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Study of the temperature regime of soils in the city of Omsk for use in heat transfer transformers at railway transport facilities

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Abstract. The article is devoted to the analysis and research of the geological elements of the city of Omsk for the possibility of using reliable data of the soil temperature regime in the design of soil probes used in the operation of heat transformers.

1. Introduction

The Siberian Federal district is the most important transport hub of the Russian Federation, where 17.5% of the total length of Russian Railways is concentrated.

On the territory of the Siberian Federal district carry out their economic activity 23 of the branch of JSC "RZD", including four railroads: the Western-Siberian (it is located in the following subjects of the Russian Federation – Altai Krai, Kemerovo, Novosibirsk, Omsk, Tomsk), Krasnoyarsk (Krasnoyarsk Krai and Republic of Khakassia), East Siberia (Irkutsk region and Buryatia), Transbaikalia railroad located within the boundaries of the Chita and Amur oblast and Agin-Buryat AO.

For maintenance and operation of the railway infrastructure, Autonomous buildings and structures are being designed (reconstructed) (crossing duty stations, switch posts, security posts, stationary or modular heating points, and other buildings and structures that are part of the structure of JSC "Russian Railways"), which are connected mainly to engineering power supply networks, due to the long distance from localities. These facilities have high operating costs for heating and hot water systems.

At the present time the priority areas of energy development in the Russian Federation are the usage of renewable energy sources, energy conservation and the rational use of fuel and energy resources. The necessity for energy efficiency is caused by the demand to reduce operational costs for heating buildings and structures, depletion of natural resources of ecosystems (natural capital), exacerbation of environmental issues within large industrial and urban areas.

The adoption of modern materials and technologies can significantly reduce the cost of maintenance (operation) and increase the energy efficiency of capital construction projects [1, 2]. The introduction of affordable low-potential thermal energy of soil, air, water, domestic wastewater, mine water, industrial emissions and the others is one of the most promising ways to increase the profitability of thermal energy sources. Without changing of the existing engineering infrastructure, the conversion (transformation) of such energy allows to provide thermal energy to both existing

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industrial, administrative, residential facilities, and new ones, without using additional fuel and energy resources.

In the work, we study the low-potential energy of the soil in the city of Omsk and analyse the potential of its helpful adoption, as well as the possibility of reducing the cost of extracted heat from thermal wells based on the studies conducted to increase the accuracy of the measurements of soil probes used in the operation of heat transformers (heat pumps).

The aim of the research work:

– to analyse the geological elements (soils) in the city of Omsk;

– to determine the values and dynamics of soil temperatures in the exploratory wells for applying the actual data in the measurements of the soil probe of the heat transformer.

2. Main part

While using low-potential renewable soil energy through geothermal transformers for heat and cold supply of buildings and structures, the most important part of the system is a soil probe (heat exchanger). Based on the analysis of the operation of various types of soil probes, the most optimal are vertical and deviated wells when used for their technical characteristics, in the pipes of which ethylene glycol (non-freezing fluid) circulates.

A significant advantage of thermal springs is recreation, high regional distribution, environmentally friendliness and simplicity in production of heat / electric resource, in comparison with traditional heat supply systems.

The thermal conductivity of soils increases significantly in the case of high soil moisture and reaches maximum values when all pores are completely filled with water, thereby displacing the gaseous components of the air (oxygen, carbon dioxide and others) which having a low coefficient of thermal conductivity.

Nowadays the share of electricity received in the world through geothermal resources is only 0,5%. Thermal power of geothermal energy accounts for about 50% of the whole World Energy. Geothermal energy accounts for 8.5 GW of electricity and 59 million kWh of thermal energy [5].

In fact, the Earth heat energy is concentrated in the thickness of the Earth’s crust at a depth of 0.5–5 km, which can substantially meet the demand for heat production for many decades. Geothermal resources that are currently open make up only a small part of these potential resources, but each year they increase by 2-3%, and over the 10-year period they grow by 12-20%. The average growth of geothermal energy from 2000 to 2015 was 15%.

World leaders in geothermal energy:

1) The United States;
2) Philippines;
3) Indonesia;
4) Italy;
5) Japan;
6) New Zealand.

Due to substantial government support programs, the greatest development of low-potential energy technology was received in the USA, Sweden, Canada, Germany, Switzerland and Austria [7].

The Russian Federation, which was one of the world leaders in geothermal energy until 1992, due to the collapse of the USSR, the production of most of the advanced technological processes for the production of heat transformers (heat pumps) turned out to be unclaimed, and subsequently led to physical and moral obsolescence, a lag in the direction [6].

The energy resources of geothermal energy in our country are comparable in volume to all combined hydrocarbon reserves. Figure №1 shows a map of geothermal springs in the Russian Federation, on the basis of which the knowledge of thermal springs is visible, and it is also shown that this industry is most promising for the south of Russia and the Far East.

Figure 1. Map of geothermal sources in the Russian Federation.

The advantages of geothermal energy:

– the possibility of adoption in different climatic conditions and at different seasons of the year;
– the cost of electricity is lower than electricity produced from other renewable energy sources;
– low labor intensity of equipment operation;
– renewable source of energy;
– the possibility of starting a heating system at the discretion of the building owner;
– no expenditures when starting a heating system (compared to central heating).

These advantages lead to the fact that geothermal energy, in spite of its youth (a history of about 100 years) is developing now all over the world.

The disadvantages of geothermal energy:

– low temperature potential of the heat-carrier;
– high cost of drilling operations;
– high cost of equipment (heat transformer);
– intransportable;
– limited industrial experience.

The development of geothermal energy is halted by the cost of plants, as well as a lower energy output in comparison with gas and oil wells. On the other hand, they can be used much longer than deposits of traditional sources. The advantage of geothermal plants is also that they practically do not require maintenance.

One of the key problems arising in the design of geothermal heating (energy) systems is the search for reliable field data on the temperature regime of the soil mass surrounding the operating thermal wells. An analysis of available publications shows that there is no information in the press about the typical climatic year of the natural conditions of soil temperatures. The published data mainly contain the results of measurements by weather stations of soil temperature to the freezing depth from the soil surface. In addition, in accordance with the recommendations of the World Metrological Organization, data recorded for at least 30 years should be used to form a base of typical climate data. Based on the above analysis, the relevance of research in this area is confirmed.

The Omsk Oblast, using low-grade heat, is included in the favorable (profitable), but little explored territories of the Siberian Federal District. According to available archival data (a report on the state and environmental protection of the Omsk Oblast in 2007), one area of thermal (heat and power) water

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was explored in the region - Chistovsky (Okoneshnikovsky Rayon), whose groundwater are confined to the Lower Cretaceous deposits of the Tara and Kiyalin suite. The water temperature at the wellhead is 60-65 °C.

The southern parts of the Omsk Oblast are promising for thermal waters, where groundwater with a temperature at the mouth of +25 °C and higher (Novovarshavsky, Russko-Polyansky, Sherbakulsky, Okoneshnikovsky Rayons) is discovered in the deposits of the Pokursky suite at a depth of 600–900 m [8].

Characteristics of the research area of the city of Omsk:

– the territory belongs to the I climatic region, subarea I B, within which the average monthly air temperature in January ranges from minus 14 to minus 28 ºC, and in July from plus 12 to plus 21 ºC. [9];

– the moisture in the zone of Omsk is dry [4]. The climatic characteristic of the research area was compiled from observations of the Omsk weather station;

– the climate of the region is sharply continental with severe long winters and relatively short but hot summers;

– the average annual air temperature is plus 1,7 ºC. The coldest month of the year is January with an average monthly air temperature of minus 17,2 ºC, in some years the air temperature in winter can drop to minus 49 ºC;

– the average monthly temperature of July, the warmest month, is plus 19,5 ºC;

– the highest temperature was observed in June, July and accounted for plus 40 ºC;

– the duration of the warm and cold periods is 7 and 5 months;

– the measured temperature of the coldest five-day with exceedance probability of 0,92 is minus 37ºC, with exceedance probability of 0,98 is minus 39ºC;

– Soil temperature is related to air temperature. The lowest average monthly soil surface temperature is observed in January (minus 19 ºC), the highest – in July (plus 24 ºC). The average annual soil surface temperature was plus 2 ºC. With depth, the soil temperature decreases in the summer months, in the winter, on the contrary, the temperature of the soil with depth is higher, since its surface is first cooled. Starting from a depth of 2,0 m, the average monthly soil temperature in this area has only positive values.

The standard depth of seasonal freezing in the city of Omsk [10] is:

– loam, clays – 1,82 m;

– sandy loam and fine sand – 2,22 m.

In 2020, the «Siberian Project Company/ Сибирская проектная компания» Limited Liability Company carried out geotechnical work, as a result of which, laboratory work and field researches of exploratory wells were performed.

Groundwater (soil) levels recorded for the period of drilling operations for geological wells are shown in table 1.

Table 1. Groundwater level of geological wells.

Number (depth) of the well	The established groundwater level for the period of drilling. m		Date of measurement. year
	depth	mark	
C-1 (26 m)	3.2	85.42	13.02.2020
C-2 (30 m)	3.2	111.77	21.03.2020
C-3 (26 m)	4.8	82.10	

Based on laboratory tests, an analysis of soils was carried out, the results of which are presented in table №2. According to the actually performed survey work, it was found that the selected soil samples (monoliths) have: humidity 7,1-26,9%, natural density 1,58-2,07 g/cm3, deformation modulus at natural humidity 2,9-10,6 MPa.

Table 2. Soil analysis of exploratory wells №1-3.

№ wls.	Engineering and geological elements	Title of soils	Layer power. m	Average natural humidity.%	The average natural density of the soil. g/cm3	Deformation modulus at natural humidity. MPa
1	IGE 1 (edQIII)	Solid sandy loam	0.5-2.8	7.1	1.68	6.7
	IGE 2 (edQIII)	Refractory loam	0.9-5.8	22.7	1.93	3.3
	IGE 3 (edQIII)	Soft-plastic loam	0.6-1.4	23.6	1.94	2.9
	IGE 4 (edQIII)	The sand is small. with medium-sized interlayers. loose. heterogeneous	0.6-2.2	9.0	1.58	8.7
	IGE 5 (edQIII)	Semi-solid loam	3.5-5.0	25.1	1.95	4.1
	IGE 6 (edQIII)	Plastic sandy loam	3.6	21.1	2.03	6.2
	IGE 7 (N1tv)	Semi-solid clay with inclusion of marl gravel up to 10%.	2.8-13.4	22.8	1.98	7.0
	IGE 8 (N1tv)	Refractory loam	1.3-13.2	24.5	1.96	4.2
	IGE 9 (N1tv)	Soft plastic loam	1.0-1.4	26.4	1.95	2.9
	IGE 10 (N1tv)	Semi-solid loam	0.5-5.3	21.6	1.95	5.7
2	IGE 2 (edQIII)	Refractory brown loam with interlayers of soft plastic loam	3.5-4.5	20.2	1.93	3.7
	IGE 3 (IQEks)	Semi-solid gray clay. with marl inclusions up to 2%	13.3-15.3	26.5	1.95	7.6
	IGE 4 (IQEks)	Soft-plastic gray-brown loam with interlayers of refractory loam and sandy loam	9.7-11.0	26.9	1.95	3.3
3	IGE 2 (edQIII)	Semi-solid loam	3.5	14.4	1.89	5.0
	IGE 3 (a2QIII)	Soft-plastic loam with interlayers of sandy loam	1.0-4.5	26.5	1.96	3.5
	IGE 4 (a2QIII)	Fluid plastic loam	1.0-7.0	24.9	1.97	4.4
	IGE 5 (N1tv)	Semi-solid clay	0.5-7.0	19.7	2.07	10.6

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To determine the temperature of the soil, after performing exploratory work, temperature sensors for the geothermal recorder were installed in exploratory wells [11] (certificate of state registration of computer program №2020611929 dated February 12, 2020). The plan diagram of the installation of equipment for determining the temperature of the soil is presented in Figure №2.

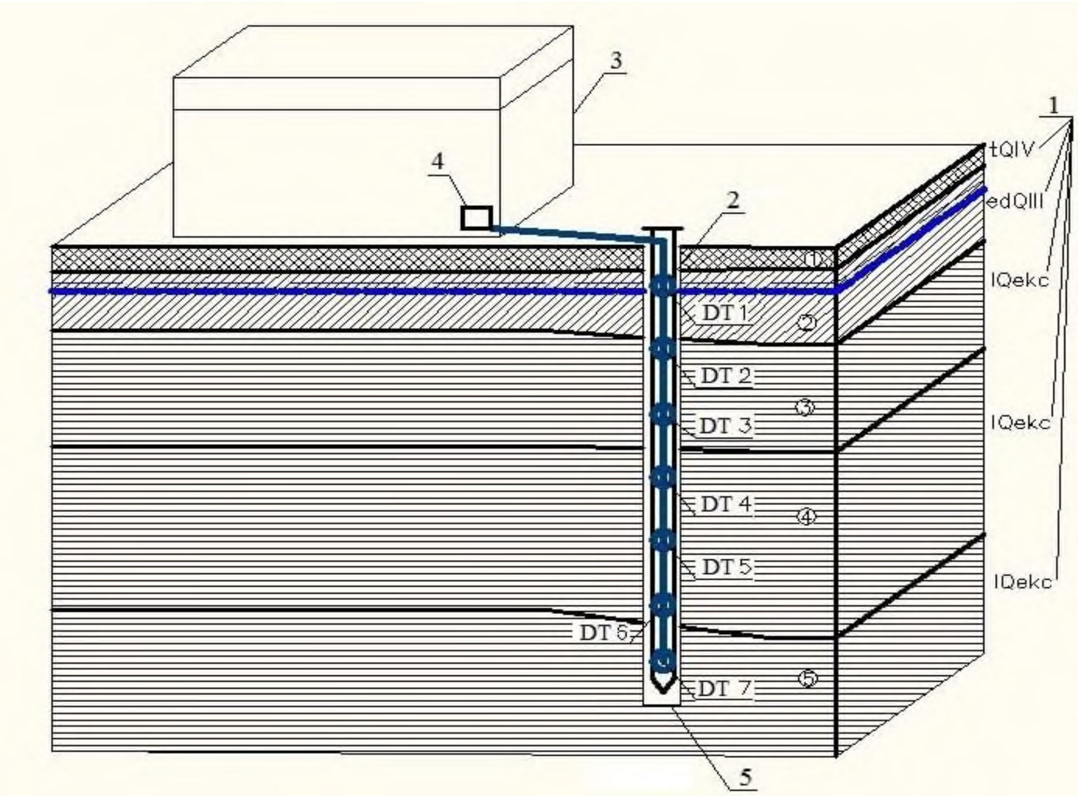

Figure 2. The plan diagram of the installation of temperature sensors in the exploratory well.

Where: 1– geological and engineering elements; 2 – temperature sensor (TS); 3 – construction; 4 – geothermal recorder; 5 – geological well.

Description of the used software «Geothermal Recorder»:

The software was developed on the basis of «Arduino» and is designed for annual (two-year) monitoring of the temperature of the soil of an exploratory well, in real time, as well as automatic recording (every 360 minutes) of recorded actual readings of thermal sensors (TS) on a memory card. The results of the data are recorded on the memory card, in a text document with the extension "txt" indicating - the date, month, year, hour, minutes, seconds and temperature of each sensor. Indications of soil temperature data (online) are displayed on the LCD display in digital and text form.

The software provides the following:

– visual monitoring of soil temperature in real time on the LCD display in digital and text form;

– automatic recording (every 360 minutes) of the recorded actual readings of thermal sensors on the memory card, in a text document with the extension "txt" indicating the date, month, year, hour, minutes, seconds and temperature of each sensor..

While performing installation work, temperature sensors are installed in increments of 2,5 meters starting at minus 2,0 meters above ground level. In connection with the performance of work in the winter period of time, freezing the well at sub-zero levels during drilling operations, upon completion of the installation of the equipment, the upper part of the well was insulated (to prevent opening and cold). The average daily readings of the data record from the memory card, taken into account in the processing, were taken from the third day from an archived text document. The processed average daily readings of the data record of the Geothermal Recorder program are presented in table №3.

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Table 3. Average daily readings of the data record of the «Geothermal Recorder» program.

№ wells	№ TS	Depth of installation TS. from ground level. m	Average daily temperature TS by date of data recording. °C (average daily outdoor temperature according to www.gismeteo.ru. °C)								
			24.02.20	25.02.20	26.02.20	02.03.20	03.03.20	04.03.20	22.01.20	23.01.20	24.01.20
1	1	2.0	0.5(-7.5)	0.5(-7.0)	0.5(-5.5)						
	2	4.5	5.7(-7.5)	5.7(-7.0)	5.7(-5.5)						
	3	7.0	8.1(-7.5)	8.1(-7.0)	8.1(-5.5)						
	4	9.5	8.8(-7.5)	8.8(-7.0)	8.8(-5.5)						
	5	12.0	9.0(-7.5)	9.0(-7.0)	9.0(-5.5)						
	6	14.5	9.0(-7.5)	9.0(-7.0)	9.0(-5.5)						
	7	17.0	9.0(-7.5)	9.0(-7.0)	9.0(-5.5)						
2	1	2.0				0.0(-13.5)	0.0(-14.0)	0.5(-6.0)			
	2	4.5				5.3(-13.5)	5.3(-14.0)	5.7(-6.0)			
	3	7.0				8.0(-13.5)	8.0(-14.0)	8.1(-6.0)			
	4	9.5				8.8(-13.5)	8.8(-14.0)	8.8(-6.0)			
	5	12.0				9.0(-13.5)	9.0(-14.0)	9.0(-6.0)			
	6	14.5				9.0(-13.5)	9.0(-14.0)	9.0(-6.0)			
	7	17.0				9.0(-13.5)	9.0(-14.0)	9.0(-6.0)			
3	1	2.0							1.0(-2.5)	1.5(0)	1.0(-5)
	2	4.5							6.1(-2.5)	6.3(0)	6.1(-5)
	3	7.0							8.2(-2.5)	8.4(0)	8.2(-5)
	4	9.5							8.9(-2.5)	9.0(0)	8.9(-5)
	5	12.0							9.0(-2.5)	9.0(0)	9.0(-5)
	6	14.5							9.0(-2.5)	9.0(0)	9.0(-5)
	7	17.0							9.0(-2.5)	9.0(0)	9.0(-5)

Based on the tested results of the «Geothermal Recorder» program, it was found that during the period January-March 2020, from a depth of 12,0 to 17,0 m, the soil temperature is +9 ºC. Based on the experimental daily average readings, a graph of the change in soil temperature depending on the depth is drawn up (Figure 3).

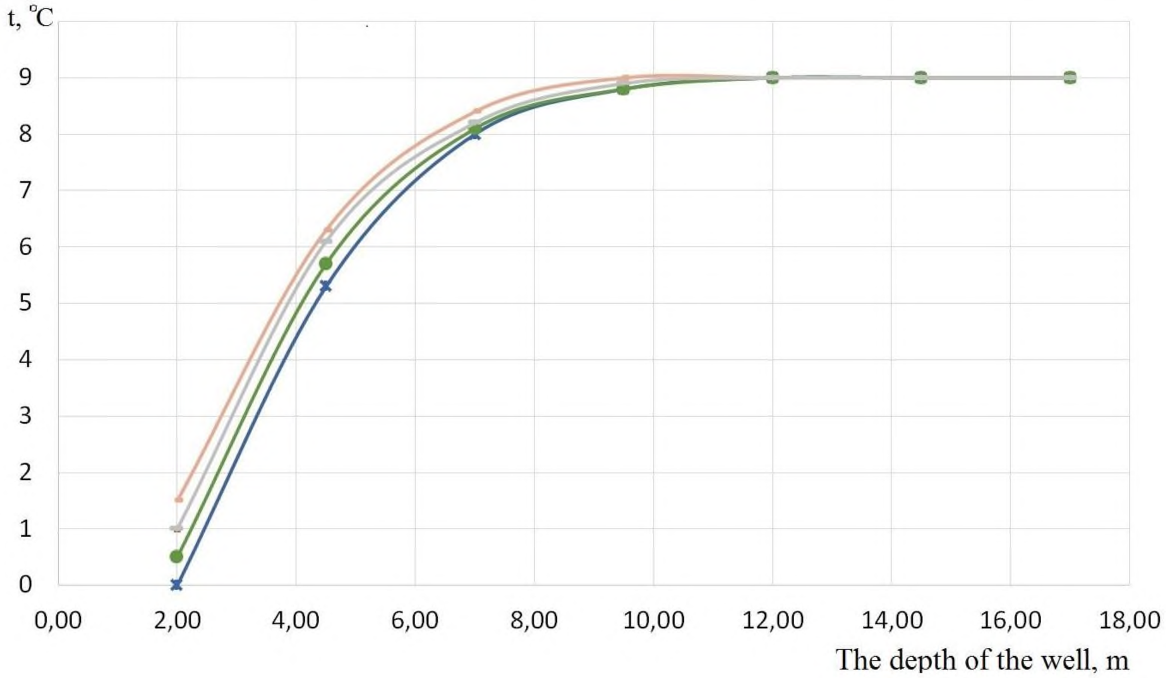

Figure 3. Line graph of soil temperature changes according to depth.

3. Conclusions

Conclusions can be drawn based on the analysis and studies carried out.

1) Based on laboratory research, the analysis of geological elements of three exploratory wells in the city of Omsk was made. According to the actually performed survey work, it was found that the selected soil samples (monoliths) have: humidity 7,1-26,9%, natural density 1,58-2,07 g/cm3, deformation modulus at natural humidity 2,9-10,6 MPa.

2) According to the results of research work carried out on the basis of engineering surveys in exploratory wells, using the «Geothermal Recorder» program (certificate of state registration of computer program №2020611929 dated February 12, 2020), it was established that from January to March 2020 from a depth of 12,0 to 17,0 m soil temperature is +9 ºC.

3) In the city of Omsk, prior to the ongoing research, there was no reliable data on the temperature regime of soils from the level of 2,5 meters from the surface of the earth. The presented survey results will allow to perform reliable measurements of soil probes while projecting, thereby reducing the number of drilling operations and increasing the efficiency of heat transformers, thereby increasing its economic attractiveness.

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