Acta Technica Napocensis: Civil Engineering & Architecture Vol. 57, No. 2 (2014)
Journal homepage: http://constructii.utcluj.ro/ActaCivilEng

The Behavior of the Heat beneath the Surface of the Ground Influences Underground Homes

Ioana M. Moldovan[*1]

[1, 2] *Technical University of Cluj-Napoca, Faculty of Civil Engineering. 15 C Daicoviciu Str., 400020, Cluj-Napoca, Romania*

(Received 6 July 2014; Accepted 17 September 2014)

Abstract

One of the main goals constructing an underground or half-buried home is to reduce energy consumption used for heating or cooling the interior space, by preventing the ingress of the air at an unwanted temperature and by preventing heat loss at the level of the envelope of the building. Thus, the earth can act as a thermal barrier between the dwelling's envelope and the exterior environment even the house is constructed completely underground or above ground and covered with earth. This paper aims to analyze the behavior of the heat at different depths in the earth and to compare it to the regulations in effect.

Rezumat

Unul dintre scopurile principale ale semi-îngropării sau îngropării unei locuințe este reprezentat de reducerea consumului de energie, folosită pentru încălzirea/răcirea spațiului interior, prin împiedicarea pătrunderii aerului cu temperatură nedorită și prin împiedicarea pierderilor de căldură la nivelul anvelopei. Astfel, pământul poate să funcționeze ca o barieră termică între anvelopa locuinței și mediul exterior, fie că vorbim despre o locuință subterană sau despre una supraterană protejată cu pământ. Aceasta lucrare dorește să analizeze comportamentul căldurii la diferite adâncimi în pământ și să îl compare cu normele în vigoare.

Keywords: underground, temperature, fluctuation, earth, thermal insulation.

1. Introduction

The concept behind earth-sheltering a house claims to require no active heating or cooling system, regardless of the climatic conditions [1:208]. Even if the house is surrounded by earth, some heat losses can appear at the level of the envelope. These losses are cause by the temperature difference between the ground and the heated indoor environment. If a comparison of the behavior of a conventional house and one buried in the ground was to be made, it would be obvious that these heat losses will occur differently in the two cases. It is important to reveal "the principles that makes a building in earth significant as a conservation system" [2:1214]

The thermal transfer between the heated interior space and the exterior environment, affected by the diurnal and seasonal temperature, will occur more slowly in underground dwellings. Between the

[*] Corresponding author: Tel.: +40-264401529
E-mail address: ioana.muresanu@ccm.utcluj.ro

two environments there is interposed a considerably thick layer of earth, which moderates the "daily and/or yearly temperature oscillations" [3:476]. However, in order to avoid any sort of heat loss, the specific legislation in our country proposes the thermal insulation of all elements in contact with the soil [4], [5].

2. Regulations that refer to the earth's temperature

The C107/5 – 2005 [4] norm explains that the depth at which the temperature is considered to be invariable during the entire year is 7.00 m below the surface. The conventional temperature variations in the ground, as well as the thermal conductivities are presented in Table 1. and in Figure 1. The conventional character is specified as being covering for the earth temperature variation between the exterior air temperature and the ground temperature at 7.00 m below the surface. [4:9]

Table 1. Soil temperatures according to C 107/5 - 2005

Characteristic		M.U.	Climatic area			
			I	II	III	IV
Exterior temperature		°C	-12	-15	-18	-21
Ground temperature (at 7 m from the surface)		°C	+11	+10	+9	+8
The measured temperature from the ground surface at which T = 0 °C		m	2,56	2,96	3,60	4,19
Temperature	at ground surface	°C	-11,6	-14,6	-17,6	-20,5
	at 3 m ground surface	°C	+2,0	+0,2	-1,6	-3,4

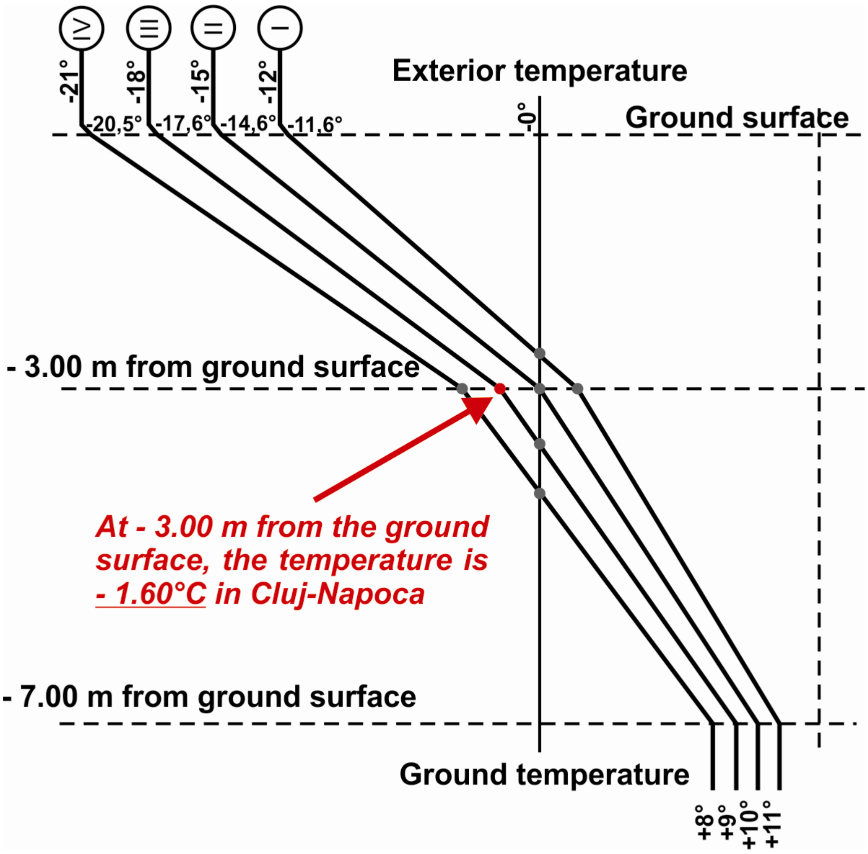

Figure 1. Temperature variations. According to C 107/5 – 2005, in Cluj-Napoca at 3.00 m below

the surface of the earth the temperature of the soil is -1.6°C.

The information provided by C 107/5 – 2005 is in contradiction with the STAS 6054 – 1977 [6], which sets the maximum depth of the soil where frost will occur in our country. The maximum freezing depth is expressed by the 0 °C geoisothermal line, which indicates the maximum depth, in centimeters, down to which the temperatures can reach ≤ 0 °C values." [6:1] According to this map, Figure 2, in the Cluj-Napoca area, the maximum frost depth is 80-90 cm. „For constructions elevated in the built perimeter of the cities, the minimal values of the frost depths will be considered." [6:1] Therefore, the maximum depth of frost in buildable are of Cluj-Napoca city, is 80 cm. Below this depth, the values will always be positive.

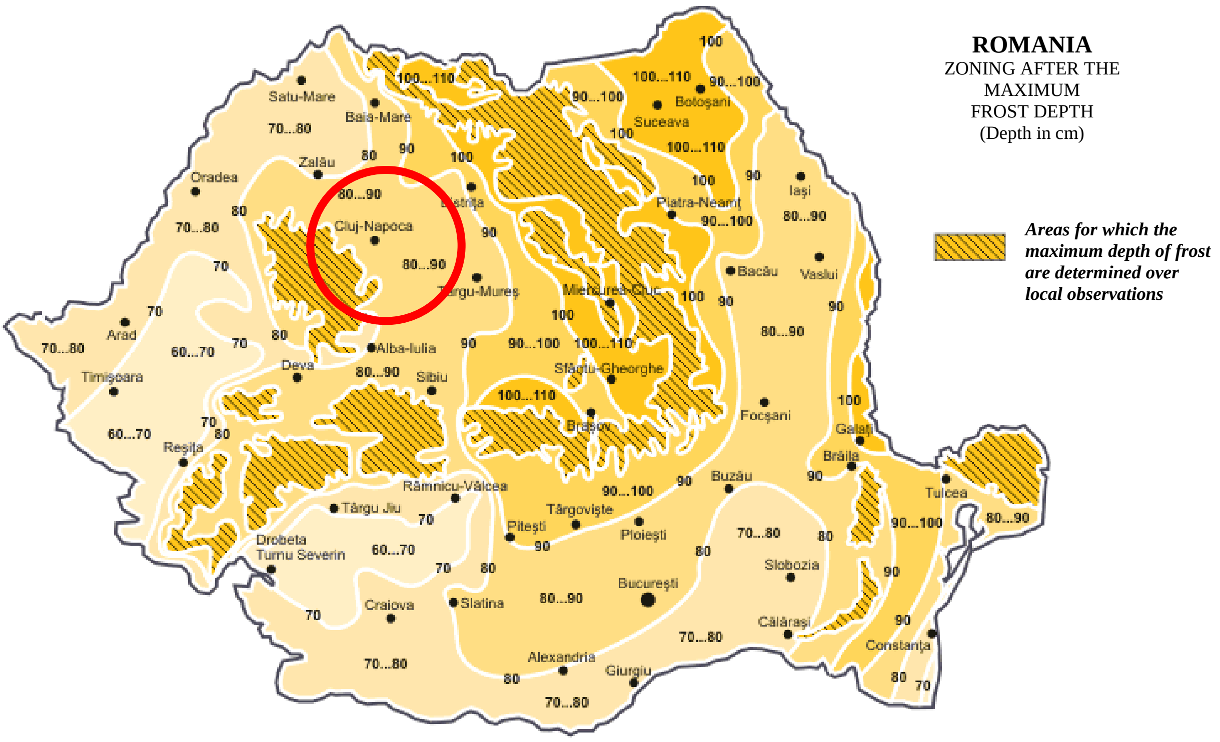

Figure 2. NP 112 – 2013 [7], Anexa C. Frost depth, C.3. Zoning the Romanian territory area according to the maximum frost depth, after STAS 6054-77.

3. Heat behavior in the earth

The differences of the outdoor temperature, both diurnal and annual, are determined by the local weather conditions. In what concerns the temperature fluctuations in the ground, the diurnal variation is almost negligible, as seen in figure 3. "The wide daily air temperature swing is essentially eliminated below 0.2 m: this demonstrates the advantage of even 0.2 m of earth cover." [8:53]

Advancing deeper underground, the daily fluctuations are not significantly affecting the earth's temperature, only the seasonal one do. By the seven meters depth, the temperature steadies around 10 °C [9:199]. The temperature variation in the ground is influenced by the quantity of water in the soil, quickly increasing and decreasing when it is present.

In what regards a regular terrain (meaning one where the groundwater level is not high) it can be noted that the most pronounced heat transfer occurs during the period of abundant rainfall, namely the period from September to November and from April to June (Figure 5. A.). Also, in the same figure it can be noted that in the cold season, starting late in autumn, until early in the spring, the temperature fluctuations in the ground are less pronounced. This is caused by the water again, but this time rather the absence of water in the ground. In winter, when the outdoor temperatures are negative, the water in the superior layer of the earth will freeze (the thickness of the layer varies according to the climate zoning). This stops the descent of cold water from the surface, meaning that the earth will slowly dry beneath the frost limit and consequently the thermal conductivity of the earth will decrease.

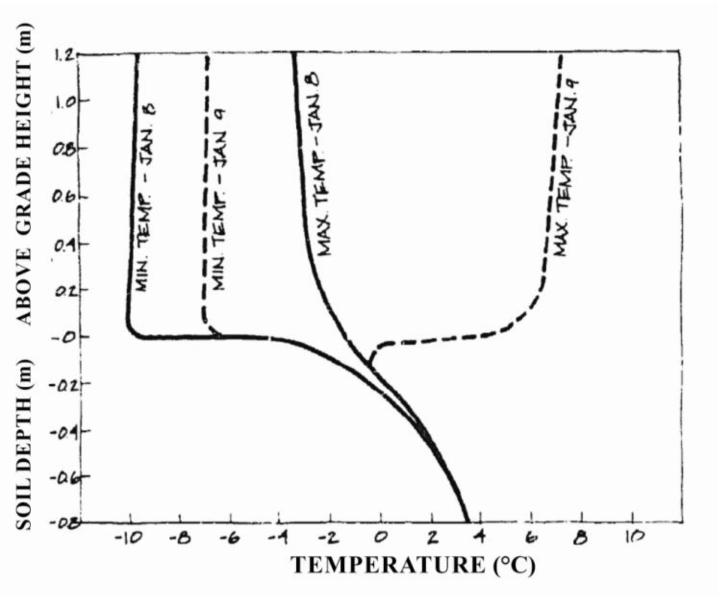

Figure 3. Temperature fluctuations for two days, In January for Minneapolis (after Underground Space Center, Minnesota University, 1979).

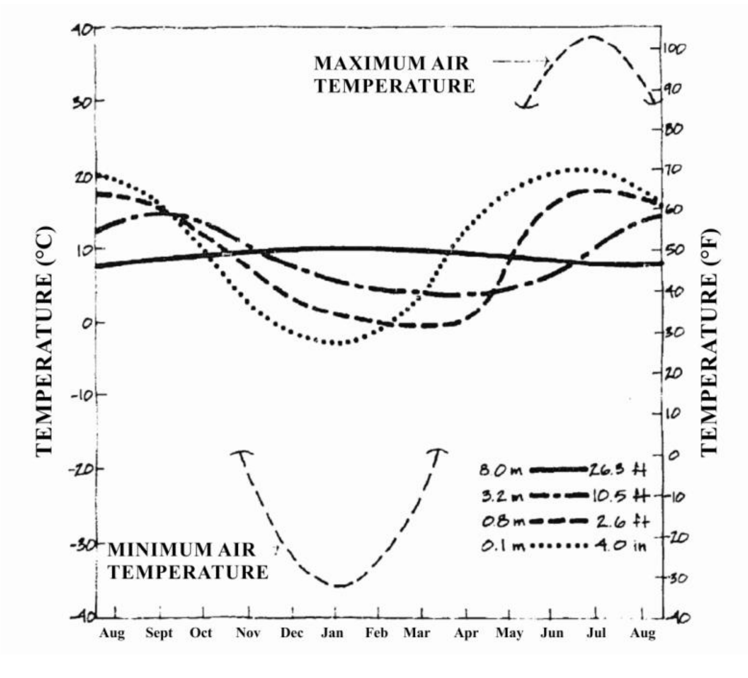

Figure 4. Annual temperature fluctuations up to 8.00 m depth, in Minneapolis[2] (after Underground Space Center, Minnesota University, 1979).

[2] Minneapolis is positioned near the 45th parallel and has a temperate continental climate, similar Cluj-Napoca.

At greater depths, where the temperature is almost constant throughout the year, we see a total phase shift (Figure 5. B.), in the sense that while the outdoor air records the highest temperature, eight meters deep, the earth has the lowest temperature of the year.

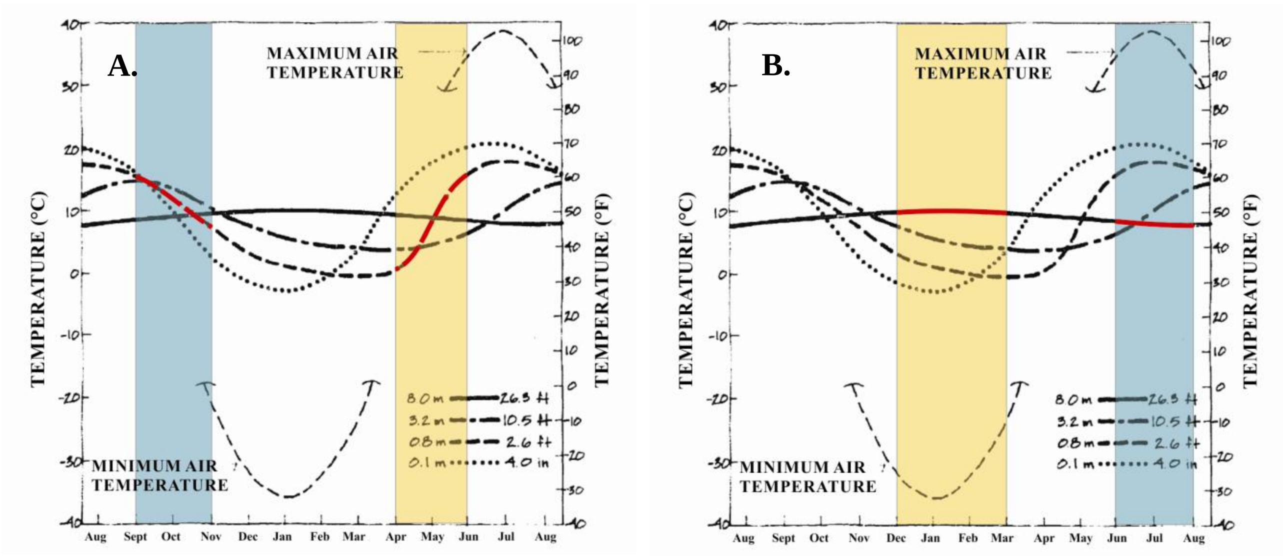

Figure 5. Analysis on the annual temperature fluctuations, in Minneapolis.

The phase shift is also visible on the curve of the temperature variation at 3,2 m below the surface, where the period of time when the earth begins to warm and cool down is delayed by a few months. This is translated through the fact that the periods of time during which an underground or half-buried home needs to be heated or cooled will be reduced.

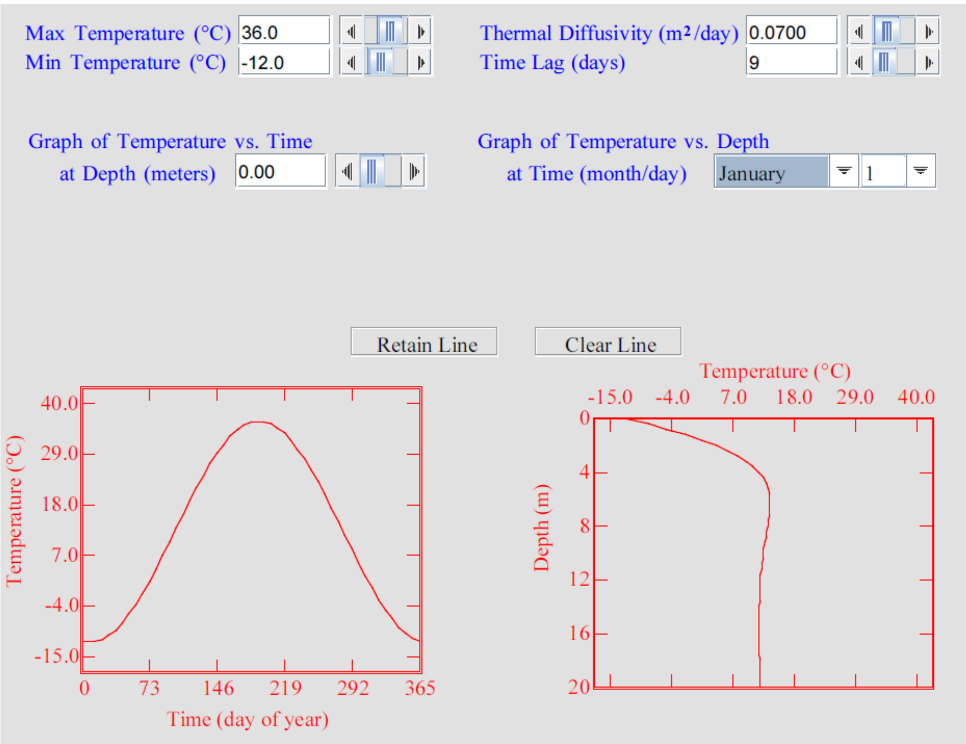

Figure 6. Simulation for the ground's temperature fluctuations, in time and depth [6].

Based on the analysis made by the Research Centre of the University of Minnesota, related to the temperature variation in the ground and using a simulation program, offered by the Oklahoma State University [10], several simulations for the temperature variation in the earth, in the area of Cluj-Napoca, ware carried out. The chosen reference year was 2013, and the temperatures were extracted from the database of Weather Underground [11].

The program employed for finding the thermal fluctuations of the earth is presented in Figure 6, exemplifying the variations of temperature, in January the 1st, 2013, at the surface of the ground. Thus, knowing the maximum and minimum temperatures in 2013, recorded in July 29th (+36°C), and January 9th (-12°C)[3], the heat flow curves can be found for any day of the year, up to a depth of 20 m and also the yearly fluctuations down to 20 m below the surface.

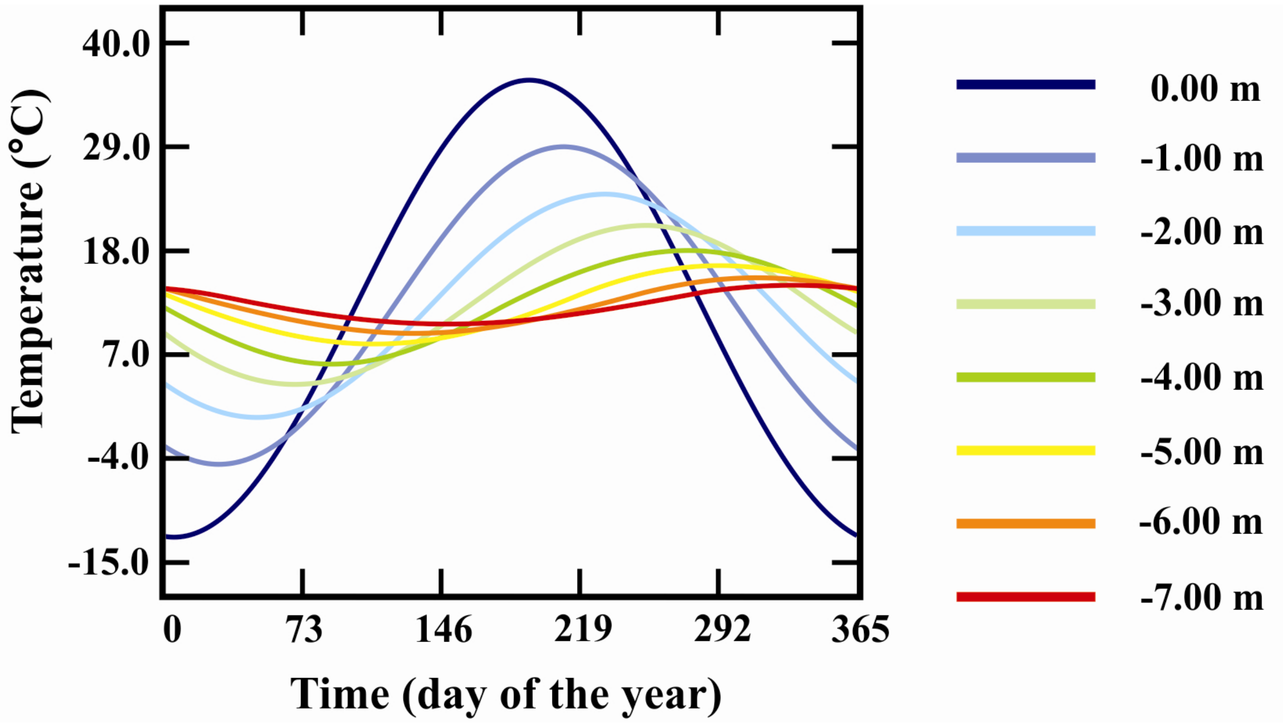

Figure 7. Annual temperature fluctuation at different depths for Cluj-Napoca, in 2013.

Thus, after a series of simulations, the chart of the annual temperature variation, at different depths, with reference to the outdoor temperatures recorded in Cluj-Napoca, in 2013, was drawn by overlaying the results (Figure 7.). Analyzing the chart, we can see that below 1.00 to 2.00 m no negative temperatures are recorded, throughout the entire year. The delay of the heating and cooling periods of the soil is also becoming increasingly visible and, as we descend deeper into the ground, it will eventually lead to an offset of six months in the vicinity of seven meters below the surface of the earth.

The same phenomena, can be noted in the monthly variations in soil temperature chart (Figure 8.) and also that the temperature of the earth becomes constant throughout the year, after a certain depth. This means that the temperature of the earth reaches positive values closer to the surface of the ground, in contradiction with the affirmation of C 107/6 – 2005.

[3] In the 9th of January the lowest temperature of the year 2013 was recorded, this is why a 9 days offset "Time Lag" appears.

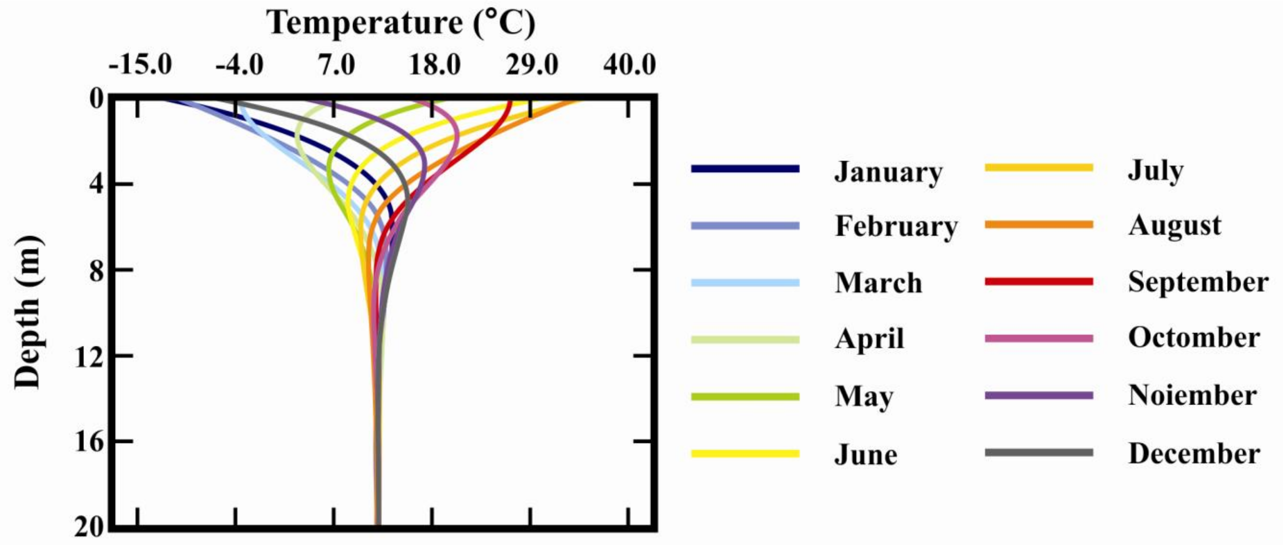

Figure 8. Monthly temperature fluctuations of the earth for Cluj-Napoca, in 2013.

The chart in Figure 9. shows the variation in soil temperature considering the thermal diffusivity coefficient. Thus, as the coefficient lowers, the fluctuation of the temperature of the earth stabilizes closer to the surface, and the annual temperature variations are smaller.

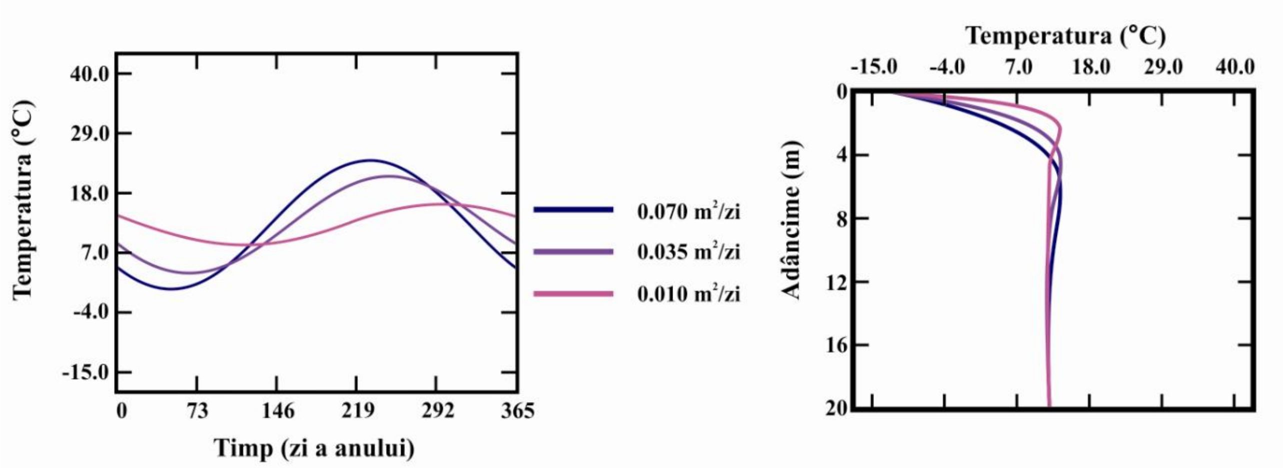

Figure 9. Temperature fluctuations of the earth, considering the thermal diffusivity coefficient for January the 1st, 2013, for Cluj-Napoca,

All of the above analysis refer to the earth's natural temperature variation, which is not affected by the presence of any heated buildings in the area. Inserting a heat source into the ground, such as a heated basement, an underground or half-buried house, will increase the annual temperature of the earth by a few degrees.

4. Conclusions

It is safe to state that the temperature of the earth is different than the one employed in the specific regulation for the thermal calculation of elements in contact with the earth, C107/5-2005. There are other official regulations that appreciate different depths of the earth below which the soil does not freeze anymore, STAS 6054-77 and NP 112 – 2013. The analysis conducted with the simulation program reveals similar results as the ones in STAS 6054-77 and NP 112 – 2013. This translates into an error in calculating the minimal thermal resistance of all elements in contact with the earth and thus in over dimensioning the thermal insulation for those specific elements.

5. References

[1] Freney M, Soebarto V, Williamson T. *Earthship monitoring and thermal simulation*, Architectural Science Review, Vol 30, Issue 3, pp. 208-219, 2008, http://dx.doi.org?10.1080/00038628.2013.809688 .

[2] Anselm AJ. *Passive heat storage principles in earth sheltered housing, a supplementary energy saving system in residential housing*, Energy and Building, vol. 40, issue 7, pp. 1214-1219, 2008, http://dx.doi.org/10.1016/j.enbuild.2007.11.002 .

[3] Homuller P, Lachal B. *Air-soil heat exchangers for heating and cooling of buildings: Design guidelines, potentials and constraints, system integration and global energy balance*, Applied Energy, vol 199, pp. 476-487, 2014, http://dx.doi.org/10.1016/j.apenergy.2014.01.042 .

[4] C 107/5 – 2005 *Normativ privind calculul termotehnic al elementelor de construcție în contact cu solul*.

[5] MC-001/1 *Metodologie de calcul al performanței energetice a clădirilor. Partea I – Anvelopa clădirii.*

[6] STAS 6054 – 1977 *Teren de fundare. Adâncimi maxime de îngheț. Zonarea teritoriului Republicii Socialiste România*.

[7] NP 112 – 2013 *Proiectarea fundațiilor de suprafață*.

[8] The Underground Space Center, Univesitatea din Minnesota. *Earth Shelter Housing Design: Guidelines Examples, and References*, New York: Van Nostrand Reinhold Company Inc., 1978.

[9] Stefanescu DP. *Higrotermica* (Courses, Civil Engineering Faculty in Iași).

[10] www.soilphysics.okstate.edu

[11] http://www.wunderground.com/history/airport/LRCL/2013/1/1/CustomHistory.html?dayend=31&monthend=12&yearend=2013&req_city=NA&req_state=NA&req_statename=NA