CLIMATIC FEATURES OF DIFFERENT KARST CAVES IN HUNGARY

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Due to some extreme weather conditions (e.g., droughts, inland waters or floods etc.) occurring in Carpathian Basin, climatic fluctuations can be detected in Hungary which can modify some environmental factors in caves. In our study we were determined to enquire to which extent do surface temperature changes influence cave air temperature. Three different types of caves were selected for the analysis: a hypogene cave (Hideglyuk), a tectonically performed epigenetic cave (Hajnóczy Cave) and a typical swallet cave (Trió Cave). Cave air temperature was determined in order to delineate the degree of anthropogenic impact, as well as to investigate how long it takes the surface temperature to have an effect on the cave air temperature. To test applicability of a wireless sensor network in cave temperature measurement, UC Mote Mini low power wireless sensor module was used for our measurements. Temperature data were recorded at 10 minutes intervals. The obtained data were evaluated using a matrix of correlation coefficients as to identify the communication network between the passages.

In Hajnóczy Cave the delay effect of the passages can be detected: a decrease in surface temperature can only be seen after 2 days and 4 days at measurement points No. 2 ("Entrance") and No. 3, ("Housetop"), respectively. In Hideg-lyuk, two different circulations can be distinguished: a large one covering the studied area and a small one that most probably connects the channel with undiscovered passages. The human impact on the air temperature of Trió Cave is unambiguous, raising the inside temperature with 0.05 °C or 0.6 °C in the case of three and twenty-eight visitors, respectively.

1. Introduction

Cave air temperature is mostly considered to be constant, nevertheless several factors, such as surface temperature, affect cave air flow even if their influence is more moderate in the passages. Cave climate is dependent on the energy balance of the cave and on the energy exchange between the cave and the surface. Furthermore, the climatic conditions and the morphology of the surface are also important controlling factors of cave climate (Fodor 1981). Hence, each cave has a unique air flow and a special climate. Caves are different in their morphology, fracture network, as well as in their entrance position and all these parameters exert an influence on the air flow (Rajczy 2000). The beneficial effects of caves have been shown due to the high humidity and the constant temperature of cave air, which is about 10 °C in Hungary. This dust, germ and allergen-free environment can mitigate the unpleasant symptoms of many people suffering from upper respiratory tract infections, leading to complete recovery (Jakucs 1999).

The long-term monitoring of climatic parameters in caves can provide information on whether the surface climate change has any negative influence on cave climate and its therapeutic effects. Moreover, these measurements are very essential from the viewpoint of cave utilization since visitors can also modify cave climate. The climatic studies of caves can support the cave tourism of national parks as the surplus heat caused by several visitors can have an adverse effect on the characteristics of caves (Kaffai 2008).

The major aims of present study can be summarized as follows:

(1) to delineate how surface temperature influences cave air temperature in the three different karst caves; (2) to reveal how long it takes the surface temperature to modify the temperature of cave air; (3) to test a wireless sensor network in order to determine its applicability in cave air temperature, relative humidity and atmospheric pressure measurements; (4) with the help of the investigations mentioned above we intend to study the convectional system of these caves, and the degree of anthropogenic impact on them.

2. Sampling area

Three Hungarian caves were selected as sample areas (Fig. 1).

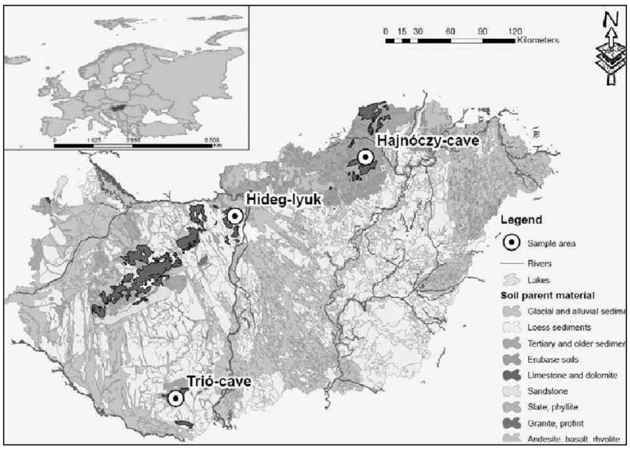

Figure 1. The petrographic map of Hungary and the location of the monitored caves.

2.1. Hajnóczy Cave

Hajnóczy Cave is situated in the SW Bükk and was formed in Ladinian-Carnian flint and flint-free grey limestone. It is a shallow cave with more than 3 km long passages and with a maximum depth of 135 m. The entrance of the cave is located on a hillside, 475 meters above sea level (Varga 2003).

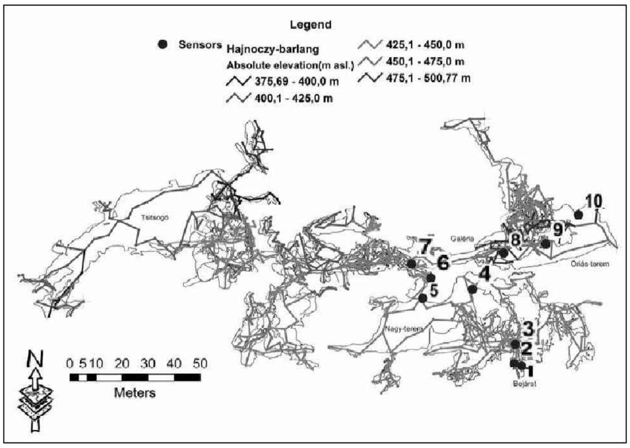

Figure 2. The polygon of Hajnóczy Cave with the places of the sensors.

The cave passages are of N-NE-S-SW direction with a perpendicular joint system. The cave can be divided into two distinct parts: (1) the passage system which is rich in keyholes and was formed by anastomosis and corrosion processes. This extends from the entrance to the Great Hall. (2) The section that was formed by dominant erosion processes and is characterized by large forms (e.g., Giant Hall: 40 × 20 m), debris fans and keyholes between large rooms (e.g., Almond: 0.7 × 0.4 m) (Fig. 2).

2.2. Hideg-lyuk

Hideg-lyuk is of hypogenic origin and is situated in Buda Hills, in the NW part of Pálvölgyi quarry composed of Triassic limestone and dolomite. Since Buda Hills. were elevated along a fault line, thermal waters could emerge from the depth along the cracks (Kordos 1984).

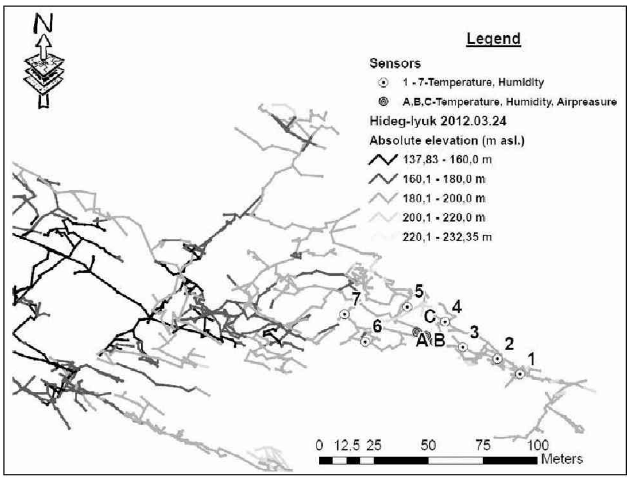

Figure 3. The location of the sensors in Hideg-lyuk.

József Szabó Cave Research Group began the research in 2008 of Hideg-lyuk, since the intense cold summer airflow attracted the researchers' attention. The maximum depth was 92 m at that time. In December 2011 the cave was connected to the other caves in the quarry and became the member of the 28.6 km long Szépvölgyi Cave System (Fig. 3).

2.3. Trió Cave

Trió Cave is situated in the lithologically homogeneous Triassic limestones of the Western Mecsek karst area. It is a typical swallow cave (255 m, depth: -58) of the Szuadó Valley, however due to the development of other sinkholes Trió Cave has only a temporary activity nowadays (Barta and Tarnai1999).

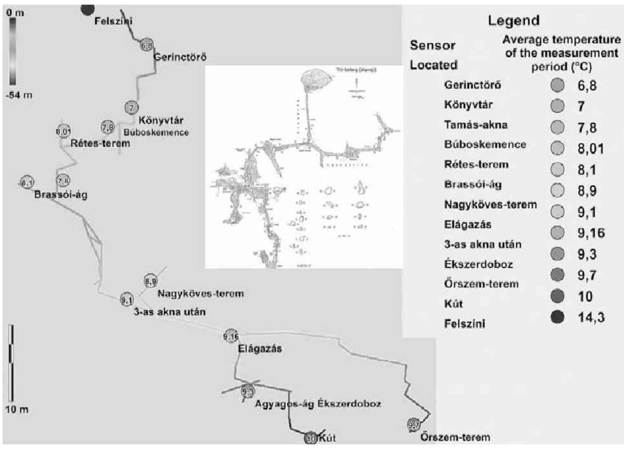

Figure 4. The cross-section of Trió Cave and the location of the deployed devices.

It is the seventh longest (255 m), and the second deepest (58 m) cave in Mecsek Mountains. The cave can be morphologically divided into three parts (Fig. 4). The first section is a narrow passage system. After passing the second part of the cave, the pit-system, the two end-points can be reached along Agyagos and Vizes branches (Bauer 2011).

3. Material and methods

UC Mote Mini low power wireless sensor module, which was developed at the University of Szeged, was used for our measurements. This device promotes IEEE 802.15.4/ZigBee wireless communication protocol in order to realize low data rate. The radio module can operate at a data rate of 250 kbps in ISM 2.4 GHz band. The control is regulated by 16 MHz Atmel ATmega128RFA1 microprocessor with 128 kB RAM. Several types of sensors are integrated into this device (Fig. 5):

1) light sensor
2) pressure sensor
3) temperature sensor
4) humidity sensor

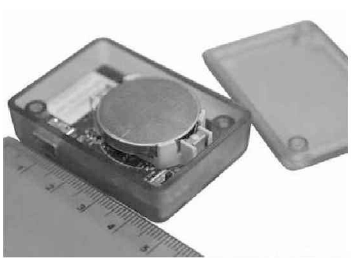

Figure 5. Uc Mote Mini (source: www.unicomp.hu).

Figure 6. Uc Mote Mini in Hideg-lyuk.

The accuracy and the scale of SHT21 temperature and the humidity sensor are ±0,3 °C, 0,01 °C and ±02.0% RH, 0,04% RH, respectively. Data collection can be realized with 2MB external flash TinyOS, which is a small open-source energy-efficient software operating system, supporting large scale self-configuring sensor networks. The device is powered by LIR2450 battery (Fig. 5). During our study, data were recorded in every 10 minutes. The sensors could be used for more than 3 months without battery replacement (Senirion).

The temperature and relative humidity of cave air were detected using ten sensors (three of them can also measure air pressure) in Hajnóczy Cave and in Hideg-lyuk. In each case one out of ten sensors was placed near the cave entrance to measure surface temperature (Figs. 2, 3 and 6). In Trió Cave only periodic observations were performed using thirteen sensors (Fig. 4).

Even thought the sensors can communicate up to 100 m on the surface, this distance is reduced to 20–25 m in the underground depending on cave geometry (Muladi 2012). The radio module was only used while data were downloaded and sensor network maps were created.

The data obtained in every 10 minutes were evaluated using a matrix of correlation coefficients. First, data were averaged according to hour and day, resulting in a new dataset. Then these data were processed with pairwise correlation coefficients in order to investigate the direct and indirect relationships among cave airflows.

4. Results and discussion

4.1. Hajnóczy Cave

The climate of this cave was periodically studied in the past (e.g., cave temperature was measured by Gábor Miklós and József Városi from 1975 to 1977 in summers and Gyula Németh performed some radon measurements in the 1980s). These investigations can provide reference data for our current research.

Our monitoring started in December 2011 and lasted more than a year in order to observe the differences of cave air flow between the summer and the winter period.

Due to the limited length of the paper only the data collected between 10. 03. 2012 and 14. 04. 2012 are presented (Fig. 7).

The cave air temperature data measured by ten sensors can be seen here. The data of measurement sections No. 1 ("Surface") and No. 2 ("Entrance") are illustrated in the secondary axis, whereas those of other measurement points are demonstrated in the primary axis.

According to the daily minimum and maximum values of point No. 1, we could examine how surface temperature influenced the different sections of the cave. Based on the data of No. 2 and No. 3 ("Housetop"), the diurnal fluctuation of temperature is obvious, although various differences can be detected. This daily variation ranges between 0.5 and 1 °C in the case of point No. 2, while it changes between 0.2 and 0.3 °C in the case of point No. 3. Furthermore, the retarding effect of temperature can also be observed: the decrease in surface temperature can be registered after 2 and 4 days in the case of points No. 2 and No. 3, respectively (Fig. 7). The correlation value between the measurement points No. 2 and No. 3 is 0.7290. Point No. 3 shows strong correlation with some measurement points: 0.8040 and 0.8996 are with No. 3 ("Leyla") and No. 7 ("Amygdala"), respectively (Table 1).

Point No. 4 ("Flat hall") is further and deeper than point No. 2. Even though the diurnal temperature range can not be detected, a temperature change caused by a drop in surface temperature can be noticed. Based on the correlation coefficient, point No. 4 has a very strong (0.9960) and a strong (0.7272) relationship with points No. 2, 3, respectively (Table 1). No. 4 shows moderately strong correlation with point No. 7 (0.5639), and No. 6 (0.6424).

In the case of points No. 6 and No. 7, the cross-sections of the passages is narrowed. Thus, higher diurnal temperature range could be registered in their cases. Although, the cross-section of passage No. 7 is smaller than that of No. 6, the values are still very similar. This is also confirmed by their correlation coefficient (0.8280).

Table 1. The correlation matrix of Hajnóczy-cave's temperature data (12. 03. 2012. – 11. 04. 2012) (significance level 0.01; 0.05).

Measuring points	**Between Gallery and Giant hall (9)**	**Housetop (3)**	**Almond (7)**	**Leyla (6)**	**Flat hall (4)**	**Surface (1)**	**Gallery (8)**	**Giant hall (10)**	**Entrance (2)**
Between Gallery and Giant hall (9)	1								
Housetop (3)	**-0.6174**	1							
Almond (7)	-0.2911	**0.8996**	1						
Leyla (6)	-0.3172	**0.8040**	**0.8280**	1					
Flat hall (4)	**-0.4941**	**0.7272**	**0.5639**	**0.6424**	1				
Surface (1)	-0.1984	-0.2953	-0.4924	**-0.4679**	-0.2286	1			
Gallery (8)	-0.0765	0.1808	0.3089	0.3663	-0.2242	-0.3119	1		
Giant hall (10)	-0.1986	-0.2651	-0.4102	-0.1385	0.1223	0.1502	0.1257	1	
Entrance (2)	-0.4356	**0.7290**	**0.5927**	**0.6577**	**0.9960**	-0.2670	-0.2372	0.0818	1

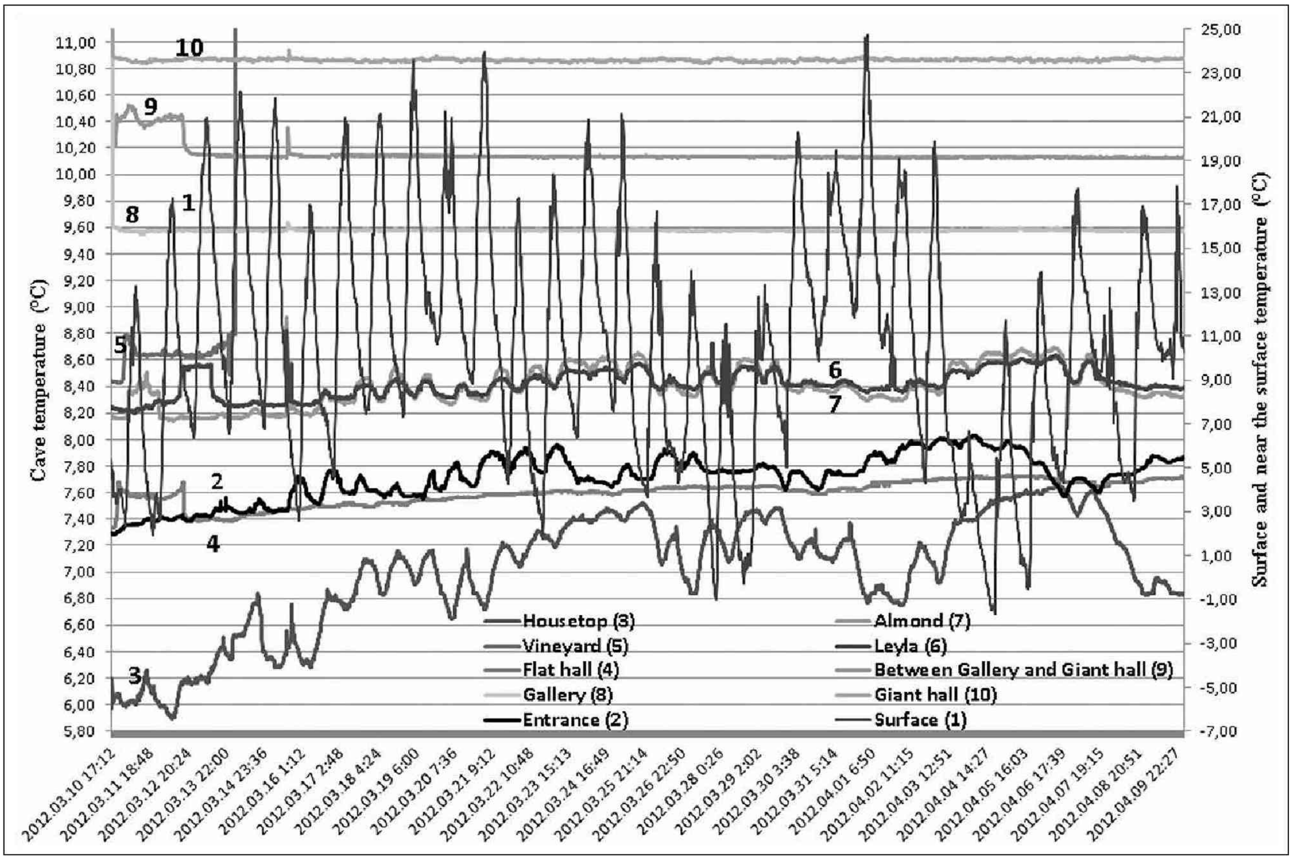

Figure 7. Temperature data for Hajnóczy Cave (10. 03. 2012–14. 04. 2012).

All this can be explained with the spatial proximity of the two measurement points (<5 m). The minimum and maximum values can be detected better in the case of point No. 7 due to the narrow cross section of the measurement point. Here, the diurnal fluctuation of temperature range only varies between 0.1 and 0.2 °C, while point No. 1 shows inverse correlation with No. 7 (-0.4924) and No. 6 (-0.4679). Point No. 2 shows a moderately strong correlation with points No. 7 (0.5927) and No. 6 (0.6577).

There is temperature difference among the passages where point No. 8 ("Gallery"), No. 9 ("Between Gallery and Giant hall Giant") and No. 10 ("Giant hall") were set (Fig. 4). The surface temperature has small effect on these sections of the cave in studied period. The diurnal temperature change can be slightly detected in the point No. 10 owing to its spatial proximity to the surface. Point No. 9 shows an inverse correlation with points No. 3 (-0.6174) and No. 4 (-0.4941).

4.2. Hideg-lyuk

The aim of cave researches in Hideg-lyuk is to discover new passages using air circulation investigations. Our intention was to contribute to these discoveries by studying the characteristics of airflow inside the cave.

We started our study here on 21. 04. 2012. In this paper, data from the period between 11. 09. 2012 and 21. 10. 2012 are presented (Fig. 6). In Fig. 8, the data of measurement points No. 4 ("Surface") and No. 1 ("Entrance") are illustrated in the secondary axis. Overall, the difference in average temperatures between the passages can also be detected here. The mean air temperature is increasing towards the inner passages. The extent of diurnal temperature fluctuation can be observed at the different measurement points.

During the data evaluation an interesting phenomenon was discovered: at measurement point No. 1 cold air flows out intensely, which is supported by its moderately strong correlation with point No. 4 (0.4364). Interestingly, No. 1 has an even stronger correlation (0.5858) with the deeper passages, e.g., measurement point B ("Guillotine") (Table 2).

Measurement point No. 2 ("Mine support") has much stronger relationship (0.6748) with No. 4 than No.1.

Since too many relationships can be detected concerning the other sites due to the fact that the various passages can communicate with each other through the fractures, we would like to highlight only some of them. The strongest correlation (0.9939) can be explored between points No. 3. ("Copper canon") and No. 6 ("Reference bivouac") while the weakest relationship (0.4068) can be revealed between point A (Bear trap) and No. 7 ("Christmas").

In accordance with the results of selected points, point No. 5 ("Seal") do not participate in the large air flow. As its correlation coefficient is inversely proportional to the others, its microclimate is affected either by upper passages or a new passage system. Measurement point B is the only site that has moderate or strong correlation with all measurement points except for No. 5 with which the correlation is reverse.

Table 2. The correlation matrix of the temperature data collected in Hideg-lyuk (11. 09. 2012.–21.10.2012) (significance level 0.01; 0.05).

Measuring points	Bear trap (A)	Guillotine (B)	Step screws (C)	Entrance (1)	Mine support (2)	Copper cannon (3)	Surface (4)	Seal (5)	Reference Bivouac (6)	Christmas (7)
Bear trap (A)	1									
Guillotine (B)	0.5084	1								
Step screws (C)	0.4584	0.4828	1							
Entrance (1)	0.1959	0.5858	0.4071	1						
Mine support (2)	0.2703	0.4692	0.7177	0.3866	1					
Copper cannon (3)	0.3140	0.7395	0.0735	0.3623	0.0827	1				
Surface (4)	0.4969	0.5526	0.6597	0.4364	0.6748	0.0146	1			
Seal (5)	-0.1143	-0.4237	-0.4148	-0.5289	-0.2271	0.0017	-0.3036	1		
Bivouac (6)	0.3355	0.7920	0.1113	0.3952	0.1091	0.9936	0.0601	-0.0899	1	
Christmas (7)	0.4068	0.8358	0.7391	0.3034	0.7219	0.5795	0.7240	0.1149	0.7336	1

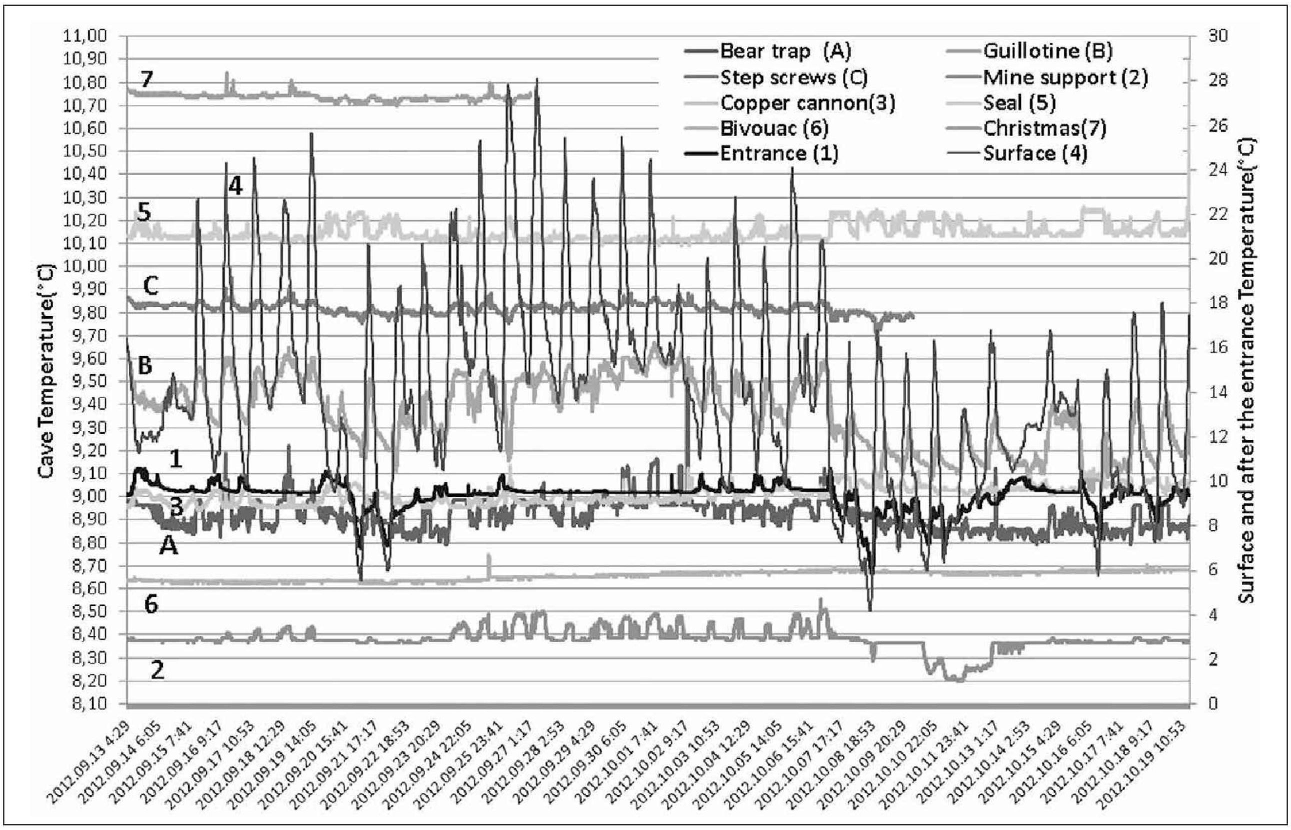

Figure 8. Data for Hideg-lyuk (11. 09. 2012–21. 10. 2012).

4.3. Trió Cave

The investigation period lasted from 19. 04. 2012 till 16. 06. 2012. Twelve sensors were deployed at different sections of the cave: the entrance, the pits and the two end points (Fig. 4). During the monitoring period the number of visitors and the times of the guided trips were recorded. According to average temperature values, the temperature was higher in the end points than in the entrance (Fig. 4). The surface temperature has not had any influence on the inner cave sections from pit No. 3.

In the section called "Beehive oven", a temperature rise that was caused by a tour group can be observed (Fig. 9). Comparing the number of visitors with the temperature change, it can be claimed that the 28 visitors initiated a 0.6 °C rise. During the two-month monitoring period the diurnal temperature fluctuation was 0.05 °C inside the cave. Besides, a rising trend in temperature (0.4 °C) can be noticed most probably due to gradual increase in the daily average surface temperature (Fig. 9).

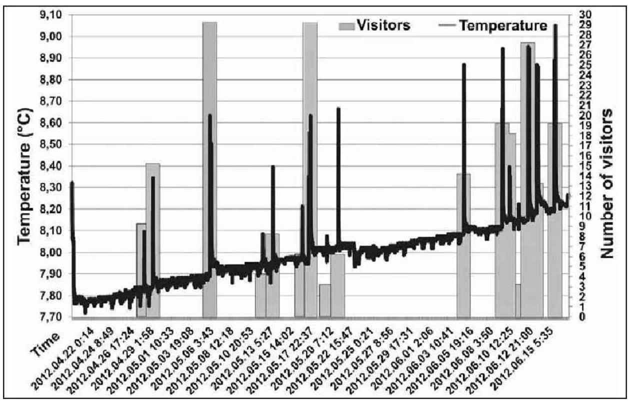

Figure 9. Relationships between cave air temperature and the number of visitors at "Beehive oven", Trió Cave (19. 04. 2012. – 16. 06. 2012).

5. Conclusions

Cave climate measurements can greatly contribute to gaining more information on environmental factors in caves.

The investigations mentioned above have proven that the UC Mote Mini wireless sensor network applied in this study is eligible for measuring the temperature and relative humidity of cave air. Temperature difference among the passages can be clearly seen in all the studied caves.

The delay effect of the influencing factors in Hajnóczy Cave can be observed: a drop in surface temperature can be registered after 2 and 4 days at measurement points No 2, 3, respectively.

In Hideg-lyuk, two distinct air flows can be distinguished: a large one covering the studied area and a small one circulating in the passage where measurement point No. 5 was set ("Seal"). It is likely to be connected to other, perhaps undiscovered sections of the cave, which is justified by the negative correlation (-0.5289) experienced between measurement points No 5. and No. 4 ("Surface").

In Trió Cave human impacts on cave air temperature were shown. This rise in temperature caused by visitors ranged between 0.05 °C and 0.6 °C in the case of three and twenty-eight visitors, respectively.

Future plans include the more precise thermal mapping of the various cave sections. We are about to prepare an isotherm map and to expand the number of devices as to explore the connections among the cave sections more profoundly. Besides, we will focus on gaining more information on the turning points of the direction of air flow in caves. We would also like to measure the radon and the CO_2 concentration of cave air and carry out the statistical analysis of all the above mentioned parameters in order to explore more relationships among them and visualize these data by modelling air circulation.

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