Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

UTES Capability Evaluation and Mapping

Eloisa Di Sipio[1*], Elisa Destro[1], Michele De Carli[3], Angelo Zarrella[3], Giuseppe Emmi[3], Antonio Galgaro[1-2]

[1] Institute of Geosciences and Earth Resources - National Research Council (IGG-CNR), Via Gradenigo 6, I-35131 Padova, Italy

[2] Department of Geosciences, University of Padua, Via Gradenigo 6, I- 35131 Padova, Italy

[3] Department of Industrial Engineering, University of Padua, Via Venezia 1, I- 35131 Padova, Italy

eloisa.disipio@gmail.com

Keywords: thermal energy storage, sensible heat storage, thermal properties, GIS

ABSTRACT

During the last decades, the increasing number of co-generation plants and solar thermal systems developed worldwide and the need for more efficient energy use in buildings and cooling made the employment of Underground Thermal Energy Storage (UTES) systems increasingly interesting.

The possibility to store the waste heat and the excessive heat production generated by solar panels, biomass plants, and industrial processes in the underground in the warm season to recover it during cold periods, enables energy cost savings and reduction of greenhouse gas emissions. However, the thermal efficiency of storage is strictly dependent on the different geological conditions characterizing the territory. Among others, one of the key priorities for the proper assessment of the heat storage suitability in the underground is the knowledge of the thermal properties of rocks and sediments, as heat capacity and thermal conductivity, necessary to quantify the heat storage capability and the potential losses of the system.

This paper aims to show the first results related to the thermal characterization of several lithotypes belonging to Eastern Italian Alps. Moreover, an example of subsoil thermal properties mapping through geographical information systems (GIS) is presented. These maps allow to obtain a low enthalpy geothermal cartography and constitutes an important support, suited to real underground conditions, for UTES plants design and for policy makers taking decisions concerning promoting and control diffusion of the shallow geothermal solutions.

1. INTRODUCTION

According to the energetic strategies developed by the EU Commission, in the future the energy systems currently adopted in Europe will undergo fundamental transformations. Stated that today over 50% of the total energy consumed in member states is used to satisfy mainly the heat and cooling demand for either domestic or industrial purposes, the role played by the renewable energy resources will become increasingly significant to diversify the energy supply, to reduce the total amount of greenhouse gas emissions and to maintain a world leader position in developing clean technologies (RHC-Platform 2011; RHC-Platform 2012a-b; EREC 2007).

In this framework in the residential sector the recurrence in cross-cutting technologies involving shallow geothermal, thermal storage, solar thermal systems and biomass is desirable and has already been well tested (Hendriks et al 2008; Schmidt et al 2004; De Vries et al 2007; Lund 2007). However, considerable progress can still be made to reach the nearly zero-energy building solution. Improving the synergies between environmental knowledge, plant design, and heating/cooling demand the performance of the different technologies adopted can be enhanced.

In details this paper focusses on the integration of seasonal heat storage and solar heating plants in a mountainous region, taking into account the importance of defining the thermal properties of the underground and the environmental conditions that, locally, may affect the efficiency of the system. In addition to the difficulties associated with proper design of the integrated system, a validated and reasoned selection of rocks and unconsolidated material parameters, such as thermal conductivity and heat capacity, is essential to estimate the plant yield.

As well stated by literature, the idea to combine ground thermal storage and solar energy using solar assisted ground source heat pumps (SAGSHP), dates back to early 1970. This solution allows on one hand, to overcome the discontinuous and intermittent availability of the solar energy resource, influenced daily by the atmospheric conditions and seasonally by the highest amount of solar radiation available in summer, and, on the other hand, to guarantee the thermal balance of the ground all year-round (Han et al 2008; Bi et al 2004).

In fact, in a typical alpine territory as the one selected as case study area (the Province of Trento, northern Italy), the conditioning needs are generally skewed towards winter heating. Cooling loads are required mainly in the valley during the warmer summer months (June, July, August). In this context the use of a geothermal heat pump involves almost exclusive/predominant heat exploitation during the long winter period, causing a long-term temperature imbalance. The annual energy budget in the vicinity of the geothermal probes registers a thermal evolution characterized by a progressive lowering of the temperature, responsible for a decay of the ground thermal properties, a lower efficiency (coefficient of performance, COP) of the heat pump (more power consumption to meet the same energy needs, user side), as well as possible freezing problems for the heat carrier fluid belonging to the borehole heat exchangers (BHE) adopted (Badescu 2003; Yumrutas et al 2004). The coefficient of performance (COP) of a heat pump is a ratio able to represent the efficiency of a heat pump in terms of heating or cooling, delivered over the electrical energy power consumed, respectively (Banks 2012). In case of cooling, it is indicated as the energy efficiency ratio (EER). Higher COP or

EER values equate to lower operating costs in heating or cooling mode. In this study only the COP was considered, because the plant is conceived mainly for heating purposes.

To avoid these problems and raise the level of efficiency of such systems, in recent years the combination of a geothermal heat pump and solar thermal with thermal energy storage (TES) has been tested worldwide providing satisfying results (Xu et al 2014). Solar energy TES systems are designed to collect solar energy during the summer months and retain the heat in storage for use during the following winter. Rock sort materials or water are usually involved as storage medium for low temperature applications adopted for residential building conditioning and domestic hot water supply (Dincer & Rosen 2011; Paksoy 2007). Borehole thermal energy storage (BTES) and aquifer thermal energy storage (ATES) are the most used techniques, consisting of drilling the subsoil to insert vertical or horizontal tubes or wells to be used as heat exchangers. The amount of stored heat depends on thermal parameters as thermal conductivity, heat capacity and diffusivity of the material involved and also on the temperature increase produced, both able to strongly influence the heat transfer performance in the soil and the overall efficiency of the storage system (Xu et al 2014; Tomlinson & Kannberg 1990; Clauser 2011a; Clauser 2011b).

In order to verify the possibility of SAGSHP application in Italy, where still few examples are available and in use, a case study related to a small office building located near the city of Trento (northern Italy) was selected. A multidisciplinary approach, involving geological, geothermal and engineering skills was performed. At first, a geological model of the area was established. Then the climatic conditions, the thermo-physical properties of rocks and unconsolidated material, and the presence of water table were determined, carrying out literature data review of lithologies representative for the entire territory. Finally, the optimal design for the plant, able to maximize its efficiency coupling the underground and solar thermal source was modeled.

2. GEOLOGICAL SETTINGS

The municipality of Trento is located in the Trentino-Alto Adige region (northern Italy) and is crossed by the Adige river, flowing in N-S direction from the Alps towards the Garda lake (Fig.1). The city is located within a wide syncline connected easterly to the Valsugana Valley.

The variety of landscapes, that passes from elevated culminations (Paganella Mt.) to ample valleys with characters of highland (Terlago area) and then to the Adige furrow, is mainly the result of erosion and deposition processes related to the last glacial expansions. The surface hydrography is strictly related to lithology and tectonics, resulting in narrow and deep valleys, as well as asymmetrical and wide alluvial valleys. The Adige River represents the main watercourse of the territory.

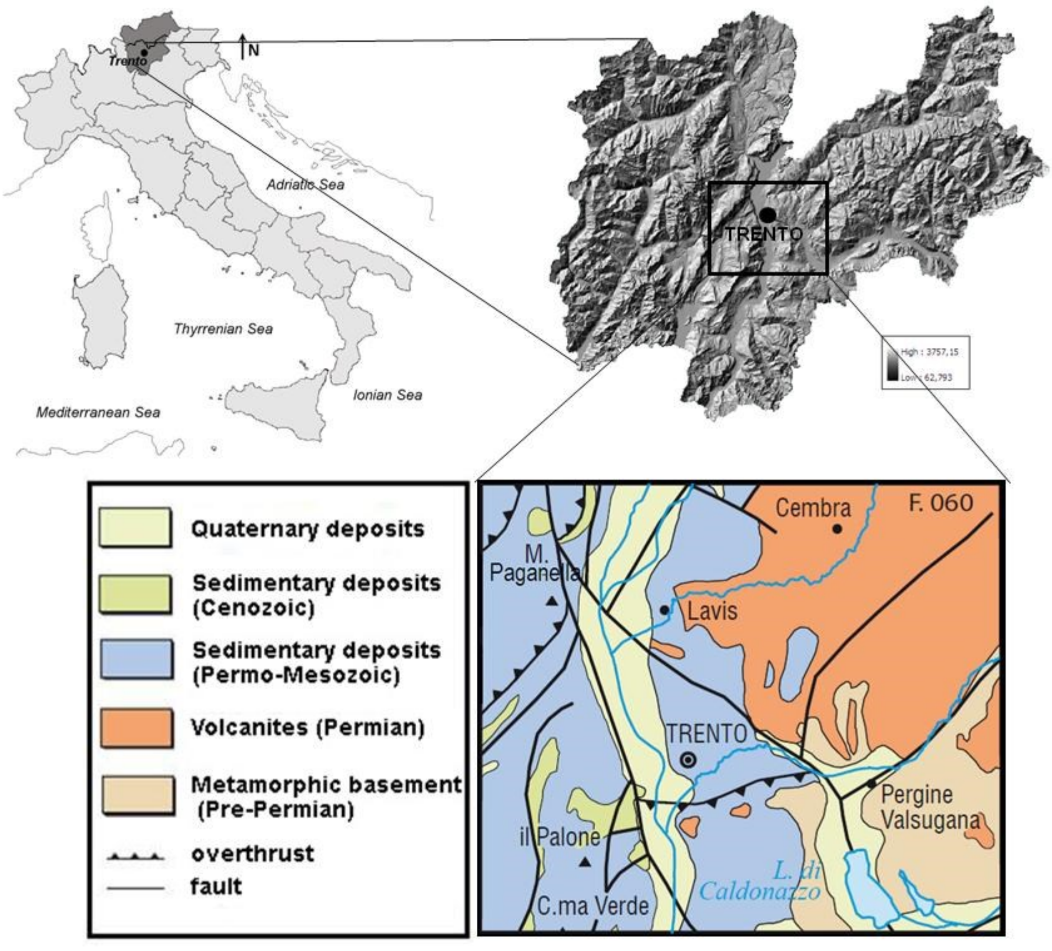

Figure 1: Location and simplified geological settings of Trento municipality (modified from Geological Map of Italy, Foglio 060 Trento 1:50.000).

Rocks exclusively belong to the Southern Alps structural domain. The oldest rocks are represented by the Pre-Permian crystalline Basement (Valsugana Unit), mainly composed by phyllites. The crystalline basement is crossed by a series of Lower Permian sub-volcanic bodies of various composition (Avanzini et al 2010).

The overlying volcanic rocks are represented by a sequence of lava and ignimbrites, characterized by different chemical composition (andesite, rhyolite), whose maximum thickness is estimated at about 2000 m. The Adige volcanic district is related to an important extensional tectonics that took place in the Early Permian. The Valsugana Line represents the tectonic southern border of the volcanic district. The sedimentary formations mainly crop out in the southern and western sector of the province and include units from the Upper Permian to the Lower Oligocene; important and continuative tectonics is recorded in their variations of facies and thickness. Permian formations are represented by alluvial (Val Gardena sandstone) and marginal marine deposits outcropping near Trento and in the Valsugana.

During the Mesozoic rifting the Adige volcanic district turns into a structural high (Trento Platform). The stratigraphic evolution of the Trento Platform during the Jurassic is characterized by its inundation at the end of the Early Jurassic. Two main stages may thus be recognized, each one represented by a typical sedimentary package: the thick Calcari Grigi Group corresponds to the first phase of shallow-water sedimentation, during the Early Jurassic; the second phase, corresponding to the pelagic sedimentation on the top of the drowned Trento platform, is summarized by the Rosso Ammonitico Veronese Formation. Cretaceous to Paleocene sediments follow in the eastern side of the Adige Valley (Maiolica Fm. Scaglia Variegata alpina Fm., Scaglia Rossa Fm.).

In the Eocene the inherited structural arrangement originated a new Carbonatic Platform (Calcare di Torbole, Calcare di Malcesine, Calcare di Nago) and a volcanic activity took place (Basalto della Vallagarina). The Quaternary is mainly represented by Pleistocene deposits left by the Adige glacier, by late glacial deposits related to the withdrawal phases (fluvioglacial deposits, glacial contact) and by slope and alluvial deposits (Avanzini et al., 2010).

3. METHODOLOGY

The research activities were directed, on one hand, to determine the underground geo-exchange potential for heat transfer and thermal storage devoted to building's heating/cooling. The existing geological, hydrogeological, meteorological and thermal features were analyzed, based on literature data review and existing datasets screening, to produce thematic maps, such as the average annual air temperature map, the map of depth to groundwater, the map of the aquifer temperature, and the map of the thermal conductivity. The main factors impacting the design of the ground and solar thermal component of the cross-cutting technologies adopted were analyzed. For example, the determination of annual mean temperature of the ground, exposition to sun, thermal conductivity, thermal capacity, groundwater depth and temperature, for example, are essential for optimizing the exploitation and transfer of heat from the subsoil to the heat exchangers.

On the other hand, in order to quantify the real benefits derived from a geothermal plant coupled with a solar system compared to a traditional geothermal one, once taken into account the environmental conditions arising from the previous research activities, the results obtained by the two types of systems were compared by numerical simulations in terms of reduced energy consumption.

Digital cartographic instruments useful for territorial planning and environmental control were realized using Geographic Information System (GIS) software. This support allows to organize and process all the data collected using specific algorithms and statistical functions to create digital cartographic maps in international recognized format. The databases obtained are easily accessible, upgradeable, and able to synthesize geological knowledge of the underground thermal properties. At first it is necessary to assess the ground temperature of the area that directly impacts the length and heating/cooling performance of the BHE foreseen in the plant (Busby, 2009). Generally this value, deeper than a few meters, is not influenced by diurnal and seasonal thermal variation, but is steady and equal to the average annual air temperature registered in the area (Banks, 2012). It was calculated using meteorological data collected over time in meteorological stations located in the territory, successively modified considering latitude and elevation values following a simplified algorithm firstly proposed by Claps et al. (2003) and then modified by Destro et al 2013 (Fig.2a). Moreover, the climatic analysis performed taking into account the annual solar radiation and the thermal differences between the indoor (constant) and outdoor environmental temperature allow to quantify the thermal needs of the buildings located in the Trento area. Moreover, given that the presence of water enhances the thermal properties of rocks and unconsolidated materials, mainly the thermal conductivity, the aquifer depth and temperature collected on duly selected wells were digitalized using the GIS software package (Kriging statistical analysis, Fig.2b-c).

Thermal properties values, as thermal conductivity (λ) and heat capacity of the main representative lithologies documented in the Foglio Trento geological map (1:50000) were derived by a review of bibliographic data (more than 80 authors considered). However, in order to better describe how suitable an area is for shallow heat exploitation and storage, it is necessary to consider the influence of the entire stratigraphic sequence along the whole thickness of the subsoil directly affected by the geothermal probes, about 100 m depth. For example, the thermal conductivity values obtained by literature review were directly assigned to outcrops formations (Fig.3a), taking into account the different lithologies they contain and considering the stratigraphy constant to 100 m depth (Destro et al 2013). For quaternary deposits the thickness of each lithological variation is not directly deducible from geological maps but needs to be confirmed using the available soundings (wells, piezometers, ...). Quaternary deposits were therefore treated differently, as summarized below:

- 1775 soundings (Geological Service of Trento, professional work sources) were collected to improve the stratigraphic knowledge of the Trento sedimentary basins
- The lithological description of the soundings was standardized in order to obtain a simplified stratigraphic model. The encoding of information led to the identification of 31 main lithological categories which were then organized into a GIS database (Table 1, Baldessari 2012). Average λ values ($Wm^{-1}K^{-1}$) in dry and wet conditions derived from literature review were assigned to each lithological category.

- A specific MATLAB toolbox, called Modalstrata, developed to improve the correlation of the stratigraphic succession, was applied to obtain a stratigraphic description for the Quaternary deposits. The Modalstrata toolbox allows a statistical analysis of available data, based on mode computation, aimed at extracting significant stratigraphic information. The mode is used as statistical operator because it can analyze the qualitative characteristics of data distribution, when they are defined in a sufficiently precise way to allow measurements but that cannot be expressed by a number, as in the case of lithologies of a layered subsoil (Cultrera et al., 2012; Di Sipio et al., 2014).

- In order to process the data using Modalstrata, the local area was subdivided into a regular mesh (3-km side regular grid), where the number of real stratigraphic surveys included in each subarea of the mesh can be significantly different in adjacent subareas. An equivalent stratigraphy (a mode-based stratigraphic sequence) was obtained in each subarea. Since differences due to the grid choice could appear, a check of the results aimed at evaluating possible grid-induced effects was performed.

- The outputs of the mode-based modeling were interpolated by the weighted average geostatistical deterministic method in order to create the subsurface thermal conductivity map for Quaternary deposits (Fig.3b).

- The equivalent thermal conductivity summary map for Trento Province was created by overlapping the lithological and stratigraphic conductivity charts (Fig.3c).

Finally, to evaluate the plant efficiency of a normal insulated office building of about 100 m^2, according to the environmental condition and energy needs, analytical simulations over a period of 20 years were performed using TRNSYS software.

Table 1 Simplified lithological categories derived from the analysis of available stratigraphic soundings. Each category is specified by a code number in ascending order according to the increasing values of thermal conductivity (Wm-1K-1) assigned on the basis of bibliographic data (dry and wet conditions, modified by Baldessari 2012).

code	lithology	λ_dry (W/mK)	λ_wet (W/mK)
1	air	0.02	0.02
2	peat	0.4	0.4
3	tuff	0.5	0.5
4	organic soil	0.7	0.9
5	basalt and tuff	1.1	1.1
6	travertine	1.4	1.4
7	clay	0.9	1.5
8	silty clay	0.7	1.6
9	clayey gravel	0.7	1.6
10	conglomerate and clay	0.7	1.6
11	basalt	1.7	1.7
12	silt	0.5	1.7
13	silty sand	0.5	1.7
14	gravel	0.4	1.8
15	gravel and conglomerate	0.4	1.8
16	sand, gravel and clay	0.6	1.9
17	andesite	2.0	2.0
18	clay and sand	0.8	2.0
19	high grade metamorphite	2.0	2.0
20	phyllite	2.2	2.2
21	sand and clay	0.5	2.2
22	shale	2.5	2.5
23	marl	2.5	2.5
24	sand	0.6	2.6
25	calcarenite	2.7	2.7
26	sandstone	2.8	2.8
27	limestone	2.8	2.8
28	conglomerate	2.8	2.8
29	dolomite	3.0	3.0
30	porphyry	3.3	3.3
31	quartzite	5.3	5.3

4. RESULTS AND DISCUSSION

4.1 Thematic Maps

The local climatic data used to create the average air temperature map of Trento (Fig.2a) is derived from the Meteorological Services Authority of the Province of Trento. The database consists of 112 weather stations; 22 of those are located within the Foglio Trento, the study-area of this work. These stations are homogeneously distributed in the territory and the records of meteorological data date back to 1920. The data processing (1920-2012) reveals an average air temperature value of 12.40 °C, while the average minimum and maximum temperature are equal to 7.65 °C and 17.15 °C, respectively. In addition, the temperature distribution map highlights that most of the territory requires only heating, while cooling needs can be expected mainly during the summer season (from June to August) only in the valleys (i.e. Adige and Valsugana Valleys), characterized also by the maximum population density.

Cooling is necessary only in June, July and August while warming affects the entire period from September to May. In these areas, therefore, the ability to recharge the subsoil by means of solar thermal and thermal storage is a practical and cost-effective technical solution. The temperature of the soil, in the first 100 m, can be considered constant throughout the year and equal to the value of the average annual air temperature (12,40 °C), whereas the geothermal flux is estimated 50-60 mW/m^2 (IGG-CNR data) and the geothermal gradient is of about 3 °C/100 m.

The presence of water in the subsurface is able to increase the thermal properties of rock and sediments, such as the ability to transfer heat by conduction, and to influence the dispersion rate of heat. Therefore, an overview of the hydrogeology is necessary for a better design of the plants. The maps related to the depth to groundwater and the temperature of water table are derived from the acquisition and processing of data collected in autumn 2011 by the Geological Survey of Trento, performed with 91 piezometers placed mainly in the Adige Valley. Geostatistical analysis of punctual information carried out by kriging method allowed us to obtain the results shown in Figure 2b-c. The water table depth (> 9 m) and temperature (> 14°C) are greater where alluvial fans are present. The lowest temperature (< 12°C), instead, are registered where tributary rivers, characterized by cold water, flow into the Adige. In addition, the hydrogeological studies identify along the mountains two local hydrogeological prevalent complexes. The former is made mainly of glacial deposition, characterized by very low and low hydraulic conductivity values, while the latter consists of Permo-Triassic rock characterized by low permeability, responsible for localized water circulations.

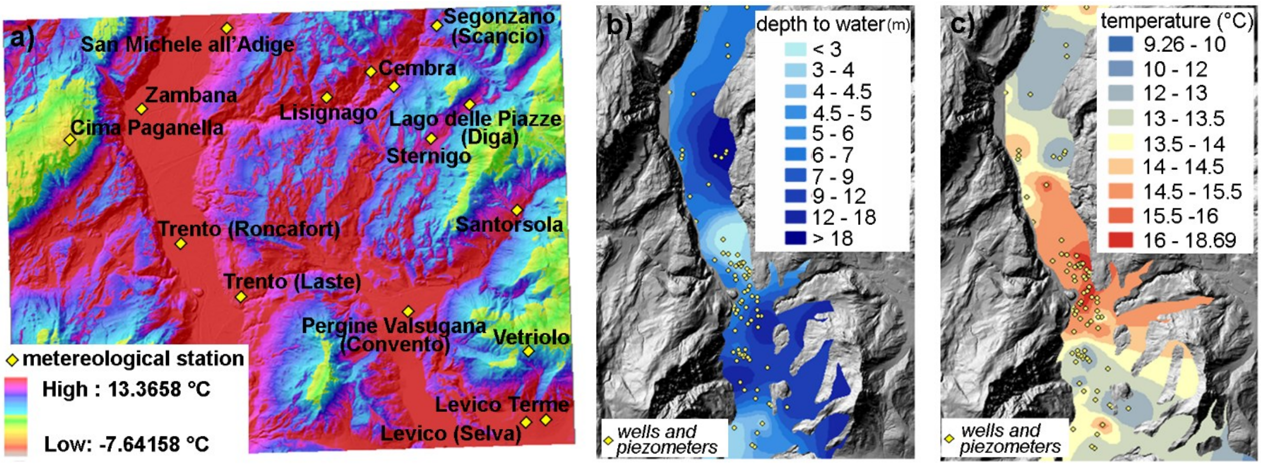

Figure 2: Trento thematic map related to (a) annual mean air temperature distribution; (b) depth to groundwater and (c) temperature of water table in the Adige Valley (modified by Baldessari 2012)

The equivalent thermal conductivity map of Trento (Fig.3c), obtained by overlapping the thermal conductivity maps of outcrops (Fig.3a) and quaternary deposits (Fig.3b), clearly identifies 5 subareas:

- the right side of Adige river, where limestone and dolomite are dominant, characterized by λ values of 2.8 Wm^{-1}K^{-1};
- the north-eastern area, where high thermal conductivities (> 3W m^{-1}K^{-1}) belong to the recent formation of the Volcanic Atesino Group;
- the central-eastern area with medium-low thermal conductivity belonging to the oldest formations of the Volcanic Atesino Group;
- the central-southern area, with high thermal conductivity typical of phyllites and metavulcanites
- the Quaternary sediments area, where the groundwater presence greatly affects the thermal conductivity values of the sediments

Based on the information collected so far, the village of Povo, situated on the eastern part of Trento, at an altitude of about 380 meters above sea level, was selected as an ideal test site to verify the feasibility to realize a SAGSHP plant. The geological sounding performed on site allowed to determine the stratigraphy and to assign correct thermal and hydrogeological values to each lithology. These parameters, listed on Table 2, were used as input parameters for the energy modeling. Moreover, the water table is at about 7.8 m of depth.

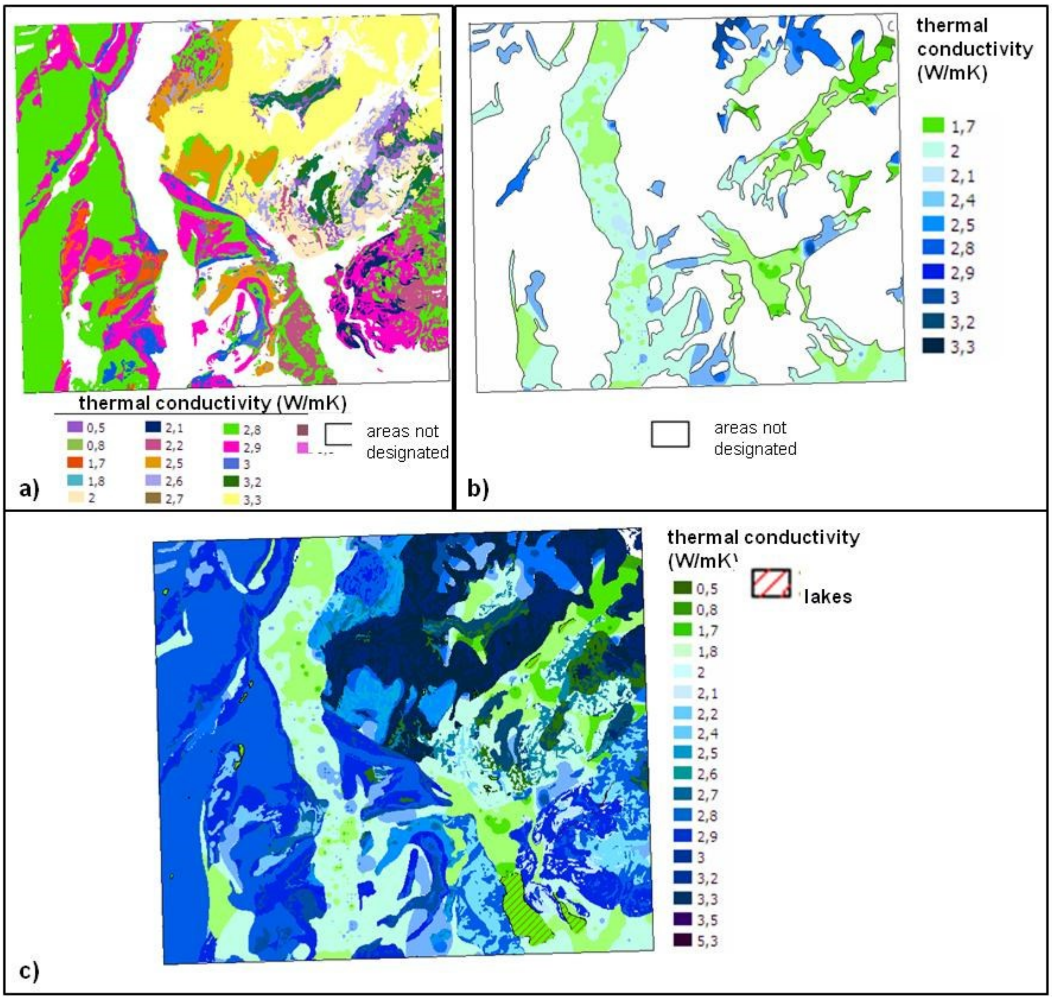

Figure 3: Thermal conductivity map of the bedrock (a) and the quaternary deposits (b) and the equivalent thermal conductivity map of the Trento municipality (modified by Baldessari 2012)

Table 2 Geological, thermal and hydrogeological characterization of the Povo test site (modified by Visintin 2012)

depth from ground level (m)	thickness (m)	lithology	λ_{dry} (W/mK)	Volumetric heat capacity (MJ/m^{3}K)	hydraulic conductivity (m/s)
0-7	7.00	silt and clay	0.5	1.5	$1*10^{-8}$
7-13	6.00	siltstone (weathered substrate)	2.5	2.2	$1*10^{-8}$
13-72	59.00	siltstone	2.5	2.2	$1*10^{-8}$
72-78	6.00	limestone and marly limestone	2.65	2.2	$3.15*10^{-5}$
78-88.50	10.50	limestone	2.8	2.3	$3.15*10^{-5}$

4.2 The case study

The case study is a small office building with a peak thermal load during the heating season of 6kWt. The heating period is from the 15th of October to the 15th of April. The building is located in a mountain zone in the north of Italy, near Trento. In Figure 4 the trend of the thermal loads for heating is represented. The inside set-point temperature used for the simulations is 25°C. The climatic data for the simulation were downloaded from the weather page of energy plus site and the properties of the ground have been selected as previously mentioned.

The first step of the work was the definition of the building and the calculation of the energy demand during the heating season. The building is well isolated: the U-values of the structures are less than 0,2 W/(m^{2}K) and the U-value of the glazing components is 1,6 W/(m^{2}K). The total energy demand of the building for heating is 14466 kWht. Cooling is not required. All the results have been obtained by using the dynamic simulation tool called TRNSYS. The set-point temperature of the hot water produced by the heat pump is controlled in function of the external ambient temperature.

The investigated plant system that supply the heat to the building consists of three sections: the first one is the geothermal field with eight BHEs with a depth of 30 m, the second one is the solar collectors field connected to a tank and the last one is the heating system with the water to water heat pump connected to the emission system. The efficiencies of the distribution and emission system have been neglected in this energy simulation due to their high values, near one, and also because the main object of the study is the evaluation of ground behavior.

During the heating period the hot water from the solar field collectors helps the heat pump to improve its efficiency and, if the heating system is off, the supply solar energy is directed to two tanks, the first one for the domestic hot water DHW and a second one for a short backup of thermal energy for the heat pump.

During summer all the solar energy from the collectors is directly exchanged with the ground by the BHEs to recharge the ground storage around the BHEs field and to avoid possible thermal drift.

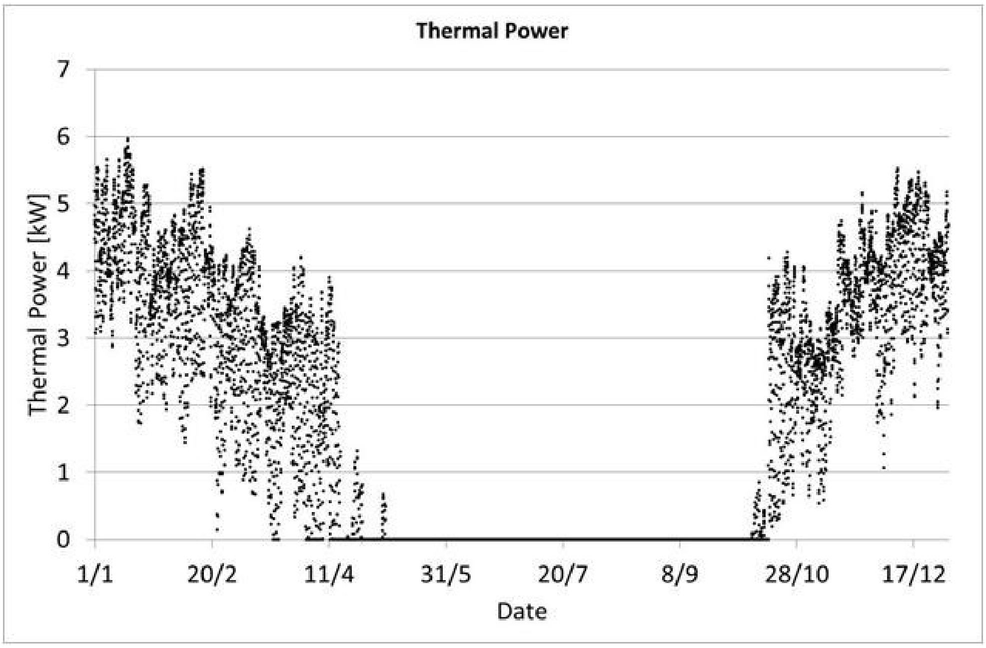

Figure 4: Trend of thermal Power for heating from the 15 of October to the 15th of April

The simulations are carried out for two different configurations of the system. Starting from the conventional system with the geothermal field coupled with the heat pump (Case 1), the behavior of the system and ground has been investigated. The seasonal efficiency of the heat pump and the trend of the mean ground temperatures have been evaluated. Afterwards the solar system was coupled with the previous plant described (Case 2). Aim of this second simulation was the evaluation of the energy efficiency improvement in comparison with the first configuration.

The simulations have been done for 20 years. Every year the energy need for the building was unchanged because the climatic data used was not modified over time. However, the performance of the geothermal system varied in the same time step considering the years in which the system has been in operation.

The main properties of the investigated cases are summarized in Table 3. The trend of the seasonal coefficient of performance (COP) values, for Cases 1 and 2, during the working years is represented in Fig.5.

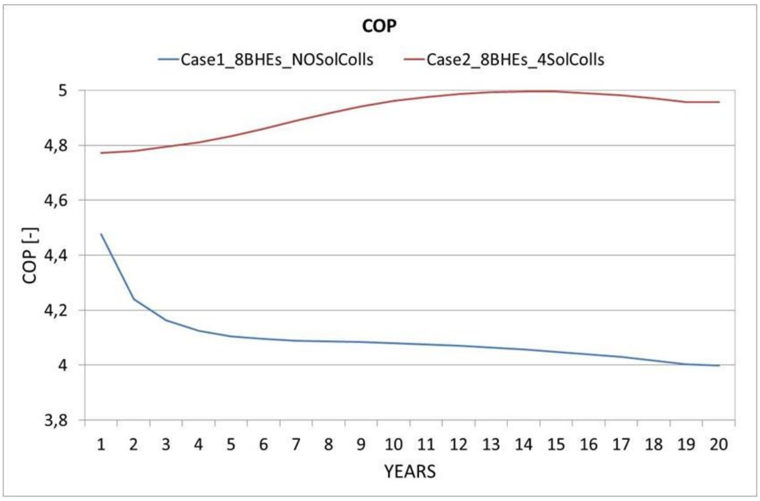

Figure 5: Variation of seasonal COP values for 20 years of simulations (Case 1 and Case 2)

Table 3. Properties of the system for the simulation with the geothermal plant only

Case	1	2
BHEs field		
Type of BHEs [-]	2U	2U
Number of BHEs [-]	8	8
Depth [m]	30	30
Connection [-]	4 parallel – 2 series	4 parallel – 2 series
Flow rate [kg/h]	2200	2200
Solar Collectors Field		
Type of collectors	-	Plane
Number of collectors [-]	-	4 in series
Total Area [m^2]	-	9,68
Orientation [-]	-	South
Tilt [°]	-	35
Flow rate [kg/h]	-	750
Solar Tank [l]	-	200
Heat Pump		
Nominal Power min-max [kW]	3 – 12	3 – 12
Refrigerant Gas [-]	R410A	R410A
Nominal COP [-]	4,73 – 4.34*	4,73 – 4.34*
	5,58 – 5,05**	5,58 – 5,05**
	4.53 – 4,13***	4.53 – 4,13***
	2,84 – 2,70****	2,84 – 2,70****
Flow rate to Fancoils [kg/h]	1000	1000

*: Outdoor Heat Exchanger W 0/-3 Indoor heat Exchanger W 30/35
**: Outdoor Heat Exchanger W 5/2 Indoor heat Exchanger W 30/35
***: Outdoor Heat Exchanger W 20/15 Indoor heat Exchanger W 48/55
****: Outdoor Heat Exchanger W 0/-3 Indoor heat Exchanger W 48/55

In Case 1, the COP of the heat pump decreases during the 20 years due to the absence of cooling request during the summer period for residential buildings located in mountain zone like the one considered in the simulations. In this way, the heat extracted from the ground during the heating period (winter) is not compensated by the cooling loads usually re-injected into the ground during summer. Consequently, this implies the progressive decrease of the mean temperature stored in the ground reducing the pump performance. In Case 2 the COP values grow due to the available heat recharge of the ground provided by the solar system during the no-heating period.

The trend of the mean ground temperature over the time interval considered is plotted in the Fig.6.

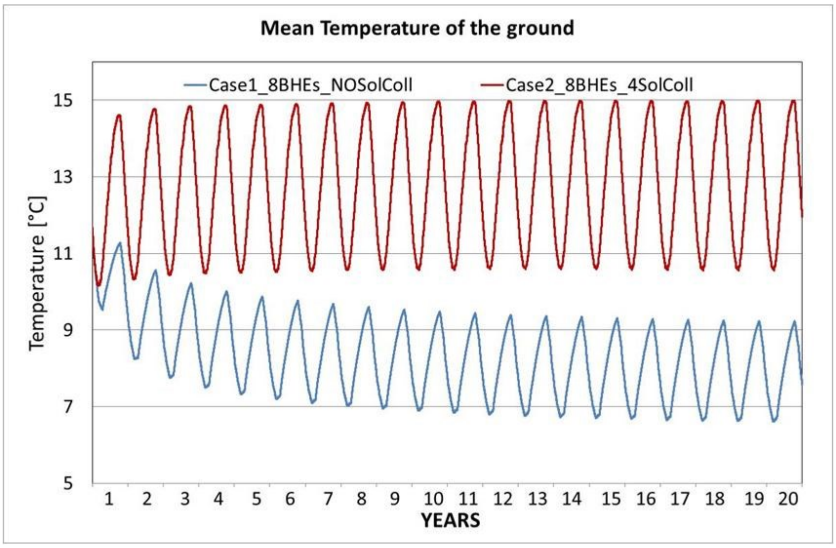

Figure 6: Trend of the Mean Ground Temperature for Cases 1 and 2

5. CONCLUSION

Determining the suitability of an area at a regional or local scale for the solar-thermal application requires the knowledge of the geological, hydrogeological, environmental and thermal features of the territory, able to affect both the energy needs of a building and the physical parameters directly involved in modeling. In fact, the construction of this kind of plant is constrained by the characteristics of the underground that can significantly affect the operation of the plant. The ground is the invariant component of the system, therefore the thermal parameters as thermal conductivity and volumetric heat capacity are fundamental to avoid oversizing and undersizing of the plant.

The use of bibliographic data offers a preliminary characterization of the site. However, to provide better input data it is necessary to perform direct measurements in laboratory of the most representative lithologies, considering all factors able to influence the measured values (presence of water, anisotropy,...). Further development of this research must foresee a detailed sampling (currently underway) of rocks and sediments, to be tested subsequently in laboratory. In fact, locally some substantial differences can be found related to weathering and structural conditions. Then, new simulations must be run considering the real thermo-physical parameters determined in laboratory.

However, the simulations carried out until now show that the use of solar collectors combined with a traditional geothermal system, using the ground as a seasonal heat accumulation, can noticeably improve the performance of the heat pump decreasing the power consumption of the season. The construction of the plant in Povo on the basis of this study is providing good confirmation of the correct design. Anyhow, future monitoring activities are planned to verify the function of the plant over time.

REFERENCES

Avanzini, M., Bargossi, G., Borsato, A., & Selli L. (2010). Note illustrative della Carta Geologica d'Italia alla scala 1:50.000: Foglio 060 Trento (TE: Notes to the Geological Map of Italy, scale 1:50,000, Foglio 060 Trento

Badescu, V. (2003). Model of a thermal energy storage device integrated into a solar assisted heat pump system for space heating. *Energy conversion and management*, **44**(10), 1589-1604.

Banks, D., 2012. An Introduction to Thermogeology. Ground Source Heating and Cooling, 2nd ed. Wiley, New York

Baldessari, G. (2012). Analysis of the geo-exchange potential for the area included in the Foglio 060 Trento -CARG (in Italian): Master degree. University of Padua

Bi, Y., Guo, T., Zhang, L., & Chen, L. (2004). Solar and ground source heat-pump system. *Applied Energy*, **78**(2), 231-245.

Busby J., M. Lewis, H. Reeves and R. Lawley: Initial geological considerations before installing ground source heat pump systems, *Quarterly Journal of Engineering Geology and Hydrogeology*, **42**, (2009), 295-306

Claps P., Giordano P., Laguardia G.: Analisi quantitativa della distribuzione spaziale delle temperature medie in Italia, *Working Paper 2003-02*, (2003).

Clauser, C. (2011a). Thermal storage and transport properties of rocks, I: Heat capacity and latent heat. In: Gupta H.K. Ed., Encyclopedia of Solid Earth Geophysics, 1423-1431, Springer Netherlands

Clauser, C. (2011b). Thermal storage and transport properties of rocks, II: thermal conductivity and diffusivity. In: Gupta H.K. Ed., Encyclopedia of Solid Earth Geophysics, 1431-1448, Springer Netherlands

Cultrera, M., Antonelli, R., Teza, G., Castellaro, S.: A new hydrostratigraphic model of Venice area (Italy), *Environmental Earth Sciences*, **63,** (2012), 1021-1030

Destro, E., Galgaro, A., Di Sipio, E., Chiesa, S., Teza, G., Manzella, A., VIGOR Team, (2013). GIS-mapping model of low entalphy geothermal potential in Southern Italy (VIGOR PROJECT). *Proceedings,* EGC 2013 - European Geothermal Congress Proceedings', Pisa (Italy), 3-7/06/2013, 1-4.

De Vries, B. J., van Vuuren, D. P., & Hoogwijk, M. M. (2007). Renewable energy sources: Their global potential for the first-half of the 21st century at a global level: An integrated approach. *Energy Policy*, **35**(4), 2590-2610.

Dincer, I., & Rosen, M. (2011). Thermal energy storage: systems and applications (2nd edition). John Wiley & Sons.

Di Sipio E., Galgaro A., Destro E., Chiesa S., Giaretta A., Manzella A. (2014) Subsurface thermal conductivity assessment in Calabria (southern Italy): a regional case study. *Environmental Earth Science* DOI: 10.1007/s12665-014-3277-7

EREC Renewable Energy Technology Roadmap up to 2020 (2007) http://www.erec.org/fileadmin/erec_docs/Documents/Publications/EREC-Technoloy_Roadmap_def1.pdf

Han, Z., Zheng, M., Kong, F., Wang, F., Li, Z., & Bai, T. (2008). Numerical simulation of solar assisted ground-source heat pump heating system with latent heat energy storage in severely cold area. *Applied Thermal Engineering*, **28**(11), 1427-1436.

Hendriks M., Snijders A., & Boid N. (2008, May). Underground thermal energy storage for efficient heating and cooling of buildings. *Proceedings*, 1st international conference on industrialised, integrated, intelligent construction (I3CON), Loughborough, UK, 14-16.

Lund, H. (2007). Renewable energy strategies for sustainable development. *Energy*, **32**(6), 912-919.

Paksoy, H. Ö. (2007). Thermal energy storage for sustainable energy consumption. Springer, Dordrecht, Netherlands

RHC-Platform: Common Vision for the Renewable Heating and Cooling sector in Europe (2011) www.rhc-platform.org/publications

RHC-Platform: Strategic Research Priorities for Cross-cutting Technology (2012a) www.rhc-platform.org/publications

RHC-Platform: Strategic Research Priorities for Solar Thermal Technology (2012b) www.rhc-platform.org/publications

Schmidt, T., Mangold, D., & Müller-Steinhagen, H. (2004). Central solar heating plants with seasonal storage in Germany. *Solar energy*, **76**(1), 165-174.

Tomlinson J.J., Kannberg L.D. (1990). Thermal energy storage. *Mechanical Engineering,* **112,** 68–72

Visintin, A. (2013). Energy analysis of an underground thermal energy storage coupled with solar recharge. Master degree. University of Padua.

Xu J., Wang R. Z. & Li Y. (2014). A review of available technologies for seasonal thermal energy storage. *Solar Energy,* **103,** 610-638.

Yumrutas, R., & Kaska, Ö. (2004). Experimental investigation of thermal performance of a solar assisted heat pump system with an energy storage. *International journal of energy research*, **28**(2), 163-175.