Activity report about field measurements in the pilot area Wałbrzych - Broumov

Deliverable D.T3.2.2 Updated database of existing and additionally measured data at the pilot areas

Template

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Content

1. Executive summary

For rocks occurring in the Polish part of the Wałbrzych - Broumov pilot area, new measurements of thermal conductivity of rocks (λ, W/m * K) were made. In 44 locations (outcrops), 69 samples of hard rocks were collected, for which 136 individual measurements of thermal conductivity of rocks in a dry state were carried out using the TCS (Thermal Conductivity Scanner) in the PIG-PIB geophysical laboratory in Warsaw.

For soils occurring in the Polish part of the Wałbrzych - Broumov pilot area, 30 TC measurements with thermal needle device was made. The collected soil samples were selected to represent the most common types of quaternary sediments.

To verify the shallow geothermal potential maps two TRT (thermal response tests) were made in order to establish the average thermal conductivity values in selected points of the Polish part of the Wałbrzych – Broumov Pilot Area. TRT measurements were made on existing borehole heat exchangers, which have been shared for the period of test by their owners. The results of in-situ TRT measurements are essential to evaluate the accuracy of the shallow geothermal potential maps delivered by GEOPLASMA CE project.

The obtained, averaged values of thermal conductivity will be used to parameterize the lithological profiles of boreholes and further preparation of maps of the potential of shallow geothermal energy for the studied area.

2. Podsumowanie

Raport zawiera opis pomiarów laboratoryjnych i badań terenowych wykonanych przez PIG-PIB w celu realizacji projektu GeoPLASMA-CE. Uzyskane w trakcie przeprowadzonych „aktywności" dane służą stanowią uzupełnienie

Dla skał występujących po polskiej części obszaru pilotażowego Wałbrzych – Broumov wykonano nowe pomiary przewodności cieplnej skał (λ, W/m*K). W 44 lokalizacjach (odkrywkach) pobrano 69 prób skał zwięzłych, dla których wykonano 136 pojedynczych pomiarów przewodności cieplnej skał w stanie suchym za pomocą urządzenia TCS (Thermal Conductivity Scanner) w laboratorium geofizycznym PIG-PIB w Warszawie.

Dla próbek gruntów spoistych I niespoistych z polskiej części obszaru pilotażowego Wałbrzych-Broumov wykonano 30 laboratoryjnych oznaczeń przewodności cieplnej przy wykorzystaniu tzw. Igły termicznej. Próbki pobierano w taki sposób, aby jak najbardziej reprezentatywnie odzwierciedlić najczęściej występujące grunty czwartorzędowe.

W celu zweryfikowania poprawności map potencjału geotermii niskotemperaturowej wykonano 2 badania TRT (test reakcji termicznej). Pozwoliły one na wyznaczenie średniej przewodności cieplnej w wybranych lokalizacjach na obszarze pilotażowym Wałbrzych-Broumov. Badania TRT wykonano na istniejących wymiennika ciepła, w istniejących inwestycjach, których właściciele wyrazili zgodę na przeprowadzenie pomiarów TRT i wykorzystanie ich wyników na potrzeby projektu GEOPLASMA CE.

Uzyskane, uśrednione wartości przewodności cieplnych zostaną wykorzystane do parametryzacji profili litologicznych otworów wiertniczych i dalszego sporządzenia map potencjału płytkiej geotermii dla badanego obszaru.

3. Introduction

3.1. Aim and scope of this report

This report describes the field measurements performed in the pilot area Wałbrzych – Broumov (Polish part), which have been performed within the frame of Activity A.T2.3.2. It aims at a full documentation of the assessed field data, which will be published at the GeoPLASMA-CE web portal (www.geoplasma-ce.eu).

This report contains:

- An overview of parameters measured in the pilot areas for creating the aimed project outputs
- A brief description of the methods applied for measurement and data processing
- A documentation of the field measurements performed in the PA area.
- A short description of the results achieved and how these results contribute to the generation of thematic outputs.

3.2. Overview of the chosen strategy for field measurements

The aimed output of new field measurements executed in the Wałbrzych-Broumov area is a dedicated lookup table with values of thermal conductivities of rocks, in wet and dry conditions, specified for all rock types recorded as layers in all boreholes (so called pet-keys). The values will be assigned for petrographically classified rocks types basing on available literature, reports and new laboratory measurements – reported in this document.

For soils occurring in the Polish part of the Wałbrzych - Broumov pilot area, 30 TC measurements with thermal needle device was made. The collected soil samples were selected to represent the most common types of quaternary sediments.

The thermal conductivity values of rocks and soils will be used to parameterize borehole logs used for construction of the 3D model and finally to obtain thematic maps of a shallow geothermal potential.

To verify the shallow geothermal potential maps two TRT (thermal response tests) were made in order to establish the average thermal conductivity values in selected points of the Polish part of the Wałbrzych – Broumov Pilot Area. TRT measurements were made on existing borehole heat exchangers, which have been shared for the period of test by their owners. The results of in-situ TRT measurements are essential to evaluate the accuracy of the shallow geothermal potential maps delivered by GEOPLASMA CE project.

4. Documentation of field measurements

4.1. Measurements of thermal conductivity of hard and soft rocks

In 2017, during field trip to the Polish part of the Walbrzych - Broumov pilot area, 44 localities (natural outcrops, quarries, railway cuttings) were visited and more than 70 hard rock samples were taken to conduct thermal conductivity (λ, W/m*K) measurements for rocks in the dry state. In a field, a photo documentation of outcrops and rocks samples was made (Fig. 1,2), as well as GPS coordinates recorded.

Fig.1. Natural outcrop of the Lower Carboniferous boulder and cobble conglomerates (locality G07).

Fig.2. Field photo of the sample G07 of the Lower Carboniferous polymictic conglomerates.

The samples were taken from various rock varieties representing most of the lithological-stratigraphic units (so-called HGK) older than the Quaternary, distinguished in the common geological map of the studied area. The locations of the collected samples chosen for further laboratory measurements are presented in Fig.3.

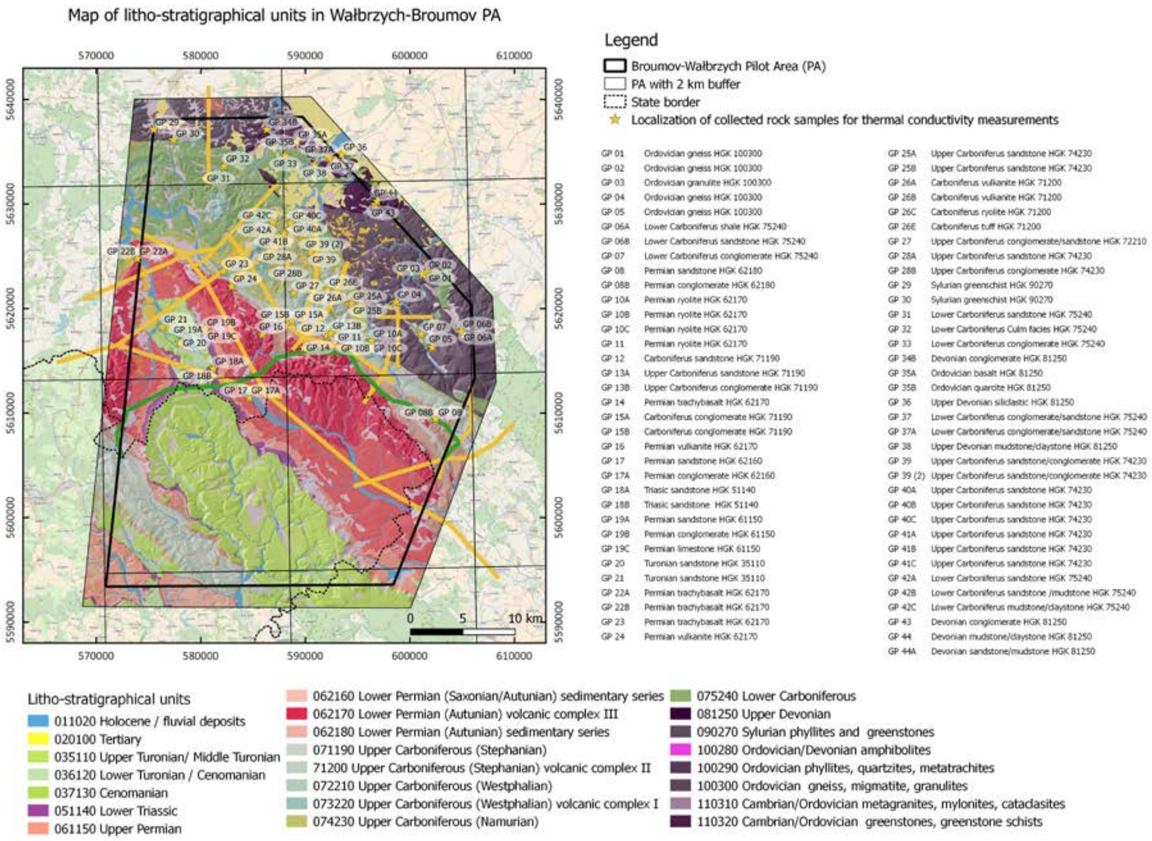

Fig.3. A unified Polish-Czech geological map of the Wałbrzych-Broumov pilot area with a marked locations, where samples of hard rocks for thermal conductivity measurements were collected.

The thermal conductivity of hard rocks was carried out in 2018 using Thermal Conductivity Scanner (TCS) in PGI-NRI geophysics laboratory in Warsaw (Fig.4).

Fig.4. Thermal Conductivity Scanner (TCS) in PGI-NRI geophysics laboratory in Warsaw.

The theoretical model of TCS (description source: http://www.geophysik-dr-rauen.de/tcscan/principle.html) is based on scanning a sample surface with a focused, mobile and continuously operated heat source in combination with infrared temperature sensors. Using a two-channel sensor in combination with advanced processing techniques allows the simultaneous measurement of thermal conductivity and thermal diffusivity as well. The method is realized in the TCS apparatus, which is an semi-automatically operating Thermal Conductivity and Thermal Diffusivity meter. The results are measurement of complete thermal properties of rock and material samples:

- thermal conductivity and thermal diffusivity,
- profiles of thermal properties along the samples,
- inhomogeneity of thermal properties,
- anisotropy: components of the thermal properties tensor for anisotropic solids.

The technical procedure of measurements using TCS include the following steps:

1. Cutting of rock samples.
2. Painting flat rock surfaces using TCS black paint
3. TCS temperature calibration.
4. Execution of measurements.
   - A) using two standards of 1.35 W/m*K
   - B) three repeated measurements along one or two runs (Fig.5)
   - C) calculation using the stable interval in the temperature curve

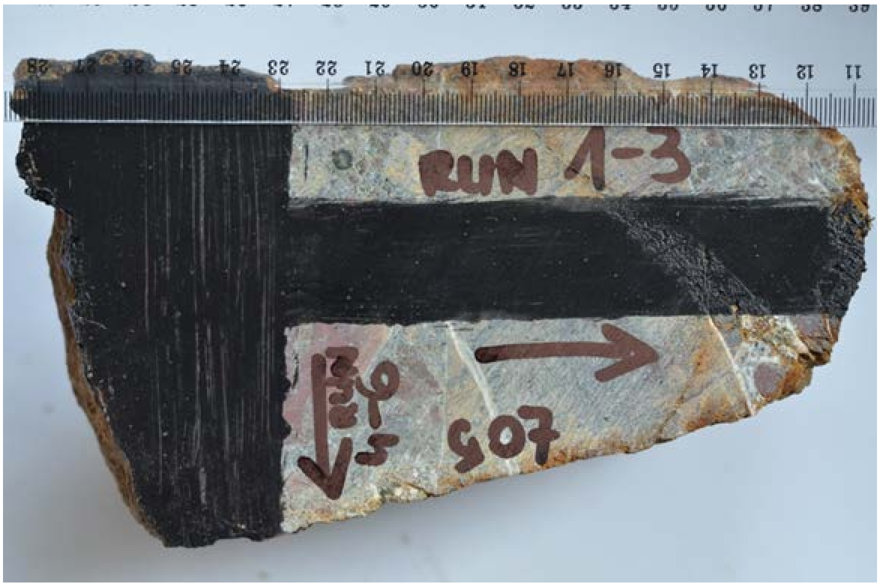

Fig.5. Photo of exemplary rock surface covered with black paint and marked TCM run traces (sample G07 – Lower Carboniferous conglomerate).

The scanning curves include two temperature curves: the temperature curve before heating (blue one) and after heating (red one). These curves can be divided into seven intervals (see example of a scanning photo, Fig.6), following from the left to the right:

1. Measurement interval before the first standard sample (only red curve)
2. Measurement interval along the first standard sample (high red, lover blue)
3. Low peak in the interval between the first standard and the proper sample
4. Measurement interval along the proper sample (different peaks are related to lithological changes – clasts, veins, weathered intervals and so on)
5. Low peak in the interval between the proper sample and the second standard sample
6. Measurement interval along the second standard sample (high red, lover blue)
7. Measurement interval after the second standard sample (low values)

Calculation is provided from the 4th interval with selection of the most stable and representing parts of both curves.

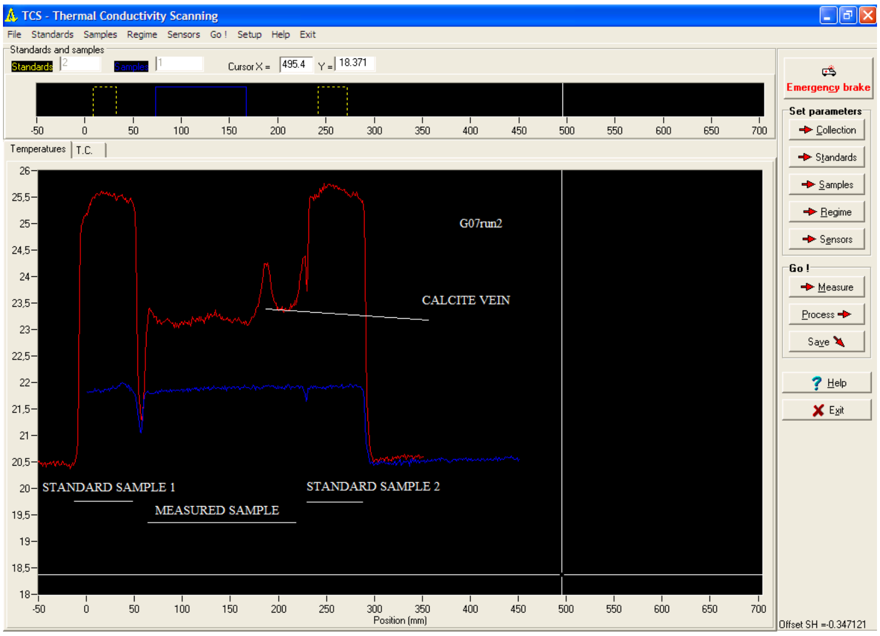

Fig.6. Example of scanning photo (screenshot from the TCS software).

For all the 69 hard rock samples collected in the Wałbrzych area a total number of 136 single measurements were executed. Final results of thermal conductivity investigation, processed by TCS software are presented in a form of a standard table (see Fig.7) and stored in the dedicated database prepared for the GeoPLASMA-CE project.

SAMPLE	RUN	TC [W/mK]			G (standard deviation)	Inhomogenity	Starting point chosen of calculation [mm]	Ending point chosen for calculation [mm]
		mean	min	max				
G06B	1	2,093	1,986	2,174	2,122	0,09	82,8	165,7
	2	2,039	1,922	2,228	2,298	0,15	84,6	164,8
	3	2,014	1,916	2,117	2,094	0,1	84,6	164,8
	mean (1-3)	2,049						
G07	1	3,685	2,089	4,456	13,472	0,642	73,9	208,5
	2	3,921	3,413	4,43	4,726	0,259	73	167,5
	3	3,669	2,146	4,309	13,394	0,59	73	209,4
	mean (1-3)	3,758						
	4	3,834	3,362	4,248	6,576	0,231	81	148,8
	5	3,869	3,409	4,392	6,391	0,254	74,8	141,6
	6	3,801	3,266	4,298	6,07	0,272	74,8	143,4
	mean (4-6)	3,835						
G10A	1	2,830	2,621	3,034	2,583	0,146	78,3	183,5
	2	2,867	2,679	3,073	2,567	0,138	86,4	192,4
	3	2,813	2,676	2,993	2,674	0,113	102,4	159,4
	mean (1-3)	2,837						
	4	2,917	2,765	3,096	2,817	0,113	70,3	112,2
	5	2,878	2,655	3,086	3,458	0,15	70,3	115,8
	6	2,898	2,732	3,067	2,419	0,115	70,3	109,5
	mean (4-6)	2,898						

Table 1. Example of final table with thermal conductivity results for three samples produced by TCS software (sample G07 is the same as shown in Fig.1, 2 and 5). Row with mean values calculated for all single runs (numbers in red) were added later by the author of this report.

Data files abbreviation: SAMPLE – name of the sample, RUN – 1,2,3 runs along the long section; 4,5,6 runs along the short perpendicular section, TC – thermal conductivity [W/m*K], mean – mean values in the measured interval, min – minimal value in the measured interval, max - maximal value in the measured interval, G – standard deviation, I – inhomogeneity = (max-min)/mean, Starting and ending points – interval in mm used for calculation (see the scale bar in the example scanning photo)

As a final result of the conducted thermal conductivity measurements using TCS is a table with list of several rock types occurring in the Wałbrzych area with a given, average "λ" values for rocks in dry conditions (Fig.8,9). These values will be used for parameterization of the borehole lithological profiles in the whole Wałbrzych-Broumov area.

Location	Litho-stratigra-phic unit [HGK]	Sample	Lithology	Average λ value [W/m * K]
Glinno	75240	G06B	sandstone	2,049
		G06A	slate	1,83
Walim-wzg.Wawel	75240	G07	conglomerate	3,8
Głuszyca	62170	G10A	dark gray rhyolite	2,89
		G10B	rhyolite	
		G10C	pink rhyolite	
Golińsk	62160	G17	sandstone	3,14
		G17A	conglomerate	1,76
Różana (Czartoskie Skały)	51140	G18B	red sandstone	1,887
		G18A	light yellow sandstone	2,11
Czadrów - nieczynny kamieniołom melafiru	62170	G22A	trachybasalt with amygdaloidal structure	1,97
		G22B	trachybasalt with aphanite structure	
Wałbrzych Podgórze - stary kamieniołom	71200	G26A	vulcanite with aphanite structure	2,16
		G26B	vulcanite with amygdaloidal structure	
		G26C	rhyolite	
		G26E	weathered tuff	
Zagórze Śląskie - zapora	100300	GP02	gneiss	3
Zagórze Śląskie - zapora	100300	GP01	gneiss	2,46
Walim + sztolnia	100300	G05	gneiss	3,06
Jedlina Zdrój	74230	G25B	pebble sandstone	2,76
		G25A	fine-grained sandstone	2,4
Kondratów	75240	G42A	coarse-grained sandstone	2,87
		G42B	fine-grained sandstone / mudstone	1,61
		G42C	mudstone / claystone	2,22
Rybnica Mała	71190	G13A	sandstone	3,06
		G13B	conglomerate	3,49
Unisław Śląski	71190	G15A	fine- grained conglomerate	2,94
		G15B	coarse-grained conglomerate	4,22
Krzeszówek - nieczynna kopalnia piasku	35110	G21	sandstone	1,65
Jugowice	100300	GP04	gneiss	2,48
Szczawno Zdrój (stary kamieniołom)	74230	G40A	coarse-grained sandstone with pebbles	3,61
		G40B	medium-grained sandstone	2,63
		G40C	fine-grained sandstone	3,26
Biały Kamień	74230	G41A	medium-grained sandstone	2,61
		G41B	coarse-grained sandstone	2,43
		G41C	pebble sandstone	2,68
Zagórze ŚL - Fregata	100300	GP03	granulite	2,76
Kochanów	61150	G19A	sandstone	3,59
		G19B	conglomerate	2,12
		G19C	limestone	3,67
Gorzeszów (close to Głazy Krasnoludków)	35110	G20	sandstone	1,94
Nowe Bogaczowice	75240	G31	sandstone	2,48
Chwaliszów	81250	G34B	conglomerate	2,59
Witoszów	81250	G44	mudstone / claystone	2,76
		G44A	sandstone / mudstone	2,8
Rybnica - kamieniołom melafiru	62170	G14	trachybasalt	2,03
Boguszów-Gorce	62170	G23	trachybasalt	2,16
Rybnica Mała	62170	G11	rhyolite	2,49
Pełcznica - 1	75240	G37A	pebble sandstone	2,89
Pełcznica -2		G37		
Ludwikowice / Świerki Dolne	62180	G08A	sandstone	3,53
		G08B	conglomerate	3,85
Świebodzice	81250	G36	siliclastic rock	2,85
Unisław Śląski (parking)	62170	G16	vulcanite	1,81
Wałbrzych - Glinik	72210	G27	sandstone	3,37
Stare Bogaczowice	75240	G32	sandstone	2,52
Wałbrzych - Sobięcin	74230	G28A	sandstone	2,64
		G28B	conglomerate	2,64
Nagórnik	90270	G30	greenschist	2,29
Cieszów	90270	G35A	greenschist	2,43
		G35B	quartzite	2,9
Lesieniec Stary	62170	G24	volcanites	1,81
Domanów	90270	G29	greenschist	2,61
Góra Czyżowa - Krucza	75240	G33	breccia - polymictic conglomerate	2,71
Pełcznica	81250	G38	mudstone and claystone	2,47
Wałbrzych - Parkowa Góra	74230	G39	pebble sandstone	2,53
Głuszyca Górna - nieczynny kamieniołom	62170	G09	trachybasalt	1,86
Ludwikowice	71190	G12	sandstone	3,66
Witoszów	81250	G43	sandstone	2,99

Table 2. Final table with calculated average values of thermal conductivity for hard rocks in the Wałbrzych area.

Fig.8. Examples of rocks from the Wałbrzych area with average values of thermal conductivity (in W/m*K). Note two values with significant difference obtained for the gneiss G02 sample, due to measurements done along or perpendicular to the metamorphic foliation.

4.2. Measurements of the thermal parameters of cohesive and non-cohesive soil

In 2018, during field trip to the Polish part of the Walbrzych - Broumov pilot area, 5 localities (natural outcrops, shallow drilled boreholes) were visited and 10 cohesive and non-cohesive soil samples were taken to conduct thermal conductivity (λ, W/m*K) measurements for soil in the dry and saturated state. In a field GPS coordinates were recorded.

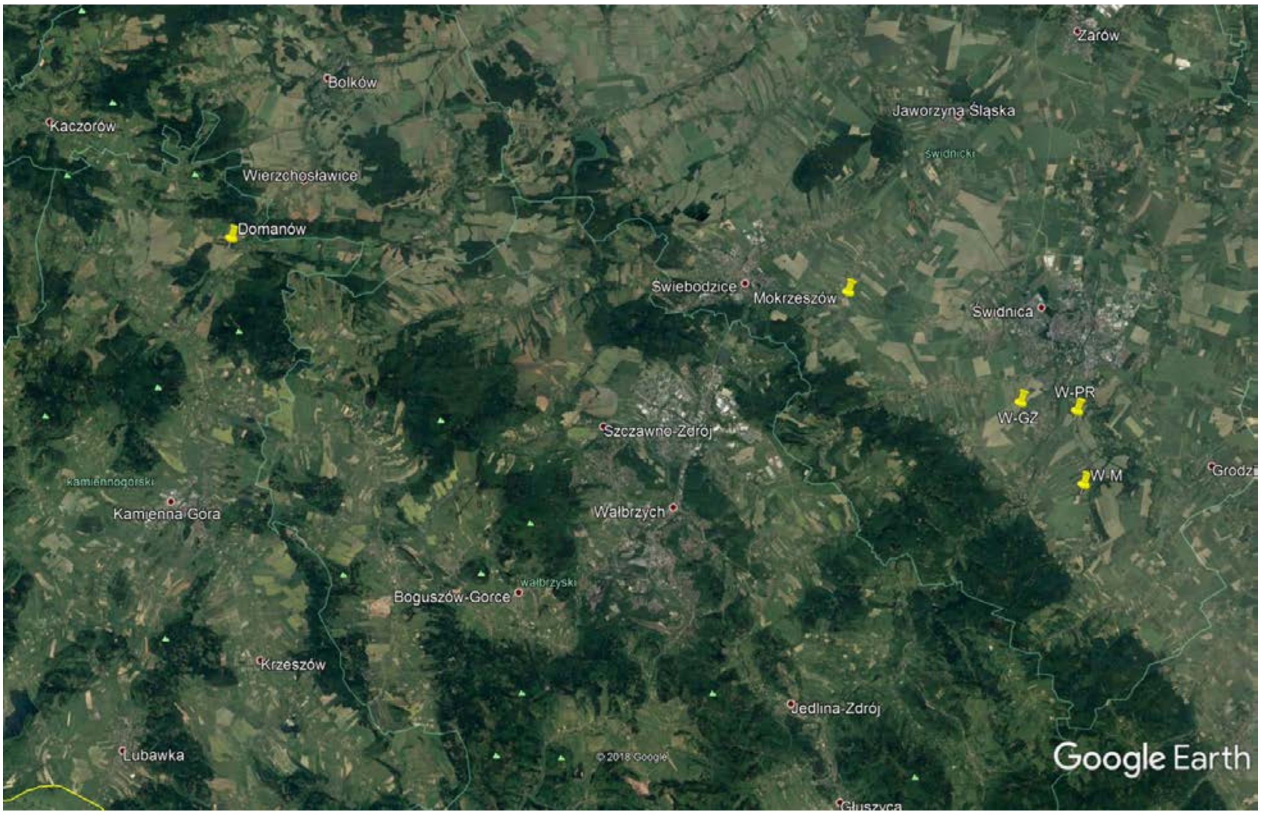

Fig. 9. Satellite image of the Wałbrzych area with a marked locations, where samples of cohesive and non-cohesive soils for thermal conductivity measurements were collected.

The samples were taken from quaternary soil types commonly found in the pilot area. The locations of the collected samples chosen for further laboratory measurements are presented in Fig.9.

Object Name	Object Type	Sample name	Lithology
Domanów	Outcrop	PR01a	medium-grained sand with gravel
Domanów	Outcrop	PR01b	fine-grained sand with gravel
Mokrzeszów	Outcrop	PR02a	fine-grained sand with gravel
Mokrzeszów	Outcrop	PR02b	sandy gravel
W-GZ	Borehole	PR03a	saprolite
W-GZ	Borehole	PR03b	saprolite
W-GZ	Borehole	PR03c	saprolite
W-PR	Borehole	PR04a	silty fine-grained sand with $CaCO_3$
W-PR	Borehole	PR04b	loamy sand

W-M	Borehole	PR05	sandy silt

Table 3. List of cohesive and non-cohesive soil samples.

The thermal conductivity of cohesive and non-cohesive soils was carried out in 2018 using KD2Pro in PGI-NRI Soil and Rock Testing Centre in Warsaw.

Laboratory equipment

The KD2 Pro is a handheld device used to measure thermal properties. The base KD-2 Pro package consists of a handheld controller and one sensor kit of your choice. There are several sensors available for purchase that operators can insert into almost any material. The single needle sensors measure thermal conductivity and resistivity; while the dual-needle sensor measures thermal conductivity, resistivity, volumetric specific heat capacity and diffusivity.

Fig. 10. PGI-NRI KD2 Pro thermal conductivity analyzer.

Sample preparation and performing of the analysis

Depending on the sample quality class the process of sample preparation differs. Three thermal conductivity measurements are performed on each sample. This allows the correct identification of results. The consecutive results should not differ more than 10%.

In order to characterize physical properties of examined soil and to identify their possible influence on acquired results of thermal conductivity coefficient authors recommend performing supplementary analyses:

- determination of water content,

- determination of particle size distribution,

- determination of bulk density for cohesive soils and relative density for non-cohesive soils,

- determination of liquid and plastic limits,

We recommend that those test were performed according to international geotechnical standards, for example ISO 17892 Geotechnical investigation and testing - Laboratory testing of soil (Parts 1 to 12).

Sample preparation

The minimum mass required to perform the analysis according to proposed procedure should stand 2000 g and 1500 g minimum for cohesive and non-cohesive soil respectively. Cohesive soils should be examined in two conditions: wet (in their natural moisture content) and after drying the soil to a constant mass. Non-cohesive soils should be tested in two extreme cases: dried to constant mass and fully saturated with water.

All cohesive soil samples should always be to properly packed directly after sampling and store in the refrigerator to prevent the loss of water content.

Prepared samples should be placed in the examination room at least 24 hours before starting the test for the sample to reach equilibrium with the room temperature. It is recommended to keep the room temperature as stable as it is possible. There should be no intensive air flows or humidity changes during the test as it is proven that this kind of fluctuations in environmental conditions can affect the results. During the examination wet samples should be protected from changes in moisture content by covering in stretch wrap. Temperature and humidity level should be registered during the test.

Preparation of cohesive soil samples

A. samples with natural water content

To prepare cohesive soils samples cylindrical mold made of stainless steel has been used. Small lumps of soil were placed inside the form with layers and firmed to desired density with a metal rammer. The soil should be rammed to the point in which it will reach bulk density specific for the soil of the same water content in situ. When the soil sample reaches the form level it was cut with a straight edge knife. Cutting should be done from the sample center towards rims. Molded sample should be removed from the form without intruding its previously molded structure. The test can be also conducted directly in the sample container, which can be particularly useful in case of the soils of very soft consistency (Fig. 11.).

B. dry samples

The sample should be placed in evaporating dish and dried to a constant mass in the laboratory drying oven for 72 hours minimum. The drying oven should be capable of maintaining a temperature of 105 °C ± 5 °C (ISO 17892-4:2004). When the sample is dry drill a hole longwise the sample so that inserting thermal needle is possible. The drill should reach both sides of the sample. The drill should have a diameter as close as it's possible to the diameter of used needle probe (2,4 mm for TR-1 probe). Once drilled the hole should be cleaned with the dust and filled with thermal grease to ensure good thermal contact between the sensor and the tested soil.

Non-cohesive soils

A. dry specimen

The sand should be dried to a constant mass in the laboratory drying oven for at least 12 hours. The drying oven should be capable of maintaining a temperature of 105 °C ± 5 °C (ISO 17892-4:2004). The specimen should be gently grind in a mortar to get rid of the aggregates that might have formed in the drying process. We recommend using rubber-headed pestle to grind the soil to avoid crushing the grains. The soil should be placed in the cylinder with a funnel.

B. fully saturated with water

Water should be poured to the cylinder to the 1/5 of its total volume. Soil should be placed in the cylinder using a funnel. Water should be gradually added during filling in order to keep the specimen fully saturated. All sample volume should stay under the water level. Cut the specimen to the level of the upper rim of the cylinder and densify the soil desired bulk density. Determine the water content.

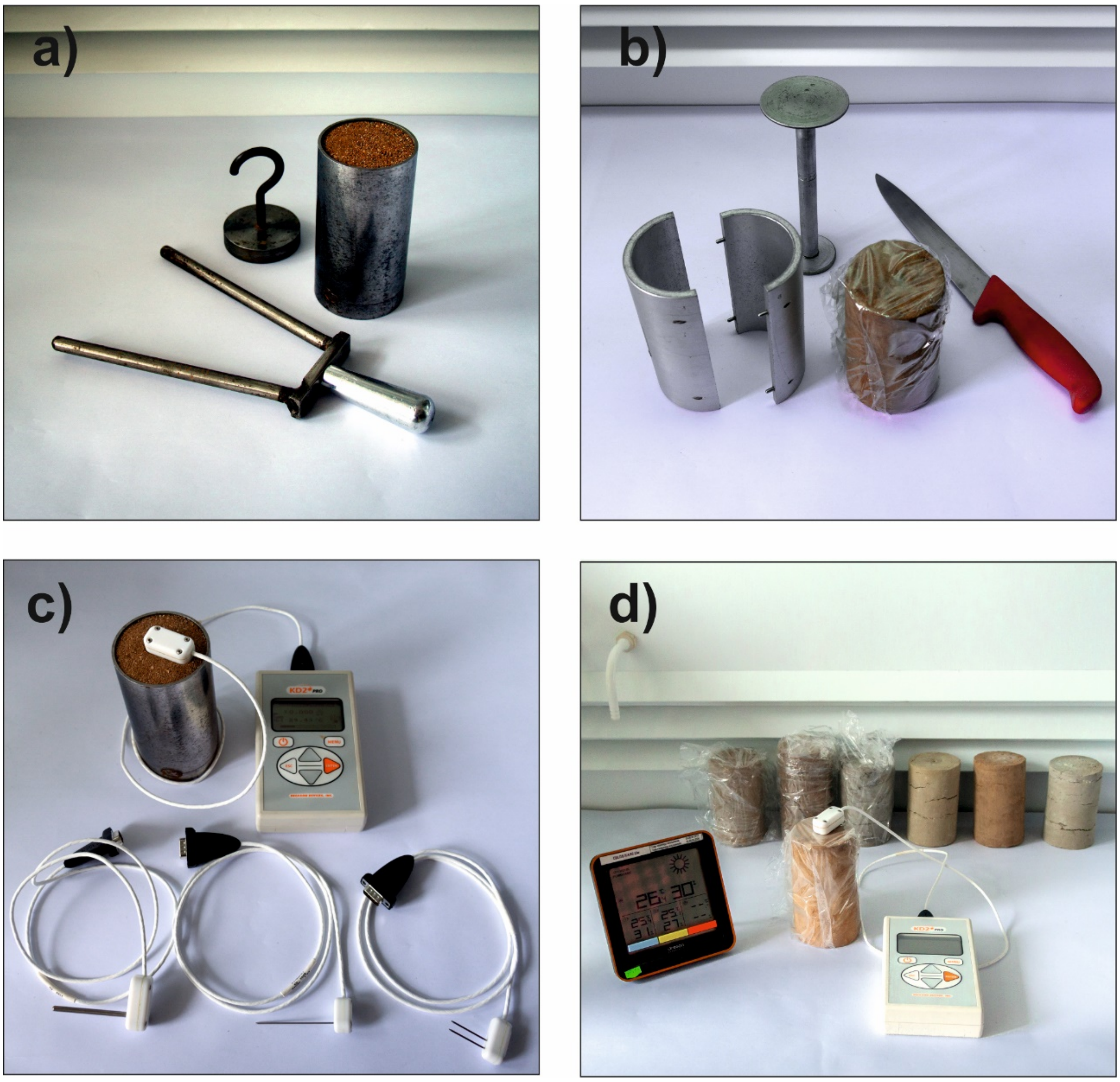

Fig. 11. Samples prepared for analysis.

Thermal conductivity test procedure

Depending on the physical properties of tested materials, different type of thermal probe should be chosen. For the purpose of testing soft soils, TR-1 sensor is recommended. Before starting the measurements it is considered a good practice to verify sensor performance by measuring thermal conductivity of the certified reference material. If the result of the verification is valid, test procedure can be conducted on soils samples. The needle sensor should be placed carefully in the center of the sample. A minimum of 2 cm of material should be allowed parallel to the sensor in all directions. The sensor should be inserted all the way into the measured soil. Once it is placed inside the specimen, the sensor position should not be changed in order to provide best possible thermal contact between the sensors and the measured medium. To allow samples and sensors to come to temperature equilibrium, it is advised to wait 15 minutes time before starting the measurement.

Three measurements should be performed on each sample. Probe’s location should not be changed during or between the readings. Fifteen minute pause between measurements is optimal for the sensor-sample temperature to equilibrate.

As it was mentioned before each sample was tested three times, which gives a total of 30 determinations of thermal properties.

4.3. Thermal response test

In order to avoid underestimation or overestimation of the ability of the soil to transfer heat, especially in the case of the design of a ground source heat exchanger for the supply of large objects, a thermal response test (TRT) is performed. TRT is a test "In-situ" in the pilot borehole - the first in the series to be drilled in the planned geothermal investment. The thermal conductivity obtained by the TRT is very reliable since it is calculated under the actual operating conditions of the heat exchanger.

The TRT method involves the injection of heat energy of known value into the borehole and measurement on the surface the energy supply temperature plus the temperature of the returning heat medium (in the GERT). The heat exchanging fluid is circulating in the closed tube and the heat injection, in the form of fluid heating, is carried out throughout the test. The measured coefficient of thermal conductivity is the effective value, i.e. taking into account the whole soil/rock-water system as well as the filling material (grout). The correct investigation result depends on properly long time of the test. Time is needed to bring the temperature changes not only within the fill material but also in surrounding rocks and soils. The minimum recommended duration of the test is 48 hours.

The GERT (Geothermal Response Test) kit manufactured by the German company UBeG was used to determine the thermal conductivity of the soil (Fig. 13).

4.3.1. Site description.

Tests were performed in Dobromierz and Boguszów Gorce, Poland in newly drilled borehole heat exchangers, with depths respectively 92 and 100 m, both single-U borehole heat exchanger (BHE), with HDPE pipes, external diameter 32 mm. BHE is a part of a ground source of a shallow geothermal system in a newly buildings. The borehole and sites were available for TRT test by local private investors.

Performed TRT and temperature profiles tests carried out within the framework of the GeoPLASMA-CE project are aimed at exchanging experience in the scope of the methodology of researching efficiency of borehole heat exchangers between specialists from PGI-NRI and GeoPLASMA-CE partners. Cooperation in the area of standardization of methodology will concern the comparison of obtained results and the methods used for interpretation of TRT measurement.

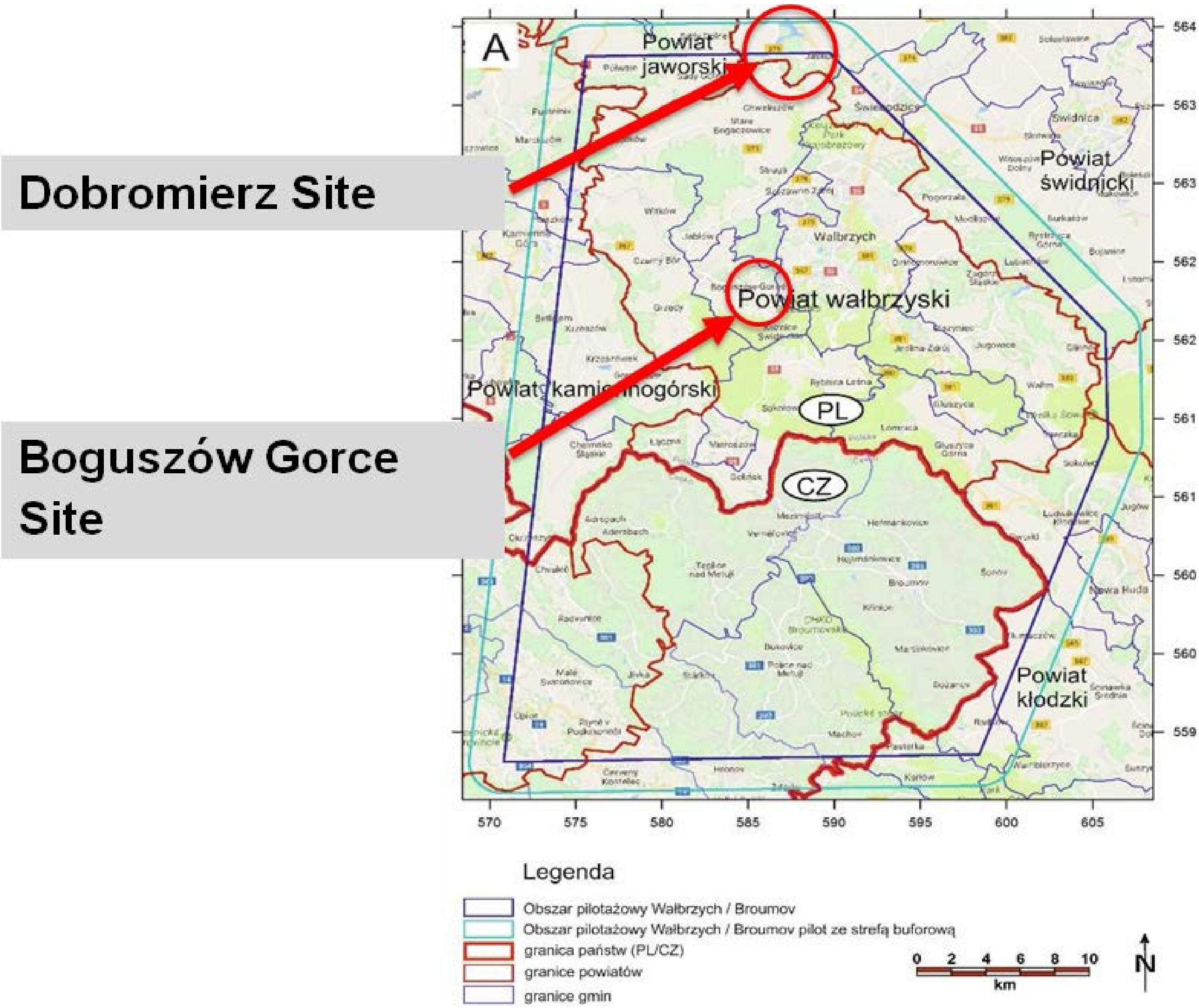

Fig. 12. TRT investigation sites location.

4.3.2. The scope of the research

Measurements were taken by one TRT probe (Model GeRT produced by UBEG) (Fig. 13.)

- Date of commencement of TRT measurements
    - Wałbrzych Dobromierz 23.08.2018
    - Wałbrzych Boguszów-Gorce 31.07.2018
- End of the TRT measurements

Fig. 13. PGI-NRI TRT probe (Model GeRT produced by UBEG).

4.3.3. Temperature logging

Logging was done with a meter TC Hydrotechnik type 110, measuring range from -15°C to 80°C. Logging was done prior to the start of the TRT to obtain a graph of the natural temperature distribution in the ground source for the tested borehole. Details of the tested borehole are given in Table 4.

A measuring interval of 2.0 m was applied to the depth of 20.0 m. Below, measurements were taken at 5.0 m intervals.

Logging results are shown in the graphs (Fig. 14.).

The average values of natural soil temperature for the entire profile are given in Table 4. The thermal logging was made to a depth of 96 meters.

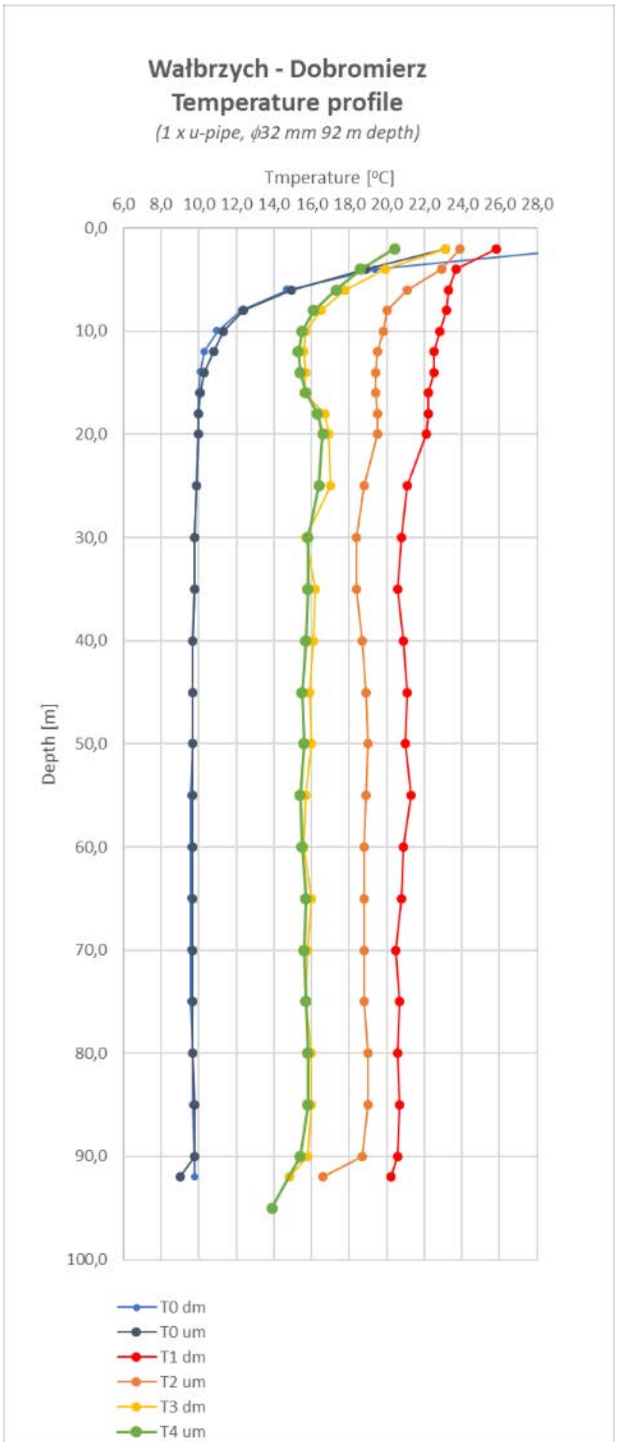

Fig. 14. Temperature logging profile, Dobromierz site.

4.3.4. TRT results

Within the framework of the survey, a thermal reaction test (TRT) were performed for a 92 and 100 m borehole heat exchangers - a single "U" shape tube design with a diameter of 32 mm. The results of tests are presented on Table 4. and attached figures (15, 16, 17, 18, 19, 20).

Localisation	Start of TRT test	TRT duration	Depth	BHE construction	λ [W/m x K]	average t_0 (temperature profile) [°C]	t_0 (TRT test) [°C]
Wałbrzych Dobromierz	23.08.2018	43	92	single U	2,60	11,3	11,3
Wałbrzych Boguszów-Gorce	31.07.2018	49	100	single U	2,85	no data	9,9

Table 4. Thermal response test results from Dobromierz and Boguszów-Gorce sites.

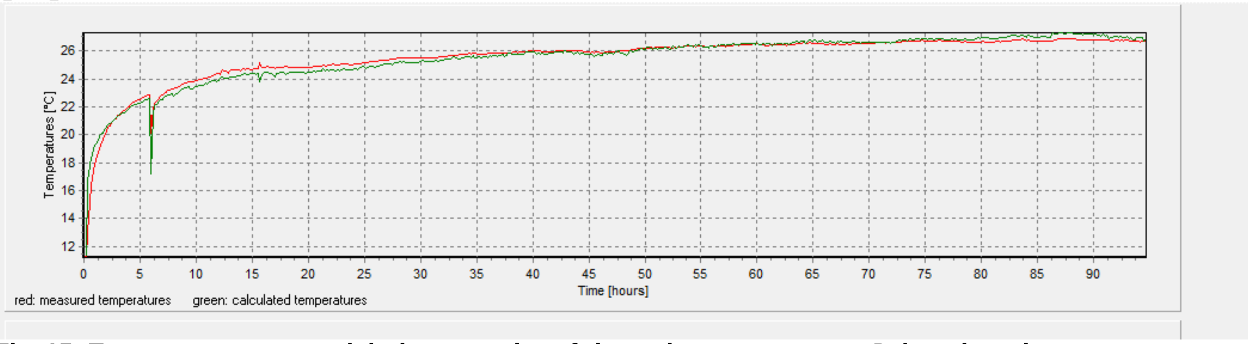

Fig. 15. Temperature measured during operation of thermal response test on Dobromierz site.

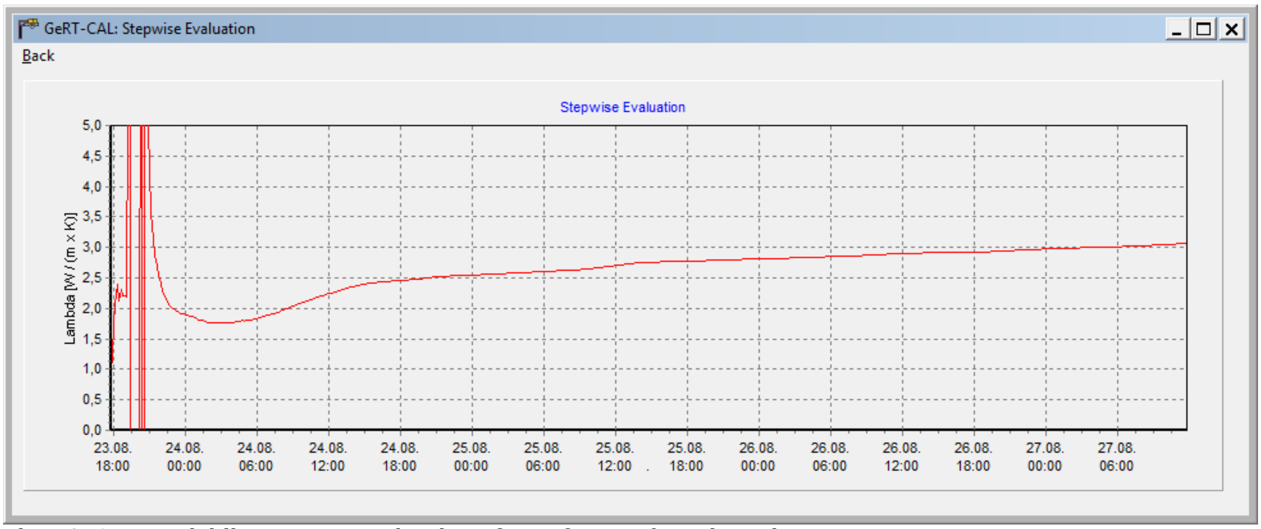

Fig. 16. Sequential line-source evaluation of TRT from Dobromierz site.

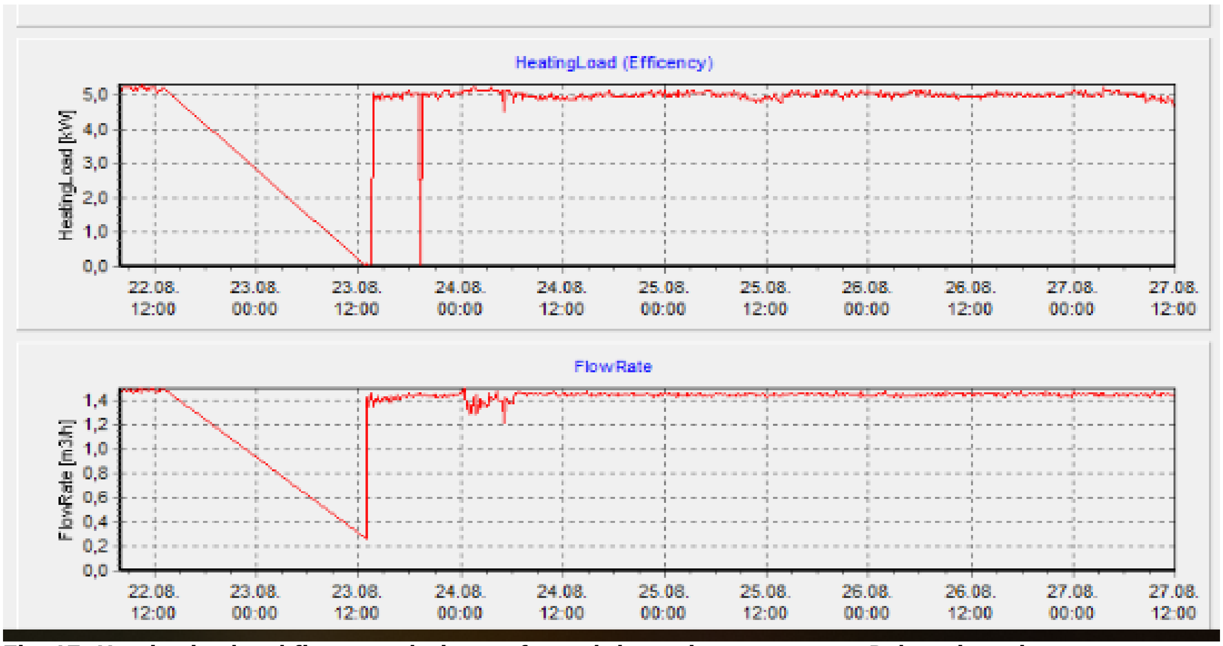

Fig. 17. Heating load and flow rate during performed thermal response test. Dobromierz site.

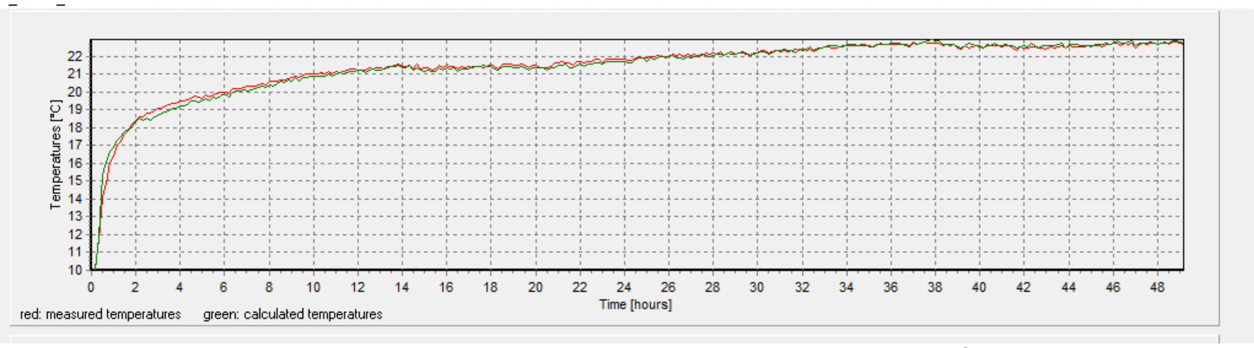

Fig. 18. Temperature measured during operation of thermal response test on Boguszów-Gorce site.

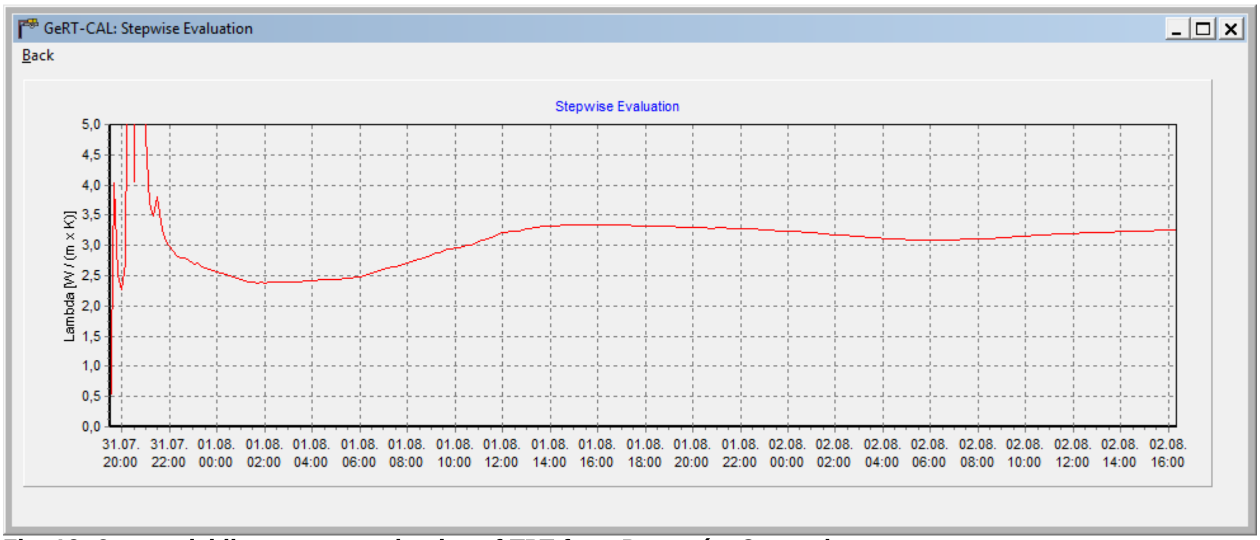

Fig. 19. Sequential line-source evaluation of TRT from Boguszów-Gorce site.

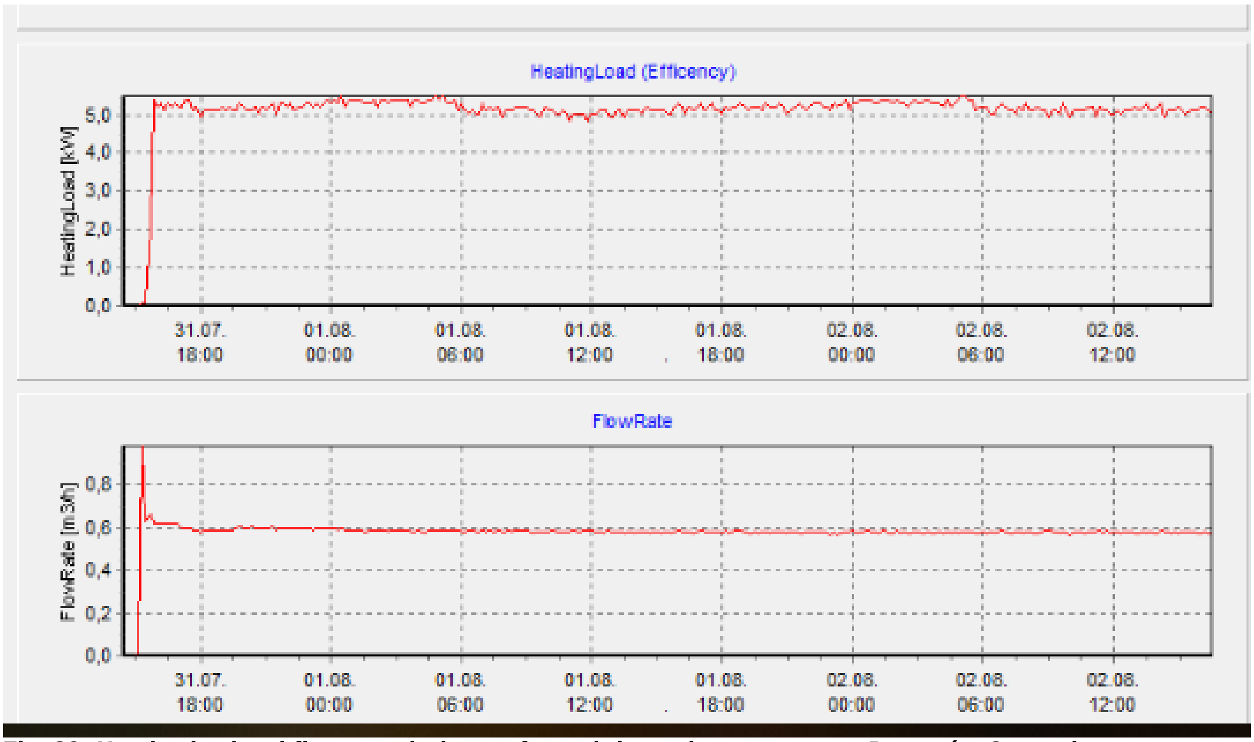

Fig. 20. Heating load and flow rate during performed thermal response test. Boguszów-Gorce site.

5. Data processing

5.1. Transfer of field data to the joint databases

In a last step, the processed field data have been summarized and documented for a transferring them to the following databases:

- Metadata database of relevant input data (D.T3.1.2) for a full documentation of the achieved datasets.
- Key value database for publishing the achieved results (D.T3.2.1).

The metadata description of the produced datasets follows the joint concept on geodata management, which is described in Deliverable D.T2.3.1.

The summarized of datasets, shown in the key value database are characterized by:

- Number of individual measurements (≥1)
- Presentation of either alpha-numeric (e.g. <0,01 mg/l) or numeric values
- The dataset is characterized by a single or mean-, minimum- and maximum value as well as by the standard deviation (in case of at least 3 single datum points).
- All presented values are allocated to a measurements period, a surface location and a depth interval of the measurements.

6. Results

A total of 432 measurements of thermal conductivity of soils and rocks were made - 402 for solid rocks using thermal conductivity scanner and 30 for cohesive and non-cohesive soils using the KD2 Pro thermal needle probe.
In addition, 2 thermal response test for Dobromierz and Boguszów-Gorce sites and 6 temperature profiles of the Dobromierz site were made.
The results of measurements were included in the GeoPLASMA-CE project's database.

7. Summary and conlusions

In the case of solid rocks, the results unambiguously correlate that the highest TC values reach conglomerates rich in homogeneous quartz grains. The lowest values are achieved by dry sandstones, shales and mudstones. In the case of quaternary cohesive and non-cohesive soils, the water content is crucial.

In the case of thermal response test, the time of measurement plays a key role. Any downtime during the construction of ground source heat exchanger involves additional costs. It is recommended to conduct a TRT before the final completion of the investment in order to correct the planned number of boreholes, which significantly affect the final reduction of GSHE installation costs.

The results of thermal conductivity measurements and thermal response test therefore will be used to create 3D models and maps of borehole heat exchangers potential for the purposes of GeoPLASMA-CE project.