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DETERMINING UNDISTURBED GROUND TEMPERATURE AS PART OF SHALLOW GEOTHERMAL RESOURCES ASSESSMENT

ODREĐIVANJE STATIČKE TEMPERATURE TLA KAO DIJELA VRJEDNOVANJA PLITKIH GEOTERMALNIH POTENCIJALA

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Ključne riječi: statička temperatura tla, plitka geotermalna energija, termogeologija

Abstract

The undisturbed ground temperature is one of the key thermogeological parameters for the assessment and utilization of shallow geothermal resources.

Geothermal energy is the type of energy which is stored in the ground where solar radiation has no effect. The depth at which the undisturbed ground temperature occurs, independent of seasonal changes in the surface air temperature, is functionally determined by climate parameters and thermogeological properties. In deeper layers, the increase of ground temperature depends solely on geothermal gradient.

Determining accurate values of undisturbed ground temperature and depth of occurrence is crucial for the correct sizing of a borehole heat exchanger as part of the ground-source heat pump system, which is considered the most efficient technology for utilising shallow geothermal resources. The purpose of this paper is to define three specific temperature regions, based on the measured ground temperature data collected from the main meteorological stations in Croatia. The three regions are: Northern Croatia, Adriatic region, and the regions of Lika and Gorski Kotar.

Sažetak

Statička temperatura tla jedan je od najvažnijih termogeoloških parametara nužnih za vrjednovanje i iskorištavanje plitkih geotermalnih resursa. Geotermalnom energijom smatra se energija pohranjena u tlu na dubinama gdje nema utjecaja sunčevog zračenja s površine. Vrijednost dubine na kojoj se pojavljuje statička temperatura tla, neovisna o sezonskim promjenama temperature zraka na površini, u funkciji je klimatskih parametara na površini i termogeoloških karakteristika samog tla. Nakon dubine gdje se pojavljuje statička vrijednost temperature, njezin daljnji porast uvjetovan je veličinom geotermalnog gradijenta.

Točno determinirane vrijednosti statičke temperature tla i dubina pojavljivanja nužne su za pravilno modeliranje duljine bušotinskog izmjenjivača topline u sustavu s dizalicom topline, kao najučinkovitije tehnologije za iskorištavanje plitkih geotermalnih resursa. U radu su, temeljem mjerenih podataka temperatura tla s glavnih meteoroloških postaja, definirane tri specifične temperaturne regije: sjeverni dio Hrvatske, Jadransko područje i Lika i Gorski kotar.

Introduction

Solar radiation can penetrate Earth's surface only to a certain depth, and its intensity depends on geographic location, morphology and plant diversity. Ground temperature is a function of heat transfer by means of radiation, convection and conduction.

At the ground temperature observation sites monitored by the Meteorological and Hydrological Service of the Republic of Croatia (DHMZ), ground temperatures have been measured at depths of 2 to 100 cm.

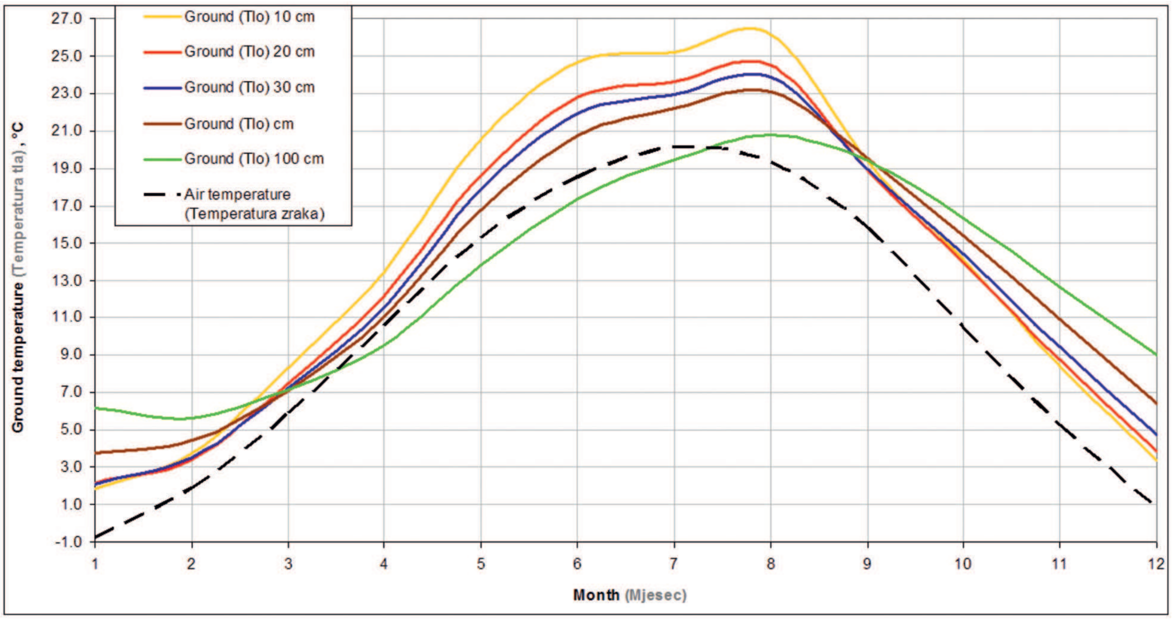

Figure 1 Average monthly ground temperatures measured at several depths by the meteorological station Zagreb.
Slika 1. *Srednje mjesečne temperature tla mjerene na različitim dubinama meteorološke postaje Zagreb*

Figure 1 shows a comparison of the average monthly ground temperatures measured at specific depths in the period between 1990 and 2005. The data used was taken from the raw statistics reported by DHMZ Zagreb-Maksimir in that period, and includes surface air temperature data. It can be concluded that the average maximum yearly temperatures at depths of up to 100 cm are higher than air temperatures, due to the measurements of air temperature being taken in shadow. Also, the ground absorbs incoming solar radiation and transfers it further into the ground by means of conduction.

The annual maximum amplitudes of the ground temperature (25.1°C) were observed at a depth of 2 cm. The amplitudes are found to decrease to 15.1°C at a 100 cm depth. The values for the damping of the temperature amplitude can then be used to obtain an analytical solution by means of extrapolation of temperature amplitude in depth.

According to Jelić (1989, 1997), the depth of the undisturbed ground temperature could be taken as the depth where the temperature amplitude lowers to 0.1°C.

Undisturbed ground temperature correlation

If measured data are unavailable, annual temperature oscillation at different depths can be estimated by using a sinusoidal function in order to solve the differential equation (Hillel, 1982):

$$\frac{\partial t(H,\tau)}{\partial \tau} = \psi_p \frac{\partial^2 t(H,\tau)}{\partial H^2} \qquad (1)$$

where $t(H,\tau)$ is the ground temperature in degrees Celsius at depth H (m) and time τ (month), and ψ_p is the damping depth (m) of annual ground temperature amplitude.

In the final expression (Eq.2), τ_0 is the time lag from an arbitrary starting month (taken as January in this analysis) to the occurrence of the minimum temperature in a year.

$$t(H,\tau) = t_{m,a} + A_0 \cdot e^{-H/\psi_p} \cdot \sin\left[\frac{2\pi(\tau-\tau_0)}{12} - \frac{H}{\psi_p} - \frac{\pi}{2}\right] \qquad (2)$$

and t_{gm} is the average annual temperature (°C) and A_0 (°C) is the annual amplitude of air temperature (difference between the average maximum temperature of the warmest month and the average minimum temperature of the coldest month, Figure 2).

The annual amplitude of ground temperature changes is decreasing with depth, H (m):

$$A_H = e^{-H/\psi_p} \qquad (3)$$

Damping depth refers to the depth at which the annual temperature amplitude of the ground decreases to *1/e* of the surface air temperature (Farouki, 1986).

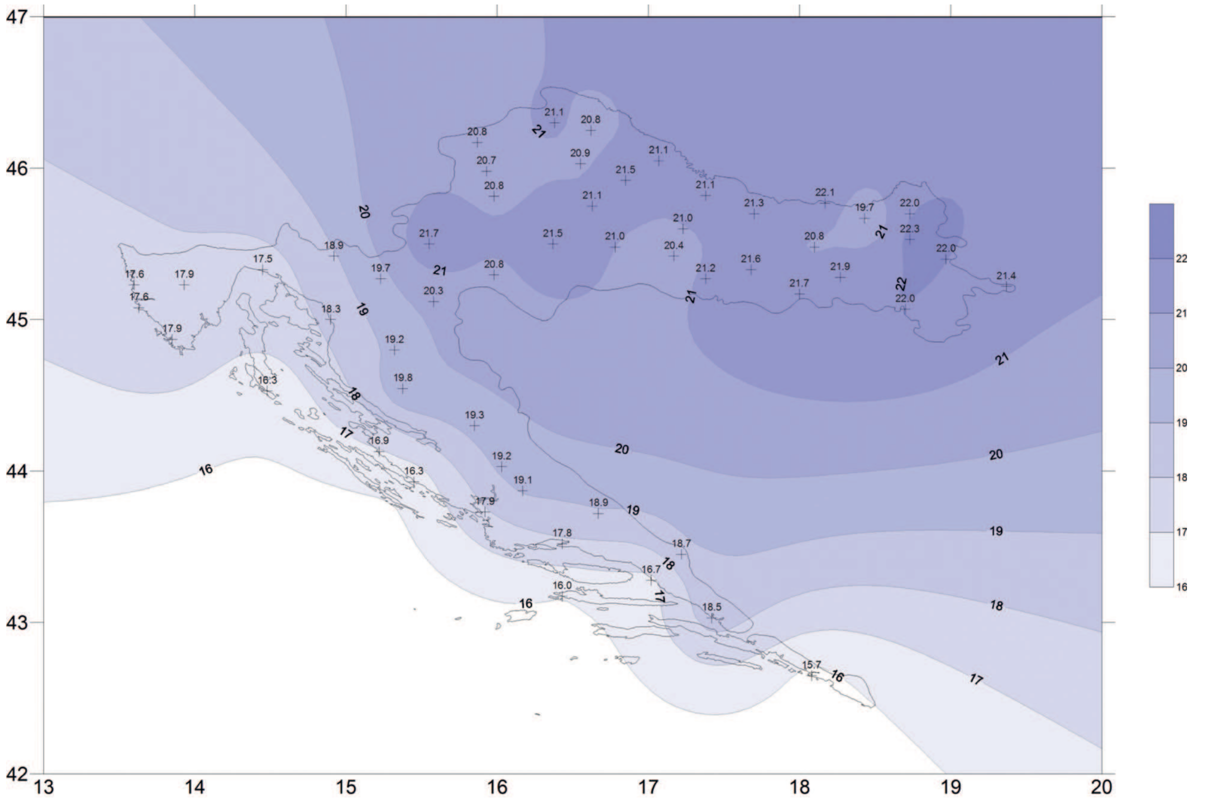

Figure 2 Isotherms of annual air temperature amplitudes in °C as recorded by meteorological stations, interpolated with Kriging method
Slika 2. *Izoterme godišnjih amplituda temperature zraka u °C, podaci s meteoroloških postaja, interpolirano običnim Krigingom*

Damping depth will be shallower in case of larger annual air temperature fluctuations, and can be expressed by the following:

$$\psi_p = \sqrt{\left(\frac{2\alpha_g}{\omega}\right)} = \sqrt{\left(\frac{2\lambda_g}{\rho_g c_{pg}\omega}\cdot 8,64\cdot 10^4\right)} \quad (4)$$

$$\alpha_g = \frac{\left(H_2 - H_1\right)^2 \pi}{\left(\ln A_1 - \ln A_2\right)^2 \cdot 365} = \frac{\lambda_g}{\rho_g c_{pg}} \quad (5)$$

where:

α_g - thermal diffusivity of the ground, m^2/d
ω - frequency of sinusoidal function in a yearly temperature analysis,

$$\omega = 2\pi / 365 d^{-1}$$

ρ_g - ground density, kg/m^3

λ_g - thermal conductivity of the ground, W/m °C

c_{pg} - specific heat capacity of the ground, J/kg °C

$H_{1,2}$ - depths, m

Zagreb location ground temperature

The monthly oscillations of the ground temperature (including the sinusoidal function) that were calculated at depths up to 100 cm by adjusting the thermal diffusivity of the temperature at 100 cm, gave a basis for creating a correlation for greater depths (Figure 3).

The Zagreb ground consists of unconsolidated clay and sand where thermal conductivity and diffusivity changes depend mainly on monthly precipitation and moisture contained in the ground. For a yearly average thermal diffusivity of 0.028 m^2/d that is calculated from the changes in amplitudes at depths of 2 and 100 cm (Eq. 5) the correlation well describes the data collected by DHMZ at 100 cm. The matching of the measured and correlated data is best done in spring and autumn because of a higher level of ground moisture and less deviation of measurements and calculations of the average monthly thermal diffusivity.

Thermal properties of the ground at the Zagreb observation site vary with depth. If Eq. 5 is applied, the obtained calculated value of the thermal diffusivity at 1200 cm equals 0.04 m^2/d. This value corresponds to the earlier published data (Kappelmayer, 1974) pertaining to the thermal diffusivity of moist clay as well as the results of the geomechanical studies (Jelić, 1989, 1997).

According to the study (Jelić, 1989, 1997), ground density was calculated by averaging the results of 121 measured samples that had been collected from shallow wells (5 m deep). The average ground density was $\rho_g = 1950 \pm 80$ kg/m^3.

Specific heat of the samples was calculated based on the measurements of the volumetric content of moisture and air, porosity, matrix density and specific heat of each component. The average calculated specific heat of the samples was $C_{pg} = 1420$ J/kg °C

Keeping in mind the values of thermal diffusivity for Zagreb, namely 0,045 m^2/d, from his earlier research (Jelić, 1979), Jelić calculated heat conductivity of the ground at a depth of 5 m, $\lambda_g = 1{,}44$ W/m°C.

Once the sinusoidal function for the ground temperature is solved, it can be perceived that the temperature amplitude at a depth of 1200 cm equals 0.1°C, and the undisturbed ground temperature equals 13.1°C. This is one of the most important parameters in modeling of a borehole heat exchanger.

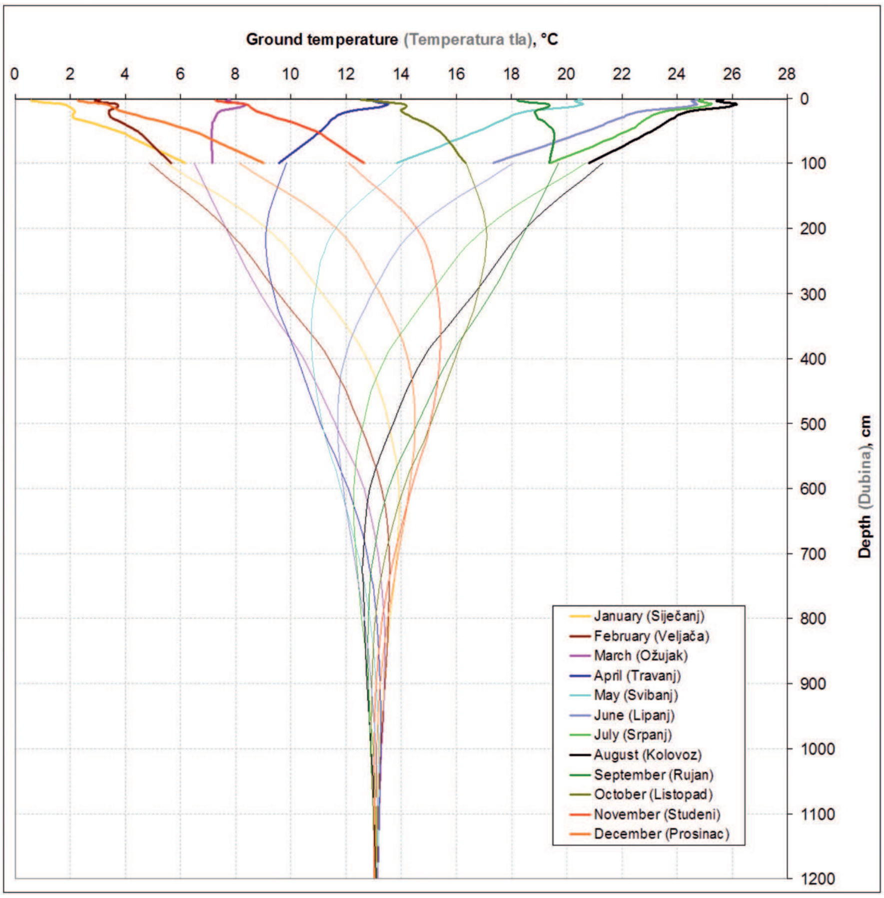

Figure 3 Measured average monthly temperatures of the ground at depths to 100 cm as reported by the meteorological station Zagreb-Maksimir and calculated monthly ground temperature oscillations (Kurevija, 2010)

Slika 3. *Mjerene srednje mjesečne temperature tla do 100 cm i izračunate vrijednosti prigušivanja temperature tla u zavisnosti o promjeni dubine za lokaciju Zagreb- Maksimir (Kurevija 2010)*

Undisturbed ground temperature can be determined by means of correlation in the form of exponential function. The values of the average measured monthly temperature amplitudes for depths of 2, 5, 10, 20, 30, 50 and 100 cm were fitted into the exponential function:

$$A_{H\,Zg} = 25{,}767e^{-0{,}0054H} \qquad (6)$$

where $A_{H\,Zg}$ is the amplitude of ground temperatures at a desired depth (for the Zagreb sites) in °C and H is the depth (cm).

When solved numerically, the equations for the ground temperature amplitudes of 0.1°C, reveal a depth of 10.28 m. This means that there is a discrepancy of 1.5 m when compared with the sinusoidal function (Table 1, depth=1200 cm).

Table 1 Average measured (gray cells) and calculated monthly ground temperatures (white cells) to 1200 cm depth at the meteorological station Zagreb-Maksimir
Tablica 1. *Mjerene i proračunate vrijednosti mjesečnih temperatura tla u°C do dubine od 1200 cm*

Month	Depth, cm																		
	2	5	10	20	30	50	100	100	200	300	400	500	600	700	800	900	1000	1100	1200
1	0,6	0,7	1,8	2,2	2,1	3,7	6,2	5,5	9,1	11,1	12,8	13,7	13,9	13,7	13,5	13,3	13,1	13,1	13,05
2	3,1	2,9	3,7	3,4	3,5	4,4	5,7	4,9	7,7	9,5	11,4	12,8	13,5	13,6	13,5	13,3	13,2	13,1	13,08
3	7,8	7,7	8,3	7,5	7,2	7,1	7,2	6,5	7,6	8,9	10,5	12,0	12,9	13,3	13,4	13,3	13,2	13,2	13,11
4	13,1	13,0	13,5	12,2	11,6	11,1	9,6	9,8	9,1	9,4	10,2	11,5	12,4	13,0	13,2	13,3	13,2	13,2	13,13
5	20,5	20,3	20,6	18,6	17,9	16,8	13,8	14,1	11,6	10,9	10,8	11,4	12,1	12,7	13,0	13,2	13,2	13,2	13,14
6	24,8	24,5	24,7	22,8	22,0	20,7	17,3	18,0	14,5	12,9	11,9	11,7	12,0	12,5	12,8	13,0	13,1	13,2	13,14
7	25,0	24,8	25,2	23,6	23,0	22,2	19,4	20,7	17,1	15,1	13,4	12,4	12,3	12,5	12,7	12,9	13,0	13,1	13,13
8	25,7	25,5	26,1	24,5	23,9	23,1	20,8	21,3	18,5	16,6	14,8	13,3	12,7	12,6	12,7	12,9	13,0	13,1	13,10
9	18,2	18,3	19,4	18,9	19,0	19,5	19,4	19,7	18,5	17,3	15,7	14,2	13,3	12,9	12,8	12,9	12,9	13,0	13,07
10	12,5	13,1	14,2	14,0	14,4	15,4	16,3	16,4	17,1	16,8	15,9	14,7	13,8	13,2	13,0	12,9	12,9	13,0	13,05
11	7,3	7,4	8,4	8,7	9,5	10,9	12,7	12,1	14,6	15,3	15,4	14,8	14,1	13,5	13,2	13,0	13,0	13,0	13,04
12	2,3	2,4	3,4	3,8	4,7	6,5	9,0	8,1	11,7	13,2	14,2	14,5	14,1	13,7	13,4	13,1	13,1	13,0	13,04

Fitting the exponential function for a minimum possible ground amplitude (near 0°C) results in an amplitude 1.926 x 10 $^{-9}$°C and a corresponding depth of 4318 cm. At that depth exists a thermal equilibrium between seasonal solar radiation effects and geothermal heat flux. In deeper layers the ground temperature increases solely as a function of geothermal gradient, g_g (in the Zagreb area g_g = 0.05°C/m, Jelić, 1997). At 100 m, which is a common depth of borehole heat exchangers, the temperature will be as follows:

$$t_{bZG\,100m} = t_{gZG} + (H - 43{,}18)\cdot g_g$$
$$= 13{,}14 + (100 - 43{,}18)\cdot 0{,}05 = 15{,}9°C \qquad (7)$$

The result concurs with the measured temperature data collected from test borehole in the ground source heat pump system (Soldo et al. 2009) where the ground temperature at a depth of 100 m was 15,2*°C.*

The average undisturbed temperature of the ground at the calculated depth of 1028 cm (by using Eq. 5) can be expressed in terms of the logarithmic function of all the average temperatures shown in Figure 4.

$$t_{gZG} = -0{,}0041\cdot \ln(H) + 13{,}164$$
$$= -0{,}0041\cdot \ln(1028) = 13{,}14°C \qquad (8)$$

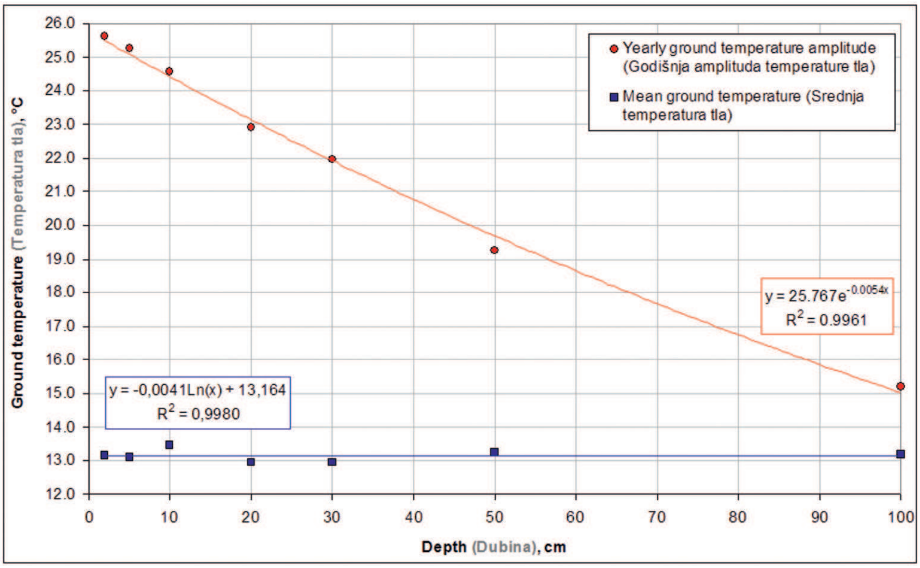

Figure 4 Yearly amplitudes of the measured ground temperatures obtained at depths to 100 cm by the meteorological station Zagreb-Maksimir.
Slika 4. *Godišnje amplitude mjerenih temperatura tla na lokaciji Zagreb-Maksimir do dubine od 100 cm*

Extrapolation of ground temperatures in Northern Croatia

In the northern part of Croatia, the ground surface consists mainly of clastic sediments. The correlations of the measured ground temperature amplitudes for several meteorological stations were fitted with an exponential function.

Table 2 shows values of the yearly ground temperatures, namely minimum, maximum, and average temperatures, as well as values of yearly amplitudes. Five meteorological stations were chosen in order to obtain quality measured data and geographic setting.

Figure 5 shows yearly average amplitudes (a difference between the average yearly minimum temperatures and the average yearly maximum temperatures) at given depths. The correlation with the exponential function shows that the maximum difference in amplitudes is 2°C.

Damping function of the ground temperature amplitude for the northern part of Croatia is as follows:

$$A_{H\,Panon} = 25,392 \cdot e^{-0,0053H} \tag{9}$$

This clearly shows that the numerical solution for an amplitude of 0,1°C corresponds to a depth of 1045 cm which is the depth at which seasonal solar effects from the surface can be neglected.

The equation for the minimum ground temperature amplitude is:

$$1,292 \times 10^{-9} = 25,392 e^{-0,0053(4477)}$$

i.e. the amplitude of 1.292 x 10^{-9}°C numerically corresponds to the depth of 4477 cm.

Table 2 Average measured ground temperatures in the northern part of Croatia for a period 1990-2005. (raw unpublished DHMZ data)
Tablica 2. *Podaci o srednjim temperaturama tla na pet lokacija u sjevernom dijelu Hrvatske za razdoblje od 1990-2005*

Depth	Temperature,°C	Zagreb	Osijek	Slavonski Brod	Varaždin	Daruvar
2 cm	Average	13,2	12,7	13,2	12,0	12,5
	Maximum	26,0	26,2	26,6	24,7	24,9
	Minimum	0,4	0,2	0,5	0,2	0,2
	Amplitude	25,6	26,0	26,1	24,5	24,7
5 cm	Average	13,1	12,5	13,2	11,9	12,6
	Maximum	25,7	25,1	25,7	24,4	24,6
	Minimum	0,4	0,5	0,6	0,1	0,5
	Amplitude	25,3	24,7	25,1	24,2	24,2
10 cm	Average	13,5	13,4	13,0	12,1	12,7
	Maximum	25,9	24,8	25,2	23,9	24,6
	Minimum	1,3	0,8	0,7	0,8	0,8
	Amplitude	24,6	24,0	24,5	23,0	23,9
20 cm	Average	13,0	12,7	13,2	12,2	12,8
	Maximum	24,4	24,1	24,5	23,8	24,4
	Minimum	1,5	1,4	1,4	1,1	1,3
	Amplitude	22,9	22,7	23,1	22,7	23,1
30 cm	Average	12,9	13,0	13,2	12,1	12,9
	Maximum	23,8	23,7	23,9	22,7	23,9
	Minimum	1,8	2,0	2,0	2,0	2,5
	Amplitude	21,9	21,7	21,8	20,7	21,5
50 cm	Average	13,3	13,1	13,2	12,4	13,2
	Maximum	22,9	23,0	22,4	21,9	23,1
	Minimum	3,6	3,1	3,3	3,3	3,4
	Amplitude	19,3	19,8	19,1	18,6	19,7
100 cm	Average	13,2	12,6	13,1	12,5	13,3
	Maximum	20,5	20,3	19,9	19,7	21,4
	Minimum	5,3	5,2	5,7	5,2	5,3
	Amplitude	15,2	15,1	14,2	14,4	16,1

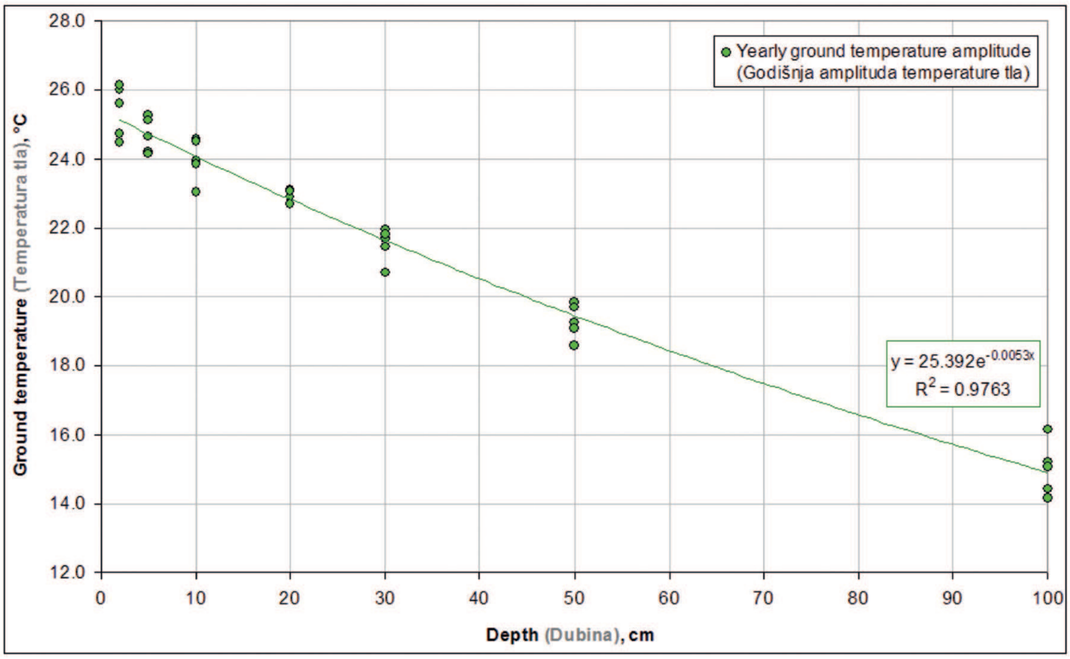

Figure 5 Yearly amplitudes of measured ground temperatures obtained at depths to 100 cm by five meteorological stations in the northern part of Croatia.
Slika 5. *Godišnje amplitude mjerenih temperatura tla na pet lokacija sjevernog dijela Hrvatske, do dubine od 100 c*

After a regression of the measured average ground temperatures the equation for the average ground temperatures in the northern part of Croatia are as given:

$$t_{g\ Northern\,HR} = 0{,}0702 \cdot \ln(H) + 12{,}632$$
$$(10) \quad = 0{,}0702 \cdot \ln(1045) + 12{,}632 = 13{,}12\,°C$$

During the modeling of a geothermal heat pump system, the undisturbed ground temperature should be provided by fluid circulation before conducting a thermal response test. When the measured data are not available, we can use the calculated temperature at a depth of 1045 cm (13.12°C) obtained from the correlation with the undisturbed ground temperature in northern Croatia. It can be seen that the ground temperature in the Zagreb area corresponds almost entirely to the correlated data of the five sites.

Extrapolation of ground temperature in Adriatic region

In the coastal region, geological and climate characteristics are more diversified. The ground is composed mainly of carbonate rocks, often characterized by secondary porosity (karst). Climatic fluctuations are apparent in the northern, middle and southern Adriatic.

Figure 6 shows yearly average amplitudes (a difference between the average yearly minimum temperatures and the average yearly maximum temperatures) recorded at four selected meteorological stations.

Table 3 Measured average ground temperatures in Adriatic region for a period 1990-2005. (raw unpublished DHMZ data)
Tablica 3. *Srednje temperature tla na četiri lokacije u priobalnom području za razdoblje od 1990-2005*

Depth	Temperature, °C	Dubrovnik	Split	Rijeka	Zadar
2 cm	Average	18,5	17,0	15,6	17,4
	Maximum	32,5	31,3	28,1	30,7
	Minimum	6,9	3,7	4,7	6,0
	Amplitude	25,6	27,5	23,4	24,7
5 cm	Average	18,3	16,7	15,1	17,3
	Maximum	31,5	30,8	26,9	29,7
	Minimum	7,1	3,8	4,8	6,2
	Amplitude	24,4	27,0	22,2	23,6
10 cm	Average	18,2	16,4	14,8	17,2
	Maximum	30,9	30,6	26,2	29,2
	Minimum	7,1	3,9	4,0	6,2
	Amplitude	23,9	26,8	22,1	23,0
20 cm	Average	17,9	16,0	15,0	17,0
	Maximum	29,9	29,4	25,6	28,2
	Minimum	7,3	3,8	5,0	6,6
	Amplitude	22,7	25,6	20,6	21,6
30 cm	Average	17,9	16,3	14,7	17,2
	Maximum	29,2	28,7	24,3	27,9
	Minimum	7,6	4,0	6,0	7,1
	Amplitude	21,5	24,7	18,3	20,8
50 cm	Average	18,2	-	14,8	17,3
	Maximum	29,1	-	22,8	27,3
	Minimum	8,6	-	7,2	8,1
	Amplitude	20,4	-	15,6	19,1

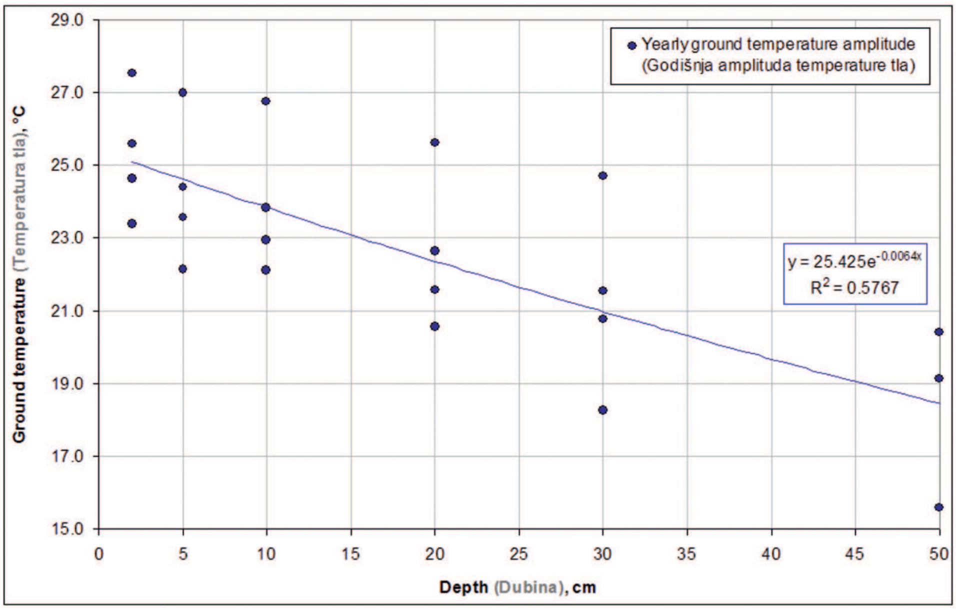

Figure 6 Correlation of yearly amplitudes of the ground temperatures measured up to a depth of 50 cm at four meteorological stations in the Adriatic regions.
Slika 6. *Korelacija godišnjih amplituda temperatura tla za četiri lokacije priobalnog područja, do dubine od 50 cm*

The correlation of the data from table 3 with the exponential function shows a large data dissipation (Figure 7) and therefore it can not be used for determining the undisturbed ground temperature.

Consequently, the northern, middle and southern parts of the Adriatic region should be observed separately (Figure 7).

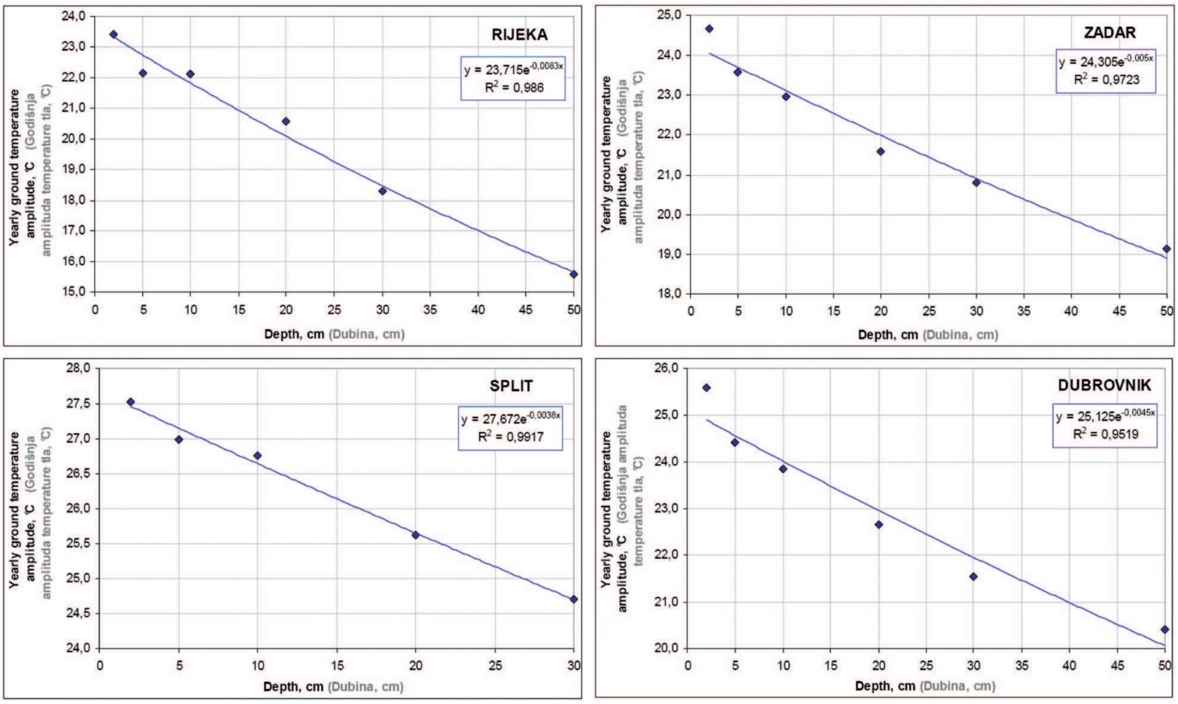

Figure 7 Yearly amplitudes of measured ground temperatures obtained at depths to 50 cm at four observation sites in the Adriatic region .
Slika 7. *Godišnje amplitude mjerenih temperatura tla za četiri lokacije priobalnog područja do dubine od 50 cm.*

The resulting equations and depths corresponding with amplitudes of 0.1°C are:

$$A_{H\,RI} = 23,715 \cdot e^{-0,0083H};\ H = 659cm$$
$$A_{H\,ZD} = 24,305 \cdot e^{-0,005H};\ H = 1107cm \qquad (11)$$
$$A_{H\,ST} = 27,672 \cdot e^{-0,0038H};\ H = 1480cm$$
$$A_{H\,DU} = 25,125 \cdot e^{-0,0045\,H};\ H = 1228cm$$

Finally, the undisturbed ground temperatures measured at the four sites in the coastal region are determined by using logarithmic functions for depths at which the amplitudes equal 0.1°C:

$$t_{g\,RI} = -0,2335 \cdot \ln(H) + 15,566 = 14,1°C$$
$$t_{g\,ZD} = -0,0478 \cdot \ln(H) + 17,357 = 17,0°C \qquad (12)$$
$$t_{g\,ST} = -0,3469 \cdot \ln(H) + 17,228 = 14,7°C$$
$$t_{g\,DU} = -0,1637 \cdot \ln(H) + 18,586 = 17,4°C$$

Ground temperature in Gorski kotar and Lika region

The data for the regions of Lika and Gorski Kotar are insufficient; available are only data from the meteorological station in Ogulin (Table 4.).
The resulting equation and depths corresponding with the amplitude of 0.1°C are:

$$A_{H\,OG} = 23,409 \cdot e^{-0,0046H};\ H = 1137cm \qquad (13)$$

The undisturbed ground temperature as calculated by use of logarithmic functions for the depths at which the amplitude equals 0.1°C is then (Figure 8.):

$$t_{g\,OG} = -0,0058 \cdot \ln(H) + 12,288 = 11,9°C \qquad (14)$$

Table 4 Average measured ground temperatures in the Ogulin region for a period 1990-2005 (raw unpublished DHMZ data).
Tablica 4. *Srednje temperature tla na lokaciji Ogulin za razdoblje od 1990-2005.*

Temperature	2 cm	5 cm	10 cm	20 cm	30 cm	50 cm	100 cm
Average	12,3	12,2	12,3	12,3	12,3	12,3	12,2
Maximum	24,1	23,9	23,7	23,3	22,9	21,6	19,7
Minimum	1,0	1,0	1,3	1,9	2,2	3,2	4,8
Amplitude	23,1	22,9	22,4	21,4	20,7	18,3	14,9

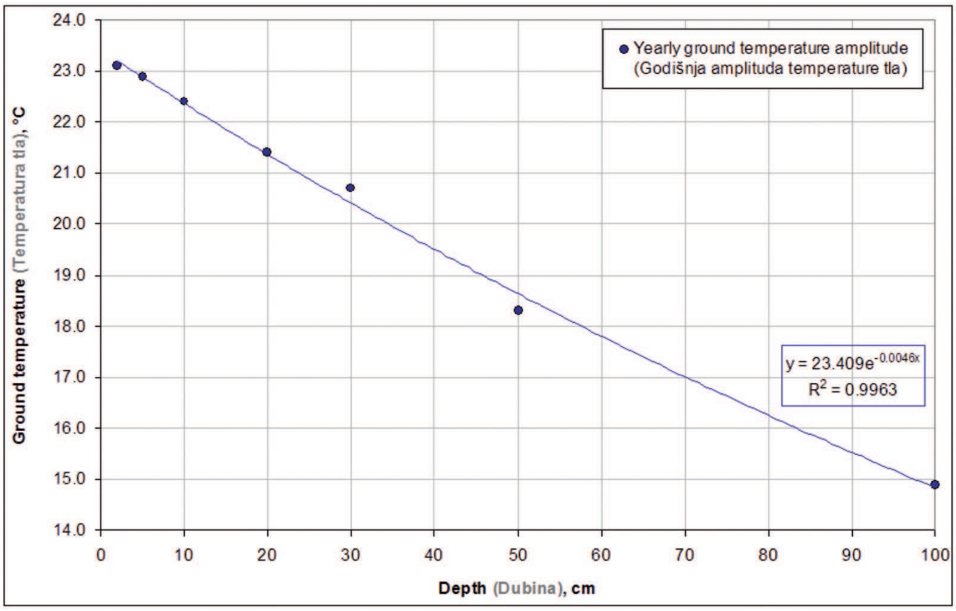

Figure 8 Yearly amplitudes of measured ground temperatures collected in Ogulin at depths up to 100 cm.
Slika 8. *Godišnje amplitude mjerenih temperatura tla za lokaciju Ogulin do dubine od 100 cm*

CONCLUSION

The undisturbed ground temperatures were calculated based on the values of the measured ground temperature obtained at depths of up to 100 cm. This subsequently led to defining the depth at which the influence of solar radiation from the surface becomes negligible.

Based on the data collected at five meteorological stations in northern Croatia a correlation was made between the damping of the temperature amplitude and the depth, the result of which was a ground temperature amplitude of 0.1°C. By using the temperature amplitude damping it was determined that the undisturbed ground temperature at a depth of 10.45m is 13.1°C. Since the undisturbed ground temperature determines directly the amount of available energy stored in the ground that can be utilized for any assumed temperature change, it makes it one of the key parameters to calculate the required length of a borehole heat exchanger.

Due to climate diversities in the Adriatic region, a correlation with the representative undisturbed ground temperature was found impossible. Each of the four coastal observation sites in the Adriatic region can represent the surrounding area where the measurements were taken and the calculated undisturbed ground temperatures are as follows: 14.1°C for Rijeka, 17.0°C for Zadar, 14.7°C for Split and 17.4°C for Dubrovnik.

Separately, ground temperatures in Gorski Kotar and Lika (data of the meteorological stations in Ogulin) were analyzed and resulted in an undisturbed ground temperature of 11.9 °C at a depth of 11.4 m.

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References

Farouki, O.T. (1986): Thermal Properties of Soils, Series on rock and soil mechanics. Vol. 11. Trans Tech Publ., Clausthal-Zellerfeld, Germany, pp136.

Hillel, D. (1982): Introduction to soil physics, Academic Press, San Diego, USA, pp.364

Jelić, K. (1979): Termičke osobine sedimentacionog kompleksa jugozapadnog dijela Panonskog bazena, doktorska disertacija, Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, pp.76

Jelić, K.; Kevrić, I. (1997): Plitka geotermalna energija u Hrvatskoj, 6. forum Hrvatskog energetskog društva , Zagreb, Hrvatsko energetsko društvo, pp. 181-190

Jelić, K.; Lukačević, M. (1989): Solar Heat Energy in the Soil of the Pannonian Basin in the Socialst Republic of Croatia, Zbornik radova skupa Solar energy, IUC Dubrovnik, pp 1-12.

Kappelmayer, O.; Haenel, R. (1974): Geothermics with Special Reference to Application, Gebruder Borntraeger, Berlin, pp.238

Kurevija, T. (2010): Energetsko vrednovanje plitkih geotermalnih potencijala Republike Hrvatske, doktorska disertacija, Sveučilište u Zagrebu, Rudarsko-geološko-naftni fakultet, pp183.

Soldo, V.; Ruševljan, M.; Ćurko, T. (2009): Ispitna geotermalna dizalica topline sa sondom dubine 100 metara, Klima forum, Zadar