to verify plant performance as well as impact on the aquifer. On the basis of pilot plant results, it will be possible to develop a reliable business model for the realization of cold district heating systems.

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