



FONDAZIONE INTERNAZIONALE TRIESTE PER IL  
PROGRESSO E LA LIBERTÀ DELLE SCIENZE

**PROCEEDINGS OF THE WORKSHOP ON  
GEOTHERMAL ENERGY**  
**Status and future in the Peri – Adriatic Area**  
Veli Lošinj (Croatia), 25 - 27 August 2014



Edited by: DELLA VEDOVA Bruno, VACCHI Andrea, BRADAMANTE Franco

## Editor - in - Chief

FONDAZIONE INTERNAZIONALE TRIESTE PER IL PROGRESSO E LA LIBERTÀ DELLE SCIENZE – F.I.T.

c/o ICTP - Abdus Salam International Centre for Theoretical Physics, Strada Costiera 11, 34151 Trieste, Italy

Telephone: +39 040 2240238 Fiscal Code: 90035410324  
Fax: +39 040 2240224 E-mail: fit@ictp.it; fit.ts@pec.it

## Edited by

- **DELLA VEDOVA Bruno**, Trieste University (via A. Valerio 6/1, 34127 Trieste, Italy, [dellavedova@units.it](mailto:dellavedova@units.it)) and Italian Geothermal Union – UGI,
- **VACCHI Andrea**, F.I.T. (Strada Costiera 11, 34151 Trieste, Italy, [fit@ictp.it](mailto:fit@ictp.it)) and National Institute for Nuclear Physics – INFN,
- **BRADAMANTE Franco**, European Centre for Science Arts and Culture – ECSAC (Strada Costiera 11, 34014 TRIESTE Trieste, Italy; [ecsac@ictp.it](mailto:ecsac@ictp.it)),

with the collaboration of CIMOLINO Aurélie (Trieste University and F.I.T.).

## Scientific Advisory Committee

BERTANI	Ruggero	KUREVIJA	Tomislav
CAMERLENGHI	Angelo	MENDRINOS	Dimitrios
COCIANCIG	Bernhard	PINAMONTI	Piero
FERMEGLIA	Maurizio	PIPAN	Michele
GRAZIANO	Gianvito	PRESTOR	Joerg
KRALJ	Peter	TAYLOR	Steve

## Authors

AL - ARIFI Nassir S.N., ALOISIO Fabio, ANGELINO Luca, ANTICS Miklos, BERTO Raul, BRANCATELLI Giuseppe, BUSCAROLI Franco, BÜSCHER Eckehard, CASTELLI Eugenio, CECHET Giovanni, CIMOLINO Aurélie, COCIANCIG Bernhard, CONTI Paolo, CORUBOLO Piero, COZZI Gianni, DEL BEN Anna, DELLA VEDOVA Bruno, ĐJURIC Dijana, ĐJURIC Nedjo, DOSSI Matteo, FARINA Biancamaria, FERRARESI Fausto, FLOREANI Mario, FORTE Emanuele, GRASSI Walter, JOVANOVIĆ Dalibor, KACHYŇA René, KARYTSAS Constantine, KRALJ Peter, KUREVIJA Tomislav, LASHIN Aref, LAURENI Umberto, LUGHI Vanni, MANGANARO Andrea, MASELLA Andrea, MENDRINOS Dimitrios, MOCNIK Arianna, MOLINARI Fabio Carlo, PALMIERI Francesco, PELLEGRINI Gianfranco, PERONIO Marco, PESTOTNIK Simona, PETRINI Riccardo, PETRONIO Lorenzo, PIEMONTE Carlo, PIPAN Michele, POLETTO Flavio, PRESTOR Joerg, RAJVER Dušan, ROMANO Giuseppe, SCHLEIFER Andrea, SKOPLJAK Ferid, STEFANELLI Silvia, STIVAL Carlo Antonio, STRADA Mauro, TARANTINO Paolo, UNGEMACH Pierre, VALCOVICH Edino, WITTIG Volker and ZUDEK Alfredo.

## Workshop Secretary

BALDINI Serena (ECSAC) and CIMOLINO Aurélie (Trieste University and F.I.T.).

## Editorial plan, cover and layout

CIMOLINO Aurélie (Trieste University and F.I.T.).

ISBN 978-88-941071-0-4



9 788894 107104

The content of the present publication is under the sole responsibility of the authors; it should not be attributed to and does not necessarily reflect the opinion or position of *the editor - in - chief, the editors or the supporting institutions*. All rights reserved. This book may not be translated, reproduced, adapted or electrically stored, in whole or part, by any means (including microfilms, photocopies and other reproductions), in any country, without the permission of the Editor - in - Chief.

First edition, August 2015.

E - ISBN 978 - 88 - 941071 - 0 - 4

Printed online. The digital edition is fully available (open - access) at:

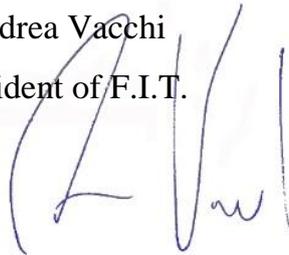
[www.fondazioneinternazionale.org](http://www.fondazioneinternazionale.org)

*The Trieste International Foundation has firmly inserted among its leading lines of actions the issue of energetic sustainability through a consistent use of renewable sources.*

*The different aspects through which geothermal energy can be brought to effective direct applications in the enlarged Adriatic region represents, at present, our front edge in this effort.*

*The formulation of pilot projects aimed at opening ways to consolidate the use of this natural source of energy is the challenge of the Adriatic - Jonian Geothermal Platform.*

Andrea Vacchi  
President of F.I.T.

A handwritten signature in blue ink, appearing to read 'A. Vacchi', positioned to the right of the printed name and title.



# SUMMARY

<b>GEOHERMAL RENEWABLE HEATING AND COOLING: STATUS AND PROSPECTS (DELLA VEDOVA B. ET AL.)</b> .....	<b>I</b>
Geothermal Resources and Energy Production .....	II
Projects and applications .....	III
<b>FOSTERING THE GEOHERMAL DEVELOPMENT IN THE COLD ADRIATIC - JONIAN AREA (DELLA VEDOVA B. AND CIMOLINO A.)</b> .....	<b>V</b>
Aim of the Workshop and the Adr.Jo. Geothermal Platform .....	V
Geological play and Geothermal Potential .....	V
2014 Lošinj Workshop .....	IX
Critical issues and challenges .....	X
<b>LAUNCH AND PERSPECTIVES OF THE ADR.JO. GEOHERMAL PLATFORM (DELLA VEDOVA B. ET AL.)</b> .....	<b>XV</b>
<b>EXTENDED ARTICLES</b> .....	<b>1</b>
<b>Introduction Paper</b> .....	<b>2</b>
Energy as a Global Challenge (LUGHI V.).....	3
<b>Status and perspectives of geothermal technologies</b> .....	<b>9</b>
Geothermal District Heating in Europe: Market, Potential and Framework Conditions (ANGELINO L.) .....	10
Recent Achievements in Geothermal Technology (UNGEMACH P.).....	19
How Heat Pumps Work: Criteria for Heat Sources Evaluation (CONTI P. AND GRASSI W.) .....	25
<b>Resources Assessment and Geothermal Applications</b> .....	<b>35</b>
Integrated Geophysical Characterization of Geothermal Reservoirs (POLETTO F. ET AL.).....	36
Geothermal Reservoir Characterization and Management (ANTICS M. AND UNGEMACH P.).....	44
Low Temperature Geothermal Applications and Projects in Slovenia (RAJVER D. ET AL.) .....	51
Geothermal Development and Activities in Germany (BUSCHER E. AND WITTIG V.).....	61
Geothermal Heating and Cooling in the FVG Region: the Grado District Heating and the Pontebba Ice Rink Plants (DELLA VEDOVA B. ET AL.).....	65
Ecological and Economic Aspects of Using Geothermal Energy for Heat Supply Town of Bijeljina and Other Areas Bosnia and Herzegovina (ĐJURIĆ N. ET AL.).....	77
Low Temperature Geothermal Applications in Greece, Including Water Desalination (MENDRINOS D. AND KARYTSAS C.).....	86
<b>Integration of energy sources in the Peri - Adriatic Areas</b> .....	<b>91</b>
Heat Pumps for Exploitation of Geothermal Sources in Milano City (MASELLA A. AND PIEMONTE C.).....	92
The future of sustainable energy policies in the Friuli Venezia Giulia Region (STEFANELLI S.) .....	100
The GROUND - MED Project - Advanced Ground Source Heat Pump Systems for Heating and Cooling in Mediterranean Climate (MENDRINOS D. AND KARYTSAS C.) .....	105
<b>New ideas and proposals for cooperation in the Peri - Adriatic Areas</b> .....	<b>113</b>

Methodological Approach for Recovery and Energetic Requalification of Historical Buildings (VALCOVICH E. ET AL.) .....	114
Cold District Heating with Heat Pumps at High Temperature (PELLEGRINI G.) .....	123

## ABSTRACTS ..... 131

Geothermal Energy: How Does It Stack Up in the Future Energy Mix (COCIANCIG B.) .....	132
High - Resolution Geophysics for Porosity and Fracture Network Assessment in Shallow Geothermal Applications (PIPAN M. ET AL.) .....	133
Geothermal Applications in Croatia (KUREVIJA T.) .....	134
Thermal Springs and Balneology in the Peri - Adriatic Area: Geochemical Status and Prospects (PETRINI R.)	135
Deep Geothermal Project from the Perspective of a Drilling Contractor (KACHYŇA R. AND COCIANCIG B.) ....	136
The Integrated Ferrara Plant, 50% Geothermal (BUSCAROLI F. AND FERRARESI F.) .....	137
District Heating of Benedikt, 1st Stage - Northeast Slovenia (KRALJ P.).....	138
Area Science Park Innovative Systems and Open - Laboratories for the Diffusion of Small Size Plants based on Renewable Energy and High Efficiency Technologies Including Geothermal Applications (FLOREANI M. AND COZZI G.) .....	139
New Projects for Geothermal District Heating and Cooling Systems in the Brescia Province - Northern Italy (MOLINARI F. AND TARANTINO P.) .....	140
Altheim in Upper Austria – an Example of Cascaded Geothermal Energy Use (COCIANCIG B.) .....	141
LEGEND Project Mobilizing Ground - Source Heat Pumps Investments in Adriatic (JOVANOVIĆ D.) .....	142
New Applications of Heating and Cooling Using Geothermal Resources (ZUDEK A. AND ALOISIO F.).....	143
The Trieste SEAP – Action Plan for Sustainable Energy (LAURENI U.) .....	144
M19 – A New School Complex Module in a Historical Building based on Leed Certification and Geothermal Application in Trieste Port (MANGANARO A. ET AL.).....	145

## INDEX OF AUTHORS ..... 147

## INDEX OF INSTITUTIONS..... 148

# GEOHERMAL RENEWABLE HEATING AND COOLING: STATUS AND PROSPECTS

DELLA VEDOVA Bruno, VACCHI Andrea and BRADAMANTE Franco

The energy problem is a crucial question at global scale that cannot be tackled by a one - sided approach, being tightly interconnected with several major issues such as, food, water, health, mobility and living environmental conditions that, in turn, might strongly change the life quality indexes.

The World energy demand is continuously increasing, mainly in developing countries, whereas the global stocks of resources and their amount available per person are dramatically decreasing [*Energy as a Global Challenge*, LUGHI - extended article in this book]. August 19 2014 was the Earth Overshoot Day 2014, marking the date when humanity had exhausted nature's budget for the year. For the rest of the year, we operated in overshoot maintaining and/or increasing our annual deficit by drawing down local resource stocks and accumulating greenhouse gases in the atmosphere.

The European Union has extensively addressed the energy issues in the last ten years delivering specific laws such as:

- Directive 2009/28/EC on the Promotion of the Use of Energy from Renewable Sources,
- Directive 2010/31/EC on the Energy Performance of Buildings,
- Directive 2012/27/EC on Energy Efficiency.

The main goals of the Energy Efficiency Directive 2012/27/EC are: i) energy security, ii) reduction of energy costs and iii) climate change mitigation, together with the achievement of Lisbon objectives.

“High - efficiency cogeneration” and “district heating and cooling infrastructures” have been recognized as appropriate tools to reach these objectives, for their huge potential to strongly reduce the consumption of fossil fuels and their impact on the climate, by means of the synergic optimization of production, transport, integration and management of all potential energy sources locally available. The contribution of the Renewable Heating and Cooling (RHC) sector to contribute reaching the above objectives will be determined by the availability of reliable, efficient and affordable technology through targeted, collaborative research and development activities.

The European Technology Platform on Renewable Heating & Cooling (RHC-ETP, [www.rhc-platform.org](http://www.rhc-platform.org)) has developed a *Strategic Research and Innovation Agenda for Renewable Heating & Cooling* to the 2020, 2030 and beyond, aiming to:

- significantly reduce the cost of RHC technologies (for the geothermal sector it means to reduce exploration, drilling costs and geologic risk),
- enhance RHC system performance and reliability,
- reduce RHC system payback time.

The demand of thermal energy for heat production and use in stationary applications in Europe accounted for 47% of the final energy consumption in 2010 (Figure 1). The Strategic Research and Innovation Agenda set out a common strategy for increasing the use and integration of renewable energy technologies, including geothermal energy, for heating and cooling.

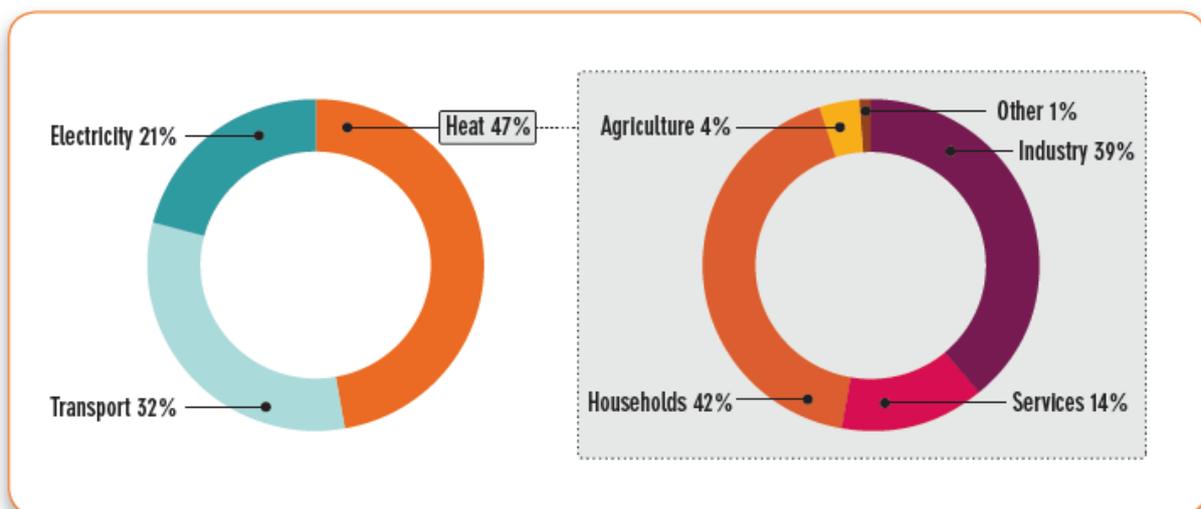


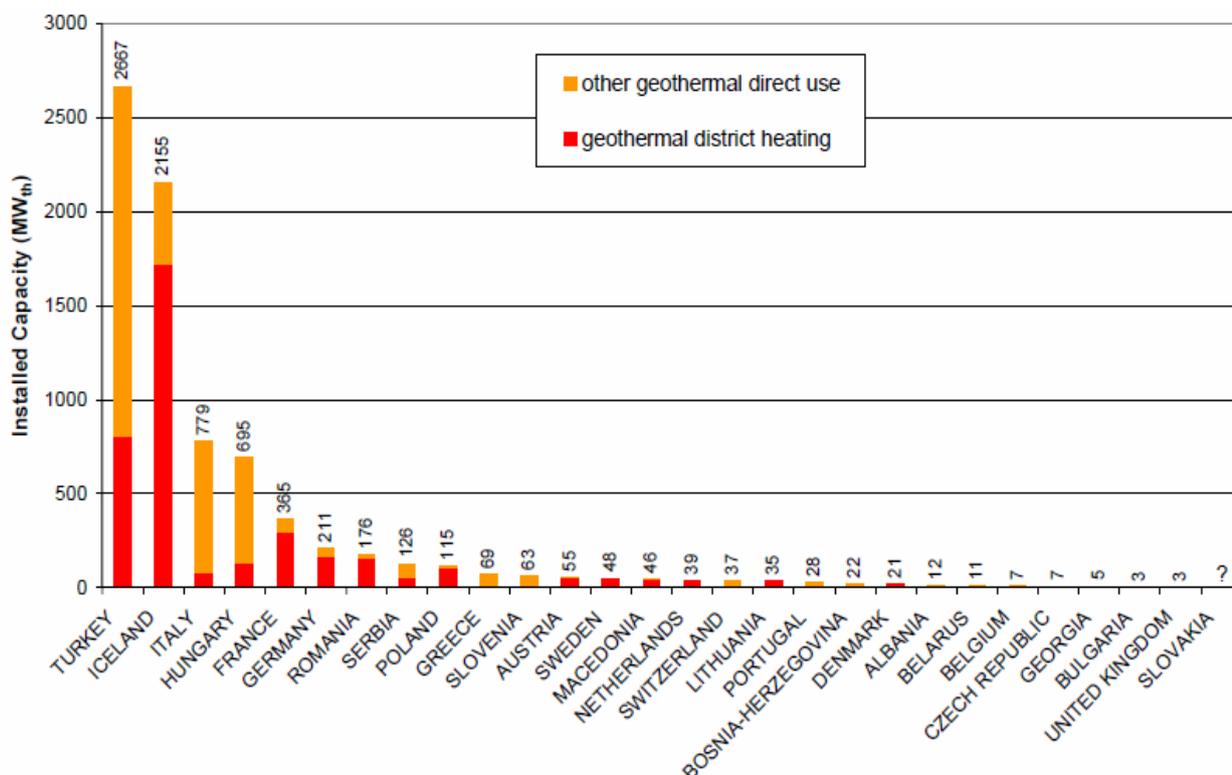
Figure 1. Final energy use in EU - 27 by type of energy, on the left, and final energy use for heat by individual sector, on the right, for the year 2010 (from [www.rhc-platform.org](http://www.rhc-platform.org) 2013 publications: “Strategic Research and Innovation Agenda for Renewable Heating & Cooling”).

## **GEOHERMAL RESOURCES AND ENERGY PRODUCTION**

The geothermal energy is a huge and continuous primary source that has a great potential to provide low cost and low impact energy, but despite being a mature technology, it is largely untapped due to the high exploration costs and high resource assessment risk, which are peculiar to geothermal and not to the other Renewable Energy Sources (RES). Geothermal resources have been identified in several European countries, out of which only five countries within the EU (Austria, Germany, France, Italy and Portugal) and three outside EU (Iceland, Russia and Turkey) are producing electricity: 943 installed MW<sub>(el)</sub> and 913 MW<sub>(el)</sub>, respectively (Antics et al., 2013<sup>1</sup>). The projection to 2020 is for an increase of +27% for the EU countries, with 5 new entries (Greece, Czech Republic, Hungary, Slovakia, Netherlands), and +233% increase for Iceland, Turkey and Russia, bringing the installed capacity to a total production of 3317 MW<sub>(el)</sub>.

Besides the limited on land high enthalpy geothermal areas in Europe, there is a large potential for direct uses in most of the other areas (including sedimentary basins, foreland and mountain areas, islands, coastal and offshore shelf areas), where temperatures between 50 and 90 °C could be found within 2 km depth. This resource is adequate as a main base - load energy for space heating and cooling applications, providing local security of supply and reducing the environmental impact. There are presently 247 geothermal district heating (DH) systems in Europe with a total installed capacity of approximately 4.5 GW producing some 13 GWh<sub>(th)</sub> (Dumas and Angelino, 2015<sup>2</sup>). They could be installed almost everywhere, including the cold Adriatic and Jonian domains. Moreover, they can be cost competitive. The levelled cost of electricity for geothermal district heating and ground - source heat pumps range from 0.06 to 0.13 USD/kWh (REN21, Renewable Global Status Report 2014). On the other side, the required investment for direct uses and the associated exploration and resource assessment risks are substantially lower than those pertaining to high enthalpy power production.

The installed capacity in geothermal direct use in the European countries at the end of 2012 and the share of the geothermal district heating is shown in Figure 2.



**Figure 2. Installed capacity in geothermal direct use in Europe 2012 and share of geothermal district heating from country updated reports (Antics et al, 2013<sup>3</sup>).**

Several research and development projects were conducted in single countries, aimed mainly to resource assessment, geothermal district heating and other direct uses (spas utilizations and heating and cooling of public buildings, as schools, universities, municipalities, gymnasiums, etc). Some of them are mentioned some of the papers of this book:

<sup>1</sup> Antics M., Bertani R., Sanner B. (2013) - Summary of ECG 2013 Country Update Reports on Geothermal Energy in Europe, 2013 European Geothermal Congress.

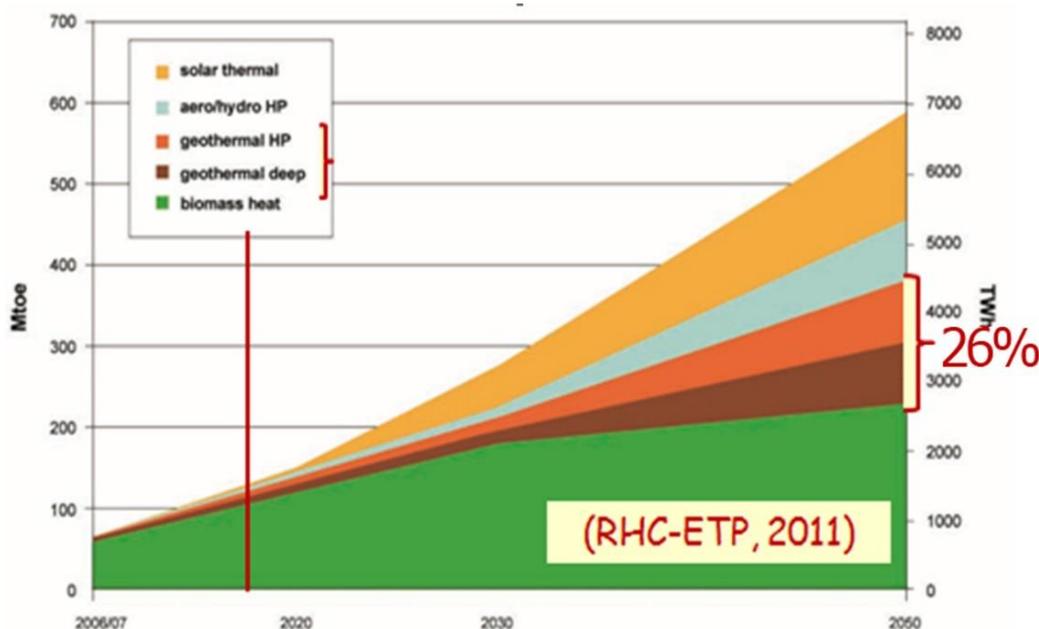
<sup>2</sup> Dumas P. and Angelino L. (2015) - Geothermal Market Report for Europe. Proceedings World Geothermal Congress 2015. Melbourne, Australia, 19 - 25 April 2015.

<sup>3</sup> Antics M., Bertani R., Sanner B. (2013) - Summary of ECG 2013 Country Update Reports on Geothermal Energy in Europe, 2013 European Geothermal Congress.

- ITALY: Vigor Project and Grado Geothermal Project [*Geothermal Heating and Cooling in the FVG Region: the Grado District Heating and the Pontebba Ice Rink Plants*, DELLA VEDOVA et al.; *Integrated Geophysical Characterization of Geothermal Reservoirs*, POLETTO et al. - extended articles in this book];
- SLOVENIA: Murska Sobota, Lendava and Benedikt heating district [*Low Temperature Geothermal Applications and Projects in Slovenia*, RAJVER et al. - extended article in this book];
- BOSNIA AND HERZEGOVINA: the exploitation of Bijeljina (Semberija), Ilidza (near Sarajevo) and Kakanj (in central Bosnia) reservoirs [*Ecological and Economic Aspects of Using Geothermal Energy for Heat Supply Town of Bijeljina and Other Areas Bosnia and Herzegovina*, DJURIĆ et al. - extended article in this book].

During the workshop, several examples of exploitation of the geothermal reservoirs in CROATIA (such as: Zagreb, Bizovac, Kutnjak - Lunjkovec and Draškovec) were also mentioned.

The 2050 share of the heating potential for the renewable energy sources was estimated by RHC - ETP for Europe (Figure 3); the expected total contribution from the geothermal heat could be about 26% of the overall mix, jointly provided by geothermal heat pumps and by deep geothermal sources (mainly district heating facilities). This remarkable share could be reached if the geothermal sector will substantially increase the present modest growing rate of about 3 - 4% per year, reducing the gap with respect to other RES.



**Figure 3. Individual contributions of Renewable energy sources for heating to 2050, evaluated by the RHC - ETP European Technology Platform on Renewable Heating & Cooling (2011).**

## PROJECTS AND APPLICATIONS

Several geothermal research and demonstration projects have been recently carried out partly in the countries of the broad Adriatic and Ionian region, some of which supported by EU funding and/or in cooperation among different countries, such as:

- *GROUND - MED* (demonstration and monitoring of groundsource heat pump systems in different Mediterranean climate conditions) [*The GROUND - MED Project - Advanced Ground Source Heat Pump Systems for Heating and Cooling in Mediterranean Climate*, MENDRINOS and KARYTSAS - extended article in this book];
- *LEGEND* (Low Enthalpy Geothermal Energy Demonstration cases for Energy Efficient building in Adriatic area);
- *ENERCOAST* (exploitation of renewable energy sources in the marine - coastal areas of the Adriatic - Ionian region, by solar cooling systems, tidal/current plants, heat pumps and wind turbines plants, little and medium sized);
- *AlterEnergy* (Energy sustainability for Adriatic small communities);
- *GeoCom* (demonstration actions, including geothermal district heating system development, integration of geothermal heating with other RES and energy efficiency measures);
- *ThermoMap* (mapping of the very shallow, up to 10 m, geothermal potential across Europe);
- *Transthermal* (geothermal potential evaluation Between Austria and Slovenia based on database and GIS maps);
- *T - JAM* (cooperation between thermal water resources managers for future perspectives of geothermal energy uses between NE Slovenia and W Hungary),

- *Groundhit* (Ground Coupled Heat Pumps of High Technology) and *Ground - Reach* (sustainable implementation of ground coupled heat pumps);
- *Transenergy* (transboundary geothermal energy resources of Slovenia, Austria, Hungary and Slovakia);
- *Geo.Power* (project on low enthalpy energy supply for Bulgaria, Hungary, Greece, Italy, Sweden, Estonia, UK, Belgium and Slovenia);
- *GeoSEE* (uses of low - enthalpy geothermal resources in combination with further RES for heating/cooling and electricity production in 8 countries in SE Europe);
- *NxtHPG* - Next Generation of Heat Pumps working with Natural fluids.

Direct uses of geothermal resources represent a challenge and a valuable contribution to economic and social development of cities, towns, islands and local communities within the Adriatic - Ionian macroarea, considering also the need of regulatory frameworks.

The above mentioned projects, and several others not mentioned here, demonstrate the presence of a proactive multidisciplinary community of experts and stakeholders already working in the geothermal sectors (public, domestic, commercial and industrial), though quite often there is limited information and cooperation, very limited or absent technology transfer and, sometimes, presence of substantial non - technical barriers and gaps that need to be removed or filled.

# FOSTERING THE GEOTHERMAL DEVELOPMENT IN THE COLD ADRIATIC - JONIAN AREA

DELLA VEDOVA Bruno and CIMOLINO Aurélie

## AIM OF THE WORKSHOP AND THE ADR.JO. GEOTHERMAL PLATFORM

The main goal of the Workshop on “GEOTHERMAL ENERGY: STATUS AND FUTURE IN THE PERI - ADRIATIC AREA”, that took place in Veli Losinj - Croatia in August 2014, was to convene research institutions, public administrations, enterprises and professionals to discuss research, applications, perspectives, barriers and future projects concerning the development and integration of the geothermal direct uses for RHC applications at local scale in the countries of the broad Adriatic and Jonian area. This could be achieved by setting up a network of several subjects acting as a heterogeneous but clutched cluster, for a cross - border cooperation in the geothermal field.

This book of proceedings collates the contributions speakers to the international workshop and presents the main outcomes and suggestions shared by the participants, together with other specific issues to work on.

A dedicated cooperative network should be more efficient to tackle and overcome the critical points affecting the geothermal energy sector in the Adriatic – Jonian macroarea. The building up of a dedicated multidisciplinary geothermal platform should foster the development of geothermal direct applications, allowing to: improve transnational communication and exchange, share of knowledge and transfer of technology, conceive geothermal joint projects, connecting partners and stakeholders from various countries.

The Lošinj workshop turns out to be the kick - off meeting laying down the foundations for the multidisciplinary “ADRIATIC - JONIAN GEOTHERMAL PLATFORM” (“Adr.Jo. G.P.”).

This book represents its first shared product.

## GEOLOGICAL PLAY AND GEOTHERMAL POTENTIAL

From the geographic point of view, the Adria - Jonian enlarged region is clearly imaged by the countries surrounding the Adriatic Sea and the Eastern part of the Jonian Sea, whereas, from the geologic and geothermal resources point of view, this domain is mainly represented by the sedimentary basins (such as the Po Plain, Adriatic foredeep and foreland basins, Bradano Trough) and stable carbonate platforms (such as Istria, Dalmatia and Apulia) of the foreland areas, which are all belonging to the Adria microplate.

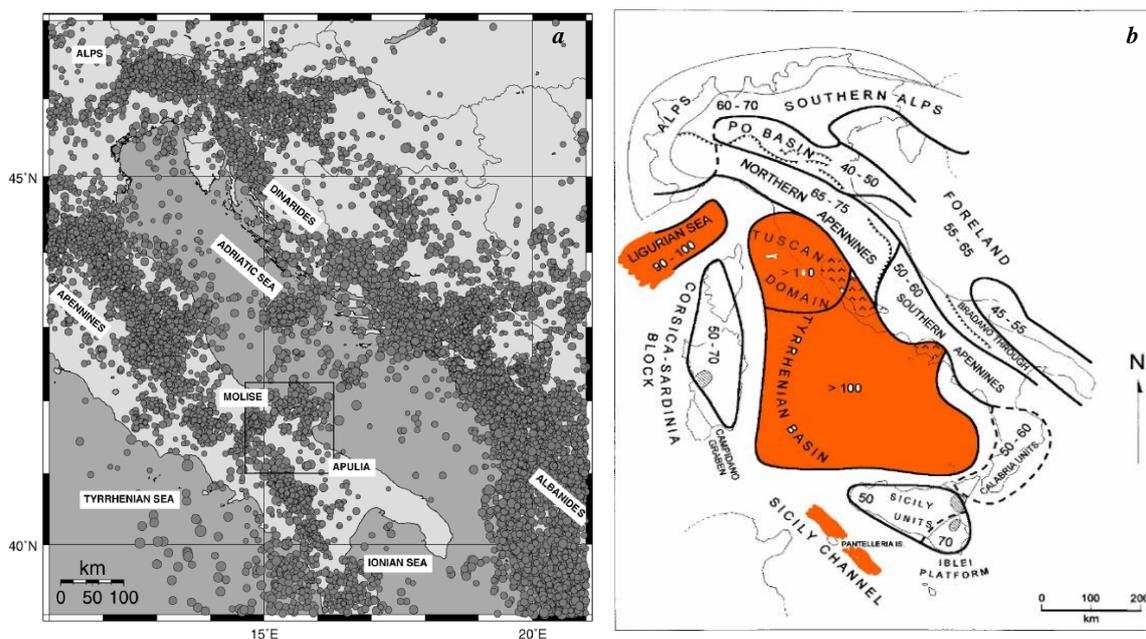


Figure 4. a) Map of epicentres of events with magnitude >2.0 from 1975 to 2005 (source: Del Gaudio et al., 2007<sup>4</sup>), data from the US Geological Survey Earthquake Database. b) Map of the estimated heat flow at the basement for the geodynamic sectors of Italian area. It highlights the different heat flow provinces corresponding to the various blocks of the Adria microplate.

<sup>4</sup>Del Gaudio V., Pierri P., Frepoli A., Calcagnile G., Venisti N., Cimini G.B. (2007) - A critical revision of the seismicity of Northern Apulia (Adriatic Plate – Southern Italy) and implications for the identification of seismogenic structures. Tectonophysics, 436, 9 - 35.

At a regional scale, the Adria microplate represents the stable Mesozoic foreland towards which the Alpine, Apenninic and Dinaric orogenic fronts are migrating in different times, from Cretaceous to Present. The extent, partition in various blocks and active edges of Adria are well identifiable in the actual seismicity map of the area (Figure 4a) and roughly imaged in the heat flow regime at the basement (Figure 4b). Figure 4b shows the estimated basement heat flow in the Italian region, computed removing the contribution for the disturbances interesting the upper few km of the sedimentary cover (Della Vedova et al., 2001<sup>5</sup>). In the peri - Adriatic region, the basement heat flow ranges between 35 to 60 mW/m<sup>2</sup>, with the highest values observed in correspondence to the more tectonically active central Adriatic basin. Assuming an average thermal conductivity for the sedimentary cover ranging from 1.8 to 2.2 W/(m·K), the conductive vertical thermal gradient could be approximately estimated to vary between 15 °C/km, in the Adriatic foredeep basins, to about 30 °C/km, in the central Adriatic basin. In this central area, the presence of fluids and good vertical permeability, within the buried carbonate platform, likely contributes to a more efficient vertical heat transfer. Temperatures of the order of 50 °C could then be expected within 2 km depth in the cold basins of the peri - Adriatic geologic framework, whereas temperatures up to 90 °C could be expected in limited portions of the central Adriatic basin.

High enthalpy geothermal resources are present within a couple of km depth in the Pannonian Basin and in some locations in correspondence of the NNW - SSE neotectonic structures deeply cutting across the Balkan peninsula (Hurter and Haenel, 2002<sup>6</sup>), roughly oriented with the direction Budapest - Belgrade - Athens (Figure 5). On the other side, in correspondence of the outcropping carbonate platforms (such as Istria, Dalmatia and Apulia) the thermal gradients within the upper 1 - 2 km could be as low as 10 °C/km.

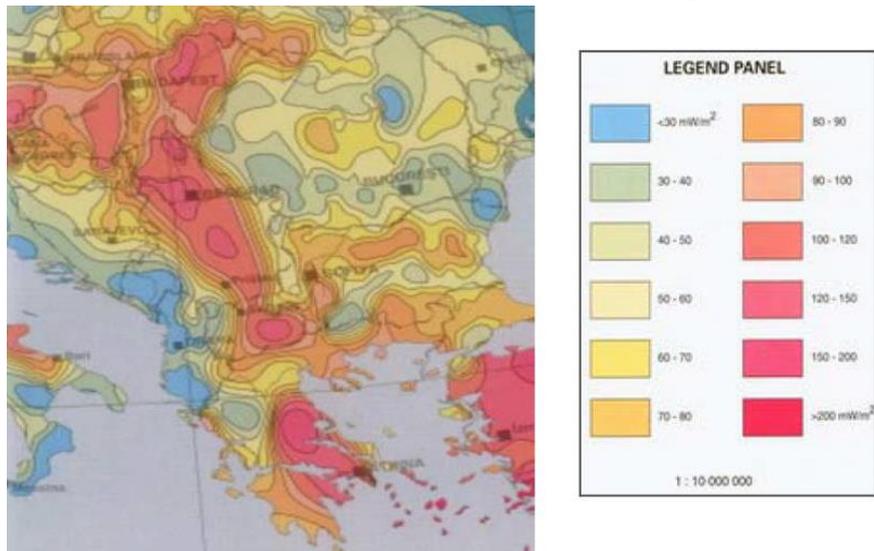


Figure 5. Heat flow map of the Balkan Peninsula (source: Hurter and Haenel, 2002).

Electric energy production has no good perspectives, so far, in the cold Adriatic - Jonian domain, in contrast with the high enthalpy geothermal areas, present to the SE, particularly in the Aegean volcanic region and in the Pannonian Basin. Nonetheless, the low enthalpy peri - Adriatic geothermal resource is suitable for direct applications and it could significantly contribute to the targets of the European Directives, particularly where deep aquifers are present. The main characteristics of this resource are:

- available almost everywhere for shallow open or closed loop heat pump geothermal applications,
- excellent base - load contribution for RHC plants in towns and cities where good shallow/deep aquifers could be exploited,
- sustainable and economic for year round balneotherapeutic utilization (Spas, pools, etc.), eventually integrated with cascade RHC utilizations in coastal and resort areas and on the Adriatic - Jonian islands.

The Adriatic carbonate platform is one of the largest Mesozoic platforms of the peri - Mediterranean region; it includes a large succession of rocks from middle - Permian to Eocene, that outcrop in Italy, Slovenia, Croatia, Bosnia and Herzegovina, Serbia, Montenegro, and Albania. It is part of the largest central Mediterranean carbonate platform, relicts of which are present from Italy to Greece and Turkey. In places, the carbonate platform is more than 8 km thick (Vlahovic et al., 2005<sup>7</sup>).

The Alpine, Dinaric and Apenninic orogenic phases contributed to disrupt the Adria microplate and overlying carbonate platform into several blocks and provided abundant clastic successions of sediments, from Late Cretaceous - Eocene to Present, to fill the main Po Plain - Adriatic foredeep basin and other inner basins. These Neogene successions constitute the low permeability cap rock for the potential gas and oil reservoirs in the Adriatic and peri - Adriatic basins. Significant seismicity is affecting the borders of the deformed Adria blocks, favouring vertical permeability and hydrothermal fluid

<sup>5</sup> Della Vedova B., Bellani S., Pellis G., Squarci P. (2001) - Deep temperatures and surface heat flow distribution. In: Vai G.B. and Martini I.P. [Edts.] (2001) - Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins. 65 - 76.

<sup>6</sup> Hurter S. and Haenel R. [Edts.] (2002) - Atlas of Geothermal Resources in Europe. Office for Official Publications of the European Communities, Luxembourg.

<sup>7</sup> Vlahović I., Tišljarić J., Velić I., Matičec D. (2005) - Evolution of the Adriatic Carbonate Platform: Palaeogeography, main events and depositional dynamics. Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 220, Issues 3-4, May 2005, 333-360.

circulation. This complex geological and structural domain provides the playground for the geothermal heat transfer and heat storage processes, including the generation and migration of hydrocarbon resources (Figure 6a, b), within a low temperature gradient province (Figure 4b and Figure 5).

Low temperature geothermal resources (50 - 90 °C within 2 km depth) are expected in this geological play of the coastal and offshore of the Adriatic – Jonian macroarea where the top of the carbonate platform may locally represent a good reservoir with a good geothermal potential (temperature, permeability and geochemistry) for district heating, mainly when resources and potential users insist on the same area.

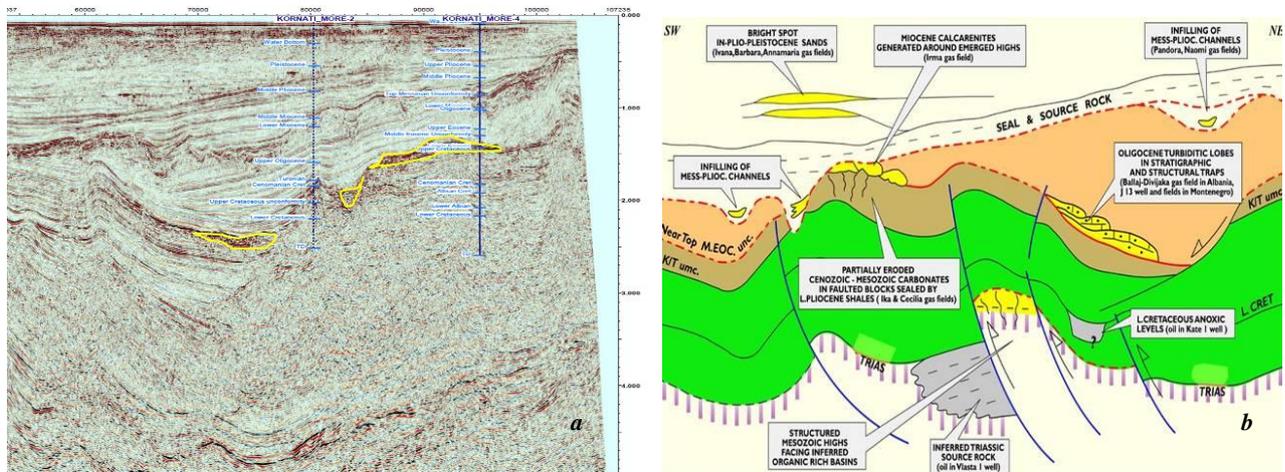


Figure 6. a) Example of a good quality seismic section in the Adriatic Croatian offshore Koronati Is. b) Sketch of a SW - NE geological interpretation, representative of the tectonics in the Croatian side of the Northern and Central Adriatic domains (source: Croatian Hydrocarbon Agency, <http://www.azu.hr/en-us>).

Moreover, besides the traditional geothermal heating and cooling applications, there are several locations around the edges of the Adria blocks where thermal springs could support Spas, balneotherapeutic uses (Figure 7) and, in cascade, contribute to RHC applications. Bojadgieva (2008)<sup>8</sup> reports a total installed capacity for of 652.7 MW<sub>(th)</sub> with a produced energy of 9456 TJ/yr and an average capacity factor of 0.33 (referred to the 2005), for the direct applications of thermal waters in the Balkan peninsula, which includes continental Greece, Bulgaria, European Turkey and SE - Romania, besides the eastern Adriatic - Jonian countries.

Country	N. of SPAs	Total average flow rate (kg/s)	Annual Total average water used (10 <sup>6</sup> *m <sup>3</sup> )	T (°C)	Average T (°C)	Resource potential capacity (MWt)	Total geothermal energy used (TJ/yr)	Estimated number of tourists <sup>(1)</sup>	Source <sup>(2)</sup>
Slovenia	26	115*	3.6	23-63	33-38	25	311	751000 (2010) ?	WGC 2010
Croatia	18	96*	3.0	25-85	42-47	33	216	400000 (2010) ?	WGC 2010
Bosnia and Herzegovina	20	79*	2.5	21-76	39-44	13	100	192000 (2009) ?	WGC 2010
Montenegro	1	?	?	?	?	?	?	?	WGC 2010
Albania	6	21	0.7	27-60	45-50	12	8	?	WGC 2010
Greece	>60	>1500	≈ 47	18-100	?	39?*	238?*	>100000 (2010) ?	WGC 2010
Serbia	59	700-800 ?	≈ 23	29-96	45-50	40	647	?	WGC 2010
<b>TOTAL</b>	<b>&gt; 191</b>	<b>&gt; 2.561</b>	<b>≈ 79,8</b>			<b>162</b>	<b>1520</b>	<b>&gt;1.443.000</b>	

(1) Data taken from different sources, they likely contain large uncertainties.

(2) Proceedings World Geothermal Congress 2010

Figure 7. Outline table of the status of the geothermal exploitation in the countries overlooking the Adriatic and Jonian seas.

<sup>8</sup> Bojadgieva K. (2008) – Status and outlook of geothermal development on the Balkan Peninsula. 30th Anniversary Workshop, August 26 - 27, 2008, UNU, GTP, Reykjavik, Iceland. (<http://unugtp.is/id/11247>).

Geothermal resources are often widespread, or located in narrow bands nearby the tectonically active faults interesting the buried carbonate platform. In several places they are characterized by good permeability (fractured and/or karstified) and generally recharged by seawater or groundwater systems from the highlands inland. Geothermal resources within 1 - 2 km depth generally present a much lower geological and drilling risks with respect to deeper resources. The temperature potential in the upper 1 - 2 km of the Adriatic - Jonian macroarea is very limited in comparison with the resources available in other more favourable areas (Figure 8).

The exploitation of such resources deserves particular attention mainly when deep aquifers are present near cities and towns; it is exploitable by shallow or deep open (with or without re - injection) or closed loop geothermal plants for single buildings [*Heat Pumps for Exploitation of Geothermal Sources in Milano City, MASELLA and PIEMONTE - extended article in this book*] or larger districts (district heating and cooling networks). These systems generally require low - medium initial investment (shallower drillings) and imply easier and quicker administrative procedures (even if not always clear and well defined in all countries), allowing faster realization time and more effective payback times. In comparison, power generation from geothermal resources (available in the Pannonian Basin and Aegean Sea) achieves positive economic and environmental benefits, mainly when accompanied by heat recovery using combined heat and power plants.

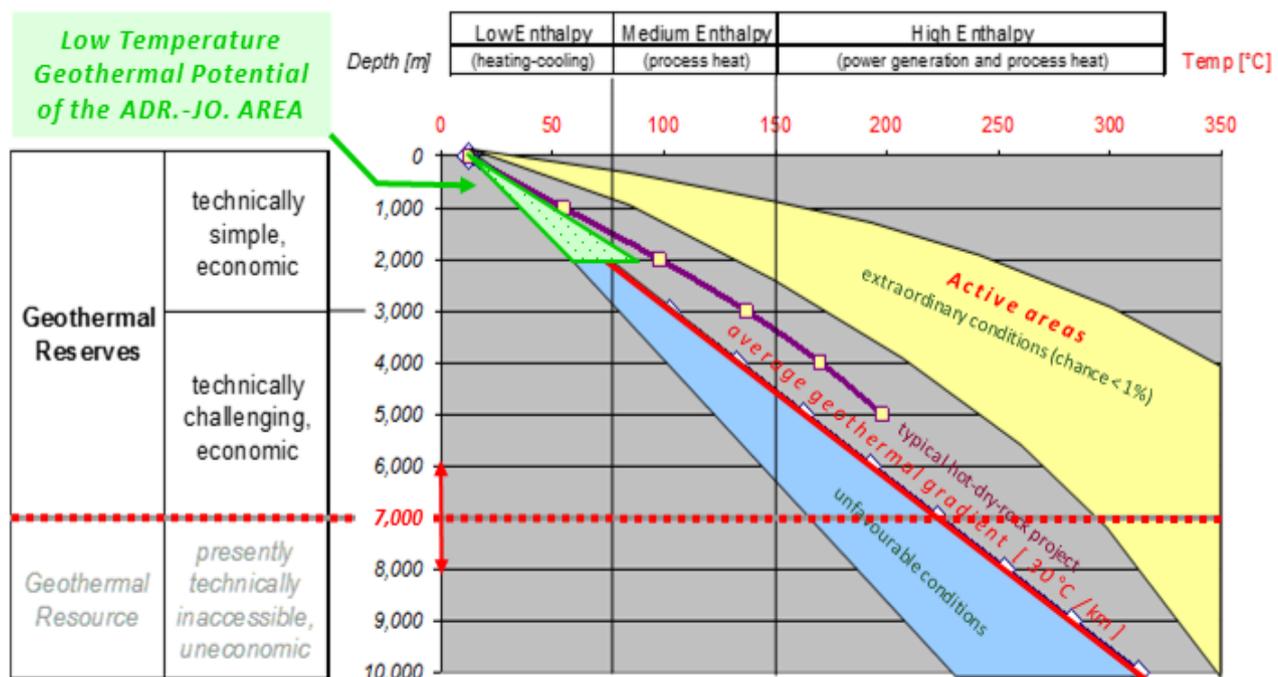


Figure 8. Temperature and depth ranges of low, medium and high enthalpy geothermal resources and reserves. Exploitation opportunities are suggested in consideration of their technical feasibility and risk (after Cociancig's presentation of Losinj workshop, August 2014).

Geothermal systems are flexible for multiple and cascade heat recovery utilizations; moreover, they could be easily integrated as base - load source with both conventional sources and other RES available in the surroundings (such as biomass, wind, urban waste in treatment plants, industrial heat recovery or photovoltaic and solar energy). As an example, the district heating system of Ferrara city – Italy distributes about 200 GWh of thermal energy, integrating the geothermal source (42%) with thermal recovery from waste - to - energy plant (50%) and back up stations (8%).

On the contrary, high enthalpy resources –considering their high temperatures and potential - are usually present only in active areas and are localized in limited geographic sectors (as Ionian Aegean ones). Their exploitation (e.g. for power generation and process heat) needs expensive systems and plants and it requires complex administrative procedures; they generally determine high costs of design and completion. At present, only small plant sizes are possible (limited by mass flow) and electrical efficiency is still low (small steam turbines).

The *Geothermal Lexicon for Resources and Reserves Definition and Reporting* (Lawless, 2010<sup>9</sup>) and the *Geothermal Reporting Code* (AGRCC, 2010<sup>10</sup>) are valuable guidelines for the assessment and reporting of geothermal resources and reserves; they can be downloaded from the IGA website (<http://www.geothermal-energy.org/index.html>).

<sup>9</sup>Lawless J. (2010) - Geothermal Lexicon for Resources and Reserves Definition and Reporting. 2nd Edition (2010) Edition. Adelaide, Southern Australia: Australian Geothermal Reporting Code Committee (AGRCC).

<sup>10</sup> AGRCC Australian Geothermal Reporting Code Committee (2010) - The Geothermal Reporting Code. Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves 2nd Edition (2010). Prepared by a Joint Committee of the Australian Geothermal Energy Group (AGEG) and the Australian Geothermal Energy Association (AGEA).

## 2014 LOŠINJ WORKSHOP

**Organizers.** The workshop on geothermal energy was organized by the *Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze* (hereinafter FIT), the *University of Trieste*, the *Italian Geothermal Union* (hereinafter UGI) and the *European Centre for Science Arts and Culture* (hereinafter ECSAC). The workshop was the XIV International Conference organized in Lošinj by ECSAC (<http://ecsac.ictp.it/ecsac14/>), which is a multidisciplinary institution that promotes cultural events to stimulate reciprocal scientific knowledge and cooperation amongst different countries and subjects.

**Funding and Supporting Institutions.** The Organizers and the following institutions funded the event: ICTP - Abdus Salam International Centre for Theoretical Physics of Trieste; Consortium for Physics of Trieste; HERA Group - Environmental Services Multiutility; OGS - National Institute of Oceanography and Experimental Geophysics of Trieste. Other institutions supported and gave patronages to the workshop: AREA Science Park; INFN - National Institute for Nuclear Physics; Italian Institute of Culture, Ruđer Bošković Institute and University of Zagreb; UniAdrión; Friuli Venezia Giulia Region, province and Municipality of Trieste.



**Figure 9. Group photo taken at the conclusion of the 2014 Lošinj workshop on “STATUS AND FUTURE OF THE GEOTHERMAL ENERGY IN THE PERI - ADRIATIC AREA”.**

**Partecipation.** A large group, coming from both public institutions than companies, participated and contributed to the positive workshop outcome (Figure 9); this cross - border community represents many countries: Italy, Slovenia, Croatia, Bosnia and Herzegovina, Czech Republic, Greece, Germany, Belgium, France and Saudi Arabia. A total number of 60 appearances (out of 66 registrations) were recorded (on average over 45 each day), including:

- researchers and students from universities, scientific research and cultural institutions,
- technicians and managers of public administrations and services,
- professionals (both employees and holders) of environmental private companies,
- technical staff from Industrial Corporation.

**Scientific program.** The workshop Directors (Bradamante F., Della Vedova B. and Vacchi A.) and the Rector of the University of Trieste (Fermiglia M.) opened the event: they suggested some interesting aspects regarding the socio - political, economic and technical framing of the direct use of geothermal resources. The program (Figure 10) included thirty presentations and the final open round table, stimulated by invited keynote speakers: it was focused on networking, projects and future perspectives of the geothermal energy in the Adriatic and Jonian macroarea<sup>11</sup>.

The outline of the program included several topics:

<sup>11</sup> The files pdf of all the presentations are available from October 2014 and downloadable in the section dedicated to conference proceedings in the FIT website (<http://www.fondazioneinternazionale.org/attiConvegni.php>). Further information about the workshop and several digital contents are published on the conference webpage <http://ecsac.ictp.it/ecsac14/>.

- Status and perspectives of geothermal technologies,
- Resources Assessment and Geothermal Applications,
- Integration of energy sources in the Peri - Adriatic Area,
- New ideas and Proposals for cooperation in the Peri - Adriatic Area.

**VELI LOŠINJ, CROATIA: XIV INTERNATIONAL CONFERENCE ON SCIENCE, ARTS AND CULTURE**  
**WORKSHOP ON GEOTHERMAL ENERGY: STATUS AND FUTURE IN THE PERI - ADRIATIC AREA**

MONDAY 25 <sup>TH</sup> AUGUST	TUESDAY 26 <sup>TH</sup> AUGUST	
<p><b>MORNING</b></p> <p><b>ORGANIZERS OPENINGS</b> by <i>Bradamante F., Della Vedova B. and Vacchi A. (IT)</i></p> <p><b>WELCOME REMARKS</b> by <i>Mali Lošinj Major (HR), Vito S. (Regional Minister of Environmental, Energy Mountain Policies, RFVG, IT) and Giadrossi A. (Mali Losinj Italian Community, HR)</i></p> <p><b>KEY NOTE ADDRESS.</b> <i>Fermeglia M. (Rector of Trieste University, IT)</i></p> <p><b>INTRODUCTION PAPER.</b> <i>Lughi V. (Trieste University, IT): Energy as a global challenge</i></p> <p><b>STATUS &amp; PERSPECTIVES OF GEOTHERMAL TECHNOLOGIES</b></p> <p><i>Angelino L. (EU Geothermal Energy Council, Bruxelles, BE): Geothermal energy in Europe: market development, perspectives and framework conditions</i></p> <p><i>Cociancig B. (MND Group, CZ): Geothermal energy: how does it stack up in the future energy mix?</i></p> <p><i>Ungemach P. (GPC, Paris, FR): Recent achievements in geothermal technology</i></p> <p><i>Conti P. and Grassi W. (Pisa University and UGI, IT): How heat pumps work: criteria for heat sources evaluation</i></p> <p><b>AFTERNOON</b></p> <p><b>RESOURCES ASSESSMENT &amp; GEOTHERMAL APPLICATIONS</b></p> <p><i>Pipan M. (Trieste University, IT): High-resolution geophysics for porosity and fracture network</i></p> <p><i>Poletto F. (OGS, Trieste, IT): Integrated geophysical characterization of geothermal reservoirs assessment in shallow geothermal applications</i></p> <p><i>Antics M. and Ungemach P. (GPC IP, Paris, IT): Geothermal reservoir characterization and management</i></p> <p><i>Prestor J. et al. (GeoZS, Ljubljana, SI): Low temperature geothermal applications and projects in Slovenia</i></p> <p><i>Kurevija T. (Zagreb University, HR): Geothermal applications in Croatia</i></p> <p><i>Petrini R. (Pisa University, IT): Thermal springs and balneology in the Peri - Adriatic Area: geochemical status and prospects</i></p>	<p><b>MORNING</b></p> <p><i>Kachyna R. and Cociancig B. (MND Group, CZ): Deep geothermal project from the perspective of a drilling contractor</i></p> <p><i>Buscaroli F. and Ferraresi F. (AIRU, Milano and HERA Group, IT): The integrated Ferrara plant (50% geothermal)</i></p> <p><i>Della Vedova B. and Cimolino A. (Trieste University, UGI, IT): Geothermal heating and cooling in the FVG Region: the Grado district heating project and the Pontebba ice rink</i></p> <p><i>Kralj P. (Gejzir, Ljubljana, SI): District Heating of Benedikt, 1st stage (Northeast - Slovenia)</i></p> <p><i>Floreani M. and Cozzi G. (AREA Science Park, Trieste, IT): Area Science Park innovative systems and open-laboratories for the diffusion of small size plants based on renewable energy and high efficiency technologies including geothermal applications</i></p> <p><i>Djurić N. et al. (Subotica University, RS): Ecological and economic aspects of using geothermal energy for heat supply town of Bijeljina and other areas Bosnia and Herzegovina</i></p> <p><i>Mendrinis D. and Karytsas C. (CRES, Greece, EL): Low temperature geothermal applications in Greece, including water desalination</i></p> <p><b>EXCURSION (IN THE AFTERNOON) AND SOCIAL DINNER</b></p> <p><b>WEDNESDAY 27<sup>TH</sup> AUGUST</b></p> <p><b>MORNING</b></p> <p><b>INTEGRATION OF ENERGY SOURCES IN PERI-ADRIATIC AREA</b></p> <p><i>Masella A. (Brescia University, IT): Heat pumps for exploitation of geothermal sources in Milano City</i></p> <p><i>Molinari F. and Tarantino P. (Cogeme SpA, Brescia, IT): New projects for geothermal district heating and cooling systems in the Brescia Province (Northern Italy)</i></p> <p><i>Büscher E. and Wittig V. (IGO - GZB, Bochum, DE): Down the hole hammer drilling technologies: status and future development</i></p> <p><i>Cociancig B. (MND Group, CZ): Altheim in Upper Austria – an example of cascaded geothermal energy use</i></p> <p><i>Stefanelli S. (FVG Region, IT): ALTERENERGY: Energy sustainability for Adriatic small communities</i></p>	<p><i>Jovanović D. (IRENA, HR): LEGEND PROJECT mobilizing ground-source heat pumps investments in Adriatic</i></p> <p><i>Mendrinis D. (CRES, EL): GROUND-MED Project - Advanced GROUND source heat pump systems for heating and cooling in MEDITerranean climate</i></p> <p><i>Zudek A. (Zudek s.r.l, Trieste, IT): New applications of heating and cooling using geothermal resources</i></p> <p><b>AFTERNOON</b></p> <p><b>NEW IDEAS AND PROPOSALS FOR COOPERATION IN PERI-ADRIATIC AREA</b></p> <p><i>Stefanelli S. (FVG Region): The Friuli Venezia Giulia energy strategy</i></p> <p><i>Laurenzi U. (Trieste Municipality, IT): The Trieste PAES – Action Plan for Sustainable Energy</i></p> <p><i>Stival C.A., Valcovich E. et al. (Trieste University, IT): Methodological approach for recovery and energetic requalification of historical buildings (Trieste port)</i></p> <p><i>Manganaro A. (STEAM Srl., IT): M19 – A new school complex module in an historical building based on Leed Certification and Geothermal application (Trieste port)</i></p> <p><i>Pellegrini G. (STP, IT): Feasibility study for district heating and cooling downtown Trieste by seawater heat pumps</i></p> <p><b>ROUND TABLE: FUTURE PERSPECTIVES</b></p> <p>Key note speakers invited to stimulate the round table: <i>Büscher E., Cociancig B., Graziano G., Kurevija T., Mendrinis D., Prestor J., Ungemach P.</i></p> <p><b>CLOSING REMARKS</b></p> <p><i>Della Vedova B. and Vacchi A.</i></p>



Figure 10. Topics and interventions programmed in occasion of the 3 days of the workshop on geothermal energy (25 - 27 August 2014, Lošinj).

## CRITICAL ISSUES AND CHALLENGES

### Technical issues and challenges of the geothermal exploration and exploitation

Several examples of successful geothermal projects and plants are operating in Europe (such as the doublets in the Paris Basin) and many others in the Peri - Adriatic area (such as: Benedikt, SI; Ferrara and Grado, IT; Zagreb, HR, and others). The *Strategic Research and Innovation Agenda for RHC - ETP* has identified two important technical issues that are critical for the growth of the geothermal sector and need to be properly addressed in the near future:

- reduction of exploration and drilling costs, which implies a corresponding reduction of the geological risk and of the payback time,
- enhancement of the performance and reliability of the RHC systems by RES integration, energy efficiency and innovative technical and management solutions.

Even in highly promising resource zones, geophysical exploration and geothermal resource assessment by drilling may not yield economically exploitable resources at any given location. The *Geothermal Exploration Best Practices Handbook* (Harvey and Robertson - Tai, 2013<sup>12</sup>) provides guidelines and field examples for developers to undertake a

<sup>12</sup> Harvey C. and Robertson - Tait A. (2013) - Overview of Geothermal Exploration Best Practices. In: IGA International Geothermal Association [Edt.] - Geothermal Exploration Best Practices. Launch Event; 2013/03/27; Istanbul, Turkey.

more effective exploration, reducing risk and thereby attracting investment, mainly, but not exclusively, for power production. The development cycle of a typical geothermal power project takes from 5 to 10 years and consists of seven steps: preliminary survey; exploration; test drilling; project review and planning; field development; construction; and start - up and commissioning; this sequence of steps is characteristic of geothermal (power and thermal) exploitation [*Recent Achievements in Geothermal Technology*, UNGEMACH; *Geothermal Reservoir Characterization and Management*, ANTICS and UNGEMACH - extended articles in this book].

The exploration stage is the most critical step that can take up to 4 years and includes the selection of promising areas, exploration (including surface geophysics [*Integrated Geophysical Characterization of Geothermal Reservoirs*, POLETTO et al. - extended article in this book], geology, geochemistry), pre - feasibility studies, exploration drilling, and reservoir simulations. This part is usually perceived as the most risky part of the project development and it is expected to confirm if geothermal reservoir is suitable for power/heat generation and sufficient to recover the costs or not. The reduction of exploration and drilling costs for direct use applications requires quite an effort in different directions:

- Preparation of atlases of resources, by collection, validation and compilation of existing geological, geophysical and geochemical data; this will significantly improve the process of selection of the most promising areas;
- Preparation of atlases of opportunities, combining available resources with nearby sustainable applications in towns, cities, transport infrastructures and resort areas; they should be accompanied by preliminary cost/benefit analysis; this should provide better chances of fund raising attracting public and private investors and improve communication and social acceptance;
- Improvement and innovation in exploration and drilling technologies, by more accurate and appropriate planning of the essential exploration activities and of the drilling program (slim holes, downhole measurements, drilling rigs, ...); drilling cost reduction could be also achieved by positive market growing and know - how technology transfer among countries;
- Formation of skilled professionals in exploration, well design and drilling, resource and risk assessment, fund raising, social acceptance, communication and dissemination.

The risk assessment for the consistency of the geothermal resource and its careful mitigation is a critical and essential issue for the entire project. Besides the heat mining risk, the project developers should be able to understand and manage the associated drilling, project development and realization and plant management risks; all these have in sequence a strong impact on the overall financial risk and on return on investment for private investors. Financing costs must be maintained as low as possible particularly in the early steps to ensure the greatest chance of success to the project. To mitigate the high initial risks related to the development of the geothermal resources, various risk mitigation facilities were established and operated by development partners and regional organizations, mainly for geothermal power production, but also for district heating infrastructures.

The enhancement of performance and reliability of RHC systems requires, on the other hand, working on several different aspects, some of which are:

- Better assessment of the sustainability and utilization time (life time) of the geothermal resource, by reservoir engineering, operational monitoring and management optimization of the coupled resource - plant system (also by innovative approach for heat sources evaluation criteria and characterization of operative performances of heat pump systems [*How Heat Pumps Work: Criteria for Heat Sources Evaluation*, CONTI and GRASSI - extended article in this book]); this is beneficial also for the risk and cost reduction;
- Increased performance, reliability and operational time of technical solutions, by better materials, improved heat exchangers and heat pumps; increased performance could also be pursued by integration of local available RES and by extending utilizations year around, including balneotherapy specific utilizations and Spas; being a continuous resource, the geothermal applications should care particularly and optimize the capacity factor with respect to investment and managing costs;
- Minimization of environmental impacts is an indirect way to enhance the overall performance and reliability of geothermal plants; time reduction of the plant realization is also an indirect effective measure.

### **Other specific issues and challenges to work on**

Better design and planning. Considering the actual status of the geothermal energy sector in the Adriatic – Jonian macroarea, a common problem to several projects under development is the weakness of some important aspects, such as: the overall project design, the risk assessment and mitigation, the project review and planning and the economic and operational risks. The economic viability and profitability of plants, framed within the local regulatory and fiscal regimes, is in fact a real critical factor for the attraction of investors.

Removing non - technical barriers. The ADR.JO. G.P. and the cross - border cooperation should particularly improve the information exchange and the knowledge sharing to identify and possibly remove the non - technical barriers such as the policy uncertainties and differences in the regulatory and fiscal regimes among RES (feed - in tariffs FITs, regulated

price, social tariffs) and the correct communication about the hazard perception related to drilling activities. These actions should strengthen the RHC market and improve the social acceptance of the geothermal energy.

Regarding the existing regulatory and fiscal regimes, geothermal developers often report long national administrative times required to complete the authorization process, that often turns out to be not clear and rather fragmented among countries and, sometimes, even among regions within the same country. Relevant political stances and enabling policies are presently active in some EU countries; they positively stimulate the geothermal market by means of specific measures, such as: FITs and/or incentives, investment aids, CO<sub>2</sub> tax, phase out fossil fuels subsidies, tax credit or relief and implementation of existing legislation. Many countries around the world adopted FITs systems mainly to entice small Private Power Plants and RES generation; concentration solar and photovoltaic systems seems to be favoured with high FITs while geothermal remains, generally, at an average [*Geothermal District Heating in Europe: Market, Potential and Framework Conditions*, ANGELINO - extended article in this book].

Incentives and funding. In Germany, the government currently supports the development of the geothermal energy market through long term national tax incentives, adopting FITs (even when geothermal use integrates other RES). FITs, *de facto*, fostered new widespread investments throughout the country. At present, Germany produces some 32% of its energy demand from RES; over 300 000 people are employed in the RES industry, which has an annual turnover of ~40 billion €. The Nuclear Exit Strategy has provided a large boost to RES.

In France, a specific geothermal market arose quickly in the last years in several geothermal areas, following the early geothermal doublets in the Paris basin, also because of the adopted incentive policies. This market is based on a network of investors, traders, developers and technical professionals (engineers, performers, installers, maintenance technician, etc.) who work in a close interaction in the geothermal field.

Financial incentives for renovation and requalification of public buildings in Slovenia (2012 - 13) launched the use of geothermal heat pumps for various heat utilizations: residential (single family houses, villas, multifamily houses), recreation (hotels, spas, farm holidays, swimming pools, sport facilities), agriculture (greenhouses, wine cellars), public buildings (schools, kindergartens, theatres, libraries), commercial and industrial (shopping malls, sheds) [*Low Temperature Geothermal Applications and Projects in Slovenia*, RAJVER et al. - extended article in this book].

Specific funding and incentive policies could speed up the geothermal market and also stimulate the cooperation between involved subjects, allowing the transfer of methodologies, knowledge and technologies, also by means of specific agreements<sup>13</sup>.

Oil & Gas and geothermal bridging. Oil and gas companies and smaller service companies are more and more considering converting unproductive and/or exploration wells for geothermal heating and cooling applications, where potential users are nearby available. This should open new perspectives for direct uses, besides heating and cooling, such as seawater desalination [*Low Temperature Geothermal Applications in Greece, Including Water Desalination*, MENDRINOS and KARYTSAS - extended article in this book], agriculture and food treatment and environmental requalification. Oil & Gas and Geothermal sectors bridging could be effective in sedimentary basins only, with exclusion of the metamorphic and volcanic provinces; it should favour a more effective technology transfer, with benefits and cost reduction both in the exploration and drilling phase and in the performance, reliability and operational time of the technical solutions.

Atlas of Resources and Catalogue of opportunities. Besides the early European Atlases of Geothermal Resources published in 1988 (Haenel and Staroste<sup>14</sup>), 1992 (Hurtig et al.<sup>15</sup>) and in 2002 (Hurter and Haenel<sup>16</sup>), two useful new web map viewers of the geothermal potential in Europe are now available:

- *ThermoMap*<sup>17</sup> for the shallow geothermal resources (soil and groundwater data) down to 10 m depth, and
- *GeoDH*<sup>18</sup>, geothermal potential in Europe at macro - regional scale for district heating [*Geothermal District Heating in Europe: Market, Potential and Framework Conditions*, ANGELINO - extended article in this book].

They constitute a very good starting tool, that need to be detailed and completed at local scale, particularly in complex areas and where there is significant tectonics with important lateral changes. Accurate geologic maps, including neotectonic activity, seismicity and reconstruction of the stress regime fields, are very important at local scale to start deep geothermal projects.

<sup>13</sup> The approach of Green Certificates and Renewable Electricity Standard concurs to favour connection through corporate ownership structures.

<sup>14</sup> Haenel R. and Staroste E. [Edts.] (1988) - Atlas of Geothermal Resources in the European Community, Austria, and Switzerland. Commission of the European Communities, 1988; Brussels; Publication EUR 11026; 74 pp. + 110 plates.

<sup>15</sup> Hurtig E., Cermak V., Haenel R., Zui V. [Edts.] (1992) - Geothermal atlas of Europe. Hermann Haack; Gotha (Germany); 1992; 156 pp.

<sup>16</sup> Hurter S. and Haenel R. [Edts.] (2002) - Atlas of Geothermal Resources in Europe. Office for Official Publications of the European Communities, Luxembourg.

<sup>17</sup> <http://geoweb2.sbg.ac.at/thermomap/> (2013)

<sup>18</sup> <http://geodh.eu/geodh-map/> (2014)

During the concluding Round Table of the workshop, it was pointed out and unanimously agreed about the need to prepare and make available to the stakeholders a catalogue of opportunities, projects and technologies in the Adria - Jonian enlarged region. It should be mainly addressed to public administrations and private investors and should take into account:

- geothermal and groundwater resources, other RES locally available and their potential of integration,
- present and future public and private RHC demand and other potential applications,
- technology available for the RHC applications,
- project duration and impact on the resources and environment,
- preliminary cost/benefit assessment.

The catalogue preparation could be eventually part of activities for proposals to submit under the *Horizon 2020* program, which also aims to create a network for know - how transfer and sharing.

The completion of the catalogue is not easy and requires a selection of pilot sites in different countries, with likely different geological framework and different mix of applications. It would require also a pre - feasibility study regarding the partners, funding schemes, realization, management, monitoring and optimization of plants. The risk assessment and preliminary cost/benefit analysis might be very difficult to trust.

Drilling and DH network costs. Regarding the realization of DH plants, it must be notice that currently the drilling costs and the deployment of the main distribution network largely control the cut - off between geothermal reserves and resources (Figure 8): the cost of one km of drilling and the cost of one km of a double pipeline deployment at 1 - 2 m depth downtown are comparable, when the depth of the DH geothermal doublet is within 1 - 2 km.

The new advanced drilling technologies, such as the DTH downhole fluid hammer [*Geothermal Development and Activities in Germany, BUSCHER and WITTIG - extended article in this book*] can now significantly reduce the drilling costs up to 15 - 30% by increasing the penetration rate of the high - tech percussion tools.

Hybrid Heating and Cooling systems. Hybrid heating and cooling systems (geothermal, solar, biomass, waste heat, ...) and heat storage applications represent the best future perspectives to reach the main goals of the EC Directives. Several demonstration projects, such as the ones above mentioned, are operational in the broad Adriatic - Jonian area. They prove the feasibility of competitive, low emission and easy to integrate geothermal heat plants for a variety of direct - use applications, including space and district heating, domestic hot water supply, greenhouses and fish farming, balneotherapy and process heat for industry and agriculture. They are running best - practice examples essential to foster a wider acceptance and adoption of geothermal energy. The low awareness and limited information about geothermal technology and associated environmental risks are often the main barrier to its development.

As main proponents of the Grado DH geothermal pilot project [*Geothermal Heating and Cooling in the FVG Region: the Grado District Heating and the Pontebba Ice Rink Plants, DELLA VEDOVA et al. - extended article in this book*], which is located on a beautiful resort island of about 10 km<sup>2</sup> in the northern Adriatic coastal area, we had to tackle two important issues among the others, related to potential environmental risk for the residents:

- the non - realistic induced seismicity risk associated to drilling 1.2 km deep wells and to the functioning of the DH geothermal doublet (production and re - injection),
- the very low risk associated to the hydraulic interference between producing and re - injecting geothermal salty waters from/to the deep carbonate reservoir and the freshwater aquifers confined in the upper 280 m of soft sediments.

A further general major concern about the energy savings and economic return of the geothermal DH projects is the quite low capacity factor of these plants (often lower than 0.3), because of heating during winter time only. Further year around uses of the geothermal resource could be searched in hot water supply, balneotherapy and process heat for industry and agriculture. Combining and integrating locally available RES to support larger and composite facilities, hopefully integrating RHC, is another way to increase the overall capacity factor.

This integration possibility fits perfectly within the *Intelligent Smart Thermal Grids* that can play an important role in the future of Smart Cities (Schmidt et al., 2013<sup>19</sup>) by ensuring a reliable and affordable heating and cooling supply to various customers with low - carbon and renewable energy carriers like waste heat, waste - to - energy, solar thermal, biomass and geothermal energy [*The future of sustainable energy policies in the Friuli Venezia Giulia Region, STEFANELLI - extended article in this book*]. This Smart Cities vision will concretely sum on fund rising and investors.

An example of small - scale RES integration and retrofitting measures is the *GeoCom Project* for Geothermal Communities, within several pilot sites were completed demonstrating the cascading use of geothermal energy for district heating. This project allowed the construction of distribution network in small cities (Mórahalom in South - East Hungary, Galanta near Bratislava) and in the historic centers of Montieri in the Lardarello Geothermal District (Italy).

---

<sup>19</sup> Schmidt RR., Fevrier N., Dumas P. (2013) - Smart Thermal Grids - Key to Innovation Integrated Solution. Smart Cities Stakeholder Platform. <https://eu-smartcities.eu/>.

Another concrete opportunity of smart integration of local resources in coastal areas is provided by the realization of integrated district heating and cooling systems including seawater heat pumps, as the proposal submitted to Trieste Municipality for the sustainable requalification of the Trieste sea - front urban system [*Methodological Approach for Recovery and Energetic Requalification of Historical Buildings*, VALCOVICH et al. - extended article in this book].

Balneotherapy and Spas. There is a growing attention for health and balneotherapeutic utilizations worldwide, supported by an increasing market demand. Geothermal springs and thermal aquifers have a large potential and wide improvement margins to naturally feed Spas and thermal pools [*Ecological and Economic Aspects of Using Geothermal Energy for Heat Supply Town of Bijeljina and Other Areas Bosnia and Herzegovina*, ĐJURIĆ et al. - extended article in this book] as well as to locally contribute to RHC applications by means of heat exchangers and/or pump systems on the inlet/outlet of the thermal waters.

Several working thermal districts in the broad Adriatic - Jonian area could substantially optimize the utilization of the thermal waters, guarantying long - term sustainability and resource protection, but also increasing the thermal efficiency of the Spas, by heat exchange with the wastewaters. Moreover, there are several new areas where these applications could be developed.

## **LAUNCH AND PERSPECTIVES OF THE ADR.JO. GEOTHERMAL PLATFORM**

DELLA VEDOVA Bruno, VACCHI Andrea and CIMOLINO Aurélie

An important issue addressed by several speakers, and largely discussed during the closing round table of the workshop, was about the best way to foster the development of the geothermal energy sector in our area. Building up a dedicated multidisciplinary platform for the geothermal direct applications in the Adriatic - Jonian macroarea among the main components of the cluster, was identified as the most appropriate leverage tool to improve communication, facilitate knowledge sharing, transfer technology and reduce viscosity in the process of collaborative research and joint projects among stakeholders of the various countries. Moreover, the platform should improve cooperation and exchange to overcome some of the most important non - technical issues, which inhibit the growth rate of the geothermal sector and the found rising from public and private sectors. Among the most critical non - technical issues, we mention:

- policy uncertainties,
- environmental hazard perception related to drilling activities,
- shortage of experts in the various steps of the production chain and
- limited information and dissemination activities.

**The main objective of the proposed  
“Adriatic - Jonian Geothermal Platform”**

**is to realize the network among stakeholders with the perspective of aggregating a strong geothermal cluster composed by advanced research institutions, high - tech specialized professionals and enterprises, industry and public administrative offices,  
working on research and development of the geothermal heating and cooling applications.**

Moreover, the Adriatic - Jonian Geothermal Platform could provide support to countries with emerging geothermal markets to enable adequate policy and regulatory schemes for investment promotion and to share the best know - how to minimize the risk in the various phases of the geothermal projects.

Several platforms already exist within the RES sector, such as:

- RHC-ETP - European Technology Platform on Renewable Heating & Cooling,
- DHC+, District Heating and Cooling plus Technology Platform,
- EGIP, European Geothermal Information Platform,
- GEOELEC, Geothermal Electricity Platform,
- Smart Cities Stakeholder Platform,
- GEOPLAT, Spanish Geothermal Technology Platform,
- GANDOR, Geothermal Academic Network in the Danube Region [*Geothermal Development and Activities in Germany*, BUSCHER and WITTIG - extended article in this book],
- etc.

These could be of great interest at the macro scale area level, but do not specifically address several basic problems of some countries of the broad Adriatic - Jonian area, that need to develop strategies and policies to properly face the major global issues. We think that a new ADR.JO. dedicated Geothermal Platform (laboratory?) could be an appropriate tool for a quick development of the geothermal sector of our area for several reasons; the ADR.JO. region is not too large and logistically easy to travel, it is very focused on similar resources and applications, it is the target of the European strategy for the Adriatic and Jonian Region, it could largely benefit from technology transfer and human mobility and it could substantially benefit from the development of the direct uses of the geothermal heat, mainly for small, insulated towns and communities living around the Adriatic Sea and on the eastern side of the Jonian Sea.

In perspective, the ADR.JO. Platform should become a reference laboratory for know - how exchange, technology transfer and development of national and cross - border cooperation in joint research programs. It could stimulate:

- transfer of information as methodologies, knowledge and technologies (other than personnel),
- communication and sharing of ideas, research supports and funding,
- widespread dissemination and education of the population (and students in particular), who are basically unaware of the geothermal resources potential.

Several subjects should be involved in the platform building - up, such as: universities and research institutions, public administrations, companies and industry, professionals. These subjects could be, potentially, both partners and stakeholders of new geothermal projects focused on direct uses of geothermal energy.

The geothermal community participating to the 2014 Workshop in Lošinj already represents the seed of a cluster of partners and stakeholders (experts from the research field, the developers and the market operators). Several countries of the broad Adriatic - Jonian region were represented: Italy, Slovenia, Croatia, Czech Republic, Bosnia and Herzegovina, Greece, with the support of other countries (Belgium, France, Germany and Swiss Confederation) from Europe. A few other countries of the Adriatic - Jonian macroarea were not represented.

The very qualified speakers invited to the meeting were able to transfer interest, grit and passion into the audience, both during the scientific presentations and during the concluding round table. We thank them all for their essential contribution to the success of the meeting.

During the Round Table, which was held at the conclusion of the 2014 Lošinj workshop, the geothermal community discussed the status of geothermal energy in the broad Adriatic – Jonian area, starting from its geothermal potential, and focused on the technical issues and challenges of the geothermal exploration and exploitation of the reference area, on which the community should work in a cross boundary and multidisciplinary cooperation. Participants shared a common vision about problems and perspectives of development to be expected in the future for the geothermal sector, supporting the networking among:

- the research field (research institutions, universities, technology centers , ... ),
- the economy and the market sector, with significant repercussions for the different subjects involved (such as investors, insurers, companies and technicians, ... ) from small and medium businesses to large companies.

Some of the key issues and challenges addressed during the workshop and discussed in the round table are listed here below, though the list is not exhaustive:

- risk and cost reduction,
- removal of non - technical barriers and set - up of supporting policies,
- geothermal gas and oil bridging (where appropriate),
- increase performance, reliability and operational time of technical solutions by technology transfer,
- compilation of atlases of resources and opportunities,
- minimization of environmental impacts,
- realization, management, monitoring, modelling and optimization of geothermal plants,
- time reduction of the plant realization,
- realization of demonstration projects and pilot sites, maybe including water desalination,
- integration of RES for local, small/medium size RHC hybrid systems and heat storage solutions,
- improvement of district cooling from geothermal fluids and other RES, including seawater HPs,
- integration of balneotherapeutic specific utilization with cascade RHC applications,
- intelligent Smart Thermal Grids in the smart cities vision with fund raising and investors,
- transfer of information, communication and sharing, widespread dissemination,

The establishment of a cooperation network to setting up of a multidisciplinary technical platform is the first result of the Veli Lošinj International Workshop on Geothermal Energy.

From the digital point of view, the ADR.JO. Geothermal Platform is hosted in a webpage owned by the  
**Trieste International Foundation for the Progress and Freedom of Sciences**

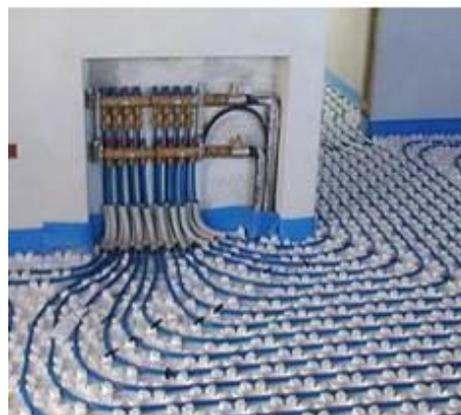
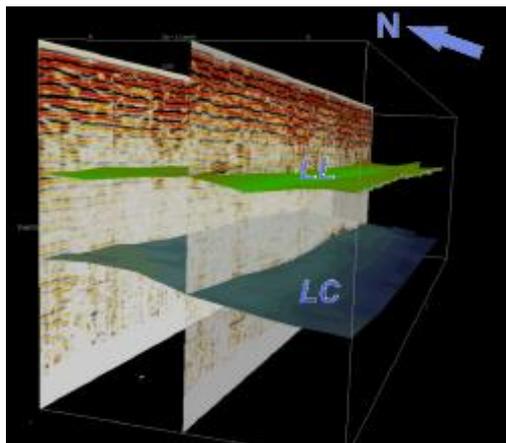
which is one of the leader of the technical community

<http://www.fondazioneinternazionale.org/geothermalPlatform.php>

*Figure 11. Snap - shots of productive discussion during the 2014 Lošinj Workshop on Geothermal Energy.*



Figure 12. Some shots about recent geothermal studies and plants shown during the 2014 Lošinj Workshop on Geothermal Energy.



*The list of the contributors and participants follows below:*

Universities

Marche Polytechnic University - UniAdriano, Ancona; ITALY (Pacetti M.)  
SISSA - International School for Advanced Studies, Trieste; ITALY (Martinelli G.)  
University of Brescia; ITALY (Masella A.)  
University of Chieti; ITALY (Palmucci W.)  
University of King Saud; SAUDI ARABIA (Lashin A., Al - Arifi N.)  
University of Padova; ITALY (Stival C.A.)  
University of Pisa; ITALY (Grassi W., Petrini R., Conti P.)  
University of Subotica; SERBIA (Đjurić N.)  
University of Trieste; ITALY (Fermeglia M., Della Vedova B., Valcovich E., Lughì V., Pipan M., Del Ben A., Castelli E., Cimolino A., Brancatelli G., Berto R., Cechet G.)  
University of Udine; ITALY (Nardin G.; Pinamonti P.)  
University of Zagreb; CROATIA (Kurevija T., Pallua S.)  
Several students from the Universities of Trieste, Chieti (ITALY), Ljubljana (SLOVENIA) and from the Technical Institute of Bijeljina (BOSNIA AND HERZEGOVINA).

Research and Culture Institutions

Area Science Park, Trieste; ITALY (Floreani M., Cozzi G., Taylor S., Guaiana M.)  
Consortium for Physics of Trieste; ITALY (Ghirardi G.)  
CRES - Centre for Renewable Energy Sources and Saving, Pikerimi; GREECE (Mendrinòs D., Karytsas C.)  
ECSAC - European Centre for Science Arts and Culture, Trieste; ITALY (Bradamante F.)  
FIT - Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze; ITALY (Vacchi A., Fratnik F., Cimolino A.)  
GZB - Internationalen Geothermiezentrum, Bochum; GERMANY (Wittig V.)  
ICTP - Abdus Salam International Centre for Theoretical Physics of Trieste; ITALY (Quevedo F., Treleani D.)  
IGO - International Geothermal Office of Germany, c/o GZB, Bochum; GERMANY (Buescher E.)  
INFN - National Institute for Nuclear Physics, Trieste; ITALY (Vacchi A.)  
INGV - National Institute of Geophysics and Volcanology; ITALY (Italiano F.)  
OGS - National Institute of Oceanography and Experimental Geophysics of Trieste; ITALY (Poletto F., Busetti M., Camerlenghi A., Giorgi M., Farina B., Corubolo P., Petronio L., Schleifer A., Palmieri F., Peronio M.)

Public Administrations and Associations

Abruzzo Region (Flacco I., De Blasis R.)  
AIRU - Associazione Italiana Riscaldamento Urbano, Milano; ITALY (Ferraresi F., Buscaroli F.)  
CNG - National Geology Council; ITALY (G. Graziano)  
EGEC European Geothermal Energy Council, Brussels; BELGIUM (Dumas P., Angelino L.)  
ENEL Green Power; ITALY (Bertani R.)  
Energy Institute Hrvoje Požar; CROATIA (Živković S.)  
Friuli Venezia Giulia Region; ITALY (Vito S., Stefanelli S.)  
Geological Survey of Bosnia and Herzegovina, Sarajevo; BOSNIA AND HERZEGOVINA (Skopljak F.)  
Geological Survey of Slovenia, Ljubljana; SLOVENIA (Prestor J., Rajver D., Pestotnik S.)  
IRENA - Istrian Regional Energy Agency Ltd., Labin; CROATIA (Jovanović D.)  
Italian Institute of Culture of Zagreb; CROATIA (Zovko N.)  
Ruđer Bošković Institute of Zagreb; CROATIA (Zovko N.)  
Trieste Municipality; ITALY (Laurenì U.)  
Trieste Province; ITALY (Bassa Poropat M., Magistri De Francesco M., Stolfo P.)  
UGI - Unione Geotermica Italiana; ITALY (Della Vedova B., Cataldi R., Grassi W., Conti P.)  
Veneto Region; ITALY (Tosoni D.)

Companies

ITALY: Cogeme SpA, Rovato (Tarantino P.); Hera Group, Bologna (Buscaroli F., Ferraresi F.); Steam Srl, Padova (Romano G., Strada M., Manganaro A.); STP Srl, Torino (Pellegrini G., Valle F.); Studio Associato di Ingegneria, Milano (Piemonte C.; Masella A.); Studio Idrogeologico Geoeco, Udine (Droli G.); Turboden Srl, Brescia (Menin C., Di Prima M., Bonafin J.); Zudek s.r.l., Trieste (Zudek A., Aloisio F.)

SLOVENIA: Gejzir Consulting, EON Research Centre, Ljubljana (Kralj P.); Harpha Sea d.o.o., Koper (Žerjal A., Cinc Gregoric P.)

FRANCE: GPC Instrumentation Process, Paris (Ungemach P., Antics M.)

CZECH REPUBLIC: MND Group (Kachyňa R., Cociancig B.)

CROATIA: Petroprom d.o.o., Premantura (Cociancig B.)

Some Freelance Geologists (Klingendrath A., Molinari F.C.) are already in connection within the ADR.JO. G.P.

## **EXTENDED ARTICLES**

## **Introduction Paper**

## Energy as a Global Challenge

LUGHI Vanni<sup>1</sup>

<sup>1</sup> Department of Engineering and Architecture, University of Trieste, Italy

Corresponding author's e-mail: vanni.lughi@di3.units.it

**Keywords:** renewable energy, fossil fuels, energy demand, energy supply.

### ABSTRACT

Appropriate matching of energy supply with energy demand is one of the most formidable challenges that humankind has to face today and in the near future. On the supply side, although fossil fuels do have the potential for satisfying energy demand for at least a few decades – especially in light of the recent massive introduction of shale gas in the international market, heavily relying upon such resources does not appear to be a sustainable solution even in the medium term, as questions and doubts arise from both the economic and the environmental standpoint. Renewable resources are gaining importance as alternative energy supply: they have an enormous potential and many renewable - based technologies are competitive on the market today. However, renewables face and pose major challenges (but also offer great opportunities) while entering the current very structured energy system, and a broad rethinking is needed of energy policies, market dynamics, and infrastructures. On the demand side, there are two opposite trends at the global level. In the Organization for Economic Cooperation and Development (OECD) countries, there is a strong push towards the reduction of energy demand by acting along the entire energy value chain, both by considering efficient energy conversion technologies, and by promoting awareness and technology - based energy - saving solutions for the end user. Conversely, the countries of Brazil, Russia, India, China and South Africa (BRICS) and developing countries strongly rely on energy for sustaining their economic growth, resulting in a marked increase in energy demand.

### 1. ENERGY: A COMPLEX AND GLOBAL CHALLENGE

Energy one of the most challenging emergencies that humankind is now facing. The challenges arise from the *large number of players*, whose relationships have been evolving at an extremely fast pace, as well as from the *high interconnectedness* of the energy issue with a number of other global challenges such as food, water, the environment, health and security (Figure 1). For example, the delicate relationship between food, water and energy has been widely investigated over the past few years (IRENA, 2015). Also, the stress that conventional energy systems put on the environment, e.g. in terms of carbon dioxide emissions and their now irreversible effect on climate, has been demonstrated (IPCC, 2013). These challenges are all the more daunting as growth of population is not expected to stop for several decades, and no reasonable projection foresees a population of less than 9 billion people by 2050 (Gerland et al., 2014). Population growth might lead to direct scarcity effects on food, water, and energy. Also, feedback loops might appear, especially in developing areas, whereby population growth reduces and already scarce per - capita availability of energy, a reduction that in turn further accelerates the population growth process (DeLong et al., 2010).

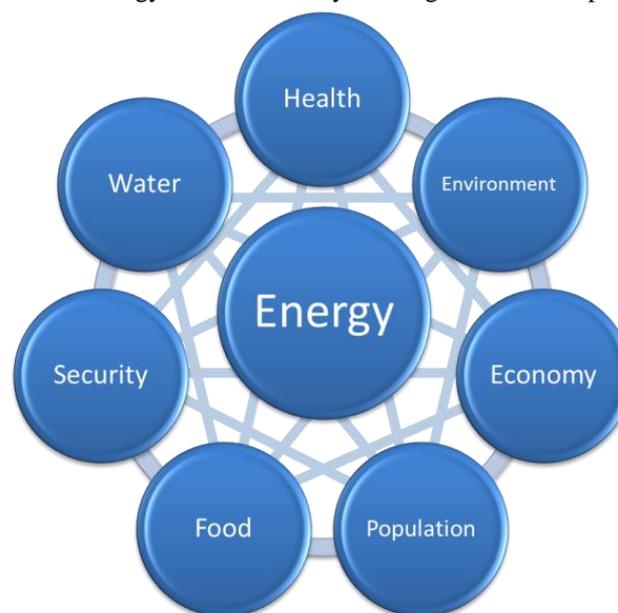


Figure 1. Interconnectedness of global challenges.

Large number of players and high interconnectedness are the key characteristics of complex systems, and complex systems cannot be treated with the classic simple cause - effect approach. An example that well represents the dramatic transition from a “linear” system to a complex one is the shift in the structure of the electrical grid. The typical tree - like infrastructure, with a few centralized power production plants, long - range distribution lines branching towards increasingly smaller users, and a one - directional power flux, is now slowly being replaced by a multiscale network - like infrastructure, characterized by distributed power generation, shorter power lines, two - way power flux, lack of distinction between energy producers and consumers. Transitions like this one are happening throughout the global energy system; the behavior and the control of such systems, complex by definition, need new approaches and new tools.

In this context, the problem of matching energy supply with energy demand is a tremendously difficult one, especially considering the need for appropriateness (e.g. avoiding further stress on the environment and on the food and water systems, avoiding global security unbalance, guaranteeing affordability) and the challenges of an ever - changing demand dynamics.

## 2. ENERGY DEMAND

On the demand side, there are two opposite trends at the global level (Figure 2). In the OECD countries, there is a strong push towards the reduction of energy demand by acting along the entire energy value chain, both by considering efficient energy conversion technologies, and by promoting awareness and technology - based energy - saving solutions for the end user. This has resulted in a marked stagnation of the energy consumption, which initially seemed only due to the economic crisis, but has persisted even upon the return of the economic growth. For example, in 2014, the economy of G20 Countries has grown by 3.5%, while the energy demand only by 0.3%, indicating for the first time the possibility of decoupling the historical link between economy and energy consumption (Enerdata report, 2015). Conversely, BRICS and developing countries strongly rely on energy for sustaining their economic growth, resulting in a marked increase in energy demand. India's demand in particular is growing at an extremely fast pace (6.5% in 2014), while for the first time since the Chinese economic boom, energy consumption in China did not grow in 2014. These two opposite trends in energy demand, with OECD on one side and BRICS and developing Countries on the other side, are expected to continue at least for the next few decades (GEA, 2012).

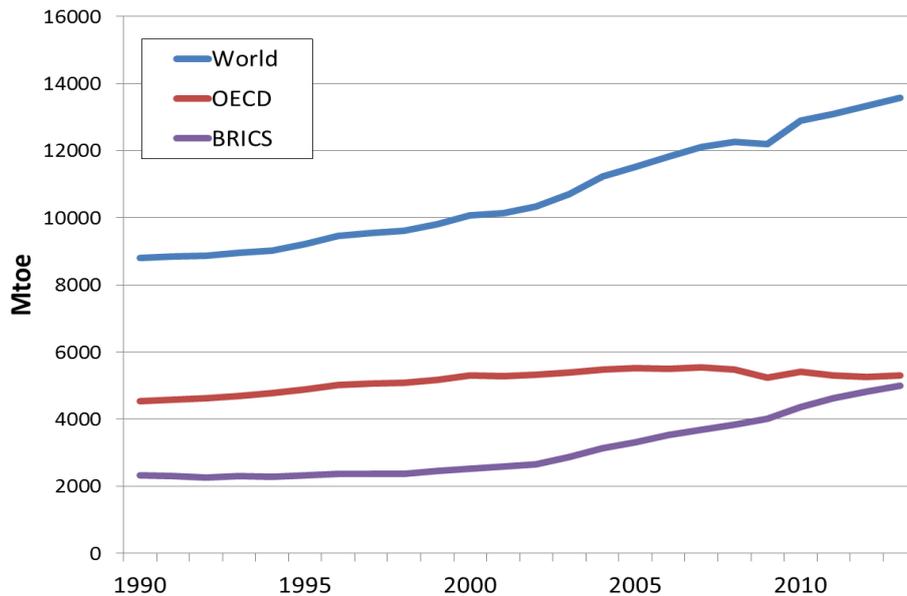


Figure 2. Recent trends of the energy demand in OECD Countries, BRICS Countries, and globally (source: Enerdata, 2014).

The energy supply chain, where primary energy is converted to secondary energy, then transported and distributed, delivered as final energy and used in the form of useful energy, is affected at each step by quite important losses. The total rejected energy (e.g. not utilized) in OECD Countries amounts typically to about 60%. In other words, only about 40% of the total primary energy supplied is converted to services.

Therefore, to reduce the demand for primary energy, one should increase the efficiency of the single steps of the energy supply chain (e.g. increasing the conversion efficiency from primary to secondary energy, reducing the losses of secondary energy distribution, increasing the efficiency in the final energy uses). An important observation is that this strategy becomes more and more effective as the improvement occurs near to the end of the energy supply chain, as benefits are amplified upstream. Another strategy is energy savings; again, this is most effective when the savings occur at the end of the energy supply chain. In other words, end - user efficiency and end - user energy savings can have the strongest impact on the reduction of primary energy demand, with obvious economic benefits but also leading to a much - needed reduction of carbon dioxide emissions. It is estimated that about half of the CO<sub>2</sub> emission cut needed to stabilize CO<sub>2</sub> concentration will have to come from end - user energy savings (Enerdata, 2014).

A growing portion of the slowdown and eventually the stop in energy demand growth in OECD Countries is indeed associated to increasing efficiency throughout the energy value chain as well as a reduced end - user demand thanks to behavioral changes, domotics, and investments.

However, it should also be noted that part of the demand growth reduction and eventually of the demand stall in OECD Countries is associated to the fact that these Countries' economies have shifted to services and high added value manufacturing, moving away from energy - demanding heavy manufacturing. Incidentally, such heavy manufacturing has been externalized to countries where cost of labor is low, including BRICS Countries, contributing to their energy demand growth.

### 3. ENERGY SUPPLY

On the supply side, fossil fuels do have the potential for satisfying the energy demand for at least some decades, although predictions vary broadly, especially in light of the development of extraction technologies for shale gas and more recently for shale oil.

However, a number of considerations suggest that maintaining the *status quo*, e.g. heavily relying on fossil energy resources, is ultimately a poor choice, and that a shift towards a massive use of alternative resources should be pursued regardless of the predicted reserves' lifetime. From a long - term standpoint, this is an obvious observation, as fossil reserves are finite. It might be a matter of decades or even centuries as in the case of coal, but if we keep consuming fossil fuels at the current rates, the readily accessible resources will eventually end or, more likely, extraction will not be "convenient" anymore. It is worth noting that the extraction "convenience" is normally assessed from an economic standpoint, e.g. by comparing the price of an energy unit with the cost of extracting it; this kind of assessment is the obvious one in the short term, however it is quite sensitive to volatile parameters such as the source price, the end - user energy prices, current and local policies, etc., and does not say anything about the true, long - term sustainability of extracting such energy source. A better long - term assessment for the extraction "convenience" should be based on the Energy Return on Energy Invested (EROEI), e.g. the amount of energy that can be extracted by spending one unit of energy. As exploitation of fossil fuel reserves continues, not only the economic convenience, but also the EROEI of fossil sources are expected to dramatically drop over time. The lifetime of fossil resources does remain, however, a complex matter: the inertia of the current system drives exploration for new reserves and better exploitation of the existing ones; on the other hand, there is a push for the reduction of the use of fossil fuels (through displacement by alternative resources, increased energy conversion efficiency, increased energy savings); the combined effect is an extension of the timeframe in which fossil fuels will be available – of course, at increasingly reduced consumption rates.

In the short term, displacement of fossil fuels in favour of alternative resources is necessary for a number of reasons, perhaps the most pressing one being the impact that fossil fuels usage has on carbon dioxide emissions. A drastic reduction of emissions is in fact needed immediately: it has been calculated that a global reduction of Green House Gas (GHG) emissions of approximately 100 MtCO<sub>2</sub>eq per year over the next 15 years is required to stabilize the CO<sub>2</sub> - equivalent concentration and contain global temperature increase to less than 2 °C (Enerdata Global Energy Scenarios, 2015), and approximately 25% of such reductions is expected to come from switching from fossil fuels to alternative resources – while, as mentioned above, about 50% should come from end - user energy savings.

Alternative resources currently contribute to about 21.7% of the global energy demand include all renewable resources as well as nuclear power (REN21, 2015). All have strengths and weaknesses, have an enormous potential, have a much reduced CO<sub>2</sub> footprint with respect to traditional fossil sources, but all pose and face a number of important challenges.

Nuclear power is very controversial as in principle it could contribute to a large portion of the electricity production for a long time (estimates range between several decades to several centuries for the nuclear reserves lifetime, depending of course on the rate of utilization, which in turn depends on future policy), but at the same time it is strongly adversed for a number of reasons. Because of the magnitude of the negative effects of potential accidents, real or perceived, plant design and construction need to match extremely high security standards. Building a nuclear power plant can take today a very long time (in some cases over fifteen years from the idea to an operational plant) because of the very careful review at every step of the process, from the site selection to the building phase itself. In addition, there is a need of properly managing nuclear waste. These needs have led to an increase of the cost of nuclear power over the years (GEA, 2012), essentially annihilating the economic advantage that had characterized this energy source in the past. In summary, although some analysts still foresee an increase in nuclear power production for the next decades, it is unlikely that this source of energy, currently providing 2.6% of the overall energy demand, will be one of the major players - unless radically new technology is developed.

Renewable energy sources (RES) such as hydropower, solar photovoltaics, solar thermal, wind power, biofuels, traditional biomass (currently covering 19.1% of the global demand, a share that has been steadily increasing over the past decades), have the common feature of being constantly regenerated by the Sun in a short timeframe (a major exception is geothermal energy, which is drawn from the Earth's core). This suggests that, in the long term, RES will have to be the major players in the energy system, as Sun's energy is "*the only big number out there*": in a year, the Earth receives from the Sun more than 7000 times the energy we consume. Clearly, a better usage of this free, virtually unlimited, and abundant resource should be pursued.

Renewable energy technologies are currently at the core of the shift from centralized to distributed energy systems, as they lend themselves to small - scale, local installations. However, renewables still have to overcome a number of entry barriers in the very structured and conservative energy infrastructure and market.

RES are by nature intermittent sources, and this has been pointed out as an problem. However, proper management of the electrical grid has already solved what initially seemed insurmountable issues – incidentally, way beyond what was initially thought possible. We are currently reaching the limits of the current infrastructure; a shift towards better grid designs is becoming necessary (e.g. "smart grid", where the network morphology is redesigned to accommodate the new needs, the infrastructure is integrated with a capillary remote monitoring and actuation system), as well as the integration of the grid with storage systems at all scales.

Although the Sun delivers such a large amount of energy, the surface power density is quite low (in the range of 1 kW/m<sup>2</sup>). Large scale photovoltaics have therefore a strong visual and, potentially, a local environmental impact, and for this reason have been quite controversial over the past few years. This is true not only for photovoltaics (PV), but also for essentially all other major RES: wind power, hydropower, biofuels have all been criticized because of their need for large surfaces. In fact, current trends show a shift towards mini - and micro installations of RES, where the installation (be it a PV plant, a wind turbine, a water turbine) is small in terms of size, compatible and oftentimes well integrated within the building or the environment, properly sized in terms of power in order to serve mainly as a local energy provider. The low power density which RES can count on further suggests that RES are best suited as distributed energy sources.

Finally, cost has been often pointed out as an issue, even though it has been constantly decreasing for all RES thanks to both improved technology and economies of scale. The cost of all major RES technologies is today competitive with the price of energy produced by traditional, fossil - based energy technologies. An example of this is photovoltaics, which in a number of Countries has attained the *grid - parity* regime for domestic as well as commercial and industrial (C&I) users: the cost of the kWh produced by domestic or C&I PV plants is less than the price of the kWh acquired on the electric grid (Massi Pavan and Lughi, 2013). Moreover, in some regions the regime of *fuel parity* has been attained, where the cost of the kWh produced by PV equals the cost of energy production from traditional sources.

On a final note, it should be pointed out that both cost and price of any energy source or service are intrinsically controversial, as they are based on a number of assumptions that might be quite different depending on the technology under examination. The Levelized Cost of Energy (LCOE) is currently assumed as the golden standard for comparing the actual cost of different technologies, but even here the correct assumptions are hardly uniquely determined. Moreover, prices and costs are always biased by the presence of subsidies: in 2011, subsidies for fossil fuel technologies have been 523 billion \$, and 88\$ for RES technologies (IEA, 2013).

## CONCLUDING REMARKS

A decisive, unhesitant shift towards renewable energy sources is needed. Although fossil reserves could in principle keep sustaining global economies for a long time, and will still be major players for at least a few decades, a change of course must be undertaken immediately. A drastic reduction of CO<sub>2</sub> emissions cannot be delayed, and focusing on nuclear power would not be of help in this sense, because of the very long time currently needed to build nuclear power plants: it would take several decades to create a supply able to displace significant amounts of CO<sub>2</sub> emissions; moreover, we would get back to the beginning, e.g. to a point where humanity will again be dependent on a finite source – not much of a progress. Transitioning to renewable energy sources will, too, take some time, as all energy transitions do. But at least we will be shifting towards an energy system that is sustainable both in the sense that the resources fueling such system cannot be depleted, and in the sense of environmental sustainability.

It should be noted that all major renewable resources (photovoltaics, wind, hydro) contribute mainly to electric power generation (and so does nuclear power). However, electric energy represents only about one third of the global energy demand, while a large portion of energy consumption and especially of CO<sub>2</sub> emissions is associated to transportation, industrial production, residential and commercial heating. Unless a transition towards electrical energy is promoted in these final energy uses, the contribution to emission abatement of renewable energy will never be more than marginal.

Renewable sources are at the core of a transition from a centralized energy system to a distributed one. Distributed energy systems, where the consumer can also be a producer (concept of prosumer), will have a major impact at the social and economic level. In this sense, renewable energy resources have a “democratic” character, as the source is free (sun, wind, water) and everyone can access it, regardless of status, capital availability, or geographical position. A transition to distributed, renewable based energy systems would most likely reduce or eradicate the causes of most or all the conflicts related to energy issues and control of the energy resources, contributing to global political stabilization

Technology is only one of many factors playing a role in this transition. Renewable technologies are already available and in many cases competitive in terms of cost and performance. At this stage, policy, social factors, market structures are going to be the true key factors to determine the dynamics and the extent of the transition.

Renewable energy is the only choice in the long term, since any solution involving finite resources (fossil fuels, nuclear) can be only temporary by definition. The reserves might well last for a long time, but it is not wise to keep using them at the current rates, even if environmental and political issues had been solved. We are wasting what are ultimately the most precious – as they are the most concentrated – forms of energy, that in the long run should be conserved only for special uses. It is perhaps true that fossil fuels will never end, but this will only happen if we stop using them – certainly not if we keep consuming them at the current rates.

## REFERENCES

- DeLong J.P., Burger O., Hamilton M.J (2010) - Current Demographics Suggest Future Energy Supplies Will Be Inadequate to Slow Human Population Growth. PLoS ONE 5(10), e13206 (2010). Open access from: <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0013206>.
- Enerdata (2014) - Global Energy Statistical Yearbook 2014. Available from <https://yearbook.enerdata.net/>.
- GEA Writing Team (2012) - Global Energy Assessment: toward a Sustainable Future. Cambridge University Press (2012).

Gerland P., Raftery A.E., Ševčíková H., Li N., Gu D., Spoorenberg T., Alkema L., Fosdick B.K., Chunn J., Lalic N., Bay G., Buettner T., Heilig G.K., Wilmoth J. (2014) - World population stabilization unlikely this century. *Science* 346 (6206), 2014, 234 - 237. Published Online September 18 2014.

IEA - International Energy Agency (2013) - Renewable Energy Status Report. 2013.

IPCC - Intergovernmental Panel on Climate Change (2013) - Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker T.F., Qin D., Plattner G. - K., Tignor M., Allen S.K., Boschung J., Nauels A., Xia Y., Bex V., Midgley P.M. [Eds.]). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp. Available for download from <http://www.climatechange2013.org/report/full-report/>.

IRENA (2015) - Renewable energy in the water, energy & food nexus. IRENA - International Renewable Energy Agency Report (2015). Authors: Ferroukhi R., Nagpal D., Lopez - Peña A., Hodges T., Mohtar R.H., Daher B., Mohtar S., Keulertz M., Available for download from [www.irena.org/Publications](http://www.irena.org/Publications).

Massi Pavan A. and Lughi V. (2013) - Grid parity in the Italian commercial and industrial electricity market. *Clean Electrical Power (ICCEP)*, 2013 International Conference on Clean Energy Power, 332 - 335.

REN21 (2015) - Renewables 2015 Global Status Report. Paris: REN21 Secretariat.



## **Status and perspectives of geothermal technologies**

## Geothermal District Heating in Europe: Market, Potential and Framework Conditions

ANGELINO Luca<sup>1</sup>

<sup>1</sup> EGEC - European Geothermal Energy Council, Brussels, Belgium

Corresponding author's e-mail: [Langelino@egec.org](mailto:Langelino@egec.org)

**Keywords:** geothermal, heat, European union, renewable energy, policy, market development, financing.

### ABSTRACT

Most of the heat we use in Europe originates from burning fossil fuels - that means greenhouse gas emissions, pollution, volatile prices, and expensive fuel imports. It is unsustainable and we urgently need to find clean alternatives - that means renewable energy such as geothermal, the energy stored in the form of heat beneath the surface of solid earth.

More than two thirds of Europe's population live in cities and towns, and geothermal district heating is particularly a good solution in this case as it can provide stable, sustainable, secure, renewable, and carbon neutral heating, cooling and hot water to homes, businesses, and manufacturers, as well as municipal buildings such as hospitals and schools.

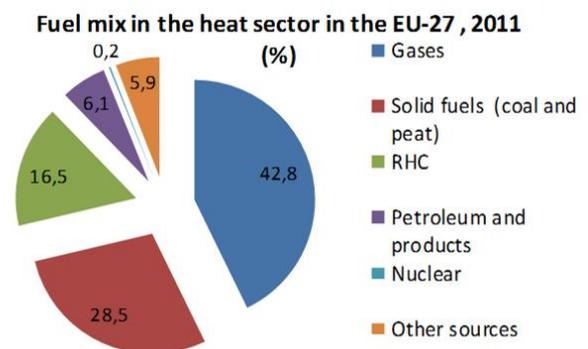
Geothermal district heating is indeed the geothermal segment with the most dynamic development and the most interesting perspective in the coming years. Eight new systems have been installed in five European countries in 2013, increasing the installed capacity to more than 4.3 GW<sub>(th)</sub>, with nearly 13 TWh<sub>(th)</sub>/yr used for heating. Furthermore, the GeoDH project has estimated that over 25% of the EU population lives in areas suitable to geothermal district heating.

However, comparing the actual geothermal production with the projections in the National Renewable Energy Action Plans, it is easy to note how we are lagging behind the expected trajectory. Against this background, the regulatory and financial framework remains crucial to facilitate the further market uptake of this technology. Most of the findings of this paper stem from the work undertaken within the EU co - funded project GeoDH "Promoting Geothermal District Heating Systems in Europe".

### 1. INTRODUCTION: FUEL MIX IN THE HEAT SECTOR, SECURITY OF SUPPLY AND THE ROLE OF RENEWABLES

In 2012, heat represented some 46% of the gross final energy consumption in the European Union [EU - 28, including Croatia] (Eurostat, 2013). Most of this energy was generated by burning fossil fuels. To highlight this dominance, the Figure 1 shows the distribution of fuels that contributed to the gross heat generation in EU - 27 in 2011, according to which 42.8% of this heat was generated by gases, 28.5% by solid fuels, 16.5% by renewables (90% of which from biomass), and 6.1% by petroleum and products (European Commission, 2013a)<sup>20</sup>.

*Figure 1. Fuel mix in the heat sector in the EU - 27, 2011 (percentage). EU Energy in figures, Statistical Pocketbook 2013.*



Today's fossil fuel dominated energy supply for heating is unsustainable from the economic, environmental and social point of views. With the Ukraine crisis and the destabilization of EU - Russian relations, decision - makers and citizens are reminded of the EU's vulnerability in terms of energy supply. The analysis below shows the implications of the current fuels mix in terms of security of supply and trade of balance, as well as the potential benefits of switching from fossil fuels to renewables in the heat sector.

About one third of the EU's total crude oil (34.5%) and natural gas (31.5%) imports in 2010 originated from Russia. The EU energy dependency contributed not only to weaken the EU geopolitical influence on the international arena but fuelled the dramatic GDP - leakage with the EU spending 545 billion € or 4.2% of its GDP on importing fossil fuels in 2012 alone (European Commission, 2014a).

Security of energy supply was the main driver of the EU's energy policy in the mid - 1990s in the move towards renewable energy. This concern has further increased over recent years as domestic conventional gas production in EU Member States, mainly originating from mature production basins, has decreased by 25% over the last decade. In the same period, the overall EU gas consumption has increased by 10% (European Commission, 2013b). As shown in Figure 2, the result has been a

<sup>20</sup> The share of renewable differs slightly from the official reported share of renewable energy on heating and cooling due to statistical definitions.

steadily increasing dependency rate for natural gas from 47.1% in 2001 to 65.8% in 2012. Without additional measures, imports will continue to rise dramatically.

### Natural gas dependency rate, EU-28, 2001-2012 (%)

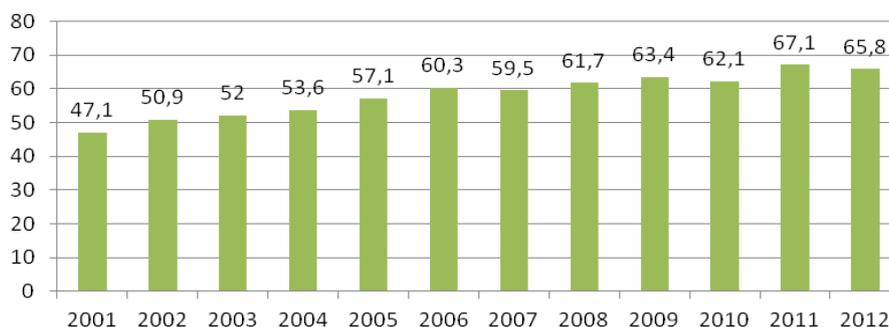


Figure 2. Natural gas dependency rate, EU - 28, 2001 - 2012 (percentage). source: EUROSTAT.

A very significant part of this imported fuel is used for heating purposes. Indeed, natural gas is mainly being used in the following sectors: 41% for heating of buildings, 31% for industrial processes, and only to a lesser extent in power plants (25%) (Eurogas, 2013).

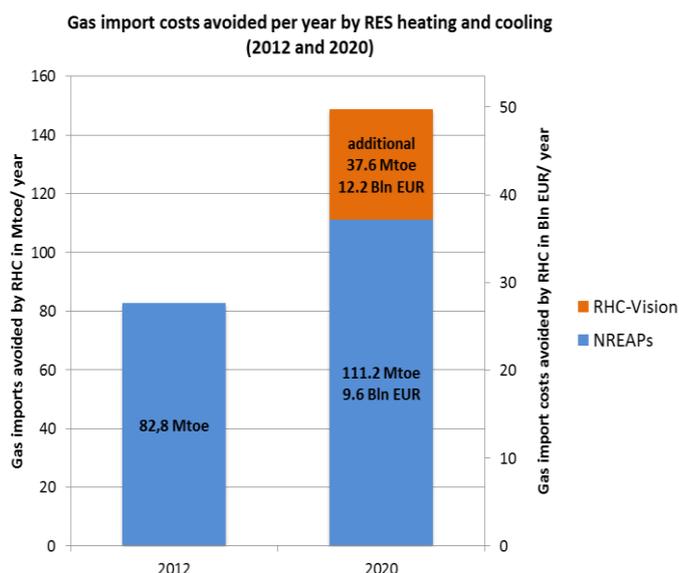
As security of supply of natural gas becomes increasingly critical, the only secure way to reduce import dependency in the heating sector is, together with energy efficiency, to further accelerate the deployment of renewable energy for heating and cooling.

In 2012, the consumption of heating from renewable energy in the EU amounted to 82.8 MTOE (Figure 3). According to the National Renewable Energy Action Plans (NREAPs), in 2020 renewables will make a total contribution of 111.2 MTOE, or 21.4% of the total heat consumption projected for that year. Assuming this additional renewable energy consumption substituted imported natural gas, the EU would reduce its fossil fuel imports from third countries by the equivalent of 28.7 MTOE annually from 2020. With current average import prices (\$ 11.5/MMBtu or € 8.4/MMBtu)<sup>21</sup>, this would save the EU some 9.6 billion €.

However, it is worth highlighting that with clear enabling policies it could be possible to generate 148 MTOE from renewable heating and cooling technologies (Sanner et al., 2011). By the end of this decade the EU could therefore produce some additional 65 MTOE from RHC compared to 2012. By applying the same assumptions as above, the EU could save every year as much as 21.8 billion € in reduced fossil fuel imports compared to 2012.

The results of the NREAPs and RHC Common Vision scenarios are depicted in the figure overleaf: The evidence is overwhelming: Renewables for heating and cooling, together with energy efficiency, stand out as a key factor to ensure security of energy supply, reducing foreign energy dependency.

Figure 3. Gas import costs avoided per year by renewables for heating and cooling (2012 and 2020).



## 2. MARKET DEVELOPMENT OF GEOTHERMAL FOR DISTRICT HEATING

One of the technologies that can contribute to reducing imports of fossil fuels, thereby stabilizing energy costs and decarbonizing the heat sector is geothermal for district heating (GeoDH). The development of deep geothermal resources for district heating is becoming increasingly popular as local authorities look for ways to make their energy supplies local, competitive and reliable.

<sup>21</sup> In January 2014, according to the World Bank.

District Heating is the geothermal segment currently with the most dynamic development and the most interesting perspective in the coming years. The renewed momentum observed since 2009 continues, with five countries installing new Geothermal DH systems in the past year. The technology is developing: in 2013, smaller systems, targeting shallower resources and assisted by large heat pump systems, have been installed. In France, more triplet systems have been installed (Dumas et al., 2013).

In 2013 there were 237 GeoDH plants (including cogeneration systems) in Europe representing a total installed capacity of more than 4.3 GW<sub>(th)</sub>, with nearly 13 TWh<sub>(th)</sub>/yr or 1107 kTOE in 2012<sup>22</sup>. 184 geothermal DH plants are located in the European Union. The total installed capacity in the EU - 28 now amounts to around 1.1 GW<sub>(th)</sub>, producing some 4256 GWh of thermal power, e.g. 366 kTOE in 2012.

According to the 201 planned projects, (including the upgrading of existing plants), capacity is estimated to grow from 4349 MW<sub>(th)</sub> installed in 2013 to at least 6500 MW<sub>(th)</sub> in 2016 - 17.

In 2013, the main GeoDH markets are still in France (41 systems), Iceland (32), Germany (25) and Hungary (19). The hot markets are also mainly in Germany (69 new systems being developed or upgraded), France (27), Hungary (16) and Denmark (12). As shown in Figure 4, Germany is therefore likely to become the EU leader in terms of number of GeoDH systems in operation by the end of this decade.

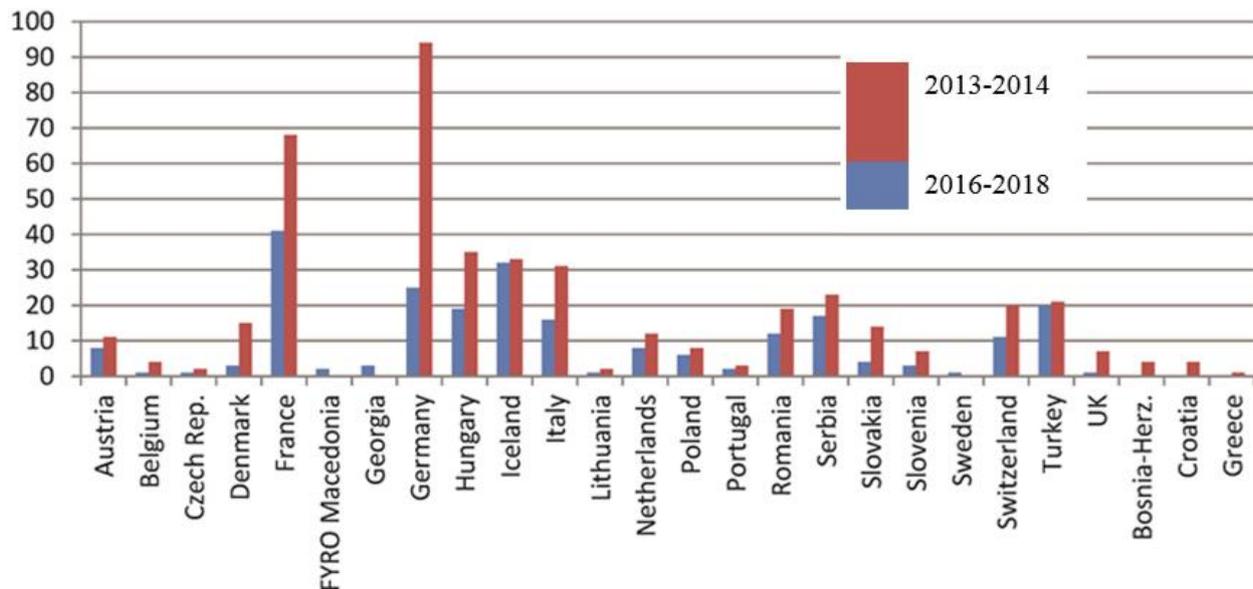


Figure 4. Number of geothermal district heating plants in operation and under development in Europe.

It is of interest to highlight the situation in Hungary, a country with a long tradition in geothermal District Heating, which now sees new development: three new GeoDH systems have been inaugurated in 2013. The high ambition exemplified by the Hungarian NREAP (For Deep Geothermal heating & cooling systems, Hungarian authorities forecast a growth from 101 kTOE in 2010 to 357 kTOE by 2020) is illustrated with the 16 new GeoDH projects being commissioned. One important new actor in the direct use / GeoDH market is The Netherlands where eight deep geothermal systems, mainly for greenhouses and surrounding buildings, have been installed recently, and where three more are planned to be online in the next years.

It is also worth mentioning that CHP helps geothermal to become more economically attractive by recovering waste heat for heating and cooling purposes. Until now, only a few combined heat and power geothermal plants supplied District Heating systems, but this situation is rapidly changing. As a matter of fact, EGS (CHP) provides more opportunities for GeoDH systems. In conclusion, it can be stated that 26 European countries (21 of which are EU Member States) show deep geothermal activity, evidence that geothermal can be developed almost anywhere in Europe.

### 3. PERSPECTIVE AND POTENTIAL FOR GEOTHERMAL DISTRICT HEATING

Figure 5 below shows the deployment projection for deep geothermal heat until 2020 as stated in the NREAPs compared to the actual production in 2012 presented in the EGEN Market Report 2013 - 2014. It is easy to note how already in 2012 several member states are lagging behind the expected trajectory.

<sup>22</sup>Excluding production in Turkey and Slovakia for which reliable data was not available.

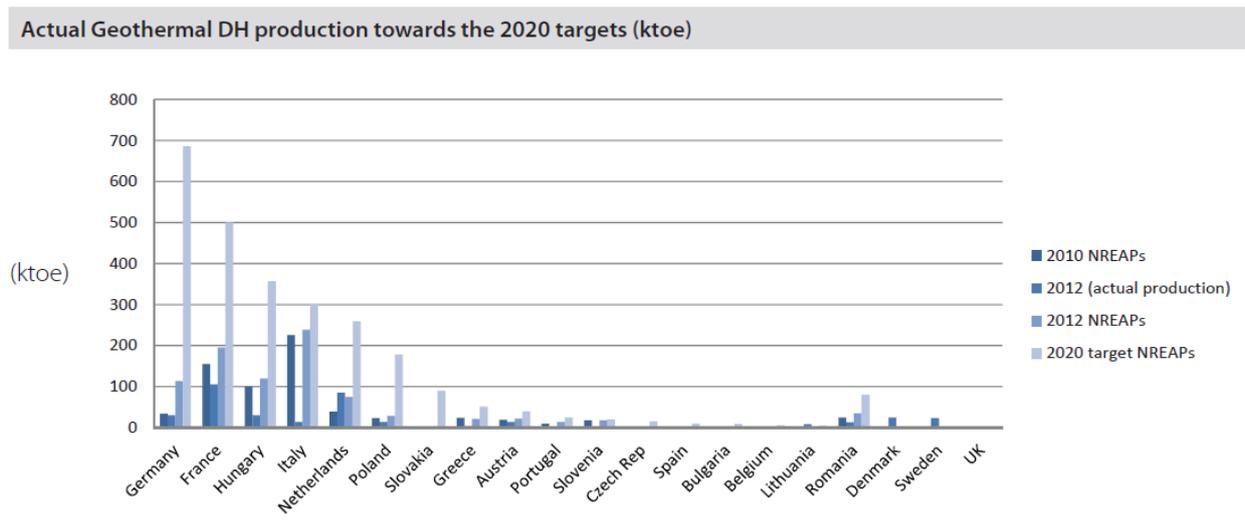


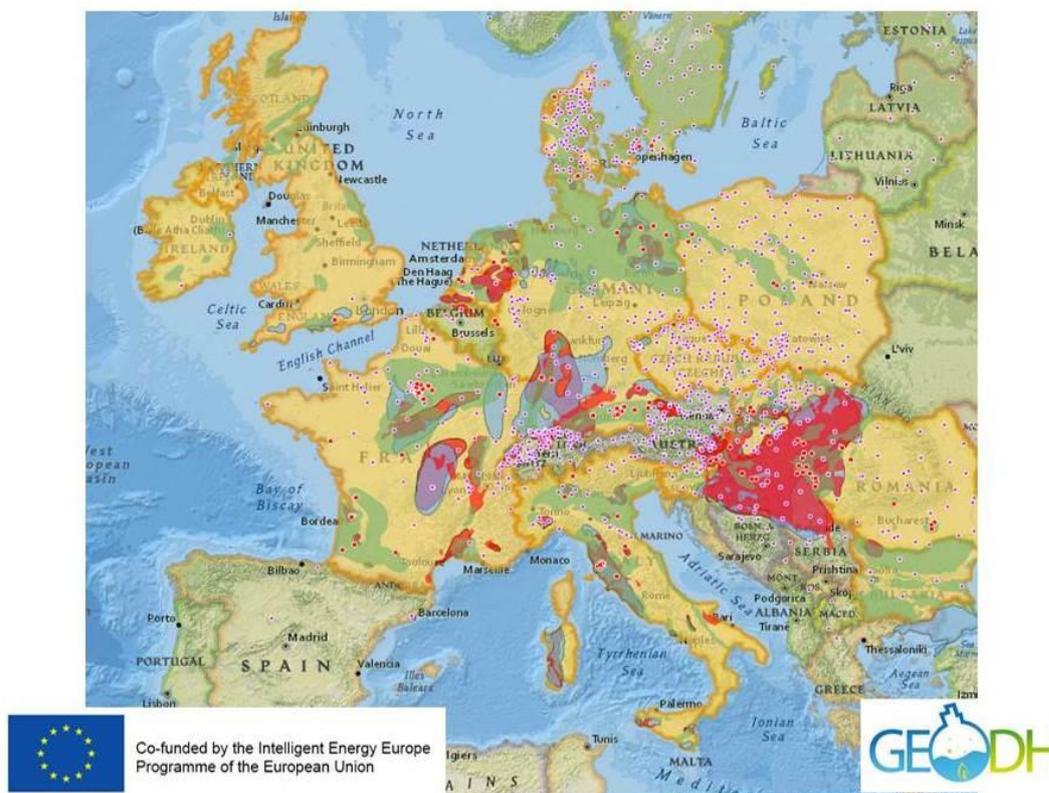
Figure 5. Actual Geothermal DH production towards the 2020 targets (kTOE, 2012).

Indeed, based on Europe’s geothermal potential, geothermal energy could contribute much more significantly to the decarbonisation of the DH sector. A considerable expansion of the district heating sector is expected in the EU28 until 2050; indeed, the GeoDH project has found that geothermal heat through future district heating systems could be available for 26% of the population. Around 20% of the EU population are located in regions where the temperature at 2000 m deep is higher than 60 °C, so are directly suitable for geothermal heating and cooling exploitation. In this context, it is crucial to target areas with urban density to ensure the economic sustainability of the project.

The GeoDH project, supported by the EU through the Intelligent Energy Europe programme and coordinated by EGEC, has provided an interactive web - map viewer that shows areas in 14 EU member states with good geothermal potential for district heating.

The web - map (Figure 6) indicates the existing DH systems, including GeoDH systems, in Europe. Moreover, regions with temperature distribution higher than 50 °C at 1000 m deep and higher than 90 °C at 2000 m deep can be visualized. Finally, the online tool provides information on the areas with potential for GeoDH and the heat - flow density.

Figure 6. Existing DH systems and GeoDH potential (with current information available) in selected 14 EU countries.



From the map, it is possible to note that:

- new GeoDH systems can be built in many regions of Europe at competitive costs;
- the potential for GeoDH development by 2020 is much higher than the forecasts of Member States in their NREAPs (Geothermal can be installed with existing DH systems during extension or renovation, replacing fossil fuels);
- the Paris and Munich basins are the two main regions today in terms of number of GeoDH systems in operation;
- the Pannonian basin is of particular interest when looking at potential development in its Central and Eastern Europe countries;
- in southern Europe, the option of District Cooling should be considered;
- the enthalpy (temperature) is not the only selection criteria; other key factors are heat flow on the supply side, and the heat users (urban density) on the demand side.

#### 4. FRAMEWORK CONDITIONS: KEY TO ENABLE GROWTH

Despite the significant potential of deep geothermal energy in several European countries, geothermal DH systems have been poorly developed so far. Four key areas have been identified as important to improve this situation:

- national and regional policies concerning district heating and geothermal district heating systems;
- the removal of regulatory barriers, and simplified procedures for operators and policy makers;
- the development of innovative financial models for GeoDH projects, which are capital intensive;
- the training of technicians and decision - makers of regional and local authorities in order to provide the technical background necessary to approve and support projects.

In addition, it is important that a **level playing field** is established. Fair competition would be established with system costs and externalities integrated in the full costs of each energy technology. Externalities are notably emissions of GHG such as Carbon dioxide (CO<sub>2</sub>), Sulphur dioxide (SO<sub>2</sub>) and Nitrogen Dioxide (NO<sub>2</sub>), but also subsidies to fossil fuels and nuclear, electricity and gas regulated prices. Ideally, also the security of energy supply should be taken into account.

The GeoDH project has worked on these issues, involving several stakeholders including:

- **policy and decision makers of national authorities** to be aware about the potential of this technology,
- **decision makers from municipal and local authorities and energy authorities** to have a better regulatory framework and simplify the procedures at local level,
- banks, potential investors and other market players to stimulate investment in the sector.

##### 4.1 Regulatory framework

Developing a geothermal project requires several authorizations and the compliance with a number of national and local regulations; for project developers, regulatory barriers can result in additional costs. It is therefore crucial that a fair, transparent and not too burdensome regulatory framework for geothermal is in place. The GeoDH consortium has particularly worked on regulatory issues (GeoDH, 2014).

Barriers against geothermal district heating can result from:

- poor national, regional, and local strategies and lack of support for renewable and efficient heating and cooling technologies;
- lack of understanding, data and reliable information;
- uncertainty over resource ownership, and for difficult procedures for obtaining exploration and development rights. In many countries, however, these issues have been solved in a satisfactory way;
- very complex administrative procedures or, in certain cases, lack of a regulatory framework;
- inappropriate environmental regulations - these regulations should both protect the environment and not hamper project development;
- regulated prices for gas/other fossil fuels for heating purposes;
- Public acceptance problems, which must be taken seriously and solved, even if this is not legally required.

From the above listed issues, some such as the definition of geothermal energy, geothermal resource ownership and protection of the resource against other uses/users, licensing, and environmental regulations are presented below in more detail.

##### Definition of geothermal energy

The lack of a common definition of geothermal energy, which was an EU - wide problem for many years, has been solved by the RES European Directive (2009/28/EC), with a binding definition provided in Article 2: “**geothermal energy**” means **energy stored in the form of heat beneath the surface of solid earth.**

### Geothermal resource ownership and protection of the resource against other uses/users

A clear title for geothermal resource exploitation rights over a sufficient period is crucial. No licenses for other uses/users that would jeopardize the resource should be granted and a certain distance (or other protection) must be kept for other uses.

Who actually owns the geothermal resource? The options are the following:

- The state / the crown:
  - could be stipulated e.g. in mining law or in mineral resources law,
  - a good option if licensing is regulated properly,
  - more difficult if included in water legislation.
- The owner of the ground on surface:
  - may result in a problematic situation where for a larger project multiple owners are concerned,
  - for deep geothermal project, this is very time consuming.
- Not regulated: It is considered as a worst case, because deep geothermal projects are almost impossible.

In case of the ownership being with the state, the following items are crucial for geothermal development:

- who can apply for a license (non - discriminatory process),
- one - or two - step - process (exploration, development),
- time period for which a license can be obtained, possible prolongations,
- royalties (based upon what parameter? fixed or as a percentage of production?),
- time for obtaining a license.

### Licensing

The main requirements / permits that may be required for a geothermal district heating project development are the following:

- water, mineral, and mining rights,
- exploration permits,
- well construction permit,
- development rights,
- payment of royalties,
- environmental impact assessment (EIA),
- building permit for the plant/distribution network,
- dismantling permit,
- environmental permit.

It is worth highlighting that complex and very long administrative procedures can result in additional and superfluous costs, which can cause a loss of willingness to invest. In line with Article 13 of Directive 2009/28/EC, it is highly recommended that the permit/licensing procedures for exploration and development of geothermal energy should be streamlined:

- by transferring the licensing procedures to the competences of regional administrations;
- by introducing a single licensing system (one stop shop);
- the geothermal licensing procedures and the issuing of licenses should be handled by a single dedicated regional authority; the sharing of responsibilities on these matters among various authorities should be avoided since this produces unfavourable effects on projects;
- the administrative process for the granting of licenses for deep geothermal for DH should be reduced and the time scale should not exceed 6–12 months;
- the duration of a geothermal exploration permit/license should not exceed 6 years;
- deep geothermal energy/water exploitation permits/licenses should be granted for a fixed duration of a minimum of 20–25 years with the possibility of extension to 50 years;
- for the district network, the local municipality should play a leading role as the planning authority carrying out the process of public procurement for (geo)DH systems on their territories and/or approving practical projects;
- the supply of energy to DH networks should be subject to an approval regime based on a socio-economic assessment comparing various alternative sources for heat supply, giving priority to locally accessible renewable energy sources.

### Environmental regulations

The state has a duty to provide regulations protecting the environment or other public interests from possible negative consequences of geothermal energy production.

The following rules should be adhered to:

- a viable equilibrium has to be found between regulations that might have not the necessary protective effect, and those that might prevent geothermal development,
- full Environmental Impact Assessment (EIA) procedures are required only for large projects with considerable risk potential,
- EIA screening, which is useful for a preliminary understanding about the possible impact of the project, is different to the EIA procedure and it has to entail a lower bureaucratic burden,
- keep environmental regulations focused on the protection of ground, groundwater, and surface from possible harm caused by the geothermal plant, and do not address unrelated issues!

Regarding the protection of water, Article 11 of EU Directive 2000/60/EC (Water Framework Directive) gives member states the option to authorize the reinjection into the same aquifer used for geothermal purposes. It is therefore within the competence of the national governments to decide as to whether reinjection of the geothermal fluids is required.

The list of barriers resulting from environmental regulations can be rather long. There will be cases, of course, where environmental issues make a project impossible. However, this should be limited to as few cases as possible, and be known as early as possible.

Negative example:

Drilling and safety regulations for hydrocarbon exploitation are imposed on geothermal drilling.

### Spatial Planning Regulation

Local authorities are obliged to draft plans for spatial planning in their region, based on a national Spatial Planning Act. According to this legislation, member states may have the possibility to establish a requirement for connection to a DHC network, when new buildings are erected in an area.

There should be a clear policy at the level of the local authority dealing with DHC, in order to facilitate and safeguard investments. Aspects that need to be safeguarded are the tariffs for heating and cooling for customers and possible infringement procedures in case of non-compliance with energy market rules.

In order to remove these barriers, and in collaboration with local authorities and private bodies involved in District heating, the GeoDH project put forward some key recommendations for the regulation of Geothermal District Heating in Europe (GeoDH, 2014).

- National and local rules must include a definition of geothermal energy resources and related terms, in line with Directive 2009/28/EC,
- Ownership rights should be guaranteed,
- Administrative procedures for geothermal licensing have to be fit to purpose,
- The rules concerning the authorization and licensing procedures must be proportionate and simplified, and transferred to regional or administration level - the administrative process must be reduced,
- Rules for district heating (DH) should be as decentralized as possible in order to be adaptable to the local context, and stipulate a mandatory minimum level of energy from renewable sources, in line with Article 13 §3 of Directive 2009/28/EC,
- A unique geothermal licensing authority should be set up,
- Information on geothermal resources suitable for GeoDH systems should be available and easily accessible,
- GeoDH should be included in national, regional and local energy planning and strategies,
- Policy-makers and civil servants should be well informed about geothermal,
- Technicians and Energy Service Companies should be trained in geothermal technologies,
- The public should be informed and consulted about Geothermal DH project development in order to support public acceptance,
- Geothermal energy should be given priority in legislation over other uses such as for unconventional fossil fuels, CCS, and nuclear waste deposits.

## 4.2 Financial framework

A geothermal DH project is based on the estimated geothermal heat that can be generated from the reservoir and an analysis of the heat demand. The estimation of costs and revenue streams are specific to each individual project.

In a Geothermal District Heating project, both risk and capital expenditure are concentrated in the early phases of a project; the existence and quality of the geothermal resource can only be proven after the initial drilling has been completed. As the project progresses, both the risk and investment curves shallow, although the long term risk of the resource depleting over time remains.

The specific risk profile and concentrated need for capital (Figure 7), compounded by a general lack of awareness and understanding, are challenges for financing GeoDH projects. The estimations of cost and resource will improve with increased development of GeoDH, but projects will always involve some risks. Because of this, specific financial tools, particularly a risk mitigation fund is needed are required.

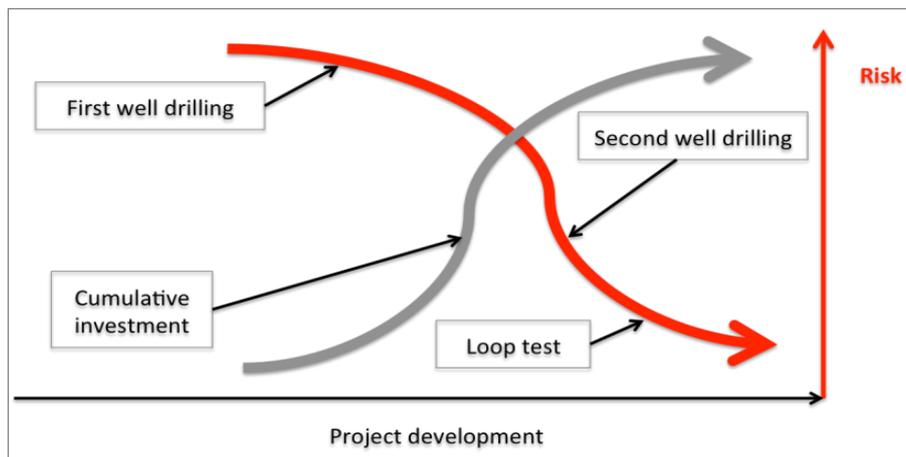


Figure 7. Risk management for a geothermal DH project and capital investment.

In the geothermal heating sector, there is a predominance of investment grants, in certain cases accompanied with or substituted by zero interest loans. Operational aid similar to a feed - in tariff system is now beginning to be explored in some Member States, partly because of the inclusion of the sector into the European regulatory framework and therefore its relevance in achieving the 20% RES target.

Compared with the amount of subsidies across the power sector, public intervention for geothermal has been negligible. The need for more public support stems from the fact that in several cases market conditions in the EU heat sector prevent geothermal from fully competing with conventional technologies developed historically under protected, monopolistic market structures where costs reduction and risks were borne by consumers rather than by plant suppliers and operators.

The primary objective of financial incentive schemes is indeed to compensate for market failures. They are also intended to favour the deployment of a given technology by creating a secure investment environment catalyzing an initial round of investment and thereby allowing the technology to progress along its learning curve. Hence, support schemes should be temporary and can be phased out as this technology reaches full competitiveness in a (then) complete and open internal market where a level playing field is fully established.

Support measures for geothermal technologies are therefore needed in some cases to favour the progress towards cost - competitiveness of a key source in the future European energy mix and to compensate for current market - failures.

## 5. CONCLUSIONS

In this paper, it was observed how most of the heat we use in Europe originates from burning fossil fuels - contributing not only to greenhouse gas emissions, pollution, and volatile prices, but also to a dramatic GDP - leakage. Renewable energy such as geothermal can contribute to more sustainable and stable heat supply in Europe, thereby contributing to reduce costly fuel imports.

Geothermal district heating is particularly a good solution in this case. This is indeed the geothermal segment with the most dynamic development and the most interesting perspective in the coming years. As estimated by the GeoDH project, over 25% of the EU population lives in areas suitable to geothermal district heating.

Against this background, it was argued that that the regulatory and financial framework in place across Europe is very often not favourable to this technology. For this reason, the GeoDH project has put forward a number of proposals in terms of regulatory framework, business models, and support schemes that can enable the further market uptake of geothermal in Europe.

## REFERENCES

- Dumas P., Angelino L., Boissavy C. (2013) - Analysis of Geothermal District Heating Market in Europe, EGEC Market Report 2013 - 2014. European Geothermal Energy Council, Brussels.
- Eurogas Statistical Report 2013 (2013), Brussels.
- European Commission (2013) - EU energy in figures - Statistical pocketbook 2013. Luxembourg: Publications Office of the European Union.
- European Commission (2014a) - Member States' Energy Dependence: An Indicator - Based Assessment. Occasional Papers 145, April 2013.

European Commission (2014b) - Energy Economic Developments in Europe. European Economy 1/2014.

Eurostat (2013) - Shares 2012 results. Available on line:  
[http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/other\\_documents](http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/other_documents)

GeoDH (2014): GeoDH Final Report. Brussels. Available online: <http://geodh.eu/library>

Sanner B., Kalf R., Land A., Mutka K., Papillon P., Stryi - Hipp G., Weiss W. (2011) - 2020 - 2030 - 2050. Common Vision for the Renewable Heating and Cooling Sector in Europe. European Technology Platform on Renewable Heating and Cooling. Luxembourg: Publications Office of the European Union.

## Recent Achievements in Geothermal Technology

UNGEMACH Pierre<sup>1</sup>

<sup>1</sup> GPC IP - Gpc Instrumentation - Process, Paris Nord 2 - Roissy CDG Cedex, France

Corresponding author's e-mail: [pierre.ungemach@geoproduction.fr](mailto:pierre.ungemach@geoproduction.fr)

**Keywords:** EGC - Enhanced Geothermal System, geothermal reservoir technology, exploration - production, power generation.

### ABSTRACT

The ambitious development goals set by the geothermal community for projected geopower and geoheat capacities in year 2050, 140 GW<sub>(e)</sub> (including engineered geothermal systems – EGS) and 800 GW<sub>(th)</sub> respectively, act as a strong stimulus for technological innovation.

In this perspective, the present paper focuses on key segments aimed at (i) improving drilling success ratios, (ii) reclaiming, cogeneration eligible, medium enthalpy sources, (iii) upgrading well performance and longevities, and (iv) securing sustainable reservoir management.

Accordingly, the following key issues are addressed:

- structural geomodelling of complex reservoir,
- 3D seismic assisted well targeting,
- novel well architectures (sub horizontal, multileg, corrosion/scaling resistant wellbore designs),
- high temperature/high flow/deep seated pumping equipment,
- downhole chemical inhibition and production control lines,
- high temperature steering and logging while drilling equipment,

The seismic risk induced by water injection in sensitive, tectonically active, reservoir environments will be also discussed.

### 1. INTRODUCTION

Power generation from indigenous geothermal sources was initiated in 1904, hardly fifty years later than Colonel Drake's emblematic oil discovery in Pennsylvania. Direct uses reported historically since Roman times date back to the origins of human societies.

In June 2008, at Soultz - sous - Forêts, it was inaugurated the first European plant producing electricity from a 5000 m deep engineered geothermal reservoir, the so - called EGS (Enhanced Geothermal System) concept of heat extraction. As of late 2013, the geothermal community scored a 12 000 MW<sub>(el)</sub> geopower capacity installed worldwide of which 1300 MW<sub>(el)</sub> located in Europe at large (including Iceland and Turkey). Figures assessed from authorized energy institutional sources have estimated, on the bases of present reserve assessment standards and current power conversion processes, the geothermal potential recoverable worldwide and in Europe at ca. 140 000 and 10 000 MW<sub>(el)</sub> respectively.

Last but not least, reclamation of the geothermal energy stored as heat over Continental Europe, to a depth of 5 km at temperatures above 150 °C, would yield a 25 000 MW<sub>(el)</sub> generating capacity. The ambitious development goals set by the geothermal community for projected geopower and geoheat capacities in year 2050, 140 GW<sub>(el)</sub> (including engineered geothermal systems) and 800 GW<sub>(th)</sub> respectively, act as a strong stimulus for resource development and technological innovation.

In this perspective, efforts focus on key segments aimed at (i) improving drilling success ratios, (ii) reclaiming conventional hydrothermal and frontier EGS targets, cogeneration eligible, medium enthalpy sources, (iii) upgrading well performance and longevities, and (iv) securing sustainable reservoir management.

The EGS problematic and the seismic risk induced by water injection in sensitive, tectonically active, reservoir environments will be also discussed.

### 2. RESOURCE NOMENCLATURE

It is best structured according to source temperatures and governing heat transfer processes in relation to geothermal environments, eligible/candidate power conversion processes and medium (“*continuum*”), natural or/and induced, porosity/permeability patterns illustrated in Figure 1 (utilization potential) and Figure 2 (EGS issues).

Those suggest the following.

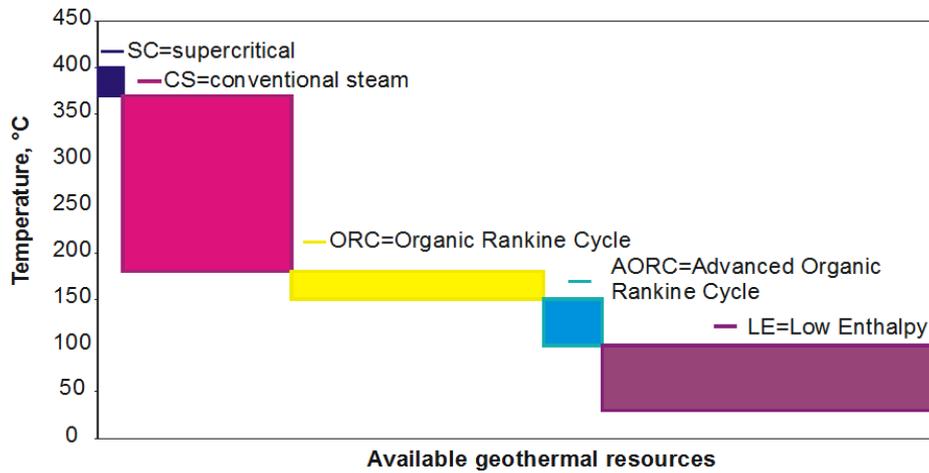


Figure 1. Geothermal resource utilization potential. A tentative assessment.

### 2.1 Natural hydrothermal geothermal reservoirs

High enthalpy settings, standing in the 180 - 380 °C range, eligible to direct steam expansion (superheated, “dry”, vapor) and flashed steam (two phase, pressurized liquid states) cycles, which actually achieve the widely dominant electricity generating share, represent only but a minor fraction of the overall power development potential.

As a matter of fact, most of it addresses the medium enthalpy, 90 - 180 °C segment, of much larger occurrence World and particular Europe wide, and, binary ORC (Organic Rankine Cycle) conversion processes, presently poorly developed respective to the huge resource potential.

Such deposits, to be commercially viable, require adequate combined heat and power (CHP) schemes, notwithstanding economic incentives (Feed in Tariffs, FIT), preferably operated as base loads and either grid connected or locally distributed power.

### 2.2 Engineered geothermal (EGS) reservoirs

Commercial development of geothermal sources requires convective heat transfer, e.g. rock hydraulic conductivity/permeability, itself dependant on connected porosity.

The basic rationale behind the EGS concept consists precisely of creating/accommodating such a porosity/permeability network capable of sustaining the target productivity/lifetime requirements, thus dramatically upgrading the pre - existing rock volumetric connectivity and the candidate geopotential accordingly.

Predominantly conductive and mid - grade EGS settings deal with either crystalline basement or tight sedimentary rock environments, addressing site - specific stimulation protocols, exclusive of any hydro fracturing whatsoever due to the induced seismicity risk.

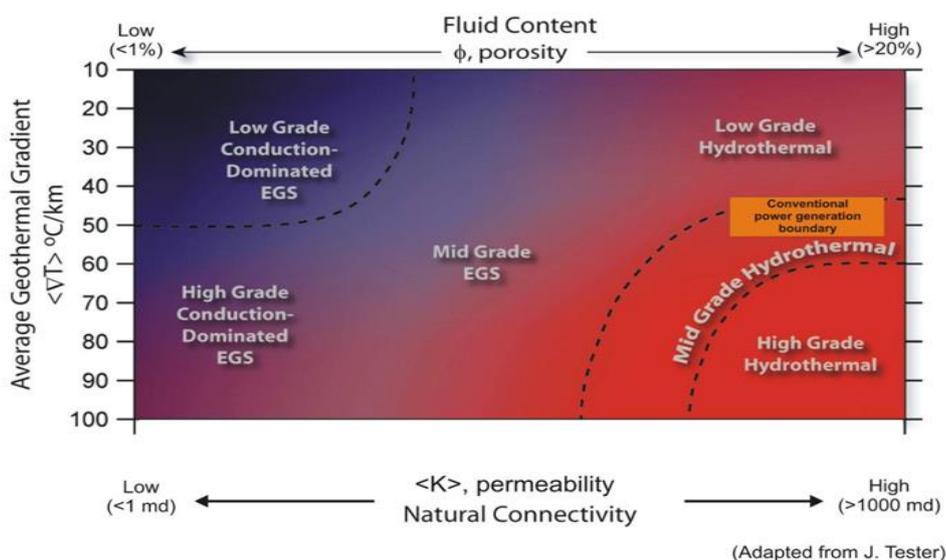


Figure 2. The geothermal continuum and the EGS issue.

### 3. TECHNOLOGY INSIGHT

#### 3.1 Exploration

Integrated approaches combining geological, geophysical and geochemical surveys have become the rule among geothermal explorationists (according to the reservoir engineering rationale highlighted in Figure 3). Noteworthy is the increasing contribution of magneto - telluric (MT), (volcano tectonic settings), 3D reflection seismics (sedimentary environments) and 2D/3D parameter inversion algorithms in assessing reservoir conceptual models and spotting drilling targets.

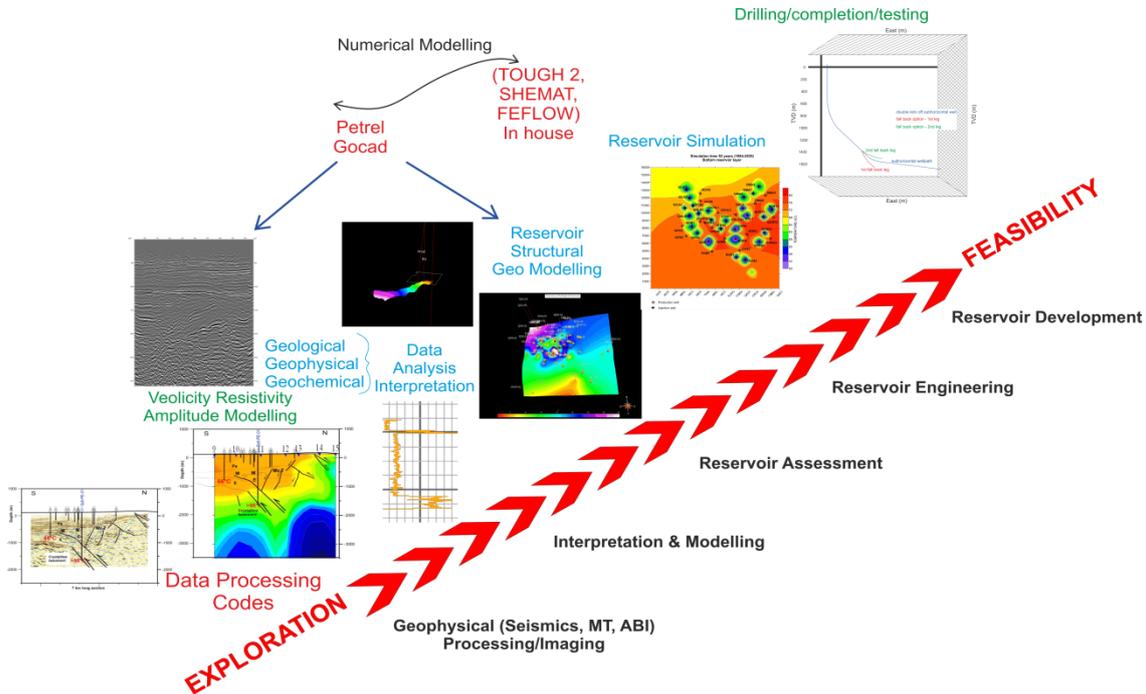


Figure 3. An integrated reservoir engineering approach.

As a result, 3D modelling of complex reservoir structures is becoming a standardized reservoir assessment and well targeting tool, as exemplified in Figure 4 and Figure 5.

#### 3D REGIONAL GEOLOGICAL MODEL

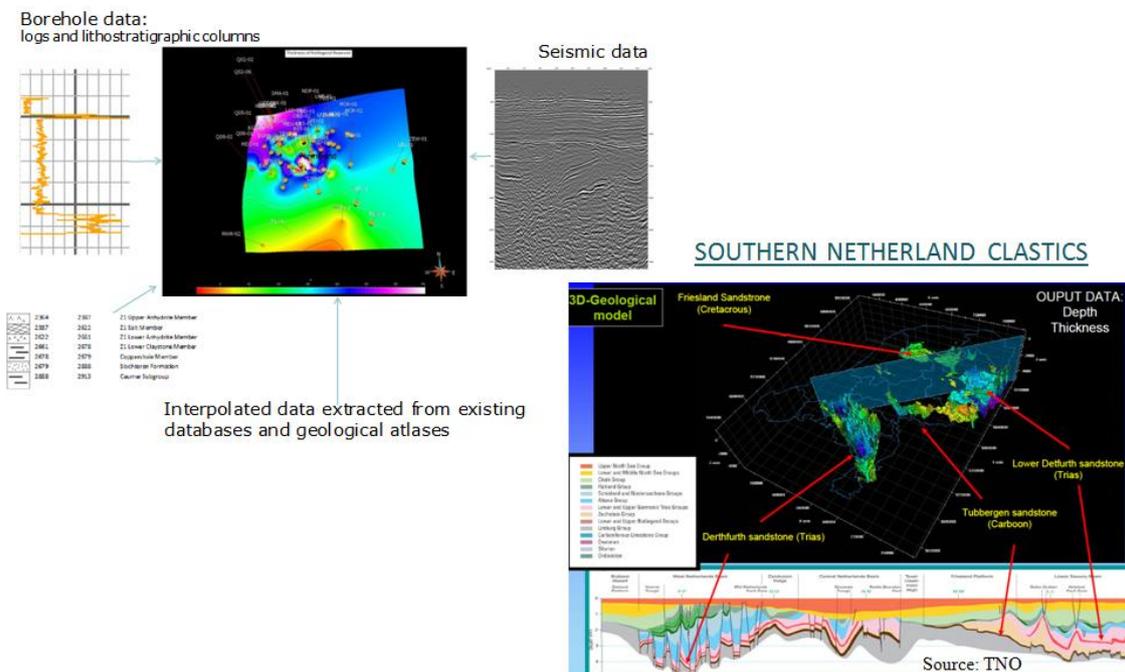
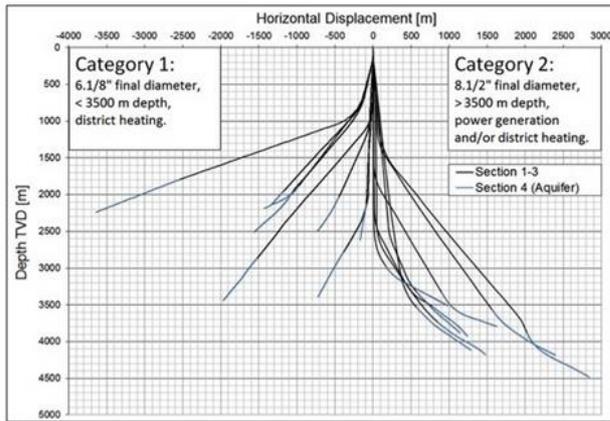


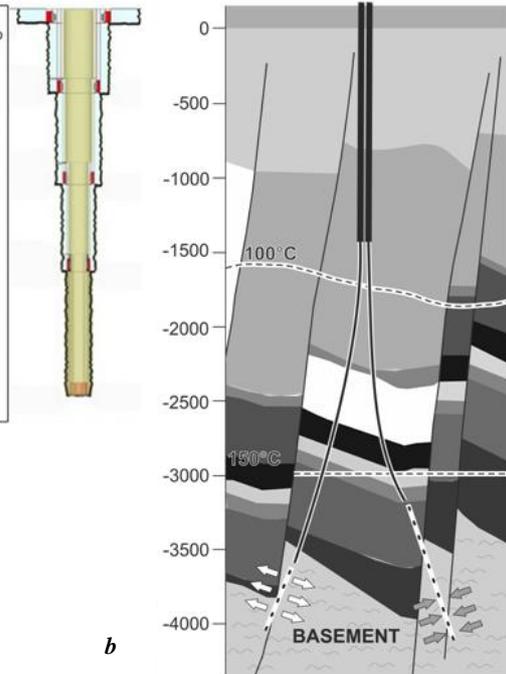
Figure 4. 3D structural geomodelling of a geothermal reservoir (example for a clastic reservoir in Southern Netherland).

**RECORDED TRAJECTORIES KARSTIFIED/  
REEF/LAGOON FACIES (MOLASSE BASIN)**



a

**FAULT/BLOCK STRUCTURE  
(UPPER RHINE GRABEN)**



b

Figure 5. Well targeting in tectonized environments. a) Example of horizontal displacement recorded in drillings (source: Erdwerk GmbH, 2014). b) Example of a faulted block structure in reservoir in Upper Rhine Graben (source: DNA, 2013).

Drilling has benefited from industry improvements in the areas of top drive, MWD/LWD (measurements/logging while drilling), under - balanced (air, foam) drilling techniques, alongside high temperature measuring equipments made available in open hole exploration and production logging (Figure 6), when tackling hostile volcano - tectonic rock environments. However, breakthroughs expected from somewhat exotic technologies such as fusion drilling, which could significantly cut down drilling costs, indeed a capital intensive segment of any development undertaking, are regarded as premature and by all means dependant on a thorough involvement of the petroleum and mineral industry. R & D programs sponsored by the US DOE ambition to achieve a high temperature directional drilling system capable of operating at 300 °C.

•Tool description & performance

Operational Specifications	
Max. Temperature	300°C for 10 hours.
Max. Pressure	800 Bar (circa 12,000 psi)
Borehole Diameter	102-635 mm ( 4-25 in)
Tool Diameter	85 mm (3.38 in)
Tool Weight	150 kg
Tool Length	5.2 m with inline centralisers
Image coverage	100% of borehole
Max. deviation	90°
Logging speed	Variable. Optimum circa 3m/min

•Combined production logging tool

**ATA High Temperature Gamma/CCL - PTS**

*Technical Specifications*

315°C (600°F) - time limit according to chart below

Memory: Non Volatile, 2MB expandable to 8 MB

Pressure: Accuracy ± 0.2 psi  
Resolution 0.01 psi  
Repeatability and Hysteresis: 0.1% F.S.

Temperature: Accuracy ± 1°C  
Resolution 0.03°C

Spinner: Resolution 0.1 rpm with direction

Gamma Ray: Scintillation: Na I(Tl)  
5/8" Dia x 3" long Crystal  
Casing Collar Locator (CCL): Velocity Type Detector  
500 Samples per second with minimum recorded

*Physical Specifications:*

OD: 1.75" (44mm)  
Length: 125" (4.92m) (without spinner)  
Weight: 60lbs (27kg)  
Memory Size: 100,000 data cells

**1-3/4 FLASKED PL TOOL OPERATING TIME vs. TEMPERATURE**

•Borehole televiewer amplitude imaging

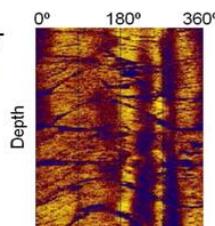


Figure 6. Example of high temperature (300 °C) performance and production logging tools (sources: Tiger Energy Inc. website, McLean and McNamara, 2011).

Elsewhere new well architectures are being implemented, particularly in geoheat production. In this respect the sub horizontal well concept, sketched in Figure 7, designed for maximizing well deliverability in stratified, multilayered, sedimentary reservoir settings is worth mentioning and its multileg cluster derivative likewise.

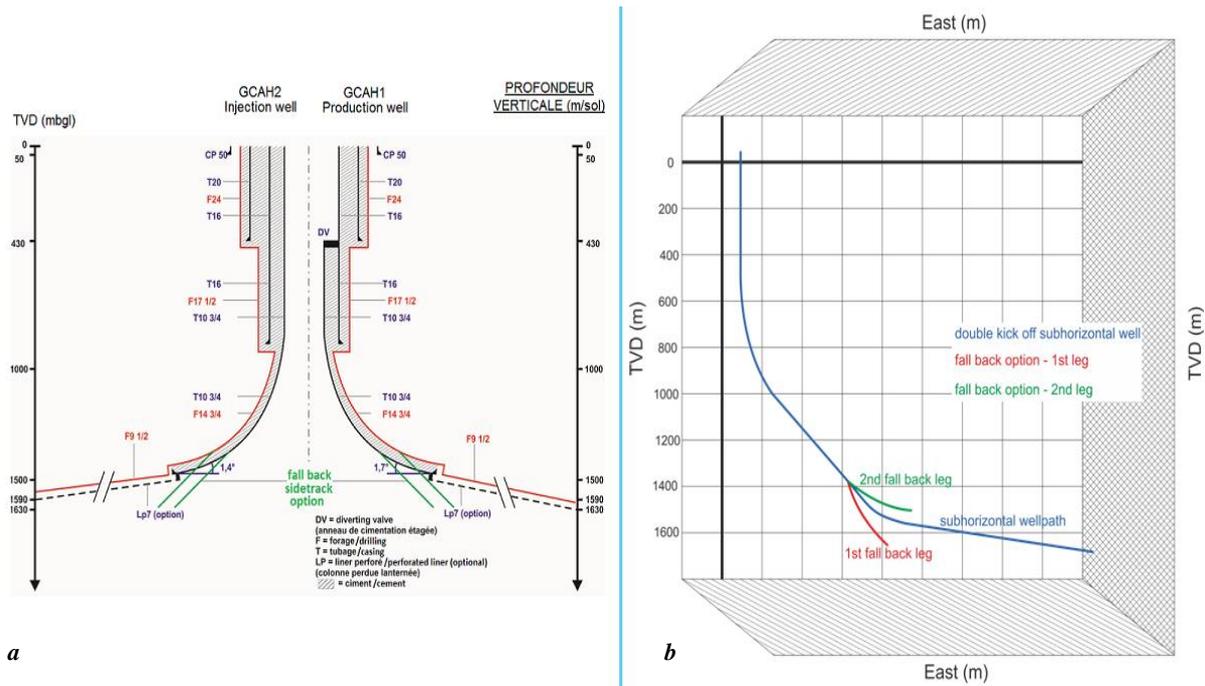


Figure 7. a) Example of sub horizontal well architecture. b) 3D Scheme of three multileg trajectories.

### 3.2 Production

Submersible pumping equipment, which can routinely withstand fluid temperatures above 200 °C, came recently into play and the 300 °C objective is underway. Such high temperature artificial lift hardware has important implications on production of steam sources as it avoids and prevents any in hole flashing and related thermochemical shortcomings inherent to presently prevailing two phase vapor lift flowing practice.

Corrosion and scaling resulting from often thermochemically sensitive, if not hostile, fluid environments can be mitigated and even defeated thanks to downhole chemical inhibition lines which can be extended, via fibre optics telemetry, to pressure and temperature recording as shown in Figure 8, indeed an asset seeking an on line reservoir management perspective.

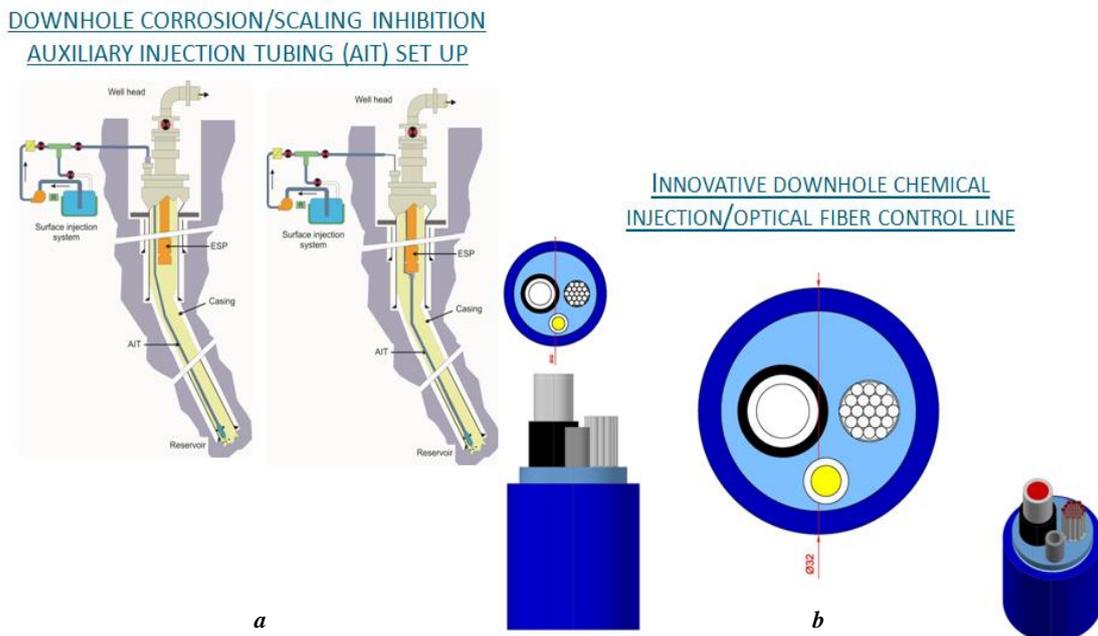


Figure 8. a) Downhole chemical injection tubing set up. b) Pressure/temperature monitoring by optical fiber control line.

### 3.3 Power generation

#### High enthalpy sources

Depending upon the fluid state, either single phase vapour (superheated steam), two phase liquid - vapor (similar to a gas cap field) or single phase liquid (hot pressurised water), the most widely encountered setting, the power generation process will either address direct steam expansion ("dry" superheated steam), single flash, non condensing, back pressure (in case of high non condensable gas contents), single flash/dual flash condensing cycles and water steam turbines. A frontier technology challenge addresses the farming of supercritical fluids assumed to exhibit extremely attractive enthalpies.

#### Medium enthalpy sources

Below 180 °C and above 100 °C Organic Rankine Cycle (ORC) and organic vapor turbines are implemented, the pumped geothermal fluid heating up, via heat exchange, a low boiling point working fluid, generally a hydrocarbon compound at subcritical or supercritical conditions. Lower than 110 °C temperatures sources may be utilized whenever a low temperature cold source is made available such as in Alaska (74 °C – 5 °C). The (licensed) Kalina Cycle generator, an ORC with no superheat and using an ammonia/water mixture, claims higher efficiency at low source temperatures, but has not yet proven long term reliability so far. Nevertheless, conversion cycles demonstrating higher efficiencies and reducing significantly parasitic loads can be expected in the near future.

## 4. KEY ISSUES

Clearly, to meet the aforementioned geopower development targets, new resources environments need to be explored and assessed, and efficient production/conversion systems designed and demonstrated accordingly. Hence, the following priorities are highlighted.

### 4.1 Resource environments

Subduction zones and double flash condensing cycles are the dominant attributes of presently exploited high enthalpy hydrothermal fields. Although much remains to be reclaimed in those areas, given the geodynamics of the European plate and boundaries, high - grade hydrothermal occurrence is limited on Europe at large to the Icelandic rift, the West Anatolian distensive grabens and Aeolian & Aegean volcanic island arcs.

The governing rationale is to extend the geopower potential to candidate medium to high temperature tight rock bodies, including in the near future medium grade EGSs. Exploration methods should therefore focus on detecting, preferably fluid filled, fracture zones nearby dry holes and on relating past tectonic episodes to fractures and stress fields whenever new drillings are anticipated, in order to significantly reduce the mining risk.

### 4.2 Resource development

Above 100 °C temperatures - below 5 000 m depths - resources, widespread worldwide and throughout Europe are eligible to ORC and combined heat and power (CHP) utilization as already confirmed on several Austrian and German prospects, in the Southern Germany Molasse Basin and Rhine Graben sites. The latter, a tectonically active continental rift, is illustrative actually of the Soultz EGS rock stimulation input in bringing to production initially dry wells, securing further commercial heat and power exploitation.

Former hydrocarbon and geothermal exploration have evidenced medium enthalpy reservoirs in tight sedimentary environments, which, thanks to relevant stimulation, could access to commercial CHP production status as already practiced in several Upper Rhine Graben localities.

Production technology is open to optimized fluid extraction (production/injection ratings, pump life) and upgraded conversion (cycle efficiency, reduction of parasitic loads) technologies.

## REFERENCES

- DNA - Dernières Nouvelles d'Alsace (2013) – Fonroche interview. From <http://www.dna.fr/edition-de-strasbourg/2013/09/12/la-geothermie-c-est-pour-demain>.
- Erdwerk GmbH (2014) - Deep geothermal drillings - a review of risk mitigation and best practices gained during the last 15 years in the South German Molasse Basin. LES JOURNÉES DE LA GÉOTHERMIE, D - GEO - DAYS PARIS, April 2014 (speaker: MIRJOLET F.).
- McLean K. and McNamara D. (2011) - Fractures interpreted from acoustic formation imaging technology: correlation to permeability. Proc. 36th Workshop on Geothermal Reservoir Engineering, Stanford, California (2011).
- Tiger Energy Inc. website: <http://www.tigerenergy.ca/>

## How Heat Pumps Work: Criteria for Heat Sources Evaluation

CONTI Paolo<sup>1,2</sup> and GRASSI Walter<sup>1,2</sup>

<sup>1</sup> DESTEC - Department of Energy, Systems, Territory and Constructions Engineering, University of Pisa, Italy

<sup>2</sup> UGI - Italian Geothermal Union, c/o DESTEC, University of Pisa, Italy

Corresponding author's e-mail: [paolo.conti@for.unipi.it](mailto:paolo.conti@for.unipi.it)

**Keywords:** heat pump systems, thermal source evaluation, optimal design.

### ABSTRACT

This work proposes an innovative approach to heat sources evaluation for heat pump applications. The initial characterization of the suitable sources (e.g. air, ground, and water) is integrated with classical considerations about HVAC design. In particular, we aim to evaluate the operative performance of overall HP system when it is coupled with each source, separately. Then, final performances are ranked according to a proper energy/economy performance index. The paper starts dealing with the basic thermodynamic principles of heat pumps, focusing on the main effects of sources' temperature on COP/EER values. Then, the paper illustrates the main pros and cons of typical heat sources and ground heat exchanger configurations. Finally, we show the achievable benefits of the proposed methodology through a test case.

### 1. INTRODUCTION

EU - 28 final energy consumption was about 1100 MTOE in 2012. Almost 434 MTOE (~39%) correspond to the energy demand of residential buildings, commercial and public services. HC technologies (Gas/Oil products/solid fuels) deliver about 215 MTOE (~50%), while the share of renewable energy in heating and cooling was about 15%. These figures hint a wide margin of growth for alternative technologies (Eurostat, 2014; IEA, 2014).

Heat pumps have experienced a huge expansion since the mid - 2000s (Observ'ER, 2013) thanks to notable technological developments and several financial incentives. European Directive 2009/28/EC has recognized HPs as a RES technology, also setting a method to evaluate the renewable share of delivered heat: the latter contributes to national and European targets in terms of renewable energy use. At present only heating and DHW services are considered, as there are no established methodologies to compute HPs contribution in cooling mode.

Despite of these favourable conditions, according to (Observ'ER, 2013), renewable energy from heat pumps was almost 5.55 MTOE in 2012. A clear development trend cannot be identified in Europe, where both contraction and expansion situations occur. Due to notable installation costs, ground - source heat pumps (GSHP) market is strongly dependent on new constructions rate, which is currently at its lowest point in many European countries. HPs sales are almost totally made of air source units (~95%), especially in Mediterranean areas where they are mainly used for summer cooling. The reasons are quite simply: ASHPs are cheap and easy to install, also in existing buildings. Besides, cooling service has not competitor technologies, while building heat needs are too low to justify expensive investments. Moreover, alternative heating technologies (e.g. condensing boiler) have already reached a notable level of reliability and do not require high - qualified designers and installers. Mixed boiler - ASHP systems are still the most attractive, especially in low capacity applications as residential dwellings.

In these circumstances, the establishment of an innovative design approach could stimulate a new growth phase of heat pumps market. This is especially true for GSHP sector, where rough and hasty design procedures result sometime in expensive installation costs compared to the actual operative performance. Currently, ASHRAE method (ASHRAE, 2011) is the most used and accurate but it requires some design parameters decided a priori; therefore, only experienced professionals are able to use this method in a proper way (Fèlix and Gosselin, 2014).

One of the main drawbacks in GSHPs design is the correct evaluation of the thermal source: generally, the assessment phase ends at the initial/undisturbed characterization of the temperature and of the thermo - physical properties of the medium. In this work, we will deal with an alternative concept of evaluation, mainly focused on the source behaviour when the heat pump system operates. In addition, we will discuss the sustainability issue, highlighting the importance of management strategy.

Several works have already demonstrated the benefits obtainable through an optimized design aimed at maximizing the overall performance of GSHP systems (Heating, Ventilating and Air Conditioning) minimizing the installation and the operative costs (Sanaye and Niroomand, 2010; Fèlix and Gosselin, 2014; Retkowski and Thöming, 2014; Conti et al., 2015). In addition, different authors have dealt with synergy among different thermal sources and HVAC technologies (Pardo et al., 2010; ASHRAE, 2011; Li et al., 2013; Conti et al., 2015; Alavy et al., 2013). Here, we will illustrate a small test case in order to show the benefits achievable through an optimized synergy among air and ground sources.

## 2. HEAT PUMPS: BASIC THEORY

As stated in every thermodynamics textbook, heat pumps are devices able to transfer heat from a cold source to a hot one, in contrast with the natural direction of the heat flow. To do that, a given amount of driven energy is required: e.g. heat or work. In the first case, we refer to “absorption systems”; in the second case, we refer to “vapor - compression systems”.

Figure 1 shows the energy balance of a generic heat pump unit (HP): the quantity  $\dot{Q}_C$  is removed from the cold source and the quantity  $\dot{Q}_H = \dot{Q}_C + \dot{W}$  is delivered to the hot source. The same unit can provide heating or cooling service, as there are no conceptual differences between the two modes of operation, aside from our definition of “useful effect”.

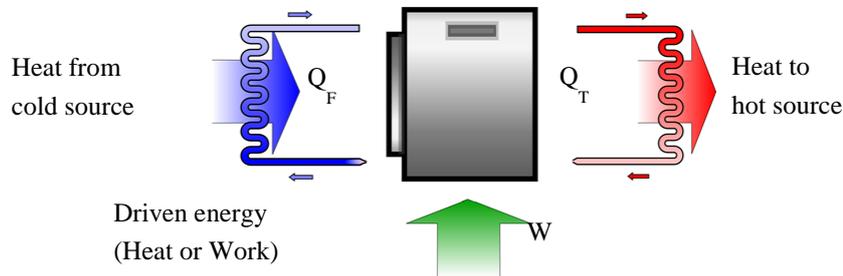


Figure 1. Energy balance of a generic heat pump unit.

The so - called “coefficient of performance” evaluates the efficiency of the heat transfer process: it is defined as the delivered/removed thermal power divided by the total power input (see Equations 1.a and 1.b).

$$COP = \frac{\dot{Q}_H}{\dot{W}} \quad (1.a) \quad \text{(heating mode)}$$

$$EER = \frac{\dot{Q}_C}{\dot{W}} \quad (1.b) \quad \text{(cooling mode)}$$

To date, a universal standardization for HPs terminology does not exist; consequently, different authors use the same generic acronym COP/EER to evaluate different quantities. E.g., COP values are used by manufacturers to express the ratio of the instantaneous thermal power delivered by HP unit and the instantaneous electrical input at the compressor; likewise, the same acronyms COP are used by designers to show the integral energetic performance of overall HP systems (auxiliaries included).

Table 1 shows a list of the main energetic indexes of performance for HP systems: in particular, we highlighted the differences among power, energy, and primary energy. Absorption heat pumps (AHPs) have lower COP/EER than electrically - driven ones: nevertheless, AHPs use a primary source of energy (e.g. natural gas) instead of electricity produced by power plants. Therefore, we could compare the two technologies only through PER values.

Table 1. Energetic indexes for heat pumps.

ACRONYM	NAME	DEFINITION
<b>COP/EER</b>		Useful <b>thermal power</b> divided by <b>power input</b> .
<COP> / <EER>	Average COP/EER	Useful <b>thermal energy</b> divided by <b>total energy</b> input. The coefficient refers to a <b>specified time interval</b> .
<b>SCOP / SEER</b>	Seasonal COP/EER	Useful <b>thermal energy</b> divided by <b>energy input</b> . The coefficient refers to the <b>entire heating/cooling season</b> .
<b>PER</b>	Primary Energy Ratio	Useful <b>thermal energy</b> during a season divided by <b>primary energy input</b> .

**Note:** Primary energy factor was considered equal to 2.5 for electrical energy.

### Reference thermodynamic cycle: effect of source temperature

The physical model of an HP unit consists in a reverse thermodynamic cycle (Figure 2), in which the working fluid follows four main processes. Referring to Figure 2.a, we have:

1. (A – B) heat is transferred from the cold source to the working fluid that evaporates.  $q_c$  [kJ/kg] is the specific heat exchanged during the evaporation process: it corresponds to the blue area under D – A line (extended to 0 K).
2. (B – C) pressure and temperature are increased through a compressor or an absorption device;
3. (C – D) heat is delivered to the hot source by the working fluid, that condensate.  $q_h$  [kJ/kg] is the specific heat exchanged during the condensation process: it corresponds to the blue area under B – C line (extended to 0 K).
4. (D – A) pressure is reduced by means of a lamination process through an expansion valve.

According to thermodynamic principles, it is possible to draw an equivalent Carnot cycle (Figure 2.b), that operates between two equivalent temperatures resulting in the same energy exchanges of the reference HPs cycle. The definitions of  $\bar{T}_H$  and  $\bar{T}_C$  read:

$$\bar{T}_H = \frac{q_H}{s_B - s_C} \quad (1.a)$$

$$\bar{T}_C = \frac{q_C}{s_B - s_C} \quad (1.b)$$

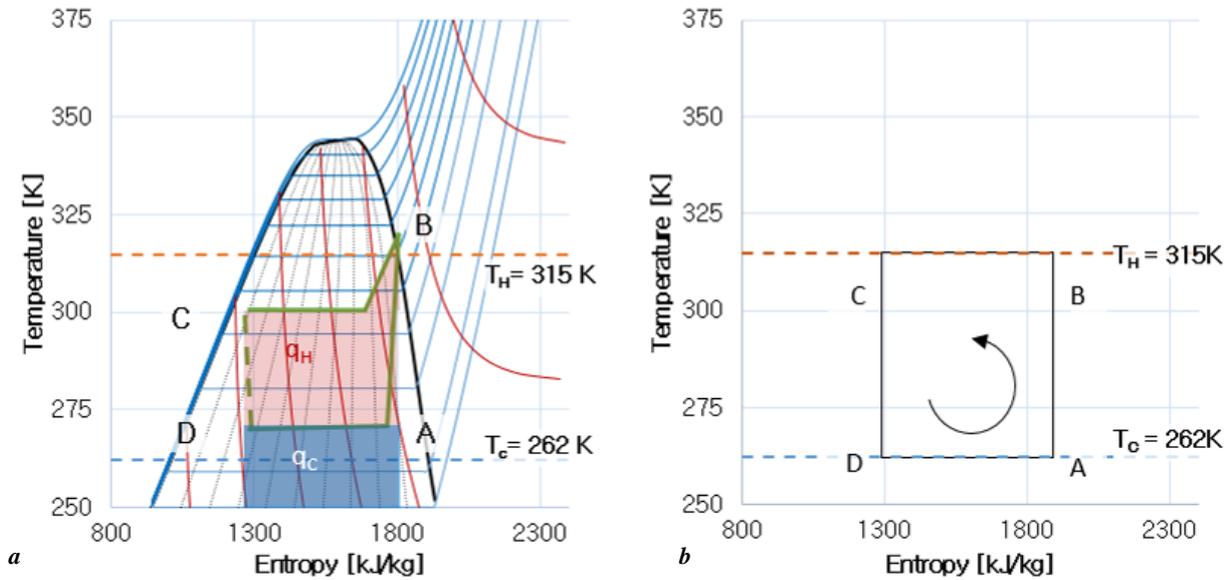


Figure 2. a) Reference thermodynamic cycle of a real heat pump; working fluid: R410A. b) Equivalent Carnot cycle.

The coefficients of performance of this equivalent Carnot cycle correspond to the COP of the reference HP cycle:

$$COP = \frac{q_H}{q_H - q_C} = \frac{\bar{T}_H}{\bar{T}_H - \bar{T}_C} \quad (2.a)$$

$$EER = \frac{q_C}{q_H - q_C} = \frac{\bar{T}_C}{\bar{T}_H - \bar{T}_C} \quad (2.b)$$

As well - known COP and EER values increase when  $\bar{T}_H$  and  $\bar{T}_C$  are close. This is the main effect of heat sources on heat pump performances. Theoretically, the temperature level is the main criterion for rating the heat sources. Nevertheless, design of real HP systems cannot neglect other typical engineering issues.

We note that the equivalent condensing/evaporating temperatures are necessarily higher/lower than those of cold/hot sources; otherwise, the heat transfer process does not occur. Therefore, using sources temperature to estimate COP/EER value results in an optimistic overestimation of HP efficiency; instead, real performances are notably affected by the effectiveness of the heat transfer apparatus and HP components. The coupling among thermal sources and HP unit always needs a proper equipment design.

Manufacturers refer their datasheet to outlet temperatures of secondary fluids from evaporator  $T_{E,out}$  and condenser  $T_{C,out}$  (see Figure 3), in accordance with current technical standards for HPs rating. We can use these temperature to define COP\* and EER\* as in equations 3.a and 3.b.

$$COP^* = \frac{T_{C,out}}{T_{C,out} - T_{E,out}} > \frac{\bar{T}_H}{\bar{T}_H - \bar{T}_C} \quad (3.a)$$

$$EER^* = \frac{T_{E,out}}{T_{C,out} - T_{E,out}} > \frac{\bar{T}_C}{\bar{T}_H - \bar{T}_C} \quad (3.b)$$

According to the second law of thermodynamics, the ratios COP/COP\* and EER/EER\* are necessary lower than one: typical values are 0.5 and 0.4, respectively.

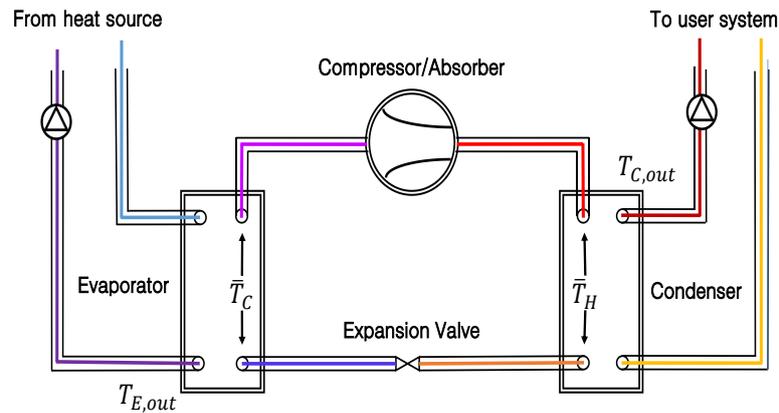


Figure 3. Generic diagram of a water/water heat pump.

### 3. HEAT SOURCES: TERMINOLOGY

Air, water and soils are the principal media used as heat sources in heat pump applications. In this work, we refer to ASHRAE terminology and classification (ASHRAE, 2008, 2011): the generic term ground - source heat pump (GSHP) is applied to systems that use either ground, groundwater, or surface water as heat source or sink. Other terms are usually used by the scientific and technical community, e.g. “open - loop” and “closed loop” systems: according to Figure 4, the former refers to SWHPs and GWHPs, the latter refers to GCHPs. Manufacturers classify devices as “air/air”, “air/water”, “water/water” systems: this terminology refers to the secondary fluid circulating within the evaporator/condenser.

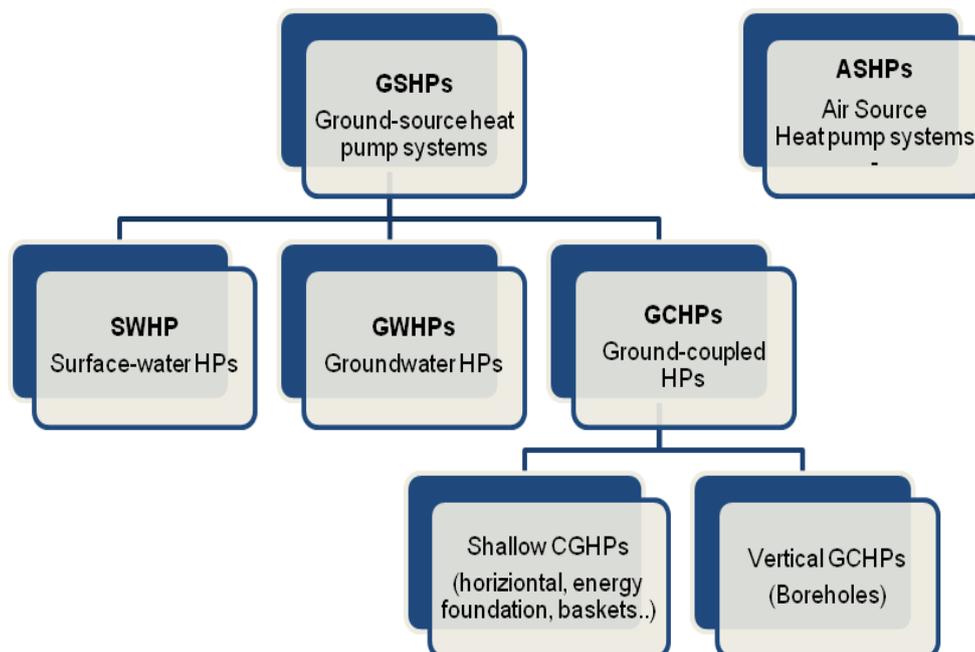


Figure 4. Ground - source heat pump systems (GSHPs) classification and terminology (source: ASHRAE, 2011).

### 4. CRITERIA FOR HEAT SOURCES EVALUATION

Selecting the best heat source for any specific heating/cooling application is a very hard task: the best solution depends on many technical and economic factors: e.g. geographic location, climate, thermo - physical properties of the source medium, service provided, building characteristics, thermal load evolution, available budget, economical, legal and environmental contexts. However, it is possible to outline some general features for a proper approach to heat source assessment.

First, it is important to distinguish two sequential steps:

- *Characterization of the initial/undisturbed state of the medium (ground/water/air).* Typical analysis concerns: annual climate for ASHPs, aquifer temperature, volume, permeability, and depth for GWHPs, ground temperature and thermal diffusivity for GCHPs. Different methodologies and techniques can be found in literature (see for instance Zhang et al., 2014; Osborne, 1993). This is the fundamental starting step, but it is not sufficient to complete the assessment of the source for heat pump applications.
- *Evaluation of medium potential in terms of energy/economic performance of the HPs system.* This step involves typical matters of HVAC design: we aim to evaluate technical and economic suitability of the source medium. Different design alternatives are compared according to a selected performance index. Therefore, the final decision does not only depend

on sources characteristics, but it results from the coupled performances of all system components: viz. sources, heat pump unit, thermo - hydraulics equipment, back - ups generators, and building. The evaluation of a heat source coincides with the evaluation of the overall HP system. Therefore, we suggest evaluating heat sources with the same methodology used to evaluate a HVAC project, namely, the final performance of overall system. We will discuss some suitable performance indexes in section 5.

Table 2 (next page) shows a qualitative comparison among the most common sources alternative, according to the following properties:

- *Sustainability*, seen as the aptitude to maintain advantageous conditions for exploitation during all the operational life of the HP system;
- *Availability*, seen as the level of accessibility and technical feasibility with current technologies;
- *Installation costs*, seen as the total expenditure to purchase equipment and installation works;
- *Operating & Maintenance costs*, seen as the estimation of the operative performance and maintenance required;
- *Temperature*, seen as the typical temperature level of the source at its undisturbed/initial state.

## 5. EVALUATION CRITERIA FOR HEAT PUMP SYSTEMS

As above - mentioned, source evaluation is included in the design process of HP systems; therefore, criteria for heat source and HPs evaluation coincide. The design of every HVACs aims to figure out the best technological solution able to match building needs, both in terms of thermal power and energy. In other words, we investigate different technologies and configurations, at equal services provided, according to a performance index. Typical evaluations concern both energetic and economic performance:

### Energetic criteria

Primary energy consumption is the main energetic performance index. The use of any technology is energetically convenient when it delivers useful thermal energy with a primary energy utilization lower than alternative solutions.

HPs design process includes sources selection, equipment sizing (back - ups included), and apparatus arrangement: all these elements should be evaluated according to their impact on the final operative performance of the overall system. Traditional design methodologies aims to match a reference thermal power demand under nominal conditions, but do not consider the behaviour and the actual performances of system components during its operational life. We will compare these different approaches in section 5.1 *Operational vs. nominal performances*.

### Economic criteria

We can compare economic viability of different HP configurations according to their impact on investment profitability. Traditional methods for investment evaluation are applicable. Widely used indicators are: payback period (simple or discounted), internal rate of return (IRR), net present value (NPV), and profitability index (PI). Key non - energetic parameters for the economic evaluation are: fares of electric energy and fossil fuels, retail price of the equipment, drilling costs, and availability of convenient financial incentives. Depending on the particular economic context, the same system and the same energy savings can lead to opposite conclusions on economic viability of the project.

We note that economic evaluations are inevitably based on cash/energy fluxes during operational life of the system. Therefore, an accurate simulation of system behavior seems to be the necessary tool for efficient and favourable designs.

### 5.1 *Operational vs. nominal performances*

In the previous section, we illustrated how the evaluation of operative performances is the pivot information to decide which thermal source and system configuration are more advantageous in every specific case. Traditional design methodologies use nominal performances under precautionary conditions, which often coincide with the peak thermal load. This approach is not appropriate, especially in GSHPs design because of two main reasons.

Table 2. Qualitative evaluations of main heat pump sources (after ASHRAE, 2011).

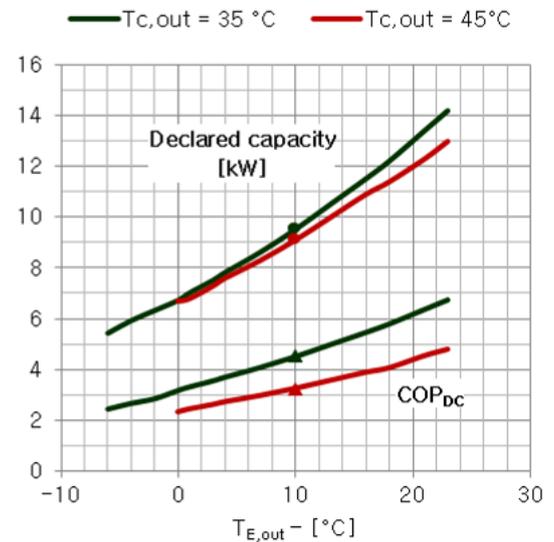
	Suitability	Availability	Installation	O&M	Source temperature	PRO	CONS
<b>ASHPs (Air)</b>							
- Outdoor	☆☆☆	☆☆☆	\$	\$\$	☆☆	Wide source availability; Standard and common technology;	Defrosting; Performance variation according to local climate.
- Exhaust air from building ventilation	☆☆☆	☆☆☆	\$	\$	☆☆☆☆		
<b>Vertical GCHPs (Ground)</b>							
- Borehole	☆☆	☆☆	\$\$\$\$	\$	☆☆	Favorable and constant temperature of the ground source, especially for moist soils.	Installation costs; High quality design and system management are required to avoid temperature drift of the source.
- Shallow configurations (horizontal, energy foundations, baskets...)	☆☆	☆☆	\$\$	\$\$	☆☆	Possible trade-off between performances and installation costs.	Large area required (horiz. GCHPs); Moderate performance; Possible interactions with building structures (energy foundations); Influence of external climate.
<b>GWHPs (Water)</b>	☆☆☆	Varies by locations	\$\$	\$\$	☆☆☆	Low temperature drift of aquifer; Excellent performances for large aquifers and high flow rates;	Aquifer depth, volume, and permeability; Legal and environmental limits; Permitting and bureaucracy; Possible fouling or scaling.
<b>SWHPs (Water)</b>	☆☆☆	Varies by locations	\$	\$	☆☆☆		Adequate flow-rate required from wells Legal and environmental limits; Permitting and bureaucracy; May clog, foul or scale (e.g. seawater)

☆ = LOW; ☆☆ = MODERATE; ☆☆☆ = GOOD; ☆☆☆☆ = EXCELLENT  
\$ = LOW; \$\$ = MODERATE; \$\$\$ = FAIR; \$\$\$\$ = HIGH;

First, real HP units do not have a unique value of nominal power output and efficiency: the values declared by manufacturers are referred to standard rating conditions (EN 14511 - 2, 2013). Usually, manufacturers provide additional tables and/or charts to show the maximum thermal output (e.g.

“declared capacity”  $\dot{Q}_{DC}$ ) and the corresponding efficiency (  $COP_{DC} / EER_{DC}$  ) as a function of outlet temperatures from evaporator (  $T_{E,out}$  ) and condenser (  $T_{C,out}$  ). Figure 5 shows an example of these charts for a real water/water unit; the markers highlight the declared capacity and the reference COP of the device. We note that in a typical operative range of  $T_{E,out}$  (  $0 \div 10$  °C ) the output power and COP vary with an average rate of 0.2 kW/°C and 0.15 kW/°C, respectively.

Figure 5. Maximum thermal capacity and COP values of a real heat pump, as a function of outlet temperature from evaporator and condenser. The markers point out the reference values provided by manufacturers.



Operative performances are also affected by the unit capacity ratio (CR). CR is defined as:

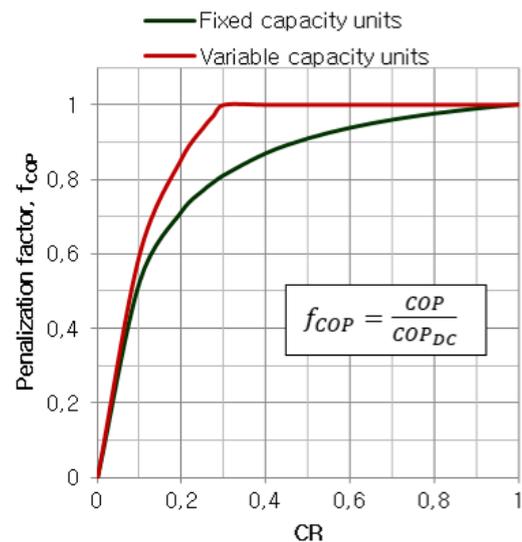
$$CR = \frac{\dot{Q}_u}{\dot{Q}_{DC}} \quad (4)$$

where:

- $\dot{Q}_u$  is the useful thermal power delivered by the HP, (W);
- $\dot{Q}_{DC}$  is the maximum capacity of the HP unit (W), when operating at the actual values of  $T_{E,out}$  and  $T_{C,out}$ .

The effect of CR depends on HP modulation capability in response to the evolution of the thermal load. Figure 6 shows the penalization factor (  $f_{COP/EER}$  ) as a function of CR and implemented control of power output (EN 14825:2012).  $f_{COP/EER}$  is defined as the ratio between the actual COP/EER and the declared  $COP_{DC}/EER_{DC}$  at the same operating temperatures.

Figure 6. COP/EER penalization factor, as a function of CR and modulation capability (EN 14825, 2012).



The second reason, for which we cannot refer to a unique value of nominal power output and efficiency, is that HP operation can alter the initial state of the sources, resulting in a variation of system performances during its operative time. This effect is one of the main design issues of GCHPs, especially in dry soils: indeed, due to its high thermal capacity, the ground temperature evolution and the corresponding HP performance depend on the full history of heat exchanges (e.g. control strategy). For open - loop systems (GWHPs and SWHPs) using reinjection, this phenomenon is known as “thermal feedback” of wells (see for instance Banks, 2009). Consequentially, operative conditions of the ground source can notably differ from its initial/undisturbed state. Sustainability of GSHPs refers to this issue.

Current design methodologies consider this phenomenon through several penalization factors: e.g., ASHRAE method uses three effective thermal resistances to take into account ground temperature drift at different time scales (ASHRAE, 2011). However, only operative simulations can provide accurate information on the reciprocal effects among HP and thermal sources.

We can simulate the behavior of the overall HP through appropriate models of its subsystems: ground reservoir, ground heat exchangers, ground - coupled loop and connecting ductwork, HP unit, back - up generators, and building end - user loop. Several authors have already simulated the GSHP operative - life interconnecting different mathematical models of system components; simulation software (e.g. Trnsys) are widely used, too. Thus, GSHP modelling formulas and methods can be easily found in literature (Arteconi et al., 2013; Conti et al., 2015; Nagano, 2006; Montagud et al., 2013; Pardo et al., 2011) or in technical standards (see for instance CEN. EN 15316 - 4 - 2, 2008; UNI/TS 11300 - 3, 2010; UNI/TS 11300 - 4, 2012).

## 6. ADVANCED DESIGN: OPTIMAL SYNERGY AMONG DIFFERENT SOURCES AND TECHNOLOGIES

According to section 5, the final goal of HVACs design is not to guarantee that a certain peak thermal power is delivered by a unique technology, but that the energetic and/or economic performances of the overall system (back - up generators included) are maximized. HVAC designers do not have to decide which source is better among air, ground, water, or whether HPs is better than other generation technologies: they have to ensure indoor comfort conditions, maximizing a suitable performance index.

Therefore, GSHP design should not be aimed at maximizing the building load share at the ground source, but finding the best share among ground systems and back - up units. Thus, different thermal sources should be exploited in a synergic way. A GSHP simulation model is an effective tool to achieve this goal. Different design solution can be simulated and compared during the design phase of the project, seeking the best one.

As above - mentioned, the heat source evaluation does not finish with the characterization of the initial/undisturbed state of the medium, but it comprises the investigation of the best exploitation strategy in order to exchange heat in a sustainable way, maximizing the overall system performance. Therefore, both size and control strategy of GSHP components have to be concurrently determined to preserve the ground source and maximize the synergy among GHP and back - up generators. Sustainability and efficiency results in the very similar goal, as ensuring a proper ground temperature corresponds to better energy performance. We have described this innovative approach in Conti et al. (2015) and Grassi et al. (2015). In the next subsection, we will provide a brief example in order to demonstrate the positive energetic and economic effects of optimal sources synergy:

### Test case

In this test case, we consider a heating system made of a GHP and an AHP (as back - up). For the sake of simplicity, we do not consider all the necessary elements of a real design, but we deal with a plain analytical model, in order to highlight the main thermodynamic mechanisms that determine a minimum value of energy consumption.

We investigated the primary energy consumption of a vertical GCHP system depending on the BHEs number and the share of building thermal load delivered by ground - coupled heat pump unit ( $f_H$ ). The total energy use,  $E_{in}$  (kWh), of the two heat pumps after a period of time  $\tau$  was calculated as in Equation 5:

$$E_{in} = \int_0^{\tau} L(t) \left( \frac{f_H}{COP_{GHP}(t)} + \frac{1-f_H}{COP_{AHP}(t)} \right) dt \quad (5)$$

where:

- $L$  is building load profiles, kW;
- $f_H$  is the share of building thermal load delivered by ground - coupled heat pump unit;
- $COP_{GHP}$  and  $COP_{AHP}$  are the actual COPs of the ground - coupled and air - coupled heat pump units. They depend on respective operative equivalent condensing/evaporating temperatures (for further details see Conti et al., 2014);
- $\tau$  is the considered operative life of the overall system, namely 20 years.

We imposed a typical Mediterranean/continental profile for outdoor air temperature (from 0 to 15 °C). The ground is assumed as moist, with advantageous values of thermal conductivity and diffusivity ( $\lambda_g = 2$ , W/mK),  $\alpha_g = 9 \cdot 10^{-7}$ , m<sup>2</sup>/s); its undisturbed temperature is assumed equal to 13 °C. At a first glance, ground characteristics seem more favourable than air, therefore we would expect that the optimal value of  $f_H$  is equal to unity. However, the results of the simulation show that further energetic and economic benefits can be obtained through an optimal cooperation between air and ground technologies. Further details on systems modelling and simulation method can be found in Conti et al. (2015) and Grassi et al. (2015).

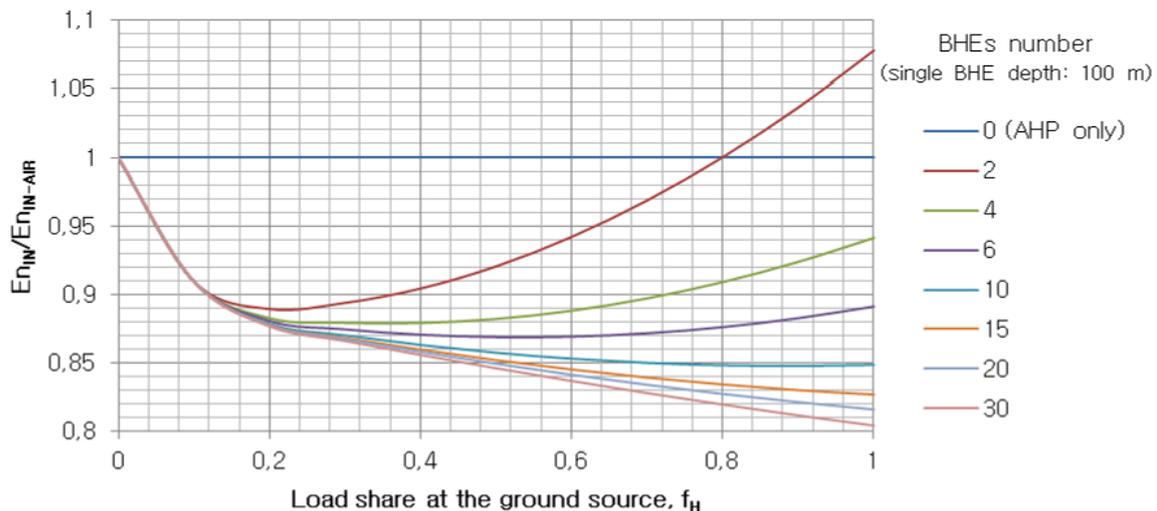


Figure 7. Normalized energy consumption as a function of the load share assumed by the ground source ( $f_H$ ) and BHEs number.

Figure 7 shows that an optimal share of the building load between the two sources can be found. For a given BHEs number, the minimum use of electric energy is the result of an optimal compromise against two impairing effects: at high  $f_H$ , the soil temperature at the borehole surface decreases and can even become lower than air temperature; at low  $f_H$ , we are not fully exploiting the ground thermal storage.

Regarding BHEs size, we can observe how the energy use monotonically decreases with borehole number, as a consequence of a reduced alteration of the ground temperature; however, energy savings show a saturation trend, hinting that an oversized system is not going to be cost effective.

The conclusions of this small example provide useful thermodynamic indications for a proper design of GSHP systems. In particular, energetic synergy between ground and back - up technologies can be optimized according to the local external climate, building thermal load, BHEs depth, and soil thermo - physical properties. Besides, boreholes number and depth have to be chosen as the optimal trade - off between savings in operative costs and installation investment.

## 7. CONCLUSIONS

In this work, we illustrated an innovative approach to heat sources evaluation for HP systems. We described a procedure made of two main steps: the characterization of the source at its initial/undisturbed state and the simulation of the operative performance of overall HP system. A test case was presented, in which the achievable benefits of a proper synergy between ground and air sources were demonstrated.

The test case showed how the simulation of the operative performances provides useful indications on optimal sizing and control of a GSHP system. If we had stopped at the initial characterization of the two media, our conclusion would be that ground was more favourable than air. Instead, the simulation results show a disproportion between energy savings and installation costs at unitary  $f_H$  (no back - up contribution). The optimal design consists in a synergy between GHP and AHP units: this solution ensures savings in overall energy consumption and installation costs.

Source evaluation process is one of the main issues of HPs design. We note that the goal is not to decide which source is the best among air, ground, and water: we aim to maximize overall system performances. Following this approach, different sources and generation technologies can be employed at the same time, ensuring indoor comfort conditions and maximizing the cost - benefit ratio of the entire project.

## ACKNOWLEDGEMENTS

The authors congratulate the organizers for the high level of the meeting and express their thanks for being invited as speakers.

## REFERENCES

- Alavy M., Nguyen H.V., Leong W.H., Dworkin S.B. (2013) - A methodology and computerized approach for optimizing hybrid ground source heat pump system design, *Renewable Energy*, vol. 57, (2013), 404 - 412.
- ASHRAE - American Society of Heating, Refrigerating and Air - Conditioning Engineers (2008) - The Ashrae Handbook 2008: HVAC Systems and Equipment, Atlanta, American Society of Heating, Refrigerating and Air - Conditioning Engineers, (2008).

- ASHRAE - American Society of Heating, Refrigerating and Air - Conditioning Engineers (2011) - The Ashrae Handbook 2011: HVAC Applications, Atlanta, American Society of Heating, Refrigerating and Air - Conditioning Engineers, (2011).
- Arteconi A., Brandoni C., Rossi G., Polonara F. (2013) - Experimental evaluation and dynamic simulation of a ground coupled heat pump for a commercial building. *International Journal of Energy Research*, vol. 37, n°5, (2013), 1971 - 1980.
- Banks D. (2009) - Thermogeological assessment of open - loop well doublet schemes: a review and synthesis of analytical approaches. *Hydrogeology Journal*, vol. 17, n° 5, (2009), 1149 - 1155.
- Conti P., Grassi W., Testi D. (2015) - A holistic method for optimal design of ground source heat pump systems – part 1: model definition and discussion. Submitted to: *Applied Energy*, (2015).
- EN 14511 - 2 (2013) - Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling – Part 2: Test conditions. Brussels, European Committee for Standardization; (2013).
- EN 14825 (2012) - Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling – Testing and rating at part load conditions and calculation of seasonal performance. European Committee for Standardization (CEN), Brussels, (2012).
- EN 15316 - 4 - 2 (2008) - Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4 - 2: Space heating generation systems, heat pump systems. Brussels: European Committee for Standardization (CEN), Brussels, (2008).
- EUROSTAT (2014) - Energy balance sheets 2011 - 2012. © European Union, (2014).
- Félix R., Louis G. (2014) - New methodology to design ground coupled heat pump systems based on total cost minimization. *Applied Thermal Engineering*, vol. 62, n° 2, (2014), 481 - 491.
- Grassi W., Conti P., Schito E, Testi D. (2015) - On sustainable and efficient design of ground - source heat pump systems. *Journal of Physics: Conference Series*, *In press*.
- IEA - International Energy Agency (2014) - World Energy Statistics, (2014).
- Li F., Zheng G., Tian Z. (2013) - Optimal operation strategy of the hybrid heating system composed of centrifugal heat pumps and gas boilers, *Energy and Buildings*, vol. 58, (2013), 27 - 36.
- Montagud C., Corberán J.M., Ruiz - Calvo F. (2013) - Experimental and modeling analysis of a ground source heat pump system, *Applied Energy*, vol. 109, (2013), 328–336.
- Nagano K., Katsura T., Takeda S. (2006) - Development of a design and performance prediction tool for the ground source heat pump system, *Applied Thermal Engineering*, vol. 26, n° 14 - 15, (2006); 1578–1592.
- Observ'ER (2013) - Heat pumps barometer. EurObserv'ER Project, (2013).
- Osborne P.S. (1993) - Suggested Operating Procedures for Aquifer Pumping Tests, US Environmental Protection Agency, (1993).
- Pardo N., Montero Á., Martos J., Urchueguía J.F. (2010) - Optimization of hybrid – ground coupled and air source – heat pump systems in combination with thermal storage. *Applied Thermal Engineering*, vol. 30, n° 8–9, (2010), 1073 - 1077.
- Pardo N., Montero Á., Sala A., Martos J., Urchueguía J.F. (2011) - Efficiency improvement of a ground coupled heat pump system from energy management. *Applied Thermal Engineering*, vol. 31, n°2 - 3, (2011), 391–398.
- Retkowski W. and Thöming J. (2014) - Thermo-economic optimization of vertical ground - source heat pump systems through nonlinear integer programming, *Applied Energy*, vol. 114, (2014), 492 - 503.
- Sanaye S. and Niroomand B. (2010) - Horizontal ground coupled heat pump: Thermal - economic modeling and optimization, *Energy Conversion and Management*, vol. 51, n° 12, (2010), 2600 - 2612.
- UNI/TS 11300 - 4 (2012) - Energy performance of buildings – Part 4: Renewable energy and other generation systems for space heating and domestic hot water production. Milan: Ente Nazionale Italiano di Unificazione, (2012).
- UNI/TS 11300 - 3 (2010) - Energy performance of buildings – Part 3: Evaluation of primary energy and system efficiencies for space cooling. Milan: Ente Nazionale Italiano di Unificazione, (2010).
- Zhang C., Guo Z., Liu Y., Cong X., Peng D. (2014) - A review on thermal response test of ground - coupled heat pump systems. *Renewable and Sustainable Energy Reviews*, vol. 40, (2014), 851–867.

## **Resources Assessment and Geothermal Applications**

## Integrated Geophysical Characterization of Geothermal Reservoirs

POLETTO Flavio<sup>1</sup>, FARINA Biancamaria<sup>1</sup>, CORUBOLO Piero<sup>1</sup>, PETRONIO Lorenzo<sup>1</sup>, SCHLEIFER Andrea<sup>1</sup>, PALMIERI Francesco<sup>1</sup> and PERONIO Marco<sup>1</sup>

<sup>1</sup> OGS - National Institute of Oceanography and Experimental Geophysics, Trieste, Italy

Corresponding author's e-mail: [fpoletto@ogs.trieste.it](mailto:fpoletto@ogs.trieste.it)

**Keywords:** geothermal reservoir, geophysical characterization, integrated characterization.

### ABSTRACT

This work describes some relevant experiences of OGS in the investigation of low-, medium- and high-enthalpy geothermal systems through the acquisition of integrated geophysical data. Among OGS research activities, here we mainly focus our attention on two experimental works: the first one is related to the characterization of a low-enthalpy geothermal reservoir in the Grado region, in cooperation with the University of Trieste, and another is related to the study of a medium-enthalpy geothermal reservoir in Nevada (USA). The Nevada geothermal survey was performed thanks to the long-term experience in supporting drilling of Oil & Gas exploration wells, by adapting for geothermal applications the seismic-while-drilling technology based on the use of the drill-bit noise as a seismic source (Poletto and Miranda, 2004). Moreover, OGS was more recently involved in a joint SWD acquisition tests at Bochum (GZB), where a DTH fluid hammer drilling was used as seismic source. As a perspective, the SWD technology is a tool suitable for high-enthalpy purposes, to perform borehole measurements at high temperatures where using conventional borehole measurement techniques can be difficult for the extreme conditions. The OGS geothermal research includes study and simulation of seismic wave propagation in very hot and melting rocks, such as those of deep drilling in the brittle-ductile transition (BDT) and magmatic zones.

### 1. INTRODUCTION

The analysis of integrated geophysical data collected at the surface and in boreholes is a key factor to better and properly characterize subsurface conditions of geothermal reservoirs, especially in complex and fractured areas. In this work we present some relevant case studies with examples of field applications performed by OGS for the geophysical characterization of geothermal reservoirs in the context of different scenarios.

Firstly we present the main results of an OGS integrated geophysical survey with acquisition and analysis of seismic data, including surface seismic lines, multi-offset vertical seismic profile (MO VSP), and gravity data, which was performed in the low-enthalpy area of the Grado Island (NE Italy). The aim of the project was to provide new subsurface information to identify the optimal location of the second well (Grado-2) of a geothermal district-heating system, through the characterization of the faulted zone around the first drilled well Grado-1 (Petronio et al., 2012, Poletto et al., 2013). The integrated geophysical data are analyzed together with the well data and geological results of Grado-1 well.

Then we show the results of an application of drill-bit seismic-while-drilling (SWD) method and technology, made by OGS in a survey performed in a medium-enthalpy area in Nevada (USA). The collected data provided structural information to characterize the geothermal area around the exploration well and locate faulted zones (Poletto et al., 2011a, b and c). In the absence of conventional surface seismic data, the SWD test was initially designed and planned by geological and gravity models of the well area. The while-drilling and after-drilling seismic results were compared and interpreted together with the electromagnetic (EM) geophysical data. With the aim to extend the technology for fast geothermal drilling, another application of the SWD technique for geothermal purposes was performed during the drilling of a shallow well at the Bochum International Geothermal Centre (GZB) facility, using a down-the-hole (DHT) hydraulic water hammer source (Poletto et al., 2015; Wittig et al., 2012, 2015). The results show the potentiality of the innovative DTH application of the SWD method with this percussion source.

The on-going OGS research is also extended to the rheology and wave propagation in high-enthalpy areas, such as the brittle-ductile transition, where high temperatures can produce partial melting. Carcione and Poletto (2013) described the behavior of seismic waves nearby the transition between the upper cooler and the deeper ductile parts of the crust. Then, Carcione et al. (2013) developed a code, based on the Burgers model showing, with realistic examples, surface and reverse-VSP synthetic seismograms in the presence of an abrupt brittle-ductile transition.

### 2. GRADO INTEGRATED SURVEY

The investigation of the low-enthalpy geothermal district of Grado Island, northeastern Adriatic Sea, was made in the framework of the *Grado geothermal project*, and performed through the acquisition and analysis of data from gravity and seismic surveys including multi-offset vertical seismic profile in Grado-1 well (Petronio et al., 2012, Poletto et al., 2013).

The main target of the combined geophysical measurements was to extend and improve the characterization of the subsurface faulted and fractured zone around Grado-1 well, in order to optimize the location of the second well (Grado-2) of the injection-production system (Della Vedova et al., 2015). Lowering a wireline 3C geophone sonde in Grado-1, the

multi-offset vertical seismic profiles (MO VSPs) were used to provide a relationship between the existing borehole data in depth and the surface seismic data, to calibrate in depth the new surface seismic data used in order to image the area around the existing well, and to estimate the variation in the geophysical properties of the carbonate formations found below the depth of 616.5 m at the well location. The VSP data furnished robust geophysical information to support the numerical evaluation of the fluid-dynamic model for the geothermal-doublet system.

The surface seismic reflection data (Della Vedova et al., 2013) were collected in different directions along three intersecting lines: G11, G12 and G13, which are 2.4, 2.6 and 1.7 km long (Petronio et al., 2012), respectively, to cover the area of interest in Grado (Figure 1, small panel at the top of the seismic section). Onshore, geophones were placed with an intertrace of 10 m, and the acquisition was performed by shooting interval 20 m. The G13 line was shot with a seismic vibrator (IVI Minivib T-2500), and the data recorded with a sampling interval of 1 ms and a recording time of 22 s. The source used for G11 and G12 lines and for the VSPs was an accelerated dropping mass Hydrapulse (about 4 energization per shooting point), and the signal was recorded with 1 ms sampling interval and registration length of 4 s. Multichannel hydrophone bay-cable and a 120 bar airgun were used to record offshore shots in shallow water, with the purpose of extending also offshore in the proximity of Grado-1 well the length of the onshore G11 line. The processed seismic sections show the signal of the interface between the terrigenous cap-rock sediments (Paleogene flysch) and the Paleogene carbonate geothermal reservoir [Geothermal Heating and Cooling in the FVG Region: the Grado District Heating and the Pontebba Ice Rink Plants, DELLA VEDOVA et al., extended article in this book]. Figures 1 and 2 show the reflection signals along the G13 line and the cross-line intersections of the three lines, respectively.

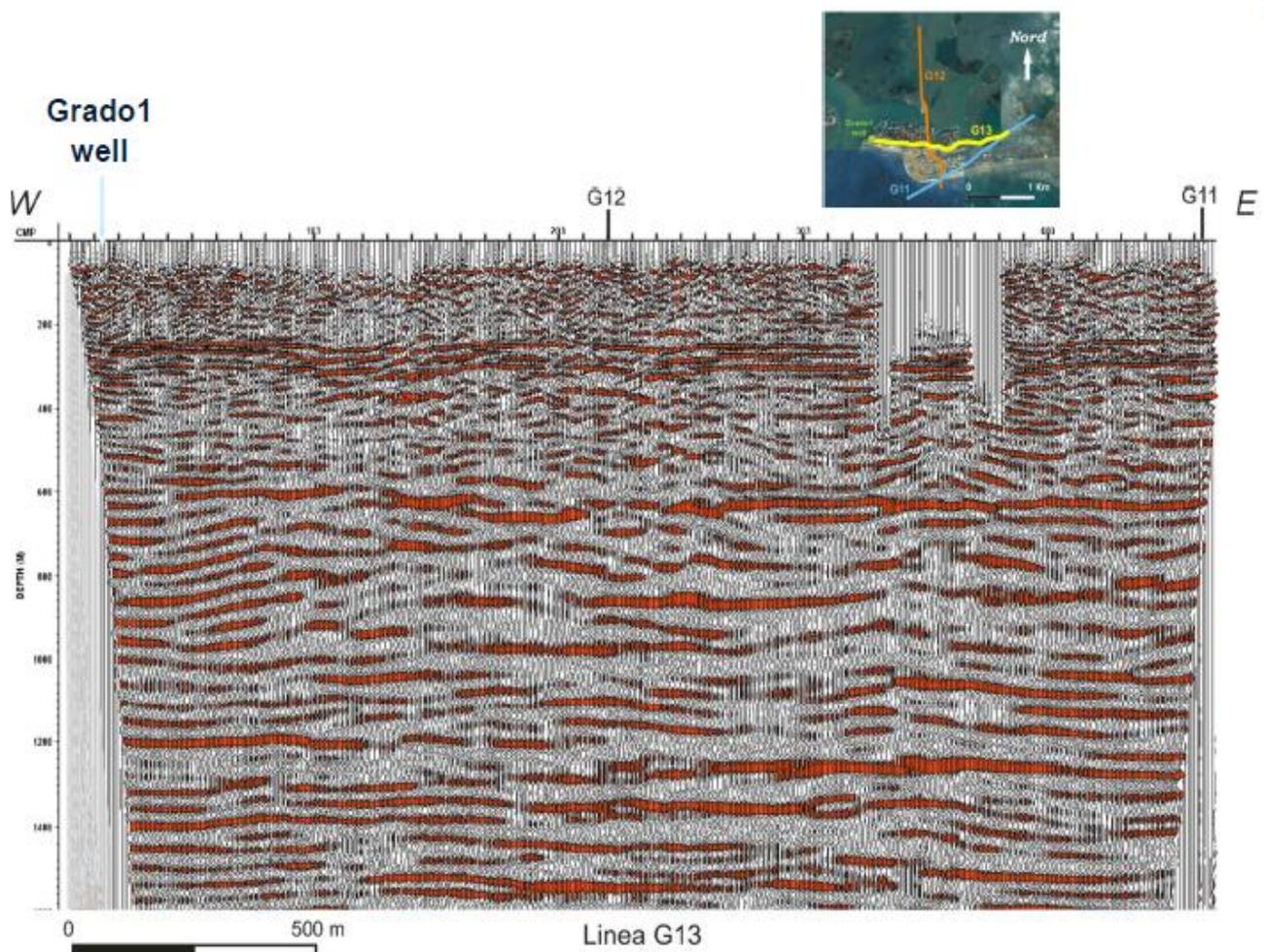


Figure 1. Reflection signal (depth section) processed from the data acquired along the G13 line. The small panel represents the map with the surface reflection seismic layout for the three seismic acquisition lines G11, G12 and G13 (after Petronio et al., 2012).

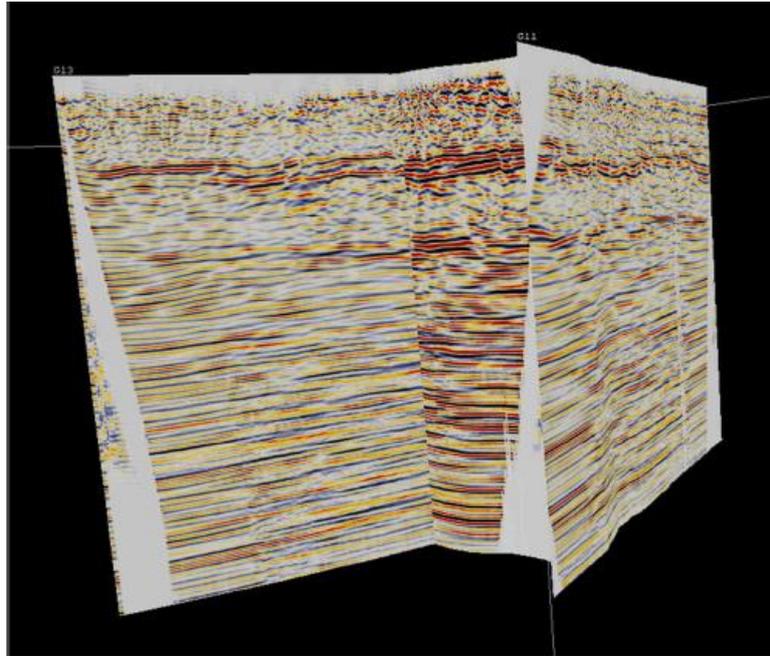


Figure 2. Cross-line seismic reflection signals, in which the corresponding reflections can be interpreted (after Petronio et al., 2012).

The borehole seismic survey consisted of VSP acquisitions with four surface source (Hydrapulse) offsets at distances of 44, 226, 449 and 939 m from wellhead in the direction of G13. The VSP's acquisition covered the total depth of 1110 m in the well, where the first 696 m are cased, and the deeper section is open hole in the fractured carbonate formations. The nearest offset (44 m) was recorded using a 5 m depth sampling intertrace in order to obtain a highly detailed seismic profile along the vertical well. The three furthest source positions at 226, 449 and 939 m offset from wellhead, acquired with the purpose of investigating the lateral formation structures, were recorded with larger depth intervals of 10 m, 10 m and 20 m, respectively. The near offset VSP was used to relate the borehole lithological profile to the high resolution well logs and the seismic data and highlights the transition within the carbonates (Poletto et al., 2013), interpretable in the lower-resolution surface reflection seismic. In Figure 3a, the high-quality total field of the vertical geophone (Z) component of the near-offset VSP can be observed. Figure 3b shows the interval-velocity profile computed by picking the direct arrivals (first breaks) of the near-offset VSP. It is interesting to note the increase of the compressional velocity at a depth of about 610 m, in correspondence of a thin transition zone at the top of the Paleogene carbonate platform.

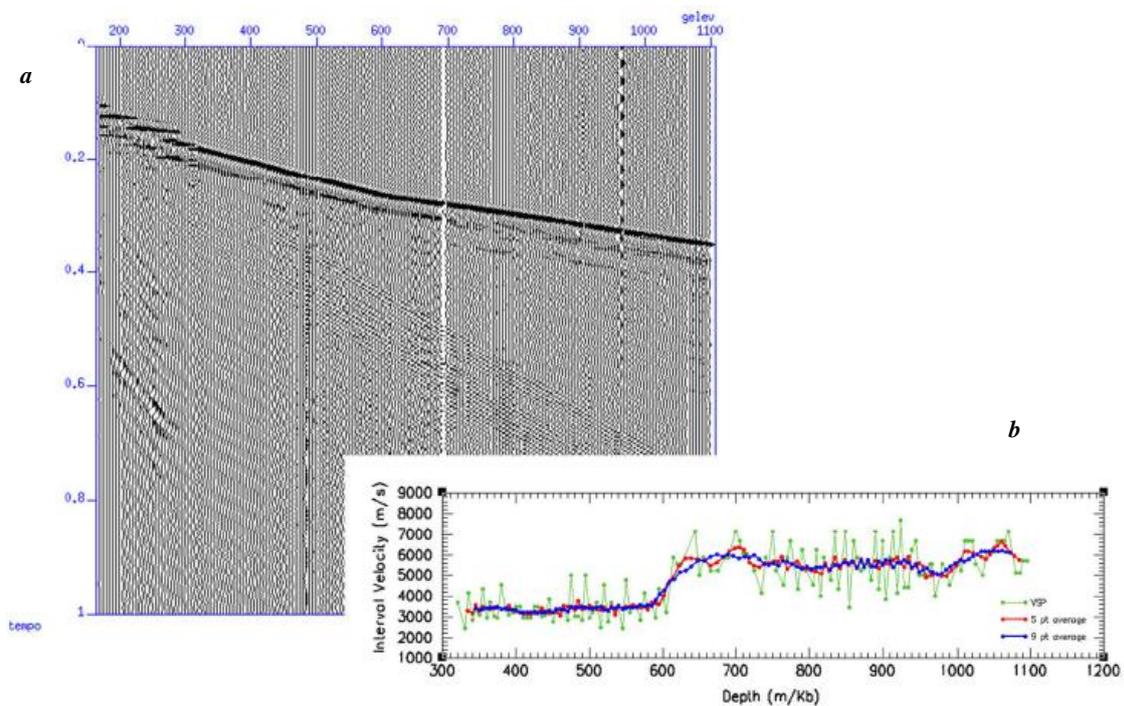


Figure 3. a) Total field (Z geophone component) of the near-offset VSP. b) the velocity function computed by picking the first break (green line), averaged on 5 points (red line) and on 9 points (blue line) (modified after Poletto et al., 2013).

Moreover, the near-offset VSP was used for formation-characterization purposes, to analyze the quality Q-factor with the aim to characterize the different attenuation behaviors, particularly in the shallower and deeper carbonate formations. The estimation of the attenuation was done using two different methods; one is based on the spectral-ratio technique (Hauge, 1981), the other uses available acoustic log data and measured travel-times in the near-offset VSP. The shallow alluvium zone appears more attenuated, with a Q-factor of the order of 20, while higher Q-factor, around 200, characterizes the carbonate formation located at 0.55 s in the two-way-time (TWT) section (Figure 4).

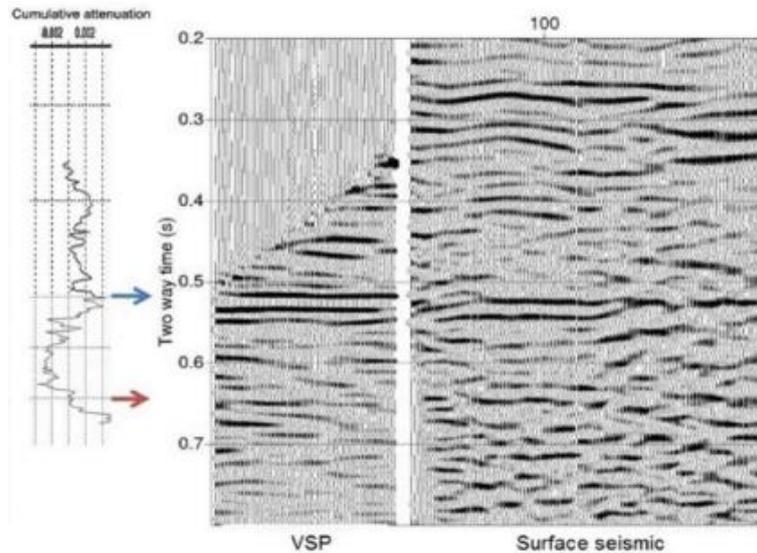


Figure 4. Comparison between the formation attenuation analysis and the reflection signal interpretation (modified after Poletto et al., 2013).

The multi-offset VSPs extend laterally the analysis with respect to Grado-1 well. They were analyzed with the support of synthetic data calculated using a 2D finite-difference (FD) viscoelastic code. In order to justify velocity variations in the overburden, which consist of loose sediments (sand/clay) and basinal marly sediments, we added, in the model, a vertical-transverse isotropy (VTI) in the 390-600 m depth range using the Thomsen's parameter  $\epsilon=0.1$  (Poletto et al., 2013). A preliminary velocity model, estimated by minimizing the error-energy of the offset VSP travel-times in synthetic and real data and consistent with the available information, is shown in Figure 5a. A further result of the multi-offset VSP analysis was the estimation of the shear wave velocity from the clearly interpretable transmitted converted PS waves. The travel-time comparison between synthetics and real data shows that the Poisson's medium hypothesis is not adequate to describe the velocity-depth model. Figures 5b and c show the compressional ( $V_p$ ) and shear ( $V_s$ ) velocity profiles and the  $V_p/V_s$  ratio estimated at 200 m offset, respectively.

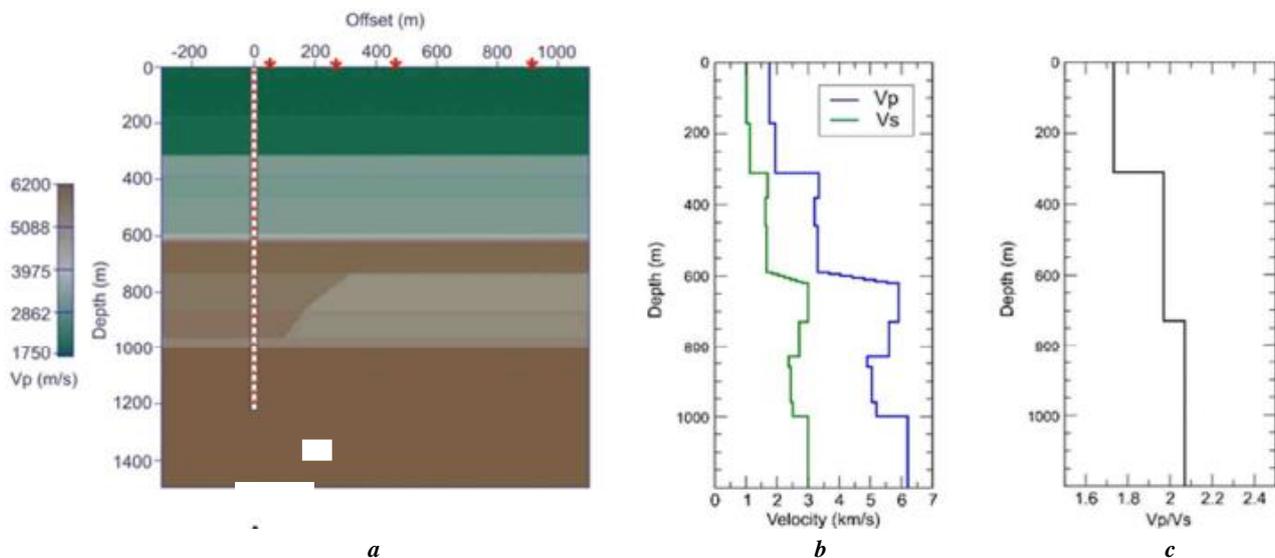
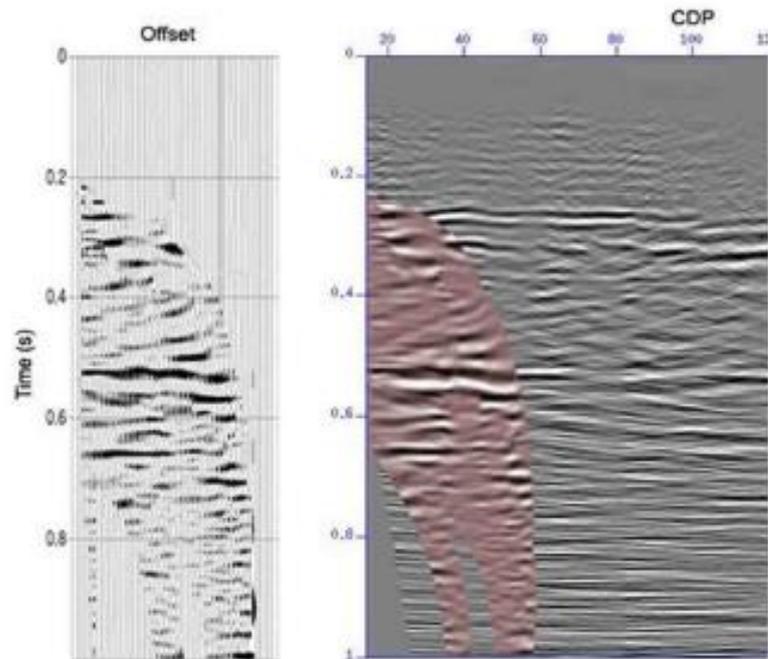


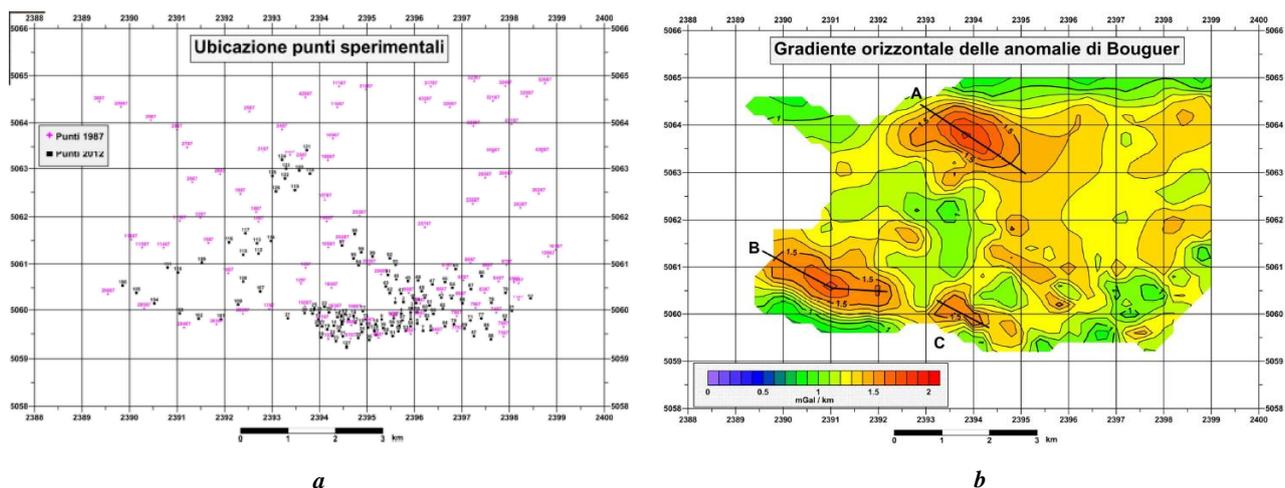
Figure 5. a) 2D velocity model estimated by minimizing the error-energy of the offset VSP travel-times. b) Compressional ( $V_p$ ) and shear ( $V_s$ ) velocity profiles. c)  $V_p/V_s$  ratio (after Poletto et al., 2013).

Finally, we calculated multi-offset time and depth sections and reflection imaging by separating and deconvolving the rotated up- and down-going wavefields. An example is shown in Figure 6.



**Figure 6.** On the left side there is a multi-offset VSP time section which is superimposed to the seismic line G13 (marked in red) in the right side (modified after Poletto et al., 2013).

Starting from 1987, gravity data were collected in the area by the Trieste University (Della Vedova et al., 1988). Moreover, in order to improve the spatial coverage of those data, new measurements were acquired in the framework of this integrated project by using 108 stations along the three seismic lines, spaced every 50 m, and 121 stations placed in the surrounding Grado area. In the new survey, the same LaCoste&Romberg mod. D instrument was used, equipped with a feedback system in order to increase the acquisition quality. Figure 7a shows the location of the gravity stations used in 1987 (pink crosses) and in 2012 (black squares). Starting from the 2D interpretations of the seismic lines and using the horizontal gradient of the Bouguer anomaly (Figure 7b) it was possible to map structural lineations and perform a 3D characterization. The axis of major anomalies, indicated as A, B and C in Figure 7b can be correlated with the frontal Dinaric thrust system, NW-SE oriented, bounded by orthogonal strike-slip transfer faults. The joint data interpretation was used as a basis for the choice of the Grado2-well location (Della Vedova et al., 2015).



**Figure 7.** a) Gravity data acquisition map with the location of the stations used in 1987 (pink crosses) and in 2012 (black squares). b) Horizontal gradient of the Bouguer anomaly. The black lines, named A, B and C indicate the axis of major anomalies.

### 3. SWD GEOTHERMAL APPLICATION IN MEDIUM-ENTHALPY AREA

Another OGS experience was the use of seismic-while-drilling (SWD) method and automated technology driven by drilling parameters for a geothermal-adapted application in a medium-enthalpy area in Nevada (Poletto et al., 2011a, b, c). This SWD method uses the vibrations generated by the drilling bit to obtain seismic data, which can be analyzed, while and after drilling, to provide geological information ahead and around the well (Poletto and Miranda, 2004). The drill-bit noise is typically acquired by multichannel lines deployed on the surface and by reference sensors (pilots) at the rig. Reverse vertical seismic profiles (RVSP) are obtained by crosscorrelating the surface data with the pilot signal and further deconvolving the data (Poletto and Miranda, 2004). The SWD RVSP are useful to better characterize and predict geothermal reservoirs and to provide information to locate possible faults and geological anomalies (Poletto et al., 2011b). The use of SWD technique helps to guide the perforation without interfering with the while drilling operations and losing rig-time

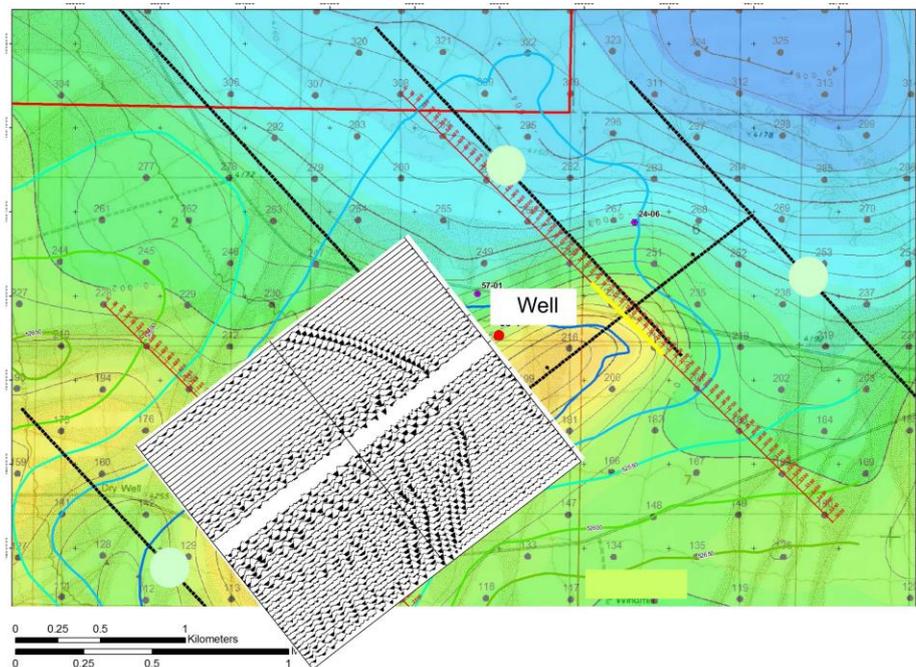
(Poletto and Miranda, 2004). Moreover, it is advantageous in geothermal high-temperature (HT) wells since it uses only surface sensors, therefore, no downhole electronics and recording tools are needed, which can be problematic especially in geothermal wells.

The geothermal survey was carried out in an exploration well drilled in the Gabbs Valley (NV), part of a trans-tensional zone characterized by the presence of a major NW trending strike slip faults, which gives rise to complex patterns and structures on the small scale (Faulds et al., 2005). The well is close to a NE striking normal fault that connects the right-lateral faults because the hydrothermal fluids up-flow is likely to occur around fractures and fault intersections. The aim of the Nevada acquisitions was to provide geophysical data to characterize the area ahead and around the bit, obtain information about main fault location and image the surrounding structural geological setting in the presence of complex structural conditions. The survey layout, SWD migration and interferometry imaging including tomographic travel-time inversion results are described in Poletto et al. (2011a, b, c).

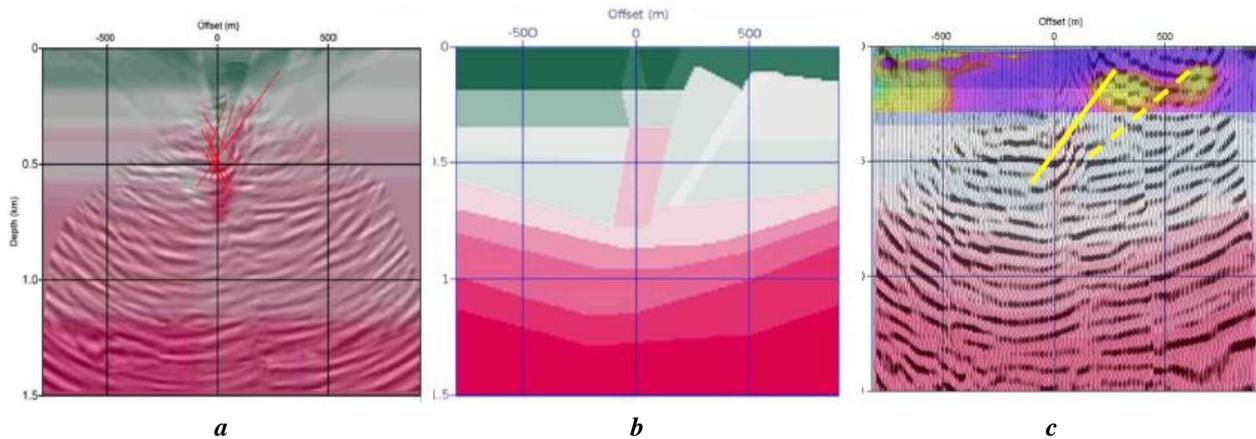
The adopted method takes the advantage of the SWD geometry characteristics which allow us to observe buried objects and normal structural settings using the bit source from lateral positions in depth and the surface receiver stations along the offset. Since no previous surface seismic reflection lines were acquired, two cross-lines of geophones, to monitor normal and lateral structures, were used. The layout was designed basing on the available geophysical (gravity) and geological information. The SWD system, hosted in and connected to the mudlogging cabin, recorded automatically the drill-bit data during near-vertical drilling in the depth range of 180 -750 m with roller cone bits. Surface pilot signals, measured at the top of the drill string, were used to obtain the SWD interpretable data. Acquisition was supported by in field data quality control (QC), and real-time remote QC from OGS headquarters (Italy) via satellite connection. We collected good quality data showing significant variations related to the complex geological area.

Figure 8 shows the SWD shot acquired along the main recording line overlapping the gravity map used to design the acquisition layout. The drilling results confirmed the main seismic events identified while drilling and corresponding to transitions between sandy alluvium, intrusive volcanic, quartzite, silicified and tuff formations (Poletto et al., 2011a, b, c).

**Figure 8.** SWD shot acquired along the main recording line which is perpendicular to the principal fault system, superimposed on the gravity map used to design the layout of the survey (after Poletto et al., 2011a).



A 2D seismic model, around the well, was iteratively designed on the basis of the picked first-breaks analysis and the further support of the tomographic inversion based on the measured travel-times. This allowed the identification of main faults along the drilling path. The model was then adopted to migrate in depth the SWD up-going reflection data using compressional signal component after separating and mitigating wavefields from the converted wave components. Moreover, the SWD data were redatumed using the seismic-interferometry approach in order to increase the seismic information below the surface recording line, and provide more structural details in the shallower part. Figures 9a and b show the SWD depth migration on which tomography results and faults interpretations (from borehole data measured after drilling) are superimposed and the 2D velocity model below the main SWD recording line, respectively. In Figure 9c it is possible to observe the combined result of the inversion, interferometry migration signals together with the SWD migrated results (after Poletto et al., 2011a, b), where main faults are interpreted along and in proximity of the well, and compared to magneto telluric results showing (yellow) the shallow location of the fault zones.



**Figure 9.** a) Tomography result and faults system (red lines) interpretation from well data measured after drilling, superimposed on the SWD data migration. b) 2D velocity model below the main SWD seismic line, used for data migration. c) magneto-telluric results superimposed on the combination of RVSP SWD migration and SWD interferometry (after Poletto et al., 2011a, b).

While-drilling signals were further analyzed to interpret diffraction-shaped events as markers and indicators of expected faults near the well location (Poletto et al., 2011c). These signals are observable already in the field shots (e.g., Figure 8). The analysis of the drill-bit SWD data performed both while and after drilling upholds the method potentiality in characterizing normal-fault systems, especially in the presence of preliminary existing geological and geophysical information. The joint analysis of SWD and other shallow refraction and reflection seismic data obtainable along the same recording lines of the SWD survey can be useful for while-drilling target-fault location in a geothermal reservoir.

#### 4. OTHER APPLICATIONS AND ONGOING RESEARCH

The improvements in new drilling technologies allow the exploration of geothermal reservoirs to be more economic and feasible. In deep and hard formation, for example, the drilling speed of rate (ROP) of bits like roller cone and PDC suffer. A new technology is the down-to-hole (DTH) hydraulic water hammer which allows fast drilling of hard rocks down to potentially any depth (Wittig and Bracke, 2012; Wittig et al., 2015). This bit generates axial signals with high energy useful and suitable for seismic-while-drilling purposes (Poletto et al., 2015). A seismic while drilling experiment, described by Poletto et al. (2015), was done in a shallow well drilled at the GBZ test site using a DTH fluid hammer and the SWD technology to acquire seismic data. The axial percussive noise produced by the DTH hammer operates as a source for SWD data production and interpretation after processing. The results show the potentiality of the innovative DTH application of the SWD method with this percussion source.

In order to study the wave motion in high-enthalpy melting areas, such as the brittle-ductile transition zones, Carcione et al. (2013) developed an algorithm based on the Burgers mechanical model which takes into account the anelastic behaviour to describe the seismic attenuation and steady-state creep flow. They simulate wave propagation in heterogeneous media in the presence of brittle-ductile transition, assuming isotropy and plane strain conditions and writing the differential equations of motion for 2D P-S and SH waves. To solve the differential equations in the time domain they used the memory variables and a direct grid method based on the Runge-Kutta method for the time discretization and the Fourier method for the spatial discretization (Carcione, 2015).

#### 5. CONCLUSIONS

We present some of the relevant OGS experiences and results in the geophysical investigation for geothermal purposes. The work includes the characterization of low, medium and high enthalpy geothermal systems. Some of these studies and applications have gained from the capability of using methods and technologies derived from our working experience with oil and gas industry. We underline as key aspect the importance of the use of the interdisciplinary approach, by integrating the results from different geophysical methods, including seismic modelling, for the characterization of complex fractured geothermal reservoirs.

#### REFERENCES

- Carcione J. (2015) – Wave fields in real media: Wave propagation in anisotropic, anelastic, porous and electromagnetic media. Handbook of Geophysical exploration, vol. 38, Elsevier (3<sup>rd</sup> edition, revised and extended).
- Carcione J. and Poletto F. (2013) – Seismic rheological model and reflection coefficients of the brittle-ductile transition. Pure Appl. Geophys., 170, 2021-2035.
- Carcione J., Poletto F., Farina B., Craglietto A. (2013) – Simulation of seismic waves at the earth's crust (brittle-ductile transition) based on the Burgers model. Solid Earth, 5, 1001-1010.
- Della Vedova B., Marson I., Palmieri F. (1988) - Gravity study of a low enthalpy hydrothermal area: Grado Lagoon-NE Italy. European Geophysical Society-XIII General Assembly, Annales Geophysicae, Special Issue.

- Della Vedova B., Petronio L., Poletto F., Palmieri F., Marcon A. (2013) - Reservoir characterization for the completion of the geothermal district heating system in Grado (NE Italy). Proceedings of the European Geothermal Congress 2013, Pisa, Italy.
- Della Vedova B., Petronio L., Poletto F., Palmieri F., Marcon A., Corubolo P., Farina B., Cimolino A., Bellezza C. (2015) - The Geothermal District Heating System on the Grado Island (North - eastern Adriatic Sea). Proceedings World Geothermal Congress 2015. Melbourne, Australia, 19 - 25 April 2015.
- Faulds J. E., Henry C. D., Hinz N. H. (2005) - Kinematics of the northern Walker Lane: An incipient transform fault along the Pacific-North American plate boundary. *Geology*, 33, 505-508.
- Hauge P. S. (1981) - Measurements of attenuation from vertical seismic profiles. *Geophysics*, 46 (11), 1548-1558.
- Petronio L., Poletto F., Palmieri F., Della Vedova B. (2012) - Geophysical investigations of the Grado deep structures (NE Italy) for the location of the second geothermal borehole. G.N.G.T.S. 31° Convegno Nazionale, Sessione 3.1, 28-33.
- Poletto F. and Miranda F. (2004) - Seismic while drilling. *Fundamentals of drill-bit seismic for exploration*. Elsevier, Pergamon, vol 35.
- Poletto F., Corubolo P., Farina B., Schleifer A., Pollard J., Peronio M., Böhm G. (2011a) - Drill-bit SWD and seismic interferometry for imaging around geothermal wells. 81<sup>st</sup> International Meeting, SEG, Expanded Abstracts.
- Poletto F., Corubolo P., Schleifer A., Farina B., Pollard J., Grozdanich B. (2011b) - Seismic While Drilling for Geophysical Exploration in a Geothermal Well. *Geothermal Resources Council Transactions*, 35, 1737-1741.
- Poletto F., Farina B., Corubolo P. (2011c) - While-drilling and Post-drilling Analysis of Drill-bit Seismic Signals of a Geothermal-well Survey. 1<sup>st</sup> EAGE Sustainable Earth Sciences (SES) Conference and Exhibition.
- Poletto F., Corubolo P., Farina B., Schleifer A., Petronio L., Della Vedova B. (2013) - Multi-offset VSP for the integrated geophysical characterization of the Grado (NE Italy) carbonatic reservoir. Proceedings of the European Geothermal Congress 2013, Pisa, Italy.
- Poletto F., Wittig V., Schleifer A., Bracke R. (2015) – Hydraulic DTH fluid hammer drilling as a seismic while drilling (SWD) source for geothermal exploration and drilling prediction. Proceedings World Geothermal Congress 2015, Melbourne, Australia.
- Wittig V. and Bracke R. (2012) – DTH fluid hammer drilling developments and latest R&D activities at GZB in Bochum. International Geothermal Conference “GeoTherm” in Offenburg, Germany.
- Wittig V., Riechers J., Lincke J., Hyun-Ick Y. (2015) – Hydraulic DTH Fluid / Mud Hammers with Recirculation Capabilities to Improve ROP and Hole Cleaning For Deep, Hard Rock Geothermal Drilling. Proceedings World Geothermal Congress 2015, Melbourne, Australia.

## Geothermal Reservoir Characterization and Management

ANTICS Miklos<sup>1</sup> and UNGEMACH Pierre<sup>1</sup>

<sup>1</sup> GPC IP - Gpc Instrumentation - Process, Paris Nord 2 - Roissy CDG Cedex, France

Corresponding authors' e-mail: [m.antics@geoproduction.fr](mailto:m.antics@geoproduction.fr), [pierre.ungemach@geoproduction.fr](mailto:pierre.ungemach@geoproduction.fr)

**Keywords:** geothermal energy, reservoir exploration - simulation - assessment, management, sustainability.

### ABSTRACT

From surface reconnaissance to reservoir management and from expectations to achievements, is an interactive process integrating the following segments and benchmarks:

- exploration, data processing and imaging,
- geostatistics, geomodelling and assessment of conceptual model,
- reservoir simulation,
- drilling targeting and assessment, well and reservoir engineering,
- planning/implementation of a heat extraction and injection strategy,
- heat development, maintenance and monitoring,
- reservoir management troubleshooting.

The foregoing will be echoed by field examples and outputs from currently operated modelling suites.

### 1. INTRODUCTION

The stream from surface reconnaissance to reservoir management, from expectations to achievements, is an interactive process integrating the segments and benchmarks displayed in Figure 1 flowchart, which highlights the phases itemized below.

- surface/subsurface exploration geology, hydrogeology, geochemistry and geophysics (MT, seismic) data processing and imaging,
- geostatistics, structural geomodelling and assessment of a relevant conceptual model,
- import into a numerical model simulating heat and mass transfers within the reservoir,
- well targeting by optimizing drilling locations and trajectories,
- direct drilling assessment, well testing and reservoir engineering,
- planning/implementation of a sustainable heat extraction and injection strategy,
- heat farming development, operation, maintenance and monitoring policies,
- reservoir management troubleshooting (pressure/temperature depletion, corrosion/scaling shortcomings, well longevities, induced seismicity),

The foregoing will be echoed by selected field examples and outputs from currently operated modelling suites, emphasizing the conceptual modelling, reservoir assessment, reservoir simulation, sustainable management and EGS issues.

### 2. CONCEPTUAL MODELLING

Once surface and subsurface exploration is completed, direct drilling assessment comes into play. It requires a preliminary so - called generic conceptual model to properly assign drilling localities, which, after due well completion, logging, testing and sampling, should validate the conceptual model thus setting the bases for further reservoir assessment and simulation stages.

The geothermal energy panorama offers a wide range of petrographic, structural, tectonic and fluid environments, of which selected representative samples are portrayed in Figure 2.

Figure 2a depicts a volcano - tectonic subduction structure (island arc) typical of most high enthalpy hydrothermal resources worldwide. Here a submittal caldera collapse, overlying a, supposed close, magma chamber gives rise to a number of shows (fumaroles, steam jets, geochemical alterations and deposits) which, after drilling, evidenced a dual reservoir structure, another distinctive attribute of such settings.

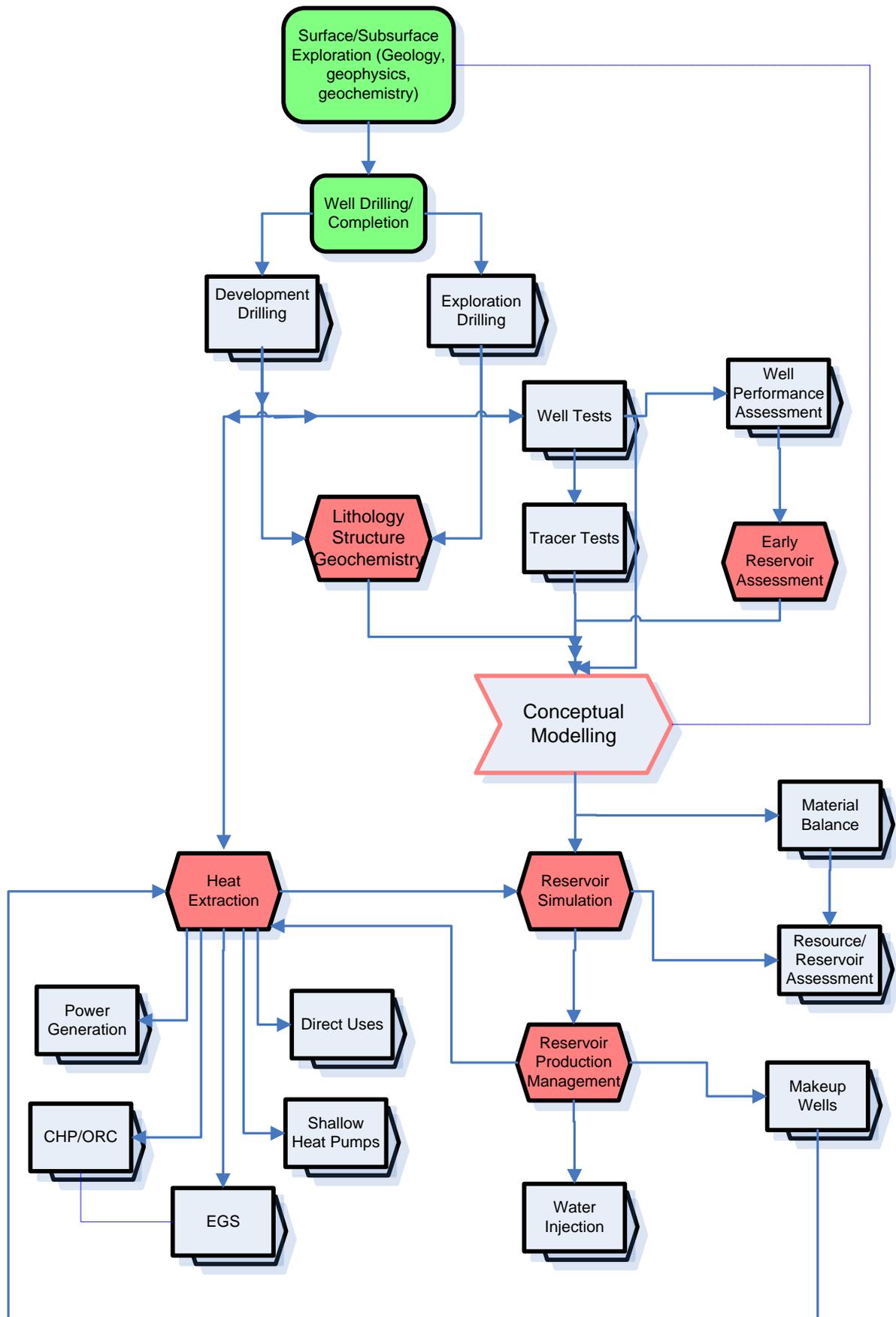
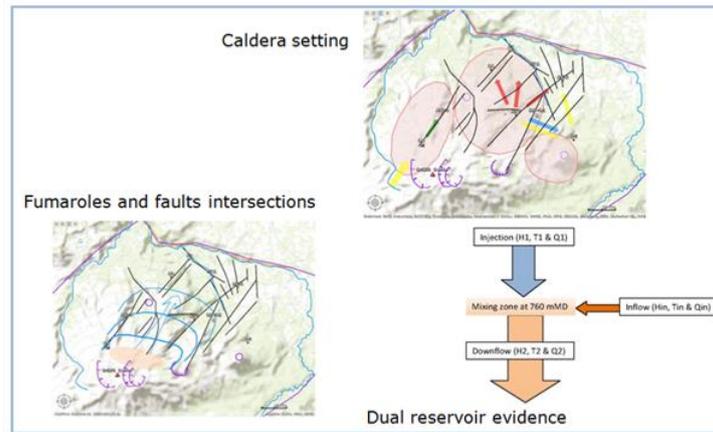


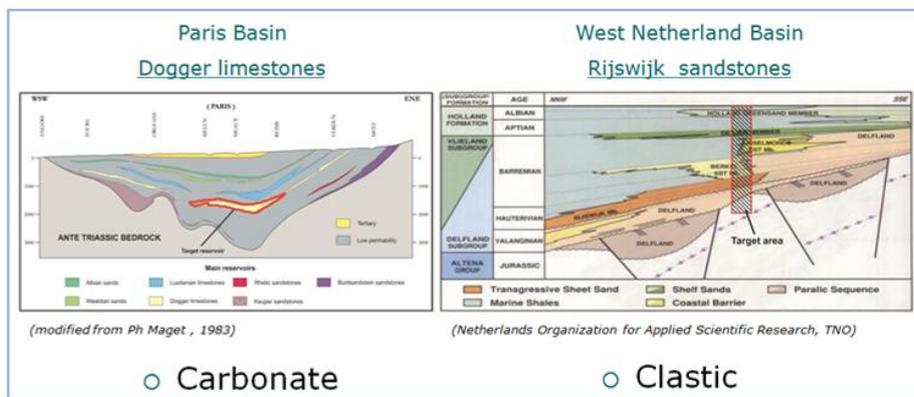
Figure 1. From exploration to production: an engineering chain.

Figure 2b illustrated two contrasts sedimentary environments, respectively marine/carbonate and continental/clastic ones. While the Paris Basin carbonates (Jurassic age) exhibit a fairly regular saucer type, intracratonic subsiding sedimentation, the West Netherland Basin Permo - Triassic clastics to the contrary demonstrate frequent, fault affected, lateral facies changes characteristic of a folded basin structural framework.

Figure 2c shows a series of fault block compartmented reservoirs taking place in the Upper Rhine Graben continental rift valley, a tectonically and seismically active area that hosts several innovative geothermal EGS, hydrothermal and CHP undertakings.



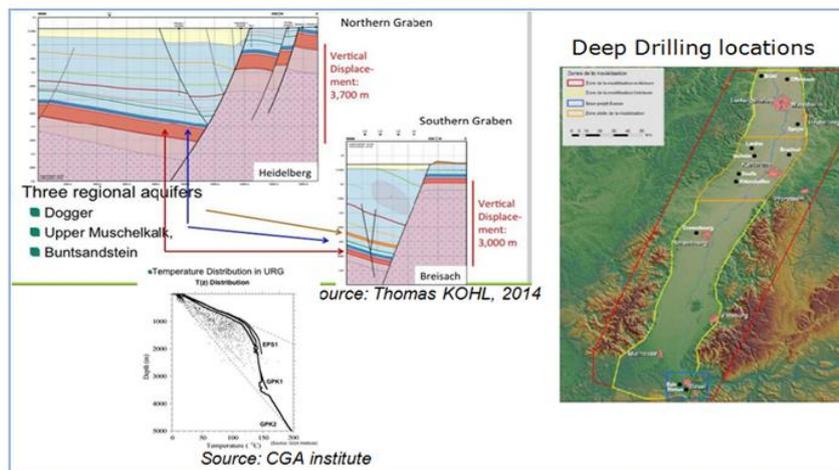
**A. Volcano-tectonic subduction environment**



○ Carbonate

○ Clastic

**B. Two contrasted sedimentary environments**



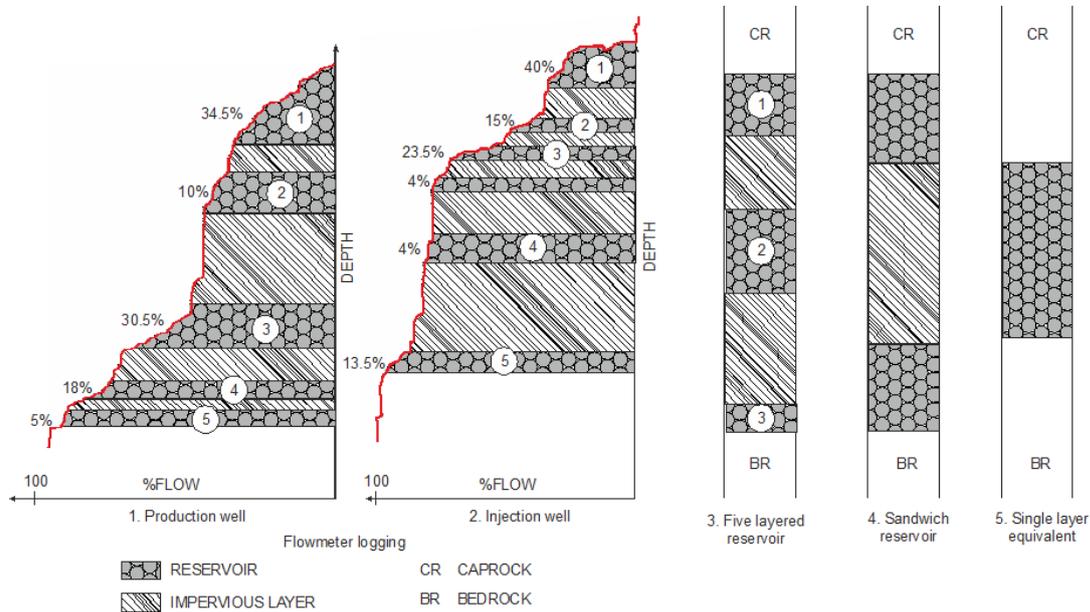
**C. Upper Rhine Graben continental rift active tectonics system**

Figure 2. Conceptual modelling for 3 selected representative samples with different petrographic, structural, tectonic and fluid environments.

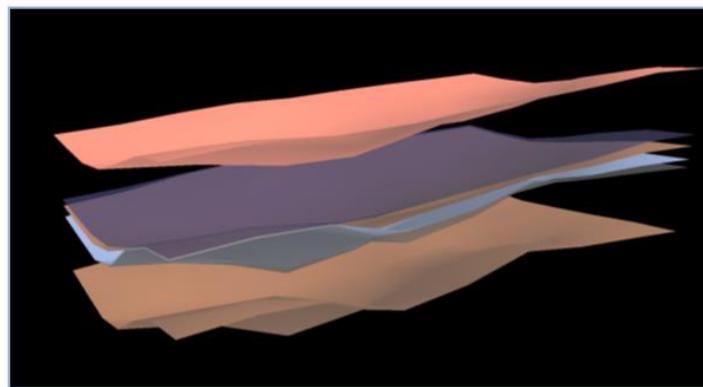
### 3. RESERVOIR ASSESSMENT

Assessing the reservoir most often consists of refining, if not reassessing, the conceptual model, based on updated drilling/logging/testing information and geophysics (seismics, MT) reprocessing.

A sample of such a (re)assessment exercise is exemplified in Figure 3. The idea here was to design a structural equivalence to the asymmetrical multilayered stratified reservoir described in Figure 2, which, although simplifying the actual reservoir structure, could reliably simulate its hydrothermal (particularly its cooling kinetics) behaviour. The sandwich equivalence proved in this respect rewarding, saving in particular considerable computer time in further simulation runs. The Figure 3b geomodel, accounting for reservoir heterogeneities (layering thicknesses and permeability), may therefore be exported to the reservoir simulation package.



#### A. Layering impact & candidate reservoir equivalences



#### B. 3D structural geomodel of the Sandwich reservoir equivalence

Figure 3. Example of refining design of the conceptual model for the reservoir assessment.

### 4. RESERVOIR SIMULATION

Geothermal reservoir simulation aims basically at solving by numerical techniques the set of simultaneous PDEs (Partial differential equations) and related equations of state and boundary/initial conditions governing the mass and heat transfers in the reservoir in view of:

- checking the consistency of the conceptual model,
- assessing reservoir structure, resource status, flow patterns and discharge/recharge mechanisms, and
- last but not least, optimizing field development in a, preferably, sustainable reservoir management perspective.

Accordingly, it has become, over the past decades, a standard, widely used, reservoir evaluation tool, whose methodology conforms to the interactive sequence sketched in Figure 4a flow chart.

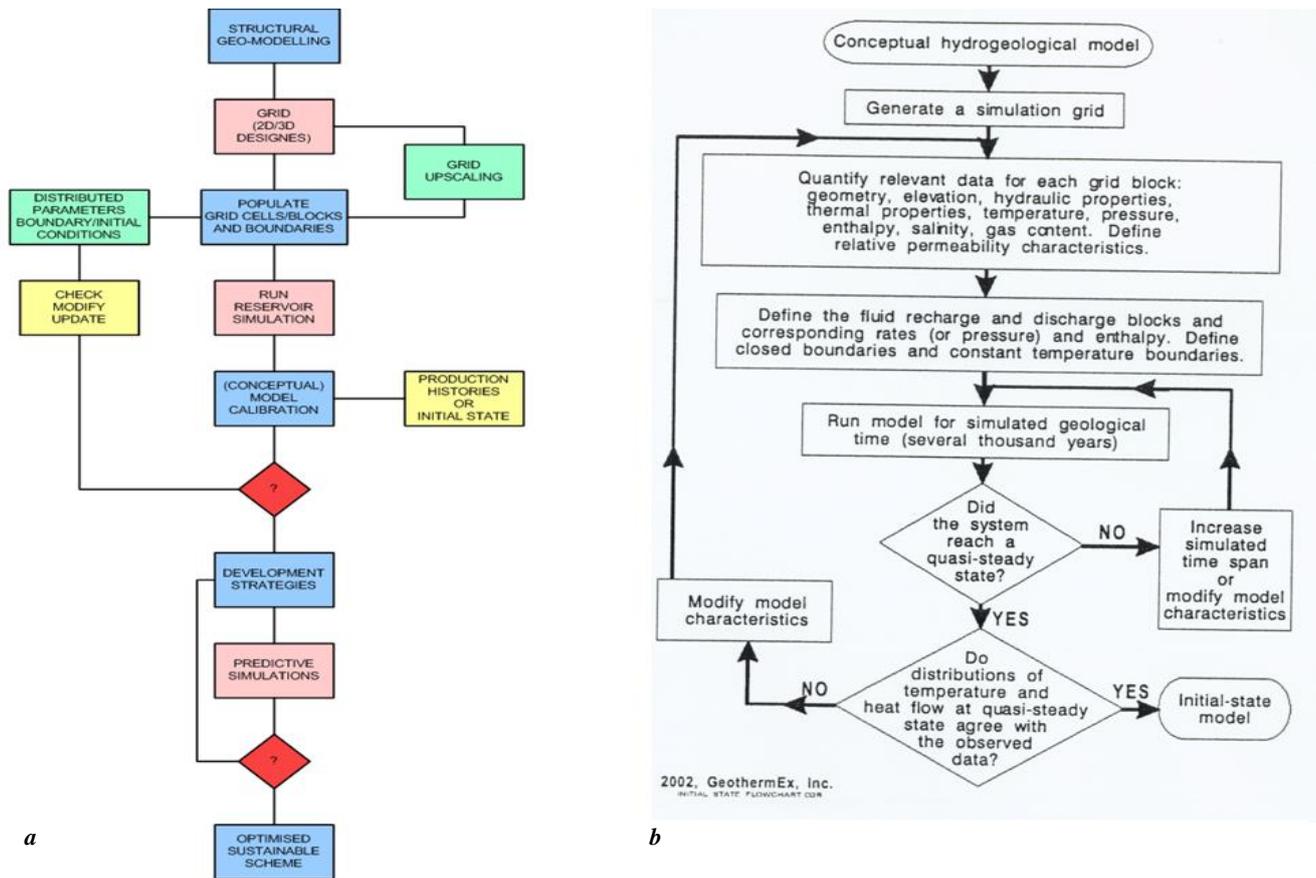


Figure 4. Reservoir simulation methodology. a) Modelling/simulation sequence. b) Natural state modelling flow chart (source: Sanyal and Lu, 2004).

It should be readily stressed here that the elaboration of a relevant conceptual model of the reservoir is, whatever the degree of sophistication of the *applied – deterministic vs. probabilistic*, forward or inversion – modelling techniques, of utmost importance in securing further simulation and assessment stages.

Hence, a reliable interpretation of all field data collected from surface/subsurface geological, hydrogeological, geophysical, geochemical surveys, drilling/logging/testing, tracer tests and their integration into a comprehensive conceptual model, imaging reservoir structure and extent, major flow paths, intake/outflow zones and temperature patterns, is a major consideration for the reservoir engineer.

Natural state modelling and model calibration phases come next. Natural state modelling often requires repeated simulation runs over long periods, several thousand years or more, until the system reaches steady state. The next step consists of matching model temperature and flow outputs against measured data according to the modelling methodology summarized in Figure 4b.

Interpolation of measured field data (temperature, pressure, enthalpies) and parameters (permeability, porosity...) is generally performed by means of statistical (Kriging) methods available from routine computer software.

Model calibration is a similar, history matching, trial and error process, carried out under transient conditions provided by well (production, pressure, enthalpy, non condensable gas contents, ...) exploitation records. It enables to assign the most consistent field parameter distribution according to a best - fit criterion between computed and recorded well data. The latter suggests parameter inversion techniques, widely applied in geophysical data processing, based on minimizing of differences between *computed vs. observed* field patterns be implemented instead of the current, somewhat tedious, forward (direct) trial and error parameter adjustment practice. As a matter of fact, most geothermal modellers have resisted so far this appealing trend preferring to rely on, physically dependable, conceptual and natural state models. They should not be blamed for that.

Figure 5 images predictive model parametering and input/output files implemented in current reservoir simulation practice.

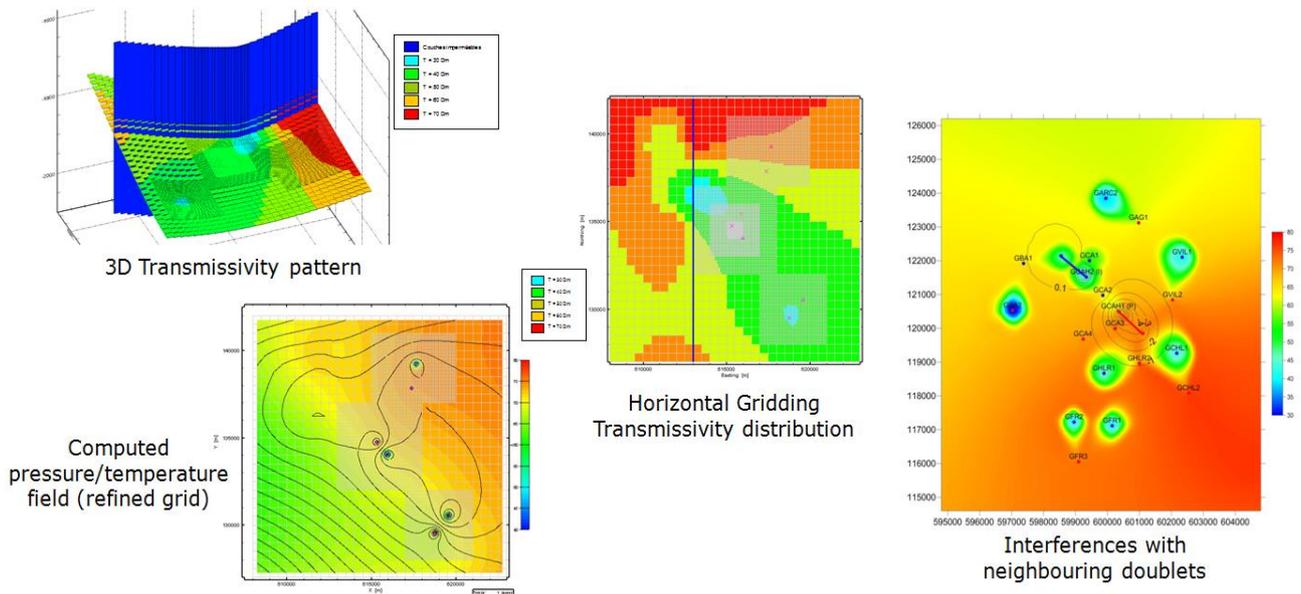


Figure 5. Example of predictive simulation parameters and outputs.

## 5. SUSTAINABILITY

Sustainable reservoir management ranks among the priority reservoir simulation goals.

It therefore addresses essentially reservoir life and hydrothermal interference concerns.

Hence well architectures, and trajectories should (i) prolong well/thermal life, by delaying accordingly reservoir cooling kinetics induced by cold water injection, and (ii) minimize inter well hydrothermal (pressure, temperature) interferences. An example of such optimized management is shown in Figure 6.

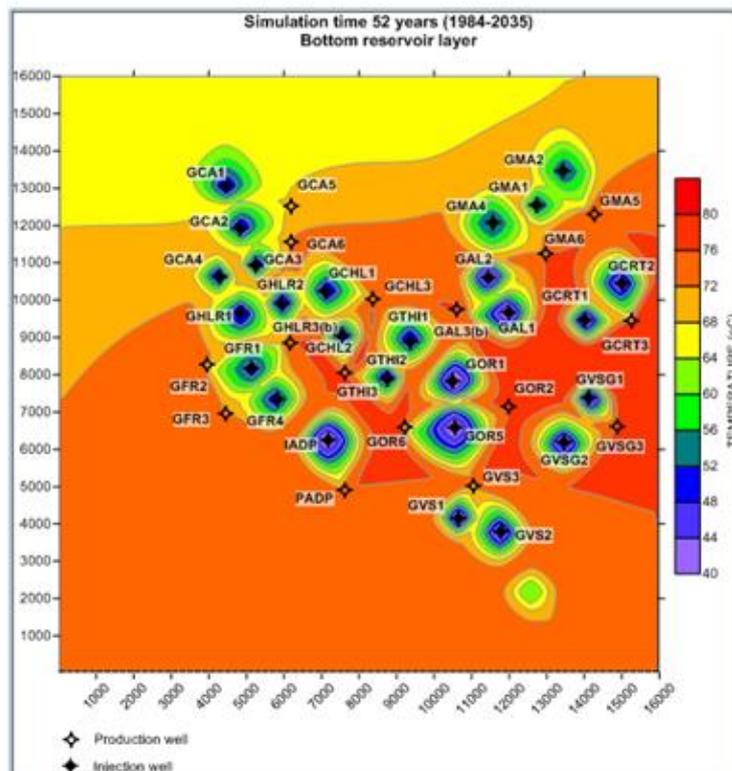


Figure 6. Example of sustainability modelling for the management strategy of a multi doublet/triplet reservoir: 2035 temperature field (source: Papachristou, 2011).

## 6. EGS ISSUES

Modelling of EGS systems proves a complex interactive simulation exercise (Figure 7) with coupled mass/heat transfers and geomechanical processes in hard rock stimulated fractured environments.

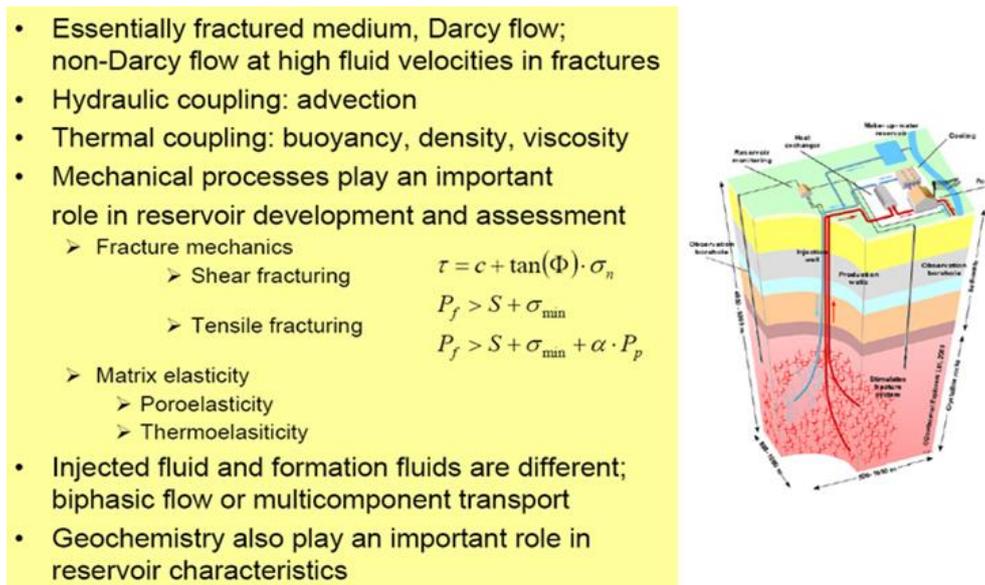


Figure 7. Hydro/thermo/Geomechanical modelling of EGS environments. Involved processes (source: Kohl, 2014).

The future of EGS is the subject of a vast debate. Is EGS future limited to engineering basement rock (crystalline, shale, ...) fractured reservoirs with intrinsically limited power outputs at dissuasive costs or to instead should it address in priority poorly performing hydrothermal environments.

Recent projects experimented in the Upper Rhine Graben shed some light on this problematic. Here the reservoir is hosted at the sedimentary overburden/underlying crystalline weathered basement interface. Whenever naturally fractured and productive the system is labelled hydrothermal, when sealed and poorly productive, thus requiring well stimulation, the system switches to EGS! As a conclusion, EGS is often a matter of wording!

## REFERENCES

- Antics M. and Ungemach P. (2010) - Quantifying Risk in Geothermal Development. The High Enthalpy and the Low Enthalpy Case, Proceeding World Geothermal Congress, WGC 2010, Bali, Indonesia, 25 - 29 April, 2010.
- Kohl T. (2014) - State and Perspectives of the Geothermal Development in the Upper Rhine Graben. Geothermal Conference, Deep Geothermal Days, Paris, 10 - 11 April, 2014.
- Papachristou M. (2011) - The Use of Numerical Simulation in Low Enthalpy Geothermal Reservoir Management. The Paris Basin Case, PHD Thesis, 02 Dec. 2011. Aristotle University, Geology Dpt. Thessaloniki, Greece.
- Sanyal J. and Lu X. X. (2004) - Application of remote sensing in flood management with special reference to monsoon Asia: A review, Natural Hazards. 33, 283 - 301 (Springer).
- Ungemach P., Piemonte C., Antics M., Borozdina O., Promis M.P. (2013) - Geothermal Low Grade Heat Reclamation. A reservoir Engineering Approach. European Geothermal Congress, EGC 2013, Pisa, Italy, 5 - 7, June, 2013.

## Low Temperature Geothermal Applications and Projects in Slovenia

RAJVER Dušan<sup>1</sup>, PRESTOR Joerg<sup>1</sup> and PESTOTNIK Simona<sup>1</sup>

<sup>1</sup> Geological Survey of Slovenia, Ljubljana, Slovenia

Corresponding author's e-mail: [dusan.rajver@geo-zs.si](mailto:dusan.rajver@geo-zs.si)

**Keywords:** geothermal energy, direct uses, geothermal heat pumps, heat pump sector applications, Slovenia.

### ABSTRACT

A small but constant progress was achieved in geothermal development and geothermal direct use during the last five years in Slovenia, especially in its northeastern part, belonging to the Pannonian Basin. New geothermal boreholes were drilled there with good characteristics and depths between 1.2 and 1.5 km. The one for greenhouse and soil heating of the tomato production has been active since October 2013 at Renkovci while two (a production and reinjection borehole) for the planned district heating of some parts of the Murska Sobota town are after testing phases currently inactive. The installed capacity and annual energy use of 32 users amounted to 67.3 MW<sub>(th)</sub> and 646.7 TJ (status in Dec. 2014), including Renkovci. Greater progress is visible in shallow geothermics, where the number of smaller geothermal heat pump (GHP) units of typically 12 kW was ca. 8202 with 102.6 MW<sub>(th)</sub> capacity and 530.5 TJ/yr energy use (Dec. 2014). The number of greater GHP systems with heat pumps of rated power over 20 kW is in constant increase during the last 5 to 8 years, resulting in 18 MW<sub>(th)</sub> and 87.4 TJ/yr, with some 224 systems accounted for so far, however, there are at least 10 such installed systems, mostly in public or private buildings (schools, kindergartens, factories, etc) with currently unknown data. The total almost complete numbers are 188 MW<sub>(th)</sub> and 1265 TJ/yr. It is expected that trend of energetic renovation of older buildings and installation of the GHP units will continue in future as one of the obligations to reach the renewable energy targets. Some examples of greater GHP systems are presented from five different typical sectors of application of GHP units of greater capacity in the country.

### 1. INTRODUCTION

The electricity production in Slovenia amounting to 16 087 GWh/yr, is based, as of December 2013, on domestic and only partly imported fossil fuels (35.2%), domestic hydropower (30.5%), nuclear power (32.9%), and other renewables (1.4%). Of these, the PV solar units predominate with small hydropower plants following and certain number of other biomass facilities. Very probably, it is not expected that at present state of knowledge any electricity production from geothermal could be realistic by 2020. Only binary technology is promising, but it is also disputable, temporal as well as geologically. The government supports in principle the direct use of geothermal energy through different projects where few leading agencies are involved in geothermal development. The water permits, important for water source geothermal heat pumps, are regulated by the Environmental Agency (ARSO) of the Ministry of Agriculture and the Environment (MKO). Some private companies and energy consulting agencies are involved in demonstration projects for greater geothermal heat pump development. Leading companies and institutes involved in geothermal development are: Petrol - Geoterm Co., Geological Survey of Slovenia, and several small business enterprises. This paper describes the present status of geothermal direct heat use and some examples of different typical sectors of application of GHP units of greater capacity. Geothermal energy use has been statistically followed by Geological Survey of Slovenia on regular basis since 1994 with update reports presented at the World Geothermal Congresses (Rajver et al., 2010, 2015 and references therein). Emphasis of direct use of geothermal energy in Slovenia is on exploitation of low temperature resources for space and district heating, and for thermal spas. During the last 15 years direct use shows only slight increase with exception of the geothermal heat pumps. The reasons depend on the locality. The problems are overexploitation of geothermal resources in some localities of northeastern part of the country (Kralj and Kralj, 2000; Rman et al., 2012; Rman, 2014; Rman et al., 2015 and references therein), occasional technical problems, and weak incentives for efficient use of the resources. An increase of experience is evident at many direct heat users, notably with introduction of heat exchangers and heat pumps for the improvement of using the available heat in a better way, and not to discard it at too high temperature. Geothermal (ground - source) heat pump (GSHP) sector is the only one showing a significant increase. Main geothermal exploration and drilling activity took place recently in the northeastern part for direct use purpose. The activities were oriented in drilling new production and reinjection wells to increase and improve the direct use of geothermal heat, notably for district heating, greenhouses and touristic purposes. However, an intensive introduction of GSHP units of greater capacity is becoming a real chance for improving the energy efficiency of many public and private buildings, which were so far dependent on other mostly fossil energy sources.

### 2. GEOTHERMAL DIRECT HEAT USE

Geothermal utilization is based on direct use from 53 production wells plus 3 thermal springs, implemented at 32 localities, while at two 2 localities (Medijske Toplice and Vrhnika) it has been stopped for unknown time due to economic reasons. Four new direct users emerged since 2009, and two are located in the north - eastern Slovenia (Figure 1). One of them uses the regional Upper Pannonian - Pontian sand and loose sandstone aquifer, while the production well at Benedikt has been

finished into Palaeozoic metamorphic rocks (Kralj, 2009). Geothermal energy is estimated to supply for direct heat uses and GHP units at least 1265 TJ/yr of heat energy (as of Dec. 2014) with corresponding installed capacity of 188 MW<sub>(th)</sub>. Of these values, direct use was 67.3 MW<sub>(th)</sub> and 646.7 TJ/yr, and the remainder (120.6 MW<sub>(th)</sub> and 618 TJ/yr) were GSHP units. The main application of use turns out to be now the GSHPs (48.9%), followed by resort and spa use for space heating (23.3%) and for bathing and swimming (10.7%), as well as for greenhouse and soil heating (13%) (Figure 2). The values for capacity and energy supplied by the GSHP units are pretty close to real numbers despite some difficulties in determining more exact number of small units installed.

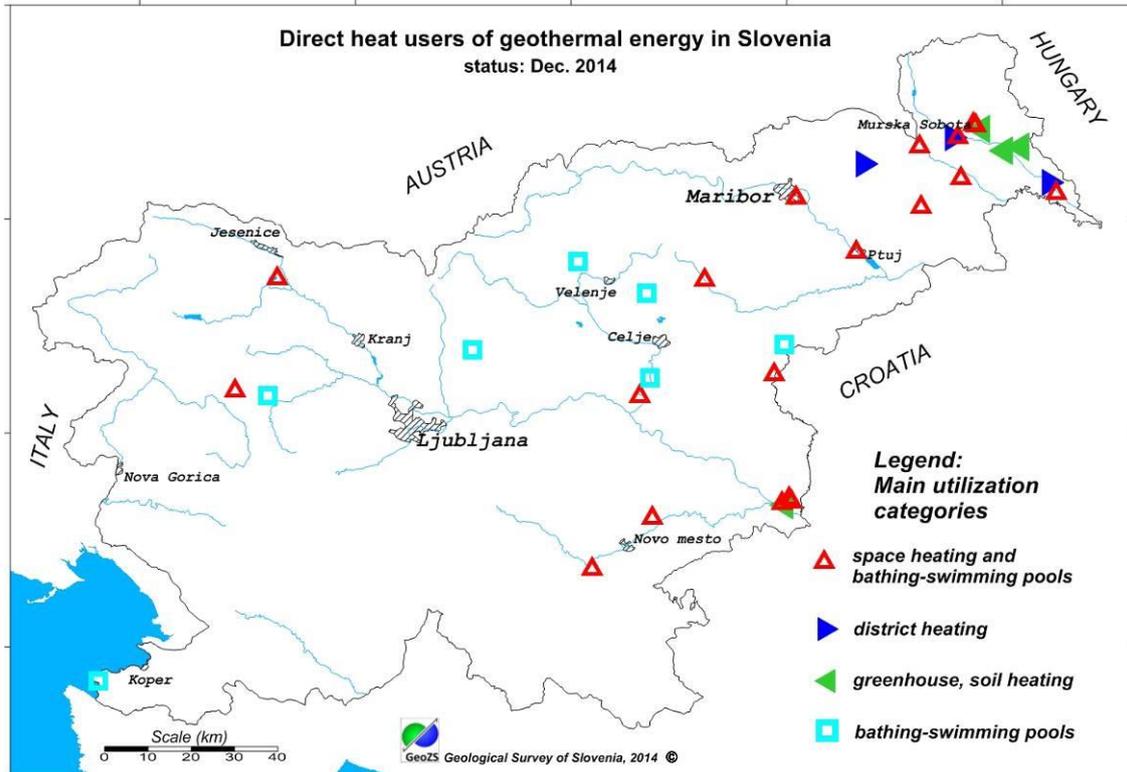


Figure 1. Direct heat users of geothermal energy from thermal water in Slovenia (status Dec. 2014).

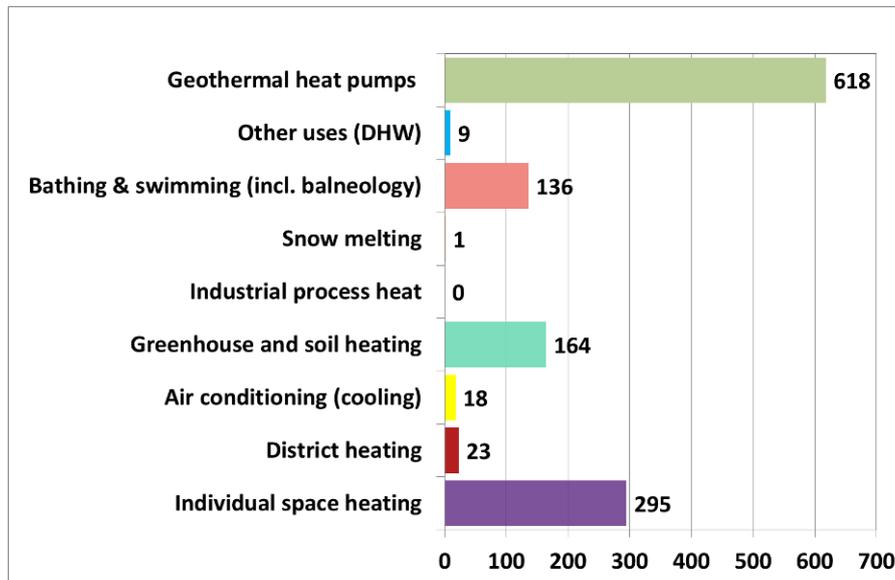


Figure 2. Geothermal energy used in TJ in Slovenia in 2014 by categories of direct use (as of Dec. 2014). DHW: domestic hot water.

### 3. GEOTHERMAL HEAT PUMPS

The number of operational GSHP units in the country is in constant increase since the first statistical report in 1995. Shallow geothermal energy use for space heating and cooling in small decentralized units is becoming more popular and widespread. The market growth in larger scale began obviously during the last ten years following some »lazy« period in the early 1990's, when there was low interest in GSHP units due to high initial costs, high price of electricity and low prices of oil and gas. The ubiquitous heat content within the uppermost part of the Earth crust is available practically everywhere

in Slovenia except in the mountainous regions. Technical, environmental and economic incentives can be considered advantageous for more rapid introduction of GSHP systems in the country. This is also backed by support programs from utilities and from the government through subsidies or credits. These units consist of ground - coupled closed loop heat pumps (horizontal and vertical heat collectors), or groundwater open loop heat pumps, depending on local conditions.

The exact number of GSHP units presently installed in Slovenia is not easy to estimate, since no national statistics are available. The numbers of heat pump sales give basically all the quantity for their estimation, but are difficult to get because domestic producers and numerous merchant agents of imported units are not always willing to give such numbers. The status in December 2013 shows about 8202 small operational GSHP units (typical 12 kW) that extract 530.5 TJ/yr of geothermal heat (Figure 3). Of these, we find that 47% are open - loop systems that extract annually about 278.6 TJ from shallow groundwater, 48% are horizontal closed - loop (215.2 TJ), and 5% are vertical closed - loop systems (36.7 TJ).

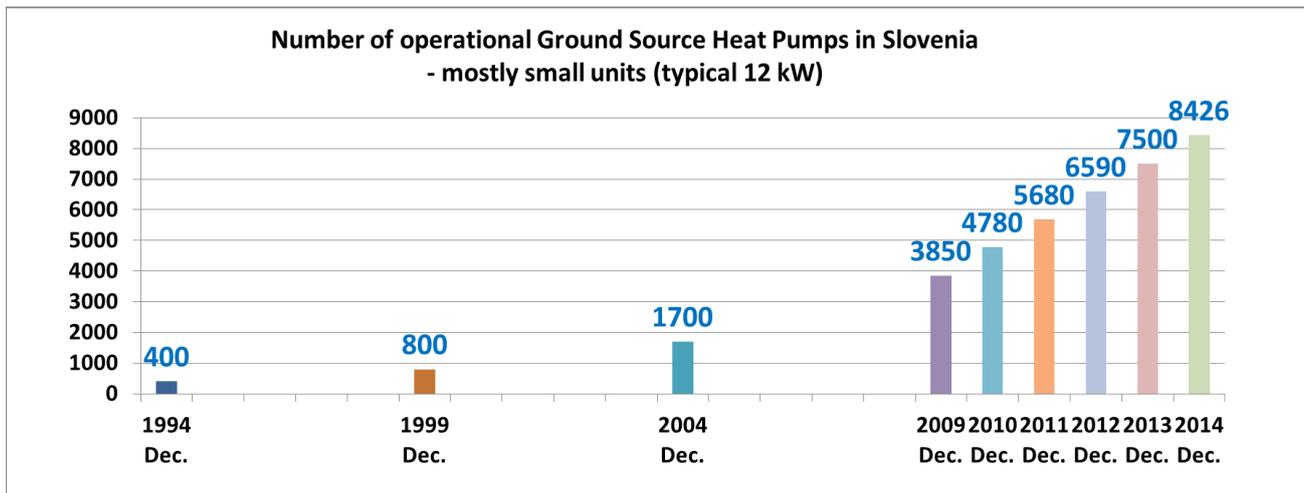


Figure 3. Number of operational GSHPs in Slovenia – small units (typical 12 kW).

Small closed - loop units together remove 251.9 TJ/yr from the ground, while 24.4 TJ/yr of heat is rejected to the ground in the cooling mode, presumably by vertical systems. From the beginning of activity in the 1980's a high increase of number of the GSHP was recorded, which is followed by moderate increase in the last 5 years. Source of data are collected numbers from producers, some energy experts and our trend analysis, however, more reliable numbers are from census in 1994, 2009 - 2010 and from 2014. Their installed thermal capacity amounted to 120.6 MW<sub>(th)</sub> in Dec. 2014 (Figure 4). Domestic HP production is presented by four main producers and three smaller ones, where three domestic producers are specialized also in greater capacity systems. Especially big domestic producers are able to adapt to specific needs.

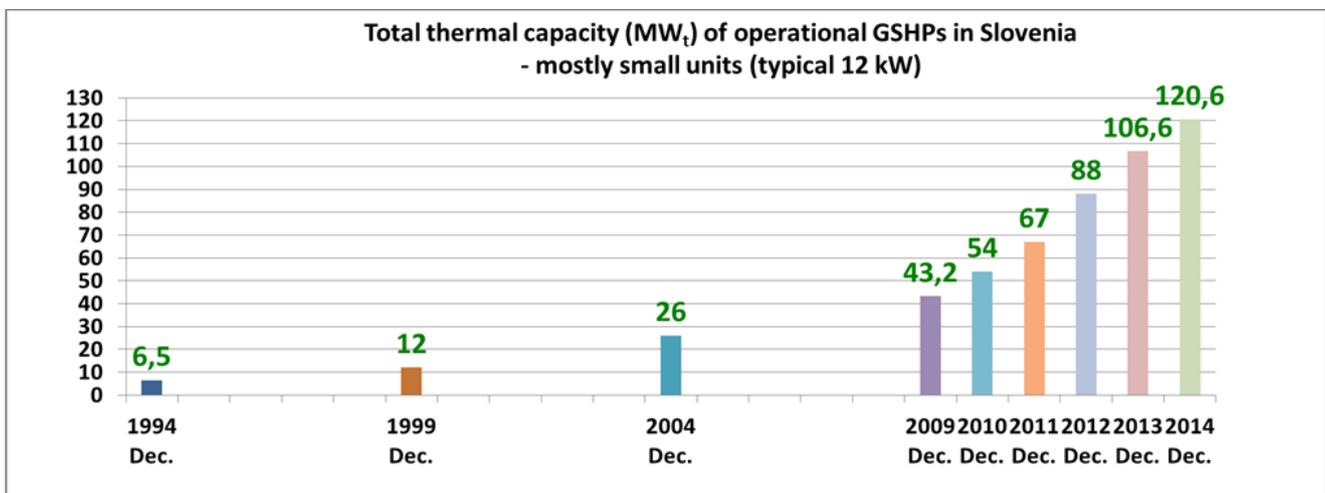


Figure 4. Total thermal capacity [MW<sub>(th)</sub>] of operational GSHPs – small units (typical 12 kW).

There are also greater capacity GSHP units (>20 kW) installed within at least 224 systems in public and other buildings, with total capacity of 18 MW<sub>(th)</sub> and energy use of 87.4 TJ/yr (as of Dec. 2014). Of them 167 are open - loop water - water type, 31 vertical closed - loop, and 26 horizontal closed - loop systems. Typical capacity of the GSHP units in large systems is 20 to 200 kW, with maximum of 816 kW. Capacity factor for the small GSHP units is 16.4%, the lowest among all the application types and for the greater units (>20 kW) is 15.4%, reflecting that small units usually utilize a rather narrow

temperature difference (< 4 deg.) and for individual heating also the shortest time of full load operating hours, which means not more than 6 months with 12 h/day in Slovenian climate conditions, therefore usually less than 2200 h/yr.

### 3.1 Potential for ground - source heat pumps

#### Ground - water systems (GCHPh and GCHPv)

Clastic rocks cover over half of the Slovene territory, carbonate rocks about 40%, while pyroclastic, metamorphic and crystalline rocks less than 8%. As ground - coupled heat pump (GCHP) units, we mean those, which operate in vertical, horizontal, direct expansion or closed loop lake configurations (Lund, 2000). More suitable rocks for horizontal heat exchangers are: sand and sandy clay, flysch rocks such as sandy marls or loose sandstone, sandy claystone. For vertical heat exchangers the most suitable are: dolomite, dolomitic limestone and limestone, and majority of magmatic and metamorphic rocks. Figure 5 shows geological and hydrogeological potential for the GSHP applications in the country. Shallow karstic underground is neither very favourable for vertical systems presenting the uncertainty in drilling, prediction and higher drilling costs.

#### Water - water systems (GSHPw)

Northeastern part of the country (Pannonian basin) appertains to major groundwater basin with relatively high recharge (100 – 300 mm/yr) in Quaternary and shallow Tertiary layers. The rest of the territory has complex hydrogeological structure with very high recharge (> 300 mm/yr). About 7% of territory is covered by extensive and highly productive gravel and sand alluvial aquifers, which are very favourable for open GSHP systems. The major cities are situated on these alluvial plains.

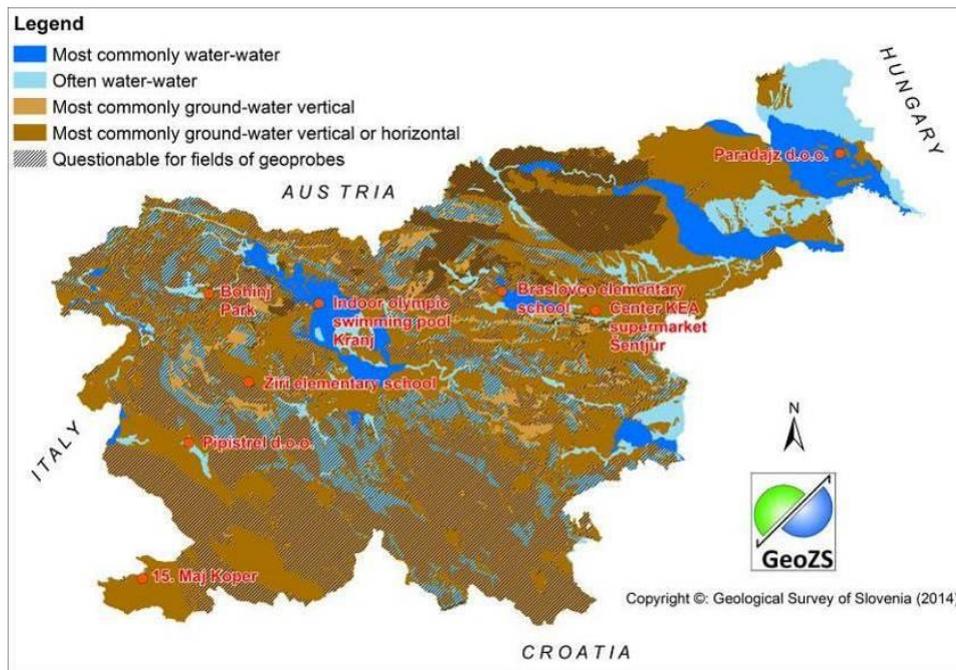


Figure 5. Potential for the GSHP applications in Slovenia (Prestor et al., 2012).

Temperature of groundwater is characteristically between 10 and 15 °C. Groundwater table is 2 to 25 m deep and the water quality is rarely aggressive (see more details in Rajver et al. 2013). Individual open vertical systems can be successfully used also in the areas of inter - granular aquifers of medium hydraulic conductivity and also above the fissured aquifers of medium hydraulic conductivity (dolomitic aquifers). Limestone aquifers cover about 35% of territory, where the groundwater accessibility is rather low and conditions not favourable for open vertical systems. There closed vertical systems are more applicable. Similar conditions are for the other 35% of territory with only minor and discontinuous aquifers (flysch layers, marl, sandstone, siltstone, claystone) where closed vertical and horizontal systems are mostly applicable. Temperature distribution at a depth of 100 m below the surface (Figure 6) shows the best conditions for GSHP systems (mostly >14 °C) in northeastern part, and elsewhere only average temperatures between 8 and 14 °C. In case of deeper geoprobes for closed vertical systems, map of formation temperatures at a depth of 250 m might be also useful (Figure 7).

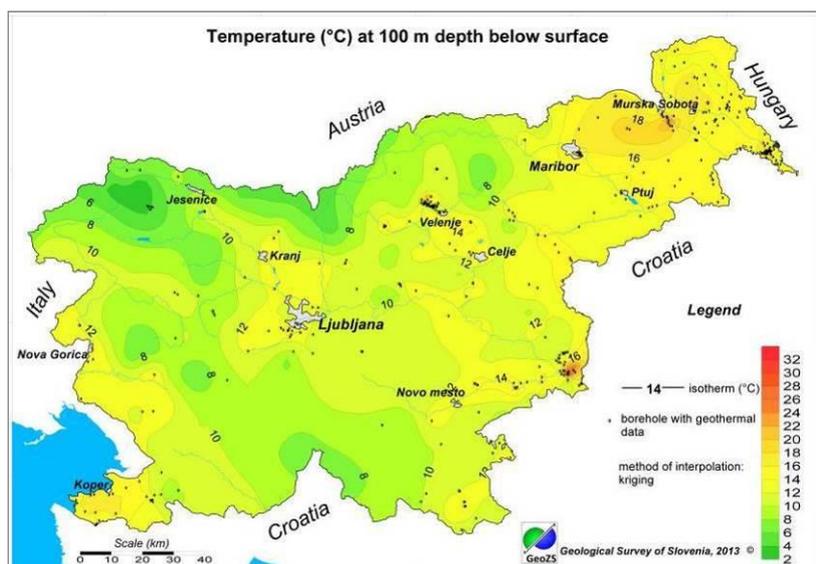


Figure 6. Temperature distribution at 100 m depth below the surface in Slovenia (Rajver et al., 2013).

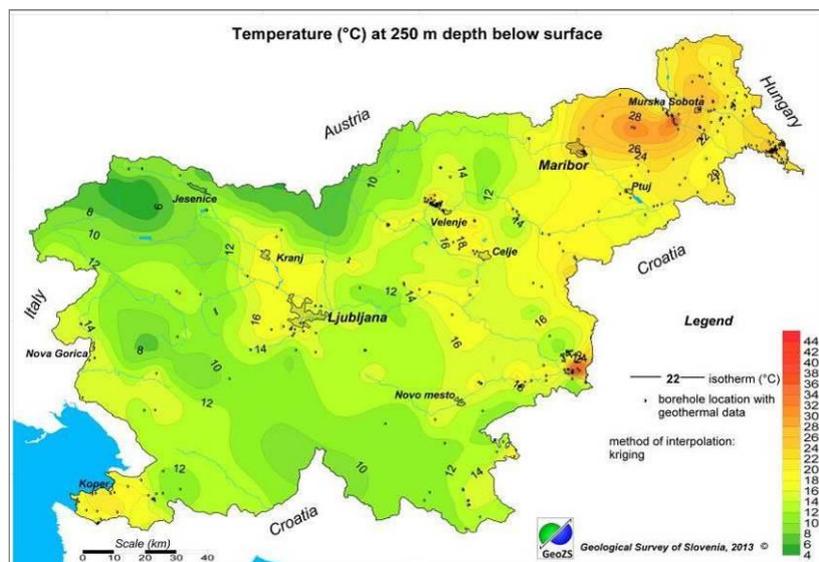


Figure 7. Temperature distribution at 250 m depth below the surface in Slovenia.

### 3.2 GSHP market growth in Slovenia

Shallow geothermal energy use for space heating in small decentralized units in Slovenia is becoming more popular and widespread. The market growth in larger scale began obviously during the last ten years following some »lazy« period in the early 1990's, when there was low interest in GHPs due to high initial costs, high price of electricity and low prices of oil and gas. The ubiquitous heat content within the uppermost part of the Earth crust is available practically everywhere in Slovenia except in the mountainous region. Technical, environmental and economic incentives can be considered advantageous for more rapid introduction of GSHP systems in the country. This is also backed by support programs from utilities and from the government through subsidies or credits. These units consist of ground - coupled closed loop heat pumps (horizontal and vertical heat collectors), or groundwater open loop heat pumps, depending on local conditions.

## 4. TYPICAL SECTORS WITH EXAMPLES OF APPLICATION OF GSHP SYSTEMS

In order to give a picture on suitability of different GSHP installation systems in different geological and geographical conditions, we present one typical example for each of the five chosen application sectors, which are:

- **residential** (single family houses, villas, multifamily houses),
- **recreation** (hotels, spas, farm holidays, swimming pools, sport facilities),
- **agriculture** (greenhouses, wine cellars),
- **public** (schools, kindergartens, theatres, libraries),
- **commercial and industrial** (shopping malls, sheds).

Localities of eight examples are depicted in Figure 5, however only five are described here in detail, the rest three together with some other interesting cases are just mentioned shortly in the last chapter.

#### 4.1 Residential sector: the settlement “15th Maj” in Koper (southwestern Slovenia)

This is the first settlement in the country with cheaper and ecological heating. It is composed of 3 residential buildings with 67 apartments and one commercial building for offices and retail spaces (Figure 8). Total area for heating with radiators is 8800 m<sup>2</sup>. They are situated in a flat area of the city where geological and geothermal conditions are as follows. Soft mud silty soil extends to depth of ca. 30 m with possible flysch rocks as sandstone and marl beneath. The estimated thermal conductivity is ca. 1.9 W/(m·K) for silt and 2.4 W/(m·K) for flysch, for which specific heat extraction rate is about 45 to 50 W/m. The underground temperature is ca. 12 to 15 °C down to 40 m depth, and surface heat flow density (HFD) of the area is 65 mW/m<sup>2</sup>. The buildings are built on 240 foundation piles, which are 32 to 40 m deep and 4 m apart. Of them, 211 are energetic piles, but of them 192 piles are functional energetic piles with 3 - tube loops in each pile, which gives 5 m of tubes/1 m of pile (Figure 9). The main features of the system are: 2 reversible HP modules of 250 kW (5 compressors) and 200 kW (4 compressors). The amount of used renewable energy is 0.47 GWh, with equivalent full load of 1500 hours. The electric power used is 163 kW, and power of compressors is 51 kW.



**Figure 8. Residential buildings of the settlement “15th Maj” in Koper.**

The calculated heating SPF is 3.3, and cooling SPF is 5 to 5.5. The whole investment is just 10% higher than the one would be without the energetic piles.



**Figure 9. An inside look of the energetic foundation pile of the settlement's residential buildings in Koper.**

#### 4.2 Recreation sector: Bohinj Park EKO hotel - Aqua Park in Bohinjska Bistrica (northwestern Slovenia)

This hotel has a heated net floor area of 11 500 m<sup>2</sup> and a brute area of 15 000 m<sup>2</sup>, a garage space (1500 m<sup>2</sup>) is not considered (Figure 10). The hotel uses an open - loop GSHP system from a well BB - 1 drilled in 2008 to a depth of 430 m into main aquifer of Dachstein limestone with dolomite inclusions of Late Triassic age. Geothermal parameters of the well and area show average outflow 7 L/s with T = 13.7 °C, with wellhead pressure of 4 bar. Surface HFD of the area is only 36 mW/m<sup>2</sup>. The system has these main features: 2 HP units with 2 x 238 kW heating power and 2 x 170 kW cooling power for the underfloor heating and heating/cooling beams. The equivalent full load is 1314 hours. The amount of renewable energy supplied by HP technology is 0.766 GWh with SPF 3.5. Use of electricity for hotel and aquapark amounts to 1 940 000 kWh/yr, of which 40% is used for the HP running, and 20% for heating through the HPs. The cooling is carried out by using the water from the well, more precisely, after being used by the HP, it flows cooled to the chilling beams. The costs or savings are up to 30% of primary energy with simultaneous production of heat and electricity.



Figure 10. Bohinj park EKO hotel – Aqua park in Bohinjska Bistrica.

#### 4.3 Agriculture sector: Greenhouse Paradajz d.o.o. in Renkovci (northeastern Slovenia)

The complex Paradajz d.o.o. in Renkovci consists of 4 ha of greenhouses for tomato production (Figure 11). The open-loop system uses thermal water from an exploitation borehole Re - 1g/11, drilled to a depth of 1485 m. Main geothermal aquifer is embedded within the Mura formation of sand and silty sand sections of Pontian age. The screened depth sections are 891 to 1475 m deep. Static temperature and pressure at 1475 m depth is 70.7 °C and 148 bar, respectively. Wellhead temperature of thermal water is 58 to 65 °C, while the outlet temperature from the greenhouse is ca. 30 °C. Water is of NaHCO<sub>3</sub> type, mineralization is 900 mg/l with little gas. Surface HFD of the area is 110 mW/m<sup>2</sup>, typical for the Pannonian basin. The system main features show that water is pumped by submersible pump, then flows to the plate heat exchanger, transfers heat to ordinary water that circulates in a closed system of pipes in the greenhouse, and then cooled down thermal water is discharged into the environment. Thermal energy is provided by geothermal and solar energy. During the lowest temperatures greenhouses are heated also by natural gas. The CO<sub>2</sub> is used to promote photosynthesis. Waste heat is also used and stored. A plan for reinjection exists for the used thermal water, probably into the Fi - 5 borehole.



Figure 11. Paradajz d.o.o. greenhouses in Renkovci.

The costs in the 1st phase were 6 million €, and investments into the greenhouse enlargement 2.9 million €. About 40% are covered by the European funds. Annual tomato production will increase to 3,000 t, which will cover 20% of needs in Slovenia. Since thermal water use started in October 2013, and was still not in full exploitation in 2014, nevertheless data on direct use of geothermal energy in 2014 are close to real exploitation possibilities. Table 1 presents some scenarios of possible geothermal utilization, with the last two rows showing the most realistic cases (average utilization with 10 L/s and maximum annual utilization with 17 L/s).

Flow Rate (kg/s)	Maximum Utilization Temperature (°C)		Capacity (MW <sub>t</sub> )	Annual Utilization		
	Inlet	Outlet		Ave. Flow (kg/s)	Energy (TJ/yr)	Capacity Factor
17	60	30	2,13	5	19,8	0,29
20	60	30	2,51	10	39,6	0,50
17	65	30	2,49	10	46,2	0,59
20	65	30	2,93	15	69,2	0,75
20	65	27	3,18	10	50,1	0,50
20	65	27	3,18	17	85,2	0,85

Table 1. Scenarios of possible geothermal direct energy use of thermal water in Renkovci greenhouse.

**4.4 Public sector: elementary school Braslovče (central Slovenia)**

The closed - loop vertical system at elementary school in Braslovče, a rather small settlement west of Celje, is finished in Quaternary sediments (clay, gravel, sand) and possibly also Oligocene sediments as marly clay below. The estimated thermal conductivity is  $\geq 2.1$  W/(m·K) for sand - gravel with clay and  $\geq 2.2$  W/(m·K) for marly clay. This gives specific heat extraction rate of about 60 W/m. Surface HFD of the area is 54 mW/m<sup>2</sup>. The system main features (including energy parameters) shows there is a HP unit of 158 kW (2 x 79) of heating capacity with 20 borehole heat exchangers (BHEs) of 100 m depth each and 5 m apart. Total electric power is 39 kW, consequently COP is 4.05. The heated net floor area of the school and kindergarten is 4800 m<sup>2</sup> (Figure 12) and that of gym hall is 1000 m<sup>2</sup>. This new system is used for heating (with radiators) and domestic hot water (DHW) preparation, as well as for passive cooling of the gym hall with convectors together with school and kindergarten in the summertime. It is foreseen that the GSHP system will cover 80 to 90% of the heating needs. The amount of renewable energy supplied by HP technology is ca. 0.209 GWh with SPF 3.75 and equivalent full load for heating of 1800 hours.



Figure 12. Elementary school in Braslovče.

Before the renovation the annual use of heating with oil was 50 000 litres (or 504 MWh). Energy improvement investments amounted to 230 700 €, while the payback time is 5 years. The foreseen savings of primary energy for heating will be 373 MWh/yr, or in other words, annual energy consumption should be reduced by 74% (source: VTV Magazine).

**4.5 Commercial & Industrial sector: Pipistrel Research & Development building in Ajdovščina (western Slovenia)**

The Pipistrel Research & Development building is energetically independent and self - sufficient from renewable resources. It is environmentally friendly, with solar power plant and BHEs with thermal field, cogeneration and no emissions. Geothermal parameters important for the BHE installation are as follows: alluvial sediments (sand, clay, gravel) in the upper 30 m, Eocene flysch below (marl and sandstone, breccia, calcarenite and conglomerate). The estimated thermal conductivity is 1.9 W/(m·K) for alluvial and 2.6 W/(m·K) for Eocene rocks. Specific heat extraction rate is about 70 W/m. Surface HFD of the area is 35 mW/m<sup>2</sup>. The system main features are 6 BHEs with 200 m depth each, giving some 14 to 15 kW per BHE (Figure 13). The HP unit has 35 kW heating capacity with 3 hermetically closed compressors. The heated net floor area of the new building measures 2400 m<sup>2</sup>.

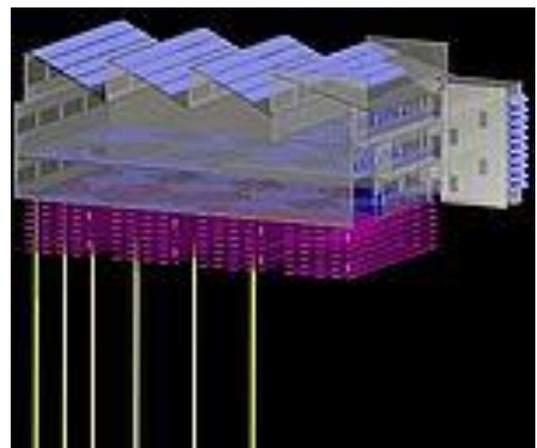


Figure 13. The Pipistrel R & D building with a concept of BHEs field.

Space heating and cooling takes place with SPF for heating of 3.5, and with equivalent full load for heating of about 1500 hours. The amount of renewable energy supplied by HP technology is about 0.039 GWh. In summer the space temperature is cooled down to 15 - 17 °C, while in winter it is heated to 25 - 30 °C, therefore  $dT$  is < 15 °C. Heating and cooling was established in an innovative and efficient manner using ground radiation. This allows for the minimum possible temperature difference between highest and lowest water temperature in the building and yields maximum efficiencies and savings. The ground radiation system consists of a mesh of pipes made of high - density polyethylene PE - Xc. The temperature system of heated water is 35/25 °C, and in the summer 13 °C.

As regard to costs and savings few main challenges were to be solved. Thermal energy for heating in winter and cooling in summer is generated using vertical BHEs in conjunction with geothermal field to store energy (Figure 14). Electric energy is produced by the solar power plant, with a help of cogeneration units with fuel gas to cover all the needs of the facility's electricity.



Figure 14. a) Construction of the geothermal accumulation field. b) Solar power plant panels at Pipistrel Co.

Geothermal accumulation field is a ground collector that functions as a storage for exchange and deriving of thermal energy at rate of 25 W/m<sup>2</sup>. The capacity of the accumulation field measures 5000 m<sup>3</sup> and it is placed underneath the entire building in form of 4 collectors each 250 m<sup>2</sup> in footprint. The solar power alone reduces their CO<sub>2</sub> emissions by 65 000 kg/yr. Rough estimate of energy savings is 95 000 kWh/yr. Total reduction of CO<sub>2</sub> emissions through the use of energy - saving systems amounts to 180 635 kg/yr, which is less than if the building was built with conventional energy systems, which are now no longer used.

## 5. DISCUSSION AND CONCLUSIONS

Beside detailed presented examples from application sectors, some other interesting systems may be mentioned though (see Figure 5 for their localities). In **Velenje** in central part of the country a **school center MIC2** uses 3 BHEs and 10 energy baskets for space and DHW heating. The closed - loop system with so far greatest number of BHEs is installed in **Pesnica near Maribor** where 24 BHEs with 130 to 170 m depth (150 m on average) are used for heating and cooling of the **multipurpose Mercator building** of 5600 m<sup>2</sup>. The BHEs are 6.5 m apart. The GSHP capacity is 180 kW for heating and 156 kW for cooling. The amount of renewable energy supplied by HP technology is ca. 0.716 GWh with SPF 3.2 and equivalent full load for heating of 5'782 hours. The open - loop system with the greatest number of water source wells is installed in **Kranj** where the **indoor olympic swimming pool** is heated with the GSHP of 266 kW heating capacity with full load of 6570 hours and SPF of 3. The pool utilizes four production wells, other four are reinjection wells and the remaining four are put occasionally in use. Their depth is about 30 m each. A system with the longest horizontal collectors (over 6 km of pipes) in the country has been installed in **Radovljica** for the **indoor olympic swimming pool** with the GCHP heating capacity slightly over 1MW<sub>(th)</sub>. In **Šentjur** east of Celje the **KEA supermarket** has the heating and cooling system with air conditioning for 4000 m<sup>2</sup> of space by using 20 BHEs which are 10 m apart. The GSHP heating capacity is 90 kW. The amount of renewable energy supplied by HP technology is about 0.144 GWh with 2000 equivalent full load hours and SPF close to 5. Less than 25 kW/h/m<sup>2</sup> is the utilization of heat energy owing to active air - conditioning.

### Large GSHP systems - summary and challenges

Presently about 74% of large systems in Slovenia are open - loop (water to water) type. They are mostly installed in alluvial aquifers, somewhere also in dolomite rocks. There are 26 examples of horizontal GCHP systems. The largest BHE field so far has 24 boreholes with typical depth 100 m, while the largest foundation construction has 192 energy piles. The biggest open loop system so far has 12 abstraction wells drilled (4 of them function as reserves).

There is need for definition of the areas with the highest GSHP potential in spatial plans. Long - term renovation strategy of buildings is still ahead of us. We need a good promotion of large systems and good promotion of combined energy sources systems with energy storage, as well as promotion of GSHP utilization in industrial facilities. It is important to use shallow geothermal energy potential wherever it is available, especially in the areas with more suitable conditions, such as relatively

shallow groundwater availability and rich aquifers in more populated areas and/or increased geothermal gradient in the superficial rocks and sediments. Our task is, among others, to promote the usefulness of this renewable energy source also to the planners of energetic renovations.

## ACKNOWLEDGEMENTS

The authors greatly acknowledge support of the Environmental Agency (ARSO) of the Ministry of Agriculture and the Environment. We express great thankfulness to many users and energy experts for useful data acquisition and permission to present them in the paper.

## REFERENCES

- Kralj P. and Kralj P. (2000) - Overexploitation of geothermal wells in Murska Sobota, northeastern Slovenia. Proc. of the World Geothermal Congress 2000, Kyushu - Tohoku, Japan, (2000), paper #0434, 837 - 842.
- Kralj P. (2009) - Three years of Benedikt geothermal heating system - stage 1 operation. In: International geothermal days Slovakia 2009, Conference and summer school, Session 2: Geothermal district heating projects, (2009), 1 - 5.
- Lund J.W. (2000) - Ground - source (geothermal) heat pump. In: Lienau P.J. (conv.), Course on Heating with geothermal energy: Conventional and new schemes. CNR, Italy. WGC 2000 Short Courses, Kazuno, Tohoku District, Japan (2000), 209 - 236.
- Prestor J., Rajver D., Pestotnik S., Lapanje A. (2012) - Low - temperature geothermal energy. Inexhaustible energy source just below our house (in Slovene). Geological Survey of Slovenia, Ljubljana, (2012), booklet.
- Rajver D., Lapanje A., Rman N. (2010) - Geothermal development in Slovenia: Country update report 2005 - 2009. Proc. of the World Geothermal Congress 2010, Nusa Dua, Bali, Indonesia (2010), paper #0130, 1 - 10.
- Rajver D., Prestor J., Lapanje A., Rman N. (2013) - Geothermal energy use, Country update for Slovenia. Proc. of the European Geothermal Congress 2013, Pisa, Italy (2013), 1 - 17.
- Rajver D., Rman N., Lapanje A., Prestor J. (2015): Geothermal development in Slovenia: Country update report 2010 - 2014. Proc. of the World Geothermal Congress 2015, Melbourne, Australia (2015), paper #01034, 1 - 14.
- Rman N., Lapanje A., Rajver D. (2012) - Analysis of thermal water utilization in the northeastern Slovenia. *Geologija*, 55/2, Ljubljana, (2012), 225 - 242. doi:10.5474/geologija.2012.014.
- Rman N., Gál N., Marcin D., Weilbold J., Schubert G., Lapanje A., Rajver D., Benková K., Nádor A. (2015) - Potentials of transboundary thermal water resources in the western part of the Pannonian basin. *Geothermics*, 55, (2012), 88 - 98. <http://dx.doi.org/10.1016/j.geothermics.2015.01.013>.
- Rman N. (2014) - Analysis of long - term thermal water abstraction and its impact on low - temperature intergranular geothermal aquifers in the Mura - Zala basin, NE Slovenia, *Geothermics*, 51, (2014), 214 - 227.

## Geothermal Development and Activities in Germany

BÜSCHER Eckehard<sup>1</sup> and WITTIG Volker<sup>2</sup>

<sup>1</sup> IGO - International Geothermal Office of Germany, c/o GZB, Bochum, Germany

<sup>2</sup> GZB - International Geothermal Centre, Bochum, Germany

Corresponding author's e-mail: [Eckehard.buescher@geothermie.de](mailto:Eckehard.buescher@geothermie.de)

**Keywords:** DTH Hammer Drilling, percussion rock drilling, geothermal district heating, GANDOR, Danube.

### ABSTRACT

This paper, presented at Veli Losinj, Croatia 27.08.2014, reflects to three different examples of geothermal developments in Germany.

#### 1. Developments in DTH (air) hammer percussion rock drilling at the GZB

Drilling methods for shallow and deep geothermal applications are discussed, with the focus on DTH water hammers including case studies, recirculation and recycling systems, DTH mud hammers. Furthermore, DTH fluid hammers do make for an excellent logging tool, being used as a good noise source for seismic-while-drilling (SWD) logs and measurements. These greatly help predict and find good geothermal reservoirs as well as reducing drilling risks.

#### 2. Developments in geothermal district heating

In Germany 27 deep geothermal projects are operational, 10 are under construction and more than 30 are in the planning phase. All the operational projects are providing heat, seven of them producing electricity as well. These figures show a strong and rising interest in GDH in Germany, which are operated by private and by municipal companies as ppp-projects.

#### 3. Academic geothermal network in the Danube region

The GANDOR (Geothermal Academic Network of the Danube – Donau - Region) will establish a network of universities and private companies in the Balkan area. The project addresses, through transnational cooperation, the challenge of turning geothermal research results into new geothermal products and services, by building sustainable partnerships between academia, local authorities and the geothermal industry, resulting in further development of geothermal clusters and emerging industries.

## 1. DOWN THE HOLE HAMMER DRILLING TECHNOLOGIES: STATUS AND FUTURE DEVELOPMENT

Geothermal resources tend to be found in deeper and harder geologic formations than typical hydrocarbon reservoirs. Therefore, drilling technologies from the oil and gas field need to be improved constantly to make for more efficient, economic drilling. Yet today drilling cost is the largest factor in any geothermal project.



Figure 1. Drill site at GZB during DTH fluid hammer drilling and development, 1st sedimentation stage (white container) always in use; 2nd stage cleaning optional with blue container on left side including lamella cleaner and flocculents.

One innovation over the past ten plus years has been the development of downhole fluid hammer systems at GZB drill site in Bochum (Figure 1 and Figure 2) and elsewhere worldwide for geothermal, hydrocarbon, and mining applications. These tools, commonly powered with compressed air for shallow (< 400 m) drilling, have shown and proven to increase ROP in the order of tenfold over conventional drilling methods based on tricone or PDC bits.

However, several disadvantages of these hydraulic, DTH water hammer systems do hold back their widespread use so far. Main hindrances are e.g. the required water quality of almost clean tap water, missing recirculation systems and thus, no possibility of using drill mud additives for borehole control and improved flushing capabilities (Bussmann et al., 2015).

With new hydraulic hammer systems being developed in Bochum and gradually coming onto the market, some of these problems have been addressed or even solved by now, also pushing their drilling applications further down to 5000 m.

Drilling methods for shallow and deep geothermal applications are discussed, with the focus on DTH water hammers including case studies, recirculation and recycling systems, DTH mud hammers. Furthermore, DTH fluid hammers do make for an excellent logging tool, being used as a good noise source for seismic-while-drilling (SWD) logs and measurements. These greatly help predict and find good geothermal reservoirs as well as reducing drilling risks.



Figure 2. 6 inch DTH fluid hammer with 7 1/4 inch drill bit designed by GZB as used for drilling and SWD tests at GZB (Vollmar et al., 2013).

Thus, the DTH mud hammer drilling technology will greatly help the geothermal industry to make their drilling efforts far more economic, especially but not exclusively in deep, hard rock drilling situations.

## 2. DEVELOPMENT OF GEOTHERMAL DISTRICT HEATING IN GERMANY

The heating and cooling sector plays an important role with respect to the primary energy demand, as within the EU (Figure 3) and all over the world heating and cooling demand accounts for about 50% of the overall energy consumption. The potential of geothermal heat energy for this sector and not only for electric power supply is vast: the RHC-ETP (Sanner et al., 2011) estimates in 2020 over 25% of heat consumed within the EU could be generated with renewable energies. By 2030 RHC technologies could supply over half of the heat used within EU - Europe. Besides geothermal energy, biomass and solar power are the base of RHC. One of the reasons for an optimistic look into a renewable future in Germany is the increasing use of highly effective district heating systems with geothermal energy as base load.

Figure 3. Developments of Geothermal District heating in Europe (Büscher, 2014).

- Existing Systems and New Developments
  - Denmark
  - England (Newcastle) : poor geothermal potential
  - France – Paris Basin
  - Germany, Bavaria in the Molasse Basin
  - Hungary: small nets existing, large potential
  - Netherlands: DG Potentials well known due to gasdrillings
  - Poland: large Potential
  - Spain: Centralregion Madrid and Burgos
  - Others: Bosnia-Herzegowina, Croatia, Norway
- Small heat-networks for 1,000 – 1,500 building units with 15 °C < ̑ ≤ 40 °C; decentral heatpumps in the houses

### Current state in Germany

In Germany, existing district heating systems mainly rely on conventional fossil fuels. They have been in operation for centuries, but coal mining has to be phased out in Germany by 2018 due to European laws. Some operators of heat plants and combined heat and power plants will experience great difficulties in extending their operating permits. As the use of locally produced heat is the fundamental idea behind modern district heating systems, DH becomes more and more relevant. Heat, cold and fuel sources that normally would be lost remain in the local systems for both: the residential, as well as the non - residential sector, including industries. Another important aspect is the political target to become more and more independent from external gas and oil resources.

In Germany, as of April 2014, 27 deep geothermal projects are operational, 10 are under construction and more than 30 are in the planning phase (<http://www.geothermie.de/wissenswelt/geothermie/in-deutschland.html>). All the operational projects are providing heat, seven of them producing electricity as well. These figures show a strong and rising interest in GDH in Germany. Many of these projects organized in two different companies that work as ppp - projects (public private partnership). While the drilling and the heat production is mainly with the private partners, the operation of the district heating network and the contact to the end customer is often operated by a company with municipal majority.

The city of Munich, with more than 2 million inhabitants, has ambitious targets on its future energy supply (Figure 4): Munich wants to become the first CO<sub>2</sub> free capital of the world. 100% of the electricity should be produced from renewable sources until 2025. Munich wants to generate 100% of its heat demand on renewable energies with biomass and geothermal energy until 2040 (Pletl, 2014). In many cities all around Munich (e.g. Ismaning, Kirchweidach, Sauerlach) about 3000 m deep holes are being drilled to contribute to the heat supply via district heating systems.

Figure 4. Future Development of Energy Supply of Munich (Pletl, 2014).

#### Heating of the City of Munich

- more than 2 million inhabitants
- Munich wants to become the first CO<sub>2</sub>-free capital of the world.
- 100% of the electricity should be produced from renewable sources until 2025.
- 100% of its heat demand on renewable energies with biomass and geothermal energy until 2040.

Besides to the construction of new DH systems, the conversion from existing district systems with temperatures of more than 100 °C to new systems with lower temperatures is one of the challenges Germany's heat market has to solve. The first phase of the German "Energiewende" is focusing solely on renewable electricity. Meanwhile more than 25% of German electricity is produced mainly by wind and photovoltaic and the phase out of nuclear power plants will be managed without power cuts; in contrast, Germany is still exporting electricity.

Now it is the time to concentrate on a sustainable development on the heat market, which is responsible for more than 50% of energy consumption (electricity just 16%). This projected development uses the advantage, that geothermal district heating is efficient concerning cost and environmental impact by producing the smallest emission of CO<sub>2</sub>. Furthermore, geothermal energy is an inexhaustible heat source, which has a high security of supply 24/7 as it is not affected by outside temperature, season or time of day and can be installed in nearly every (European) state (Büscher, 2014).

### 3. GEOTHERMAL ACADEMIC NETWORK IN THE DANUBE REGION - GANDOR

The GANDOR project (Figure 5) addresses, through transnational cooperation, the challenge of turning geothermal research results into new geothermal products and services, by building sustainable partnerships between academia, local authorities and the geothermal industry, resulting in further development of geothermal clusters and emerging industries.

GANDOR concentrates on the Danube area with participating universities from:

- Croatia - University of Zagreb, Faculty of Civil Engineering, Department of Geotechnics;
- Germany - International Geothermal Centre GZB at Hochschule Bochum,
- Hungary - University of Szeged, Department of Mineralogy, geochemistry and Petrology,
- Serbia - University of Belgrade - Faculty of Mining and Geology, Department of Hydrogeology.

The network analyses existing geothermal clusters and their working environment in different regions participating, and the partners' complementarities towards geothermal. In the second phase, GANDOR will define Joint Action Plan for future growth and prosperity and taking measures towards its implementation.

- Support of the geothermal energy sector
- Establishment of a network of experts in geothermal
- Phase 1: Essential exchange of knowledge in three workshops
- Development of a Joint Action Plan in Phase 1
- Development of ideas for following activities in Phase 2
- Turning geothermal research results into new geothermal products and services
- Funded by the BMBF and DLR

Figure 5. Tasks of the Project GANDOR - Geothermal Academic Network of the Danube Region.

Geothermal energy is a carbon free renewable energy source, able to provide base load power for electricity, heat generation and other direct usage in many countries around the world. In several European countries it is also used on a small or district scale, mainly for heating supply. More and more the geothermal potential is being used as well for cooling purposes. Many offices, apartment, hotels and public buildings like universities, hospitals and the German “Bundestag” in Berlin are heated and cooled with geothermal energy. The geothermal energy source is located deep in the subsurface, thus complicating research, development, and assessment of its energy utilization potential. Over the last 50 - 60 years, the sector has benefitted a lot from technology innovations in the oil and gas drilling industry.

The GANDOR project also includes the analysis of industry trends and market challenges, in order to find the most attractive strategic segments for the Danube region. The main backbone of the project realization will be three workshops or conferences in the hometowns of the consortium partners.

The first workshop was held in Germany from 13 - 14th of November 2014 in Bochum and Essen.

## REFERENCES

- Büscher E. (2014) - Development of Geothermal District Heating in Germany. GRC2014, Portland Oct. 2014.
- Bussmann G., Bracke R., Eicker T., Wittig V., Tuente H., Gueldenhaupt J., Groening L., Kiel F., Maeggi K., Montag B. (2015) – GeoStar. A Scalable Borehole Heat Exchanger System for District Heating Systems and Constricted Large Urban Infrastructures. Proceedings World Geothermal Congress 2015, In Press 2015.
- GtV - German Geothermal Association, <http://www.geothermie.de/wissenswelt/geothermie/in-deutschland.html>.
- Pletl C. (2014) - Geothermie-Heizkraftwerk Sauerlach. Mitteilungsblatt des GtV Geothermische Energie, N°79, May 2014.
- Sanner B., Kalf R., Land A., Mutka K., Papillon P., Stryi - Hipp G., Weiss W. (2011) - 2020 - 2030 - 2050. Common Vision for the Renewable Heating and Cooling Sector in Europe. European Technology Platform on Renewable Heating and Cooling. Luxembourg: Publications Office of the European Union.
- Vollmar D., Wittig V., Bracke R. (2013) - Geothermal Drilling Best Practices: The Geothermal translation of conventional drilling recommendations - main potential challenges. IGA Academy report, International Finance Corporation IFC; International Geothermal Centre Bochum – GZB, Germany.

## Geothermal Heating and Cooling in the FVG Region: the Grado District Heating and the Pontebba Ice Rink Plants

DELLA VEDOVA Bruno<sup>1,2</sup>, CIMOLINO Aurélie<sup>1,3</sup>, CASTELLI Eugenio<sup>1</sup> and BRANCATELLI Giuseppe<sup>1</sup>

<sup>1</sup> Department of Engineering and Architecture, University of Trieste, Italy

<sup>2</sup> UGI - Italian Geothermal Union, Firenze, Italy

<sup>3</sup> F.I.T. - Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze, Trieste, Italy

Corresponding author's e-mail: [dellavedova@units.it](mailto:dellavedova@units.it)

**Keywords:** low temperature geothermal resources, geothermal heating and cooling, Grado district heating, Pontebba ice rink, groundwater heat pumps.

### ABSTRACT

We present two running applications of direct use of low temperature geothermal resources for heating and cooling of public buildings, recently realized in the Friuli Venezia Giulia (FVG) Region - Northeastern Italy - with public fundings.

The *Grado Geothermal Pilot Project* was an ambitious challenge, initiated in 2002 and completed in early 2015, aimed to demonstrate the feasibility and sustainability of a geothermal doublet on the Grado Island (GO), in the northern Adriatic coastal area, by: i) characterizing the geothermal carbonate reservoir of the Grado area, ii) estimating its heat potential, iii) drilling a geothermal doublet, with one production and one re - injection well. The project had a total cost of 5 million € and included two phases. The 1<sup>st</sup> phase, completed in 2008, confirmed the existence of a low temperature geothermal reservoir within the buried carbonate platform, assessed its geothermal potential and verified the feasibility of the district heating plant in Grado. Seismic and gravity surveys were completed to locate the first exploratory well. Grado - 1 borehole was drilled down to 1110 m, into a terrigenous cover and a Paleogene - Mesozoic carbonate basement high. The 2<sup>nd</sup> phase (2012 - 2015) included further geophysical prospecting to extend reservoir investigations and to locate the second borehole. Grado - 2 was drilled in 2014, at about one km distance to the East of Grado - 1, down to 1200 m. By December 2014, two km of district heating distribution network was deployed and the first two public buildings were connected.

We focus here mainly on the geophysical and well data and on the pumping tests that were acquired before, during and after the drilling of the two wells. The data set allowed the characterization of the reservoir and the assessment of its geothermal potential. Some of the main results are: the identification of major fault systems and production areas, the comprehension of the hydraulic circulation systems, the assessment of the geochemical facies of waters and of their sustainable utilization. The Grado reservoir is a confined fractured aquifer hosting anoxic fossil seawaters with temperatures up to 49 °C in Grado - 2 (7 °C higher than Grado - 1), pressure of 250 kPa at wellhead and spontaneous artesian outflow of about 100 t/h. Pumping test results indicate a sustainable water production up to 140 t/h. The circulating system is a complex network of permeable vugs and highly transmissive karst-fractured discontinuities, intersected by several fault systems driven by Alpine and Dinaric deformation phases. Interference pumping tests proved the hydraulic connectivity between wells, but, due to the poor system recharge, the hydraulic sustainability of the geothermal doublet must be guaranteed by re - injection. The initial functioning of the district heating plant, envisaging a geothermal heating of several connected public buildings during cold seasons (up to about 3 MW<sub>(th)</sub> heating load), will allow a significant economical saving of the order of 80 000–100 000 €/yr. Nevertheless, the geothermal reserve affords to foster other relevant uses besides the district heating. Several future perspectives of development are suggested for Grado geothermal potential; 3D thermo - fluid dynamic numerical modelling will optimize the system production and manage the sustainability of the geothermal plant.

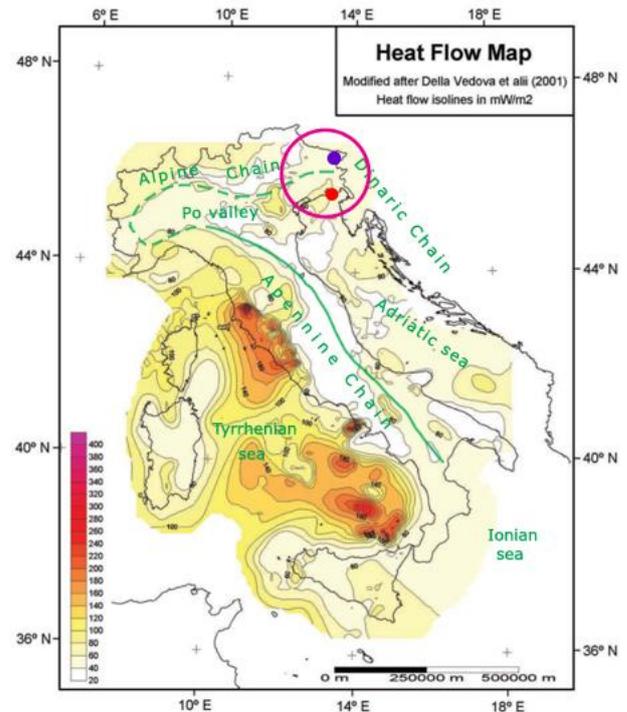
The existing cooling system of the *ice rink of Pontebba* town (UD), located close to the Austrian border, was totally renovated in late summer 2012: a open loop heat pump system using groundwater thermal energy was realized and functions both for the ice production and maintenance, and for the heating and hot water needs of the ice stadium. Two ammonia heat pumps (350 kW each) were installed, supported by two production water wells (32 m deep) and one re - injection water well (30 m deep), drilled into the alluvial deposits of the Fella River. A total production rate of up to 200 t/h could be achieved from the shallow unconfined aquifer, with an average temperature of about 8.5 - 9.0 °C. Numerical modelling of groundwater flow supported the assessment of the production and re - injection rates, as well as the evaluation and the minimization of the impacts on the groundwater resource during the plant management in various hydraulic regimes. Over the first two years of operation, cost reductions of the order of 45% have been achieved.

## 1. INTRODUCTION

The heat flow map of Italy and surrounding Seas (Figure 1) shows several geothermal provinces, ranging from young and active magmatic provinces (e.g. the Tuscan - Tyrrhenian area), where high enthalpy geothermal resources are usually available at shallow depths, to old and cold sedimentary basins (e.g. the Adriatic and Po valley basins) or mountain belts (e.g. Alpine and Apennine chains), where these resources are far too deep. The FVG Plain belongs to a “cold” foreland area having a surface heat flow ranging between 40 - 60 mW/m<sup>2</sup>.

The FVG geologic framework is interested by the eastern and the northern part of the Alpine and the Dinaric active belts (with their foredeep and foreland, respectively), by the eastern part of the Po Valley sedimentary basin and by the northern part of the Adriatic basin.

**Figure 1. Heat flow map of Italy (modified after Della Vedova et al., 2001). The FVG Region is situated in the pink circle: red and violet dots indicate Grado and Pontebba locations, respectively.**



Some weak positive heat flow anomalies are present in correspondence of the buried Mesozoic thrusts, because of the vertical fluid circulation in the carbonate formations. This is particularly noticeable in the FVG southern areas, where low temperature geothermal resources ranging between 40 - 70 °C can be present within 1 - 2 km depth. Local low temperature geothermal systems were detected in correspondence of thrusts system areas, as shown in the Cargnacco - 1 and Cesarolo - 1 boreholes, drilled for oil and gas exploration. Interesting resources are related to local highs in the buried basement and they are well documented by oil exploration and water boreholes in the southern FVG Plain. These highs are approximately present in correspondence of the Cesarolo - Lignano and Grado structural highs (Figure 3). These geothermal resources have an adequate potential to sustain direct use district heating plants.

In the northern FVG mountain areas, the heat flow is quite low (30 - 40 mW/m<sup>2</sup>) mainly because of meteoric water circulation; these low temperature resources can foster heating and cooling in closed and open loop system supported by heat pumps.

The abundance of groundwater and recharge in the FVG have, however, a large heat potential since it usually represents a steady source, available at shallow depth and largely renewable. In recent years, the FVG Region launched several calls focused on low temperature geothermal applications (5 calls since 2007) to support heating and cooling of public buildings: they guaranteed substantial EU contributions (up to 300 000 €) to beneficiary public administrations and were designated for geothermal direct uses, including borehole heat exchangers, shallow aquifers and deep geothermal resources (>700m depth).

This paper will present two existing demonstration projects of direct uses of groundwater energy for heating and cooling of public buildings, realized in the FVG Region, thanks to EU contributions and integrational support by national, regional and municipal fund:

- the Grado Geothermal Pilot Project (GGPP), aimed to the realization of a district heating system supported by a geothermal doublet on Grado Island (Gorizia Province),
- the open loop groundwater heat pump system realized for the ice rink stadium in Pontebba (Udine Province).

## 2. THE GRADO DISTRICT HEATING PROJECT

### 2.1 Geological Framework

Grado Island is situated in the lagoon part of the FVG Plain (Gorizia province); this plain constitutes the eastern extension of the Po Valley and hosts well developed unconfined and confined aquifers within a complex hydrogeological system evolving in a mainly N - S direction. The Northern (Upper) Friuli Plain is characterized by an alluvial unconfined aquifer made out of highly permeable gravels, extending from the Pre - Alps to the resurgence spring line. The resurgence belt sets a hydrological boundary, between the Northern and Southern Plain, which extends in almost E - W direction and generates spring and river arising, where the water table surface intersects the surface topography. Here - hence, the unconfined aquifer evolves into several multi - layered confined aquifers; this complex hydrogeological system is hosted in a heterogeneous sedimentary wedge, showing a progressive thickness increase in a W direction and towards the Adriatic Sea and locally overtaking a thickness in excess of 500 m; it is made of a wide stratigraphic succession:

- Plio - Quaternary sediments deposited in alluvial - littoral - shallow marine environments at several trasgressive - regressive cycles; this terrigenous cover is mainly made by sandy and silty layers, having a wide range of primary porosity: several artesian aquifers, hosted in higher permeability sediments, are separated by acquicludes and aquitards;
- Oligo - Miocene Alpine Molasses made of prevailing marly intervals with few sandstones, deposited in dominant shallow marine environments, that can host artesian aquifers;
- Paleogene Dinaric foredeep Flysch turbidites made of prevailing marly intervals rich of pelagic deep marine faunas; these sediments generally lack of relevant aquifers.

The Paleogene - to present clastic wedge lays on Mesozoic (principally) limestones, having a combined morphological ("Friuli Platform", with platform-shelf-talus facies; "Belluno Basin"; "Dinaric Foredeep") and structural (fractures, faults, thrusts) genesis: its upper surface presents several culminations having mainly dinaric and antidinaric directions (Figure 2 and Figure 3). The whole system is interested by tectonic features still in progress, as part of the complex regional framework due to the coexistence of the foredeep and the foreland of both the Alpine and the Dinaric active chains.

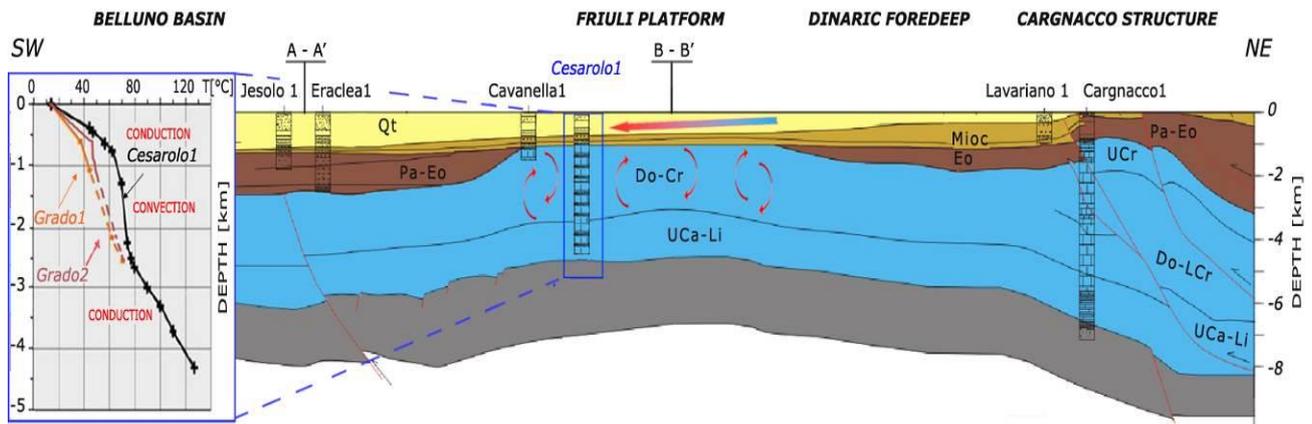


Figure 2. A simplified NE - SW regional geological section of the low Veneto - Friuli Plain: Plio - Quaternary sediments (yellow), Neogene (mustard) and Paleogene marls (brown), Mesozoic limestones (cyan). Positioning of the section is indicated in Figure 3. The box on the left shows the trend of the geotherms measured in Cesarolo - 1, Grado - 1 and Grado - 2 wells.

## 2.2 Conceptual Geothermal model

The carbonate platform highs host a porous and fractured hydrothermal reservoir that allows convective circulation of geothermal waters in the upper 1 - 2 km, with advective flux and heat upwellings, whereas deeper carbonate intervals are characterized by predominant heat conduction. The upper convective cells generate anomalous temperature gradients in the overlapping soft sediments, hosting hydrothermal fresh aquifers warmed up by heat conduction from below (Figure 2). In this framework, without taking into consideration local faults or limited structures, Neogene and Paleogene marly successions can be considered as a very low - permeability seal, functioning as a hydraulic barrier. The carbonate hydrothermal reservoir and its covering successions were the target of several studies and geophysical campaigns conducted in the Friuli Plain in the last few decades and conducted by the Department of Engineering and Architecture of Trieste University, DEA - UNITS (Della Vedova et al., 1988, 2008; Calore et al., 1995; Nicolich et al., 2004, 2006, 2008).

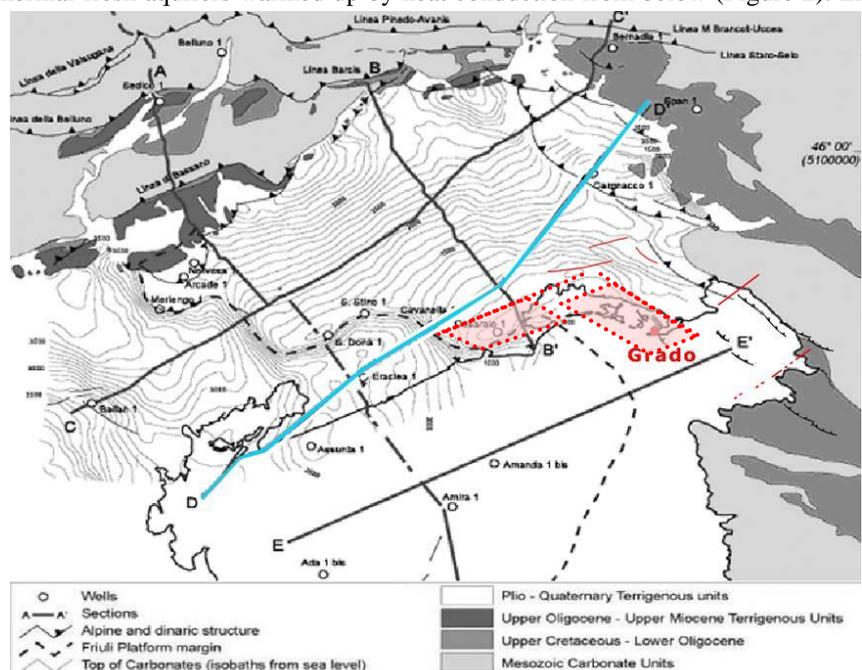


Figure 3. Isobaths map of the carbonate top in the Veneto - Friuli Plain. The dotted line tracks down the western limit of the platform; the positive geothermal anomalies are pink; cyan line indicates the section of Figure 2. The location of Grado Island is indicated.

Geophysical data were integrated with published geological and geochemical data, including oil deep boreholes and water wells. This data set allowed to:

- reconstruct several regional geological sections, across the Plain,
- map the top of carbonate and of alpine molasses,
- draw depositional limits of formations and main tectonic structures.

The isobath map of the Mesozoic carbonates top is characterized by culminations with mainly dinaric NW - SE and antidinaric NE - SW orientations (Figure 3): these structural highs turn out to be located in the Cesarolo - Lignano area and in the Grado Lagoon area.

### 2.3 The Grado pilot project

The Geological Survey of the FVG Region and the Grado Municipality carried out the two main phases of the *GGPP* with the support of European and national fundings:

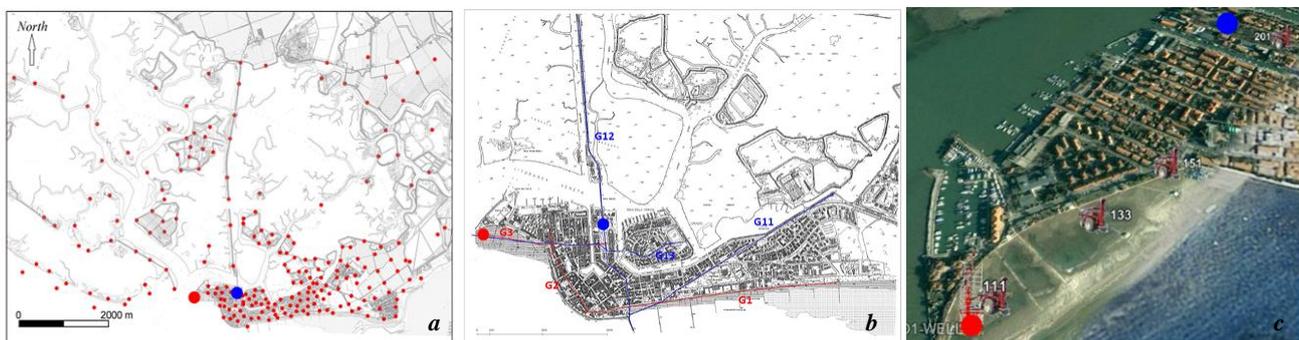
- The first phase was aimed to characterize the geothermal carbonate reservoir of the Grado area, to estimate its geothermal potential and to obtain a preliminary geothermal potential assessment of the deep geothermal reservoir by geophysical surveys and by the drilling of the first exploration borehole; it was supported by 2000 - 2006 DOCUP – 2 EU fundings (2.5 million €) and was completed in July 2008;
- The second phase was aimed to the drill the second borehole, to carry out the new potential assessment and the production capacity, and to realize the surface distribution network connecting the two wells; this phase was supported by POR - FESR fundings (2.5 million €), started in 2012 and was completed in December 2014 – January 2015.

#### Geophysical Surveys and Boreholes drilling

Several geological and geophysical surveys were carried out to characterize the system and to locate the wells: seismic and gravity surveys were completed on land (in the surroundings of Grado Is.) and offshore, both in shallow waters of the Grado and Marano Lagoons, and in offshore areas of the Gulf of Trieste (Nicolich et al., 2006; Buseti et al., 2009). According to the geological context highlighted from the geophysical data, Grado - 1 exploration borehole was drilled (using direct circulation rotary rig) on the sand beach at the westernmost end of Grado city, at about 100 m from the shoreline. The well intercepted the carbonatic reservoir at 618 m and reached a total depth of 1110 m.

The second geophysical campaign was completed in 2012 (Figure 4) in downtown Grado and in its surrounding lagoon (Della Vedova et al., 2013). Several data sets were acquired to extend the investigation and improve the knowledge of the local reservoir, highlighting faulted areas and relative highs, and to reduce the geothermal resource risk for the second well:

- 121 new gravity stations acquired in the surroundings Grado area, integrated with 108 gravity measurements collected every 50 m along the three seismic lines (location in Figure 6c);
- 7.5 km of multichannel seismic reflection profiles acquired with seismic vibrator source and Hydrapulse, along three lines crossing each other and integrating the previously acquired seismic dataset;
- multi - offset vertical seismic profiles (VSP) performed in Grado - 1 with the seismic source located at increasing distances from the well of 45, 266, 449 and 939 m (Poletto et al., 2013).



**Figure 4.** Map of the geophysical survey in the Grado area; Grado - 1 and Grado - 2 boreholes are shown in red and blue full dots, respectively. a) Map of gravity stations including measurements acquired in 1987. b) Location map of the seismic reflection surveys completed during 1st and 2nd phase (respectively red and blue lines). c) Location map of Grado - 1 multi - offset VSP survey.

The results of the geophysical investigations allowed to appropriately locate the 2nd borehole of the geothermal doublet; Grado - 2 borehole was drilled on a local structural high in the center of the city, about one km to the East of Grado - 1. The drilling was accomplished by a reverse circulation rotary rig, down to 272 m, and by a direct circulation rotary rig on derrick, down to the borehole bottom (Figure 5).

The drilling program of both boreholes adopted decreasing bit diameters with depth (24", 17"½, 12"¼, 8"½); from almost 680 m deep, the lower interval into the carbonatic reservoir was initially left open hole for logging and downhole measurements. K55 API casings (20", 13"¾, 9"⅝) were installed and cemented in the upper sections. During the completion of both wells, an accurate monitoring of geology, drilling parameters, mud logging (in terms of temperatures, density, viscosity, conductivity, pH, total dissolved solids) was conducted. Advanced geophysical borehole logs were acquired in open-hole carbonate reservoir, such as: resistivity, acoustic full waveform velocity, neutron, porosity, spectral gamma ray, density, caliper, deviation, circumferential borehole imaging, spinner and fluid temperature logs.

Three cores were acquired in Grado - 1 at the top and the bottom of the intercepted reservoir; moreover, permanent Pt temperature sensors were installed on the outside casing at 300 and 695 m depth in order to monitor temperature recovery after reinjection. Well development included washing - back, airlifting (Figure 8) and packer acidification focused on crucial intervals of the deeper section, in order to reduce the skin effect, improve permeability and remove mud cake and cuttings. A 7" diameter production liner was installed in the reservoir of the production well Grado - 2.

Integration and interpretation of multidisciplinary data

All data collected in Grado - 1 well, such as cuttings, cores biostratigraphy, borehole geophysical measurement (Della Vedova et al., 2008; Cimolino, 2010) were integrated into a preliminary numerical thermo-fluidodynamic model and compared with geological features from on land outcrops and offshore data, including oil and water boreholes (drilled in Veneto - Friuli plain and Croatia offshore). Seismic sections were calibrated with Grado - 1 succession and water wells stratigraphies. Previous gravity data (Della Vedova et al., 1988) were integrated with the new measurements to produce the Bouguer anomaly gravity map, which highlights the basement culminations (Figure 6b). This multidisciplinary and integrated analysis, including pumping tests in Grado - 1, provided a first assessment of the geothermal reservoir and resource (artesian outflow of ~ 100 t/h, 41 - 42 °C, 250 KPa, 17‰ salinity), defining:

- stratigraphic - structural constrains, encountering for the first time Paleogene carbonatic series in the Lower Friuli Plain and new evidences of an important regional tectonic feature in the Grado area, such as the presence of a distal Dinaric thrust fault NW - SE oriented (Cimolino et al, 2010);
- average values and vertical changes in lithology, porosity, resistivity and elastic *moduli* of the reservoir rocks.

VSP measurements acquired during the second geophysical survey provided a detailed depth velocity model for P - S waves and the lateral change in elastic properties between Grado - 1 and Grado - 2 (Poletto et al., 2013; Della Vedova et al., 2015), also useful to calibrate the time to depth conversion of surface seismic data [*Integrated Geophysical Characterization of Geothermal Reservoirs*, POLETTO et al. - extended article in this book]. The reservoir was explored eastward of Grado - 1 and its geological features and physical properties were defined by VSP analyse, filling the scale gap between the Grado - 1 borehole data and the multichannel seismic profile (Figure 6a) in Grado city.

Figure 5. Grado - 2 drilling by direct circulation rotary rig on derrick.

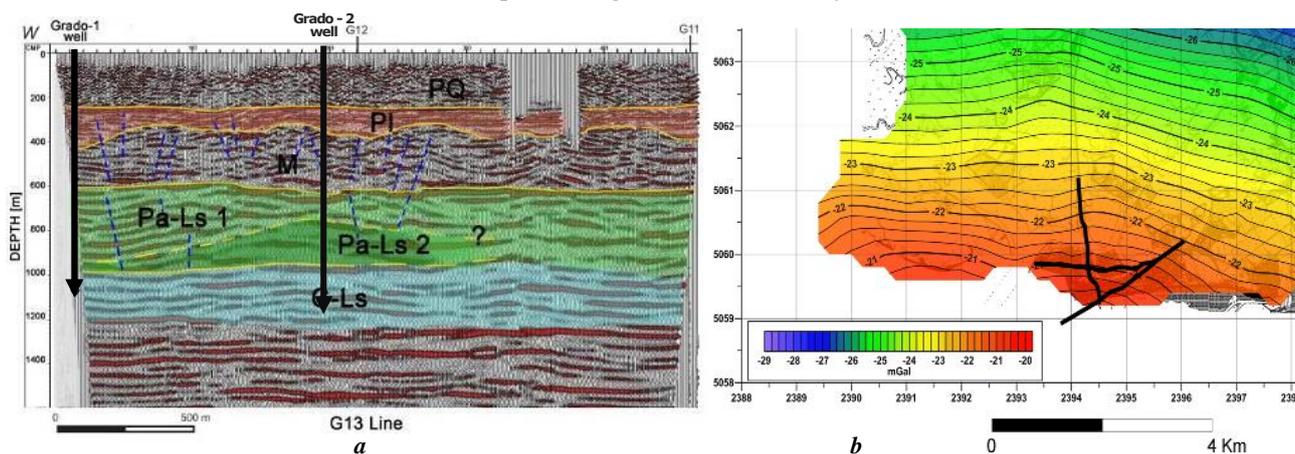


Figure 6 .a) Multichannel seismic Line G13, with geologic interpretation after Grado - 2 drilling: PQ (Plio - Quaternary sediments), PI (Pliocene sediments), M (Molasses: Alpine and Paleogene flysch), Pa-Ls (Paleogene Limestones), C-Ls (Upper Cretaceous Limestones). b) Map of the Bouguer gravity anomalies with the position of the 3 multichannel seismic lines acquired for locate Grado - 2.

The geothermal reservoir assessment was confirmed by Grado - 2 drilling, identifying also major fracture systems hypothesized in seismic interpretation. The wells stratigraphies characterize the geothermal reservoir within the carbonate platform structural highs, covered by about 620 m of terrigenous sediments. This cover is composed by less than 300 m of Plio - Pleistocene sediments, followed by about 250 m of Neogene marly - sandy successions (Alpine Molasses), rich in external neritic faunas, and more than 40 - 50 m of pelagic faunas Paleogene turbidites (Eocene Flysch).

The limestone shelf presents both Rudist rich Upper Cretaceous intervals (from about 1000 m depth) and a thick Paleogene Limestones interval, that was encountered for the first time in the Low Friuli Plain; Paleogene Limestones show classic *Alveolinidae - Nummulitidae - Orbitolites facies*. The transition from Paleogene to Mesozoic limestones includes clear evidences of sub - aerial exposure and karstic phenomena; the K - T boundary turned out to be well marked in both the boreholes at about 1005 - 1010 m depth by high Uranium picks, also recognized in the Northern Adriatic offshore (Cimolino et al., 2010).

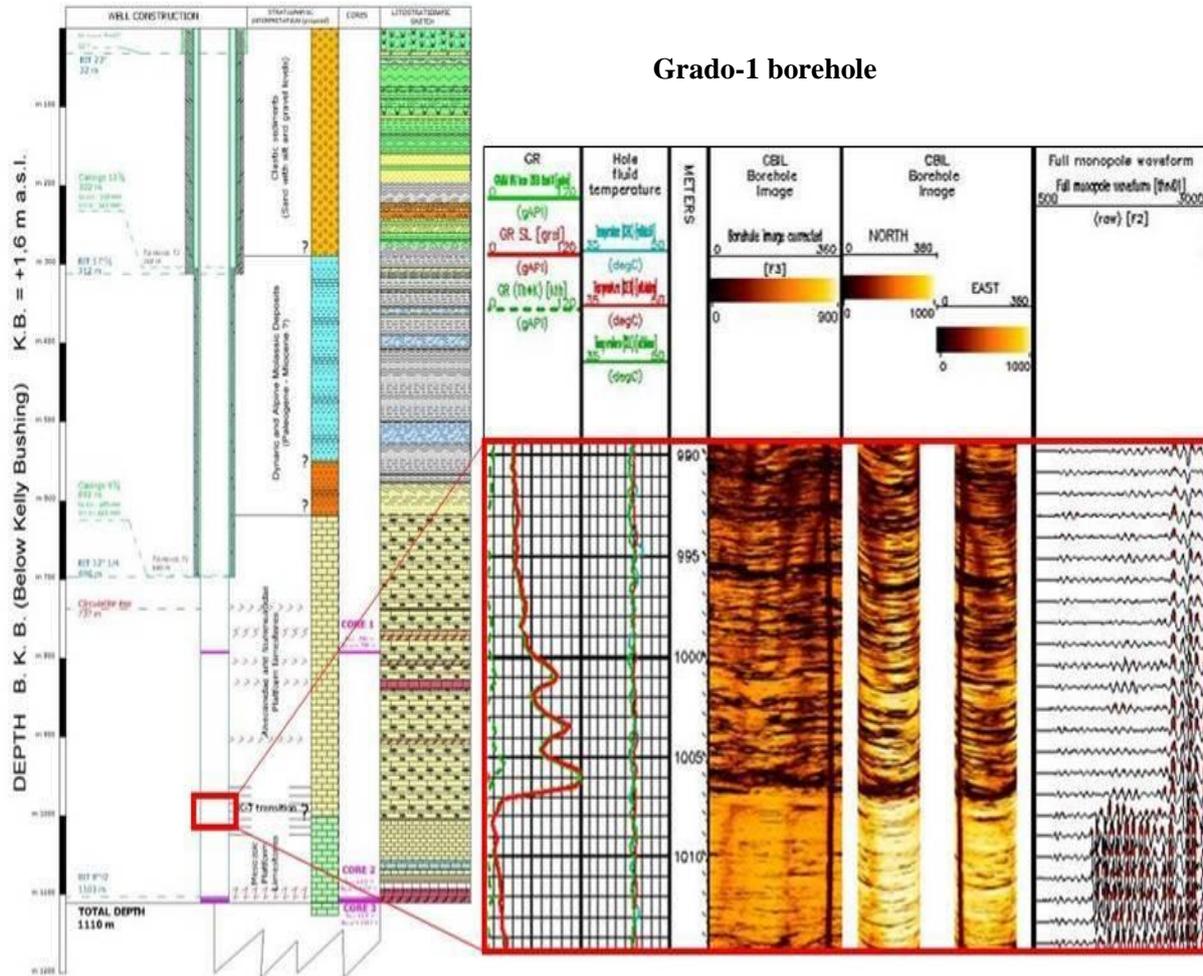


Figure 7. Grado - 1 borehole profile showing cased and open hole intervals, interpreted stratigraphy and an example of geophysical logs, such as: gamma ray, imaging and waveform in correspondence of the K - T boundary transition zone.

Geophysical logs and core data provided detailed information on the carbonate reservoir properties: the production area was detected and discontinuity families were identified according to orientation, intensity and origin. The carbonates are characterized by several fracture/faults subsystems having a combined tectonic - karst origin, with individual open karst - fractured discontinuities, widespread paths along permeable vugs and deep seated faults: these subsystems provide vertical geothermal circulation along unknown pathways. The integration of borehole and geochemistry data with the geophysical surveys allowed to roughly image the Grado Lagoon reservoir as a NW - SE oriented high, delimited by Dinaric and anti - Dinaric structures (Figure 6c): the footprint of these structures is somehow observable both in the Bouguer gravity map and in the seismic profiles acquired in the Gulf of Trieste (Buseti et al., 2009, 2010). This local high was interpreted, in accordance with the regional framework, belonging to the outer Dinaric deformation front, indicating active stress regime in the Grado Lagoon area (Cimolino et al., 2010). The stratigraphic sequence and the tectonic framework devised in the Grado area result to be rather different from the Cesarolo - Lignano structures, where the top of the carbonate platform is characterized by Lower Cretaceous formations, covered directly by the Lower Miocene Cavanello Group units (Cesarolo - 1 well; Nicolich et al., 2004) and where a SW - NE orientation dominates the area. On the contrary, the Grado reservoir geological scheme can be directly related to northern Istria geological settings and outcrops, as shown into stratigraphy and logs acquired in northern Dalmatia offshore wells (Placer, 2005, 2007; Tari - Kovačić et al., 1998).

The reservoir volume was then estimated (Table 1), as constituted, on a first approximation, by three interfingered subsystems having variable average effective porosities corresponding to massive, fractured/faulted and intermediate carbonate domains, as suggested by the porosity log data: very low porosity (<1%), low porosity (1 - 3%) and good porosity (8 - 10%). A rough total volume of 0.6 km<sup>3</sup> of moving geothermal waters was estimated for the reservoir of about 75 - 100 km<sup>3</sup>. This corresponds to about 6 - 8\*10<sup>6</sup> m<sup>3</sup> of moving geothermal waters per one km<sup>3</sup> of reservoir.

Table 1. Estimation of geothermal reservoir volume and effective porosity.

Carbonatic Reservoir		Effective porosity
Total surface	50 km <sup>2</sup>	85%: n <sub>e</sub> < 1%
Average thickness	1.5 - 2 km	10%: n <sub>e</sub> 1 - 3%
Total volume	75 - 100 km <sup>3</sup>	5%: n <sub>e</sub> 8 - 10%
<b>Moving geothermal waters = 0,6 - 0,8 km<sup>3</sup></b>		

Pumping tests and potential assessment

Airlifting and spontaneous water production tests were also realized before pumping tests (Figure 8). Several pumping tests were conducted separately in the two boreholes and a final interference hydraulic test was performed pumping from Grado - 2 and monitoring pressure changes in Grado - 1. Pumping tests were conducted with increasing drawdown steps (by submersible pumps) and a unique pressure recovery step. CTD divers were also positioned in wellheads to measure hydraulic heads (pressures), temperatures and electric conductivities for more than a month (before, during and after tests) to monitor the recovery of the geothermal system towards static conditions.

One of the project main targets was the characterization of the geothermal fluids and the assessment of the geothermal potential of the Grado reservoir.

The reservoir is a confined fractured aquifer, having a salinity of more than 30‰ and a temperature of 49.5 °C at the bottom of Grado - 2 and of about 42 °C in Grado - 1. Geochemical analyses of the geothermal waters, including Strontium isotope measurements (Petrini R., oral communication), indicate that the fluid is an anoxic seawater having presumably an age of more than 10 million of years. This means that the geothermal waters circulate through a complex network from the older Cretaceous to the younger Paleogene limestones.



Figure 8. Combined operation of washback by airlifting, performed in Grado - 2.

A spontaneous artesian outflow of about 100 t/h (laminar flow up to 28 L/s) with a pressure of 240 kPa at wellhead was reached in Grado - 2, after two acidification cycles. With a maximum pumping rate of about 150 t/h (42 L/s), the maximum drawdown in Grado - 2 turned out to be of 23 m from the initial static water level (Figure 9), with fluid temperatures of 48 °C at wellhead. Considering the spontaneous artesian outflow of about 100 t/h and assuming 20 °C as a useful temperature difference, the natural thermal power of Grado - 2 turns out to be 2,3 MW<sub>(th)</sub>. Since a sustainable production was estimated in about 126 t/h (~35 L/s), the available potential thermal power is assessed in about 3 MW<sub>(th)</sub>.

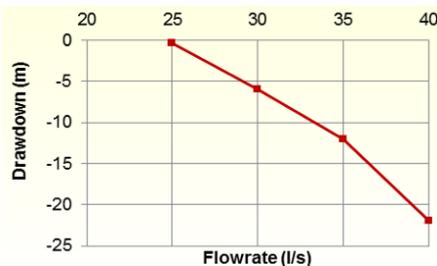


Figure 9. Drawdown vs. flow rate plot from pumping tests in Grado - 2.

In order to verify the properties of the reservoir, pumping steps in Grado - 2 (without rejection) and the hydraulic interconnection between wells were monitored. With a maximum flowrate of 42 L/s in Grado - 2, the hydraulic head in Grado - 1 decreased by about 35 cm, demonstrating that Grado - 1 is within the radius of influence of Grado - 2 (even when the latter is producing spontaneously) and highlighting the existence of a good hydraulic interconnection between wells. Following the pumping stop, there is a quick, but partial (about 20 cm), pressure recovery in Grado - 1, confirming the presence of a good permeability and transmissivity nearby; however, the full recovery of the initial static pressure (pressure build up) needs several days to be reached, yet suggesting the presence of far subsystems with low transmissivity preventing a quick system recharge. The system as a whole is practically a closed reservoir because it has no efficient recharge capacity; the re - injection is then absolutely required to guarantee the hydraulic sustainability of the production well and a long lasting life of the geothermal heating plant.

Numerical thermo - fluid dynamic modelling (*Comsol Multiphysics* software) was carried out as a support tool for the final design of the district heating system (Marcon, 2012) and for the optimization and managing of the DH geothermal plant. The numerical simulations (Figure 10) considered the coupling of the production/re - injection wells and were set up with logging, pumping and interference tests results; they constrain the initial conceptual model, the physical properties and the boundary conditions of the numerical model, including the presence of a high permeability fracture system, which acts as a preferential drain. Modelling is still in progress and will allow to: evaluate geothermal doublet performances, monitor over time reliable scenarios of the production capacity and verify long - term sustainability of the district heating system, as soon as we will gather information during operating and networking seasons to calibrate the simulations.

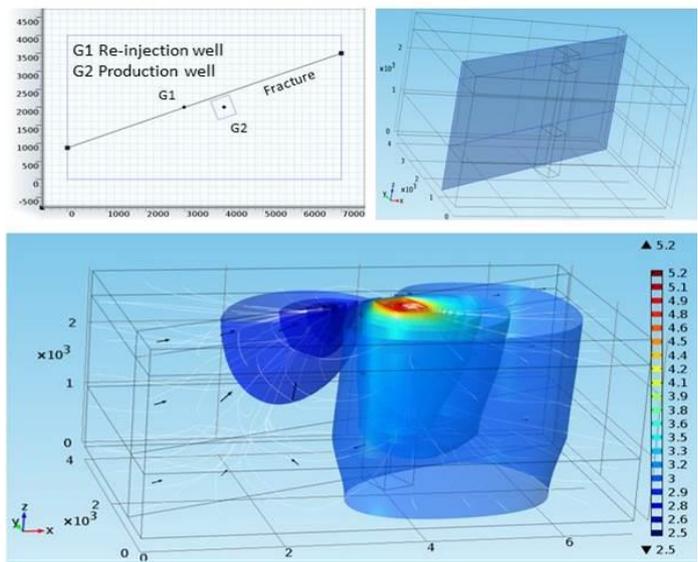


Figure 10. Reservoir modelling framework and pressure field imaging around production and re - injection wells.

## 2.4 Status and perspectives for the Grado district heating plant

The deployment of the distribution network of the GGPP required horizontal directional drillings under the port canal downtown Grado to connect Grado - 1 and Grado - 2 wells (Figure 11); the distribution network is currently about 2 km long and will be further extended. By the end of 2014, four public buildings were connected to the network (2 schools, library). The connection with other four public buildings is foreseen during 2015.



Figure 11. a) Installation of part of the distribution network after the drilling of Grado - 1 borehole. b) Horizontal directional drilling realized under the Grado port canal for the laying of pipeline in 2014.

The heat potential of the Grado Lagoon geothermal system (assessed in about 2.3 – 3.0 MW<sub>(th)</sub>) and the building thermal loads allowed to estimate the district heating capacity factor and related energy savings. The Grado district heating, when completed, is expected to work on average for about 6 month/year, 12 hours/day; with such limitation, the capacity factor will be about 0.2 and the related energy savings should be of the order of 80 000–100 000 € /yr.

However, the geothermal reservoir is able to foster further long - lasting applications (such as: heating of more buildings, greenhouses, fishfarming, balneotherapeutic uses, resort and touristic activities). On the island, there are 8450 inhabitants, which could increase to twice as much during summer seasons. The technical and economic feasibility of the geothermal pilot district heating system in Grado city could be sustainable, if the capacity factor increases to about 0.4 or more. In this case, the energy savings could double or even more.

The cost of the distribution network represents about 40% of the total investment and should not be included in the cost of the geothermal project, since it represents a primary infrastructure cost.

Several future perspectives of development can be suggested for the GGPP:

- further geophysical exploration should focus on deep structures and deformation zones, giving a contribution for the design of the heating network extensions and for the drilling of a second production well, re - injecting in one single well (Grado - 1);
- enhanced studies of the geothermal reservoir recharge and fluid geochemistry should detect recharge areas, deep circulation circuits and potential mixing phenomena;
- monitoring of the geothermal reservoir parameters and of the district heating plant during one year at least for the management optimization of the overall system and for the assessment of potential impacts during operation;
- calibration of the 3D numerical thermo - and fluidodynamic model to optimize the production and re - injection fluid rates and manage the long - term sustainability of the geothermal plant.

## 3. THE PONTEBBA ICE RINK PLANT

Pontebba is a small town of about 1500 inhabitants situated in the E - W Fella River valley, in the northeastern mountain area of the Udine province, at a few kilometer distance from the Austrian border; it is placed in the eastern part of the wide Alpine Chain. This area marks the transition from the Carnic Alps to the Julian Alps.

The Pontebba ice rink building, which hosts about 40 000 ice skaters every year and has a parterre area for almost 1800 spectators, was completed in December 2002. The requalification of the ice rink heat pump refrigeration system became quickly a problem: the existing heat pumps were obsolete and unlawful (by 2009) since they used R22 Freon rink and plant was functioning exclusively as a refrigeration system supported by a cooling tower and the parterre areas were lacking of the heating system. Moreover, the old plant was not efficient, since the heat produced by refrigeration was totally rejected in atmosphere by means of the evaporating tower.

A proposal for a new plant with groundwater Ammonia heat pumps having greater energy efficiency was suggested by DEA – UNITS considering heating and cooling and hot water production. The new project included the installation of an open loop groundwater heat pump system, with two coupled 350 kW heat pumps. The total cost amounts to about 600 000 €, whose 300 000 € were funded by PORFESR 2007 - 2013 - Activity 5.1.b “Exploitation of renewable sources

(geothermal)". The requalification works were also interested by the benefits provided by the Finance Act 2008 (Legge n°424, 28th December 2007), which allows the recovery of 55% of investment of this type of system, up to a maximum amount of 30 000 €.

The present - day ice rink plant of Pontebba represents, therefore, a working example of efficient direct use of groundwater thermal energy for heating and cooling of public buildings, completed in the RFGV territory.

### 3.1 Geologic Framework

Pontebba is located in the eastern part of the Alpine Chain, extending mainly in an E - W direction, and it is just close to the junction with the Dinaric Chain, extending mainly in a NW - SE direction. These thrust - fold orogens, produced by passive margins convergence, are characterized by complex wedges of thick and cold sedimentary successions having a thickness up to 10 - 12 kilometers. The mountain area is characterized by a surface heat flow of about 40 - 60 mW/m<sup>2</sup> (Figure 1), mainly because of the major disturbances active within the upper few kilometers (topography, erosion, water circulation, exhumation ...).

Focusing on the local geologic settings, Pontebba is located in the Fella River valley (Figure 12). The area is characterized by a carbonate rock basement (nearly outcropping or superficial), which can be wrapped by up to about one hundred of meters of deposits made of alluvials and slope debris: these porous sediments represent the river unconfined aquifer, abundantly fostered by meteoric precipitations from the surrounding catchment basin in Julian Alps. The groundwater temperature ranges from 8 to 9 °C and is excellent to support heat pumps for refrigerating the ice rink.

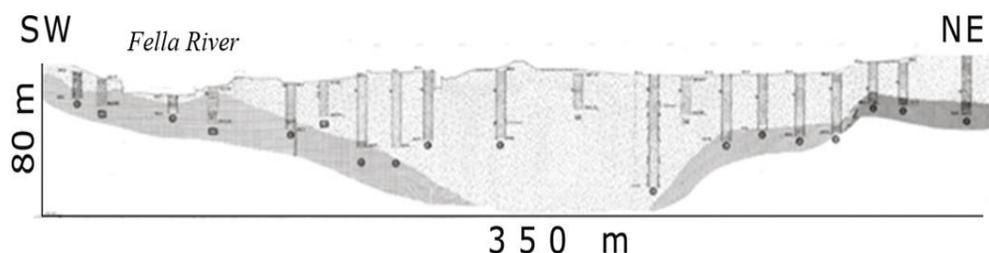


Figure 12. Lithostratigraphic section across the Fella River valley near Pontebba, from existing geotechnical investigations (Comin C., personal communication).

### 3.2 Water bodies as heat source in open loop systems

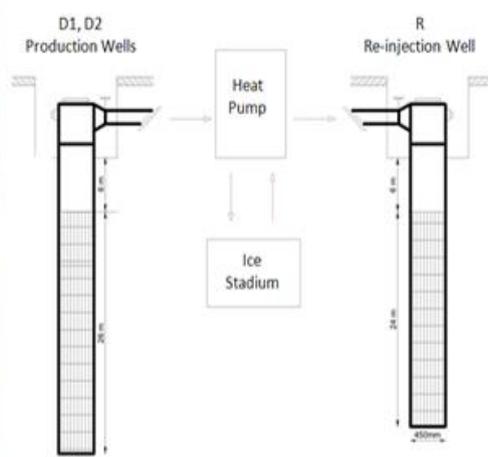
Groundwater bodies can be exploited by “open loop systems” to support “groundwater heat pumps (“GHP”)", which transfer thermal energy between the aquifer and the buildings by means of production and re - injection wells. In mountain areas, these heating and cooling plants are often feasible using surface water bodies. Open loop systems present several advantages when surface waters and groundwaters are abundant: they need limited investment, have a long lifetime and require a limited maintenance with low operational costs. Moreover, they are now particularly suitable, due to the benefits offered by ammonia heat pumps; they offer the best advantages in terms of efficiency and energy savings (with reduction of operation costs), reliability (no limitation) and minimal environmental impact with practically greenhouse effect insignificant (ozone friendly). Two ammonia heat pump groups (350 kW each), manufactured by Zudek s.r.l. - Muggia TS, were installed.

### 3.3 The new GHP system: project and realization

The FVG Region and the Pontebba Municipality carried out the requalification of the ice rink heat pump system with the installation of an open loop groundwater heat pump system: ZUDEK - EUREKA® realized the project with the contribution of DEA – UNITS for the resource characterization, wells design and the assessment of the environmental impact. The energy requalification of the old cooling system of the Pontebba ice rink was completed in late summer 2012 supported by the unconfined aquifer of the Fella River (Figure 13).

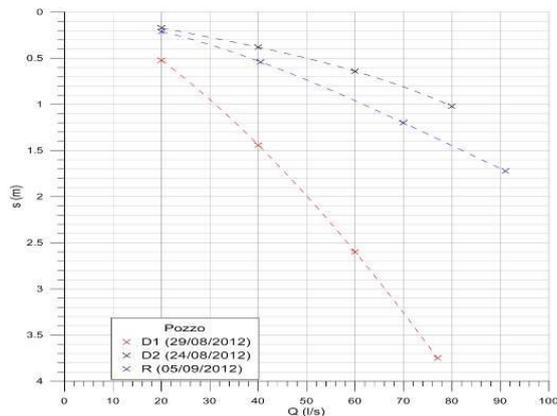


Figure 13. Location of production and re - injection wells outside the ice stadium of Pontebba (UD).



The system was designed to function both for the production and the maintenance of the ice rink, and for heating the rink itself, the locker rooms, the ice stadium seats and for the hot water needs.

The groundwater is produced with submersible pumps from two production wells (D1 and D2), located upstream the Fella River and drilled down to 32 m depth. The re - injection water is returned into the same aquifer through a 30 m deep discharge well (R), located 175 m downstream (Figure 13). Each production well is accompanied by a piezometer drilled at 10 m distance. Step drawdown pumping tests and interference hydraulic tests were completed (Figure 14) in order to assess the



transmissivity of the aquifer and to verify the hydraulic response to different production and re - injection rates (up to 90 L/s). Temperatures, conductivities and hydraulic heads were monitored by CTD divers. The characteristic curves of the three wells were elaborated individually considering the drawdown from the initial static water level as a function of the pumping rates. The single sustainable production was estimated in 20, 45 and 60 L/s for, D2, D1 and R wells, respectively. Maximum sustainable total production rates were estimated in 234 t/h for D2 and D1 wells, whereas for R well the maximum re - injection flowrate was estimated in 260 t/h (72 L/s).

Figure 14. Pumping tests drawdown for production and re - injection wells.

Numerical modelling was also carried out (*Visual Modflow* software, Figure 15) to simulate the aquifer response both in high and in low water recharge conditions, under maximum pumping rates of 72 L/s. Thermo - fluid dynamic modelling (*Fluent* software) was also carried out to evaluate the space and time evolution of the re - injected thermal plumes into the aquifer.

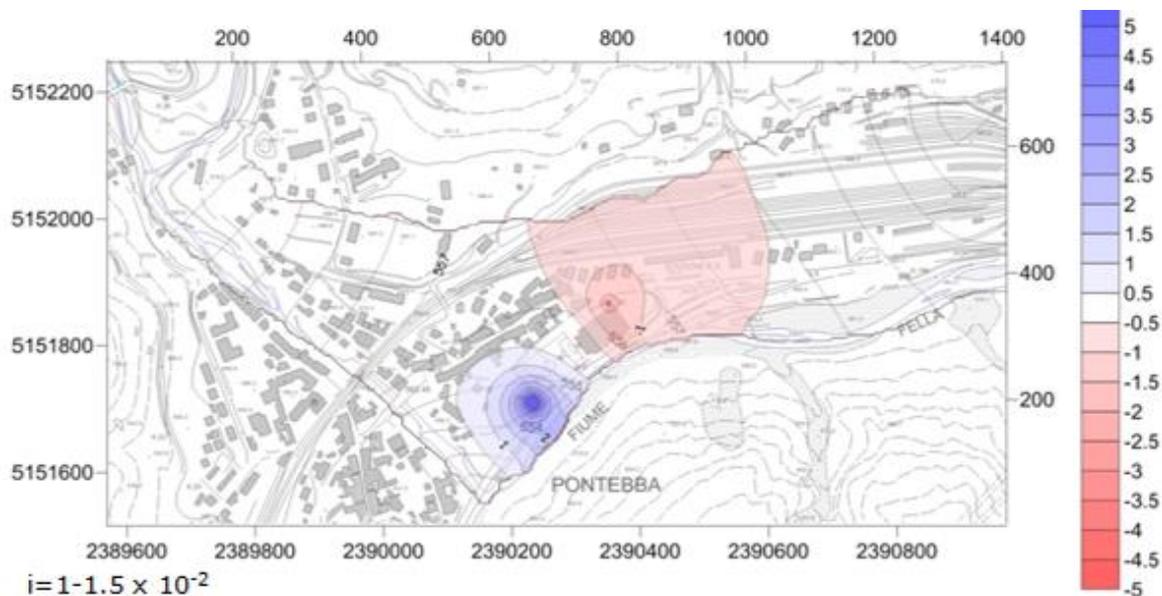


Figure 15. Numerical simulation for the groundwater flow in dry season conditions under maximum pumping and re - injection rates (72 L/s). The production and re - injection cones are shown by hydraulic head isolines.

### 3.4 Plant performance

The Pontebba groundwater open loop system started functioning in September 2012. A telemetry remote control system, which constantly monitors flow rates, temperature and quality of pumped and re - injected waters, was installed to optimize the management of the whole plants. The two ammonia heat pumps installed can operate under different working schemes, fed by on average temperature of pumped waters of 9 °C:

- the total cooling capacity is 640 kW, with cooling fluid down to - 10 °C for the ice rink,
- the total heating capacity is 720 kW, with warming fluid up to 40 °C for both the lockers room and the ice floor leveling and heating of the parterre area and eventually the rink itself.

Over the first two years of operation, the new system ran for 4400 hours (about 2200 hours/yr from statistics of September 2014); a maximum production rate of up to 200 t/h (50 L/s) was achieved from the unconfined aquifer. The open loop system first economic savings are:

- reduction of the electrical consumption of - 40.5%,
- annual energy savings were calculated in about 33 000 € per year (annual reduction of heating costs 17 000 € per year),
- annual avoided CO<sub>2</sub> emission was estimated in 244 t per year.

Moreover, Pontebba open loop heat pump plant turns out to be certainly reliable and a life cycle of 25 years can be hypothesized.

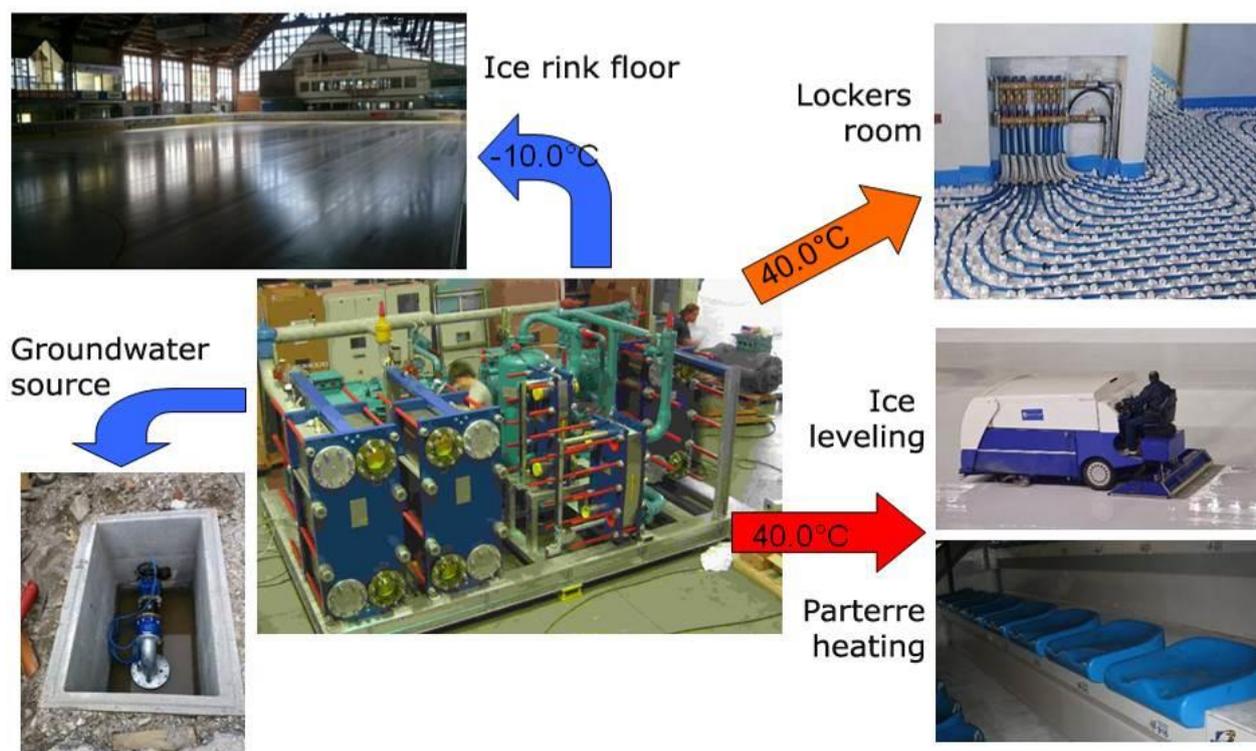


Figure 16. Working scheme for heating and cooling of Pontebba open loop heat pump plant.

#### 4. CONCLUSION

The Grado Geothermal District Heating Pilot Project and the Pontebba ice rink open loop heat pump plant represent two working example of efficient direct use of geothermal low enthalpy for non - residential heating and cooling of public buildings.

It is pointed out that low enthalpy geothermal resources have a significant heat energy potential at a regional scale, also in geologic cold areas. Since thermo - mineral and geothermal resources are present in similar geologic contexts of the cold Adriatic region, further geothermal doublets and open loop heat pump plants can be realized elsewhere.

The groundwater resources present several advantages; they are largely renewable, often available at shallow depths, easy to integrate with other conventional and locally available RES and, finally, present limited footprint and low CO<sub>2</sub> mission.

#### ACKNOWLEDGMENTS

We thank: FVG Region - Geological Service, Grado and Pontebba Municipalities for Project support and for the permission to present the results; Grado and Pontebba Municipality administratives and inhabitants for their patience and comprehension; Zudek Srl, Muggia company for Pontebba plant; Drilling company Fratelli Perazzoli - Tecnologie e servizi per l'acqua, DH network deployment company Impresa Cicuttin, field geologist F. Podda; OGS crew for geophysical data acquisition and processing; R. Petrini for isotopic analysis and interpretation; G. Meton, A. Schiavone and B. Deschmann for cooperation and support in Grado - 2 drilling and data analysis.

#### REFERENCES

- Busetti M., Volpi V., Nicolich R., Barison E., Romeo R., Baradello L., Brancatelli G., Giustiniani M., Marchi M., Zanolla C., Nieto D., Wardell N. (2009) - Dinaric tectonic features in the Gulf of Trieste (northern Adriatic Sea). *Boll. di Geof. Teor. ed Appl.* 51(2-3):117-128.
- Busetti, M., Volpi V., Barison E., Giustiniani M., Marchi M., Ramella R., Wardell N., Zanolla C. (2010) - Cenozoic seismic stratigraphy and tectonic evolution of the Gulf of Trieste (Northern Adriatic). *GeoActa*, SP 3 (2010), 1 - 14.
- Calore C., Della Vedova B., Grassi S., Marson I., Nicolich R., Squarci P. (1995) - A hydrothermal system along the coastal area of Friuli-Venezia Giulia Region (NE Italy). In: *Proceedings of the World Geothermal Congress, Florence*, vol 2, 1269-1274.
- Cimolino A. (2010) - Caratterizzazione delle risorse geotermiche della Bassa Pianura Friulana (Regione FVG). PhD Dissertation in Civil and Environmental Engineering. University of Trieste, 2010, 302 pp.

- Cimolino A., Della Vedova B., Nicolich R., Barison E., Brancatelli G. (2010) - New evidence of the outer Dinaric deformation front in the Grado area (NE - Italy), *Rendiconti Lincei*, vol. 21, supplement 1 (2010), 167 - 179.
- Della Vedova B., Marson I., Palmieri F. (1988) - Gravity study of a low enthalpy hydrothermal area: Grado Lagoon – NE Italy. *European Geophysical Society - XIII General Assembly, Annales Geophysicae, Special Issue 1988*, 27.
- Della Vedova B., Bellani S., Pellis G., Squarci P. (2001) - Deep temperatures and surface heat flow distribution. In: Vai G.B. & Martini I.P. (Eds), *Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins*, 65 - 76.
- Della Vedova B., Castelli E., Cimolino A., Vecellio C., Nicolich R., Barison E. (2008) - La valutazione e lo sfruttamento delle acque geotermiche per il riscaldamento degli edifici pubblici. *Rassegna Tecnica del Friuli Venezia Giulia*, 6/2008, 16 - 19.
- Della Vedova B., Petronio L., Poletto F., Palmieri F., Marcon A., Corubolo P., Farina B., Cimolino A., Bellezza C. (2015) - The Geothermal District Heating System on the Grado Island (North - eastern Adriatic Sea). *Proceedings World Geothermal Congress 2015. Melbourne, Australia, 19 - 25 April 2015*.
- Marcon A. (2012) - Progetto di teleriscaldamento geotermico di Grado (GO): valutazione della sostenibilità della risorsa tramite simulazioni numeriche. *University of Trieste*, (2012).
- Nicolich R., Della Vedova B., Giustiniani M., Fantoni R. (2004) - Carta del sottosuolo della Pianura Friulana. Note illustrative e 4 mappe. *RFVG – Direzione Centrale Ambiente e Lavori Pubblici, Litografia Cartografica, Firenze*, 32 pp., 4 Tav.
- Nicolich R., Masetti D., Ramella R., Della Vedova B., Barison E., Vecellio C., Rizzetto D., Cimolino A., Flora O., Busetti M., Volpi V., Zanolla C., Cucchi F., Marocco R. (2006) - Realizzazione della Carta Geologico - Tecnica della Risorsa geotermica regionale e definizione delle Linee Guida per il suo utilizzo. *Rapporto Tecnico Finale. Rapporto Tecnico - Scientifico Finale per la Regione Autonoma Friuli Venezia Giulia, Direzione centrale Ambiente e Lavori Pubblici, Servizio Geologico*. 298 pp. + annexes.
- Nicolich R., Della Vedova B., Cimolino A., Barison E. (2008) - Le acque calde della bassa pianura friulana e la loro potenzialità. *Rassegna Tecnica del Friuli Venezia Giulia*, 3/2008, 8 - 12.
- Placer L. (2005) - Strukturne posebnosti severne Istre. [Structural curiosity of northern Istria]. *Geologija* 48 (2), 245–251.
- Placer L. (2007) - Kras̃ki rob. Geolos̃ki prevez vzdolz AC Kozina - Koper. [Kras̃ki rob (landscape term). Geological section along the motor way Kozina–Koper (Capodistria)]. *Geologija* 50 (1), 29–44.
- Poletto F., Corubolo P., Farina B., Schleifer A., Petronio L., Della Vedova B. (2013) - Multi - offset VSP for the integrated geophysical characterization of the Grado (NE Italy) carbonatic reservoir. *Proceedings of the European Geothermal Congress 2013, Pisa, Italy, 2013*.
- Tari - Kovačić V., Kalac K., Lučić D., Benić J. (1998) - Stratigraphic analysis of Paleogene beds in some offshore wells (Central Adriatic area, Croatia). *Dela - Opera SAZU4 razr* 34 (2), 203–242.

## Ecological and Economic Aspects of Using Geothermal Energy for Heat Supply Town of Bijeljina and Other Areas Bosnia and Herzegovina

ĐJURIC Nedjo<sup>1</sup>, SKOPLJAK Ferid<sup>2</sup> and ĐJURIC Dijana<sup>3</sup>

<sup>1</sup> Department of Civil Engineering, Subotica University, Serbia

<sup>2</sup> Geological Survey of Bosnia and Herzegovina, Sarajevo, Bosnia and Herzegovina

<sup>3</sup> Technical Institute of Bijeljina, Bosnia and Herzegovina

Corresponding author's e-mail: [nedjo@tehnicki-institut.com](mailto:nedjo@tehnicki-institut.com), [nedjodjuric10@gmail.com](mailto:nedjodjuric10@gmail.com)

**Keywords:** geothermal energy, exploration, boreholes, heating system, spas.

### ABSTRACT

Geothermal potentiality is related to the area of Semberija, which with Macva makes a great finding of thermal water. This finding likely extends below Srem in the north and to Posavina at the west. Semberija and Posavina belong to the north-east and the northern part of the Republic of Srpska - Bosnia and Herzegovina, and Srem and Macva belong to Serbia. Area deposits of thermal waters in the area of Macva and Semberija are about 2000 km<sup>2</sup>, and geothermal potential in terms of energy as heat equivalent is about 40 million tons of oil.

Current use of geothermal energy from finding Semberija in Dvorovi is for heating buildings, spa treatment, sports and recreational purposes, then in Slobomir city for heating buildings of Slobomir P. University and Aqua Park.

In further period it is planned to use geothermal energy for the heating of the city of Bijeljina, which has about 70 000 inhabitants. Energy utilization will be in several stages, from 80 °C to 16 °C, when the cooled water will be returned through reinjection wells into the underground sewer.

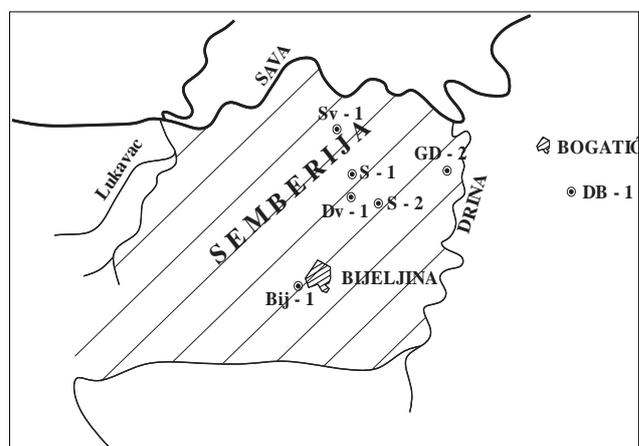
Analysis of the economic effects shown that the use of geothermal energy for the heating of the city of Bijeljina, would pay the investment in a period of 9 - 10 years. Including the possibility of utilization of geothermal energy for other purposes, the time of repayment of investments is significantly reduced.

In other parts of Bosnia and Herzegovina is present several springs of thermal and thermal mineral water, which are used as part of the built spa facilities. The most famous spa is in the area of Ilidza, near Sarajevo, where thermal mineral water is exploited from the end of the IXX century, and the construction of the spa facilities throughout the twentieth century has included this spa in one of the most important spas in Europe. Springs of thermal and thermal mineral waters in central Bosnia near Kakanj are important to the area, and in future is planned a construction of the spa facilities, which will be connected to rural tourism.

### 1. INTRODUCTION

As part of the research for oil in the fifties of the twentieth century, it was noted in several boreholes a presence of hot underground water temperature around 75–100 °C at the mouth of the borehole. Since underground hot water was not interesting at that time, with the termination for seeking oil, terminated the thoughts about hot waters. For the oil, in the area of Semberija, which is located in the northeastern part of Bosnia and Herzegovina (3) exploration boreholes were drilled S-1, S-2 and S-3, depth of 1250–1700 m (Figure 1). All boreholes are closed at the surface and further interest for them stopped.

**Figure 1.** The geothermal system of the northeastern part of the Republic of Srpska.



At the end of the sixties borehole S-1 was opened, which is located in the village Dvorovi near Bijeljina. With the opening of the borehole it was detected an outburst of water with a temperature of about 75 °C. After that, the first open poll was built in this settlement, which was filled with the water from the borehole S-1. Other boreholes stayed closed and it is not known in what conditions they are today.

In the seventies of the twentieth century, it was considered about the possibility of using the energy of hot water for heating the town of Bijeljina. Town then had about 30 000 inhabitants and an important industry in the area of food production and processing, as well as the mechanical industry.

Forty years later, it is still thought about the possibility of using geothermal energy for heating of the town of Bijeljina, and for other purposes, primarily for electricity generation.

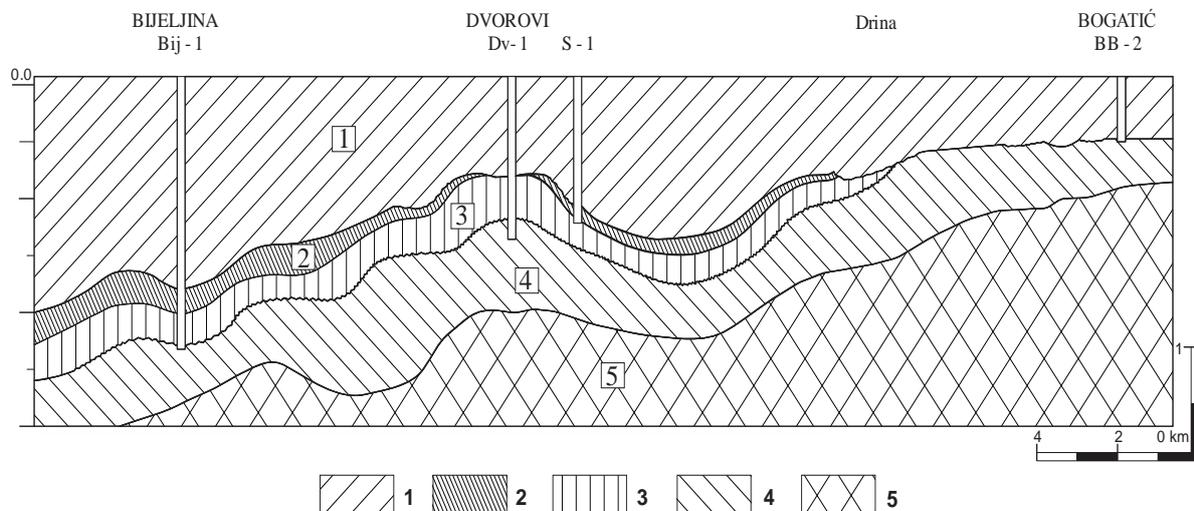
Today, geothermal energy is significantly used across Bosnia and Herzegovina, where are developed a significant spa facilities. Potentiality is significantly higher than the current utilization, so with the additional exploration of geothermal resources, is planned a new programs for utilizing of geothermal energy.

## 2. GEOTHERMAL POTENTIALITY OF SEMBERIJA

Geothermal potential of the area of Semberija (Figure 2), together with Macva, makes a great finding of thermal waters. This finding likely extends below Srem at the north and towards Posavina at the west. Semberija and Posavina belong to the northeastern and north part of Republic of Srpska – Bosnia and Herzegovina, and Macva and Srem belongs to Serbia (Milivojević and Perić, 1986). Area deposits of thermal waters in the area of Macva and of Semberija is about 2000 km<sup>2</sup>, and geothermal potential in terms of energy as heat is equivalent to about 40 million tons of oil.

Wider area besides Macva and Semberija includes Brcanska Posavina in the west, and the in the east the western part of Posavo - Tamnavska area, which makes a large geothermal system, which extends on a surface of about 6000 km<sup>2</sup> (Đurić and Jovanović, 1997).

The deposit extends with a gentle slope from Macva on the east, towards Semberija which is at the western part. The depth of the thermal waters in Bogatic (Macva) is about 450 m, while in the western part of Semberija depth is around 2500 m. There are also shallower horizons in the Cretaceous limestones, but Triassic limestones at greater depths are more significant.



**Figure 2. Geological terrain profile of Semberija. 1. Tertiary sediments, 2. Upper Cretaceous limestones, 3. Upper Cretaceous marl and sandstone, 4. Triassic limestones and dolomites, 5. Underlying stratum sediments.**

The thickness of the earth's crust in the area of Semberija is from 25.0 to 27.0 km. Geothermal field consists of thermal field, value of terrestrial heat of flow density and temperature field, temperature values at different depths of the Earth's crust.

According to some researchers of this space density of terrestrial heat flow in Semberija should be around 100 mW/m<sup>2</sup>. These values are about 50 - 80% higher than the average value of the density of terrestrial heat flow in continental Europe, which is about 60 mW/m<sup>2</sup>.

Temperature field is determined on the basis of model calculation where the temperature :

- at the depth of 5.0 km should be about 230 °C,
- at the depth of 7.0 km about 300 °C,
- at the depth of 10.0 km about 420 °C.

At the Mohorovicic discontinuity (the boundary between Earth's crust and layer, ranges from 25.0 to 27.0 km) value of temperature should be about 800 °C (Jelić 1982). Geothermal energy stored in this large geothermal system is caused by the extraordinarily high values of the density of the regional terrestrial heat flow, which ranges from 95 - 112 mW/m<sup>2</sup>.

Hydrogeothermal system in the area of Semberija is characterized by reservoir located in the Mesozoic sediments, and it consists of Upper Cretaceous limestones and Triassic limestones and dolomites. It represents a huge unique karst aquifer, where there are small mineralization waters with high content of individual components as a result of depth. Thereby the hot water can be rationally exploited in order to use the heat energy.

Geothermal reservoir of Upper Cretaceous limestone and its thermal water has the following characteristics:

- the total geothermal energy potential is about  $230 \cong 10^6$  tons of thermally equivalent oil;
- forecasting reserves of geothermal energy in the rock mass and thermal waters of the reservoir is estimated to  $57 \cong 10^6$  tons of thermally equivalent oil;
- reserves only in the thermal waters are about  $2 \cong 10^6$  tons of thermally equivalent oil.

Outlet temperature of the thermal water from the Upper Cretaceous limestone to the entire area should be  $> 75$  °C.

Geothermal energy in the Triassic limestones and dolomites, represent the main hydrogeothermal reservoir from which will be made exploitation of hot water:

- total geothermal energy potential reservoirs of Triassic limestones and dolomites is about  $1170 \cong 10^6$  tons of thermally equivalent oil;
- forecast of total reserves of geothermal energy in it, including the rock and water, is around  $315 \cong 10^6$  tons of thermally equivalent oil;
- reserves only in thermal water are about  $20 \cong 10^6$  tons of thermally equivalent oil.

The temperature in the water collector is from  $90 - 130$  °C, and the outlet temperature will be slightly less, about  $80 - 110$  °C.

Way of exploitation of geothermal energy from limestone and dolomite is by using vertical and inclined boreholes and "doubles" system.

## 2.1 Possibility of using geothermal energy

So far the use of geothermal energy if from the finding in Semberija in Spa Dvorovi for heating buildings, spa treatment, sports and recreational purposes, then in Slobomir city for heating buildings of Slobomir P. University and Aqua Park.

At the beginning of this century, it was expressed the interest in the exploration and exploitation of geothermal water in order to exploit the energy for heating of the city of Bijeljina, which has about 70 000 inhabitants. Energy exploitation would be in several stages, from  $80$  °C to  $16$  °C, when the cooled water through reinjection wells would return into the underground sewer (Đurić 2008, 2011).

Exploration and exploitation of geothermal water will be carried out in the town of Bijeljina. There will be five exploration - exploitation boreholes and they will be distributed in the peripheral part of the urban area (Figure 3).

In addition to the exploration - exploitation boreholes, several reinjection boreholes will be done for the return of exploited water in the first collector, after a certain amount of energy use. The number of boreholes and their appearance, whether they are vertical or sloping, will be defined during the implementation of the entire project.

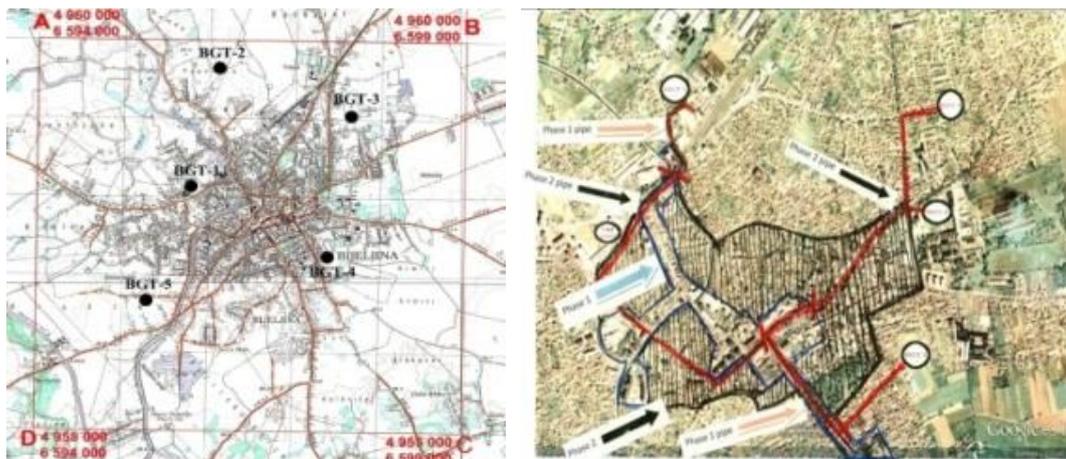


Figure 3. Exploration area with the layout exploration and exploitation boreholes BGT and transportation pipelines.

## 2.2 Exploitation characteristics

The thermal energy that would be obtained by exploitation of hot water from the boreholes located in the peripheral part of the city, will be used primarily for heating of the town (Đurićković and Đurićković, 2010; Sharma et al., 1998):

- required temperature consumption is from  $90 - 70$  °C,
- after that water can be used for the further use of heat energy to the  $16$  °C,
- then it will be return into the collector through reinjection wells. If the energy is not fully exploited in the initial phase, it would be returned at  $60$  °C at the collector after the first stage of the use.

Given that geothermal energy is a domestic resource, ecologically clean and economically beneficial, the heat energy will be used in the lower temperature range. It would consist of various economic programs, for which the thermal energy is the main energy, and also related programs for recreational purposes. Experience from countries that use geothermal energy, as well as interested business entities are sufficient to guarantee that the project of exploitation of geothermal water in order to exploit the thermal energy will be successfully implemented.

It is planned a development of five boreholes, and the number may change, depending on the capacity of utilization and the need for heating energy. Geological profile and construction of borehole given in Figure 4.

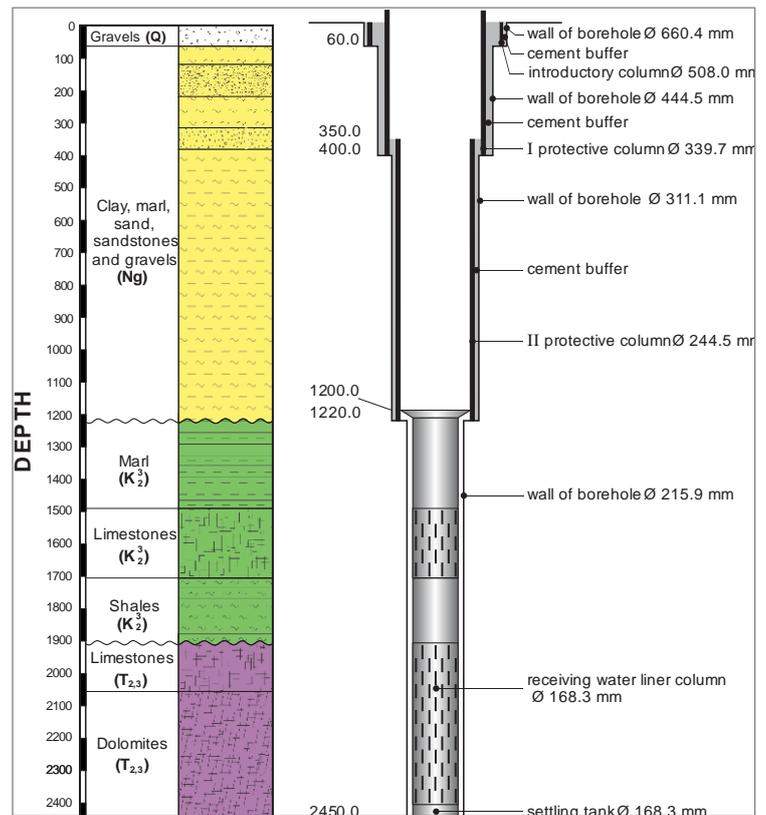


Figure 4. Geological profiles and construction of geothermal exploration and exploitation borehole.

Impacts interaction between the exploitation and injection well would be predict on hydrogeothermal simulation model at the micro level, and will also determine the duration of exploitation of reservoirs and its findings. Thereafter, the optimization work of making proper facilities for the use of geothermal energy will be done.

Realistically it is to be expected at each borehole an outburst of 20 - 25 L/s of thermal water with the push at the head of closed borehole about 3 bars. Pumping water from wells with corresponding stations can be exploited in each borehole about 50 L/s of geothermal water.

### 2.3 Economic evaluation of the profitability of exploitation

Economic analysis included in the financial investment in the exploitation of geothermal water for heating the town of Bijeljina (Acin and Bodiroža, 2002; Đurić and Radovanović, 2009):

- includes all potential users of geothermal heating in the next ten years,
- as part of the economic - financially analysis, it is given the invoice of required investments in basic and working capital as well as sources of funding and obligations according to the sources,
- results of operations and balance sheet and financial, economic and social flow project.

The economic evaluation of the action in addition to the above factors includes the need for the rational use of natural wealth. This assessment is provided through static and dynamic analysis of the project.

The current method of heating the town of Bijeljina, is related to coal, oil, present energy and wood. Use of geothermal energy as alternative energy source for heating the city of Bijeljina, improve air quality in the city and the environment, especially in the winter.

Environmental quality in the area is monitored for a dozen of years. The results show that the air quality is worse in the winter during the low temperatures, due to the use of coal with high sulfur content. The rest of the year shows the results, that quality of air, water and soil is within the required limits.

The advantages of using geothermal energy in Semberija are multiple. It is a domestic resource, then the resource that is renewable and represents a clean energy that does not pollute the environment when it is used, and it is a much cheaper energy source. This energy in the highest percentage may be a replacement energy to the existing energy sources.

Semberija is an agricultural area, which requires a completely clean environment throughout the whole year, so that its products would be acceptable on European market. In addition, it is foreseen the use of geothermal energy at lower temperatures consumers for agricultural production, especially in periods when there is no open manufacture during the year.

## 3. GEOTHERMAL POTENTIALITY OF ILIDZA

At the area of Ilidza near Sarajeva in the valley of the river Zeljeznica thermomineral waters exist, which are used from the Roman times, through the Turkish period till today. Intensive use begins before the end of IXX century, in the Austro -

Hungarian Empire, when they observed the area with favourable natural resources, where they can build a spa and other facilities for relaxation. So it raised Spa Ilidza, where it was soon built hotels with spa content, which are also present today. In time complex Spa Ilidza developed and became the most famous and most widely used treatment center in Bosnia and Herzegovina.

The region of Ilidza is geologically extensively studied and investigated in the late XIX and throughout the XX century. The works were carried out in order for better knowledge of the resources of drinking water contained in intergranular Quaternary sediments and thermal mineral water stationed in the deep horizons of the Triassic. Around the main source of thermal mineral water Ilidza were made boreholes B - 10a, IB - 1, IB - 2, PP - 1 and B - 3a, which are active (Figure 5).

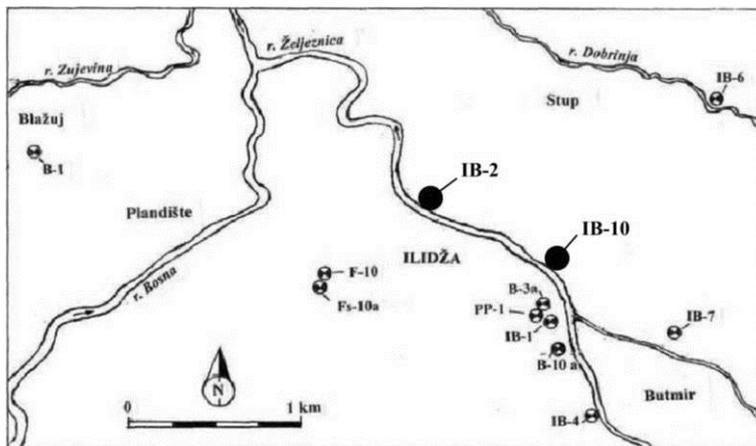


Figure 5. Schedule of boreholes of thermal mineral water of Ilidza (Skopljak and Bašagic, 2004).

However, only borehole IB - 2 is an exploitation facility, because it is properly equipped. It is completed in Triassic limestones (T<sub>2,3</sub> ?). Structure of Ilidza's part of Sarajevo's field is related to the sediments of the Triassic, Jurassic - Cretaceous flysch, Miocene and Quaternary (Figure 6).

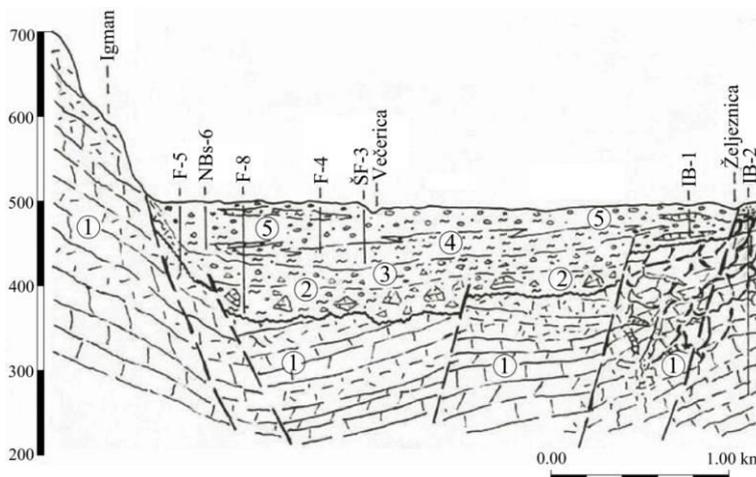


Figure 6. Geological profile from source of Bosna to Ilidza (Čičić and Skopljak, 2001, updated by Đurić N., 2014).

1. limestones and dolomites of the Middle Triassic, 2. roughly weak - bound limestone rocks, 3. gravel with less rounded grains of limestone, dolomite and subordinate sandstone with variable share of sand and clay, 4. clay with varying participation of gravel and sand, 5. gravel and sand, partly with increased participation of clay.

Thermo - mineral waters of Ilidza are of mixed descent. Waters from deeper horizons are mixed with cold water from the alluvium. It was thought that greater depths may contain water of higher temperature, for which more detailed researches are needed. The warmest collectors are Anisian limestones where forecast temperatures of thermal mineral waters of 80 °C or more, total mineralization of 3.29 g/l. Geothermal potentiality placed in the zone of thermal mineral water Ilidza, is estimated at 48.6 MW<sub>(th)</sub> (Miošić and Hrvatović, 1999).

### 3.1 Possibilities of using thermo mineral water

Current use of mineral waters is very modest compared to its potential. Total water yield of boreholes is approximately 260 L/s of water temperature from 24 to 58 °C, and currently it is used about 10 L/s of these highly medicinal waters for the heating systems of the hotel. Water with a lower temperature of about 24 °C is packaged in bottles and sold in the market under the name "Ilidza's diamond".

Sarajevo with its surroundings has about 1 million inhabitants and an area of Ilidza is suitable for agricultural production, which opens the possibility of using water in food production. It would be produced vegetables, plants, fungi and aquaculture, and production would be provided by cascading. The water temperature of 60 °C would be used in greenhouses, a temperature of 50 °C for fungi production. The lower temperature of 30 - 35 °C is suitable for aqua - culture and food production.

Spatial organization of Ilidza has a feature of Garden City. In Europe over 100 years is present an ideal of forming garden cities, whose roots stem from the late 19th century in England. This ideal is present in Sarajevo and Ilidza, and natural resources are in favour of this area.

Using the energy of hot water for heating in the settlement of Ilidza, would reduce the consumption of imported gas, and the environment would be fully harmonized with the current legislation, which creates and environmental requirements for the production of healthy food.

In the area between Health Center and the UPI Institute at Ilidza, is planned a construction of swimming pool complex and related facilities with the use of thermal mineral water from borehole IB - 2. The project is intended to become one of the largest facilities of its kind in the former Yugoslavia.

Acknowledging these plans related to the characteristics of mineral waters, it was made the borehole IB - 10 Ilidza, Figure 5, where were analyzed factors for the feasibility of investing in research and utilization of geothermal water

### 3.2 Economic and financial analysis of profitability

When evaluating the investments needed for the geothermal plant IB - 10 at the site Ilidza direct, indirect and associated investment costs are taken into account.

Analysing the total cost of the investment and its economic feasibility, it was stated that the goal of economic justification of investment is achieved if it is used a wider temperature consumption. It is necessary to fully enable the use of thermal energy from the heating of objects, until its complete utilization, up to a temperature from 20 °C, where it returns through the injection well into the interior of earth.

### 3.3 Discussion

Exploratory borehole IB - 10 was carried out according to the project, but showed significantly different results than expected. Because of that is was stopped at the depth of 1100 m. Temperature instead of increasing with depth, it reduced because there is a mixing of hot and cold water. The presence of tectonics in this area is not yet fully clarified, so that the borehole obtained unexpected results. The temperature of water at the depth of 812 - 853 m was 40 °C, and the depth of 1000 m was 21 °C (Table 1).

The borehole is completed, properly closed and now does not have its significance. Would it later be used for bottling of drinking water or any other purpose will depend on the new economic analysis of the possibility of using these waters.

Table 1. Main characteristics of waters in IB - 10 Ilidza

Interval (m)	Outburst (L/s)	Temperature (°C)	Electrical conductivity (µS/cm)
812 – 853	40	30,3	1750
888 – 902	30 – 40	31	1560
1000 – 1005	22	21 – 22	920

Geothermal potential of thermomineral waters of Ilidza is important, so one negative result on a borehole will not stop further investigation. The results of the IB - 10 shows that detailed hydrogeological research in planning such investments are necessary.

## 4. GEOTHERMAL POTENTIALITY OF KAKANJ

In the municipality of Kakanj, located in central Bosnia, it is investigated the source of thermal mineral water Ribnica and Ticici, in terms of quality and quantity, and economic justification of the use (Figure 7). Depending on the characteristics of water, it is planned the construction of the spa and / or sports and recreation center that follow this site. Area for research is 12 km<sup>2</sup>, which is a small area, but significant in terms of the presence of mentioned water. Appearance of thermal waters in Ribnica and Ticici with temperature around 30 °C, is registered in the seventies of the twentieth century (Đerković, 1971; Josipović, 1971). Then he was announced the possibility of obtaining artesian water larger temperature and capacity. Waters are related to the Jurassic – Cretaceous limestones and Turonian – senionsk flysch on the NE edge of the Sarajevo – Zenica basin (Čičić, 2002).



Figure 7. Geographical location of Ribnica i Ticici.

Thermomineral water in Ribnica and thermomineral water in Ticici in the beginning of the eighties of the twentieth century, were limited to known sources of hot water with the name "Spa" for the locals to use. Considering that close is located surface mining of coal in Vrtlište, the idea of further research in the area Ribnice was abandoned. Afterwards, it was approached to the study of thermal water at the site of Banja, near the village Ticici, west of Ribnice.

On the site called Spa Tičići (Figure 8) two exploration boreholes were made IT - 1 (300 m) and IT - 2 (203 m), at a distance of 350 mm (Miošić et al., 1997). It was drilled through the same layers as in the Ribnica and it did not reach the footwall insulators. Some researchers believe that the underlying stratum insulators are much deeper, about 1500 - 2500 m. It is estimated that the Anisian limestone (Middle Triassic T<sub>2</sub>) as the real source of hot water, are at depths of two kilometers, and hot water erupt to the surface through faults. Hot water erupts to the surface through faults such as Ribnica and Repovaca, who are managing the zone of Busovaca fraction, with which they are directly related (Milojević, 1964; Čičić, 2002).

The boreholes are of various depths, insufficient to reach the footwall insulators, and sufficient to gain insight into the basic characteristics of registered water (Table 2). It is typical that the temperature increases with the depth. On the IT - 1 borehole, the water was under strong pressure (1.1 bar), erupted and threatened surrounding buildings.

Figure 8. Geological profiles of exploratory boreholes of thermomineral waters Banja - Ticici. 1. Alluvium, 2. sandy calcareous marl with layers of coal and clay marl, 3. Cracked limestones in amending with layers of marl and brecciated limestone - hydrogeological collector of hot and cold water.

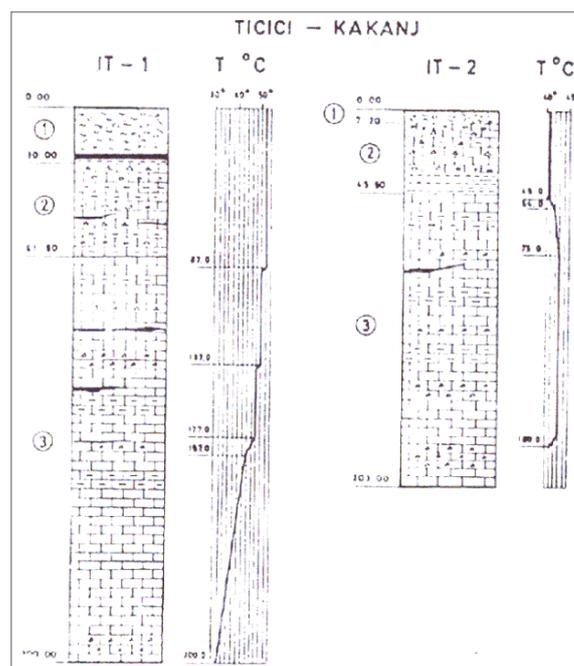


Table 2. Characteristics of water on exploration boreholes.

Borehole No.	Q (L/s)	t °C	pH	Firmness (°dH) / mg ekv/l	CO <sub>2</sub> (mg/l)	H <sub>2</sub> S (mg/l)	O <sub>2</sub> (mg/l)
IT - 1	30	54	6,9	25 / 13,9	190	0,07	9.8
IT - 2	22	39	6,5	29 / 14,73	147	0.07	6,7

Thermomineral waters in Spa Ticici According to the balneologic classification these waters belong to the thermals and hyperthermia, and have a wide range of therapeutic effects; they can be compared with Swiss spa in Austria and some famous spas in the former Yugoslavia. Thermal mineral potential of the water resources Tičići significantly is not used and the boreholes were closed from uncontrolled.

In order to increase hydro - geothermal potential, it is planned to develop a borehole to a depth of 300 - 400 m. The influx of thermo mineral waters can be expected within the first 100 m, except that predicts an increase in flow with depth and the optimum water temperature around 50 °C, in the carbonate massif. In addition to these sources in the municipality Kakanj, there are several smaller sources of thermal and thermo mineral water.

#### 4.1 Possibilities of using thermal and thermo mineral water

In the municipality Kakanj, beside the spring Ribnica and Ticici, there are several sources of thermal mineral water, but the current plans of water use are related to these two sources. In doing so, the source Ticici has the advantage of being away from surface mining Vrtliste, located next to the future highway corridor Vc. Favourable transport links to major cities Zenica and Sarajevo, which offers the possibility of becoming the center of municipality Kakanj in this area.

The central part of Bosnia and Herzegovina through the centuries, is characterized natural beauties, the presence of cultural and historical values and favourable climatic conditions which occur during the year clearly distinguish the four seasons. In this area, are crossed different cultures, religions, traditions, and in the range of 100 km can be seen largely the history of Bosnia and Herzegovina in the past years. Some of these events have had a significant influence on the development of European society.

Characteristics of the area over time have left a tradition agricultural production. Today we still cannot find local products, which are market in Europe. Also possible is the development of organic farming in all aspects of food production.

Keeping the above in mind, this is an attractive destination for tourism development. Using water with elevated temperature and mineralization, justifies the construction of the spa, sports and recreation complex. Elevated temperatures may be used in glasshouse production, especially in the period when it is not possible outdoors.

#### 4.2 Economic and financial analysis

The analysis was performed for the conditions of construction of a spa, sports and recreational tourism, and food in the open space and greenhouses. Analysis follows some other important factors for the development of this area. It is harmonized the municipal spatial plan Kakanj which this area associates with major roads towards Zenica, Sarajevo and Travnik. Distance of the center from the location of the source or primary boreholes for exploitation of mineral waters is about 2.5 km, which increases investment in part of its transportation.

The starting point for assessing the investment is quality of the geothermal energy resources. Previous research indicates that the temperature reached 50 °C and energetic potential of about 6.5 MW. According to the previous experiences and economic analyzes compliant with current legislation and credit terms of domestic and foreign banks, investments in projects of geothermal resources with the resource of given quality are justified.

#### 4.3 Discussion

Previous studies of thermo mineral waters have shown justification for further research with the possibility of development of appropriate economic programs. Advantage in further research and investment originates in Ticići because of favourable geographical features. Besides two exploration wells for which is subsequently shown that are not of sufficient depth, it is planned a development of one more borehole depth of about 400 m, temperature 50 °C.

Characteristics of the area, both in geographical and historical terms, provide justification for investment in development primarily of spa, sports and recreational tourism. Together with other spas in Bosnia and Herzegovina, as well as important historical events, it would close a circle of service activities in the above areas.

The quality of the geothermal resource in the part of its use, justifies planned investments. Analysis of environmental and social factors in an area that is undeveloped, also confirmed the justification of the investment.

### 5. OTHER THERMAL AND THERMO MINERAL RESOURCES IN BIH

According to data from the end of the twentieth century (Miošić et al., 1999; Čičić, 2002), the total thermal energy potential of the springs and boreholes analyzed at 74 sites is 166 MW, without additional research. Sources are at varying degrees of exploration and with different thermal energy capacity. However, there is a sufficient number of resources that are in use today, and can be used to a greater extent with an increase in level of exploration.

Renewable energy potential of hydrogeological thermal systems, calculated by various methods, to a depth of 3000 m is 125 x 106 TJ, (Čičić and Miošić, 1986). Sources of heat in the earth's crust on the territory of Bosnia and Herzegovina are complex and varied, the most significant being:

- conductive surface and terrestrial heat flow 2400 MW,
- radioactive heat 200 MW,
- communication of hot water in springs and wells 200 MW,
- reduction of the Earth's rotation 40 MW,
- seismicity 20 MW.

Above values are significantly lower than the potential that exists in Bosnia and Herzegovina and that can be exploited. Conductive terrestrial heat flow is calculated from the product of the average heat flow  $q = 90 \text{ mW/m}^2$  and  $P = 26\,000 \text{ km}^2$ , which is the geothermal potential in Bosnia and Herzegovina (Čičić and Miošić, 1986). Radioactivity to a depth of 3500 m is calculated on the basis of literature data on secondary Clarcovom content of radioactive elements in rocks and the amount of heat radiogene for certain types of rocks (Boganik, 1966). The heat liberated by reducing the rotation of the Earth and caused seismicity data according to the literature.

In Bosnia and Herzegovina, geothermal energy is used mainly for the spa and recreational purposes (Figure 9). Temperatures are around 50 °C, although in some locations are registered lower or higher temperatures. Highest water temperature is 75 °C at the Spa Dvorovi.

Figure 9. Spatial distribution of spas Bosnia and Hercegovina.



## 6. FINAL COMMENT

Geothermal energy in the area of Semberija and northeastern part of Republic Srpska - Bosnia and Herzegovina, is an important energy resource. The current level of exploration is sufficient that it can be planned its usage primarily for the purpose of warming of buildings in the winter. It remains insufficient exploration in terms of maximum temperatures of water on the surface, which can be obtained from a depth of 2500 m. After making the first geothermal borehole BGT - 1 we will get data on temperature and capacity borehole, e.g. how much energy can we get from one borehole. Existing economic analyzes were performed for the maximum temperature on the surface of about 90 °C.

If the temperature has reached the value of 110 °C, then it would be considered the possibility of using geothermal energy for energy purposes, e.g. construction of appropriate geothermal power plants. In doing so, the economic justification for its use would be subsequently analyzed.

The use of geothermal energy in Semberija a justification, especially as this is an agricultural area, so that energy can be used in food production and processing, and the lower the temperature consume for sports and recreational purposes. Replace fossil fuels with geothermal energy, would reduce the concentration of pollutant particles in the air, which will improve the quality of the environment. Given that Semberija is an agricultural area, by improving the environment, opens up the possibility of producing organic products.

Other parts of Bosnia and Herzegovina are characterized with the presence of warm waters from which you can get a certain amount of energy. In these areas, water temperatures are lower, but enough that it can find the appropriate application.

Isolated areas of Ilidza near Sarajevo and Kakanj in central Bosnia are just some of the areas where it is used geothermal energy with a clear perspective for the future.

## REFERENCES

- Acin Đ. and Bodiroža M.M. (2002) - Međunarodna ekonomija. Zavod za udžbenike i nastavna sredstva, (2002).
- Boganik N.S. (1966) - O roli radiogenog tepla v formirovanii geotermalnihpolej. Geotermičeskie isledovaniai ispolzovanie tepla Zemlji. Nauka, 1966.
- Čičić S. (2002) - Geološki sastav i tektonika BiH. Monografija. Earth Science Institute, 2002, 1 - 350.
- Čičić S. and Miošić N. (1986) - Geotermalna energija Bosne i Hercegovine. Geoinženjering, 1986.
- Đerković B. (1977) - Rezultati dosadašnjih istraživanja na mineralnim, termalnim i termomineralnim vodama srednje Bosne. Geološki glasnik 15 (1977), 279 - 318.
- Đuričković V. V. and Đuričković V. A. (2010) - Optimalni parametri geotermalnog toplifikacionog sistema Bijeljine. Arhiv za tehničke nauke br. 2. (2010), 16 - 23.
- Đjuric N. (2008) - Geothermal Energy New Energetic Reality in the Area of Semberija, Republic of Srpska – Bosnia and Heryegovina. 10 th International Mine Water Association Congress, 2008, Poster session 1.
- Đurić N. (2011) - Energetska potencijalnost geotermalnih resursa i mogućnost njihovog korištenja za toplifikaciju grada Bijeljine. Arhiv za tehničke nauke br. 6 (2011), 1 - 9.
- Đurić N. and Jovanović L. (1997) - Perspektive geotermalne energije u Republici Srpskoj. Međunarodni naučni skup "100 godina hidrogeologije u Jugoslaviji" (1997).
- Đurić N. and Radovanović S. (2009) - Predstudija ekonomske opravdanosti istraživnja i eksploatacije geotermalnih voda na teritoriji grada Bijeljine. FSD Tehnički institut, 2009.
- Jelić K. (1982) - Toplinski tok i Mohorovičićev diskontinuitet na profilu Sušac – Vapovo. Savjetovanje – Rezultati dosadašnjih geofizičkih istraživanja raznih fenomena vezanih proučavanje građe Zemljine kore i Gornjeg omotača na teritoriji Jugoslavije, 1982.
- Josipović J. (1971) - Mineralne, termalne i termomineralne vode u BiH. Geološki glasnik 15 (1971), 233 - 77.
- Milivojević M. and Perić J. (1986) - Preliminarna ocena energetske potencijalnosti hidrogeotermalnih resursa u mezozojskoj podlozi tercijarnih sedimenata na području Semberije radi njenog korišćenja za toplifikaciju Bijeljine. Rudarsko - geološki fakultet Beograd, 1986.
- Milojević R. (1964) - Geološki sastav i tektonski sklop Srednjobosanskog basena. Geološki zavod u Sarajevu. Posebna izdanja, vol. VII (1964), 5 - 120.
- Miošić N., Skopljak F., Turalija, A. (1977) - Projekt izrade dva probno - eksploataciona bunara TB - 1 i TB - 2, Tičići - Kakanj. Zavod za geologiju.
- Miošić N. and Hrvatović H. (1999) - Studija - Hidrogeotermalni resursi područja Ilidže. Zavod za geologiju Sarajevo.
- Sharma P.K., Tiwari G.N., Sarayan V.P. (1998) - Parametric studies of a greenhouse for summer conditions. Energy, Vol. 23, Issue 9 (1998), 733 - 740.
- Skopljak F. and Bašagić M. (2004) - Revitalizacija bunara "CC Well" Coca - Cola Beverages B - H d.o.o Sarajevo, Grad.fak. Sarajevo - Institut za geologiju, Sarajevo, 2004.

## Low Temperature Geothermal Applications in Greece, Including Water Desalination

MENDRINOS Dimitrios<sup>1</sup> and KARYTSAS Constantine<sup>1</sup>

<sup>1</sup> CRES - Centre for Renewable Energy Sources and Saving of Greece, Pikermi, Greece

Corresponding author's e-mail: [dmendrin@cres.gr](mailto:dmendrin@cres.gr)

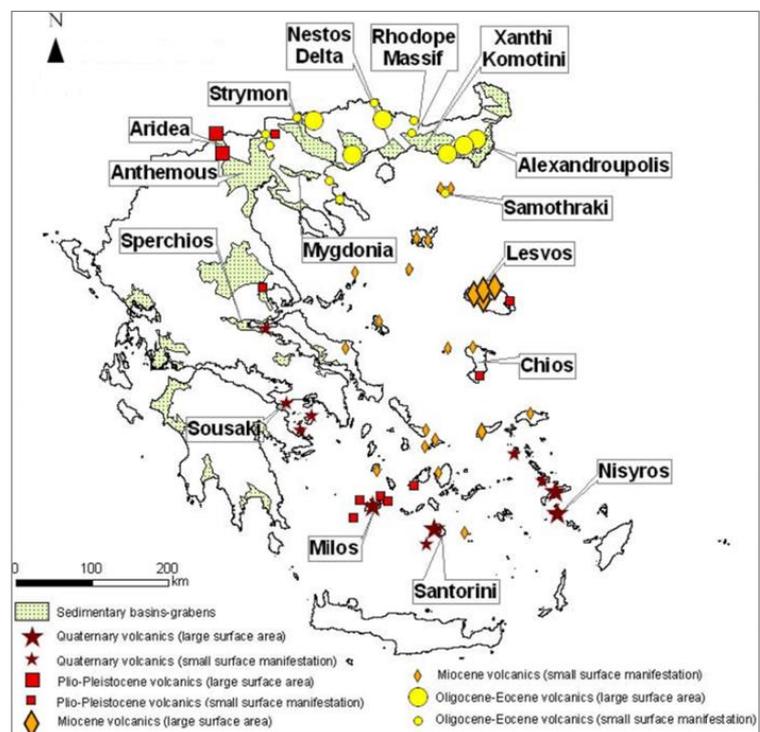
**Keywords:** geothermal energy, geothermal resources, low enthalpy, desalination, Greece.

### ABSTRACT

Greece is favoured by geothermal resources encountered in regions of Quaternary or Miocene volcanism and in continental basins of high heat flow. Although the high enthalpy (>300 °C) geothermal potential identified by deep drilling in Milos and Nisyros islands still remains unused, the low enthalpy geothermal resources (T<90 °C) identified by shallow wells in the vicinity of thermal springs are utilized mainly for spas, agricultural cultivations, aquaculture of algae and fish farming, corresponding to ~100 MW<sub>(th)</sub> of installed capacity in 2013. To these applications another 100 MW<sub>(th)</sub> should be added corresponding to ground source heat pumps exploiting shallow geothermal energy all over the country. Two European projects implemented by CRES and other partners proved the technical and economic feasibility of using low enthalpy geothermal energy (T<90 °C) for seawater desalination.

### 1. HIGH ENTHALPY RESOURCES

In Greece, medium enthalpy geothermal resources of temperature 90 - 150 °C are located within main sedimentary basins or grabens, as proven by deep wells drilled for oil exploration. High enthalpy geothermal resources of temperatures above 150 °C are expected to be found at depths 2 - 4 km in the basement beneath the sedimentary basins, as well as in the vicinity of outcropping volcanic and magmatic formations of recent geologic age, namely in areas of Quaternary, Pliocene and Miocene volcanism. The areas of geothermal interest for medium or high enthalpy resources are shown in Figure 1.



**Figure 1.** Distribution of sedimentary basins/grabens, as well as volcanic/magmatic rocks in Greece (source: Mendrinou et al., 2010).

The Greek State has already allocated 8 geothermal concessions for exploration and exploitation of geothermal energy, which belong to PPC - Renewables, a subsidiary of the Public Power Corporation of Greece (Figure 2). In the older ones of them, namely in Methana, Milos, Nisyros and Lesvos, extensive surface geothermal exploration has been carried out, including geochemical analysis of waters from springs and shallow aquifers, thermal gradient surveys, gravity surveys, resistivity surveys and others. In the most promising of them, namely in Milos and Nisyros deep exploration wells have been drilled, which revealed high enthalpy resources of temperature above 300 °C, suitable for power generation.

New concessions allocated to PPC - Renewables are Sousaki, Sperchios graben, Akropotamos and Ikaria, where exploration is expected to commence soon. In another four areas, namely in Delta Nestos, Delta Evros, Samothraki and South Chios allocation of geothermal concessions are under way for exploration of high enthalpy resources (Figure 2), following a call for tenders released in 2010.

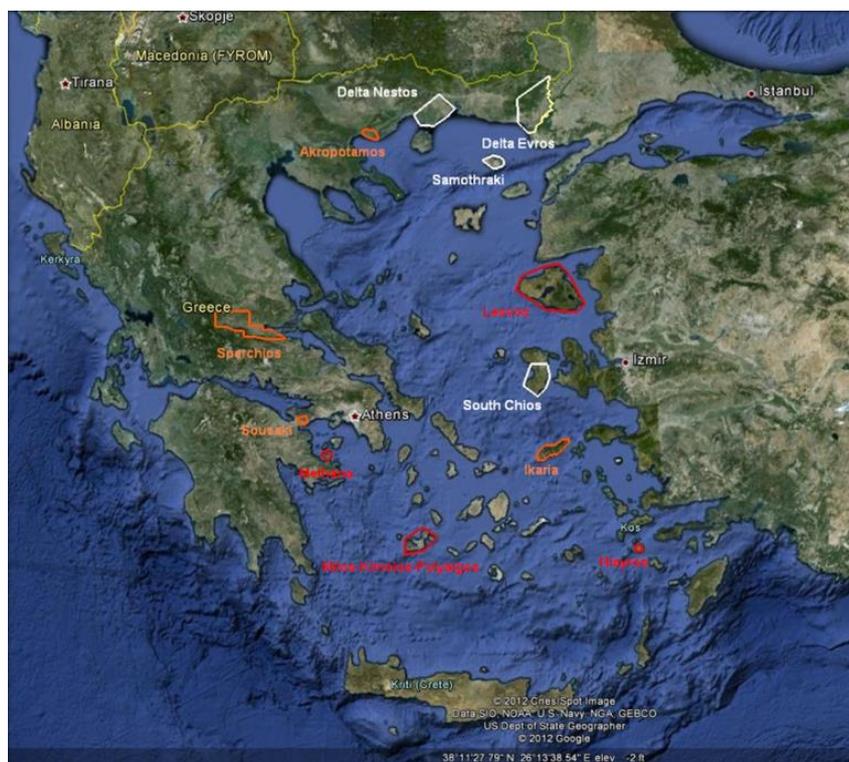


Figure 2. Allocated concessions for high enthalpy geothermal resources (source: CRES).

The most intensively explored geothermal field is Milos Island. Exploration results are summarized in Figure 3. Milos is a Volcanic island of Quaternary (Pleistocene) volcanism with extensive hydrothermal alteration. Thermal manifestations include steam vents and steaming ground mainly at the South East part of the island and hot springs at the coast. Shallow boreholes of 100 m maximum depth indicate very high thermal gradient of 0.5 - 0.9 °C/m at the East part of the island. Resistivity contours drawn by AAMT soundings indicate a closed low resistivity area at the central East part of the area, beneath Zefyria plain, extending to Vounalia area and Adamas bay, area also associated with the highest geothermal gradients. Five deep wells have been drilled on the island, 4 in Zefyria plain and one near Adamas town, which tapped geothermal resources of 300 - 323 °C temperature at 1.0 – 1.35 km depth. Evaluation of all geothermal exploration data and reservoir simulation indicate a proven geothermal resource justified for developing a 150 MW<sub>(el)</sub> power plant. In order to exploit the geothermal potential in its full capacity however, electrical interconnection to the continental grid must be established via submarine cable, as local electricity needs are limited to 7 MW<sub>(el)</sub> of the population, mainly in the summer, plus another 7 MW<sub>(el)</sub> of local mining industry. Present exploitation plans, comprise a small power plant of 5 MW<sub>(el)</sub>.

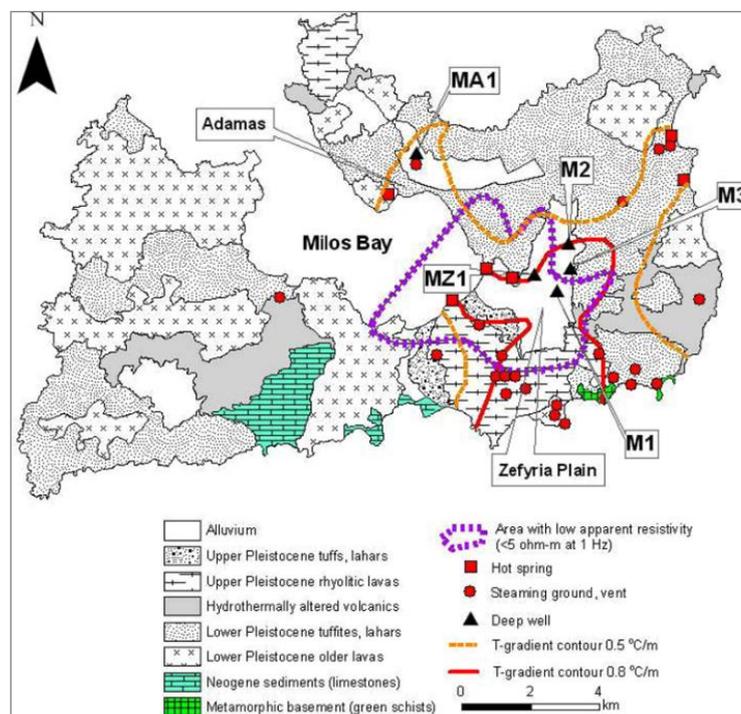


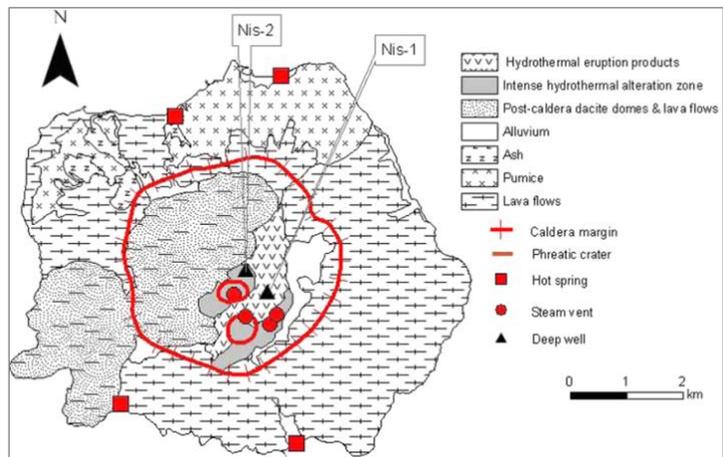
Figure 3. Milos geothermal field: geology, thermal manifestations, thermal gradient, apparent resistivity and deep wells (source: Mendrinou et al., 2010).

Nisyros Island is a volcano with eruptions, caldera formation and lava dome uprising occurring in upper Pleistocene during 20 - 45 thousand years ago (IGME, 2008). Its geology and geothermal map are summarized in Figure 4. Thermal manifestations include hydrothermal eruption craters, the last of which formed 127 years ago, hydrothermal alteration and

steam vents within the caldera, as well as 4 hot springs at the coast outside the caldera. Two deep wells drilled within the caldera identified geothermal resources of 250 - 350 °C temperature at depths 1.5 to 2.0 km.

Evaluation of local geothermal potential resulted in a justified for development geothermal resource of up to 50 MW<sub>(el)</sub> power plant capacity. Present exploitation plans comprise a 5 MW<sub>(el)</sub> power plant in order to cover local power needs. Full scale development of the geothermal field needs power interconnection with the nearby island of Kos via a submersible cable.

Figure 4. Nisyros geothermal field: geology, thermal manifestations and deep wells (source: Mendrinou et al., 2010).



## 2. LOW ENTHALPY RESOURCES AND USE

Greece is rich with low enthalpy geothermal potential (temperature 25 - 90 °C), as proven by the 100+ hot springs with temperature above 25 °C encountered in its territory, as shown in Figure 5. Thirty two (32) areas are officially classified by the Greek State as proven or probable low enthalpy geothermal fields. According to Andritsos et al. (2010) their total potential is estimated at 220 kTOE or 9200 TJ annually.

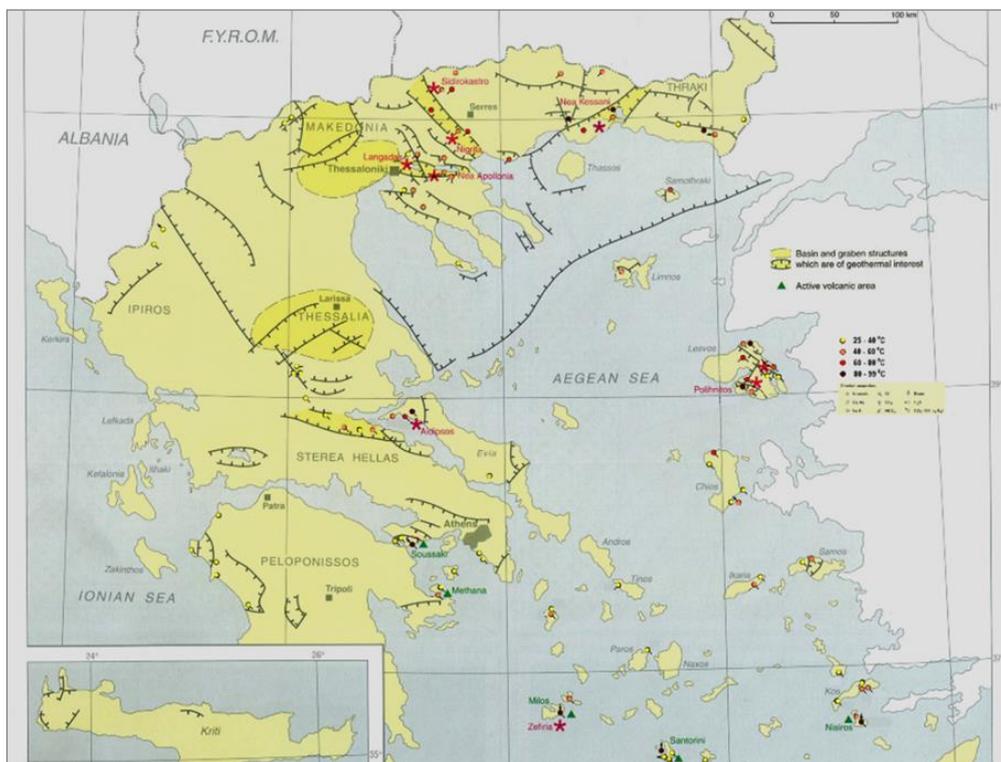


Figure 5. Map of thermal springs, main geological structures and low enthalpy uses (source: European Commission, 2002).

Geothermal applications include 100 MW<sub>(th)</sub> of ground source heat pumps for heating and cooling of buildings utilizing shallow geothermal energy of temperature <25 °C, plus slightly above 100 MW<sub>(th)</sub> of low enthalpy geothermal uses of temperatures between 25 °C and 90 °C. The latter comprise mainly spas, greenhouse or soil heating and fish farming, as well as limited applications for space heating and drying. Greenhouses produce mainly vegetable, flowers and algae, while soil heated plantations mainly asparagus and lettuce. Installed capacities and geothermal energy use of each application are shown in Figure 6.

The evolution of geothermal market during the last 10 years is presented in Figure 7, in terms of both installed capacity and annual geothermal energy use. Ground source heat pump market was booming from 2007 till 2012, but in 2013 the number of new installations has declined due to the economic recession at country level. The market segment of spas has been fairly stable during the entire 10 year period in terms of both installed capacity and geothermal energy use. The

Greenhouse and soil heating market segment however, has shown a steady increase in terms of installed capacity due to a number of new installations occurring each year, but geothermal energy use has declined during the past two years to pre - 2004 levels, as many units operate below their full capacity due to the recession. Similar trend follow the fish farming applications.

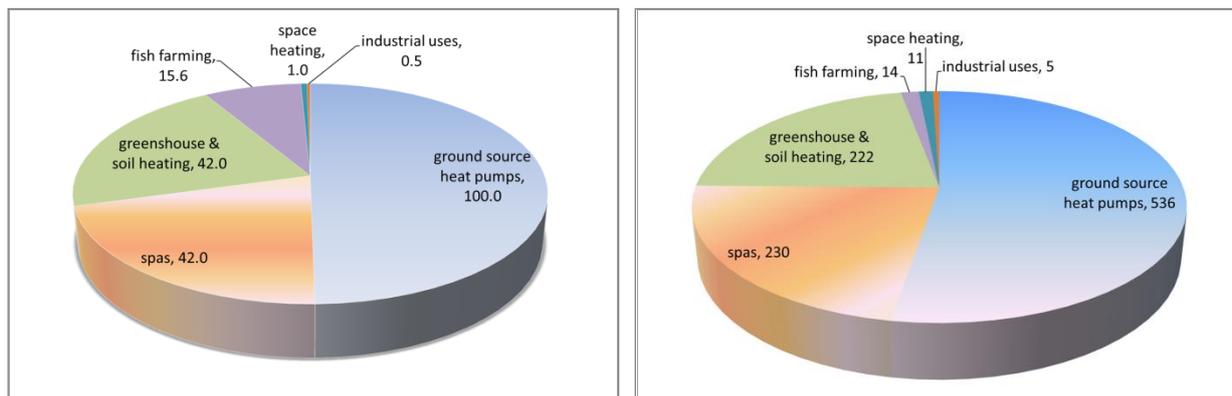


Figure 6. Geothermal applications in Greece: installed capacity in MW<sub>th</sub> (left) and annual energy use in TJ (right), (source: CRES).

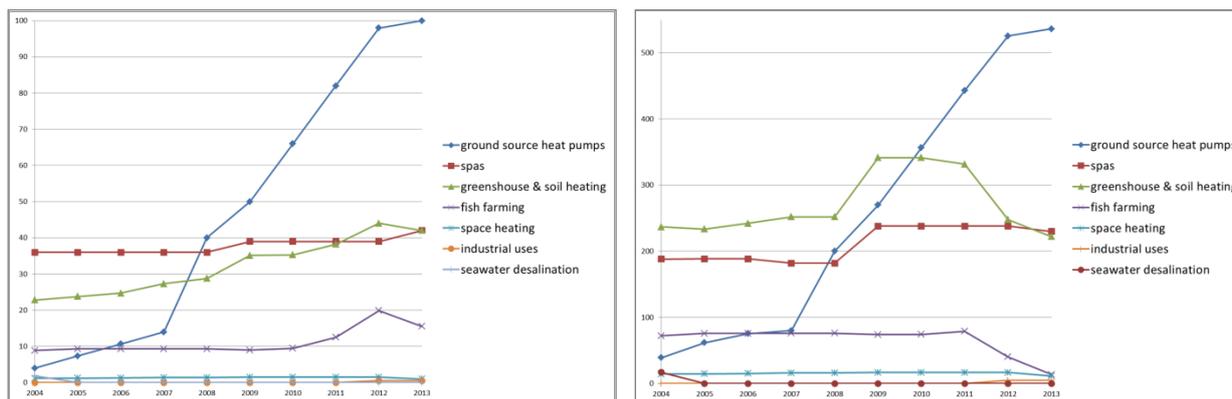


Figure 7. Evolution of geothermal market in Greece: installed capacity in MW<sub>th</sub> (left) and annual energy use in TJ (right), (source: CRES).

### 3. SEAWATER DESALINATION PROJECTS

Two projects including seawater thermal desalination (Figure 8) with geothermal energy have been implemented.

The first project concerned a geothermal pilot desalination plant installed in Kimolos Island. The project was implemented by the Centre for Renewable Energy Sources and Saving of Greece (CRES) between 1994 and 2000. It concerned demonstration of a thermal seawater desalination unit using 80 m<sup>3</sup>/h of 61 °C geothermal water as energy source, and the Multiple Effect Distillation (MED) method. Apart from CRES, other parties involved were ALFA LAVAL which supplied the MED desalination unit and the Community of Kimolos, which was the end user of the produced water. Project budget amounted at 1 million € approximately, 40% of which was financed by the European Commission through its THERMIE - A program. The pilot plant proved that a production of 80 - 120 m<sup>3</sup> per day of potable water was feasible. The plant is no longer in operation.

The second project concerned geothermal exploration of the low enthalpy geothermal resource located at 50 - 100m depth beneath Vounalia area on Milos island, drilling production & reinjection wells, feasibility analysis and engineering design of a geothermal cascade plant for power generation and seawater desalination. The foreseen plant included production of 360 m<sup>3</sup>/h of 85 - 97 °C water from 4 geothermal wells, an ORC unit delivering 470 kW<sub>(e)</sub> of electricity to local power grid, a MED seawater thermal desalination unit in cascade, 4 reinjection wells, plus all associated piping and equipment. Project partners were Gerling SDP, CRES, NCSR, the Aristotle University of Thessaloniki and Milos Municipality. The project was implemented during the years 2000 - 2004 and was supported by the European Commission (EC) through its ENERGIE European program. It had a budget of around 4.4 million €, 35% of which was the EC support. The project indicated that the cascade geothermal ORC and MED desalination plant requires an investment of 5.2 million €, and will deliver 3.7 GWh /yr of electricity with generation costs of 0.058 €/kWh and 75 m<sup>3</sup>/h potable water (TDS<50 ppm) with production costs of 1.015 €/m<sup>3</sup>. At present, a stakeholders' scheme has been formulated seeking finance to proceed to the investment.



## **Integration of energy sources in the Peri - Adriatic Areas**

## Heat Pumps for Exploitation of Geothermal Sources in Milano City

MASELLA Andrea<sup>1,2</sup> and PIEMONTE Carlo<sup>2</sup>

<sup>1</sup> Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Italy

<sup>2</sup> Studio Associato di Ingegneria, Milano, Italy

Corresponding author's e-mail: [ing.andreamasella@gmail.com](mailto:ing.andreamasella@gmail.com)

**Keywords:** district heating systems, Milano city, heat pumps, geothermal exploitation.

### ABSTRACT

The employ of geothermal heat pumps to supply large heating systems is a technology which has been developed in the last decade in Italy, in particular using shallow geothermal sources thanks to following technical, environmental and economical advantages in comparison with deep resources:

- shallow resources are easier to be found,
- no mining risk or at least reduced mining risk,
- strong reduction of drilling costs,
- simpler authorization procedures,
- lower problems for the chemical composition of the geothermal fluid,
- need in any case for the use of a heat pump system,
- possible compensation of the reduced temperature drop with a higher available flow.

For this reasons, the lecture will describe the following application cases of ground water heat pumps in Milano city:

- the geothermal heat stations feeding the A2A Company district heating systems of Milano Canavese and Milano Famagosta, each with a 15.5 MW ground water heat pump,
- the complex named “Palazzo Lombardia” in Milano, the new headquarters of Region Lombardia: the largest building in the world fully heated by means only of geothermal sources.

## 1. HEAT PUMPS FOR THE EXPLOITATION OF GEOTHERMAL SOURCES

### 1.1 Foreword

The theme of the lecture is “Heat pumps for the exploitation of geothermal sources in Milano city”, to understand how the ground water heat pump is used in Milano. At the first, shortly the following paragraph will describe some general aspects about the technology of the heat pumps.

### 1.2 Heat pump

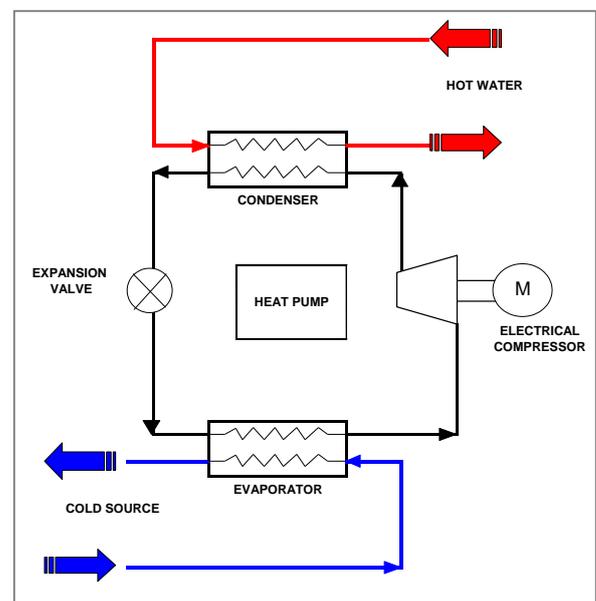
The heat pump is a particular kind of refrigerating cycle where the unit is used to extract heat from a cold source with the aim to produce thermal energy. This allows an effective use of the thermal content of the cold source suitable for thermal users.

The Figure 1 shows the conceptual flowscheme of the electrical Heat pump which is mainly composed by:

- 2 heat exchangers (evaporator and condenser),
- electrical compressor,
- expansion valve.

The working fluid used in the closed circuit is called refrigerant. The two heat exchangers are called, one evaporator where the cold source gives its heating to the refrigerant, the other one called condenser where hot water is produced.

Figure 1. Conceptual flowscheme of the heat pump.



### 1.3 Application field for different types of compressors for heat pump cycles

The heat pumps can be divided in three categories according to types of compressors:

- piston compressor,
- screw compressor,
- centrifugal compressor.

Each compression technology has a different application field related to the thermal power and the maximum hot water temperature obtainable.

As the Figure 2 shows, in relation to the thermal power:

- the heat pumps with piston compressors are suitable only for applications with thermal power lower than about 1 MW,
- the heat pumps with screw compressors are suitable for applications with thermal power comprised between 500 kW and 6 MW,
- the heat pumps with centrifugal compressors are suitable for applications with thermal power comprised between 2 MW and 20 MW.

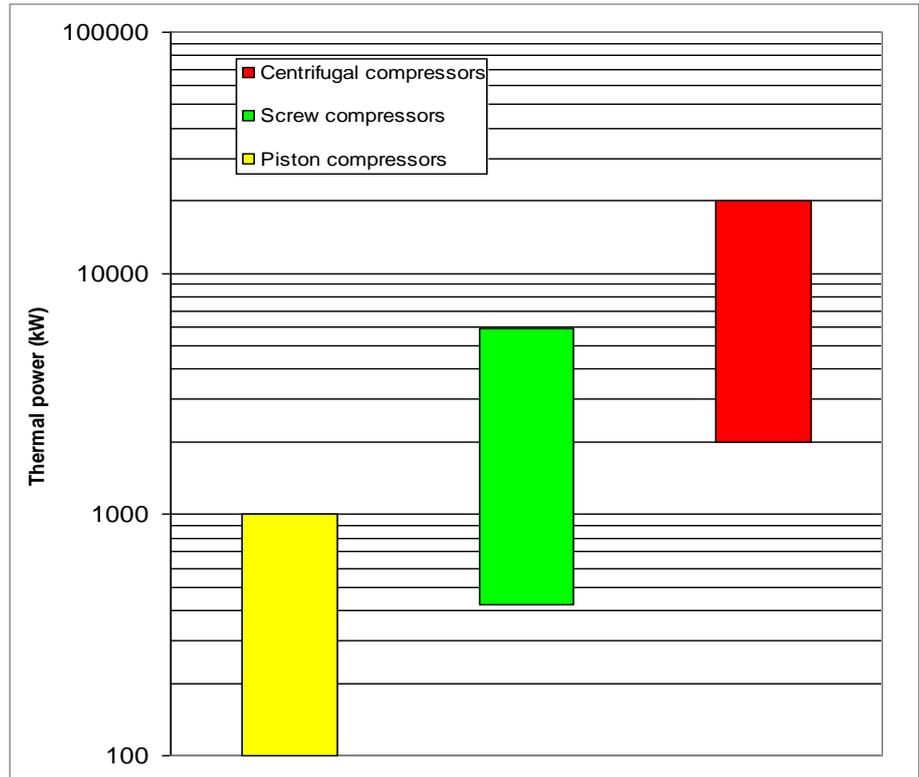


Figure 2. Application field for different type of compressors for heat pump cycles.

In the Figure 3, there is an additional information related to the maximum hot water temperature obtainable:

- heat pumps with piston and screw compressors can produce hot water at a temperature of about 75 °C,
- heat pumps with centrifugal compressors can produce hot water at a temperature of about 90 °C.

It means that the piston and screw heat pumps can be used mainly for the application for single buildings while only the centrifugal heat pumps can be used for district heating system, which has return water with high temperature.

### 1.4 Possible cold sources used for water - water heat pump

The possible cold sources used for water - water heat pump:

- shallow water from rivers, lakes or sea,
- low or deep geothermal sources,
- water from drinkable water system,
- water from treatment plant,
- waste water from sewage system,
- cooling water from industrial waste,
- cooling water from cogeneration plant.

The technology of heat pumps can be easily applied to the exploitation of geothermal sources. So to understand these concepts, the paper will describe the following application cases of geothermal heat pumps placed in Milano city:

- the geothermal heat stations feeding the A2A Company district heating systems of Milan Canavese and Milan Famagosta, each with a 15.5 MW ground water heat pump,
- the complex named “Palazzo Lombardia” in Milan, the new headquarters of Region Lombardia: the largest building in the world fully heated by means only of geothermal sources.

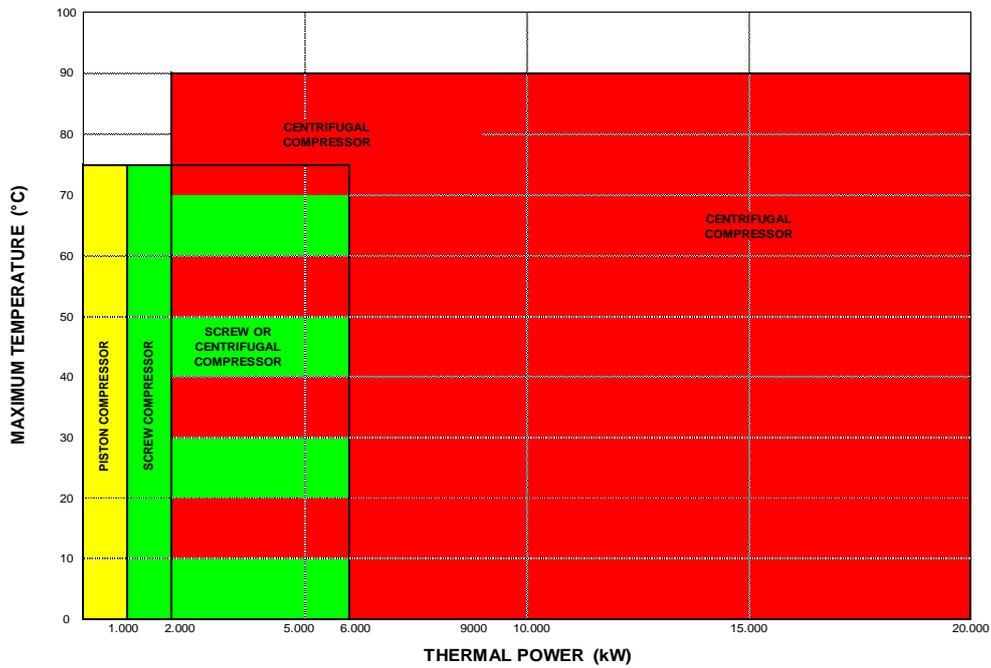


Figure 3. Maximum hot water temperature obtainable.

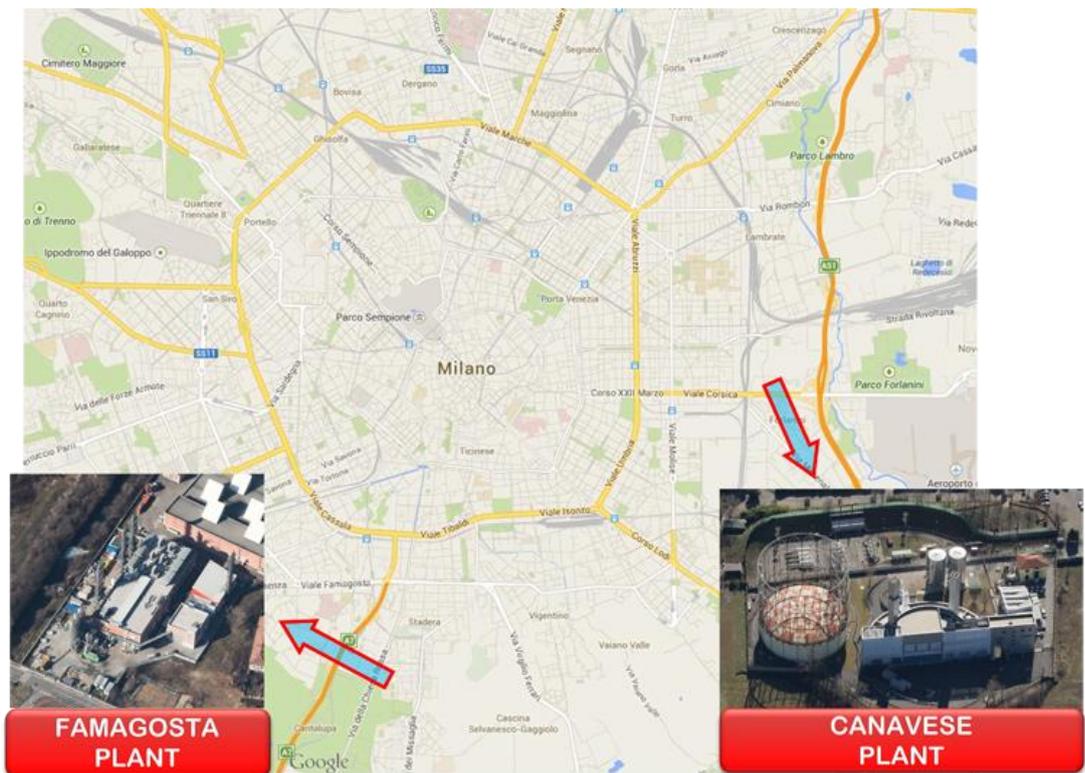
## 2. THE GEOTHERMAL HEAT STATIONS FEEDING THE A2A COMPANY DISTRICT HEATING SYSTEMS OF MILAN CANAVESE AND MILAN FAMAGOSTA

The geothermal heat stations feeding the A2A company district heating systems of Milan Canavese and Milan Famagosta are two identical geothermal district heating stations of Milano, which are the biggest ground water heat pump of the world.

These two stations supply hot water for A2A company district heating system of the town.

The Figure 4 shows the map of the town and where the plants are located: one is placed in east part of Milano, close to Linate airport: this station is called Canavese plant; the other one is located in the south part of the city and it is called Famagosta plant.

Figure 4. Map of Milano city.



## 2.1 Geothermal sources available in Milano

The province of Milan and specifically the area of the town are very rich of geothermal sources. Substantially, there are two different types of underground water.

The first type is represented by ground water, which is available nearly everywhere, at a depth comprised between 20 and 50 m, with a temperature of about 15 °C. The amount and the level of ground water in the last years in Milan had an important increase, following to the strong reduction of its utilization for cooling process by a certain number of industries (in particular, steel industries) which closed their activity. For this reason, now in certain parts of the town the level of ground water is so high that it is necessary to pumped out the aquifer water to avoid floods of underground floors of buildings, underground parking and subway tunnels.

The second type is represented by deeper sources, which can be found in the different areas at a depth in the range between 500 and 2000 m with estimated temperatures in the range between 40 °C and 70 °C.

## 2.2 Advantages in using shallow geothermal resources in comparison with deep resources

Among the above possibilities, the choice was in favour of the use of shallow geothermal resources, for the following several reasons:

- shallow resources are easier to be found,
- they aren't mining risk or at least mining risk is reduced,
- the drilling costs have a strong reduction,
- the procedures to obtain the authorization to exploit these resources are easier,
- there are lower problems for the chemical composition of the geothermal fluid (aquifer water is usually represented by soft water, without any problem with some salt content, which on the contrary could be involved by the use of deeper sources),
- possible compensation of the reduced temperature drop with a higher available flow,
- need in any case for the use of a heat pump system to have a maximum exploitation of the geothermal sources.

## 2.3 Heat pump data sheet

These geothermal stations have the biggest ground water heat pumps of the world, with a thermal capacity of 15.5 MW each. The heat pumps are equipped with a two - stage centrifugal compressor.

As the Table 1 shows, ground water is cooled down from 15 °C to 7.6 °C with a flow of 1150 m<sup>3</sup>/h and the heat extracted from ground water is about 10 MW for each unit.

Then a part of the aquifer water is discharged on a surface channel and the other part is reinjected underground by wells.

On the condenser side, the heat pump produces hot water at a temperature of 90 °C with a thermal capacity of 15.5 MW. The COP of each unit is about 2.7. This means that in winter about 67% of the heat produced by heat pumps is free, as it is taken from ground water (e.g. endogenous renewable resource). Electrical Power of motor is about 5 MW.

Operating only during heating period		
Number of units	1xFamagosta	1x Canavese
Compressor Type	Centrifugal	
Refrigerant	R134a	
Cooling medium	Groundwater	
Technical data	for each unit	
Cooling capacity	kW	9'732
Cold water temp. in/out	°C	15.0 / 7.6
Cold water flow	m3/h	1'150
Heating water temp. in/out	°C	65.0 / 90.0
Heating water flow	m3/h	546
Power at terminal	kW	5'768
Heating capacity	kW	15'500
Coeff. of performance		2.68

Table 1. Heat pump data sheet.

In addition, in each of these district heating stations there are gas motors feeding the electrical energy to the heat pump and they also produce thermal energy for district heating systems. Peak load and stand - by gas boilers completed the production structures. These heat pumps can produce hot water for the equivalent of 15 000 people in total and each thermal station allows to obtain an energy saving of 5400 TOE per year. Both plants started the operation four years ago.

The dimensions of each heat pump are about 13 m length, 7 m wide and 5 m high.

Figure 5 and Figure 6 show the Canavese heat pump during the construction phase: the heat exchangers have not been yet isolated.



Figure 5. 15.5 MW ground water heat pump with centrifugal compressor for A2A Canavese district heating system in Milano city.



Figure 6. A detail of the 15.5 MW ground water heat pump with centrifugal compressor for A2A Canavese district heating system in Milano city.

The Figure 7 shows the Famagosta heat pump in the final phase of construction: the heat pump room is without the door. Moreover, by this picture it is possible to understand the dimensions of the production unit thanks to the presence of the operator in front of the equipment.



Figure 7. 15.5 MW ground water heat pump with centrifugal compressor for A2A Famagosta district heating system in Milano city.

### **3. ADDITIONAL BENEFITS USING GROUND WATER ALREADY PUMPED OUT FOR FEEDING DRINKABLE WATER SYSTEM, AS COLD SOURCE FOR HEAT PUMP**

In case of using the ground water already pumped out for feeding drinkable water system, as cold source for heat pump, the additional benefits are the following:

- new geothermal wells are not necessary because the production wells are already built and the outlet water from evaporator of heat pump returns to a drinkable water network;
- it is not necessary to obtain a specific permission or authorization;
- the electrical costs of the pumps to extract the geothermal water are already included for the use of the drinkable water plant;
- there is not any environmental impact except for the noise produced by the heat pump, however it can be minimized by a proper acoustic insulation, for example foreseeing for the heat pump an insulation hood.

### **4. THE COMPLEX NAMED “PALAZZO LOMBARDIA” IN MILAN, THE NEW HEADQUARTERS OF REGION LOMBARDIA: THE LARGEST BUILDING IN THE WORLD FULLY HEATED BY MEANS ONLY OF GEOTHERMAL SOURCES**

“Palazzo Lombardia is the largest building (Figure 8 and Figure 9) in the world fully heated by geothermal sources: that large building is the new headquarters of Lombardia Region.

Palazzo Lombardia is located in Milano, not far from the center of the town and close to the main railway station. The construction is very recent: in fact, it has been completed and entered into operation in 2010. The whole construction required 3 years. The complex has n.6 building blocks connected the one to the other, each 9 floors height and 3 floors underground. One block is a tower with 40 - floors, whose height is more than 160 m.



Figure 8. (on the left and below) Palazzo Lombardia (new headquarters of Lombardia Region) in Milano city: the largest building in the world fully heated by geothermal sources.



The main function of the building is to collect and centralize the offices of Lombardia Region in only one building. Because before its construction the offices were spread into the city. For this reason in the complex 3000 employees are working. In the complex there are also an auditorium with 375 places, a conference room with 500 places, a space for events at the last floor, an exhibition space and commercial activities, gymnasium, restaurants, a nursery, a telephone shop, an ice cream shop, a supermarket, a shop for sport articles and under way there is the realization of a post office and of a multifunction medical clinic. About 4500 people (considering employees, visitors and others) every day are present in the Palazzo Lombardia complex. The three underground floors are mainly devoted to the services of the building (parkings, storage rooms, technical rooms).

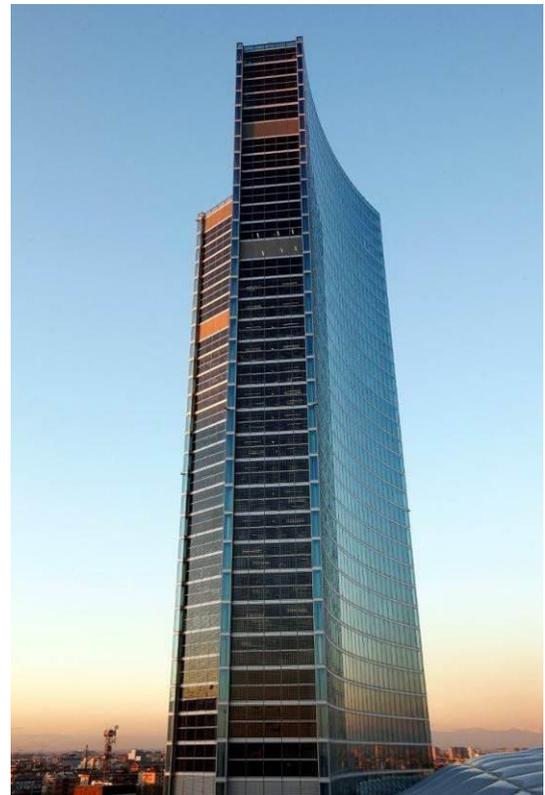


Figure 9. A view of Palazzo Lombardia.

The whole building complex is characterized by the presence of a double glass wall, which allows to minimize the winter heating needs reducing the required thermal power down to 6.3 MW. Regarding heat distribution systems, which consist mainly of chilled beams and air handling unit, the delivery and return temperatures are respectively 48/40 °C.

The choice of these heating systems and of the above mentioned operating temperatures for the heating plant have been decided in order to make the installation suitable for the utilization of a renewable energy source for the heating purposes of the building, and specifically geothermal water, which in this case is represented by ground water.

The design has been developed so that the building is fully heated by using the heat from ground water through heat pumps. As the Table 2 shows, the winter heat production is assigned to n. 3 heat pumps with a capacity of 2150 kW each, extracting heat from ground water and feeding low temperature circuits (Figure 10). The heat pumps adopted are single stage units, with a screw type compressor. In order to supply ground water, n. 8 wells were drilled under the building foundations, producing 40 L/s each, for a total of 320 L/s. The depth of the wells is 50 m.

During winter, the ground water is cooled from 15 °C to min 6 °C by the heat pumps, while in summer it is used for chillers condensers cooling: so the heat pumps operate in reversible mode (among the chillers there are also the above mentioned heat pumps, operating in a reversible mode).

The heat pumps COP (Coefficient of Performance) is about 4.5 in winter mode and about 6 in summer mode.

This means that in winter about 78% of the heat produced by heat pumps is free, as it is taken from ground water (e.g. endogenous renewable resource).

n. of production wells	8
Wells depth	50 m
Groundwater flow	8 x 40 l/s = 320 l/s
Groundwater temperature (inlet / outlet)	15 / 6 °C
Groundwater discharge	surface channel
n. of heat pumps	3
Compressor type	Screw
Thermal capacity	3 x 2.150 kW
Winter heat need coverage by means of heat pumps	100%
Winter mode COP	4,5
Summer mode COP	6,0

*Table 2. Heat pump data sheet.*



*Figure 10. 2.15 MW ground water heat pump with screw compressor for Palazzo Lombardia in Milano city.*

After using, the ground water is discharged to the underground Martesana ditch.

Heat pumps cover the thermal need of the complex, except for particular condition when the Martesana ditch cannot receive the ground water because of a huge quantity of rain. So for this reason, in the thermal station of the complex there are also some conventional boilers fed by natural gas.

The chilled water production for summer air conditioning, in addition to heat pumps, is obtained by other water cooled chillers equipped with centrifugal compressor.

During summer, both heat pumps' and chillers' condensers will be cooled first with ground water. In case of ground water unavailability (an exceptional situation limited to a really small number of hours per year) or not sufficient flow, cooling towers will be used.

**ACKNOWLEDGEMENTS**

Thanks to Della Vedova B. for his kind invitation for attending this important and interesting event.

**REFERENCES**

Piatti A., Piemonte C., Szego E. (1992) - Planning of geothermal district heating system. Kluwer Academic Publishers, 1 - 308.  
 Piemonte C. and Porro A., (2013) - Palazzo Lombardia - Geothermal heat pump capacity world record for a single building conditioning. European Geothermal Congress 2013, Pisa, Italy, 3 - 7 June 2013.

## The future of sustainable energy policies in the Friuli Venezia Giulia Region

STEFANELLI Silvia<sup>1</sup>

<sup>1</sup> Central Directorate of Environment and Energy, Friuli Venezia Giulia Region, Italy

Corresponding author's e-mail: [silvia.stefanelli@regione.fvg.it](mailto:silvia.stefanelli@regione.fvg.it)

**Keywords:** energy policy, regional renewable energy share, energy efficiency, bioenergy.

### ABSTRACT

Renewable energy sources play a relevant role at regional level in the total energy mix. They contribute to reducing energy dependence and improve energy diversification. RES at regional level increased remarkably in the last years and their share, combined with final energy demand decrease, will contribute to meeting regional RES targets by 2020, namely 12.7% of final energy consumption. In parallel with the RES increase, several energy efficiency measures carried out at domestic level had an impact on reducing energy consumption.

The analysis provides an insight into the main objectives of the energy plan and the role of renewables in the regional energy mix with particular regard to bioenergy. The share of RES - Electricity supply as percentage of total gross energy consumption in 2012 was 22%. Although hydropower remains the main renewable electricity source at regional level guaranteeing above 70% of RES - E, however since 2009 other renewables like Solar PV and biomass have come into the market gaining significant RES market share. Solar PV has taken an increasing share of the electricity mix and from 2009 to 2012 in the Region it rose by 1325%. Such regional impressive growth reflects also the leading role that Italy is playing on solar PV in Europe where it represents the third European country after Germany and Spain either for solar PV capacity and solar electricity. Solid biomass, namely forest and agricultural biomass, waste and biogas make up the third largest source of RES - E in the Region with a share of 12% in the RES mix. An example of a local successful short supply chain is provided.

Finally, in the future RES growth should be matched with a more efficient management of decentralised energy. To this end, the Region joined the RENGOV project that aims at integrating distributed renewable energy sources (solar, biomass, hydroelectric, etc.) according to a Virtual Power Plant (VPP) approach, creating a regional smart grid and using energy storage capacity.

### 1. INTRODUCTION

The overall regional energy objectives by 2020 are set by the regional energy law n°19/2012. Although the law is being overhauled, however the objectives will steer the actions and measures of the future energy plan. In fact, the energy plan is now ongoing and its key energy measures up to 2020 can be summed up as below:

- support energy efficiency in public buildings, transport and industry,
- overhaul the energy distribution system defining the main energy corridors and implementing smart grids,
- support energy audits,
- support to towns that joined the Covenant of Majors (Decree 2201/2013),
- enhancing sustainable transport and in particular electric mobility and intelligent charging stations,
- define the optimal energy RES and not RES mix and the use of local energy sources like biomass from sustainable short supply chains, hydropower, solar and geothermal sources,
- contribute to reducing regional GHG emissions,
- economic support measures (e.g. bank of white certificates, support to RES and energy efficiency upfront investment costs etc).

### 2. RENEWABLE ENERGY SOURCES TARGETS AND PROGRESS

The FVG Region has mandatory targets on RES by 2020. In fact, the Legislative Decree n° 28/2011 (Official Gazette 28 March 2011) includes provisions for the Regions in order to meet the national RES 17% target by 2020. The national target on RES - Heat and RES - Electricity has been passed on to Regions that will contribute each by a binding regional target. The Friuli Venezia Giulia Region has been assigned a target of 12.7% of RES by 2020 as Table 1 shows.

The target is broken down in RES - Heat and RES - E sub not - mandatory targets, whereas each region can adjust the overall RES-E and RES - H targets increasing more or less renewable heat and electricity, depending on the most cost - effective measures, the availability of local renewable sources and local constraints. The regional target will be monitored every two years and a target trajectory is set for every regional target.

Table 1. Friuli Venezia Giulia RES objectives and RES share.

Friuli Venezia Giulia Region	Electricity from renewable energy source (kTOE) or%	Thermal energy from renewable energy source (kTOE)	Total (kTOE)	% of total energy consumption from RES by 2020 over final energy consumption (mandatory)
RES targets 2020	213.2	228.6	442	12,7
Share of RES - Heat % 2012	-	Not known	-	Not known
Share of RES - Electricity % 2012	22%		-	
Share of RES 2012	-	-	-	10% (indicative)

The regional outlook of RES - Electricity reflects in part the national share of RES, where hydropower has been for a long time the main RES supplier of green electricity. Although hydropower remains the main renewable electricity source at regional level guaranteeing above 70% of RES – E as Figure 1 shows, however since 2009 other RES sources like Solar PV and biomass have come into the market gaining significant RES - E market share.

Solar PV has taken an increasing share of the electricity mix and from 2009 to 2012 Solar PV in FVG - rose by 1325% and in 2012 represented 18% of the total RES - E share (Figure 1). In the bioenergy mix biogas represents the main source of electricity, followed by solid biomass and bioliquids like vegetal oils.

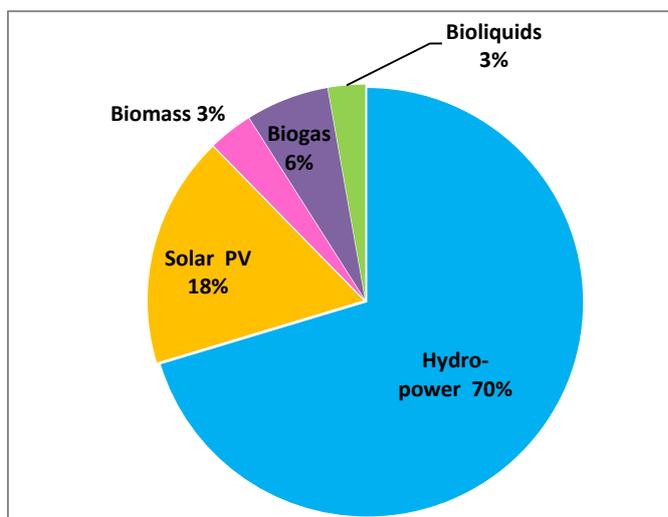


Figure 1. RES - Electricity share in the FVG Region in 2012 (source: GSE, 2012).

### 3. ENERGY EFFICIENCY: THE ROLE OF THE DOMESTIC SECTOR

With regard to energy efficiency the FVG Region has not set mandatory energy savings targets although final energy savings are part of the measures to increase the RES share on the overall final energy consumption.

The latest National Energy Efficiency Plan (July 2014) sets the three following national targets:

- 15.5 MTOE annual savings in final energy consumption by 2020 or 24%,
- avoid 55 M annual tCO<sub>2</sub>,
- 8 billion € savings in energy imports.

Although these targets have not been passed on to Italian regions, financial measures are supported at national level in order to meet these targets at the local level. These measures, altogether with regional financial support measures to investments costs, represent the main instruments at regional level to improve energy efficiency in the residential, industrial and public sectors.

The main measures of the National energy efficiency plan that target primary energy savings are the followings:

- minimum energy efficiency standards in buildings,
- fiscal rebate on expenses for buildings refurbishment,
- White Certificates – a mechanisms that allows to cash in from energy efficiency savings in kWh,
- support to cars freight update.

At regional level, these schemes have been widely implemented and have contributed to reducing energy consumption. An outlook of energy efficiency interventions, in particular building refurbishment carried out benefiting national fiscal support measures is shown in Figure 2.

The majority of interventions concerned window frames replacement (57%), followed by condensing boilers (24%) and solar thermal installations (14%).

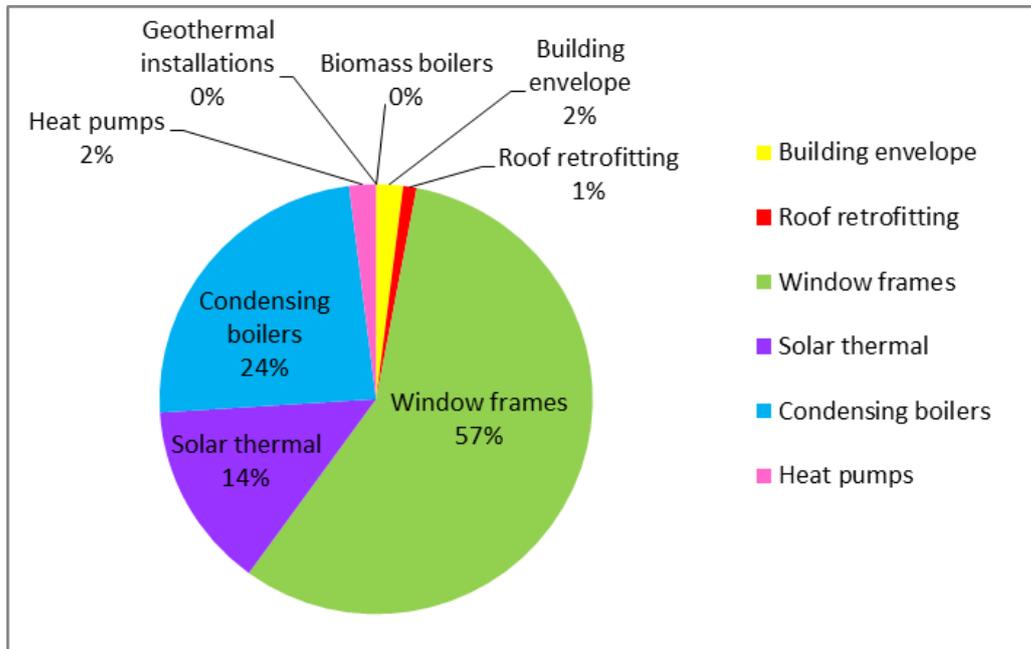


Figure 2. Breakdown of energy efficiency domestic measures in 2012 (source: ENEA 2013).

#### 4. THE FRIULI VENEZIA GIULIA APPROACH TO DECENTRALIZED ENERGY

The Friuli Venezia Giulia approach to smart grids is well illustrated by the objectives of the RENGOV project, whose partners include the Region together with other public holdings and SITI, a non - profit organization. RENGOV is an initiative of “SMART ENERGY GOVERNANCE” with the strategic objective to develop innovative energy management strategies at local level, by integrating distributed renewable energy sources (solar, biomass, hydroelectric, etc.) according to a Virtual Power Plant (VPP) approach, creating a regional smart grid and using energy storage capacity. The project includes the active involvement of local authorities, private entities and investors, creating models of public - private partnership oriented towards value oriented mechanisms. Local authorities, energy producers from renewable sources, energy transmission and distribution operators, energy storage systems producers, financial institutions, regional companies are therefore an integral part of the smart approach, which will also trigger virtuous mechanisms of communication and participation.

RENGOV is based on energy clusters, composed by groups of power plants based on renewable sources, where the impacts on the current business models (generation, distribution, transmission) of the potentialities offered by technology can be simulated or operationally assessed, providing useful elements for the forecast of innovative energy systems market development. The set of clusters represents a Context of Operational Experimentation (CSO) unique in Europe. In a second phase of the project buildings in urban areas will be considered as energy “prosumers” (producers and consumers), part of the VPP of the system. Therefore, inside the CSO it will be possible to bring about the real benefits of the adoption of coordination mechanisms aimed at optimizing the overall production of energy and its placement on the network, thus overcoming congestion phenomena and other technical limitations. The aim is on one hand to maximize the economic returns for each production unit, on the other the creation of networks stabilization mechanisms and new qualified job opportunities (in particular new smart businesses). On the basis of the actual data generated by the CSO, it will be possible to make appropriate calculations and financial and economic simulations, in order to build innovative business models.

#### 5. THE ROLE OF BIOENERGY AT REGIONAL LEVEL

Due to the distribution of forest resources in mountain areas, the social, economic and environmental benefit of short supply chains, the Region has developed a strategy that supports primarily biomass boilers and DH networks and only secondarily small scale woody biomass CHP (Combined Heat and Power) plants. However, CHP plants due to European incentives and national feed in tariffs have been developed in the last years, increasing the demand of solid biomass, including woody biomass sources.

The kick off woody energy chains and systems was mainly driven by financial opportunities provided by EU Structural Funds (POR FESR 2000 - 2006 and 2007 - 2013) and the Common Agricultural Policy (CAP 2000 - 2006 and CAP 2007 - 2013).

According to a recent survey (CETA, 2012) in 2011 there were 11 CHP biomass plants fed by solid biomass, although the origin of the biomass is mixed from agricultural and forest biomass so more detailed information on the origin and type of biomass being used are not available at the moment. More detailed data are available on biomass boilers and DH networks, which are mainly fed by woody biomass sources.

In 2012 there were 140 biomass boilers built due to public co - financing measures for an overall capacity of 18 MW. Beyond commercial installations, also the domestic sector includes a distributed network of domestic woody biomass fed installations such as fireplaces and stoves. A recent survey shows that by and large in 2011 there were around 194 000 domestic biomass installations in the Region, fed by chips, pellets and logs.

A recent survey highlights that the regional consumption of woody biomass in domestic installations equals 7.8 million GJ or 186.5 kTOE/yr. However, at the moment there are not up to date data on the origin of woody biomass whether it is from regional, national, European and international biomass markets.

## 6. A REGIONAL BENCHMARK MODEL OF A SUSTAINABLE BIOMASS SUPPLY CHAIN

The Friuli Venezia Giulia Region is rich of biomass sources and in particular of woody biomass stocked in natural forests. However only a small fraction of woody biomass is being used as biomass due to several economic and infrastructural barriers. However, some small communities in the mountain areas managed to set up a sustainable model to exploit forest biomass for bioenergy purposes.

Forni di Sopra, a small community in a mountain area within the boundaries of the regional Park of the Dolomiti Friulane, set up a bioenergy supply chain that can work as a benchmark model for other towns in mountain regions. The small town in the last years has turned a potential weakness, lying in a mountain valley far from the main services and industry hubs into an element of success, in terms of energy and social development. The town has managed to set up a short bioenergy supply chain exploiting local forest resources in a sustainable way and develop a decentralised energy model based on several RES sources that will lead to energy self sufficiency (Table 2).

The bioenergy supply chain was originally developed to serve public buildings with renewable heat generated by a biomass plant. The biomass plant and the first block of the district heating network were built in 2008 and in the following years they were enlarged to serve a wider network of consumers, mainly public buildings and a few private buildings.

The overall annual average energy distributed over the years 2010 - 2014 amounted to 1000 - 1200 MW<sub>(th)</sub> or 22% of the overall energy consumption in the public sector. With regard to the biomass, 50% comes from local forests that are sustainably managed and certified according to the PEFC scheme. The remaining woody biomass comes from local sawmills.

**Table 2. Key technical features of the Forni di Sopra sustainable supply chain.**

<p><b>Forni di Sopra bioenergy supply</b></p> <p>Biomass boiler: 1, 4 MW</p> <p>Use of local biomass from PEFC certified forest - 1270 m<sup>3</sup> /yr</p> <p><u>Biomass traceability:</u></p> <p>50% biomass from local sawmills</p> <p>40% from forest maintenance</p> <p>10% from private forests - local employment</p> <p>Heat generation: 10 153 MWh    Heat use 6600 MW<sub>(th)</sub></p> <p>2008 – 2014: 13 public buildings connected to the DH system</p>
--

The town vision on sustainable energy is to become energy self sufficient. To this end it has widely implemented a model of energy distributed generation that include on and off grid solar PV panels on buildings and solar thermal installations. In addition to that a smart wireless remote control system has been adopted to monitor energy use in public lightning, parking spaces and waste collection platforms.

The town has also adopted Green Procurement in public tenders and has introduced LCA (Life Cycle Assessment) principles in the all public buildings constructions.

## 7. CONCLUSIONS

In this paper, it was observed the underlying role of renewable sources and energy efficiency to meet RES mandatory targets and to operate the transition to a decentralised energy system. At regional level renewables like hydropower will continue to keep a dominant position in the RES - E mix however its future exploitation it is likely to be constrained by environmental factors. In the meantime, other RES sources have gained market share such as Solar PV and bioenergy sources. Solid biomass from forest, agricultural and waste sources has a remarkable untapped potential that could be exploited if barriers that hinder their deployment will be overcome. Finally the future energy plan will play a key role in defining the contribution of the different economic sectors (industry, domestic public, services) in the decarbonisation of the economy.

---

**REFERENCES**

- CETA (2012) - Aggiornamento dati sulla disponibilità di fonti energetiche rinnovabili sul territorio della Regione Autonoma Friuli Venezia Giulia.
- ENEA (2013) – RAEE. Rapporto Annuale sull’Efficienza Energetica 2011. Unità Tecnica Efficienza Energetica, Editore: ENEA Agenzia nazionale per le nuove tecnologie, l’energia e lo sviluppo economico sostenibile, Roma, 260 pp., 2013, <http://www.enea.it/it/produzione - scientifica/edizioni - enea/2013/rapporto - annuale - efficienza - energetica - 2011>.
- GSE (2012) - Rapporto statistico 2012. Impianti a fonti rinnovabili. Settore elettrico. Gestore dei Servizi Energetici – GSE S.p.A. (GSE), <http://www.gse.it/it/Statistiche/RapportiStatistici/Pagine/default.aspx>.

## The GROUND - MED Project - Advanced Ground Source Heat Pump Systems for Heating and Cooling in Mediterranean Climate

MENDRINOS Dimitrios<sup>1</sup> and KARYTSAS Constantine<sup>1</sup>

<sup>1</sup> CRES - Centre for Renewable Energy Sources and Saving of Greece, Pikermi, Greece

Corresponding author's e-mail: [dmendrin@cres.gr](mailto:dmendrin@cres.gr)

**Keywords:** ground source heat pumps, borehole heat exchangers, heating and cooling.

### ABSTRACT

GROUND - MED project (2009 - 2014), supported by the European Commission through the FP7 program, developed a new generation of ground source heat pump systems providing heating, cooling and sanitary hot water, characterized by improved energy efficiency. These systems have been installed and are being monitored in 8 buildings of South Europe. The project proved that the technological advantage of high efficiency heat pumps can be utilized in its full potential by adequate borehole heat exchangers, internal system design and advanced operation control synchronizing pumps and fans with the compressor and optimizing the heating/cooling water temperature. Monitoring results indicate system seasonal performance factors SPF<sub>2</sub> (considering electricity consumption at the compressors and external pump) up to 5.91 for heating, 6.76 for active cooling and 39.93 for free cooling directly from the borehole heat exchanger, well above the project objective of 5.0 and the EU average ground source heat pump performance of 3.5.

### 1. INTRODUCTION TO THE GROUND - MED PROJECT

The GROUND - MED project “Advanced GROUND source heat pump systems for heating and cooling in MEDiterranean climate” concerns technology development, demonstration & monitoring of a new generation of ground source heat pump systems for heating & cooling, with the objective to maximize energy efficiency, quantified as measured annual SPF >5.0. SPF is defined as the ratio of useful thermal energy (heating plus cooling plus sanitary hot water) delivered over the electricity consumption. 8 heat pump prototypes have been developed, which have been integrated into 8 demonstration systems, also designed and constructed by the project, as follows:

- CIAT regional offices, Septemes Les Vallons, Marseille, France: 48 kW<sub>(th)</sub>,
- HIREF factory, Tribano, Padova, Italy: 14 kW<sub>(th)</sub>,
- University of Oradea visual arts department campus building, Romania: 38 kW<sub>(th)</sub>,
- Regional government administration building in Coimbra, Portugal: 70 kW<sub>(th)</sub>,
- Benedikt Cultural Centre, Slovenia: 20 kW<sub>(th)</sub>,
- University Polytechnic Valencia campus offices, Spain: 17 kW<sub>(th)</sub>,
- La Fabrica del Sol renewable energy exhibition building, Barcelona, Spain: 70 kW<sub>(th)</sub>,
- EDRASIS head offices, near Athens international airport, Greece: 55 kW<sub>(th)</sub>.

The location of the demonstration sites is shown in Figure 1.



**Figure 1.** Location of GROUND - MED demonstration buildings.

GROUND - MED project commenced on 1st January 2009 and will last for 6 whole years until 31st December 2014. It has a budget of 7 237 847 €, 4 299 695 € of which is the budgeted EU support through the FP7 framework program. It is coordinated by CRES and it is implemented by the following organizations from EU:

- Centre for Renewable Energy Sources and Saving, CRES, Greece,

- Compagnie Industrielle d'Applications Thermiques, CIAT, France,
- HIREF SpA, Italy,
- OCHSNER Wärmepumpen GmbH, OCHSNER, Austria,
- Institute of Systems and Robotics - University of Coimbra, ISR, Portugal,
- University of Oradea, Romania,
- Gejzir Consulting, Slovenia,
- ECOSERVEIS, Spain,
- Edrasis - C. Psallidas S.A., Greece,
- ENEREN, Italy,
- University College Dublin, UCD, Ireland,
- Università degli Studi di Padova, UNIPD, Italy,
- Universidad Politécnica de Valencia, UPV, Spain,
- Commissariat à l'Énergie Atomique, CEA, France,
- Groupement pour la Recherche sur les Echangeurs Thermiques, GRETh, France,
- Escola Superior De Tecnologia De Setubal, Portugal,
- KTH, Royal Institute of Technology, Sweden,
- Geoteam Technisches Büro für Hydrogeologie, Geothermie und Umwelt GesmbH, Austria,
- GROENHOLLAND geo environmental solutions, Netherlands,
- Centre Technique des Industries Aérauliques et Thermique, CETIAT, France,
- Fachinformationszentrum Karlsruhe GmbH, FIZ, Germany,
- European Heat Pump Association, EHPA, Belgium,
- European Geothermal Energy Council, EGEC, Belgium.

## 2. TECHNOLOGIES DEVELOPED AND/OR TESTED

Eight heat pump prototypes have been developed, which are monitored at the project demonstration sites. They are all characterized by superior energy efficiency. This has been achieved by compressors of high isentropic efficiency, counter-flow heat exchangers in both heating and cooling mode and electronic expansion valves. All prototypes are at least externally reversible by a set of 4 three-way valves or 2 four-way valves. Different compressor configurations are considered, with 3 heat pump prototypes having single on-off compressor, 4 heat pump prototypes having tandem on-off compressors and 1 prototype having single inverter compressor. The latter apart from heating and cooling also provides sanitary hot water, allowing the heat rejection to the sanitary water loop in cooling mode, further increasing energy efficiency.

A new phase change material (PCM) with elevated melting point at 8 °C was tested for cold storage. The idea was that if tests were successful, the seasonal performance factor of heat pump systems equipped with cold storage would increase substantially, due to the higher operating temperatures at the evaporator. However, the results did not justify commercial exploitation of the technology, so improved ice cubes were demonstrated for cold storage at the Septemes les Vallons demonstration site.

As fan coil units are an important component of a heat pump heating and cooling system, with a market of 1 million units sold annually, their technology development was one of GROUND - MED key aspects. Technology development had two directions: one towards reducing the nominal heating temperature from the industry standard of 45 °C to 35 °C or even lower, and another towards reducing electricity consumption. The results were astounding. Lowering heating provision temperature objectives were achieved without any compromises in comfort by exploiting the COANDA effect, which is the induced convection current within the heated space. Electricity consumption was reduced by 80% (to 1/5 of initial value) by using new lightweight impellers and permanent magnet brushless motors of high efficiency.

A new energy efficient air handling unit was developed. Primary energy savings were achieved by utilizing condensing heat for dehumidification, replacing electrical resistors. A variety of available indoor heating and cooling systems have been tested. They included fan-coil units in most cases, both of existing and new developed technology, air handling units, as well as low temperature radiators in one case and wall heating by embedded plastic pipes in another, as shown in Table 1. The latter is able to operate at the lowest temperature in heating mode, resulting in superior energy efficiency.

**Table 1. Main heating/cooling systems at GROUND - MED demonstration sites.**

Demonstration site	Main heating/cooling system
Septemes Les Vallons	Fan coil units
Tribano	Fan coil units
Oradea	In-wall embedded piping
Coimbra	Fan coil units
Benedikt	Radiators
Valencia	Fan coil units
Barcelona	Air handling unit
Athens	Fan coil units

The flow in the water loops connecting the heat pump with the ground (ground loop) and the heat pump with the heating/cooling terminals (building loop) is induced by smart, variable speed pumps of energy class A, with the exception of the Athens site, where energy class B pumps were selected.

Borehole heat exchangers (BHE) have been considered for the project, as they are the most common type of ground heat exchangers due to limited surface area needs, extreme reliability and superior energy efficiency. As the ground heat exchanger defines the heat pump boundary conditions at its ground side, hence its overall energy performance and energy efficiency, special attention was given to BHE design and construction from the very beginning of the project. The main principle was to have as close as possible temperature approach between the ground temperature and the temperature supply to the heat pump. It was achieved by specifying more BHE meters, innovative grouting with fine gravel in the water table and bentonite grout above and by using water without antifreeze as heat transfer medium. In addition hydraulic connection kits were developed allowing the heat pumps to operate also in free - cooling mode, e.g. with the water from the BHE loop conveyed directly within the building loop, thus providing cooling directly from the BHE to the building without the heat pump intervention. As compressors are the main electricity consuming component of a heat pump system, considerable energy savings are achieved. Free cooling has been tested throughout the summer period at the Septemes les Vallons and Benedikt demonstration sites, and in the beginning of the cooling season in May at the Coimbra demonstration site.

Designing and assembling an energy efficient heat pump system alone is not sufficient enough to ensure its energy efficient operation throughout the year. This is so, because heating and cooling systems are designed for peak load conditions, while 80% of operating time they operate at partial load conditions. In addition, there are long periods where heating or cooling is not needed, but some system electricity consuming components are left on. This was realized early during the project implementation, as GROUND - MED demonstration sites correspond to offices or public buildings which are occupied only during working hours leaving long time periods without any heating or cooling needs: nights, weekends, etc. Considering the above, in order to maximize overall system energy efficiency special attention was paid to system control. For this purpose control functions were developed for the GROUND - MED systems, characterized by peak heating with maximum 40 °C water supply to the fan - coil - units, peak cooling with minimum 15 °C water supply to the fan coil units, temperature compensation of water supply to the indoor system depending on thermal load, synchronizing compressors with external pump and where possible with internal pump(s) and air handling unit, as well as frequency control of inverters driving the compressor, pumps and fans based on experimentally derived algorithms.

### 3. PERFORMANCE EVALUATION

COP is a measure of the instantaneous energy efficiency of a heat pump system defined as the ratio of useful thermal power delivered (heating plus cooling plus sanitary hot water) over the electricity consumption at a given instant. COP depends on the prevailing boundary conditions at the heat pump, which vary continuously with time.

$$COP = \frac{\text{useful thermal power}}{\text{electrical power}}$$

SPF is a measure of the overall energy efficiency of a heat pump system throughout a time period, usually taken as the entire heating or cooling seasons, but lower time periods can be also defined, with the day being the lowest time duration where SPF has a usable meaning. SPF is defined as the ratio of useful thermal energy (heating plus cooling plus sanitary hot water) delivered throughout a given time period divided by the electricity consumption during the same period. SPF is the average value of COP during the time period considered.

$$SPF = \frac{\text{useful thermal energy delivered throughout season}}{\text{electrical energy consumed throughout season}}$$

For the needs of GROUND - MED project, thermal energy delivered is measured at the heat pump boundaries using thermal energy meters (heat meters) of Brunata manufacture at 5 sites (Coimbra, Barcelona, Tribano, Oradea and Athens) and Landis & Gyr in Benedikt. At the same sites electricity consumption parameters are measured by Carlo Gavazzi electrical energy meters. At Septemes les Vallons and Valencia sites heat meters and electrical energy meters of other manufacturers are used.

In order to stimulate technology development and evaluate one by one the individual technologies and techniques developed, project objectives were defined in terms of 4 distinct levels of COP (coefficient of performance) and SPF (seasonal performance factor). As the useful energy delivered is unique, the different COP and SPF levels were defined according to the electricity consuming components considered in the calculation as follows:

- Compressor,
- Compressor and external (BHE loop) pump,
- Compressor, external (BHE loop) and internal (building loop) pumps,
- Compressor, external (BHE loop) and internal (building loop) pumps, all fans (fan - coil and air - handling units).

COP1 is used to evaluate the heat pump technology, SPF1 to evaluate its controlling algorithms and system design operating parameters, SPF2 should be used for technology comparison purposes, as the external pump is a unique feature of ground source heat pump systems, SPF3 is used to evaluate the hydraulic loops and its controls, while SPF4 is a measure of

overall system performance and its maximization should be the objective for system optimization. By monitoring and improving SPF3 and SPF4 values, the GROUND - MED project effectively contributes to overall optimizing of building heating and cooling systems.

GROUND - MED goal is to improve all four SPF values and maximize SPF4 as the ultimate measure of overall system energy efficiency. However, benchmark values are available only for SPF1=5.0 as contractual project objective and heating SPF2=3.5 as the average value for ground source systems in EU defined by the European Commission in its decision of 1st March 2013 (EU, 2013). Achieved results are presented in Figures 2 and 3. As shown in Figure 2 they outperform above benchmarks. SPF values presented correspond to the cooling season of the year 2013 and to the heating season of 2013 - 14 in all sites, with the exception of Padova (Tribano) site, where SPF values have been calculated for winter and summer 2014 respectively, after replacing the heat pump compressor with a more efficient one having a permanent magnet brushless motor.

Monitoring results from selected demo sites are presented in the next chapters 4, 5 and 6.

Figure 2. Heating and cooling SPF2 as calculated at the GROUND - MED demonstration sites from monitoring data.

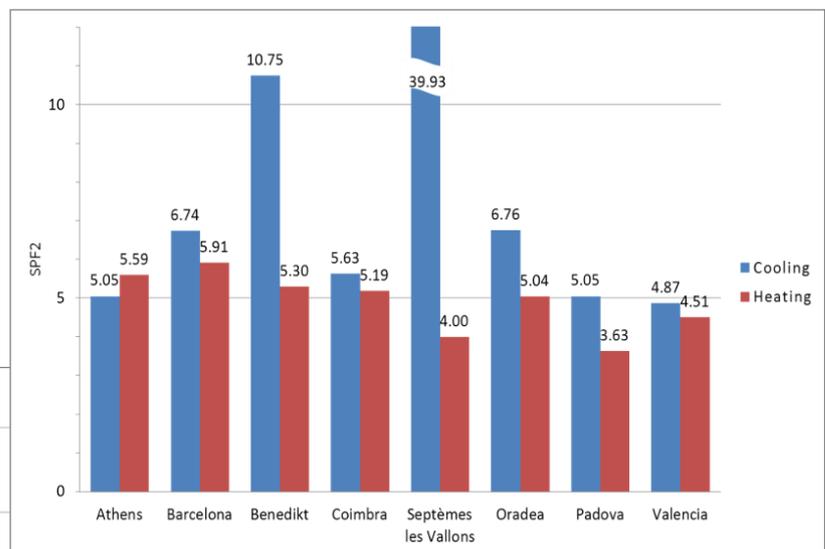
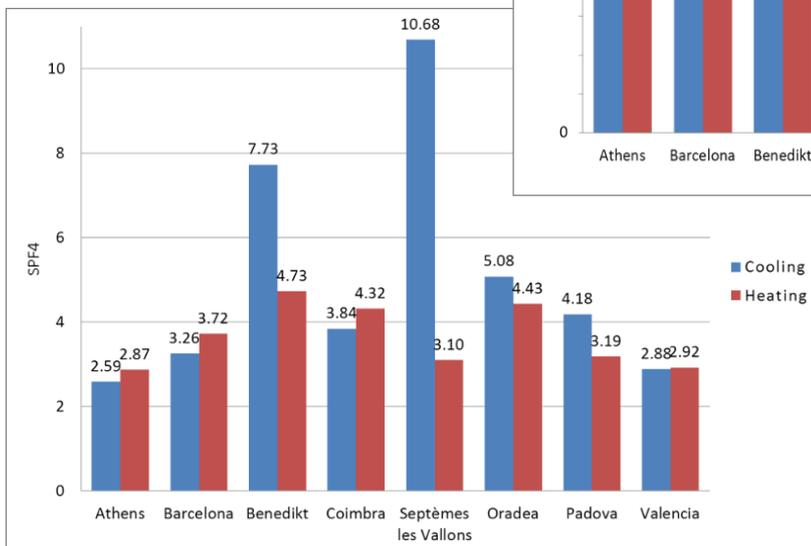


Figure 3. Heating and cooling SPF4 as calculated at the GROUND - MED demonstration sites from monitoring data.

#### 4. FREE COOLING AT CIAT REGIONAL DISTRIBUTION CENTRE IN MARSEILLE

The building is an ex - warehouse refurbished into offices. It is located at Septèmes les Vallons, at the outskirts of Marseille. On site tested technologies include a prototype heat pump developed specifically for the GROUND - MED project, which is able to provide 25 kW<sub>(th)</sub> heating and 22.5 kW<sub>(c)</sub> cooling to the building. The heat pump prototype has two compressors in tandem and is externally reversible by a set of 4 three - way valves.

It is coupled to a ground heat exchanger comprising 6 boreholes, 100 m deep each, with double U polyethylene pipe in them. The heat pump provides heating in winter, while during summer the borehole heat exchangers cool directly the building without the heat pump intervention (free - cooling). The borehole heat exchanger delivers minimum 11 °C to the heat pump during heating in winter and maximum 17 °C during cooling in the summer.

A prototype air handling unit, also developed by the GROUND - MED project is tested on site. It utilizes condensing heat from the main heat pump for reheating incoming air after its dehumidification. In order to cool incoming air, the air handling unit is connected to a cold storage PCM tank of CRISTOPIA manufacture, also developed for the GROUND - MED project. A secondary ground source heat pump, which shares the same borehole heat exchanger with the main heat pump as heat sink, feeds the cold storage unit. It is a commercial machine of CIAT manufacture. Indoor heating/cooling system includes low consumption, coanda effect fan - coil units developed for the GROUND - MED project.

Main operating parameters, as recorded by the GROUND - MED monitoring system during free - cooling operation in summer 2013 are presented in Figure 4, while energy performance is shown in Figure 5.

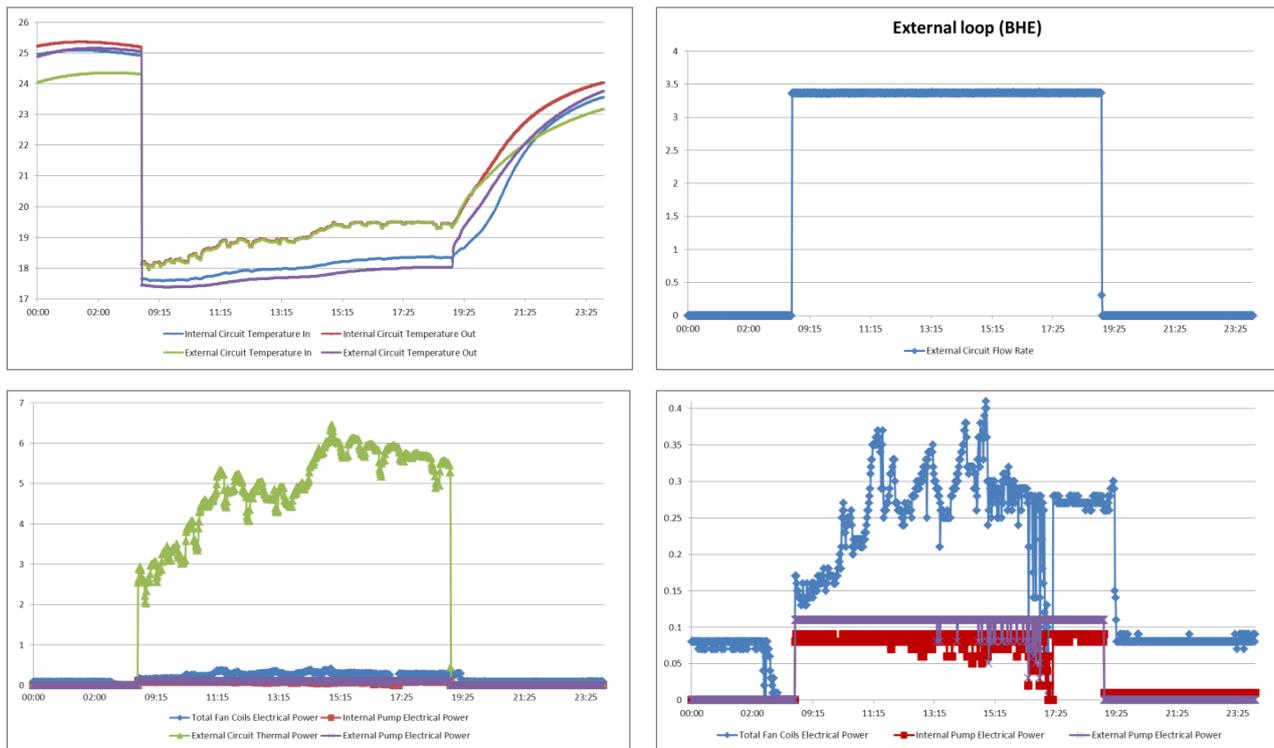
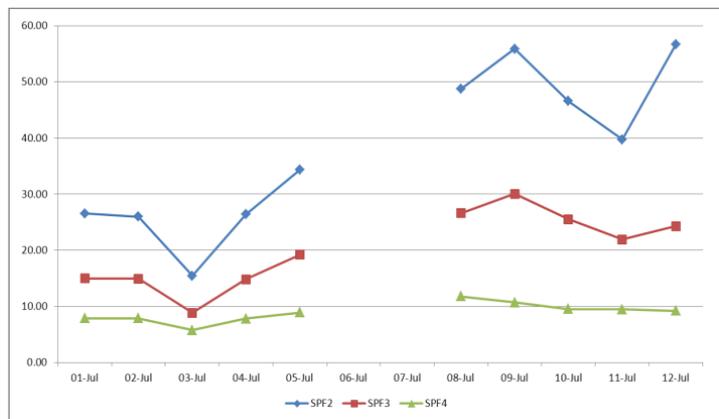


Figure 4. Free cooling at CIAT distribution center demo site on 10 July 2013: water supply and return temperatures in °C (up - left); flow rate in m<sup>3</sup>/h (up - right); cooling supply in kW<sub>(c)</sub> (bottom left); and electricity consumption in kW<sub>(e)</sub> (bottom right).

Figure 5. Daily SPF values at CIAT distribution center demo site during the first half of July 2013.



## 5. HEATING AT HIREF FACTORY IN TRIBANO, PADOVA

At the HIREF factory in Tribano, a heat pump prototype of HIREF manufacture developed for the GROUND - MED project provides heating, cooling and sanitary hot water. The ground heat exchanger comprises 4 boreholes 80 m deep each, two of which are equipped with single - U pipe and two with double - U. It delivers a minimum of 10 °C during winter heating and a maximum of 27 °C during summer cooling.

The heat pump prototype has an inverter driven compressor and is externally reversible by a set of 2 four - way valves. It is coupled to variable speed pumps. Indoor heat supply system includes variable speed inverter driven fan - coils of HIREF manufacture. The control system optimizes the frequencies of the compressor, pumps and fans continuously, so that overall electricity consumption, and hence SPF4, are optimized. The heat pump capacity is 13 kW<sub>(th)</sub> in heating mode and 14 kW<sub>(c)</sub> in cooling mode. In cooling mode, sanitary hot water is produced by diverting heat otherwise rejected at the borehole heat exchanger, further increasing SPF in cooling mode.

In heating mode, main operating parameters as recorded by the GROUND - MED monitoring system, are shown in Figure 6, while calculated energy performance in Figure 7.

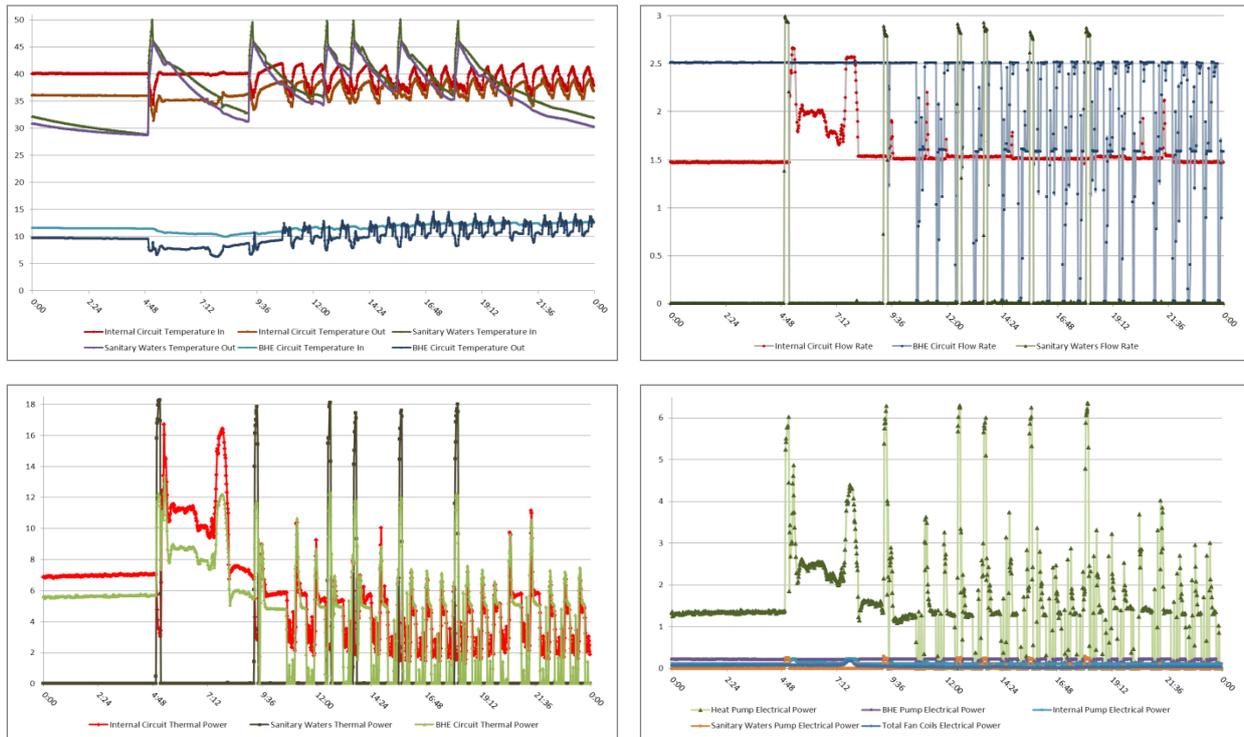
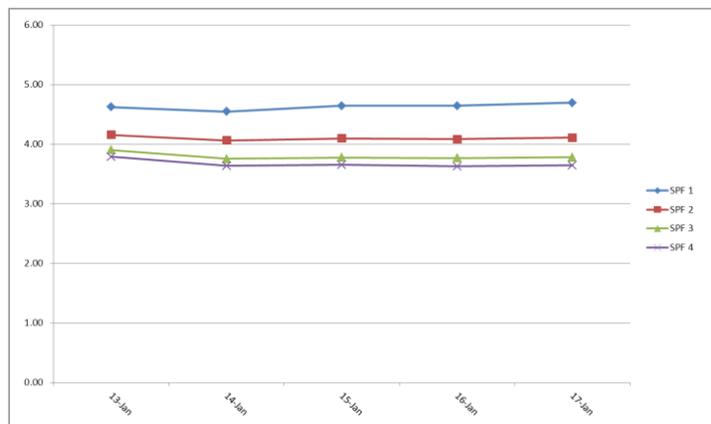


Figure 6. Heating at HIREF factory demo site on 14 January 2014: water supply and return temperatures in °C (up - left); flow rates in m<sup>3</sup>/h (up - right); heat supply in kW<sub>(th)</sub> (bottom left); and electricity consumption in kW<sub>(e)</sub> (bottom right).

Figure 7. Daily SPF values at HIREF factory demo site, in mid - January 2014.



## 6. HEATING & COOLING OF VISUAL ARTS BUILDING IN ORADEA CAMPUS

At the Oradea University campus, the visual arts building is heated and cooled by a GROUND - MED developed heat pump prototype of OCHSNER manufacture. The machine is both internally and externally reversible by a set of 4 three - way valves delivering 38 kW<sub>(th)</sub> of heating and 31 kW<sub>(c)</sub> of cooling.

It is coupled to a ground heat exchanger comprising 10 boreholes 130 m deep each equipped with single - U pipe. Unlike other project demo sites, where water is the heat transfer fluid, the borehole heat exchanger fluid contains 10% antifreeze for surface frost protection under extreme winter temperatures. Observed fluid temperatures from the ground are minimum 9 °C during winter heating and maximum 17 °C during summer cooling.

Indoor heating/cooling system comprises wall embedded polyethylene pipes, which has the advantage of heating with lower temperatures and cooling with higher ones than standard systems, resulting in improved energy performance and SPF values.

Main operating parameters as recorded by the GROUND - MED monitoring system during winter heating and summer cooling are shown in Figures 8 and 10 respectively, while energy performance is presented in Figure 9.

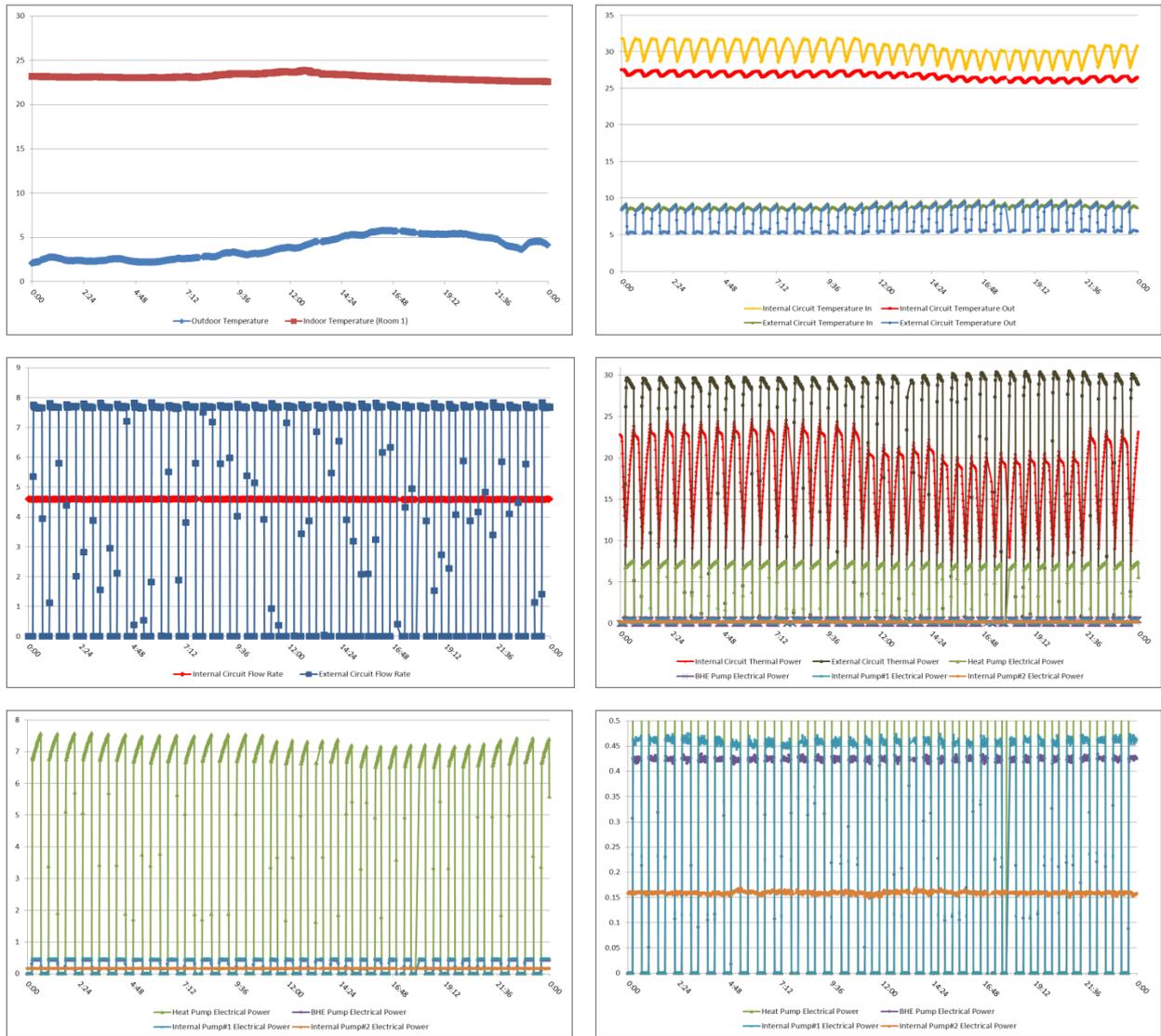


Figure 8. Heating at Oradea demo site on 9 December 2013: indoor and ambient temperature in °C (up - left); water supply and return temperatures in °C (up - right); flow rates in m<sup>3</sup>/h (middle - left); thermal power in kW<sub>(th)</sub> (middle - right); electricity consumption in kW<sub>(e)</sub> (bottom left); and electricity consumption detail in kW<sub>(e)</sub> (bottom right).

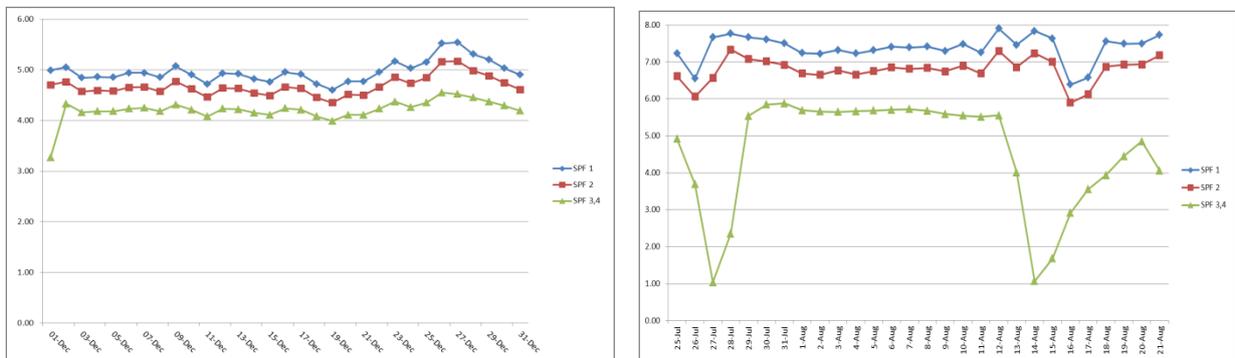


Figure 9. Daily SPF values at Oradea demo site in heating mode during December 2013 (left) and in cooling mode during summer 2013 (right).

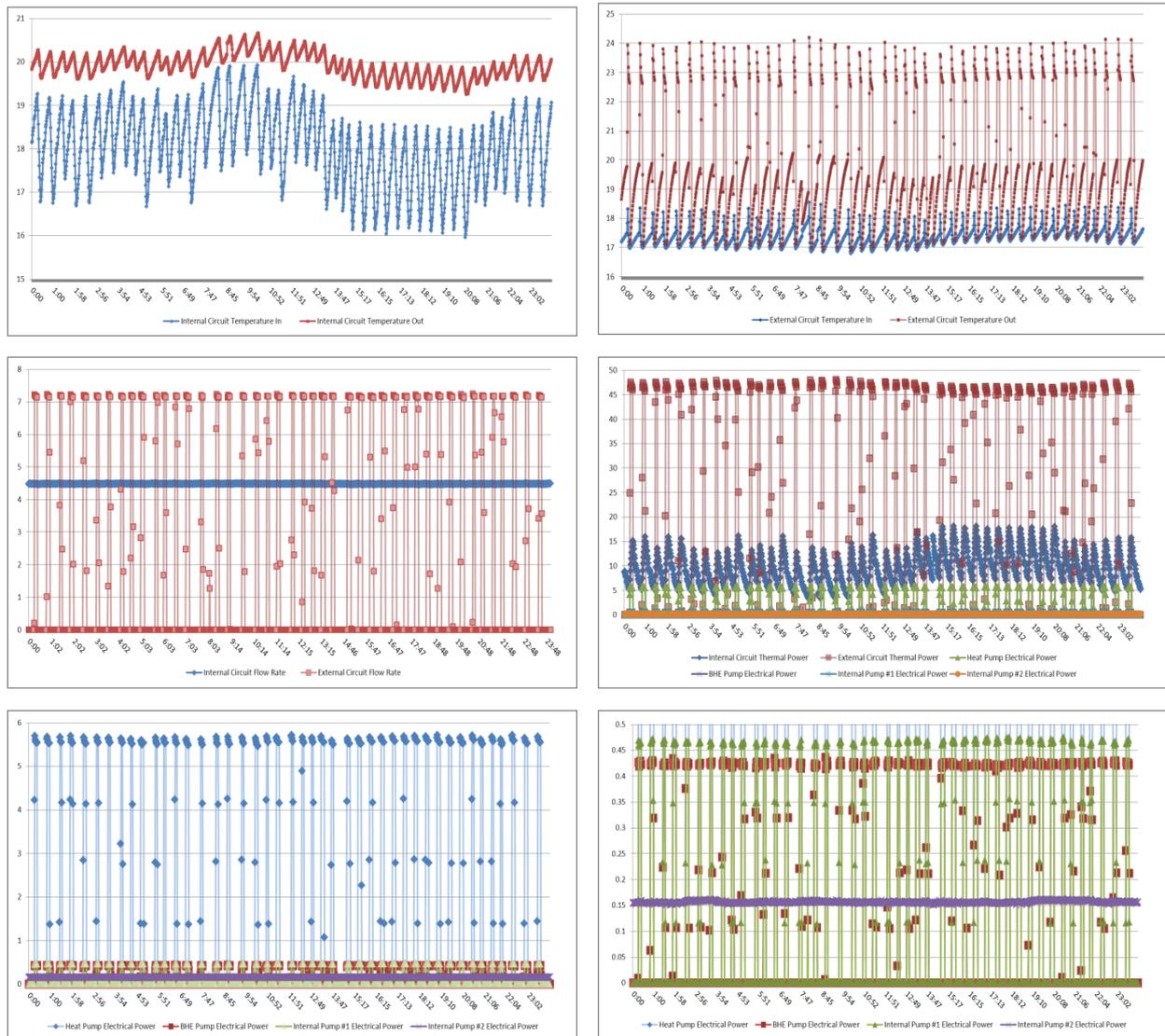


Figure 10. Cooling at Oradea demo site on 7 August 2013: water supply and return temperatures to/from the building in °C (up - left); water supply and return temperatures to/from the ground in °C (up - right); flow rates in m<sup>3</sup>/h (middle - left); thermal power in kW<sub>(th)</sub> (middle - right); electricity consumption in kW<sub>(e)</sub> (bottom left); and electricity consumption detail in kW<sub>(e)</sub> (bottom right).

## ACKNOWLEDGEMENTS

This paper has been prepared in the framework of the European project GROUND - MED, co - funded by the European Commission, which is gratefully acknowledged.

## REFERENCES

EU (2013) - Commission Decision of 1 March 2013 establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council. 2013/114/EU, OJEU L62, 27 - 35, [http://eur - lex.europa.eu/legal - content/EN/NOT/?uri=uriserv:OJ.L\\_.2013.062.01.0027.01.ENG](http://eur-lex.europa.eu/legal-content/EN/NOT/?uri=uriserv:OJ.L_.2013.062.01.0027.01.ENG).

## **New ideas and proposals for cooperation in the Peri - Adriatic Areas**

## Methodological Approach for Recovery and Energetic Requalification of Historical Buildings

VALCOVICH Edino<sup>1</sup>, STIVAL Carlo Antonio<sup>2</sup>, BERTO Raul<sup>1</sup> and CECHET Giovanni<sup>1</sup>

<sup>1</sup> Department of Engineering and Architecture, University of Trieste, Italy

<sup>2</sup> Department of Civil, Environmental and Architectural Engineering, University of Padova, Italy

Corresponding author's e-mail: [valcovic@units.it](mailto:valcovic@units.it)

**Keywords:** historical buildings, energy efficiency improvement, heat pump system, hydrothermal energy.

### ABSTRACT

Among Renewable Energy Sources (RES) defined in European Directive 2009/28/EC, as coming from renewable non-fossil sources, are included hydrothermal energy – referring to surface water – and oceanic energy. The extension of this definition to energy contained in seas should be taken into account: in specific boundary conditions, sea hydrothermal energy, mainly deriving from solar radiation, is a valuable resource for possible exploitation, occurring through heat pumps that withdraw heat from the sea transferring it to the cold sink, a heat transfer fluid.

A possible application in the city of Trieste refers to exploit this energy source to serve buildings characterized by high historical and architectural values. The plant provided for this goal consists of three main parts: an open - loop system that picks up seawater through main heat exchanger and then restores it to sea; a closed - loop ring in which a heat transfer fluid brings sea - recovered energy to final users' derivations; installations inside buildings, consisting in water - to - water heat pumps in order to meet the energy needs of those buildings.

Particular attention has to be paid to the positioning of heat pumps in historical buildings: complying rules on safety during operation, there should be considered settings for exclusive use, suitably located and partitioned form remaining part of the asset. Similar importance is due to replacements and integration of technical distribution facilities in historical buildings. The proposed system must then interface with architectural features, distribution network and plant of each building. Intervention design, therefore, must firstly identify technical elements contemporary with the construction of the building, distinguishing them from those, following, of lesser value. Based on this analysis, identifies the most suitable positions for insertion of new distribution network, realized by minimizing the invasiveness of operations in accordance with the operating principles of the restoration.

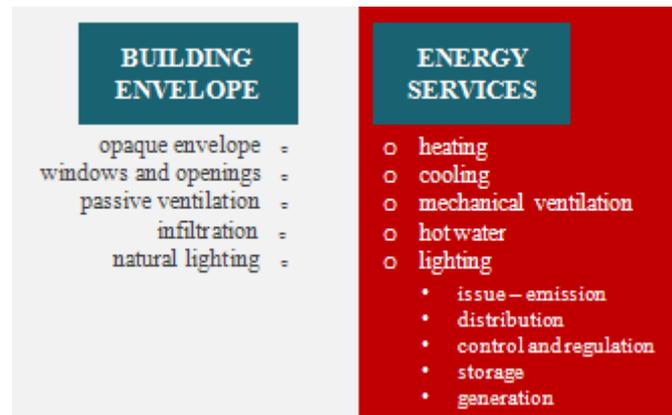
### 1. INTRODUCTION

The historic buildings were frequently excluded from the scope of regulatory framework regarding energy efficiency and environmental sustainability since the enactment of the European Directive 2002/91/EC concerning the energy performance. Yet goals concerning GHG (Green House Gases) emissions' reduction and RES (Renewable Energy Sources) improvement must also pass through the upgrading existing buildings' energy efficiency, including the high value historical - architectural heritage or otherwise restricted, subjected in Italy to Lgs. D. n. 42/2004 on cultural heritage and landscape preservation.

The primary issue in energy efficiency improvement of historic buildings, including interventions on air conditioning systems, is the identification of performance levels that are objectively achievable by historic buildings, in order to enhance their characters and to maximize their energy potential; a similar approach is typical of anti - seismic regulation (differentiation of security levels for new and existing buildings). Currently, Italian regulation framework for energy efficiency actuation in buildings (Lgs. D. n. 311/2006 as amended) does not provide any differentiation between new construction and existing heritage and, referring to air conditioning systems new plants, sets a unique performance evaluation, relative to overall seasonal average performance, without any specification on the historic building. Regulation framework will be probably be modified with R.P.D. n. 59/2009 recast (end of 2014). In European regulation framework, however, the legislation designed to preserve historical heritage is still the main constraint to the actuation of energy efficiency policy of historic buildings, since it restricts possible actions on these buildings.

It would therefore be appropriate that effectiveness assessment of the intervention on physical components and on technical facilities (systems broken down into subsystems according to the methodology for energy performance calculation, Table 1) was focused on improving efficiency goal for each subsystem, without specific requirements related to the achievement of specific performances in regulations.

Table 1. A possible subdivision of a building in envelope and technical services, in order to fix subsystems whose energy performance can be improved. In red, energy services, subject of this paper.



## 2. ENERGETIC REFURBISHMENT OF HISTORIC BUILDINGS

With specific regard to air conditioning systems and thermal plants, divided in five subsystems (sub - issue, distribution, control, accumulation and generation), it may be difficult or impossible to achieve an overall performance goal of energy efficiency: first, the energy system can be by itself part of recovery action, therefore not to be subject to energy intervention; then, it may not be possible, or economically advantageous, to act on one, or more, of these subsystems.

Thus, possible performance targets for improving energy efficiency in historic heritage, with aim to maximum flexibility, should be identified recognizing building similar in typology, considering what each single typology expresses in terms of different characters, potential to exploit and possibly enhance, usage requirements, conditions of comfort required, conservation needs and constraints in interventions.

The design of a renovated technical system, with particular reference to air conditioning service, has to be interfaced with the performances in the fulfillment of specific requirements arising from the general needs of comfort (e.g. thermal and indoor air quality), durability of building envelope, structures and partitions, conservation of valuable surfaces (giving appropriate conditions of temperature, humidity, air velocity), reduction of use of Non Renewable Energy Sources (NRES), including lighting service.

In energy efficiency upgrading interventions is therefore necessary to equip buildings with plant networks capable of meeting the needs of comfort and reduce energy consumption considering contemporary standards, consistent with typological, spatial distribution, technological characters of the building.

Quality and effectiveness of a renovation action on historic building heritage strongly depend on its energy behavior acknowledgement and related performances of existing situation; the latter, proper of an energy passive operational state, must be preserved as far as possible; in general the renovation has to consider incidence and compatibility with existing constriction techniques and materials. In historical heritage, energy balance described in EN 13790 should consider thermal inertia, which regulates heat accumulation in building's thermal masses and its subsequent release indoor: this phenomenon constitutes the fundamental issue in historical buildings' energetic passive behavior.

The application of energy balance in historic buildings, however, is difficult by their own characteristics of related to temperature and humidity conditions, distribution networks of technical systems not reliable to contemporary schemes. In absence of an air conditioning system balancing losses or heat inputs soliciting indoor spaces, indoor climatic conditions control is governed by building envelope exclusively, here taking into account peculiar losses (e.g. thermal bridges, uncontrolled infiltrations); in historical buildings, envelope technological units play several and fundamental functions such as protection of the interior from outside temperature peaks and control of ventilation, in order to ensure indoor health conditions. Thus, an effective renovation, according to architectural, historical and cultural characteristics must start from building's state of fact analysis and understanding and its interactions with surrounding environment.

It is possible to define a 3 - tier approach for methodology in energy system plants' and facilities' renovation in historical buildings (Table 2).

Table 2. A 3 - tier approach proposal for energy system plants' renovation in historical heritage.



Envelope has to be considered the first technological unit subject to technological upgrading in a historic building, in order to find critical issues in excessive heat fluxes, thermal bridges and moisture control: these operations allow for a reduction in power peak in the extreme seasons: an (also partial) intervention on plant systems is based on performance acknowledgement and relative comfort and durability conditions, in order to minimize interventions and avoid oversizing the plants themselves.

The second step consists in the recovery of functionality originally proper of existing systems, in order to restore as far as possible their purpose, using new technologies for full efficiency of these systems. If new operational state of such systems is not technically or economically advantageous, they should still be maintained by their historical evidence.

Finally, the inclusion of new technologies into total or partial replacement of existing systems must be integrated into existing factory without an intolerable formal, aesthetic or operational alteration: this is the regulation provided by the Lgs. D. 311/2006 concerning the scope of legislation on energy efficiency for buildings included in mandatory regulation of Lgs. D. 42/2004. Thus, renovation of technical facilities needs to follow an adequate integration between new additions and existing technical elements, in order to preserve its historical content in compliance with restoration fundamental principles: minimum action (attribution of proper performance levels capable of a reasonable efficiency improvement) and reversibility of intervention.

About technical system plants and equipments in historical building heritage, some situations are distinguishable depending on existing systems consistency:

- lack of technical facilities for a specific service. It is expected to be in this case a considerable intervention, in which maximum attention should be paid in positioning different subsystems in existing structure since renovation project phase, considering any technical room, shaft, duct that can accommodate new distribution systems; otherwise, visible installations can be chosen;
- obsolescence of existing technical systems. In this case it is likely an element removal - if it is devoid of historical value or functional one - and consequent space use for new plants element inclusion;
- (partial) possible re - use part of existing technical systems - this situation, occurring frequently for existing plants installed afterwards to primary building's construction phase, aims to the maintenance of acceptable elements, meeting specific performance requirement (mainly ones concerning safety), and their subsequent integration accordance with new use.

The insertion of modern technological elements in historical buildings – for more bearers of historical and architectural values – is a very sensitive operation, mainly due to missing functional connection of these new elements with the existing structure; moreover, new operational phase for existing plants could not be practicable if themselves have to be preserved. Inclusion of new plant networks depends on operational constraints as preservation of integer structures need, preservation of valuable facades, preservation of valuable floors and their thickness, spatial distribution of rooms and technical spaces.

Inclusion of new plant networks and technical equipments, as improvement or substitution of existing ones according to general project concept, must consider specific issues:

- existing technical systems and their possible upgrading,
- technical characteristics of plant components and equipments,
- location and dimensions of technical facilities,
- networks, pipes and ducts, chimneys paths,
- availability of countertops.

Heating service can be provided with punctual systems (e.g. stoves and fireplaces) or with net - widespread ones (using air or water as heat transfer fluid). In both cases the main problem refers to security issues and, specifically, to exhaust fumes evacuation in atmosphere: consequently, ducts' position planning and insertion in the building, if devoid of appropriate niches, is very invasive and can affect structure operational conditions. It could be needed to punch intermediate floors and roof. Besides, stoves and fireplaces represent, however, a good integration to net - widespread systems, as they allow to bring up temperature quickly in installation rooms.

In new central heating / air conditioning system project phase, several issues must be considered referring to each subsystem (Table 3). The first issue of choice and positioning of emission technical elements aims to preserve sensitive or valuable surfaces, considering elements' visual impact too. Comparing radiators, fan - coils and radiant floor installations, the latter improves emission efficiency and reduces driven dust movement, but is practicable only in interventions comprehensive of existing floor removal, with possible reduction of net room height; radiators and fan - coils have a lower installation cost and a more flexible positioning, but give a visual impact in historical context. It is however possible to combine multiple systems in complex buildings, capable of working independently in specific thermal zones.

Referring to new central heating distribution networks, main issues are related to pipes' path and accommodation, also depending on given emission technical elements. Reuse of existing distribution technical elements, is feasible if:

- mechanical stress acting on pipes is acceptable, even after verification by test pressure;
- replacement of deteriorated ducts and pipes is possible avoiding stresses on existing architectural elements caused by demolition or tracks and niches realization.

New installations must comply with principles of reversibility and minimum action as possible (e.g. creation of distribution networks ring - shaped, placed in visible lines anchored to walls with minimum number of berths).

Distribution networks inclusion can be done in visible or in - track lines; they both require verification of different issues: the first referring to visual and architectural values, the second with reference to valuable envelope and partitions' surfaces preservation and stability and mechanical strength of load - bearing elements. Visible network lines, in particular ceiling ones, have not to interfere with structures, openings on the facades, internal communication, lighting fixtures. Insertions in envelope and partition technical elements should be in number as low as possible, or grouped, in order to reduce tracks and drillings and, finally, to make easier maintenance operations.

The crossings in vertical and horizontal partitions has to be made, as much as possible, using existing vertical connections not actually used and, horizontally, baseboards, thresholds for doors and windows. And alternative solution may be represented by equipped walls or corridors superimposed on existing structures, not visible, that prevent tracks and punches realization.

EMISSION	DISTRIBUTION	PRODUCTION
<ul style="list-style-type: none"> <li>○ emitters' position</li> <li>○ operation conditions</li> <li>○ IAQ parameters</li> <li>○ visual impact</li> </ul>	<ul style="list-style-type: none"> <li>○ existing pipes / ducts</li> <li>○ pressure test needed</li> <li>○ technical spaces and paths availability</li> <li>○ static load control</li> </ul>	<ul style="list-style-type: none"> <li>○ technical spaces for facilities availability</li> <li>○ high consistency with existing subsystems</li> <li>○ safety in use</li> <li>○ visual impact</li> </ul>

Table 3. Renovation issues of historical buildings in energy services subsystems.

Renovation design concept therefore derives from a compromise between the needs of comfort, durability, rational use of energy resources and the possibility to use or obtain appropriate functional spaces (technical rooms, vertical crossing spaces, existing networks giving appropriate performances, etc.), already identified in the architectonic design project, in such a way that generation plant (generators, heat pumps, air handling units, etc.) are positioned at strategic locations, easily accessible for maintenance and security needs.

In historical buildings, considered as valuable situations, the position of production facilities must be defined firstly in compliance with safety standards concerning thermal power plants; it is possible to recognize two main typologies of equipment, depending on energy source (Table 4).

Methane-powered equipment	Electricity-powered equipment
<ul style="list-style-type: none"> <li>○ stringent limitations in position</li> <li>○ specific room needed</li> <li>○ sensitive situation about gas pipe</li> <li>○ exhaust fumes duct needed</li> <li>○ easy accessibility necessary</li> <li>○ existing stove changeover</li> </ul>	<ul style="list-style-type: none"> <li>○ visual impact problems for air systems</li> <li>○ specific room needed</li> <li>○ possible work during all year</li> <li>○ accurate evaluation of thermal loads to perform</li> </ul>

Table 4. Comparison between methane - powered and electricity - powered energy production subsystems in renovation of historical buildings.

Methane - powered equipment must be placed outdoors or in ventilated rooms accessible from the outdoor. Even the installation of heat pumps must follow criteria of exclusivity of the room accommodation, which should be detached from the building, or at least from the asset.

In larger buildings - such as historic buildings intended for public use - availability of rooms able to accommodate new services and to ensure safety requirements is increased; the choice of these spaces is regulated primarily by their location, e.g. location facing perimeter walls or proximity to the common corridors, stairs, entrances or corridors, in which distribution networks are easily achievable.

Incompatibility with net - widespread distribution systems guides the choice towards punctual systems, e.g. electric or methane powered stoves. A simpler installation is given, but operational maintenance is more onerous; thus, exhaust fumes evacuation is a considerable defect, which entails opening in envelope.

The installation of an air conditioning system in order to control indoor air temperature and humidity appears to be the most efficient solution in the historic buildings, where of sensitive surfaces preservation overlaps the need to achieve an adequate level of comfort; an efficient air conditioning system is due in high occupancy rooms, or characterized by decorated surfaces, floors or wooden elements. Also in this case significant spaces are required to accommodate energy production, distribution and emission technical elements.

### 3. HYDROTHERMAL ENERGY AND ITS USE

Directive 2009/28/EC defines "renewable energy" those deriving from renewable non - fossil sources (e.g. wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, residual gas from sewage treatment and biogas). The Directive also defines "hydrothermal energy" the heat stored in surface waters: this definition doesn't take into account energy stored in the seas and oceans, but considers lakes, swamps, rivers and run - off waters flowing wildly. However, it is considered appropriate to extend this definition to the energy in seas and oceans too, which, under suitable environmental conditions, represent a valuable resource for a possible exploitation. The heat in the oceans comes largely from the sun and to a lesser part from Earth's mantle, a layer of semi - fluid rocks characterized by high temperatures.

One of the primary advantages of considering sea as a cold source, thanks to its constant temperature throughout the year, is allowing any heat - pump - based systems capable of maintaining good performance without incurring significant influences from the outside weather conditions. By contrast, the additional costs related to the supply system of seawater should be carefully evaluated.

Heat extraction from seawater can occur through two major types of systems, said closed - loop and open - loop. In the first case, the ring - in which circulates a heat transfer fluid - is immersed in the heat source represented by the ocean, and there is therefore no sampling of the primary water. In the second case, the seawater is pumped to special heat exchangers, in which occurs heat transfer to a second closed - loop water circuit; the water is then pumped back into the sea.

The complementary element to these loop configuration, indispensable for hydrothermal energy exploitation, is represented by heat pumps, capable of extracting heat from the sea, giving an almost constant temperature throughout the year, not significantly influenced by weather conditions. In particular, reversible heat pumps allow absorption by, or transfer to, cold sink thanks to the expansion valve, that gives possibility to switch seasonal operational mode of the heat pump from winter to summer, without changing any position of its other technical elements: evaporator, compressor, condenser.

Heat pumps for the exploitation of marine hydrothermal can be classified in water - water pumps and water - air pumps according to the type of technical fluid of air conditioning system. The first term refers to the source from which heat is extracted while the second indicates the fluid carrier operating the heat exchange with the environment, or environments, that will be air - conditioned.

### 4. HYDROTHERMAL ENERGY FOR THE CITY OF TRIESTE

Basing on theoretical considerations above, it is identified the city of Trieste, and in particular the urban area in close proximity to the sea, as a possible place suitable to hold appropriate engineering solutions and infrastructure for hydrothermal energy exploitation. In addition, this opportunity is associated with the need to enhance and preserve the existing buildings, and in particular high - value witnesses, through appropriate retrofit operations capable of performance increase of technical facilities and respect architectural and historical values in accordance with operational principles of the restoration.

In order to identify opportunities for energy efficiency improvement and reduction of GHG emissions in historic buildings - with the purpose of preservation and enhancement of historical heritage, it is proposed a design concept which illustrates a possible solution for operative use of hydrothermal energy in Trieste gulf. The energy collected will be used for service air conditioning service and domestic hot water production in some buildings of high - value witnesses in Trieste old town area.

Two different concept systems have been evaluated for thermal energy transfer from sea to final users.

The first (Figure 1), based on open - loop ring with secondary circuit, is characterized by two separate rings and consists of the following phases:

- withdrawal of seawater (hot sink);
- passage of water through a main heat exchanger, in which part of the thermal energy is transferred to a technical fluid circulating in a closed loop;
- reintroduction of seawater in the gulf at a point far enough from hot sink in order to avoid an 'hydrothermal short circuit', e.g. mixing of the flows pumped from and re - entered to sea, and then the mutual influence between those two thermal states;
- fluid feed to various final users, each equipped with heat - pump system, which will transfer the thermal energy to a second heat transfer fluid used for air conditioning and domestic hot water production services.

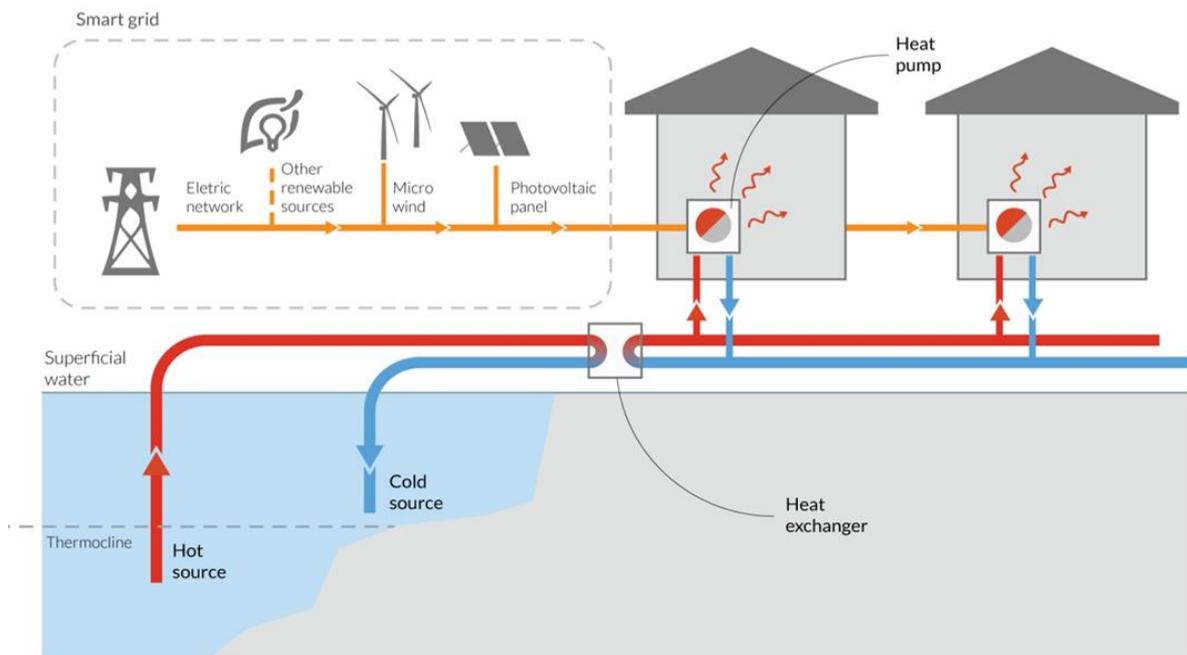


Figure 1. Scheme of an open - loop ring for seawater sampling and secondary closed - loop ring.

The second (Figure 2) differs from the first because of the secondary ring missing: the water coming from sea withdrawal is fed directly to final users, so that the heat exchange only occurs at the heat - pumps systems, without then one or more heat exchangers upstream of the plant system of the buildings.

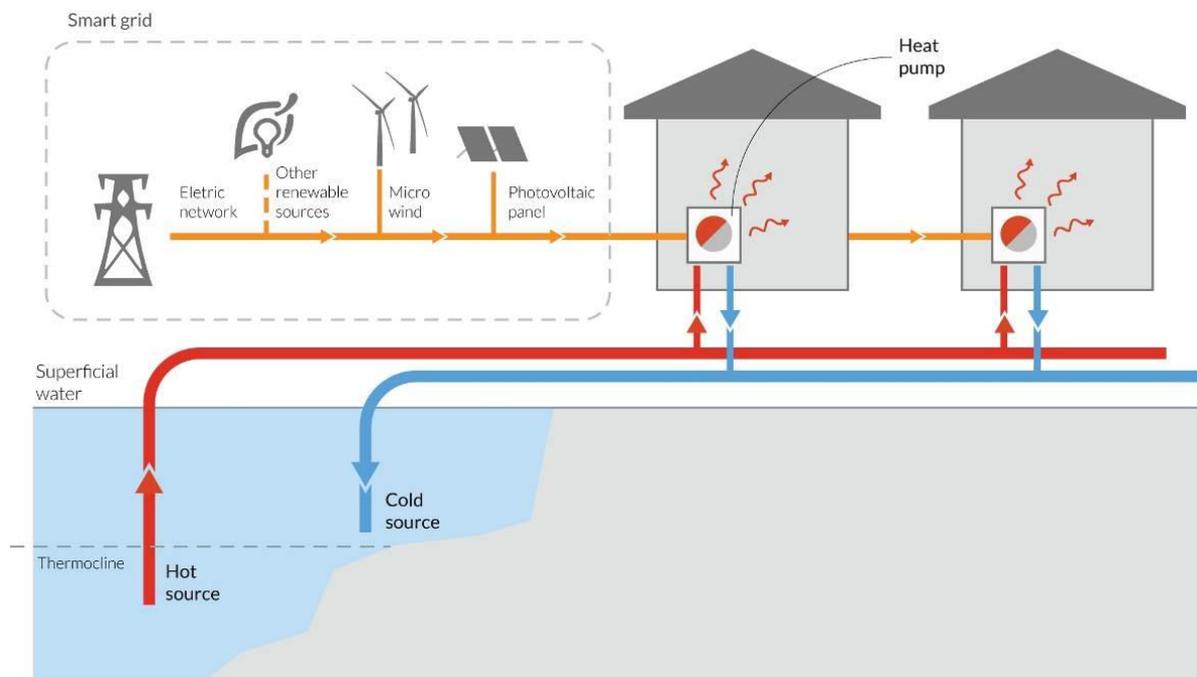
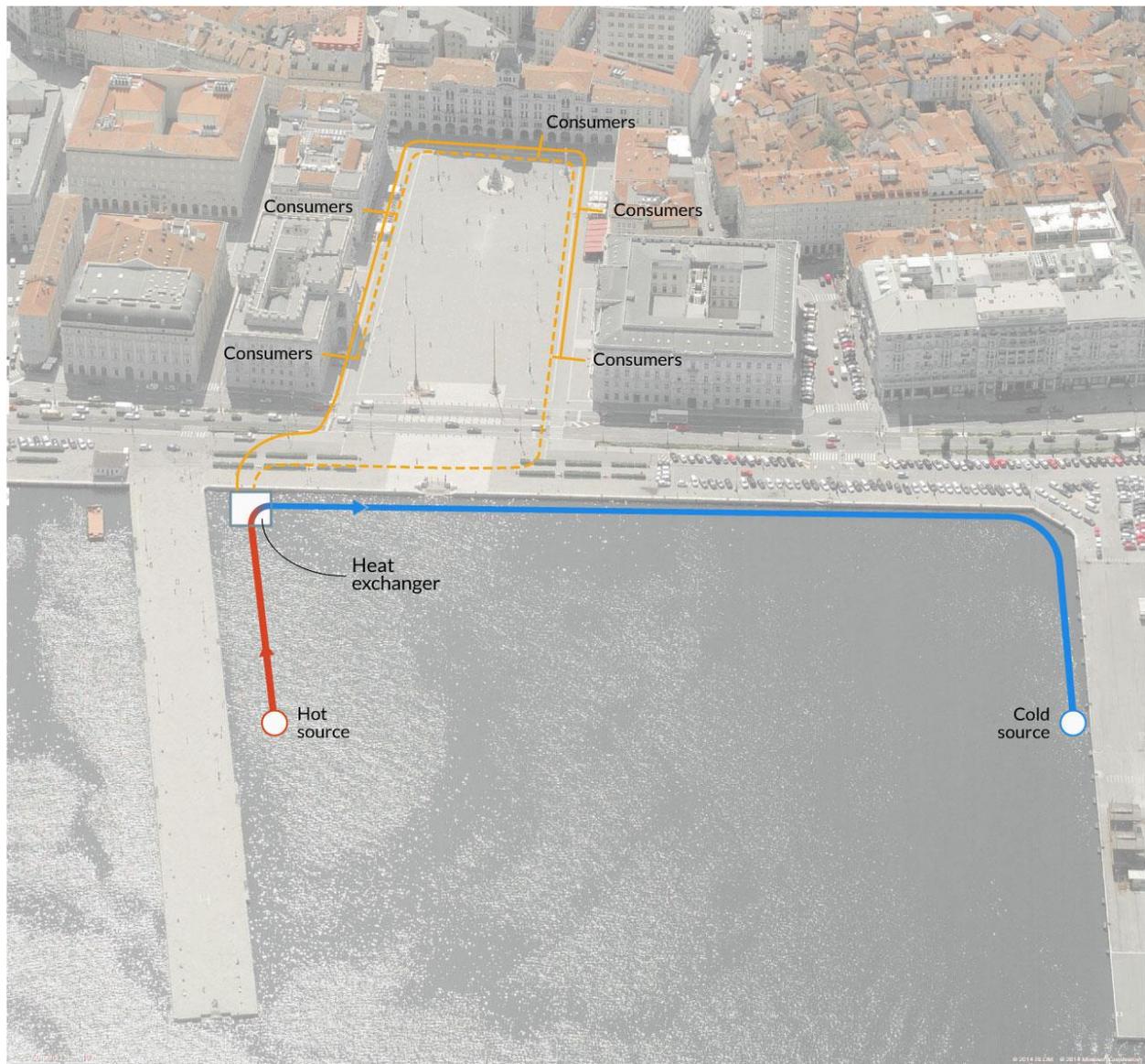


Figure 2. Scheme of direct open - loop ring for seawater sampling serving heat - pump systems at final users.

For both solutions considered, heat pumps serving individual users (buildings) and the auxiliary equipment for the collection, circulation and the release of seawater, need of power supply which can be ensured by implementation of renewable energy or smart grid application. This action, given the nature of the area under consideration and the characteristics of the buildings, certainly presents some difficulties to deal with considering possible strategies for the integration of renewable energy sources, also mentioning the opportunity to produce energy electricity in places in the city also relatively distant from the load to be served.

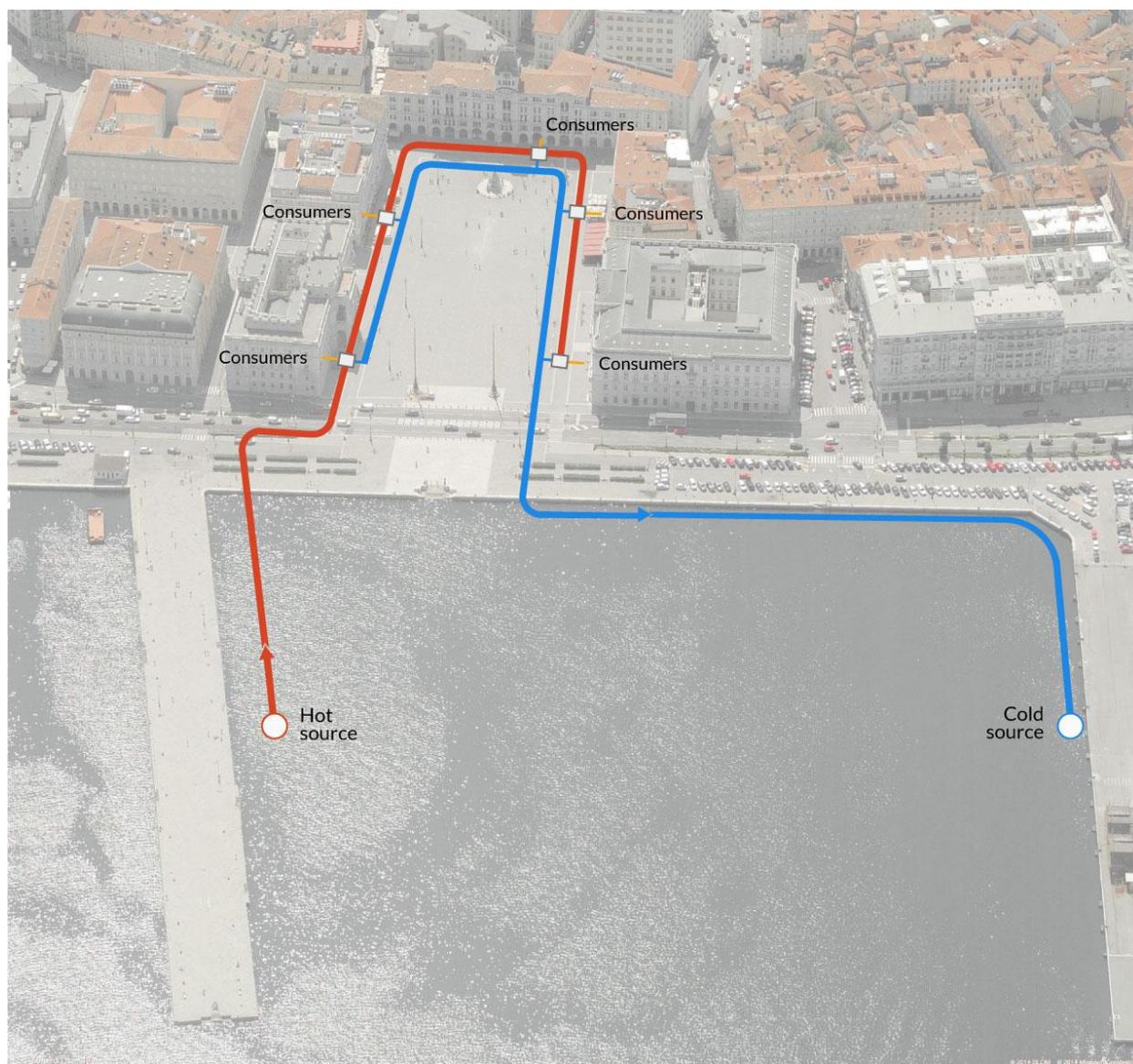


**Figure 3. Design concept for an open - loop ring for seawater sampling and secondary closed - loop ring in Piazza dell'Unità d'Italia in Trieste old town.**

The first solution involves the use of one or more heat transfer devices and a double ring, to which is linked a greater cost of implementation. By contrast, the second solution hypothesized includes the circulation of seawater to the final users, reducing the overall development of the pipes, but creating some difficulties in the operations of maintenance of the entire system related to the chemical - physical characteristics of seawater that circulate the entire perimeter of Piazza dell'Unità d'Italia (Figure 3 and Figure 4): it would need to leave the inspection and the removability of entire sections of pipe.

From the energetic point of view, the second solution is preliminarily more favourable, since this would generate a heat exchange only in correspondence of the heat pumps in service of the individual users; the first solution, with one intermediate heat exchanger, would provide the utilities a hot well (cold, in the summer season) at lower temperature (the higher, respectively) and therefore less effective.

It is also appropriate to point out that the second system is more scalable, because it would allow to implement partial heat load balanced through the system with seawater: assuming a scenario where a single user has technical infrastructure to achieve with this complex climate system, seawater circulating in the ring would be characterized by the same flow than in total heat load situation, so the second solution allows to establish the possible users in different time periods.



**Figure 4.** Design concept of for a direct open - loop ring for seawater sampling serving heat - pump systems at final users in Piazza dell'Unità d'Italia in Trieste old town.

With the first solution, on the other hand, the path of the seawater is shorter and the circulating fluid close to building structures is more physically and chemically harmless - here taking into account final users' heat pump systems - resulting in lower costs for the realization and the maintenance of the piping and plant control devices.

The concepts expressed are embedded in a context of great historical and architectural, public buildings overlooking Piazza dell'Unità d'Italia in Trieste. It is therefore necessary, in order to complete the analysis, assess the possibilities and design burden arising from the objective of upgrading the technical installations of air conditioning in winter and summer in historic buildings.

### ACKNOWLEDGEMENTS

Thanks to ECSAC Organization for given opportunity to present the work at XIV International Conference on Science Arts and Culture – Workshop on Geothermal Energy – in Velj Losinj last August 27<sup>th</sup>.

Thanks to prof. Bruno Della Vedova, to Trieste Municipality and to STEAM s.r.l. for several fruitful discussions occurred and for field support.

### REFERENCES

Adhikari R., Pracchi V., Rogora A., Rosina E. (2011) - La valutazione delle prestazioni energetiche negli edifici storici: sperimentazioni in corso. Il Progetto Sostenibile, n. 28, (2011), 20 - 27. Edicom Edizioni, Monfalcone (GO).

- ASHRAE (2010) - Green Guide, The Design, Construction and Operation of Sustainable Buildings. 3rd edition, ASHRAE (2010).
- Basta S. and Minchio F. (2008) - Geotermia e pompe di calore. Editore Associazione Geotermia.org, Verona (2008).
- Caleffi SpA Ed. (2007) - Le pompe di calore. Idraulica, n. 33, (2007).
- Campanella C. (2013) - Nuovi impianti antichi edifici. Approccio al progetto impiantistico nell'esistente, Recupero e Conservazione, n. 103 - 104, Edizioni De Lettera, Milano (2013).
- Carbonara G. [Edt.] (2001) - Restauro architettonico e impianti. UTET, Torino (2001)
- Cavallini A. (2010) - Le pompe di calore geotermiche, Technical meeting on Energy efficiency, Aermec SpA, Quarto d'Altino, Venice, Italy (2010).
- Cocco D., Palomba C., Puddu P. (2010) - Tecnologia delle energie rinnovabili. Edizioni S.G.E., Milano (2010).
- Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings.
- Directive 2010/31/EC of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast).
- Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources.
- Lgs. D. of 29 December 2006 of Italian Parliament, n. 311 execution of Directive 2002/91/EC on energy performance in buildings.
- Lgs. D. of 22 January 2004 of Italian Parliament, n. 42 on cultural heritage and landscape preservation.
- Lucchi E. and Pracchi V. (2013) - Efficienza energetica e patrimonio costruito. Maggioli editore SpA, Milano (2013).
- Trevisi A. S., Laforgia D., Ruggiero F. (2006) - Efficienza energetica in edilizia. Maggioli Editore, Rimini (2006).
- Valcovich E., Ferneti V., Stival C. A. (2011) - Un approccio ecosostenibile alla progettazione edilizia. Il Protocollo di valutazione energetico - ambientale (VEA) della Regione Friuli Venezia Giulia. Edizioni Alinea, Firenze (2011).

## Cold District Heating with Heat Pumps at High Temperature

PELLEGRINI Gianfranco<sup>1</sup>

<sup>1</sup> STP Srl, Torino, Italy

Corresponding author's e-mail: [gpellegrini@stpellegrini.com](mailto:gpellegrini@stpellegrini.com)

**Keywords:** district heating, heat pumps, boiler.

### ABSTRACT

This study concerns the application of water to water heat pumps at high temperature ( $T_m \geq 80$  °C) (hereinafter referred HT - HP) to a new concept district heating plant called "Cold District Heating - CDH" where HT - HP use, as the low temperature heat source, water distributed with networks, similar to the classic district heating ones, where, however, instead of using pre - insulated pipes, much less invasive and much cheaper PEAD not insulated pipes are laid.

These networks supply water to a series of HT - HP to be installed in various buildings to replace existing centralized boilers.

With Società Metropolitana Acquedotti Torinesi (SMAT) of Turin, we are monitoring a pilot site with a first CDH where it will subsequently be possible to connect other buildings until reaching the maximum flow compatible with said source.

The purpose of this study is to demonstrate the technical feasibility of initially exploit all existing urban infrastructures in "Piazza Unità d'Italia – Trieste" capable of providing seawater and then suggest to build new infrastructures to distribute water drawn from remote centralized sources (groundwater, irrigation ditches, rivers, lakes, sea, etc). They are therefore systems which allow the use of heat pumps at high temperature in a diffuse manner in urban contexts.

### 1. INTRODUCTION

This study concerns the application of water to water heat pumps at high temperature HT - HP ( $T_m \geq 80$  °C) to a new concept district heating plant called "CDH - Cold District Heating".

This application provides that the HT - HP utilize the seawater as a centralized low temperature heat source that, as a result of a heat exchange with fresh water circulating in a CDH at the service of the HT - HP installed in the buildings around "Piazza Unità d'Italia" in Trieste. The CDH is similar to the classic District Heating nets; in analogy to the traditional district heating heat exchangers, in this case the networks distribute cold water to the new HT - HP to be installed in the buildings around Piazza Unità d'Italia in place of the existing centralized boilers.

The proposed plant consists in installation of HT - HP, which cools fresh water that cools salt water. The HT - HP replace the existing boilers, operating in heating and, if required, in producing domestic hot water required by the buildings.

The primary system is composed by a system of pumping seawater that, once passed through a heat exchanger, is returned to the some degrees colder and by a CDH of fresh water reaching the buildings of Piazza Unità d'Italia that exchanges heat with the taken seawater.

Each building served by the CDH is equipped with an existing central heating system consists where will be installed the HT - HP to be connected to the CDH.

### 2. SYSTEM DESCRIPTION

#### 2.1 Low temperature heat source

It is a source of centralized low temperature water having enough capacity to be able to satisfy all the evaporators of heat pumps to serve.

The solution with seawater (Figure 1) involves the installation of a submersible pump a few meters deep in seawater considering a lowering of temperature between 3 and 5 °C. The prevalence should be able to overcome the geometric global height, as well as all the load losses encountered (piping and heat exchanger). The seawater passes through the primary of a titanium heat exchanger and is rejected at sea slightly cooler. The CDH begins to the secondary of said exchanger and distributes the water to all the HT - HP of the net.

Obviously, this solution must have all the accessories necessary to minimize fouling, algae, corrosion, etc.

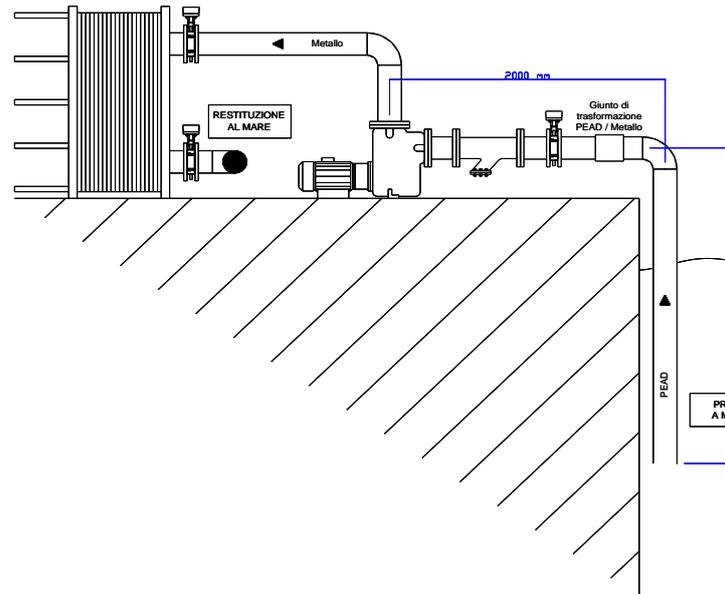


Figure 1. Example of seawater pumping.

## 2.2 Cold District Heating

These nets are similar to the classical district heating but, instead of pre - insulated pipes, are used not insulated PEAD pipes. Unlike the classic district heating plants, such nets are much less invasive and very less costly.

We list some of the advantages of CDH compared to the traditional district heating:

- the relocation of heat pumps at the end users allows to circulate water at low temperatures, avoiding the costly insulation of pipes and facilitating the installation of the net;
- any need of heavy initial investments for the central production plant of heat;
- the steps are divisible and adaptable over time, depending on the available financial resources;
- cost of infrastructure and network significantly lower (aqueduct pipes are not insulated, so no double - pass TIG welding with X - ray controls, laying depth lower, much lower widths of excavation, piping and trims much less expensive, etc.). ;
- costs of management and maintenance very low;
- any fault and stops in central plant does not affect all final users;
- any heat losses from the underground pipes, not even during the distribution of water used for production of sanitary hot water in the summer months;
- at least 67% of the thermal energy comes from renewable sources.

The classic District Heating brings undoubted environmental benefits for the town microclimate, potential economic advantages for end users and also energy benefits, in case of recovery of thermal cascame, but also causes political and social conflicts due to work on the construction of the network involving disruption transit and traffic in the affected areas.

Another problem occurs if the heat is not recovered from existing processes (cascame) and should be produced locally with related emissions.

These problems are largely overcome with CDH.

The realization of CDH is extremely simpler, fast and much less invasive, with a considerable reduction of the discomforts for the citizens. It also does not require any plant for heat production. Finally there is the problem of recover the thermal cascame produced by the plant and, at least 70% of the energy is hydrothermal and renewable.

This achievement demonstrates the technical feasibility of exploitation of seawater (Figure 2).

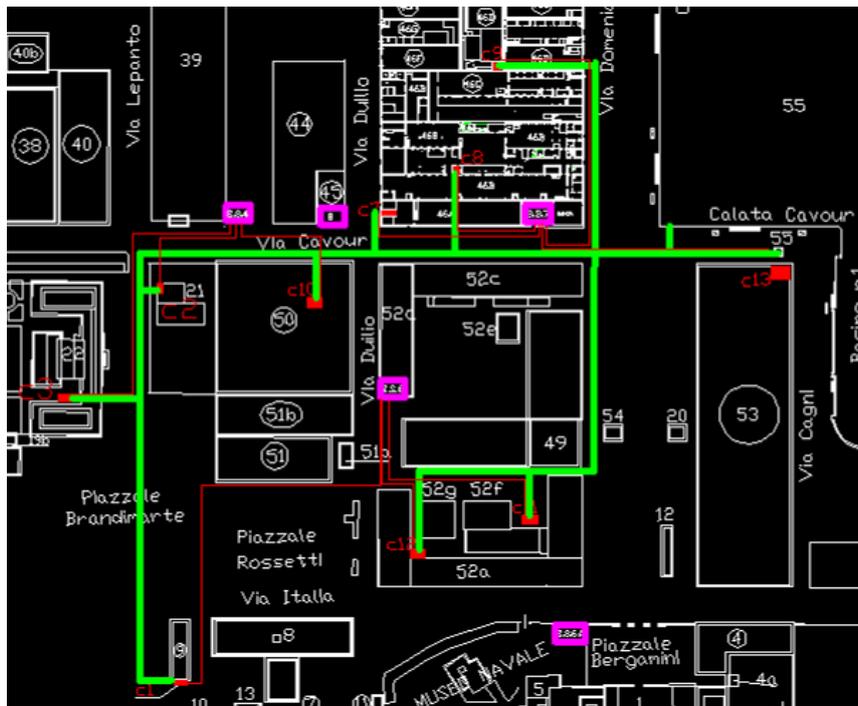


Figure 2. An embodiment with the use of seawater. In green is shown the piping for the distribution of water from the heat exchanger seawater / water to final users. In red are indicated the lines for the distribution of electricity from electricity substations to the end users.

### 2.3 End users substations

Inside the thermal power plant of each building are present heat exchangers and HT - HP.

The water coming from the source hydrothermal is conveyed toward the building through underground pipes to reach the HT - HP installed inside buildings (Figure 3 and Figure 4). To the same source can be connected a maximum number of buildings until they reach the maximum flux of seawater pumped from the sea. The water coming out of the HT - HP, returns to the heat exchanger regains the initial temperature subtracting heat from the seawater.

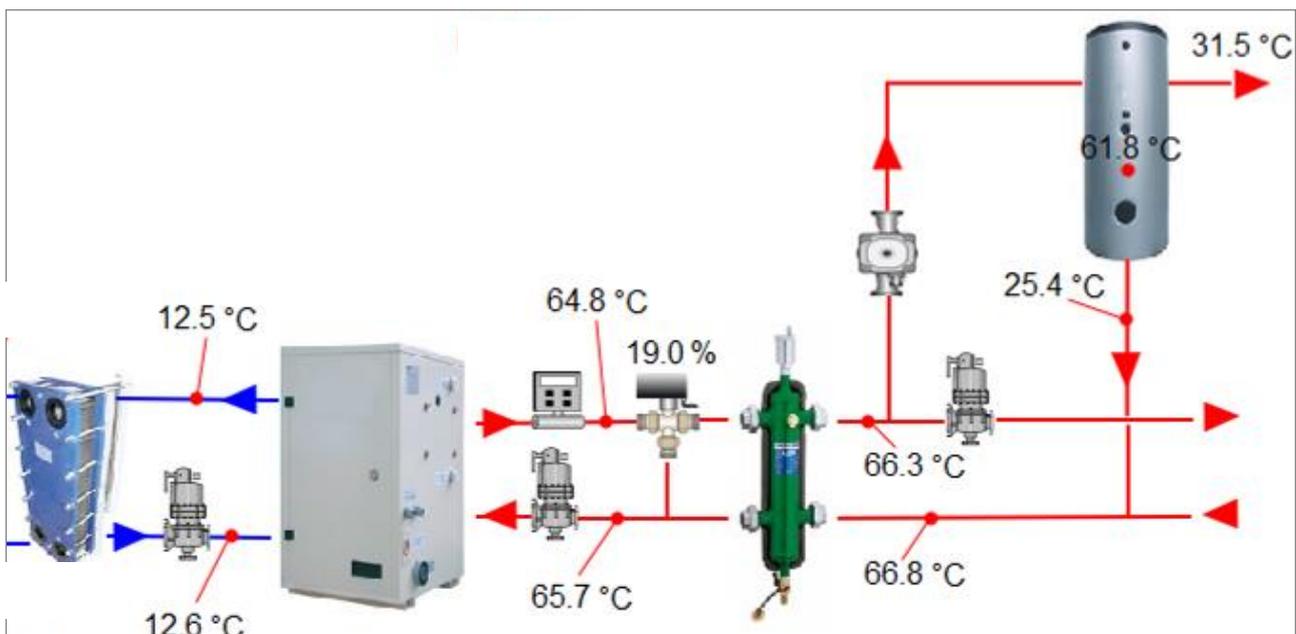


Figure 3. Synoptic panel of a high temperature heat pump installed in a site in Turin.

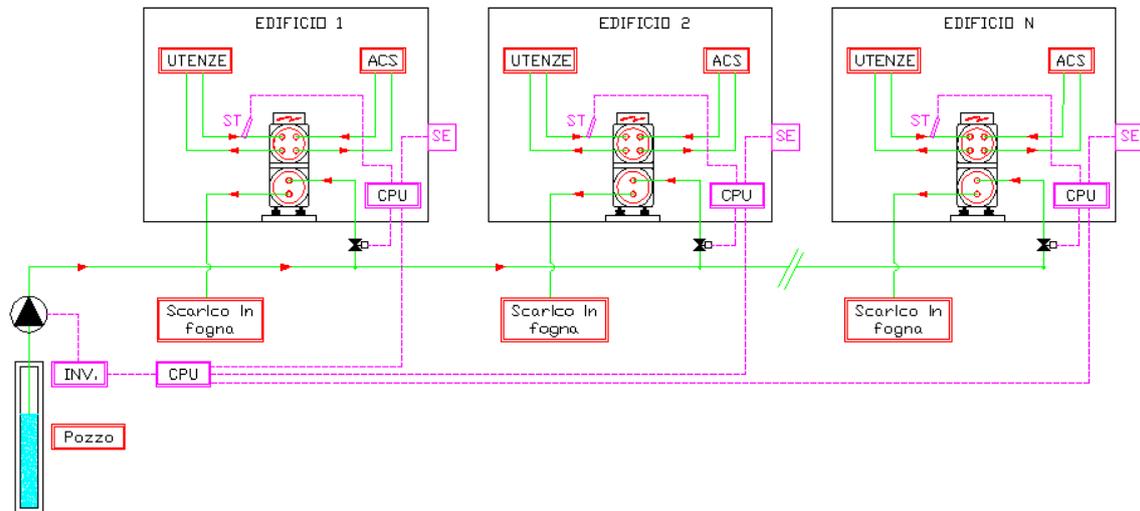


Figure 4. Block diagram relating to thermal power plants and primary in the more general case, which requires both the heating of the building and the production of domestic hot waters.

### 3. ECONOMIC, ENERGETIC AND ENVIRONMENTAL CONSIDERATIONS

Due to synthesis reasons, the following considerations are limited to the analysis to the case of:

- high Temperature Heat pumps 100 kW<sub>(th)</sub> each, all equal;
- all the same and all existing gas boilers installed on buildings such as 30 000 m<sup>3</sup> all the same.

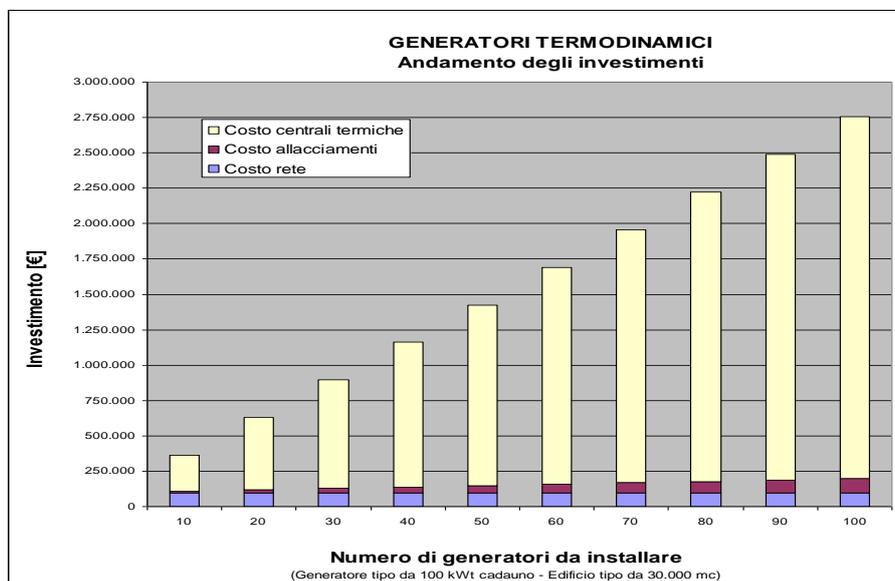


Figure 5. Investment required in function of the number of high temperature heat pumps to install.

As shown by the legend Figure 5, the cost has been divided into 3 components in order to highlight that:

- the cost of CDH is constant and independent of the number of HT - HP to install and has an increasingly marginal to grow HT - HP installed: as early as 20 machines installed becomes negligible;
- the cost of connection, although variable, is entirely neglectable;
- the cost of thermal power plants is the most important item, then the investment, for the most part goes to fund the supply and installation of HT - HP, which is a strong incentive for conversion and to growth companies that will be involved in the project (Figure 6 and Figure 7).

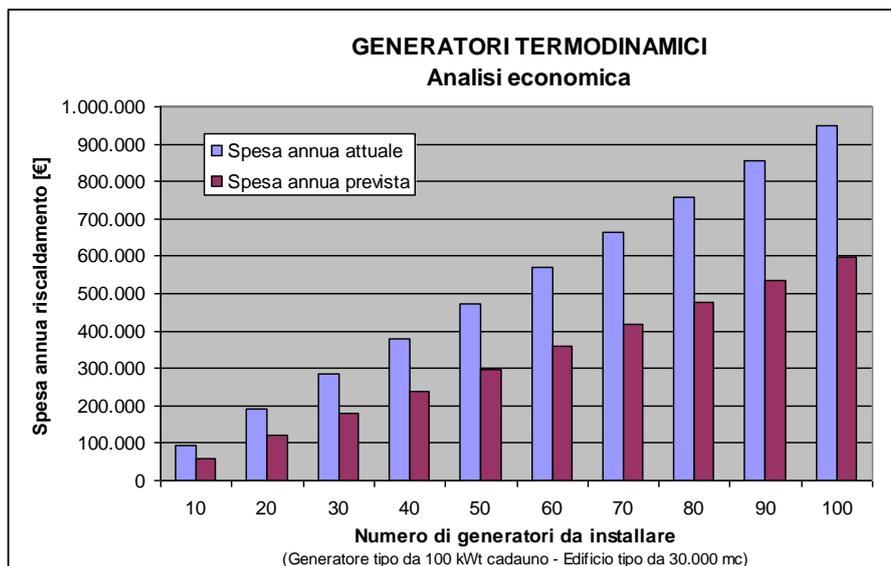


Figure 6. Comparison between the annual costs of fuel relative to the conduction current and the annual costs of electricity that would be incurred as a result of the installation of HT - HP.

It can be seen that the expected savings is interesting.

Note that it is conservatively omitted the comparison on the costs of maintenance that would also strongly in favour of the HT - HP for the following reasons:

- require much less maintenance of boilers,
- do not require “Third Responsible”,
- are not subject to the requirements of Firefighters,
- are not subject to strong Safety requirements.

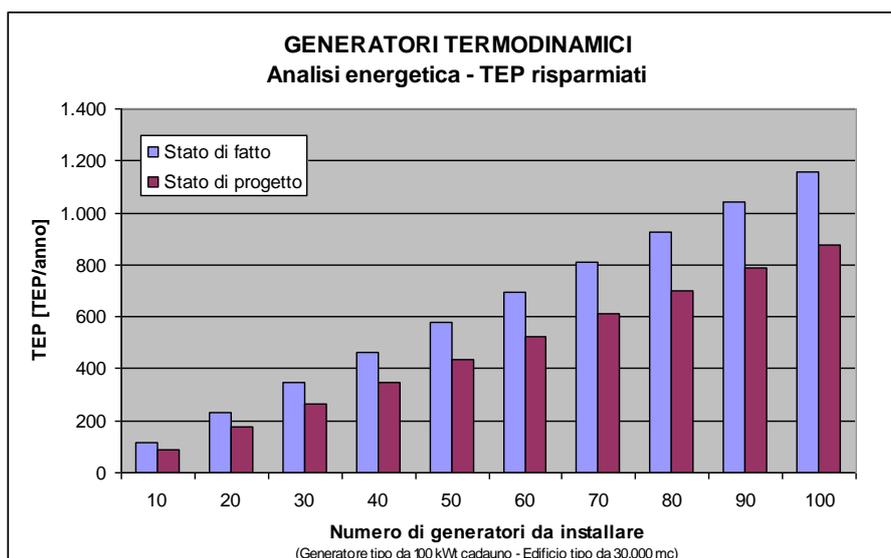


Figure 7. Comparison between the current annual consumption of primary energy, and expected as a result of the replacement of boilers with HT - HP. It is an energy saving of about 25%.

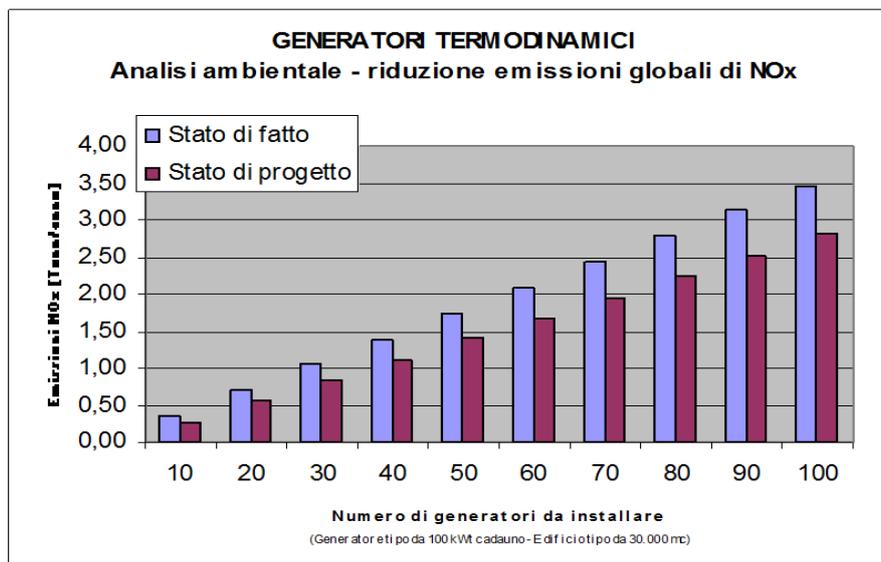
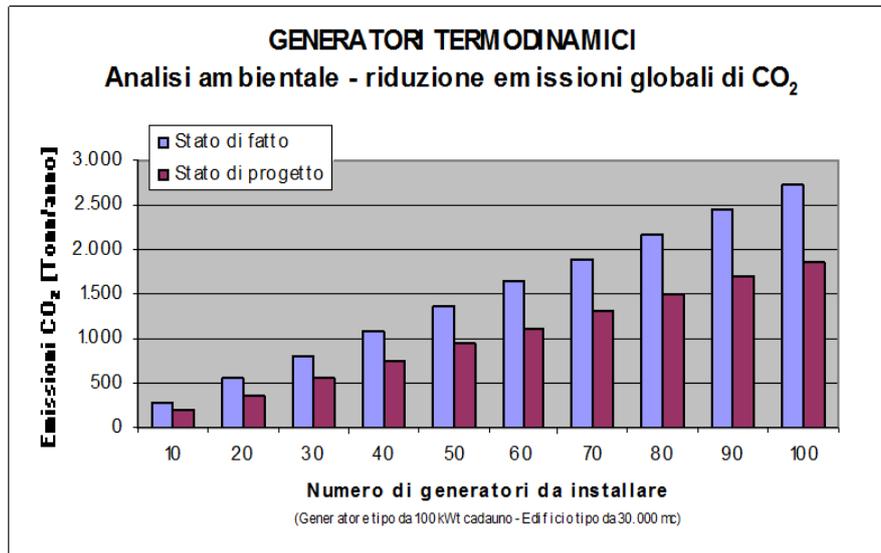


Figure 8. The graphs above show the comparison between the current annual emissions of CO<sub>2</sub> and NO<sub>x</sub> and expected as a result of the replacement of boilers with the HT - HP.

The emissions related to HT - HP (Figure 8) are of course those generated by the portion of electricity needed to power them and produced with fossil fuel. Locally emissions instead vanish completely. It is important to note that the effect of the emissions on the town microclimate is much more harmful than that the one produced in the places of production of electricity; because of their environmental characteristics, they turn out to be more suitable.

#### 4. CONCLUSIONS

CDH helps to reduce town pollution due to heating. It is enough to replace the existing boilers in system installations with radiators without the need for costly renovations on buildings and installations.

The first target market is made up of the existing urban buildings (condominiums, historic buildings, hospitals, etc.) and those commercial buildings. However, its use has considerable advantages even when there is need of new installations having low thermal inertia.

The main advantages are economic, operational, environmental and energetic.

The higher cost of initial installation, compared to traditional boilers, is compensated over the years by savings on the annual cost of managing energy efficiency (35 to 60%), mainly due to the lower cost of the electricity bill compared to that of the fuel, but also to the reduction of operating costs (third responsible, ordinary and extraordinary maintenance, combustion analysis, etc.).

In Italy, in the hypothesis of the current costs of electricity and fossil fuels, the payback is 3 to 5 years, depending on the fuel and on the installation conditions.

These cost savings are due not only to the bill, even at low operating costs because of greatly reduced maintenance requirements, permits and inspections, absence of firefighters and Safety requirements, etc.

From the energy point of view, at least 70% of the energy is renewable and therefore, free drawn from the sea, and if the electricity supplier procures whole or in part from renewable sources, this percentage increases accordingly.

Finally, from the environmental point of view, "Local Zero emissions" contribute to solve the serious problem of town microclimates.

## **ACKNOWLEDGEMENTS**

Many thank for field support and data acquisition to: ECSAC, Trieste University, Municipality of Trieste, Politechnic of Turin, Società Metropolitana Acquedotti Torinesi (SMAT) Turin, Military Arsenal of La Spezia.

## **REFERENCES**

- Laccetti A. (2012) - Utilizzo degli acquedotti come sorgente per pompe di calore ad alta Temperatura. Tesi di Laurea Magistrale, Politecnico di Torino.
- Masoero M., Silvi C., Pellegrini G. (2009) - Energy conservation in buildings: design and monitoring of an office building with GSHP and phase - change thermal storage system". Proc. Climamed 2009. Lisbona, 17 - 18 aprile 2009, 1 - 10.
- Masoero M., Silvi C., Pellegrini G. (2009) - Impianto a pompa di calore con sonda geotermica e accumulo a cambiamento di fase per un nuovo edificio terziario/industriale. Ipotesi e metodologie utilizzate per il dimensionamento e l'analisi energetico - ambientale. Il condizionamento dell'aria, Milano, anno 53, n. 11 dicembre 2009, 22 - 29.
- Masoero M., Silvi C., Toniolo J. (2010) - Potenzialità di applicazione di sistemi a pompa di calore nel terziario: risultati del progetto di ricerca IEA - ECBCS Annex 48. Atti del Convegno AICARR "Rispondere alla crisi energetica con l'integrazione edificio - impianto: la pompa di calore invertibile", Torino, 03.12.2010, 209 - 230.
- Masoero M., Silvi C., Toniolo J. (2011) - Commissioning degli impianti a pompa di calore. AICARR Journal, Milano, anno 2, Febbraio 2011, 25 - 30.
- Masoero M., Silvi C., Pellegrini G. (2013) - Retrofitting existing heating systems with water - water heat pumps fed by low temperature water networks. Latest technology in Refrigeration and Air conditioning - XV European Conference, Milan, 7 / 8 June 2013.
- Pellegrini G. (2013) - Manuale tecnico della pompa di calore ad alta temperatura denominata "TINA" prodotta da STP Srl.



# **ABSTRACTS**

## Geothermal Energy: How Does It Stack Up in the Future Energy Mix

COCIANCIG Bernhard<sup>1,2</sup>

<sup>1</sup> MND Group, Czech Republic

<sup>2</sup> Petroprom d.o.o – Petroleum Project Management, Premantura, Croatia

Corresponding author's e-mail: [bernhard@petroprom.com](mailto:bernhard@petroprom.com)

### ABSTRACT

When the government of Germany boldly decided in September 2010 to initiate the Energiewende (Energy Transition), this was only six months before the Fukushima accident.

The target of this challenging endeavour is to reduce greenhouse gases, cut down on overall energy consumption and foster renewable energy generation. Legislation to that effect was passed in 2011, which saw an expeditious and material investment in solar, wind and hydropower production. This transition was mainly facilitated by favourable electricity feed-in tariffs. Several countries around the world adopted a similar support for renewables, with different approaches - and varied success.

Geothermal energy was one element in the energy mix and as such mostly confined to areas and countries where the potential exists to exploit this resource.

- How does geothermal compare to other energy sources, now and in the decades to come?
- What are the areas of potential improvement both technically and commercially?
- What are the elements that could make geothermal energy successful?
- What can governments, consumer, producers and R+D institutions contribute to such a success?
- In addition, how can we define whether a geothermal project has the required makings and building blocks to thrive?

## **High - Resolution Geophysics for Porosity and Fracture Network Assessment in Shallow Geothermal Applications**

PIPAN Michele<sup>1</sup>, FORTE Emanuele<sup>1</sup>, DOSSI Matteo<sup>1</sup>, DEL BEN Anna<sup>1</sup>, MOCNIK Arianna<sup>1</sup>, LASHIN Aref<sup>2</sup> and AL - ARIFI Nassir S.N.<sup>2</sup>

<sup>1</sup> Department of Mathematics and Geosciences, University of Trieste, Italy

<sup>2</sup> King Saud University, Riyadh, Saudi Arabia

*Corresponding author's e-mail:* [pipan@units.it](mailto:pipan@units.it)

### **ABSTRACT**

High - resolution imaging and characterization of shallow rock and sediments volumes by means of reflection seismics and ground penetrating radar (GPR) are powerful tools in the evaluation of shallow geothermal systems.

We exploit the sensitivity of GPR to porosity and fluid content to study shallow limestone volumes and to detect fracture networks and sectors characterized by larger porosity. We further apply reflection seismics to extend the depth limits of GPR, normally not larger than few tens of meters in rock, and reach depths of interest for the analysis of aquifers and geothermal systems (hundreds to thousands meters).

The study is performed on a reservoir analogue in Italy and on a selected area in the western Saudi Arabia geothermal province. Both studies are based on multifold methods in data acquisition and attribute analysis in data processing.

The results obtained from a 3D radar dataset show that the effects of small size fractures (below the resolution limit of the method) can be detected as a global attenuation effect in the radar image through the analysis of amplitude attributes, while large fractures are successfully imaged across the volume.

Several fractures possibly connected to the surface geothermal evidences are seismically imaged up to an approximate depth of 500 m in the Arabian test - site.

## Geothermal Applications in Croatia

KUREVIJA Tomislav<sup>1</sup>

<sup>1</sup> Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Croatia

Corresponding author's e-mail: [tkurevi@rgn.hr](mailto:tkurevi@rgn.hr)

### ABSTRACT

Over the last few years, in Croatia several international companies and local developers have worked on the potential of high enthalpy geothermal fields. They have managed to get several new exploration licenses for power generation from deep geothermal energy.

The object interest is fractured carbonate geothermal water aquifers, able to produce temperatures much higher than 100 °C. Currently, investors are faced with cutting investment costs for drilling, testing and producing at the depths of more than 2000 m. First privately invested deep well for direct utilization of geothermal energy was drilled several years ago to 1300 m where sandy geothermal water reservoir was found, with water temperatures near 100 °C.

All phases of exploration, drilling and final production had been carried out in agreement with legal, regional and environmental considerations and despite high initial cost of drilling and construction of deep well, has proven itself as a reliable and favourable, in the long - term, than other locally available energy sources. Such production can also yield unconventional hydrocarbon productions from dissolved gas in regional aquifers, or enhance production in conventionally exhausted hydrocarbon fields, increasing profit and net production.

Several projects using abandoned oil exploration and production wells are in the process of legalization and utilization, also for direct heat consumption.

Exploitation of shallow geothermal resources via heat pump system has also seen significant rise in last 5 years. Although there is no central monitoring system, which could track amount of thermal power installed, there is good indication of how many borehole heat exchangers and water wells have been drilled to exploit shallow heat from the ground. There is also subsidiary system established for ground source heat pumps financed through local municipalities to improve energy efficiency of family homes.

It is expected that shallow geothermal resource exploitation will strongly dominate over the deep geothermal in the near future.

## Thermal Springs and Balneology in the Peri - Adriatic Area: Geochemical Status and Prospects

PETRINI Riccardo<sup>1</sup>

<sup>1</sup> Department of Earth Sciences, University of Pisa, Italy

Corresponding author's e-mail: [petrini@dst.unipi.it](mailto:petrini@dst.unipi.it)

### ABSTRACT

The demand for low - enthalpy thermal waters to be used in balneology, as natural curative resources in spa treatments, is rapidly increasing across Europe. However, long - term abstractions of thermal resources should be carefully planned to avoid waters overexploitation and contamination, which may cause changes in the hydrodynamic pressure of the thermal aquifers and in the chemical composition of the abstracted waters. Hence, for a sustainable water management and quality preservation, it is fundamental to enhance the knowledge about the aquifers, in particular when natural springs are replaced by boreholes.

In the characterization of thermal water reservoirs, geochemistry is becoming an expanding discipline, providing useful information on the origin of the fluids, the occurrence of mixing processes among different components, the role of water - rock and water - gas interactions, and the flow regimes at depth.

The geothermal manifestations in the Peri - Adriatic Region belong to different hydrofacies, reflecting the different origin and nature of the aquifers in the complex geodynamic and lithological settings that include the Eastern Alps, Southern Alps, Dinarides, Pannonian basin and Adriatic – Apulia foreland. These include:

- thermal waters in Mesozoic carbonate - rock aquifers,
- thermal waters in aquifers within the metamorphic basement,
- thermal waters in porous media in sedimentary basins,
- thermal waters of marine origin in coastal environments.

In the work here described, the geochemistry of thermal waters in the Peri - Adriatic region is summarized, and the application of a multiple geochemical approach to a thermal spring site is reported.

## Deep Geothermal Project from the Perspective of a Drilling Contractor

KACHYŇA René<sup>1</sup> and COCIANCIG Bernhard<sup>1,2</sup>

<sup>1</sup> MND Group, Czech Republic

<sup>2</sup> Petroprom d.o.o – Petroleum Project Management, Premantura, Croatia

Corresponding author's e-mail: [bernhard@petroprom.com](mailto:bernhard@petroprom.com)

### ABSTRACT

MND Drilling and Services (MND D&S) is a wholly owned subsidiary of the Czech domiciled MND Group. The company owns and operates a broad range of drilling and workover rigs, ranging from 50 to 450 tons hook load.

MND D&S is involved internationally as contractor for oil and gas well drilling for large petroleum firms such as ExxonMobil, ConocoPhillips, OMV and others.

The drilling rig used to drill and complete the geothermal well Geretsried 1 in Bavaria (Germany) has a horsepower rating of 2000 BHP. The geothermal project was planned and developed by ENEX Power of Germany, whereby the source well was supposed to provide 145 °C hot water energy for a 5 MW<sub>(el)</sub> power generation and a cascaded 40 MW<sub>(th)</sub> district heating system. The well was spud in Dec - 2013 and successfully drilled to a total depth of 6034 m, which made it the deepest geothermal well in Europe.

The presentation provides some insight into the achieved results and the technical and commercial challenges encountered during the construction of the well.

## The Integrated Ferrara Plant, 50% Geothermal

BUSCAROLI Franco<sup>1</sup> and FERRARESI Fausto<sup>1,2</sup>

<sup>1</sup> Gruppo HERA SpA., Bologna, Italy

<sup>2</sup> AIRU - Associazione Italiana Riscaldamento Urbano, Milano, Italy

Corresponding author's e-mail: [franco.buscaroli@gruppohera.it](mailto:franco.buscaroli@gruppohera.it)

### ABSTRACT

Ferrara “District Heating Plant”, managed by HERA group, is one of the best applications in Italy and in Europe of “Integrated Energy System”, based on geothermal source: the geothermal resource was developed as the primary source for the urban heating system, but just from the beginning it was integrated with other resource: the “Waste-To-Energy” plant and back – up boilers.

The geothermal fluid is pumped to the surface from a depth of 1000 m through two extraction wells (14 MW powered) and, after transferring the thermal energy to the network, it is re - introduced in the ground through an intake well, in order to ensure the geotechnical stability. In the existing plant, the amount of energy from renewable sources is equal to 83%, compared to the total production of thermal energy, and allows to heat about 5 400 000 m<sup>3</sup> of users.

As the system is now hydraulically saturated, and thanks to geo - structural and geothermal investigation that confirmed the presence of geothermal reservoirs, suitable for a district heating exploitation, it was decided to develop the existing scheme with a new plant (“Polo Energie Rinnovabili”), design that represent the first Italian example of several new technologies applied to District Heating.

The development project, in addition to geothermal source (14 MW), shows other innovative solutions, such as a Solar thermal Plant (1MW) and an ORC (Organic Rankine Cycle) turbine. With “Polo Energie Rinnovabili” operating at full capacity, the amount of energy from renewable sources will be equal to 91%, and allows to heat about 8 500 000 m<sup>3</sup> of users.

At the present time, the applications of authorizations are in stand - by, in order to wait the definitive conclusions on the studies of International “Commission on Hydrocarbon Exploration And Seismicity in the Emilia Region” (ICHESE).

## District Heating of Benedikt, 1st Stage - Northeast Slovenia

KRALJ Peter<sup>1</sup>

<sup>1</sup> Gejzir Consulting, EON Research Centre, Ljubljana, Slovenia

Corresponding author's e-mail: [peter.kralj@siol.net](mailto:peter.kralj@siol.net)

### ABSTRACT

In spring 2004, an 1857 m deep geothermal well Be - 2/03 was drilled in the Benedikt place, northeastern Slovenia. The temperature of thermal water exceeds 100 °C. The water belongs to the Na - HCO<sub>3</sub> hydrogeochemical facies and has been classified as a CO<sub>2</sub> - rich healing mineral water suitable for drinking, bottling and balneology. Free degassing gas is almost pure CO<sub>2</sub> (99.9 volume%). Major ion composition is dominated by sodium (1750 ppm) and bicarbonate (4700 ppm). The well testing would be an expensive and difficult operation owing to the high water temperature. For that reason, the Municipality of Benedikt, as the well owner decided to construct a part of the planned district heating project, and in this way, usefully lowered the waste water temperature.

Owing to very high investment costs, which could not be carried by the Municipality itself, and very poor engagement of the responsible governmental institutions, the Municipality council decided to make a contract with the company Gejzir Consulting from Ljubljana in the beginning of the year 2006.

The Municipality of Benedikt is the well owner and ensured an uptake of 5 L/s of thermal water to Gejzir Consulting for construction of the first stage of district heating. District heating encompasses public dwellings – the Municipality building, gymnasium, primary school and kindergarten that consume altogether 20% of total Municipality consumption.

Heat station has the power of 600 kW and annually produces 2000 MWh of heat. Gas separator and heat exchanger are located at the production well in order to simplify the system operation. Energetically used thermal water is cooled in a nearby pool. The inflow of thermal water from the production well is regulated automatically with respect to the outflow temperature from the heat exchanger, which is constant and amounts to 40 °C. The water undergoes further cooling in the pool and is less than 30 °C when disposed into a small creek.

After the enlargement of the district heating network, construction of a small power plant and a spa centre, energetically used thermal water will be reinjected into the primary aquifer. The cooling pool will not be needed any more.

The whole project of district heating is characterised by 3.3 MW of power and annual production of 4000 MWh.

---

## **Area Science Park Innovative Systems and Open - Laboratories for the Diffusion of Small Size Plants based on Renewable Energy and High Efficiency Technologies Including Geothermal Applications**

FLOREANI Mario<sup>1</sup> and COZZI Gianni<sup>1</sup>

<sup>1</sup> Area Science Park, Trieste, Italy

*Corresponding author's e-mail: [mario.floreani@area.trieste.it](mailto:mario.floreani@area.trieste.it)*

### **ABSTRACT**

Since 2008, Area Science Park has been building innovative small size plants in the fields of internal combustion engines cogeneration, gas turbine cogeneration, low enthalpy geothermal climatization, photovoltaics, LED public lighting and solar cooling.

These plants, based on the best technologies currently available on the market, are not just meant to cut energy costs and reduce green - house gases.

As a matter of facts, they are designed to operate as full - size working demonstrators and “open labs” where universities and primary schools, research institutes, enterprises and public administrations can learn about innovative solutions and compare different technologies in terms of technical, environmental and economic effects.

## New Projects for Geothermal District Heating and Cooling Systems in the Brescia Province - Northern Italy

MOLINARI Fabio Carlo<sup>1</sup> and TARANTINO Paolo<sup>2</sup>

<sup>1</sup> Freelance Geologist, Italy

<sup>2</sup> Cogeme SpA, Rovato, Italy

Corresponding author's e-mail: [fabiocarlomolinari@yahoo.it](mailto:fabiocarlomolinari@yahoo.it)

### ABSTRACT

Direct and indirect use of geothermal energy in the Brescia Province; an area with major superficial aquifers and geological irregularity, which allow the exploitation - also direct - of a geothermal source.

Analysis of the results achieved by Cogeme SpA in the research of deep geothermal fluids and in the prototyping of “cold district heating” network systems allowing a rational use of groundwater for energy purposes.

“Cold District heating” allows the transfer of a geothermal resource from the area of pumping and storage, toward revamping thermal plants which supply existing buildings, thus solving the typical issues concerning the use of renewable energy sources in old town centres, in areas with few common spaces, in contexts subject to an environmental, historical and architectural constraint of protection or to strict acoustic zoning “Cold District Heating” can represent a simple, rapid, noninvasive and “renewable” way to revamp heat production plants.

It is a valid answer to the energy needs of those small urban centers, which are interested in reaching the energy efficiency of their buildings, which cannot find a valid solution in the conventional District Heating, because of the limited dimension of their catchment area.

---

## Altheim in Upper Austria – an Example of Cascaded Geothermal Energy Use

COCIANCIG Bernhard<sup>1,2</sup>

<sup>1</sup> MND Group, Czech Republic

<sup>2</sup> Petroprom d.o.o – Petroleum Project Management, Premantura, Croatia

Corresponding author's e-mail: [bernhard@petroprom.com](mailto:bernhard@petroprom.com)

### ABSTRACT

The community of Altheim in Upper Austria has embarked on the implementation of a geothermally sourced district heating system in early 1990, serving about 700 households, which represent some 40% of the population.

Shortly afterwards, the project was expanded upstream by the installation of a hot water source and disposal well, utilized for powering a ORC turbine for electricity generation.

The 1 MW<sub>(el)</sub> turbine and the cascaded heating infrastructure is now in operation since well over 20 years and was one of the first facilities which operated from a medium enthalpy source. Information on the technical setup, facilities, and the operating system is provided along with data on capital and operating costs.

Finally, options for financing are discussed.

## LEGEND Project Mobilizing Ground - Source Heat Pumps Investments in Adriatic

JOVANOVIC Dalibor<sup>1</sup>

<sup>1</sup> IRENA - Istrian Regional Energy Agency Ltd., Labin, Croatia

Corresponding author's e-mail: [dalibor.jovanovic@irena-istra.hr](mailto:dalibor.jovanovic@irena-istra.hr)

### ABSTRACT

The Adriatic Area shows optimal climatic and geological conditions for fully exploit the potentialities of low temperature geothermal energy with Ground - Source Heat Pumps (GSHP) due to presence of medium temperature sedimentary basin across the Western Adriatic shore and the shallow geothermal conditions, which characterize the entire Eastern Adriatic Countries. However, in this area the technical expertise and the presence of successful cases are polarized mainly in the north Adriatic and along the Italian shore, whilst the awareness over the benefits of heat pumps, the legislations and - finally - the maturity of the market are still in the early stage.

With around 3 million € of budget, LEGEND “Low Enthalpy Geothermal ENergy Demonstration cases for Energy Efficient building in Adriatic area” is the largest geothermal energy investment project ever financed by the European Union in the Adriatic and Balkan area, through the financial assistance of the IPA CBC Adriatic Programme.

The purpose of the project, coordinated by the Province of Ferrara (IT) and implemented in 11 Adriatic regions of Italy, Croatia, Montenegro, Albania, Serbia, Slovenia and Bosnia Herzegovina, is to promote the use of shallow geothermal energy, in particular the GSHP technologies, through the conversion of 10 publically owned buildings to use GSHP as the primary energy source for heating and cooling.

The project represents an outstanding example of a cross - border initiative to meet the EU climate and energy targets to 2020 and it is based on a very concrete approach: LEGEND has immediate effects in terms of energy generated by renewables and CO<sub>2</sub> reduction, it encourages green - market, technological development and deployment, and public & private investments.

The project runs from October 2012 to December 2014.

More information at: [www.legend-geothermalenergy.eu](http://www.legend-geothermalenergy.eu).

---

## New Applications of Heating and Cooling Using Geothermal Resources

ZUDEK Alfredo<sup>1</sup> and ALOISIO Fabio<sup>1</sup>

<sup>1</sup>ZUDEK Srl, Muggia, Italy

Corresponding author's e-mail: [zudek@zudek.com](mailto:zudek@zudek.com)

### ABSTRACT

This paper shows application for methods and solutions for innovative heating and cooling for applications with the use of geothermal resources.

The main core of the system is the heat pump with ammonia as refrigerant for combined heating and cooling using geothermal energy as resource for the cycle. Ammonia is the refrigerant, which offers the best advantages in terms of efficiency and environmental impact with zero GWP and zero ODP.

The presentation will show real cases of installed plants with ammonia heat pumps with the use of geothermic energy across Europe and their benefits in terms of energy savings, environment respect and reduction of costs during operation.

## The Trieste SEAP – Action Plan for Sustainable Energy

LAURENI Umberto<sup>1</sup>

<sup>1</sup> Councillor for the Environment and Energy of the Municipality of Trieste, Trieste, Italy

Corresponding author's e-mail: [umbertolaureni@comune.trieste.it](mailto:umbertolaureni@comune.trieste.it)

### ABSTRACT

A reduction of over 20% of CO<sub>2</sub> emissions by 2020 is the challenge for all cities that have signed the Covenant of Mayors.

This challenge is particularly demanding for Trieste, a city that is addressing other issues in connection with its economic and industrial development and which has limited renewable energy sources on its territory.

Trieste is willing to take on these challenges and with its Sustainable Energy Action Plan (SEAP<sup>23</sup>) aims to become a model for energy efficiency, sustainable development and environmental quality.

The development and implementation of this long - term vision focuses on three strategic lines: greater efficiency and energy savings in buildings, generation of energy from renewable sources and reduction of emissions from transport. This requires a continuous effort, which must be organized with flexibility and creativity, and will be pursued over the next decade, through appropriate organizational and financial structures that allow for their implementation.

The City of Trieste takes on the challenge to achieve these results, knowing that a larger commitment is required from local stakeholders, including citizens, who need to change their habits moving towards new modes of transportation and energy consumption.

After a brief presentation of the SEAP, the fundamental role of the research particularly in the field of geothermal energy is discussed.

---

<sup>23</sup> In Italy “PAES - Piano d'azione per l'energia sostenibile”.

## **M19 – A New School Complex Module in a Historical Building based on Leed Certification and Geothermal Application in Trieste Port**

MANGANARO Andrea<sup>1</sup>, ROMANO Giuseppe<sup>1</sup> and STRADA Mauro<sup>1</sup>

<sup>1</sup> STEAM Srl, Padova, Italy

Corresponding author's e-mail: [amanganaro@steam.it](mailto:amanganaro@steam.it)

### **ABSTRACT**

Starting from the expression of interest of the “Provincia di Trieste” during recent Concession Procedure for areas and buildings in Trieste port, the M19 design started from the need to relocate the Naval College in that area, developed a modern school complex module to be settled in the historical buildings and his guidelines to reduce consistently working costs from management and energy consumption point of view.

The suggested module is suitable for a 700 students unit and it should be applicable to building “Magazzino 19” as well as many other similar buildings present in the port area, in order to create an “Educational Pole”.

The management costs should be lesser sharing support facilities between modules, while the exploitation of environmental local resources (Geothermal energy) and the application of Leed Certification should decrease the energy cost.

The approach used by the design team was the LEED certification program based on defined efficiency standards regarding energy and water use, CO<sub>2</sub> emissions, the quality of the interior environment and environmentally resource management practices. LEED recognizes the unique nature of design of schools that are healthy for students, comfortable for teachers, and cost-effective addressing issues such as classroom acoustics, master planning, mold prevention, and environmental site assessment. The use of a local resource as seawater in a heat pump to produce hot/cold water for HVAC systems together to an integrated design approach involving all disciplines allow to get a certified green building.

Optimization of building insulation and solar shading devices, selection of materials, use of low temperature heating terminal unit and study of photovoltaic panels' integration are other analysis included in the design.



## INDEX OF AUTHORS

AL - ARIFI Nassir S.N.....	133	LASHIN Aref.....	133
ALOISIO Fabio.....	143	LAURENI Umberto.....	144
ANGELINO Luca.....	10	LUGHI Vanni.....	3
ANTICS Miklos.....	44	MANGANARO Andrea.....	145
BERTO Raul.....	114	MASELLA Andrea.....	92
BRADAMANTE Franco.....	I	MENDRINOS Dimitrios.....	86; 105
BRANCATELLI Giuseppe.....	65	MOCNIK Arianna.....	133
BUSCAROLI Franco.....	137	MOLINARI Fabio Carlo.....	140
BÜSCHER Eckehard.....	61	PALMIERI Francesco.....	36
CASTELLI Eugenio.....	65	PELLEGRINI Gianfranco.....	123
CECHET Giovanni.....	114	PERONIO Marco.....	36
CIMOLINO Aurélie.....	V; XV; 65	PESTOTNIK Simona.....	51
COCIANCIG Bernhard.....	132; 136; 141	PETRINI Riccardo.....	135
CONTI Paolo.....	25	PETRONIO Lorenzo.....	36
CORUBOLO Piero.....	36	PIEMONTE Carlo.....	92
COZZI Gianni.....	139	PIPAN Michele.....	133
DEL BEN Anna.....	133	POLETTI Flavio.....	36
DELLA VEDOVA Bruno.....	I; V; XV; 65	PRESTOR Joerg.....	51
ĐJURIC Dijana.....	77	RAJVER Dušan.....	51
ĐJURIC Nedjo.....	77	ROMANO Giuseppe.....	145
DOSSI Matteo.....	133	SCHLEIFER Andrea.....	36
FARINA Biancamaria.....	36	SKOPLJAK Ferid.....	77
FERRARESI Fausto.....	137	STEFANELLI Silvia.....	100
FLOREANI Mario.....	139	STIVAL Carlo Antonio.....	114
FORTE Emanuele.....	133	STRADA Mauro.....	145
GRASSI Walter.....	25	TARANTINO Paolo.....	140
JOVANOVIĆ Dalibor.....	142	UNGEMACH Pierre.....	19; 44
KACHYŇA René.....	136	VACCHI Andrea.....	I; XV
KARYTSAS Constantine.....	86; 105	VALCOVICH Edino.....	114
KRALJ Peter.....	138	WITTIG Volker.....	61
KUREVIJA Tomislav.....	134	ZUDEK Alfredo.....	143

## INDEX OF INSTITUTIONS

AIRU - Associazione Italiana Riscaldamento Urbano, Milano, Italy .....	137
Area Science Park, Trieste, Italy .....	139
Central Directorate of Environment and Energy, Friuli Venezia Giulia Region, Italy .....	100
Cogeme SpA, Rovato, Italy .....	140
Councillor for the Environment and Energy of the Municipality of Trieste, Trieste, Italy .....	144
CRES - Centre for Renewable Energy Sources and Saving of Greece, Pikermi, Greece .....	86; 105
Department of Civil Engineering, Subotica University, Serbia .....	77
Department of Civil, Environmental and Architectural Engineering, University of Padova, Italy .....	114
Department of Civil, Environmental, Architectural Engineering and Mathematics, University of Brescia, Italy .....	92
Department of Earth Sciences, University of Pisa, Italy .....	135
Department of Energy, Systems, Territory and Constructions Engineering, University of Pisa, Italy .....	25
Department of Engineering and Architecture, University of Trieste, Italy .....	I; V; XV; 3; 65; 114
Department of Mathematics and Geosciences, University of Trieste, Italy .....	133
ECSAC - European Centre for Science Arts and Culture, Trieste, Italy .....	I
EGEC - European Geothermal Energy Council, Brussels, Belgium .....	10
F.I.T. - Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze, Trieste, Italy .....	I; V; XV; 65
Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb, Croatia .....	134
Freelance Geologist, Italy .....	140
Gejzir Consulting, EON Research Centre, Slovenia .....	138
Geological Survey of Bosnia and Herzegovina, Sarajevo, Bosnia and Herzegovina .....	77
Geological Survey of Slovenia, Ljubljana, Slovenia .....	51
GPC IP - Gpc Instrumentation-Process, Paris Nord 2 - Roissy CDG Cedex, France .....	19; 44
GRUPPO HERA SpA, Bologna, Italy .....	137
GZB - International Geothermal Centre, Bochum, Germany .....	61
IGO - International Geothermal Office of Germany, c/o GZB, Bochum, Germany .....	61
INFN - National Institute for Nuclear Physics, Trieste, Italy .....	I; XV
IRENA - Istrian Regional Energy Agency Ltd., Labin, Croatia .....	142
King Saud University, Riyadh, Saudi Arabia .....	133
MND Group, Czech Republic .....	132; 136; 141
OGS - National Institute of Oceanography and Experimental Geophysics, Trieste, Italy .....	36
Petroprom d.o.o – Petroleum Project Management, Premantura, Croatia .....	132; 136; 141
STEAM Srl, Padova, Italy .....	145
STP Srl, Torino, Italy .....	123
Studio Associato di Ingegneria, Milano, Italy .....	92
Technical Institute of Bijeljina, Bosnia and Herzegovina .....	77
UGI - Italian Geothermal Union, Firenze, Italy .....	I; V; XV; 25; 65
ZUDEK Srl, Muggia, Italy .....	143

## Supporting Institutions

- AREA Science Park
- Consortium for Physics of Trieste
- ECSAC European Centre for Science Arts and Culture
- FIT - Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze
- Friuli Venezia Giulia Region
- HERA Group - Environmental Services Multiutility
- ICTP - Abdus Salam International Centre for Theoretical Physics of Trieste
- INFN - National Institute for Nuclear Physics
- Italian Institute of Culture of Zagreb
- OGS - National Institute of Oceanography and Experimental Geophysics
- Ruđer Bošković Institute of Zagreb
- Trieste Municipality
- Trieste Province
- UGI – Italian Geothermal Union
- UniAdrion
- University of Trieste
- University of Zagreb



### Source quoting

Della Vedova B., Vacchi A., Bradamante F. [Editors] (2015) - *PROCEEDINGS OF THE WORKSHOP ON GEOTHERMAL ENERGY AND KICKING – OFF THE ADRIATIC - JONIAN GEOTHERMAL PLATFORM*. Fondazione Internazionale Trieste per il Progresso e la Libertà delle Scienze – F.I.T., August 2015, 176 pp.

---

ISBN 978-88-941071-0-4

First edition, August 2015.

E - ISBN 978 - 88 - 941071 - 0 - 4



9 788894 107104

Printed online. The digital edition is fully available (open - access) at:

**[www.fondazioneinternazionale.org](http://www.fondazioneinternazionale.org)**