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EVALUATION OF CLIMATE CONDITIONS ON ROCK MASS ENERGY BALANCE IN THE VŠB-TU OSTRAVA RESEARCH POLYGONS

OCENA WPŁYWU WARUNKÓW KLIMATYCZNYCH NA BILANS ENERGETYCZNY GÓROTWORU NA POLIGONACH BADAWCZYCH WYŻSZEJ SZKOŁY GÓRNICZEJ W OSTRAWIE

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Abstract. VŠB – Technical University of Ostrava (VŠB-TU Ostrava) has unique conditions for analysing temperature changes in the rock mass while borehole heat exchangers have been operational for a long time. The Auditory building is heated with a system of heat pumps (borehole heat exchangers). It is one of the largest such objects in the Czech Republic. The heat of the rock mass is provided by a system of technological boreholes. The research boreholes are used for monitoring temperature changes in the rock mass while using the Auditory's heating system. The system for monitoring boreholes within the area of technological borehole activity is called Large Research Polygon (LRP). Apart from LRP, the university also possesses another research polygon – Small Research Polygon (SRP) located at a distance from the LRP near the Energy Research Centre (ERC). All boreholes performed within both research fields are equipped with sensors monitoring the temperature changes while the Auditory building is being heated (thermal energy is recovered from the rock mass in winter) or cooled (thermal energy is transmitted to the rock mass in summer). The main objective of the research carried out in both research fields is checking the functionality and efficiency of the entire system. Certain aspects of thermal energy recuperation from the rock mass are described. The paper is closed with the results of monitoring and calculation of temperature in the surface layers to about 20 m of depth.

Key words: research polygon, boreholes for heat pumps, heat exchange in rock mass, heat recovery and accumulation in rock mass.

Abstrakt. Wyższa Szkoła Górnicza w Ostrawie ma niepowtarzalną możliwość badania zmian temperatury w górotworze podczas eksploatacji pomp ciepła. Budynek audytorium jest ogrzewany właśnie za pomocą systemu pomp ciepła. Obiekt ten jest największym w Republice Czeskiej z punktu widzenia liczby otworów (110) i mocy pomp ciepla (700 kW). Na obszarze zestawu otworów głębinowych w okolicy audytorium znajdują się otwory monitoringowe wyposażone w czujniki temperatury, które umożliwiają zapis zmiany temperatury górotworu podczas działania systemu pomp ciepła w otworach wiertniczych. Instalacja ta jest nazywana Wielkim Poligonem Badawczym, a jej głównym celem jest badanie zmian stanu cieplnego górotworu podczas eksploatacji tak dużego systemu. Druga instalacja jest nazywana Małym Poligonem Badawczym, który jest umieszczony w pobliżu audytorium. Składa się z dwóch pomp ciepła oraz pięciu otworów monitoringowych umieszczonych w okolicy otworów wykonanych pod pompy ciepła. Wszystkie otwory zostały wyposażone w czujniki temperatury (analogicznie jak na poligonie Wielkim). Mały poligon jest wykorzystywany do monitorowania zmian temperatury w górotworze podczas ogrzewania (magazynowania nadmiaru ciepła z klimatyzacji podczas lata) oraz chłodzenia (odbioru ciepła z górotworu za pomocą pompy ciepła w zimie). Głównym celem badań jest weryfikacja parametrów pracy tego systemu. Autorzy niniejszego artykułu posiadają bogate doświadczenia w budowie i eksploatacji poligonów badawczych eksploatowanych na VŠB. W artykule zaprezentowano możliwości działania obu poligonów badawczych oraz zachowanie górotworu na głębokości 20 m w otworze monitoringowym, na który oddziaływały zewnętrzne warunki klimatyczne.

Słowa kluczowe: poligon badawczy, otwory pod pompy ciepła, wymiana ciepła w górotworze, pozyskiwanie i magazynowanie ciepła w górotworze.

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INTRODUCTION

The research fields of the VŠB – Technical University of Ostrava (VŠB-TU Ostrava) were constructed within the research project titled "Analysis of rock mass temperature changes in the heating/cooling system based on heat pumps in the area of New Auditory building and Information Technology Centre of VŠB-TU Ostrava".

The objective of this on-going project is to evaluate the influence of endogenic and exogenic energy sources on the heat balance of the rock mass and its build-up in time for low-energy heating/cooling system. The project is also aimed at determining changes in the heat flow structure in the study area in a nonhomogeneous geologic setting (Miocene, Carboniferous) within the technological boreholes consuming heat energy of the rock mass.

Two experimental research fields were designed and gradually implemented to determine the share of endogenic and exogenic energy sources in general long-term heat balance of the rock mass and to prove the correctness of operation of the designed monitoring system. Two research fields were used for monitoring the rock mass behaviour within the technological boreholes area while recovering and accumulating energy from the rock mass, *i.e.* Large Research Polygon (LRP) and Small Research Polygon (SRP) (Bujok *et al.*, 2010)

LRP, mainly used for monitoring the recovery of large amounts of heat from the rock mass, is located in the vicinity of the Auditorium.

SRP used for analysing rock mass behaviour in the technological boreholes site (localized close to some small objects) while heating, accumulating and storing the heat, and regenerating energy in the rock mass in a function of time. SRP is located in the neighbourhood of the Energy Research Centre. Both Research Polygons are localized at the university campus in Ostrava – Poruba (Fig. 1)

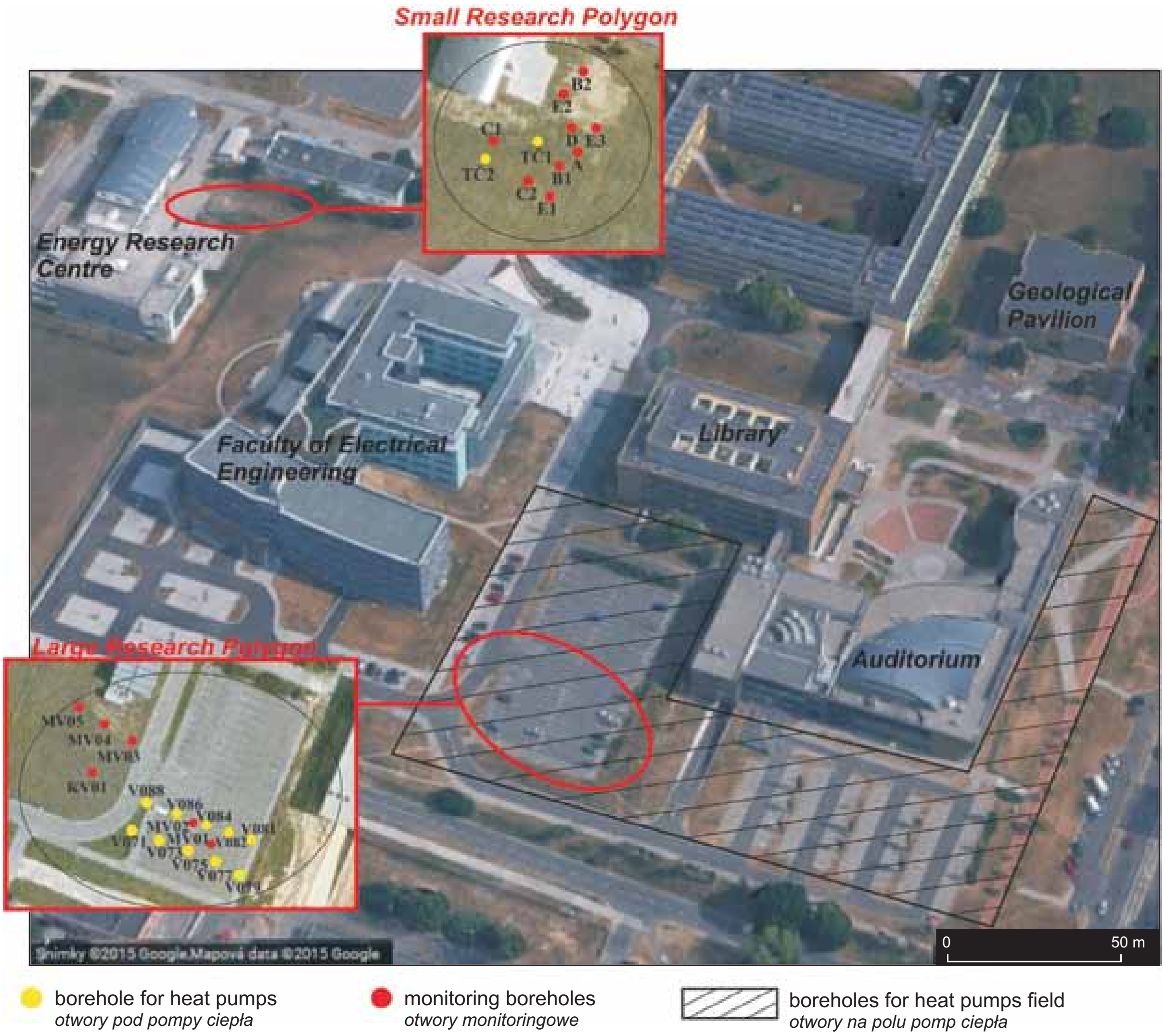


Fig. 1. Large and Small Research Polygons at the campus of VŠB – Technical University of Ostrava

Wielki i Mały Poligon Badawczy na terenie kampusu Wyższej Szkoły Górniczej w Ostrawie

RESEARCH IN THE LARGE RESEARCH POLYGON

In 2006 the first objects heated with heat pumps were implemented in the Czech Republic. The first and largest such object was the New Auditory building owned by the university. The building occupied an area of 3,197 m^2, and the space heated by borehole heat exchangers totalled to 9,234 m^2.

The system consists of 10 Swedish heat pumps IVT Greenline D70. The installed power was 700 kW. The entire system required 110 boreholes to be drilled to a depth of ca. 140 m each, giving the total of 15,400 m. The boreholes were performed under the parking lots near the Auditorium and close to the Library of the university campus (Klempa *et al*., 2011; Vojčiňák *et al*., 2011). Geological section of this site is presented in Table 1.

The project setoff was preceded by analyses of geological and energy conditions in the drilling area, carried out together with Lund University, Sweden. For this reason, two pilot boreholes were drilled and Thermal Response Tests were performed (Hellström, 2005).

Table 1

Geological section of the site of interest

Profil geologiczny terenu badań

Interval [m]	Rock type	Stratigraphy
0.00–14.00	yellow clay	Quaternary
14.00–16.00	sand	Quaternary
16.00–25.00	grey clay	Quaternary
25.00–28.00	gravel with sand	Quaternary
28.00–105.00	green clay	Miocene
105.00–106.00	grey siltstone	Carboniferous
106.00–140.00	sage-green siltstone	Carboniferous

REALIZATION OF THE LARGE RESEARCH POLYGON

All boreholes of the Large Research Polygon (schematically marked in Fig. 1) were equipped with pairs of PE collector coils, 32 mm in diameter. The input (cold) collector coils had temperature sensors Pt-1000 at a depth of 20, 50, 100 and 140 m. The output (warm) collector coils were equipped with the same type of sensors at a depth of 20 and 100 m (Kunz, 2009; Klempa *et al*., 2011).

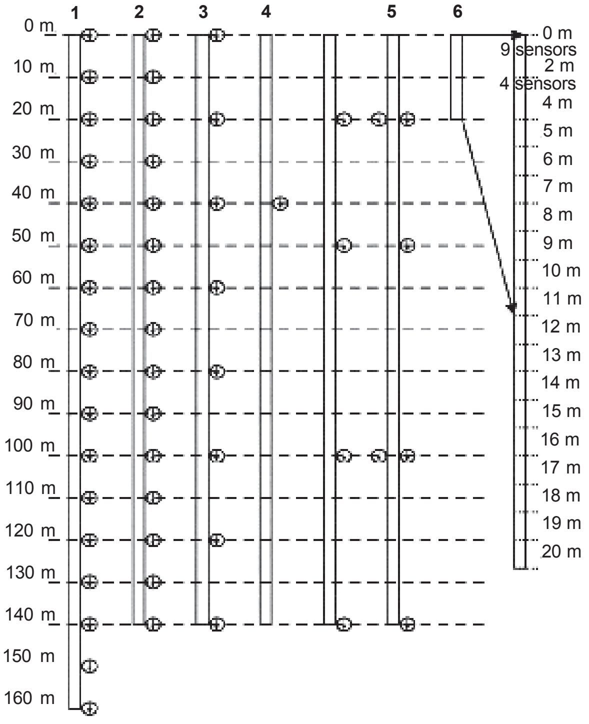
The monitoring boreholes (Fig. 1) were disposed along an arch in the centre of the research field, approximately in the N–W direction. The PE collector coils were also installed in these boreholes. Analogous to technological boreholes, also the monitoring boreholes were equipped with sets of temperature sensors Pt-1000 disposed at 20, 50, 100 and 140 m of depth. Presently, the research is conducted in four monitoring-research boreholes. Due to the construction works at the new building of the Faculty of Electrical Engineering, the MV05 borehole drilled in its close vicinity was temporarily excluded from operation. Another research borehole, KV01, was located in the research field about 10 m south of the MV04 borehole. This well was equipped with PE Stüwe collector coils with alternating perforation for monitoring long groundwater flows, and for measuring and controlling the temperature. For this reason a measuring probe Solinst Levelogger 3001 was installed in the borehole for recording long-term changes of groundwater level at the measuring point. This is only a supplementary measurement of groundwater hydraulic head changes from the Carboniferous surface. Underground water is not pumped from the wells and is not directly used by the heat pumps. Measuring data accounted for atmospheric air variations.

RESEARCH IN THE SMALL RESEARCH POLYGON

The experience gathered during the development of the Small Research Polygon was employed while constructing its small equivalent. Each of the boreholes was equipped with a small technological shaft giving access to the borehole outlet, and so the PE collector coils, electrical wires and connection boxes. The connection boxes were sealed and disposed above the groundwater level. The wires were directed to the Energy Research Centre along the shortest possible way (Bujok *et al*., 2009). Geological situation is similar to that of LRP (Tab. 1).

MONITORING SYSTEM OF THE SMALL RESEARCH POLYGON

The monitoring system of the Small Research Polygon consists of two heat pumps (IVT Greenline E 11 Plus, heating power 2 × 11 kW), connected to two140-m-deep boreholes, and a group of nine measurement boreholes in the close vicinity. The Small Research Polygon is used for measuring the influence of heat pumps on the rock mass. Unlike the Large Research Polygon its measuring scope in the function of depth was broader. It was additionally equipped with



Detailed geological profile of a shallow monitoring borehole MMV-1

Profil geologiczny płytkiego otworu monitorującego MMV-1

[m]	
0.0–0.3	clay/ *glina*
0.3–1.0	dark grey sandy clay/ *ciemnoszary piaszczysty ił*
1.0–2.0	dark brown, slightly sandy dry clay/ *ciemnobrązowy lekko piaszczysty ił, suchy*
2.0–3.0	dark brown, slightly sandy dry clay/ *ciemnobrązowy lekko piaszczysty ił, suchy*
3.0–4.0	dark brown, slightly sandy dry clay/ *ciemnobrązowy lekko piaszczysty ił, suchy*
4.0–5.0	dark brown, slightly sandy plastic clay/ *ciemnobrązowy lekko piaszczysty ił plastyczny*
5.0–6.0	dark brown, slightly sandy clay, inserts of light grey dry clay/ *ciemnobrązowy lekko piaszczysty ił, wkładki jasnoszarego iłu, suchy*
6.0–7.0	red-brows, slightly clayey dry sand/ *czerwono-brązowy lekko ilasty piasek, suchy*
7.0–8.0	light grey clayey sand/ *jasnoszary ilasty piasek*
8.0–9.0	light grey clayey plastic sand/ *jasnoszary ilasty piasek, plastyczny*
9.0–10.0	light grey clayey plastic sand/ *jasnoszary ilasty piasek, plastyczny*
10.0–11.0	dark grey plastic clay/ *ciemnoszary ił, plastyczny*
11.0–12.0	dark grey plastic clay/ *ciemnoszary ił, plastyczny*
12.0–13.0	dark grey plastic clay/ *ciemnoszary ił, plastyczny*
13.0–14.0	dark grey plastic clay/ *ciemnoszary ił, plastyczny*
14,0–15.0	dark grey plastic clay/ *ciemnoszary ił, plastyczny*
15.0–16.0	dark brown clayey sand/ *ciemnobrązowy ilasty piasek*
16.0–17.0	dark brown slightly clayey sand/ *ciemnobrązowy lekko ilasty piasek*
17.0–18.0	dark brown sand/ *ciemnobrązowy piasek*
18.0–19.0	dark brown sand/ *ciemnobrązowy piasek*
19.0–20.0	dark brown sand/ *ciemnobrązowy piasek*
20.0–21.0	dark brown sand/ *ciemnobrązowy piasek*

Fig. 2. Distribution of temperature sensors in monitoring and production boreholes in the Small Research Field

1 – monitoring borehole with 17 temperature sensors; 2 – monitoring borehole with 15 temperature sensors; 3 – monitoring borehole with 8 temperature sensors; 4 – two hydrogeological borehole; 5 – boreholes with heat pumps; 6 – shallow monitoring boreholes with 30 temperature sensors

Schemat rozmieszczenia czujników temperatury w otworach monitoringowych i produkcyjnych na Małym Poligonie Badawczym

1 – otwór monitoringowy z 17 czujnikami temperatury; 2 – otwór monitoringowy z 15 czujnikami temperatury; 3 – otwór monitoringowy z 8 czujnikami temperatury; 4 – dwa otwory hydrogeologiczne; 5 – otwory pod pompy ciepła; 6 – płytkie otwory monitoringowe z 30 czujnikami temperatury

a control and measuring system for establishing the solar intensity on the rock mass and apparatuses used for testing various types of sensors. The distribution of sensors in the boreholes is presented in Figure 2.

MONITORING BOREHOLE MMV-1

The MMV-1 monitoring borehole was drilled to a depth of 20.5 m. The lithology of the drilled rocks is presented in Figure 2. The borehole was cased to a depth of 20.0 m with 75-mm casing pipes. The borehole outlet was protected with a maintenance shaft. The borehole was equipped with temperature sensors Pt 1000 and DS18B20, disposed in two parallel rows.

The temperature sensors were distributed every 0.25 m to a depth of 2 m, then every 0.5 m to a depth of 2–4 m, and every 1 m from a depth of 4 m downwards (see Fig. 2). A total of 30 temperature sensors Pt 1000 and 30 identically distributed control sensors DS18B20 were disposed in the boreholes. All measurement sensors were connected to the measuring system in the Energy Research Centre, where data were automatically recorded.

The MMV-1 monitoring borehole was used mainly for monitoring seasonal temperature variations in the borehole's surface layer, depending on the season of the year. The averaged values of temperature changes in the function of depth obtained for various months of the years 2010–2015 are presented in Figure 3.

ANALYSIS OF MEASUREMENTS RESULTS

The measurements performed in the VŠB-TU Ostrava research polygons (Fig. 3) indicate that annual temperatures were not symmetrical as far as seasonality was concerned. In our case the temperature at a depth of 1.2 to 1.5 m ranged between 7.5 and 17.5°C. From a depth of 18 m downwards the temperature level stabilised at 12°C, regardless the season of the year. The analysis of Figure 3 shows that the temperature had a decreasing trend until it reached the neutral zone which, in the Small Research Field, was observed at a depth of 35 to 40 m. This result was obtained in other,

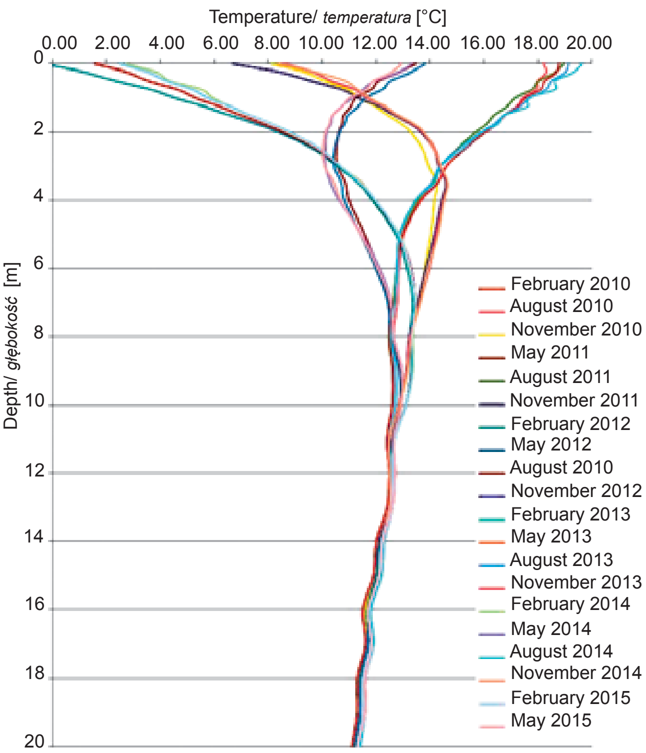


Fig. 3. Temperature variation as a function of depth in the MMV-1 borehole in various months in 2010–2015

Zmienność temperatury w funkcji głębokości otworu MMV-1 w różnych miesiącach na przestrzeni lat 2010–2015

deeper boreholes, where a constant temperature of 8°C was observed at similar depths, corresponding to the average temperature in the monitored area. The intensity of changes of external conditions and their influence on the surface rock mass was plotted in Figure 4 for the same months in the years 2010–2015. The most intense changes and a difference in temperatures took place at a depth of about 6 m. Below, the rate of temperature decrease in particular months was similar. Hence a conclusion that certain schemes presented in literature should be treated as approximations or schemes. A real distribution of the temperature profile in the surface layer can be determined only based on in situ analyses.

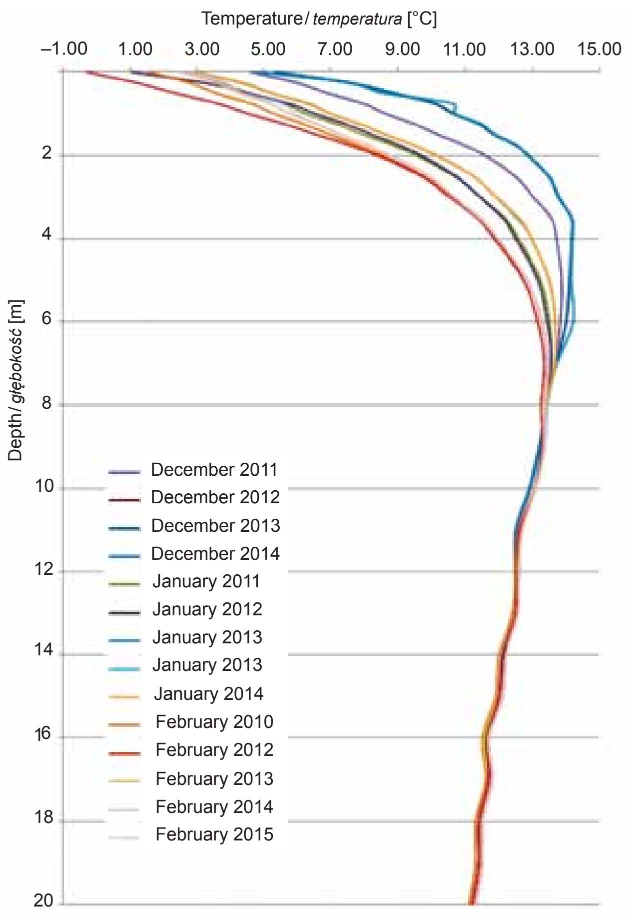


Fig. 4. Temperature variation as a function of depth in the MM V-1 borehole in winter months in 2010–2015

Zmienność temperatury w funkcji głębokości otworu MMV-1 w zimowych miesiącach na przestrzeni lat 2010–2015

This type of knowledge is necessary, especially in places where energy recovery from horizontal collector coils in the ground is planned. When energy is recuperated through boreholes with the use of vertical collectors, *i.e.*, for heat pumps, the influence of such changes can be ignored when sufficiently deep boreholes are involved. In the case of shallow boreholes and collector coils disposed horizontally, one should consider injecting materials of different thermal conductivity to the near-borehole area, or insulating the surface part of the borehole.

CONCLUSIONS

In some contributions we can read that no seasonal annual temperature variations are observed in the rock mass at a depth of 10–12 m b.g.l., even in the Scandinavian countries. Within this range the rock mass temperatures change proportionally to the surface temperature and are close to the annual average value for the air. Most authors indicate that the annual temperature is constant down to the neutral zone level, *i.e.* to a depth at which the temperature may undergo long-lasting changes under the influence of climate or seasonal variations. In fact, down to the neutral zone level, no temperature impact in a function of time was observed and its depth-related variability depended only on the geothermal gradient typical of a given geological area. In most of the areas in the Czech Republic the temperature rises with depth by 2 to 3°C per each 100 m (Rehau, 2014).

The analysis of temperature vs. depth variations presented in Fig. 5 reveals that temperature changes are symmetrical over the year. It is the most often quoted example of subsurface temperature changes. At a depth of 1.2 to 1.5 m the temperature oscillates between 7 and 13°C to reach its steady state at about 10°C at 18 m depth. From Figure 5 it is also clear that the authors proceeded from the assumption of a homogeneous, isotropic environment, both from the symmetric rise and fall of surface temperatures. Our long-term measurements in real conditions showed a different varied shapes of ground temperature curves (see Fig. 3).

A comparison with the results of other measurements on objects in the Czech Republic is not possible. Similar measurements are not routinely carried out in our country. Shallow climatic effects to a depth of 1–2 m are measured only for agricultural needs. The only long-term research was performed in a 150-m-deep borehole in the GFU ASCR area (Štulc, 1994) in Prague, which was followed (for a period of 184 days) by the return to the borehole thermal balance after drilling. From the data it is also evident the effect of temperature changes on the surface to a depth of about 17 m. The few foreign researches (Musset, Khan, 2000; Lowrie, 2007; Sidorová, Pinka, 2007) focused on studying relatively deep levels of "neutral" transition zones and its influence on the surface temperatures in the distant past.

Asymmetric curves obtained from measurements in the MMV-1 borehole confirm that the increase in spring temperatures and the drop in autumn temperatures do not occur with the same gradient. Furthermore, the geological profile of the borehole (Fig. 2) shows that the geological environment is heterogeneous, and thus the thermal conductivity of the rock at various intervals will diverge. In our opinion, our measurements in real time and real conditions more credibly show the temperature changes at the surface zone. Ground temperature development will ultimately depend on the location of the research, lithology, the presence of water-bearing intervals, and the long-term temperature "response" of the geological environment.

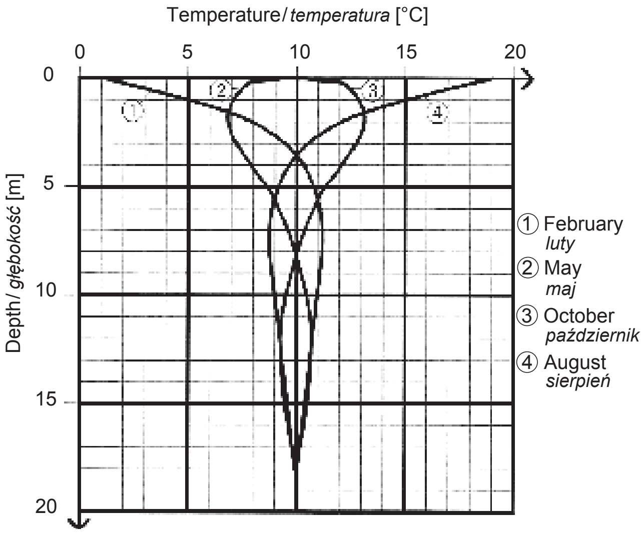


Fig. 5. Temperature *vs.* depth, after REHAU, 2014

Temperatura w funkcji głębokości wg REHAU, 2014

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PODSUMOWANIE

W artykule zaprezentowano ocenę wpływu warunków klimatycznych na bilans energetyczny górotworu na podstawie pomiarów przeprowadzonych w otworze odwierconym na terenie kampusu Wyższej Szkoły Górniczej w Ostrawie. Na wstępie autorzy opisali pole wymienników otworowych pod pompy ciepła, utworzone w celu zapewnienia ogrzewania w budynku Nowej Auli Wyższej Szkoły Górniczej. System ten zawiera 110 otworów odwierconych do głębokości ok. 140 m. Profil geologiczny składa się z czwartorzędowych iłów, piasków i żwirów z domieszką piasku do głębokości 28 m, następnie do głębokości 105 m – z mioceńskiej gliny. Ostatnim odcinkiem otworu nawiercono karbońskie iłowce. Do tych otworów, o łącznej długości 15,4 km, podłączono 10 pomp ciepła IVT Greenline D70 o łącznej mocy 700 kW.

W zachodniej części wyżej opisanego pola otworów skonstruowano tzw. Wielki Poligon Badawczy, który ma za zadanie monitorowanie wpływu pracy systemu otworowych wymienników ciepła na stan cieplny górotworu. Wielki poligon składa się z 10 otworowych wymienników ciepła, pięciu otworów monitorujących temperaturę górotworu i z jednego otworu hydrogeologicznego. W pobliżu Centrum Energetycznego utworzono dodatkowo tzw. Mały Poligon Badawczy, składający się z dwóch otworowych wymienników ciepła i dziewięciu otworów monitorujących temperaturę górotworu. Celem poligonu Małego jest ocena wpływu sezonowego magazynowania i odbioru ciepła na stan energetyczny górotworu.

Jako przykład wyników badań uzyskanych na poligonach badawczych Wyższej Szkoły Górniczej w Ostrawie autorzy przedstawili profil temperaturowy gruntu zarejestrowany na przestrzeni pięciu lat w otworze monitoringowym MVV-1 o głębokości 20,5 m. Wyniki pomiarów porównano z ogólnym przebiegiem profilu temperaturowego gruntu przedstawionym w literaturze. Autorzy stwierdzili, że profil ten dla różnych pór roku (lato–zima, wiosna–jesień) w rzeczywistości nie jest symetryczny względem pionowej osi reprezentującej średnią roczną temperaturę powietrza. Stwierdzono także dwukrotnie głębsze położenie strefy neutralnej, tj. na głębokości ok. 35–40 m, zamiast oczekiwanych 18 m. Porównano również przebieg profilów temperaturowych w zimowych miesiącach przez pięć kolejnych lat. Autorzy stwierdzili, że zmienność warunków klimatycznych ma wpływ na temperaturę górotworu wyłącznie do głębokości 6 m. Poniżej tej głębokości nie było istotnej różnicy pomiędzy profilami temperaturowymi gruntu podczas kolejnych pięciu lat.