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Heat Technical Masuring of Ground for Vertical Borehole Heat Exchangers Installations

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Introduction: Nowadays in Hungary the utilization of vertical borehole heat exchanger systems is increasingly used to buildings heating and cooling by ground-source heat pumps.

The eighth largest ground-source heat pump system of Europe has been established by the TELENOR office building in 2007, with 18,000 m BHE.

A trial drilling was carried out during the start of the construction on the area. This provided data to scale the system, in this the borehole geophysical measurements and the Thermal Response Test (TRT) were executed. The studies began with a survey of undisturbed ground condition, but since then the ground temperature is recorded, i.e. the system impact on the geological environment. It be ascertained that the BHE field caused 5-6°C temperature change by the 100 m deep BHEs in long-term heating and cooling periods (directly next to the pipe) in comparison with the undisturbed ground temperature. The heating results in 5,74°C temperature decrease close to the active BHE, and 4,30°C temperature increase caused by cooling. 3,5 m away the active BHE the heating causes 0,28°C temperature decrease, and the ground is warmed by 0,08 ° C because of the cooling influence. Temperature change is not measurable 6.6 m away the boreholes.

7 m grid is recommended to the layout of the BHEs.

Keywords: ground source heat pumps, Thermal Response Test-TRT, geothermal heating and culling

PROBLEM RAISING

Nowadays in Hungary the utilization of geothermal borehole heat exchanger systems is increasingly used to buildings heating and cooling. In general 1-3 BHEs are established at family houses (up to 10kW heat demand), at bigger family house needs 3-7 BHEs to supply the heat demand. At large institutions (e.g. office buildings with wide area, schools, community buildings) even 50-180 BHE are also installed. For smaller installations, there would be problem if the plot size is limited and the layout potential of the BHEs is bound. A possible solution is to increase the depth of the BHEs (due to the security the thermal oversizing occurs more often).

High-performance heat pump systems have been more established in Hungary. Such as the TELENOR office building, where was overall 18 000 m drilling, that means 180 pieces 100 m deep boreholes supply heating and cooling energy demand of the building.

The major data of the largest European systems are shown in table 1; the TELENOR building what was implemented in Hungary has the excellent 8th position.

The achievement of Thermal Response Test (TRT) is recommended before beginning of larger installations to determine the ground thermal conductivity and required value of heat capacity on the given area (technically still good drilling conditions) for example to 100 m depth. From these data the required number of BHE can be determined, and the relative distance between the BHEs also, that the boreholes do not affect on each other, thus cost-effectiveness of the establishment can be ensured. More accurate calculations can be performed with these data, and not only the extracted or absorbed amount of heat from/to the ground, but the intensity of the temperature change as well. In case of 50-150 pieces BHEs the cost of preventive measure is minimal compared to the cost of installation.

Table 1. The largest heat pump systems of Europe

Europe	Country	City/Project name	No. BHE	Depth BHE	Total BHE length
1.	UK	London Shopping Center	400	150 m	60 000 m
2.	NO	Loerensko, SiA hospital*	ca. 300	150 m	ca. 45 000 m
3.	NO	Oslo, Nydalen district	180	200 m	36 000 m
4.	SE	Lund, IKDC	153	230 m	35 190 m
5.	SE	Stockholm, Vällingby Centr. *	133	200 m	26 600 m
6.	SE	Kista, Kista Galleria*	125	200 m	25 000 m
7.	HU	Budapest Pillangó street, Tesco	150	150 m	22 500 m
8.	HU	Törökbálint, Telenor House	180	100 m	18 000 m
9.	TR	Istambul, Metro market	168	107 m	18 000 m
10.	HU	Törökbálint, School and Sport Centr.*	180	100 m	18 000 m
11.	DE	Golm near Potsdam, MPI	160	100 m	16 000 m
12.	SE	Stockholm, Blackeberg area	90	150 m	13 500 m
13.	HU	Budapest Pesti street, Tesco	130	100 m	13 000 m
14.	HU	Páty, Monicomp Ltd., logistics centr.	120	100 m	12 000 m
15.	SE	Örebo, Musikhögskolan	60	200 m	12 000 m
16.	DE	Langen, DFS	154	70 m	10 780 m
17.	CH	Zürich, Grand Hotel Dolder	70	150 m	10 500 m

BHE: Borehole Heat Exchanger * under construction

MATERIAL AND METHOD (Investigation of borehole heat exchanger system before designing and installation)

The utilization of TRT is recommended by many researchers [2], but the VDI4640 standard commands this test in case of large systems with over 30kW performance. This is used to subsequent inspections in so-called monitoring boreholes [3].

Already in 1995, TRT mobile device was developed in the laboratory of Luleå Technical University, which was suitable to determine heat exchange in BHE, respectively boreholes in 10-100m depths (Gehlin and Nordell, 1997). Independent of this there was a similar development previously in the laboratory of the Oklahoma State University, in 1966; that TRT device was tested at first successfully in Germany [9] in 1999, (SANNER et al., 1999).

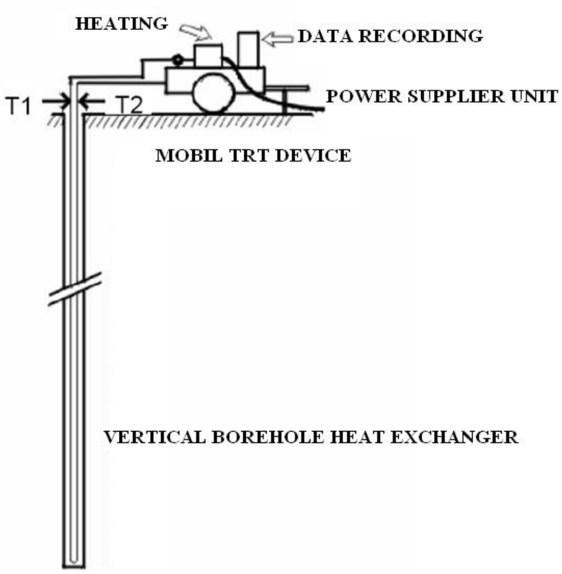


Figure 1: Conceptual design of TRT Mobil device (Source: Sanner et al., 1999)

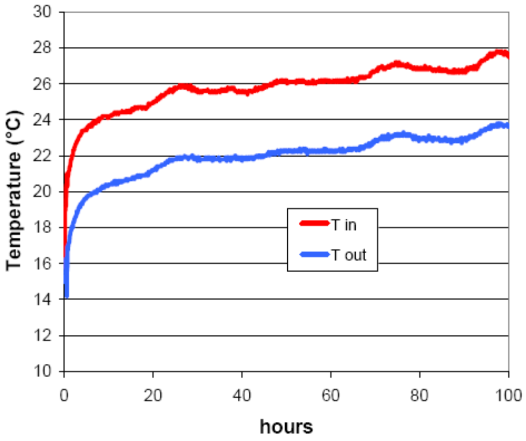


Figure 2: Data from TRT [9] (Source: Sanner et al., 1999) T_{in} = inlet temperature, T_{out}= outlet temperature)

In Hungary GEORT Ltd. has compiled procedure suggestion [5] about the practical application of the TRT. The thermal response test is a reliable procedure to determine the ground thermal conductivity. The typical thermal conductivity can be calculated with measured data by mathematical formulas, and thus the necessary number of BHE can be proportioned to capacity of heat pump.

Many debates were continued about the needed and sufficient test period. Researchers advanced argument in favour and against also the shorter and longer periods (Skouby, 1998, Spitler et al., 1999). Based on the analysis ultimately the 48-hour test period was considered the most reliable by the experts. The duration depends on thermal conductivity and borehole diameter according to Eklöf and Gehlin (1996) (longer testing time is recommended in case of larger diameter).

Spitler (1999) found 5% respectively 15% difference between thermal conductivities, if for example 50-hour respectively 20-hour test was only. Further discussion was about test reproducibility. Mancz (1999) observed very little difference between the well-defined repeated tests, for example conductivity of 0.02 W/mK (1.43 respectively 1.41 W/mK), but the difference of heat resistances was slightly higher (17%). According to Sanner the result is clear when the line source can be better approached and we adhere to the parametric process. It would be effective to perform all of the heat input and the heat output testing [5] in a uniform method. In this work this system was used.

The institution and the prepare of research

Location

In the summer of 2007 the Telenor Co. decided on the utilization renewable energy instead of fossil fuels to heating and cooling during the planning of 26 500 m^2 new headquarters building. The company is committed to environmental solutions, therefore it decided on the establishment of a heat pump system because of the environmental benefits over the economic aspects.

The building is characteristic of to fit into the environment and used other technologies, energy-efficient and environmentally friendly operation is represented.

During the designing three BHE have been installed over the planned number to ground temperature monitoring, respectively to follow in operation of the system.

The first was placed in one branch of a double BHE on the first third of the borehole field, the second measuring point was located between two boreholes (in half-distance), the third was placed 6.6 meters since the field (Figure 3 and 4).

The first 100-meter test drilling began in July 2007. A single U-loop was installed in this to prepare the designed geothermal TRT. At the first time after drilling, in situ ground temperature was measured by temperature registration.

The measuring system

The applied instruments and equipments (equipped mobile unit, Figure 5):

- DA-S-R3 3-channel temperature and impulse data logger
- DA-S-4TRB 118 temperature recorder
- DA-TIC 127 temperature remote data transfer
- DA-S-TRC 260 temperature recorder

Computer data collector and adapter:
SMART acu WIN-ESP, Version: F252-SP1,
EED 3.0 sizing software

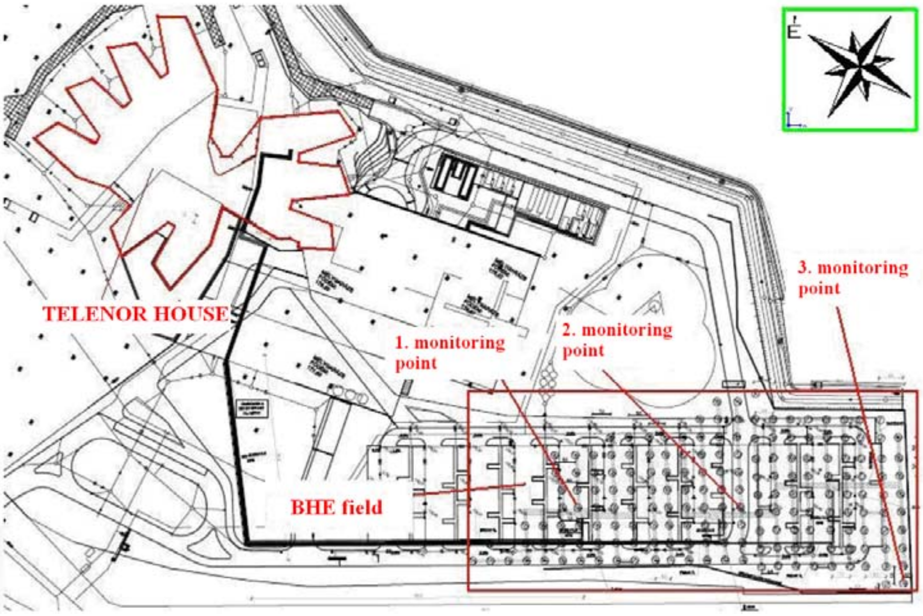


Figure 3. The location of the BHE field with the indication of 3 monitoring points

Figure 4. The location of the BHE field under afterward established car park

Figure 5. Mobile measuring system

The results were evaluated by the Kelvin-line source method [5] and [7]. The so-called equivalent thermal conductivity (λ) could be calculated by the solution of thermal conductivity differential equation according to the following formula:

$$T_f(t) - T_0 = \frac{q_c}{4\pi\lambda}\left(\ln\left(\frac{4at}{r_b^2}\right) - \gamma\right) + q_c \times R_b = \frac{q_c}{4\pi\lambda}\ln(t) + q_c\left[R_b + \frac{1}{4\pi\lambda}\left(\ln\left(\frac{4\alpha}{r_b^2}\right) - \gamma\right)\right]$$

where:

T_f= fluid temperature

T_o= undisturbed ground temperature

λ = thermal conductivity [W/m * K]

γ = standard

a= heat diffusion [m^2/s]

t = start of measuring [s]

q = heating power [W]

r_b = radius [m]

Rb= borehole thermal resistance [m * K/W]

The defined equivalent thermal conductivity value (λ) according to the above method reflects conductive heat transfer in the rock formations and convective heat transfer by ground water also.

RESULTS

Heat absorption performance

The undisturbed ground temperature was recorded before start of the TRT. We registered the temperature data in 10, 40, 70 and 100-meter depth in whole length of the 100-meter single-tube; the values changed from 11.99 to 13.97°C.

At second, the TRT was performed in a single BHE (July 17-20, 2007). The total measurement time was 68 hours 14 minutes for the 100-meter single BHE. During the measurement we recorded the inlet and outlet fluid temperature and mass flow of the circulated fluid (Figure 6).

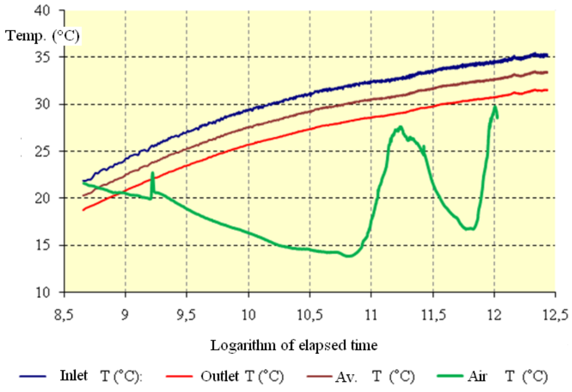


Figure 6. Assumable heat from surrounding of BHEs

(TRT)

y = 30,364ln(x) - 40,81 inlet

R² = 0,9696

y = 29,886ln(x) - 41,527 average

R² = 0,9738

y = 29,408ln(x) - 42,244 outlet

R² = 0,9774

Measuring data:

- Maximum inlet temperature: 35,34 °C,
- Δt= 3,85 °C.
- Mass flow: 1,44 m^3/h.
- Heating power: 7,0 kW.

Heat absorption power by water: 6,42 kW, by glycol: 5,91 kW.

Temperature of ground profile according to depth

The Figure 7 shows the measured temperatures in the water-filled BHE to 100-meter depth in 20 minutes, and there was not circulation. During the retraction of the measuring apparatus there was not significantly different at the character of the curves. The difference indicates the equivalent thermal conductivity of ground profile. While operation the standard deviations and changes were insignificant; there was not significant continuous increase, which would have indicated a possible flow of groundwater.

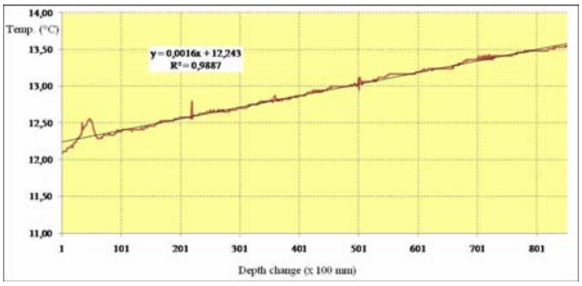
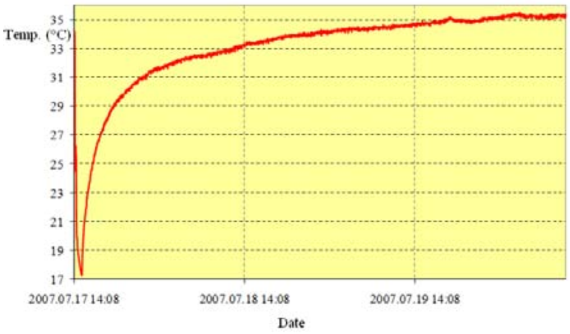


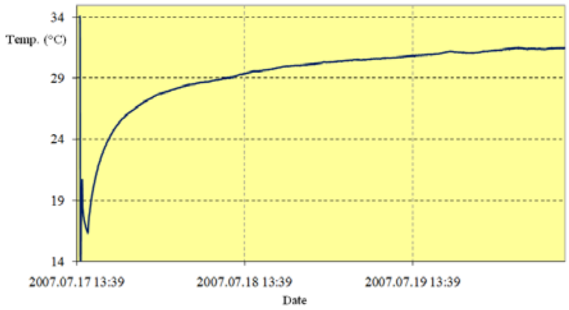
Figure 7. The ground temperature according to the depth of borehole (Undisturbed situation, Törökbálint: 17-07-2007)

2.3. The examination of the borehole heat load

The heated fluid was circulated in the BHE during the experiment, and we investigated the extent of borehole cooling effect. We checked that the temperature how approached the steady state according to the continuous heating load influence (Figures 8 and 9).



Figures 8. Inlet temperature change according to time



Figures 9. Outlet temperature change according to time

The possible heat absorption (with glycol) in 100 m single BHE was 5.91 kW in compliance with the 3x24-hour TRT. These results are approximations, the **actual number of BHE** was performed by the sizing EED 3.0 software (developed for this purpose) - using the results of the Thermal Response Test.

UTILIZATION OF RESULTS

Sizing and construction

The borehole geophysical measurement was performed (we set aside the presentation of the geophysical profile because of the length), we specified the thermal conductivity value what was gained from the TRT and we used this value to computer modelling of thermal geothermal system.

The layers are mostly dry clay, marly clay under this area, in the 80-100-meter depth there are calcareous marly layers by alternation. Based on calculations:

- Installed BHE number: **180**
- Borehole depth: 100 m
- Single BHE diameter and material: ∅ **40 mm** PE
- Base distance between the BHEs: 7 m, what was determined by reason of modelling.

Finally the BHE field was placed under the proposed car park away from the building because of this area was archaeological researched earlier, and thus the investment cost reductions could be achieved.

The BHEs are in 60-60-piece groups, connected to 3 manifolds (Figure 10).

Figure 10. Manifold

The header pipe is connected to heat centre of the building from here.

As the entire system, the building energetic characteristics determined even the heat pumps select: heating load (kW), the total heating load (hours), the heat pump for heating-cooling efficiency (COP/EER) and the seasonal performance factor (SPF), the total cooling load (hours), and heating-cooling peak loads.

Number of heat pumps: 3 units.

Heat pump capacity one by one is 287,4 kW heating and 321,9 kW cooling, and thus the total capacity is 862,2 kW heating, 965,7 kW cooling (Figure 11).

The outside temperature controls each heat pump, these automatically change between heating and cooling mode. The power could be regulated in range of 25-100%. External electronic controller and automatic regulator system keep continuous contact with building supervision. Power-controller monitoring system complements the engineering units of the heat centre. This allows the system performance data are recorded and the efficiency can be assessed.

Figure 11. The heat pumps

Monitoring of the installed system

Temperature change according to BHE depth and between the boreholes

As mentioned above, three probes have been installed in excess of 180 operating BHEs to test the operation of the system. So we can register continuously the ground temperature variations in the geological environment between the BHEs and outside the borehole field. The monitoring points can be seen on the Figure 3. At the monitoring points (along a 100 m profile) temperature registering occurs at four depth of 10, 40, 70 and 100 m. The temperature recorders have been set 30-minute sampling frequency.

The individual temperature recorders showed similar temperatures in view of situation at the 4 depth. The data of undisturbed state:

1. temperature recorder: 10m: 11,5°C; 40,0m: 12,7°C; 70m: 14,0°C; 100m: 15,0°C

2. temperature recorder: 10m: 11,4°C; 40,0m: 12,6°C; 70m: 13,8°C; 100m: 15,2°C

3. temperature recorder: 10m: 11,9°C; 40,0m: 12,3°C; 70m: 13,8°C; 100m: 15,0°C

At the **1. point** (Figure 12) during the first trial run the temperature "cooled down" to 13.41°C at 100 m, however the temperature recovered to 14.68 2°C during 2 day (A).At the second test run, the temperature decreased to 11.50°C (B) at 100 m (in 3 days), however after halt the ground temperature regenerated to 14.29°C in three days. The ground temperature increased in parallel to the decreasing heating demand. In summer the temperature was higher than 15.0°C in 100 m by the launched cooling effect (C).

At 70 m depth the thermometer recorded 14.0°C in undisturbed state. In the spring heating season the temperature decreased to 9.26°C as it can be seen on the Figure 13 (A). In the cooling mode from the end of April the ground temperature increased to 19.30°C (B) at the beginning of July, and we recorded 16.4°C on 4th August at 70 m depth (C).

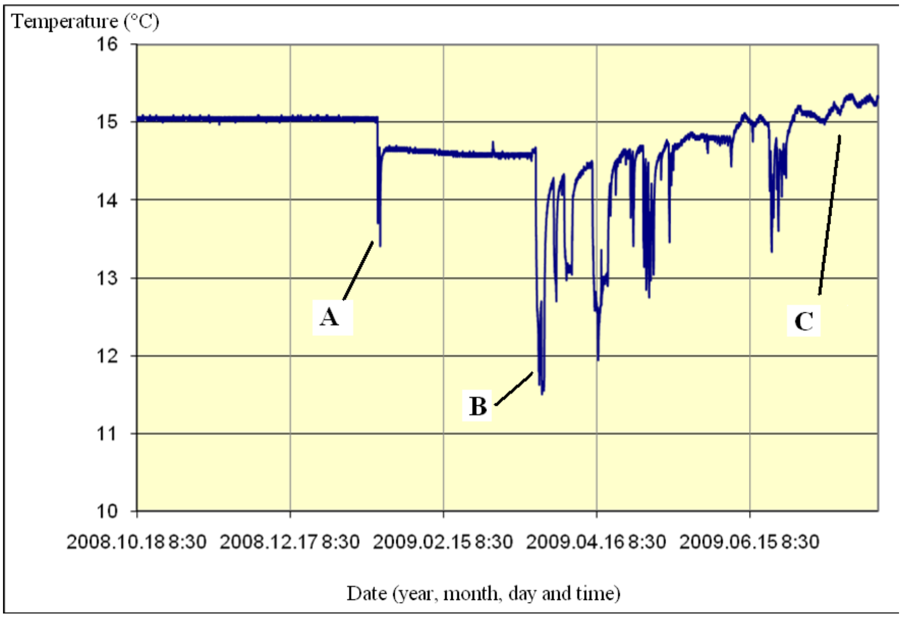


Figure 12. Temperature data at 100 m (1. point) Registration period: 18. October 2008 – 4. August 2009

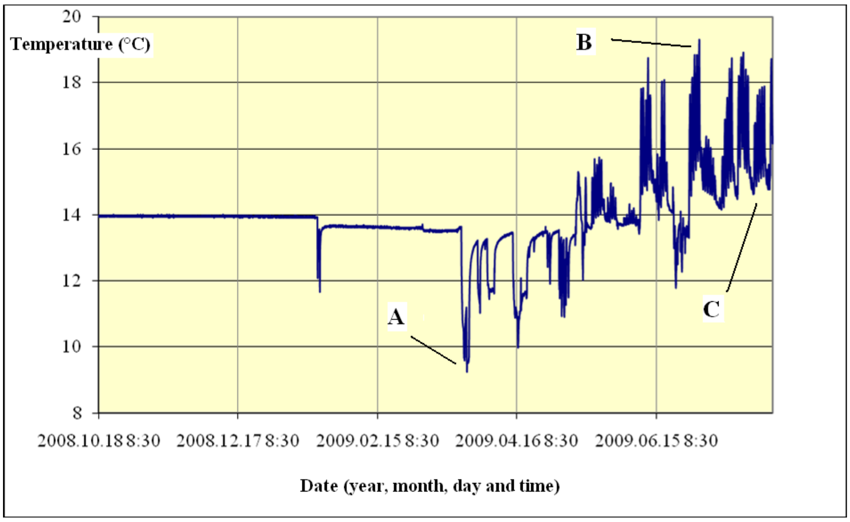


Figure 13. Temperature data at 70 m (1. point), Registration period: 18. October 2008 – 4. August 2009

Temperature decrease wasn't in the **2. measuring point** at 3.5 m from the BHE due to the test run (14 days). The temperature fell from 15.2°C to 14.92˚C because of the heating effect, when cooling started; the geological substance was warmed 15.0˚C. On the **3. monitoring** point at 6.6 m from the borehole field, there was not temperature change due to the heating and cooling.

SUMMARY OF THE RESULTS

180 piece boreholes with 100-meter depth were marked out by the result of the systematically tests to supply the heating and cooling energy demand of institution. 18 000 m BHE provide the built-in surface heating-cooling system. Immediate vicinity of BHE the ground temperature decreased to 5.74°C by the heating, the cooling resulted 4.30°C temperature increase.

At 3.5 m away from the active pipe the heating caused 0.28°C temperature decrease, the ground was warmed 0.08°C by the cooling effect.

At 6.6 m from the BHE field in the 3. measuring points, there was not observed temperature change compared to the undisturbed state. Against this background, the design can be considered successful with help of the TRT; it confirmed the indicated expected values from literary sources also.

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