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Used to Monitoring of Rock Mass Temperature Changes during Application of Heat Pumps

The largest been realized installations of heat pumps in the Czech Republic, where the primary collector of low-potential heat is formed deep wells, is heating complex building of new Auditorium and CIT in campus of VSB – Technical University of Ostrava. Currently building heats 10 heat pumps with a total output of 700 kW through 110 wells with a depth of 130 m each. To assess the proportions of individual internal and external sources to the overall heat balance, the verification of systems designed for long-term monitoring of the behaviour of the rock massive around the energy used wells and energy storage options have been proposed and gradually implemented two research measuring polygons.
Research Polygons, Heat Pump, Borehole, Temperature Profile, Renewable Energy

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Моніторинг змін температури гірської маси під час застосування теплових насосів

Найбільші установки теплових насосів знаходяться в Чеській Республіці, де основний колектор низько потенційного тепла формується в глибоких свердловинах, що дає змогу опалювати комплекс будівель на території технічного університету міста Острава. На сьогодні будівля обігрівається за допомогою 10 теплових насосів із загальною потужністю у 700 кВт та 110 свердловинами глибиною 130 метрів кожна. Для оцінки співвідношення окремих внутрішніх та зовнішніх джерел до загального теплового балансу було створено системи верифікації для довгострокового моніторингу стану скального масиву навколо свердловин, які використовують енергію та було запропоновано варіанти зберігання енергії. Цей процес поступово виконується за допомогою двох дослідницьких вимірювальних площадок.
дослідницькі ділянки, тепловий насос, скважини, Температурний профіль, поновлювальні джерела енергії

Introduction. In the Czech Republic the number of installations for low enthalpy geothermal energy utilization using the borehole heat exchangers (BHEs) increases recently. VSB – Technical University of Ostrava belongs among the pioneering organisations in the Czech Republic involved in this field.

Currently the ground source heat pumps (GSHP) are employed in 4 buildings of VSB-TU Ostrava which are the university auditorium and the Centre of Information Technology (CIT), one of the Energy Research Centre's buildings, the new building of Faculty of Electrical Engineering and Computer Science (Fig. 1) and the low-energy house of Faculty of Civil Engineering.

The GSHP installation on the university auditorium and the Centre of Information Technology, which is in fact one building, is the largest one in Czech Republic that uses BHEs as a heat source and is located at the campus of VSB – TU Ostrava in city's part Ostrava – Poruba. The construction of this building began in 2004 and was approved in 2006. This article will be focused particularly on this installation.

The main parts of the auditorium building are the lecture halls where the main hall has the capacity of 500 seats. These halls are used for lectures, graduation ceremonies, congresses and cultural events. Also the cloakroom, lavatory, buffet and other necessary facilities are parts of the auditorium along with the underground garage. The CIT's part of the building consists of offices, conference hall and hygienic facilities which are operationally separated block from those facilities mentioned above.

The GSHP utilization in this building was suggested as a change to the original project which included Ostrava's district heating system for a heat supply. The heating, ventilation and air conditioning (HVAC) system of building consists of radiators, ventilators and underfloor heating.

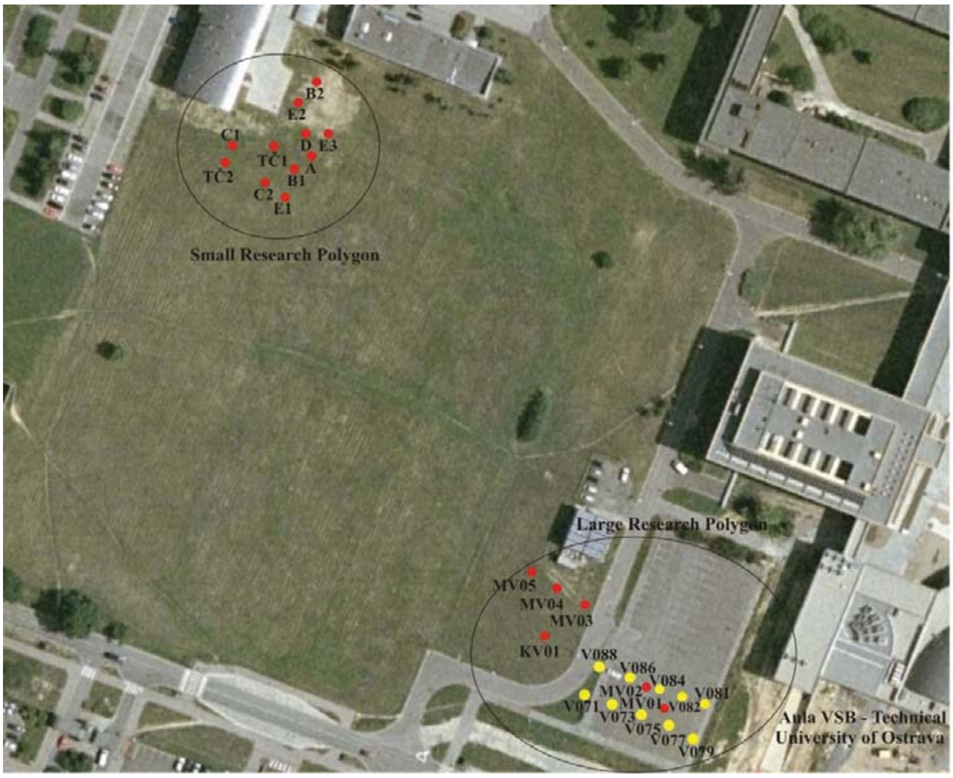

Figure 1 – Situational scheme of Large Research Polygon and Small Research Polygon [1]

Technical details of Auditorium building heating system

Building (Fig. 2) is equipped with 10 GSHP's Greenline D70, IVT (Fig. 3) with 69,8 kW power each at temperature gap 0/50°C which are exploited for water heating, heating of building and air conditioning and are situated in building's basement. Overall installed power of GSHPs is 698 kW and the district heating system is used in a bivalent heating mode. Along with the GSHPs there are two water tanks with capacity of 700 litres and other operational equipment like regulation system, etc. The connection to the secondary heating circuit of the auditorium building is done through the heat exchanger central which was originally designed for district heat supply.

Figure 2 – Auditorium

Figure 3 – 10 GSHP's [6]

The borehole heat exchangers (BHEs) which supply heat to the GSHP's are situated around the auditorium building. BHEs are under the surface covered by grass and tarmac of the parking lots. Preceding studies and measurements on the largest installation utilizing GSHPs to date were the resource of information for dimensioning the number and depth of BHEs. This previous installation is situated in Opava city and it supplies the heat for the town's multi-purpose hall with overall GSHP's power of 455 kW that uses 81 BHEs of 100 meters of length each. Along with the experience from Opava installation the two thermal response tests (TRT) were conducted and evaluated by specialist from Lund University in Sweden on the site of auditorium building. [2,4,7] Lithological and stratigraphic data from boreholes at the site can be found in Table 1.

Table 1 – Geological profile of Large Research Polygon [6]

Depth Interval [m]	Geological Profile
0,0 – 2,0	yellowish brown clay - Quaternary
2,0 – 3,0	yellowish brown clay with gravel - Quaternary
3,0 – 8,5	yellow sand and gravel - Quaternary
8,5 – 13,0	brown sand and gravel - Quaternary
13,0 – 14,2	clayey sand - Quaternary
14,2 – 78,0	green clay - Miocene
78,0 – 83,5	sandy clay - Miocene
83,5 – 130,7	clay stone, silt stone, middling sandstone – Lower Carboniferous

According to our experience with similar conditions, the value of the specific heat flux was set on 45 $mW \cdot m^{-2}$ and with other data gained thanks to the previous research and *in situ* tests the whole length of BHEs was estimated at 15400 meters which are divided into the 110 BHEs of 140 m depth each with diameter of 120 mm. During the drilling works the geological setting was evaluated and the lithology remains similar in each borehole except the surface of carboniferous strata which has variable depth. Drilling rigs Nordmeyer DSB 2/010 with down the hole drilling hammers Atlas Copco COP 44 were utilized for BHEs drilling. The completion of each BHE was done with double HDPE U-tube 32/2,9 and with the cement-bentonite grout mixture injection. Each of the U-tubes inlets and outlets are coupled by the 40/3,7 HDPE tube. There are 5 shafts and 22 BHE's inlets and outlets is lead into each. Each of these shafts is equipped by the collectors and separators for each branch of tubes from and to each BHE. The GSHPs and shafts are connected by 110/6,6 PE tube. The heat carrying medium is 30 % ethylalkohol-water mixture and is circulated by the WILO NP-50/160 pump. [3]

One of the parts of this system is also the standby coolant unit Chiller – Aermec type RV for air conditioning with whole cooling power of 475,5 kW, 67,8 $m^3 \cdot h^{-1}$ flow rate of cooled water and temperature gradient of 8/14°C. The primary circuit of heat pumps serves as the backup cooling device.

Large Research Polygon

For research purposes on long-term dynamic changes of thermal properties in the rock environment the two BHE polygons were constructed on the VSB-TU Ostrava campus (Fig. 1). The small research polygon (SRP) was set up for evaluation of small BHE installation (i.e. 2 - 4 BHEs) operational effects on surrounding rock and large research polygon (LRS) for the same purpose in large installation (i.e. 5 or more BHEs) case. The construction details of LRS were consulted with researchers from Institute for Applied Geology, Technical University of Karlsruhe in Germany.

Long-term research goals are:

- high resolution monitoring of the heating/cooling performance of BHEs in rock environment;
- research of thermal field in the vicinity of the BHEs under the real operating conditions;
- verification of parameters estimated in projection of research polygons;
- improvement of analytical and numerical models of heat transfer in the vicinity of BHEs;
- evaluation of possible utilization of available modelling programs;
- verification of applicability of the thermal sensors in the BHE with main focus on their precision, placement and working life length.

Implementation of technology for the research goals fulfilment

The thermal field in the rock surrounding the BHEs in the large polygon is logged thanks to the thermal sensors that are embedded in the BHEs themselves (10 logged BHEs) and in monitoring boreholes that were drilled for the sole purpose of temperature logging (5 boreholes) of the thermal field influenced by the BHEs operation and also for logging of region thermally undisturbed by BHEs operation to monitor natural changes in the rock environment temperature. This temperature logging is done in area of the shaft 4 which collects the heat carrying fluid from 22 BHEs.

For LRS the group of 10 BHEs was selected. This group consists of 2 parallel lines of 5 BHEs each (BHEs are labelled VO71, VO73, VO75, VO77, VO79, VO81, VO82, VO84, VO86 a VO88) and they are lead into the shaft 4 together with other 12 unlogged BHEs. Thermal sensors are permanently fixed inside the U-tubes of BHEs and there are 6 sensors per BHE. Their placement inside the BHE is as follows:

- 4 sensors on inlet tube to the BHE in 20 m, 50 m, 100 m and 140 m of tube's length;
- 2 sensors on the outlet tube from the BHE in 20 m and 100 m length of the tube (measured from the ground surface).

Thermal sensors are the Pt-1000 class A. Sensors have a sealing case which prevents the moisture from BHEs grout mixture or the ground water to affect their measuring abilities. [5]

Small Research Polygon

The experience gathered when performing the Big Research Field 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.

Monitoring system of Small Research Polygon

The monitoring system of the Small Research Polygon consists of two heat pumps (IVT type Greenline E 11 Plus, of heating power 2 x 11 kW), connected to two boreholes 140 m deep and a group of 9 measurement boreholes in the close vicinity. The Small Research Field 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 a control and measuring system for establishing the solar intensity on rock mass and apparatuses used for testing various types of sensors. The distribution of sensors in boreholes is presented in Fig. 4.

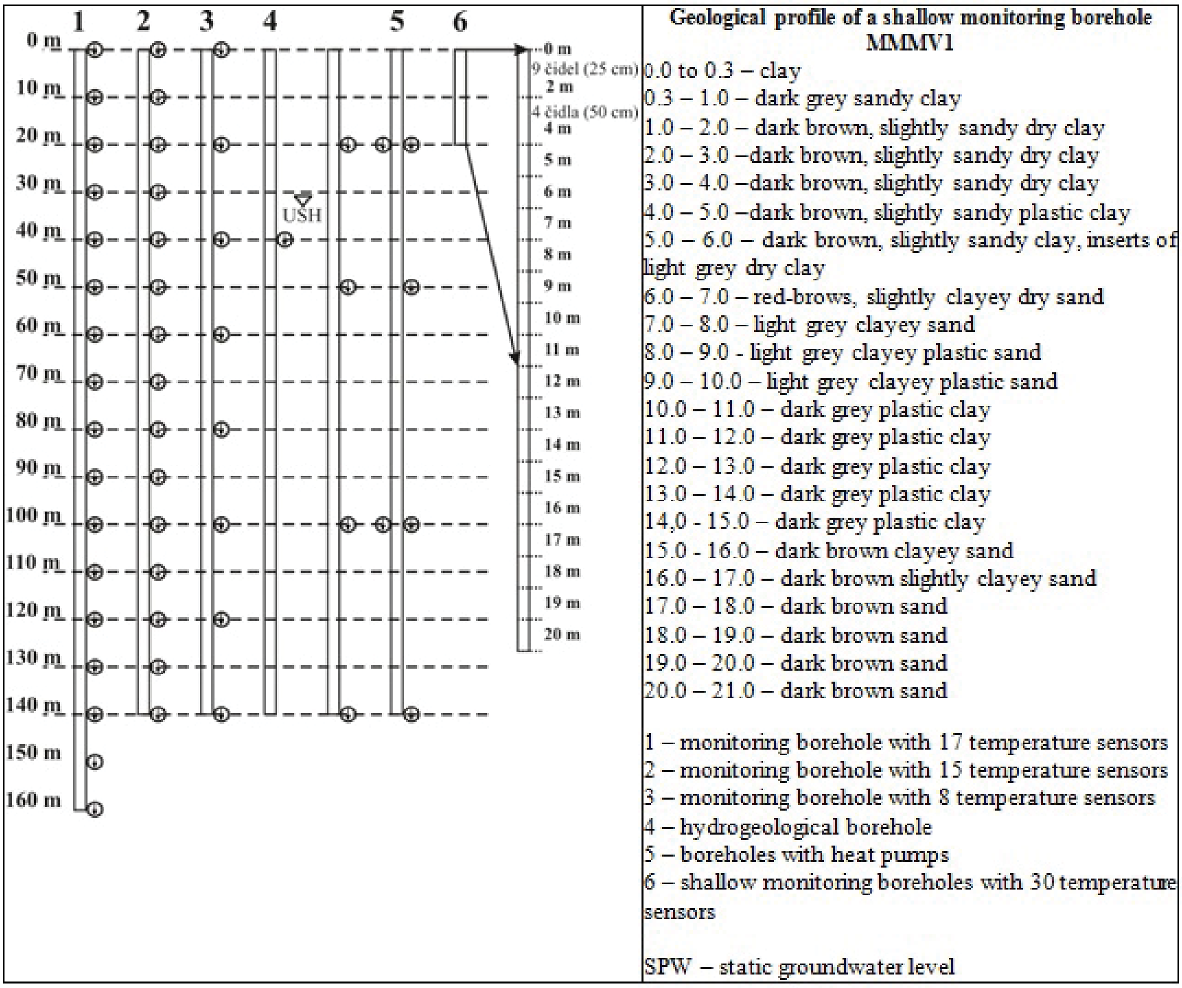

Figure 4 – Distribution of temperature sensors in the Small Research Polygon

Monitoring borehole MMV – 1 (in Fig. 4 – No. 6)

Monitoring borehole MMV - 1 was drilled to 20,5 m of depth. The lithology of the drilled rocks was as visualized in the above table. The borehole was cased to a depth of 20 m with casing pipes 75 mm in diameter. The borehole outlet was protected with a covered short 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 at a depth of 4 m downwards (see Fig. 5). A total of 30 temperature sensors Pt1000 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 monitoring borehole MMV - 1 was mainly used 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 – 2013 are presented in Fig. 5.

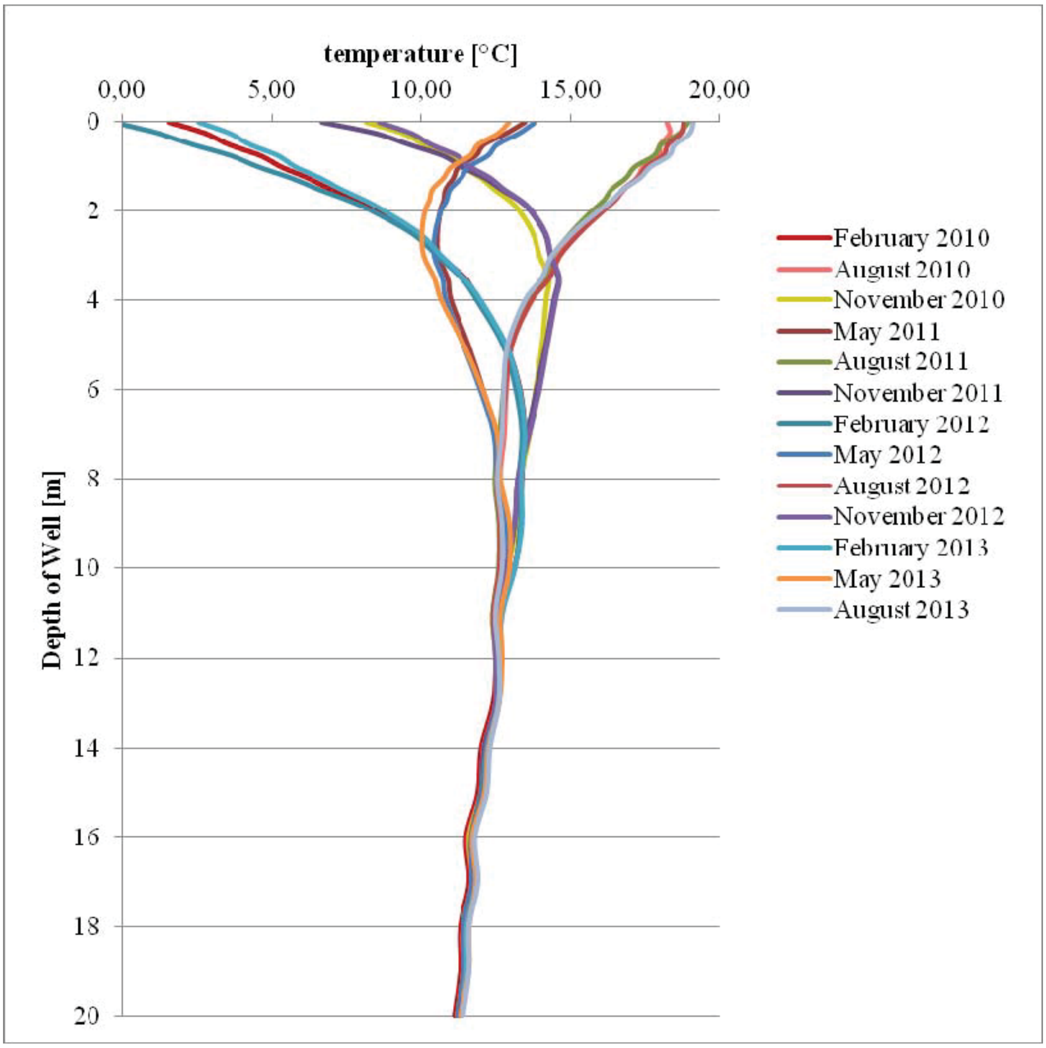

Figure 5 – Temperature profile in the years 2010 – 2013

Summary – Conclusions

To the temperature logging of BHEs the data of water table heights, ground water flow and surficial and atmospheric temperatures are added. The temperature slices through the LRP in different time steps allows us to further investigate the thermal field during heat production or thermal stabilization period without operation of the BHEs. The example of temperature log from one BHE in several time steps is introduced in Fig. 6. Temperature logs can yield a important information about e.g. neutral zone depth (i.e. zone where the temperature of deeper intervals increases according to geothermal gradient) which is situated at 45 – 50 m below the ground surface in our case

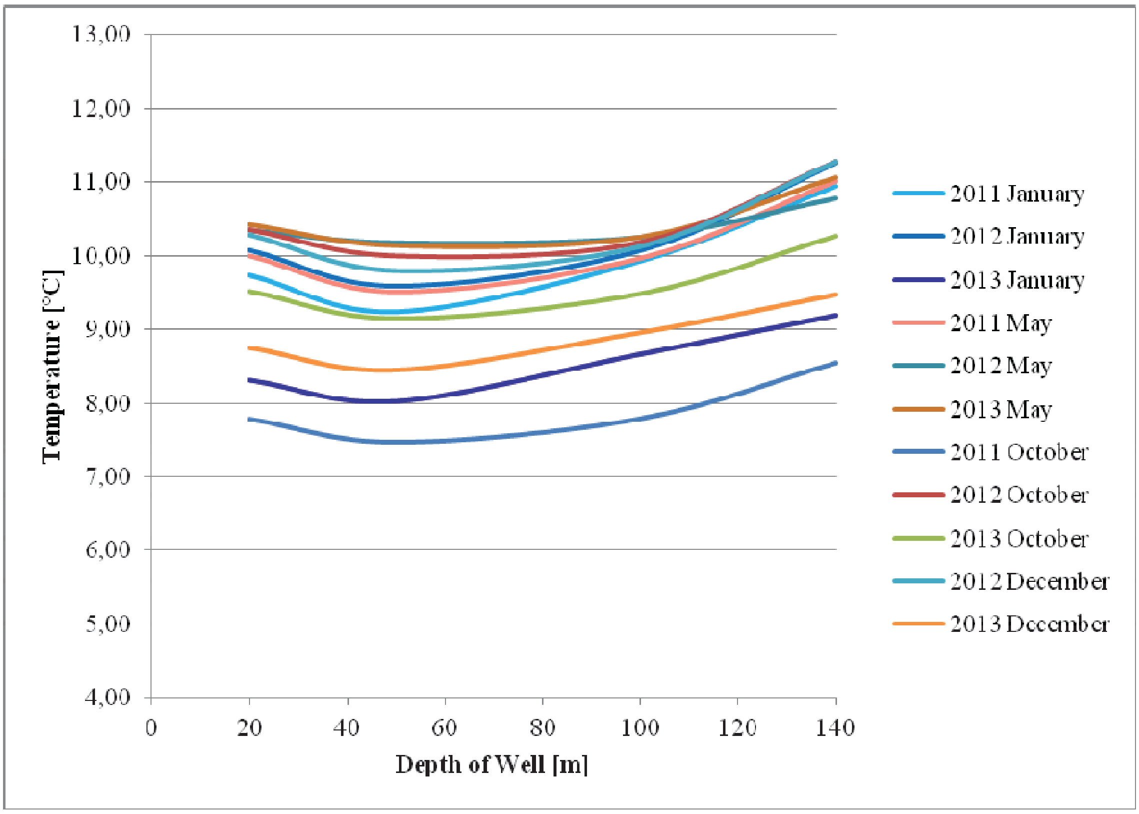

Figure 6 – Temperatures in the depth interval from 20 to 140 m

In some literature positions we can read that no seasonal annual temperature variations are observed in rock mass at a depth of 10 - 12 m b.s., 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 air. Most authors of various publications indicate that the annual temperature is constant to the neutral zone level, i.e. to a depth at which temperature may undergo long-lasting changes under the influence of climate or seasonal variations. Down the neutral zone level, no temperature impact in a function of time was observed and its depth-related variability depended only on geothermal gradient typical of a given geological area. In most of the areas in Czech Republic the temperature rises with the increasing depth by 2° to 3°C per each 100 m of depth. Fig. 7 illustrates annual temperature changes in a function of depth for selected month in 2011 [3].

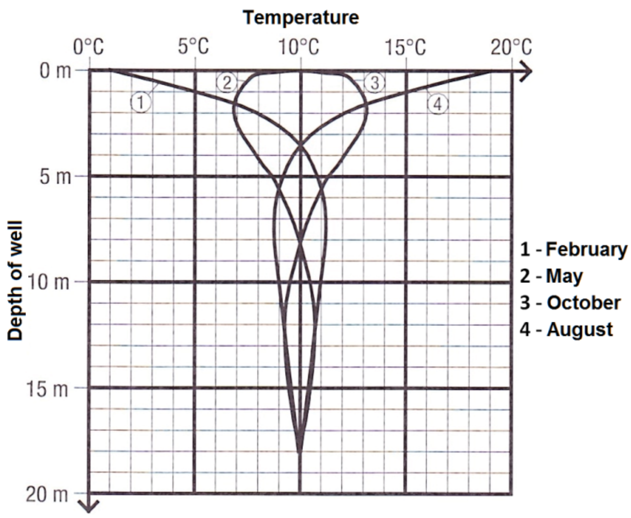

Figure 7 – Temperature vs. depth, after [3]

The analysis of temperature vs. depth variations presented in Fig. 7 reveals that temperature changes are symmetrical over the year. 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 of depth.

The measurements performed in the VSB-TU Ostrava research fields (Fig. 5) 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 established at a level of 12°C, regardless the season of the year. The analysis of Fig. 6 shows that the temperature had a decreasing tendency till it reached the neutral zone which in the Small Research Field was observed at 35 to 40 m of depth. This result was obtained in other, deeper boreholes. At analogous depths a constant temperature of 8°C was obtained there, 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 Fig. 8 for the same months in the years 2010 - 2013. The most intense changes and a difference in temperatures took place at about 6 m of depth. Below this value 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.

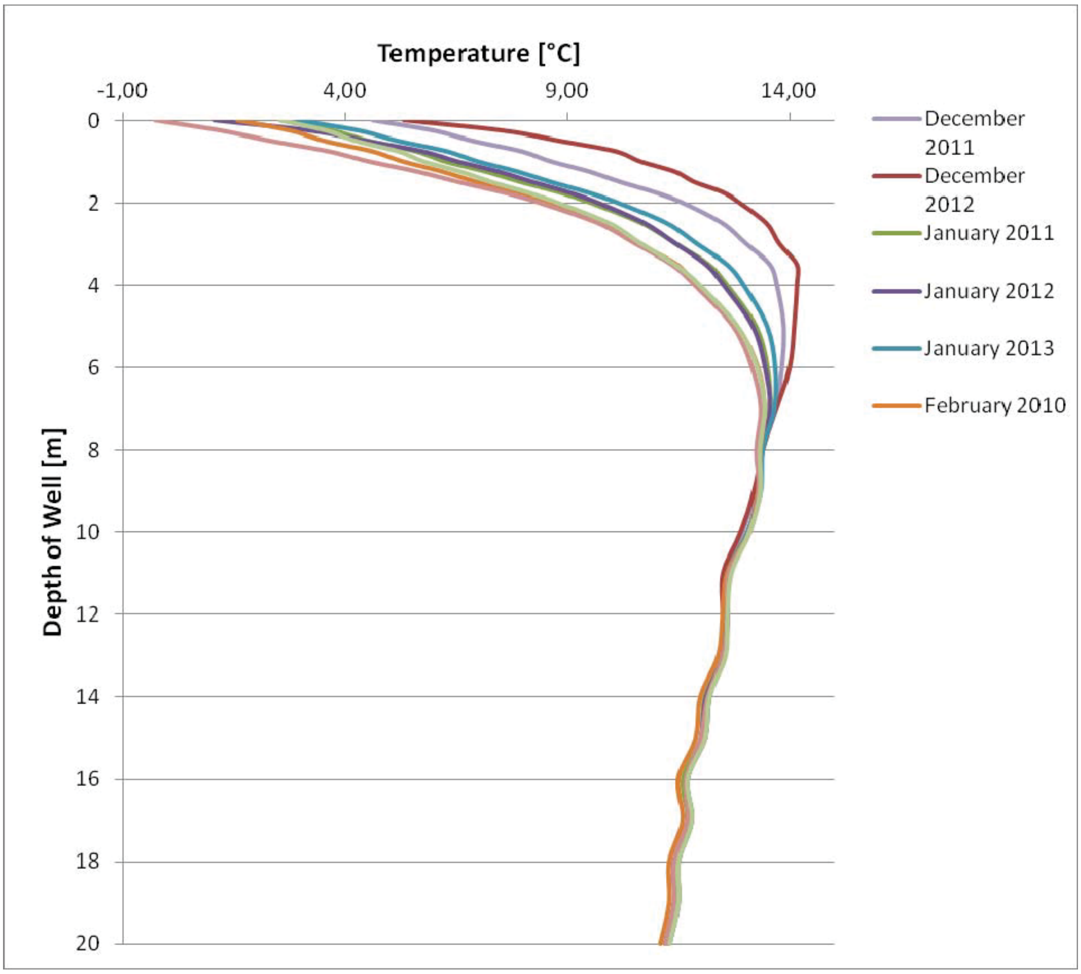

Figure 8 – Course of temperature changes in a function of depth in the years 2010 - 2013 in monitoring borehole MMV-1 in different months

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 collectors, i.e. 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.

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Мониторинг изменений температуры горной массы во время применения тепловых насосов

Статья ориентирована на проблематику использования дешевых источников энергии горных пород с помощью тепловых насосов и возможности хранения избыточного тепла такой среды. Здесь также рассматривается другая из исследуемых тем – долгосрочные изменения температуры в приповерхностном слое под влиянием климатических условий.

В настоящее время в Остравском Техническом Университете проводится мониторинг в трех научно-исследовательских центрах. Основной исследовательский центр (VVP) находится в новом актовом зале здания CIT. Для его отопления используется 110 пробуренных теплообменников. Каждая скважина достигает глубины 140 м. Скважины соединены с 10 тепловыми насосами общей мощностью 700 кВт. Измерения проводятся на 10 рабочих скважинах, оборудованных температурными датчиками и 6 наблюдательных скважинах. Малый исследовательский центр (MVP) расположен у здания Центра энергетических исследований (VEC). Для измерений здесь используются две рабочие скважины, подключенные к тепловым насосам общей мощностью 69,8 кВт и 9 наблюдательных скважин. Все они оснащены температурными датчиками. Десять скважин имеют глубину 140 м, одна – глубину 160 м.

Третий, так называемый, мини-исследовательский центр имеет одну скважину, пробуренную до глубины 140 м и соединенную с тепловым насосом 6 кВт. Для подробного мониторинга изменений

температуры в приповерхностном слое служит специальная скважина глубиной 20,5 м, которая также находится в здании VEC.

Исследования, проведенные в центрах VVP а MVP показывают, что изменения температуры в массиве горных пород происходят очень медленно и в малом объеме. В течение лета происходит регенерация температурного поля. Мониторинг изменений температуры вблизи поверхности (на территории VSB - TUO) показывает, что краткосрочные климатические эффекты (смена времен года) являются на глубине около 12 м незначительными.

исследовательские участки, тепловой насос, скважины, Температурный профиль, возобновляемые источники энергии

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Математична модель прогнозування ожеледоутворення на проводах повітряних ліній елетропередачі

Розроблено адаптивну модель прогнозування на основі ковзної лінійної регресії, що дозволяє визначати час утворення ожеледно-паморозевих відкладень на проводах повітряних ліній. Для оцінки надійності прогнозів отримано аналітичне рівняння фідуціальних меж. Виконано порівняльний аналіз результатів прогнозування отриманих за методами ковзної лінійної та лінійної регресії. Запропонована прогностична модель має достатню точність та надійність для розробки на її основі прогнозуючої системи технічного діагностування ожеледоутворення на проводах повітряних ліній електропередачі.
повітряна лінія електропередачі, обледеніння проводів, прогнозування, динамічний ряд

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Математическая модель прогнозирования гололедообразования на проводах воздушных линий электропередачи

Разработана адаптивная модель прогнозирования на основе скользящей линейной регрессии позволяет определять время гололедообразования на проводах воздушных линий. Для оценки надежности прогнозов получено аналитическое уравнение фидуциальных границ. Выполнен сравнительный анализ результатов прогнозирования полученных по методам скользящей линейной и линейной регрессии. Предложенная модель имеет достаточную точность и надежность для разработки на ее основе прогнозирующей системы технического диагностирования гололедообразования на проводах воздушных линий.
воздушная линия электропередачи, обледенение проводов, прогнозирование, динамический ряд

Вступ. Ожеледно-вітрові явища є однією з основних причин, що призводять до технологічних порушень у роботі повітряних ліній електропередачі енергопостачальних компаній України. На сьогодні запропоновано велику кількість активних методів захисту проводів (грозозахисних тросів) повітряних ліній від ожеледно-паморозевих відкладень (ОПВ). Практична реалізація конкретного способу