STSM – Short Term Scientific Missions within the Action TU1405 – "European Network for Shallow Geothermal Energy Applications in Buildings and Infrastructures".

STSM FINAL REPORT

February 2016

Topic (correlation with the existing working groups within the Action):
Sustainability and urban planning – WG 3

Research Title: Development of geothermal potential maps at the urban scale - Part 1

Home Institution: Politecnico di Torino (Italy)

Host Intitution:PGI-NRI (Poland)

Torino, 10/03/2016
Marco Barla

Table of Contents

1 Purpose & aim of the STSM 3

1.1 Background 3

1.2 Motivation and objectives 4

2 Work carried out 4

2.1 Agenda of the STSM 4

2.2 Modeling for Warsaw metro extension 5

2.2.1 Definition of the set of data needed for modeling 6

2.2.2 Definition of the areas of interest 6

2.2.3 Definition of the modeling approach 6

2.2.4 Interpretation of the results and dissemination strategies 7

2.3 Visit to geothermal system in Jozefow 8

2.4 Seminar at PGI 8

2.5 Geothermal mapping 9

2.5.1 Knowledge gained from the TransGeoTherm project 9

2.5.2 Developing advanced geothermal maps 10

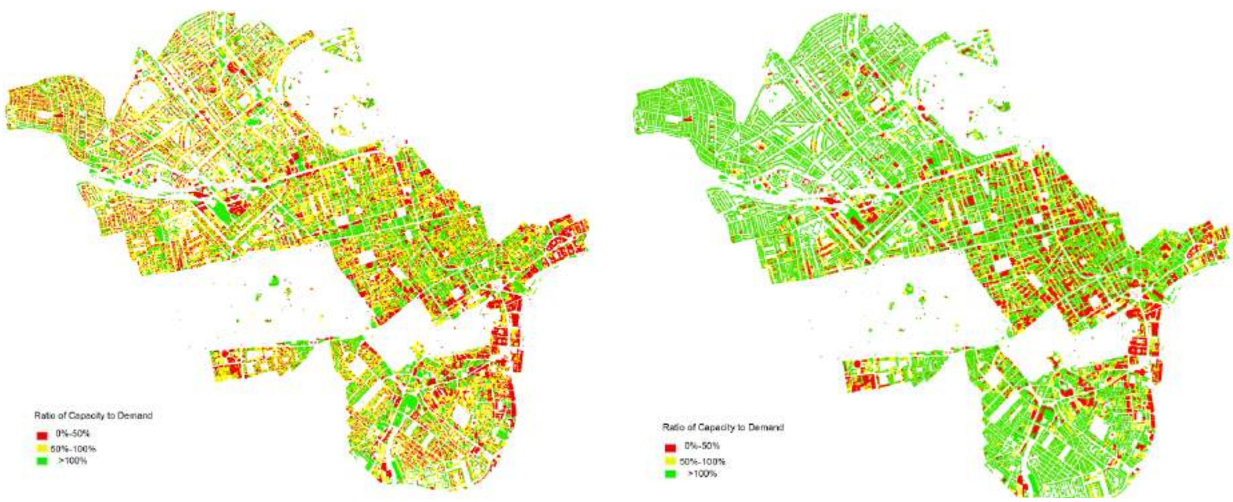
2.5.3 Dissemination strategies 11

3 References 11

1 Purpose & aim of the STSM

1.1 Background

The maps of geothermal potential serve as a tool for identification of geoenergy sources for land development and spatial planning in both regional and urban scales. The main goal of this STSM was to develop a procedure similar to the one already developed by a team of the University of Cambridge for city and district scale geothermal mapping [1,2]. In that study, the city of Westminster (London) was used as a case study to identify areas where GSHPs can serve as a viable option renewable heating and/or cooling. Two scenarios were considered in the study, ‘Boreholes under Buildings’ as Scenario 1 and ‘Boreholes around Buildings’ as Scenario 2. A parametric study was conducted to investigate the influence of how space heating and cooling demand is quantified on the ratio of capacity to demand (C/D ratio) distribution map of Westminster as shown in Figure 1.



(a) Scenario 1 (b) Scenario 2

Figure 1 - The spatial distribution of the ratio of capacity to demand for the two scenarios. The buildings in green are those in which GSHP alone can provide both the heating and cooling supply. The buildings with GSHP can provide between 50-100% and 0-50% of the heating/cooling supply are shown in yellow and red, respectively [1,2].

The results show that many buildings (51% for scenario 1 and 67% for scenario 2) can install enough boreholes to support their own annual heating and cooling demands. For the rest of the buildings that have demand greater than their capacity, neighboring buildings with surplus capacity could share boreholes, leading to a district scale GSHP system. The analysis considered the influence of annual, monthly and hourly variation in heating/cooling demand estimation on the ratio of capacity to demand (C/D ratio) distribution map, and the influence of COP difference between design and operation on the electricity consumption. It was found that the influence of the variation in building load estimation is more significant under Scenario 1 than under Scenario 2.The hourly calculation of heating and cooling demand leads to a lower C/D ratio and the operational variation of COP influences the electricity consumption of the GSHP systems. The study showed that a comprehensive analysis including the capital cost, C/D ratio distribution, energy demand, and financial risk is highly recommended for district-level planning of GSHP systems and that a district scale GSHP is feasible. Although drilling many holes such as considered in the study are possible, they can be costly. The potential development of energy geostructures which combine GSHP with underground structures provides opportunity to realise a district scale GSHP.

1.2 Motivation and objectives

Geothermal geostructures are rapidly spreading all around Europe and are increasingly employed for heating and cooling of building in urban environment. Their diffusion is destined to continue in the next future. In this scenario, the interactions between close geothermal plants have to be carefully considered and specific urban planning is definitely needed. Geothermal maps are an easy to use planning tool intended for the local and regional authorities, inhabitants, engineering and drilling companies, etc. On the one hand the maps provide information and data, which are important for urban planning and development of geothermal installations, and on the other they are needed to compose and dimension a geothermal plant in detail. ArcGIS-based simulation models are an effective tool in order to examine how many vertical closed loop GSHPs can be feasibly installed at city scale without overusing the geothermal energy underground. The objective of this mission was to share knowledge, information and work methods for the development of joined design procedures for a proper and efficient urban planning of geothermal systems.

2 Work carried out

2.1 Agenda of the STSM

The STSM was conducted both at the PGI offices in Warsaw (with the team involved in the COST action, led by Grzegorz Ryzynski) and in Wroclaw (with the team that worked on TransGeoTherm Project, led by Wiesław Kozdrój and Maciej Kłonowski).

In Warsaw the attention was posed to the PGI database of engineering-boreholes (see http://atlasy.pgi.gov.pl), analyzing the available data and identifying the steps for the preliminary assessment of the potential application of energy tunnels for the Warsaw metro (see pgf. 2.2). One day was also devoted to disseminate GABI COST Action activities (see pgf.2.3). In Wroclaw the attention was devoted to the modeling issues with 3D geological software (transfer of model data to ArcGIS software), by identifying the issues for the development of advanced geothermal maps that can constitute design tools for a proper and efficient urban planning of geothermal systems.

The agenda was as follows:

- Monday 22/2: Discussions in PGI at Jagiellońska 76 street. + visit in PGI Soil Mechanics Laboratory.
- Tuesday 23/2: Visit to Euros Energy Factory + Discussions in PGI at Jagiellońska 76 street.

- Wednesday 24/2: Seminar at PGI Headquarters at Rakowiecka 4 (till lunch) + discussions in PGI at Jagiellońska 76 street.
- Thursday 25/2: Visit to Trans Geotherm Team in Wrocław Regional Branch of PGI.
- Friday 26/2: Summary of STSM activities and future plans.

2.2 Modeling for Warsaw metro extension

The modeling activity performed for the Turin metro [3,4] was illustrated to the PGI partners who agreed that the same methodology could be adopted to study the feasibility of thermal activation of the lining for the Warsaw metro. The city of Warsaw, in fact, is currently undergoing extensive renovation of its infrastructures. In particular the M2 line of the underground will be extended in the direction NE, SE and W as shown in Figure 2. The NE extension will be constructed in a area of the city (Praga) where renovation and modernization of the buildings and surface facilities is expected to take place and will be enhanced by the underground works and the consequent increase in land value. These are all favorable circumstances for proposing the use of the tunnel lining for exchanging heat in the ground and making district heating and cooling systems available for the new constructions on the surface.

During the STSM the schedule of this activity was defined and is briefly described in the following paragraphs.

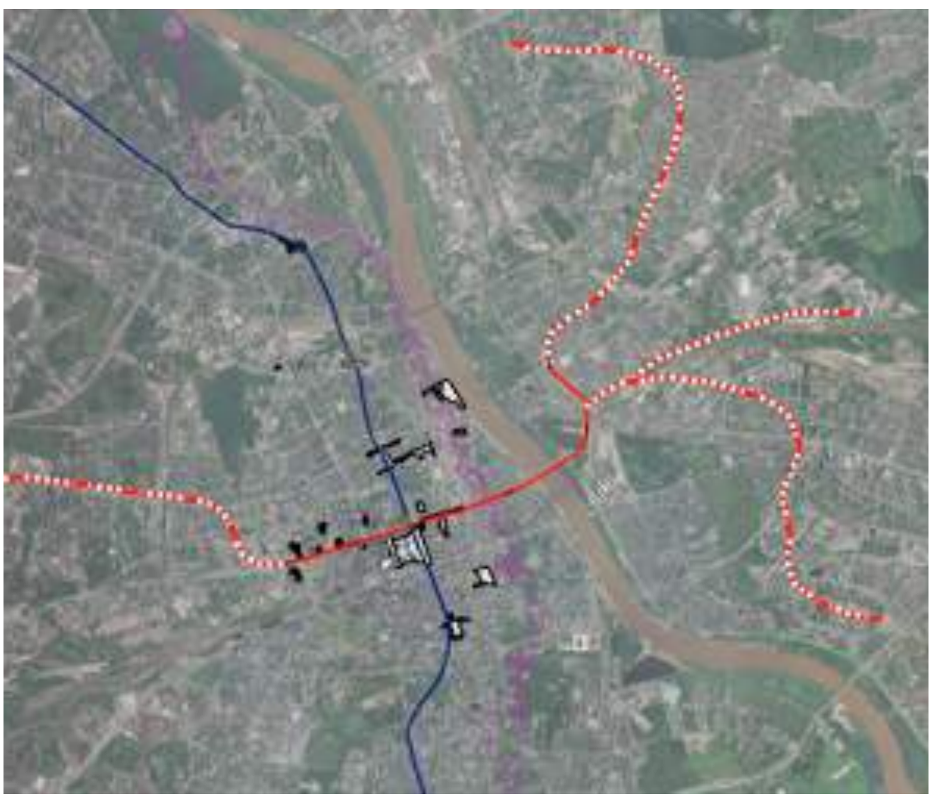


Figure 2

Figure 2 – Map of current Warsaw metro lines and future extensions of line M2 (red dotted lines).

2.2.1 Definition of the set of data needed for modeling

To prepare reliable numerical models the first step is to identify the key parameter that need to be assessed. This work was performed during the STSM. The parameters needed were identified in:

- Ground water flow conditions,
- Ground geotechnical and hydrogeological parameters (thermal conductivity, specific heat capacity, permeability),
- Initial temperature of the ground,
- Geometry and depth of the tunnel,
- Geological model of the subsurface to a depth of 40 m.

The Metro Line M2 is expected to be excavated at an average depth between 13 to 23 m with a twin circular tunnel geometry. Detailed designed alignment and tunnel dimensions will be provided by the The Office of Architecture and Spatial Planning of Warsaw Municipality. The same offices will provide spatial data on planned and existing high-rise buildings, underground car parks and new as well as existing metro lines.

The geological model used for analyses will be prepared on the basis of GIS data from Engineering-Geological Database of Warsaw, maintained by Polish Geological Institute – National Research Institute, as one of the tasks of Polish Geological Survey (see atlasy.pgi.gov.pl). Geo-engineering atlases of urban agglomerations are the largest unique collection of digital data of this type in Poland. They include detailed information obtained from geo-engineering, geotechnical, hydrogeological reports as well as borehole profiles. Thematic maps of the atlases are a visual synthesis of the geo-engineering information from the Central Geological Database (Centralna Baza Danych Geologicznych – CBDG). They allow the assessment of geo-engineering conditions of the agglomeration areas, for instance in spatial planning. Also, they help to take decisions related to planning detailed substratum surveys and minimizing the environmental damage as well as preparing prognoses and economic aspects of investments. Layers with data on geological and economic threats can be analyzed to prepare maps of risk.

2.2.2 Definition of the areas of interest

Based on the data available, PGI will produce a 3D geological model that will be adopted to identify characteristic cross sections for numerical modeling. This activity will be completed by the end of May 2016.

At first, the borehole dataset in the area will be selected, then the necessary map layers will be collected together with the necessary layer parameters. This will allow to build a longitudinal geological cross section along the alignment of the tunnel that will allow for the final selection of representative perpendicular cross sections (in a number between 3 to 5) that will allow for parametric numerical analysis to be performed.

2.2.3 Definition of the modeling approach

The numerical analyses will be conducted with the aim to quantify the efficiency of the energy tunnel system with reference to the specific case study of the Warsaw metro extension.

A thermo-hydro mathematical formulation is required to simulate the thermal exchange between the fluid circulating through the pipes, installed in the tunnel concrete lining, and the surrounding soil, submerged under the ground water table. To this end, the finite element software FEFLOW© (Diersch 2009), license available at the Politecnico di Torino, is selected where the thermo-hydro problem is governed by the following equations, written in the Eulerian coordinate system for a saturated medium composed by a solid and a liquid (water) phase. For the simulation of the absorber pipes installed in the tunnel lining, 1D discrete features elements provided in FEFLOW© will be adopted. The use of these elements to simulate pipes in geothermal systems has been validated and showed good agreement when compared to analytical solutions (Diersch 2009). The mass and energy conservation equations are satisfied also for these elements, while the fluid flow inside them is described by the Hagen-Poiseuille law.

A 3D finite element model will be built in order to reproduce a cross section of the Warsaw metro tunnel, instrumented with heat absorber pipes.

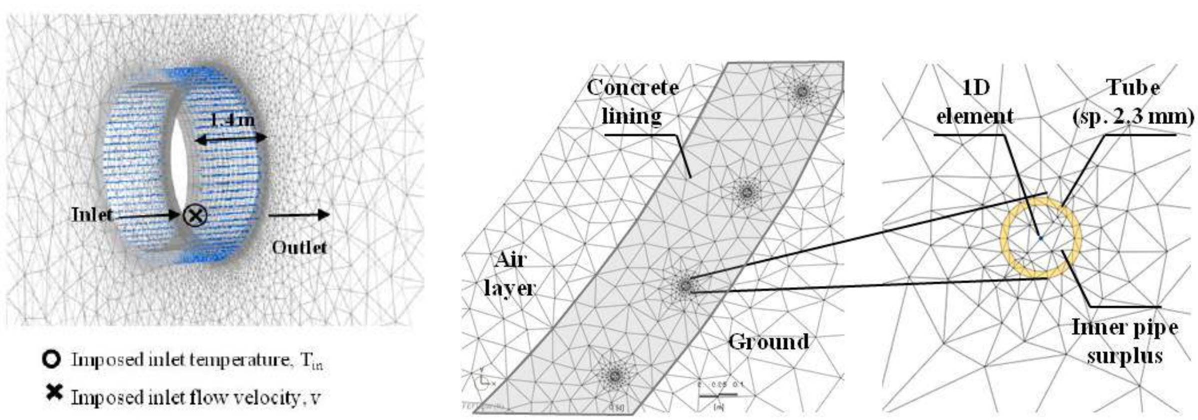


Figure 3 – Representation of the heat exchanger pipes in the tunnel lining.

The pipes will be implemented in the FEM model as shown in Figure 3.

Analyses will be conducted with reference to the specific geometry and geological, hydrogeological, geotechnical conditions identified in pgf. 2.2.2. This stage of the work is expected to be concluded by the end of July 2016.

2.2.4 Interpretation of the results and dissemination strategies

The results of modeling will allow quantifying the amount of heat in terms of W/m^2 that can be exchanged in winter and summer, for the specific conditions of the Praga district in Warsaw. The results will be extrapolated to the appropriate length of the tunnel to compute total heat exchange for the whole tunnel length that will be activated. Hypothesis of surface use of the heat extracted/injected will also be defined based on the information provided on requalification of the city areas.

A scientific paper will be prepared a the end of the work to be presented preliminarily at a national conference in Poland and to be submitted to a scientific journal, eventually within the special issue organized by the GABI CIST Action. The paper preliminary outline will comprise the following sections:

- Introduction

- Description of the case study Warsaw (description of the metro, settings, etc.)
- Geological model and geotechnical data
- Numerical model
- Conclusions

2.3 Visit to geothermal system in Jozefow

A visit to a construction site in Jozefow, near Warsaw, was organized on day 2 of the STSM. The visit allowed appreciating and discussing a real application of ground source heat pumps to implement a cooling and heating system for a small factory of cosmetics.

The machineries in the factory have the main characteristics of producing a large quantity of heat. This calls for the need to cool the working area which is associated to the building need of heating in winter and cooling in summer. The system comprises the installation of 25 borehole heat exchangers, of around 100 m depth, and four heat pumps (Figure 4) to guarantee sufficient overdesign of the system.

Figure 4 – The heat pumps and the ventilation system located in the basement of the factory.

2.4 Seminar at PGI

On day 3 of the STSM a seminar was held at PGI headquarters in Warsaw (Figure 5). The attendees were around 20 to 30 people, coming from PGI and from the technical offices of the City Council of Warsaw.

Figure 5 – Photos during the seminar at PGI.

The agenda of the seminar included:

- 10: 00 - Introduction - G. Ryzynski (PGI)
- 10:10 - Overview of GABI COST Action and introduction to Thermoactive geotructures - Marco Barla (Politecnico di Torino)
- 10:40 – Activities at the Politecnico di Torino in the field of energy tunnels - Alice Di Donna (Politecnico di Torino)
- 11:10 - Perspectives of development of shallow geothermal systems worldwide and in Poland + geothermal mapping - G. Ryzynski & W. Kozdrój (PIG/PIB)
- 11:40 - Discussion
- 12:00 - End of seminar

2.5 Geothermal mapping

2.5.1 Knowledge gained from the TransGeoTherm project

Every methodology of geothermal mapping is based on thorough analysis of geological, hydrogeological and geothermal data and involves data inquiry, detailed analysis, numerical modelling and interpretation with use of specialized software(s). Depending on the needful scale of the map and its resolution, correctness and accuracy of mapping as well as diverse data handling procedures must be chosen. In fact, some geothermal maps are rather simple, qualitative in character, and show the areas with descriptive information only, like: bad, sufficient, good for GSHP installations. More advanced, quantitative maps present spatial distribution of weighted mean values of thermal conductivity, given in pre-defined ranges (W/m·K), or heat extraction rate (W/m) down to a defined depth level(s), for example: 40, 70, 100 and 130 metres.

For the urban areas the most suitable maps of geothermal potential are those showing mean values of thermal conductivity of rocks and heat extraction rate produced in the scale of 1:10 000.

The experience and the knowledge gained by the PGI team during the Trans Geo Therm project was shared during the STSM and the visit to Wroclaw headquarters.

A crucial matter to start the mapping is to store the available data in a tailored data base, which will gather all important geological information, especially depth to the groundwater table and thermal properties of rocks and soils. Descriptions of the boreholes logs are to be appropriately coded in reference to the litho-stratigraphic units present in the investigated area and common petrographic classifications. Several geological cross-sections are to be used as a leading reference to construct 3D geological models with help of dedicated software (GOCAD, Petrel, etc.). The result is a model of subsurface soil and rock in a project area, usually down to 200 m depth, which allow to optimize the length of most of GSHP vertical heat exchangers.

At the end of the modelling procedure the raster data sets of the top, bottom and thickness of every hydrogeological unit is deduced from the 3D geological model with a grid size of 25 by 25 m. Knowing geothermal properties of the ground and the groundwater content, a specific value of geothermal conductivity is allocated to each layer of every borehole. The level of the groundwater table divides the ground into two parts: a "dry" one – positioned above the groundwater table, and the "wet" one – located below. Thereafter for every section of a borehole, belonging to a certain unit of the 3D geological model, a weighted mean value of thermal conductivity is calculated. Next, the horizontal distribution of these values within every unit is interpolated. This procedure is to be repeated at each unit. As a result of further calculations a series of maps showing the geothermal conditions for the selected depths of 40, 70, 100 and 130 m below the surface can be elaborated.

2.5.2 Developing advanced geothermal maps

A procedure to create maps for urban planning was defined during the STSM. The basic idea is to prepare multi-layered maps to superimpose the different elements. The layers considered include geology and hydrogeology, geothermal map, energy demand, types of construction, hydrodynamics, output of FE computation on thermal condition of the subsoil. In fact, the main innovation is to include in the geothermal maps the result of thermo-hydraulic numerical modeling that can assess the current situation of the thermal conditions in the subsoil based on real and existing installation and current usage. These maps may help to identify methods to evaluate the optimum location for future installations. The procedure will be applied to develop maps for the same area of the city of Warsaw considered in pgf. 2.2. Later this will be extended to a larger area and to the city of Torino.

The first step in the procedure is to define the extent of the model and the area covered by the map. When the interest is to estimate possible applications of thermal geostructures, it seems to be sufficient to investigate the first 40 m of depth only. The boundaries are to be selected based on existing rivers or equal total head lines.

Then, relevant geological and geotechnical data need to be extracted from existing PGI databases of Warsaw subsoil conditions. A 3D model is to be developed and used as input for subsequent numerical analyses. To verify compatibility in file exchange, during the STSM, a simplified model was extracted from the PGI database and imported into Feflow in order to verify the proper file formats. The tentative was successful, therefore file of the 3D geology of the area will be prepared by PGI within the next months.

3D FE numerical analysis with thermo-hydraulic coupling can then be conducted at PoliTo. The 3D numerical model will cover the whole area defined in the previous step, with the proper 3D geology. The analyses will also include the data collected from the City of Warsaw, with reference to existing GSHP systems. If monitoring data will be available, the numerical model could be validated and eventually back analysis could take place to optimize the simulation. The numerical modeling stage will require two months.

The results of numerical modeling will be exported into GIS format by considering at least two situations (summer and winter).

The last step will be to superimpose the layers to define mapping for rational planning. This will be later defined in better details. The need will arise to identify a suitable indicator to be plotted in order to have a clear image of the geothermal potential of the considered area and a suggestion for future installation planning at the urban scale.

If the procedure will demonstrate to be successful, then it could be later extended to a larger area of the city of Warsaw and also to the city of Torino.

2.5.3 Dissemination strategies

A scientific paper will be prepared at the end of the work to be submitted to a scientific journal, eventually within the special issue organized by the GABI COST Action.

Additionally, PGI and PoliTO will consider proposing a research proposal within the Central Europe call to support the larger project of extending to the cities of Warsaw and Torino (and maybe others) the methodology developed for the Praga district. Other partners could be the City Council of Warsaw and the Metropolitan City of Torino.

3 References

[1] Zhang Y, Soga K and Choudhary R. Shallow geothermal energy application with GSHPs at city scale: study on the City of Westminster. Géotechnique Letters. 2014;4(2):125–31.

[2] Zhang Y, Soga K, Choudhary R and Bains S. GSHP Application for Heating and Cooling at "City Scale" for the City of Westminster. Proceedings World Geothermal Congress. Melbourne, Australia; 2015.

[3] Barla, Marco; Di Donna, Alice; Perino, Andrea. Application of energy tunnels to an urban environment. Geothermics, 2016, vol. 61, pp. 104-113. ISSN 0375-6505

[4] Di Donna, Alice; Barla, Marco. The role of ground conditions on energy tunnels heat exchange. Environmental Geotechnics. 2016. ISSN 2051-803X

Warsaw, 14 March 2016

To the attention of Short Term Scientific Mission (STSM) Committee

COST Action 1405:
"European Network for 1 Shallow Geothermal Energy Applications in Buildings and Infrastructure" – GABI

Subject: STSM "Development of geothermal potential maps at the urban scale - Part 1" held at PGI-NRI, Warsaw, Poland, 22nd-26th February 2016

Dear STSM Evaluation Committee Members,

Within the framework of cost action TU1405 ""European Network for Shallow Geothermal Energy Applications in Buildings and Infrastructure" the PGI-NRI had a pleasure to welcome Marco Barla (Confirmed Assistant Professor) and Alice Di Donna (Research Assistant) from the DISEG-Politecnico di Torino for a one week STSM.

During the week the STSM activities were held in Warsaw and in the Regional branch of PGI-NRI in Wrocław. During Warsaw part of STSM the main attention was posed to the PGI database of engineering-boreholes (see http://atlasy.pgi.gov.pl), analyzing the available data and identifying the steps for the preliminary assessment of the potential application of energy tunnels for the Warsaw metro. One day was also devoted to disseminate GABI COST Action activities. In Wroclaw the attention was devoted to the modeling issues with 3D geological software (transfer of model data to ArcGIS software), by identifying the issues for the development of advanced geothermal maps that can constitute design tools for a proper and efficient urban planning of geothermal systems (cooperation with TransGeoTherm Project team).

The agenda was as follows:

- Monday 22/2: Discussions in PGI at Jagiellońska 76 street. + visit in PGI Soil Mechanics Laboratory.
- Tuesday 23/2: Visit to Euros Energy Factory + Discussions in PGI at Jagiellońska 76 street.
- Wednesday 24/2: Seminar at PGI Headquarters at Rakowiecka 4 (till lunch) + discussions in PGI at Jagiellońska 76 street.
- Thursday 25/2: Visit to TransGeoTherm Team in Wrocław Regional Branch of PGI.
- Friday 26/2: Summary of STSM activities and future plans.

The STSM resulted in a useful review of methodologies used by POLITO and PGI-NRI of database management, geothermal city-scale mapping and geothermal numerical modeling by FEFLOW. Also the plans for two peer reviewed papers were made.

We are confident that our collaboration will continue beyond this STSM and we already have plans for future joint research activities.

Reassuming we are very glad with our opportunity to cooperate with our guests from POLITO and we confirm the successful execution of the STSM project.

Best Regards.

ZASTĘPCA KIEROWNIKA PROGRAMU
Bezpieczna Infrastruktura i Środowisko
mgr inż. Grzegorz Ryżyński

Grzegorz Ryżyński
Deputy Head of Programme
Safe Infrastructure and Environment Program
Polish Geological Institute - National Research Institute