MIKROKLIMA KAO KOMPONENTA GEOEKOLOŠKOG VRJEDNOVANJA SPILJA – PRIMJER SPILJE U BELEJSKOJ KOMUNADI (BELEJ, OTOK CRES)

MICROCLIMATE AS A COMPONENT OF THE GEOECOLOGICAL EVALUATION OF CAVES – EXAMPLE OF THE CAVE IN BELEJSKA KOMUNADA (BELEJ, ISLAND OF CRES)

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Mikroklimatsko istraživanje Spilje u Belejskoj komunadi obavljeno je u terminu od 1. veljače do 19. kolovoza 2007. U analizi su korišteni podaci mjerenja temperature i vlažnosti zraka zabilježni elektroničkim termohigrografima. Mjerne točke postavljene su u blizini ulaza i u kanalu pri dnu spilje. Istraživanje je obavljeno kao komponenta geoekološkog vrednovanja spilje za potrebe planiranja turističkog korištenja. Mjerenje je obavljeno u toplom dijelu godine jer bi u to vrijeme spilju posjećivalo najviše turista pa je to razdoblje najinteresantnije budući da posjetitelji utječu na izmjene mikroklimatskih parametara.

Ključne riječi: spilja, mikroklima, geoekološko vrednovanje, termohigrograf, Belej, otok Cres

Microclimate research of the Cave in Belejska komunada was conducted in the period from 1 February to 19 August 2007. In the analysis of temperature and air humidity measurement data recorded by electronic thermohygrograph were used. Measurement points were installed in the vicinity of the entrance and at the bottom of the cave. The research was carried out as a component of the geoecological evaluation of the cave for the purpose of planning its tourist use. The measurement was conducted during the warm part of the year when the majority of tourists would visit, therefore the period was particularly interesting since the cave visitors have an impact on changes in microclimatic parameters.

Key words: cave microclimate, geoecological evaluation, thermohygrograph, Belej, Island of Cres

Uvod

Otok Cres obiluje površinskim i podzemnim krškim fenomenima (Buzjak, 1997). Među podzemnima prevladavaju manje spilje i jame oblikovane pretežito u krednim karbonatnim naslagama (Buzjak i dr., 1997).

Spilja u Belejskoj komunadi smještena je kod sela Belej u središnjem dijelu otoka Cresa (Sl. 1.). Od crkve u Beleju udaljena je 1,9 km u smjeru 195°. Ulaz je na nadmorskoj visini 164 m. Prema OGK, list Cres (Magaš i dr., 1968) spilja je oblikovana u naslagama uslojenih vapnenaca donjokredne starosti. To je morfološki jednostavna spilja. Sastoji se od dva kanala koji su, s obzirom na

Introduction

The Island of Cres abounds with surface and underground karst phenomena (Buzjak 1997). Among the underground karst phenomena, smaller caves and pits formed in predominantly Cretaceous carbonate beds prevail (Buzjak et al., 1997).

The Cave in Belejska komunada (Spilja u Belejskoj komunadi) is located near the village of Belej, in the central part of the Island of Cres (Fig. 1), at a distance of 1.9 km from the Belej church, bearing 195°. The entrance is at an elevation of 164 m. According to a geological map (Magaš et al., 1968) the cave was formed in Lower Cretaceous limestone beds. The cave is of simple morphology.

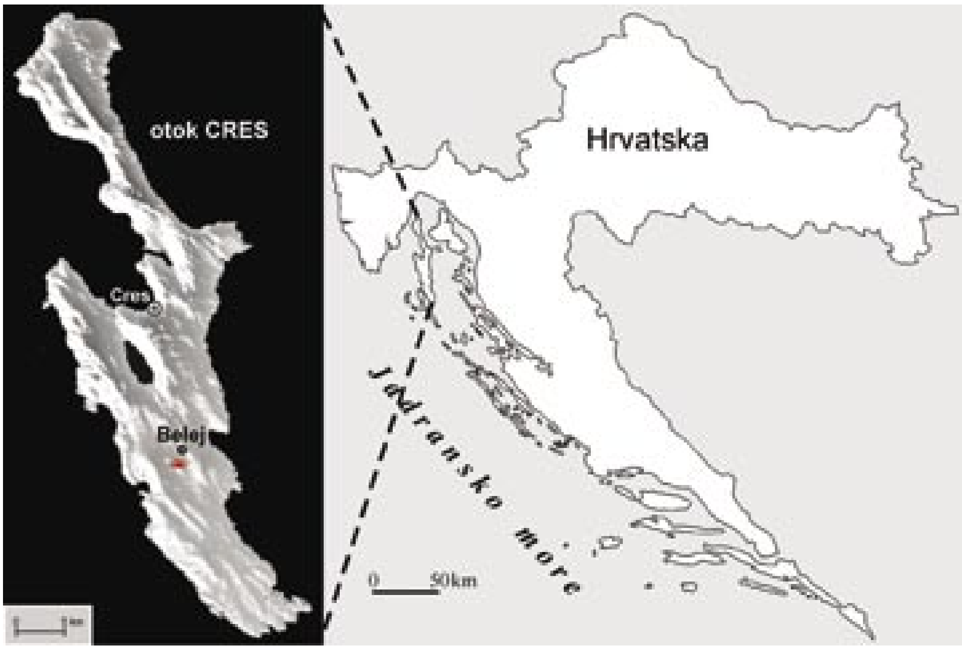
očuvane mikroreljefne oblike u bokovima i stropu kanala, oblikovani u glavnoj etapi speleogeneze djelovanjem podzemnog toka. Voda je u spilji danas prisutna samo u obliku prokapnice koja je obilna u kišnim razdobljima. U ulaznom kanalu i pri dnu taložene su ili se još uvijek talože debele naslage sige. U dijelovima kanala obilno je nataloženo kršje te sitnozrnati sediment koje je nanio vodeni tok ili je transportiran prokapnicom s površine. Tlocrtna duljina spilje je 60 m, a dubina 12 m[1]. Urušavanje kao speleogenetski proces najizraženije je u ulaznom dijelu. Ulaz je u dnu urušene ponikve nastale urušavanjem dijela stropa iznad spiljske šupljine, što je vidljivo po nišama u bokovima ponikve. Okrenut je prema sjeveru, ali ga dubina ulazne ponikve štiti od direktnog utjecaja vjetra sjevernog smjera. Sa sjeveroistočne i istočne strane padina ponikve je položena, ali je utjecaj bure smanjen jer je površina obrasla gustom šumom.

Spilja je poznata lokalnom stanovništvu od davnina o čemu svjedoče arheološki nalazi koji tek očekuju stručnu obradu. U usmenoj predaji o korištenju spilje u novijoj povijesti poznat je podatak da je tijekom talijanske okupacije otoka u spilji bila ilegalna pecara rakije. Spilju su

It consists of two passages that were formed, based on preserved microrelief forms in the sidewalls and ceiling, during the main phase of speleogenesis by underground stream. Water is nowadays present only as drip water, abundant during the rainy seasons. In the entrance passage and along its bottom, thick speleothem deposits already exist or are still in the process of formation. Parts of the passage contain abundantly deposited rock debris and fine-grained sediment flushed in by water flow or transported by drip water from the surface. The cave length is 60 m and its depth is 12 m[1]. Collapse as a speleogenetic process is most prominent in the entrance zone. The entrance is at the bottom of a collapsed doline created after a portion of the ceiling above the cavern had collapsed, the evidence of which are niches in the sidewalls of the doline. The entrance faces north, but the depth of the entrance doline protects it from the direct impact of the northern wind. From NE and E sides the slope of the doline is of slight inclination but the impact of the north-easterly wind (bora) is reduced due to the surface being covered with dense forest.

The cave has been known to the local inhabitants from times immemorial and archaeological findings, pending expert elaboration, testify to this

Slika 1. Geografski smještaj Spilje u Belejskoj komunadi
Figure 1 Geographic position of the Cave in Belejska komunada



[1] Budući da u arhivi SO HPD "Željezničar" (Zagreb) o spilji nema zapisa navedene dimenzije su dobivene mjerenjem na skeniranom i georeferenciranom nacrtu A. Novosela i O. Vukadinovića (softver Map Maker Gratis 3.5).

[1] Given the archives of SO HPD "Željezničar" (Zagreb) contain no record of the cave, the cited size has been obtained by means of measuring the scanned and georeferenced sketch by A. Novosel and O. Vukadinović (software Map Maker Gratis 3.5).

speleološki istražili članovi SOPD "Željezničar" (Zagreb) početkom 90-ih godina 20. stoljeća[2]. U to su vrijeme, vođeni Brankom Rebrovićem iz Beleja, Cres istraživali i članovi DISKF-a (Zagreb) te su tom prilikom posjetili i ovu spilju (Z. Gregurić i J. Zmaić usmeno).

Tijekom 2005. i 2006. spilju su na poziv g. Jordana Kučića iz Beleja, zainteresiranog za njeno turističko korištenje, istraživali članovi SOPD "Željezničar" (Zagreb) B. Jalžić, V. Jalžić i D. Lovretić. Oni su crtali novi nacrt koji postoji samo u radnoj verziji (V. Jalžić usmeno).

Dosadašnja speleometeorološka mjerenja na Cresu

Koliko je prema dostupnim podacima poznato, do novijeg vremena na području Cresa nisu obavljana dugotrajna mikroklimatološka istraživanja unutar speleoloških pojava. Sredinom 90-ih godina takva su istraživanja, u okviru projekta istraživanja bilja na ulaznim dijelovima spilja i jama, obavljali S. i N. Buzjak i to u jami Banićevoj pećini (Čampari), jami Gašparet i Jami na Sredi (Fiedler, Buzjak, 1998; Buzjak, 2001).

Metoda istraživanja

Mjerenje u Spilji u Belejskoj komunadi obavljeno je u terminu od 1. veljače do 19. kolovoza 2007. Korištena su dva termohigrografa tipa Hobo RH/Temp (Onset Computer Corporation, SAD) s mogućnošću bilježenja niza podataka (data logger-i). Vrijednosti temperature mjerene su u visokoj rezoluciji na dvije decimale. Programirani interval mjerenja je bio 1 sat. U analizi su korišteni podaci 4799 mjerenja koje su instrumenti zabilježili u mjernom razdoblju. Instrumenti su na mjerne točke postavljeni 29. siječnja 2007., ali ti podaci nisu uzeti u obzir zbog grešaka koje se javljaju u mjerenjima zbog prilagođavanja senzora na uvjete okoline. Za provjeru strujanja zraka korišten je anemometar TurboMeter (Davis Instruments, SAD). Prilikom postavljanja termohigrografa na mjerne točke strujanje zraka nije zabilježeno, što ne znači da se ne javlja u određenim prilikama.

[2] Točan datum topografskog snimanja spilje nije poznat jer u arhivi SO HPD "Željezničar" (kraće SOŽ) nema zapisa (arhivar M. Uroić, usmeno). Istraživanje je vjerojatno obavljeno 1990.-1992. godine kada su speleolozi SOŽ-a istraživali otok Cres.

fact. Through word of mouth on the usage of the cave in recent history, an illegal brandy distillery was known to be located inside the cave during Italian occupation of the island. The cave was speleologically explored by cavers of caving club SOPD "Željezničar" (Zagreb) in the beginning of 1990s[2]. At the time, led by Branko Rebrović from Belej, Cres was also being explored by members of caving club DISKF (Zagreb) who, on that occasion, visited this cave as well (Z. Gregurić and J. Zmaić, personal communication).

During 2005 and 2006 the cave was researched by the members of SOPD "Željezničar" (Zagreb) B. Jalžić, V. Jalžić and D. Lovretić, at the invitation of Mr Jordan Kučić from Belej, who was interested in it as a tourist attraction. They drew a new draft of the cave (V. Jalžić, personal communication).

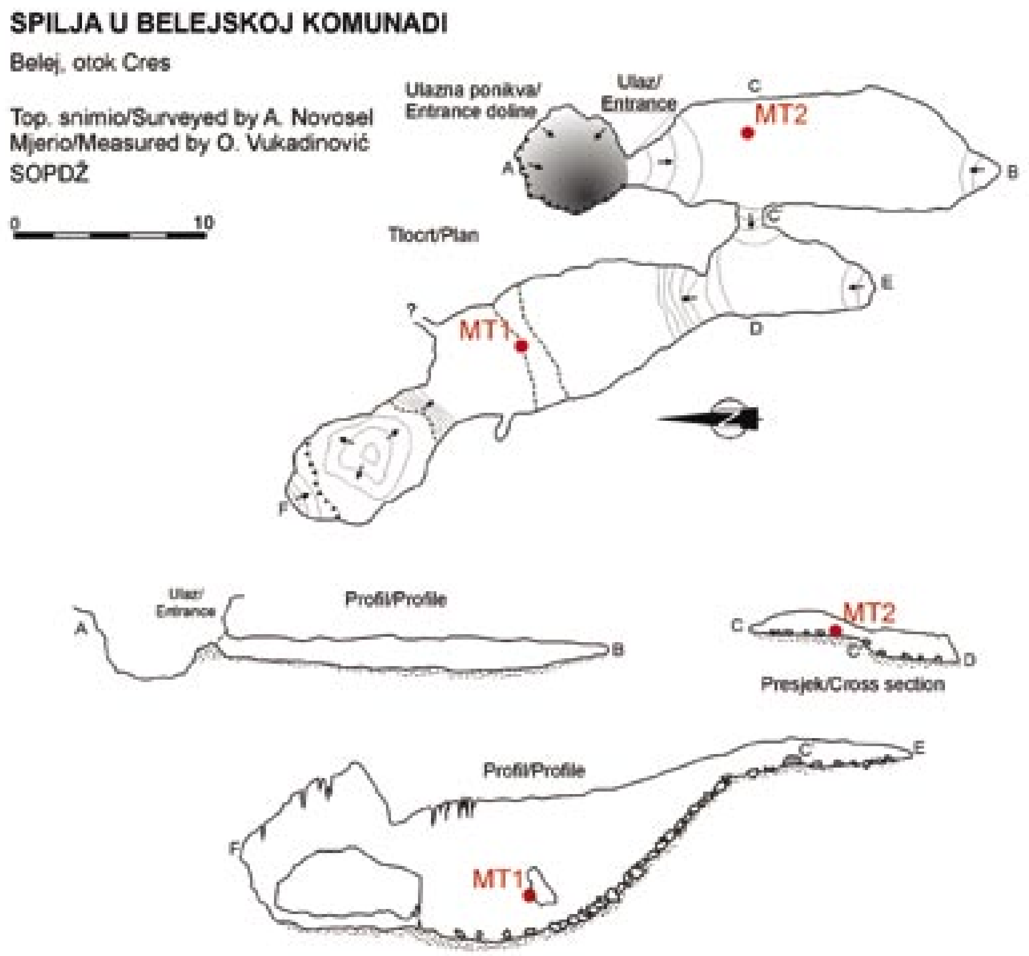
Cave microclimate researches on Cres to date

According to accessible data, to date no long term microclimatological research within speleological features has been conducted in the Cres area. In mid 90s a similar research was conducted within the framework of the *Cave and Pit near Entrance Flora Study* by S. and N. Buzjak in Banićeva spilja Cave (Čampari), Gašparet jama Pit and Jama na Sredi Cave (Fiedler, Buzjak, 1998; Buzjak, 2001).

Research method

Measurement in the Cave in Belejska komunada was conducted from 1 February to 19 August 2007. Two thermohygrographs Hobo RH/Temp type (Onset Computer Corporation, USA) data loggers were used. Temperature values were measured in high resolution. The programmed measurement interval was 1 hour. Data analysis from 4799 measurements, recorded by instruments in the measurement period, was used. The equipment was installed at measurement points on January 29, but the derived data were not taken into consideration due to errors occurring in measurements as a result of sensor adjustment to environment conditions. Assessment of cave airflow was done by means of TurboMeter anemometer (Davis Instruments, USA). Upon installation of the thermohygrographs

[2] The exact date of the cave topographic survey is unknown given the SO HPD "Željezničar" (shorter SOŽ) archives do not contain any record of it (archivist M. Uroić, personal communication). The exploration was probably conducted from1990 to 1992 when the SOŽ cavers explored the island of Cres.



Slika 2. Nacrt Spilje u Belejskoj komunadi s lokacijama termohigrografa (MT1 i MT2)
Figure 2 The plan of the Cave in Belejska komunada with the thermohygrographs' locations (MT1 and MT2)

Mjerenje je obavljeno na dvije mjerne točke (Sl. 2.):

MT1 - na dnu kamenog mosta u dvorani 25,5 m od ulaza i 1,9 m iznad dna,

MT2 - u lijevom boku na dnu kanala 6,5 m od ulaza.

Obje lokacije mjernih točaka u vrijeme postavljanja i micanja termohigrografa bile su suhe uz malu količinu vode prokapnice i cijednice.
Na ulazu su, kao zaštita od nekontroliranog ulaženja, postavljene vodoravne metalne šipke koje nimalo ne sprječavaju prirodnu cirkulaciju zraka između površine i spilje.

Rezultati mjerenja obrađeni su osnovnim statističkim metodama (srednja vrijednost, standardna devijacija i koeficijent varijabilnosti).

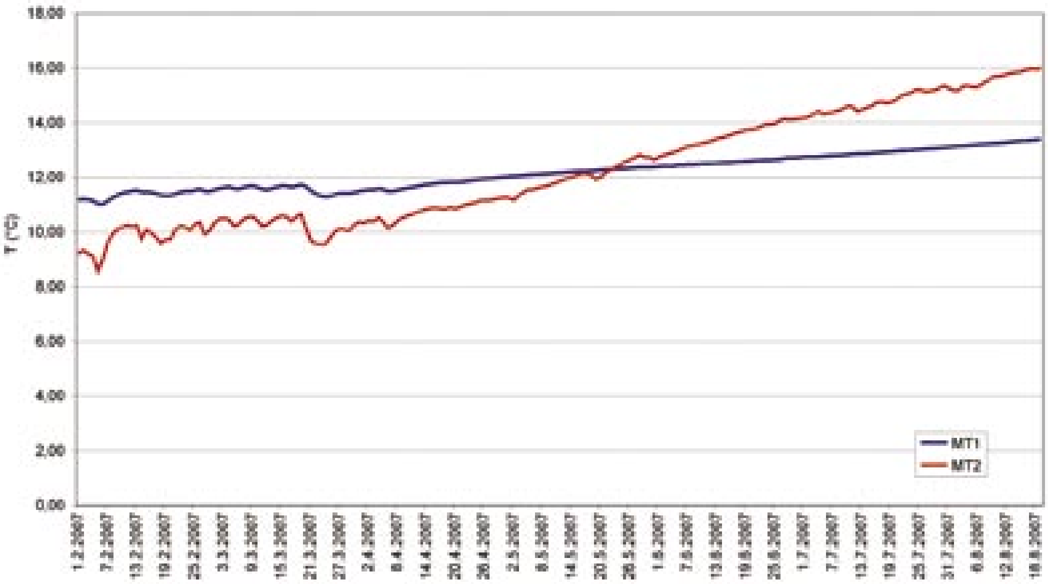
at measurement points, no airflow was detected, which does not mean that it does not occasionally occur.

The measurement was conducted at two measurement points (Fig. 2):

MT1 – at the bottom of the stone bridge in the chamber 25.5 m from the entrance and 1.9 m above the chamber bottom,

MT2 – in the left sidewall at the bottom of the passage 6.5 m from the entrance.

Both locations of measurement points at the time of the thermohygrographs installation and movement were dry with a minimum amount of drip water. At the entrance, as a protection from unmonitored entering, horizontal metal bars that do not in the least obstruct natural ventilation between the surface and the cave were fixed.



Slika 3. Hod srednjih dnevnih temperatura na MT1 i MT2
Figure 3 Mean diurnal temperature trend at MT1 and MT2

Rezultati i rasprava

Temperatura zraka

Maksimalna izmjerena temperatura zraka na MT1 je bila 13,41 °C, a minimalna 10,97 °C. Na MT2 maksimalna zabilježena temperatura zraka je bila 16,04 °C, a minimalna 8,13 °C.

Hod srednje dnevne temperature zraka prikazan je na slici 3. Primjetna je znatna oscilacija srednjih dnevnih temperatura MT2 do kraja ožujka nakon čega se smanjuje uz općeniti trend porasta temperature. Oscilacije su rezultat pritjecanja zraka različitih temperatura i vlažnosti s površine u spilju. Veći padovi vjerojatno su posljedica utjecaja bure. Utjecaj vjetra na spiljske temperature zraka vidljiv je iz usporedbe podataka sa srednjim dnevnim temperaturama i srednjom dnevnom brzinom vjetra klimatološke postaje Cres. Iako je ta postaja udaljena od Beleja, a i reljefni uvjeti koji utječu na značajke prizemne cirkulacije zraka su drugačiji nego u Beleju, korelacija postoji (Sl. 4.). 11. i 12. veljače 2007. dolazi do porasta brzine vjetra. Prevladavajući vjetar je bura jačine 4. Dolazi do pada temperature zraka u Cresu, a pritjecanje hladnog zraka izaziva pad temperature na MT2. Smanjenje brzine vjetra promjenljivih smjerova (s prevlašću onih iz južnog kvadranta) između 12. i 15. veljače 2007. je praćeno laganim rastom temperature. Od 15. veljače 2007. prevladavaju vjetrovi sjevernoga

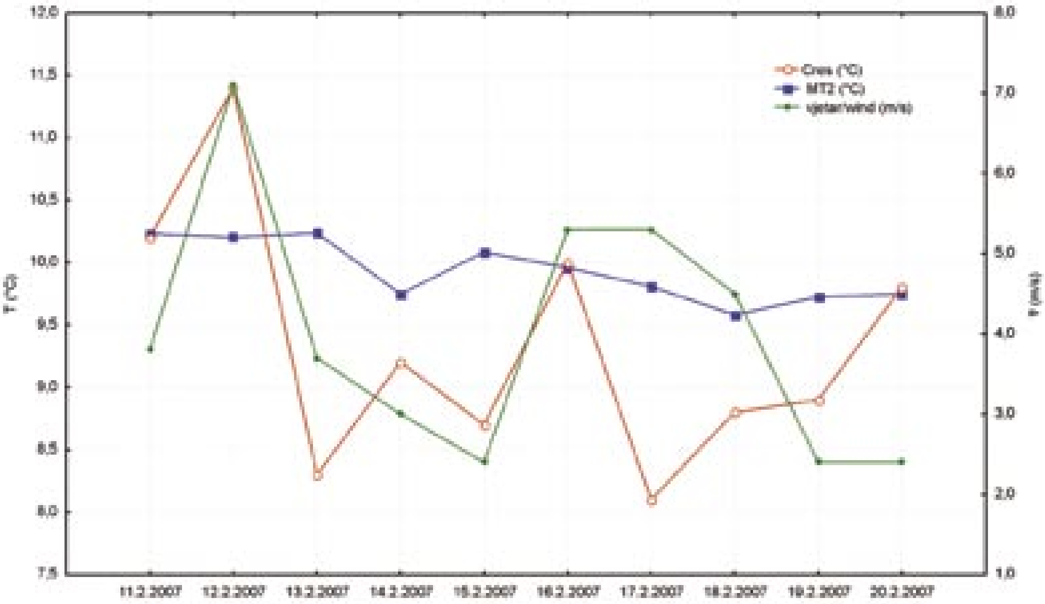
The measurement results were processed using basic statistical methods (mean value, standard deviation and variability coefficient).

Results and discussion

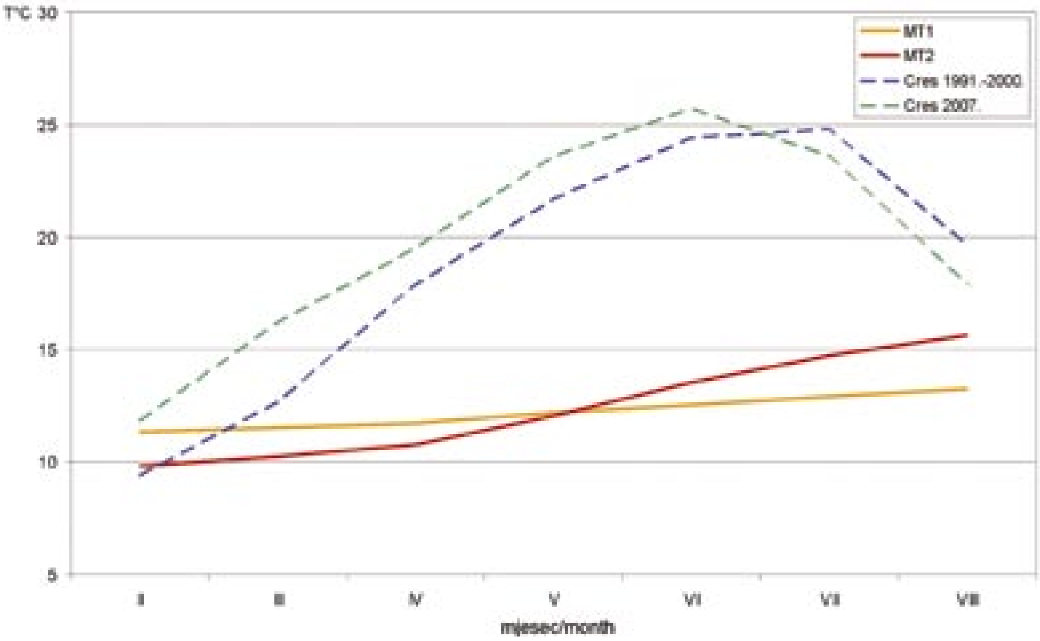
Air temperature

The maximum air temperature measured at MT1 was 13.41 °C, and the minimum was 10.97 °C. At MT2, the maximum recorded air temperature was 16.04 °C and minimum 8.13 °C.

An average diurnal air temperature trend is shown in figure 3. A considerable oscillation of mean diurnal temperatures at MT2 was observed until the end of March after which it began to decrease with the increase of temperature trend. Oscillations are a result of the inflow of various ranges of air temperature and humidity from the surface into the cave. The significant drops are likely to be caused by bora. The impact of wind on cave air temperature is evident from the comparison of mean diurnal temperature data with that of mean diurnal wind velocity, measured at the climatological station on Cres. Even though the station was far from Belej and relief conditions impacting ground air circulation features differed from those in Belej, the correlation existed (Fig. 4). On 11 and 12 February 2007 the wind velocity began to rise. The prevailing wind was a force 4



Slika 4. Usporedba dnevnog hoda srednje brzine vjetra te srednje dnevne temperature klimatološke postaje Cres i MT2 (11.-20. veljače 2007.)
Izvor: DHMZ, Zagreb
Figure 4 Comparison of diurnal trend of mean wind velocity with mean diurnal temperature at climatological station Cres and MT2 (11-20 February 2007)
Source: Meteorological and Hydrological Service, Zagreb



Slika 5. Usporedba hoda srednjih mjesečnih temperatura zraka u Spilji u Belejskoj komunadi (MT1 i MT2) sa hodom srednjih mjesečnih temperatura u Cresu za razdoblje 1991.-2000. i 2007. godine
Izvor: DHMZ, Zagreb
Figure 5 The comparison of mean monthly air temperature trends in the Cave in Belejska komunada (MT1 and MT2) with mean monthly temperature movements/trends in Cres for period 1991-2000 and 2007
Source: Meteorological and Hydrological Service, Zagreb

smjera čija brzina jača i traje do 17. veljače što je praćeno vidljivim padom temperature na površini i u podzemlju. Iza tog razdoblja brzina vjetra slabi, prevladavajući smjer je južni (S, SE i SSE), a temperatura je u laganom porastu. Sličan je utjecaj bure na temperaturu spiljskog zraka zabilježen u Đurovića spilji u Ćilipima (Buzjak, 2006b, 2006c). Na MT1 oscilacije postoje, ali su zamjetno manje jer je točka dalje od ulaza i pod manjim utjecajem vanjskih uvjeta.

Srednje mjesečne temperature zraka pravilno rastu od veljače prema kolovozu (Tab. 1; Sl. 5.), te porast na površini slijedi porast u spilji (Sl. 6.). Odstupanja od srednjih vrijednosti veća su na MT2 što je vidljivo iz amplitude, standardne devijacije (*s*) i koeficijenta varijabilnosti (*V*). Uzrok je blizina ulaza i jači utjecaj s površine jer je ulaz prostran i nije zatvoren vratima nego vodoravno položenim metalnim šipkama među kojima vanjski zrak neometano ulazi u spilju (kao što i spiljski zrak neometano izlazi van). To potvrđuje i prosječna temperatura zraka na MT2 koja je viša nego dublje u unutrašnjosti spilje što je posljedica pritjecanja toplog zraka s površine u toplom dijelu godine. S obzirom na rezultate spomenutih mjerenja na Cresu (Fiedler, Buzjak, 1998) te mjerenja u drugim speleološkim pojavama Hrvatske (arhiva istraživanja autora) opravdano je pretpostaviti da je temperatura zraka hladnijih razdoblja godine u ulaznom dijelu spilje (MT2) niža u odnosu na unutrašnjost dalje od ulaza.

Iz podataka (Tab. 1) je vidljivo da i na MT1 postoje utjecaji vanjske klime. To potvrđuje

bora (north-easterly wind). The air temperature dropped in Cres and cold air currents caused a drop in temperature at MT2. The decrease in wind velocity that blew in changing directions (with the prevailing ones from the south quadrant) between 12 and 15 February 2007 was followed by a steady rise in temperature. From 15 February 2007 the northern winds prevailed. Their velocity rose and lasted until 17 February followed by a marked drop in temperature on the surface and underground. After that period the wind velocity decreased, the prevailing directions were S, SE and SSE, and the temperature gradually rose. A similar impact of bora on cave air temperature was recorded in Đurovića spilja in Ćilipi (Buzjak, 2006b; 2006c). At MT1 oscillations do exist, but they are considerably lesser due to the measurement point being further from the entrance and subject to reduced impact of external conditions.

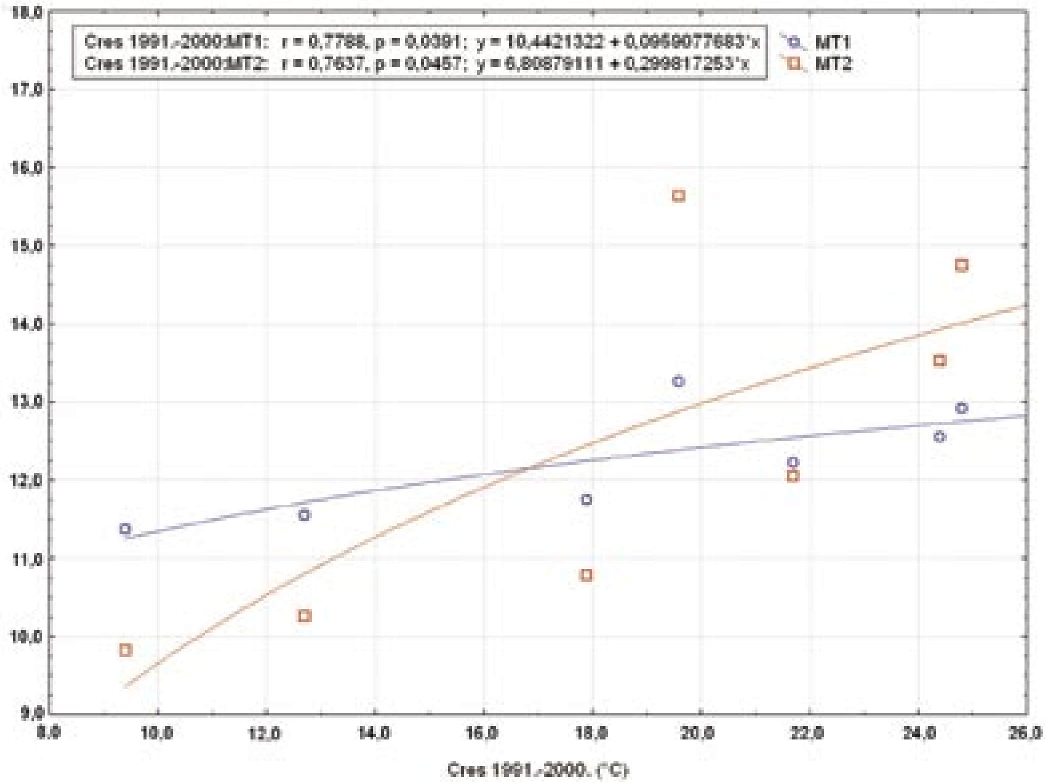
Mean monthly air temperatures rose at regular intervals from February towards August (Tab. 1, Fig. 5), with an increase on the surface followed by an increase in the cave (Fig. 6). Deviations from average values were greater at MT2 which is evident from the temperature amplitude, standard deviation (*s*) and variability coefficient (*V*). The reason for this is the vicinity of the entrance and a stronger input from the surface since the entrance is spacious and gated with horizontally placed metal bars thus allowing the external air to flow freely into the cave (much in the same way as the cave air freely flows out). That is further confirmed by the average air temperature at MT2 which is higher than in remote parts of the cave that is due to warm surface air input in the warm period of the

Tablica 1. Hod srednjih mjesečnih temperatura zraka (°C) u spilji (MT1 i MT2) te klimatološkoj postaji Cres za razdoblje 1991.-2000. i 2007. godinu

Table 1 Mean monthly air temperature trend (°C) in the cave (MT1 and MT2) and at the climatological station Cres for period 1991–2000 and 2007

Mjesec/Month	MT1	MT2	Cres 1991.-2000.	Cres 2007.
II	11,36	9,81	9,4	11,8
III	11,55	10,25	12,7	16,2
IV	11,75	10,78	17,9	19,5
V	12,22	12,04	21,7	23,6
VI	12,55	13,52	24,4	25,7
VII	12,91	14,75	24,8	23,6
VIII	13,26	15,63	19,6	17,9
$\overline{X}$	12,23	12,40	18,6	19,8
s	0,72	2,28	5,81	4,90
V (%)	5,91	18,61	31,24	24,75

Izvor / Source: Meteorological and Hydrological Service, Zagreb



Slika 6. Linearna korelacija između srednjih mjesečnih temperatura (Cres, MT1 i MT2)
Izvor: DHMZ, Zagreb
Figure 6 Linear correlation between mean monthly temperatures (Cres, MT1 and MT2)
Source: Meteorological and Hydrological Service, Zagreb

čvrsta pozitivna korelacija (*r* = 0,9928) između temperature MT2 i MT1 (Sl. 7). Ona je ujedno pokazatelj da pukotinska cirkulacija zraka[3] nema značajnijeg utjecaja na temperaturu MT1 nego da glavnina svježeg zraka s površine dolazi kroz ulaz. Na cirkulaciju prema MT1 utjecaja ima i silazni karakter kanala, osobito u hladnijim danima kada po dnu pritječe teži hladni zrak. Za turističko korištenje pozitivno je takvo (iako minimalno) "provjetravanje" kanala, jer umanjuje utjecaj porasta temperature zraka zbog osvjetljenja i ulaska turističkih grupa.

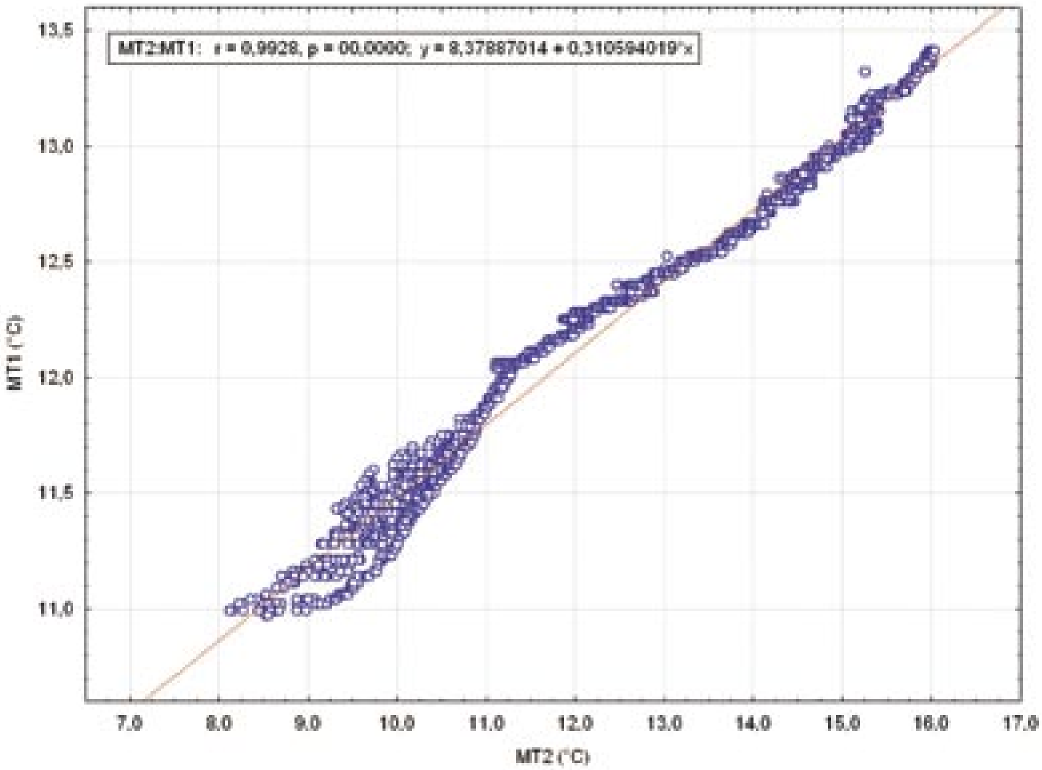
Dnevne i srednje mjesečne vrijednosti temperature zraka MT2 bile su niže nego na MT1 do druge polovice svibnja. Nakon toga im vrijednosti rastu iznad onih zabilježenih na MT1. Na takvo kretanje, osim pritjecanja toplijeg zraka izvana,

[3] Cirkulacija zraka kroz uske i za čovjeka neprolazne pukotine.

year. Based on the results of the above mentioned measurements in Cres (Fiedler, Buzjak, 1998) as well as measurements carried out in other Croatian speleological phenomena (author's research files), one would naturally assume that the air temperature at the cave entrance zone (MT2) during the cold parts of year would be lower in correlation with the remote parts located further form the entrance.

The data in Table 1 shows that even at MT1 the influence of external climate conditions existed. That was confirmed by the solid positive correlation (*r*=0.9928) between MT2 and MT1 temperatures (Fig. 7). At the same time this was an indicator that fissure air circulation[3] had no considerable impact on MT1 temperature but that the bulk of fresh surface air entered through the cave entrance. The air circulation towards MT1 was further affected

[3] Air circulation through narrow and impassable fissures.



Slika 7. Linearna korelacija između temperature zraka MT1 i MT2
Figure 7 Linear correlation between MT1 and MT2 air temperature

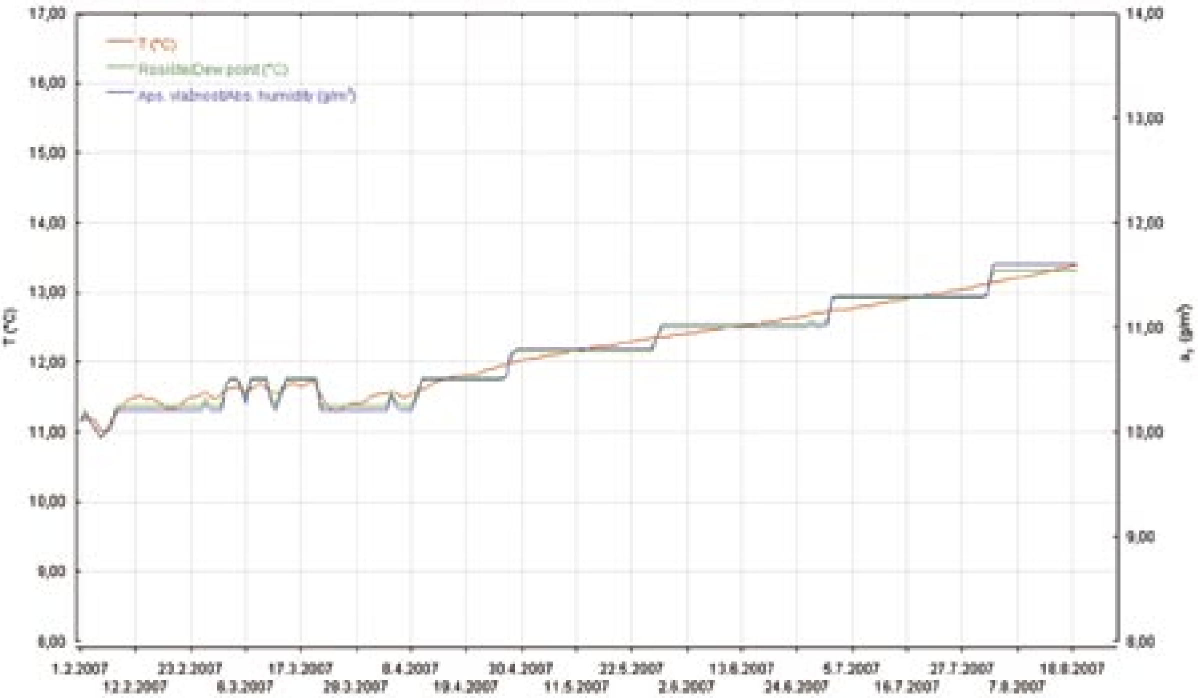
vjerojatno utječe i zagrijavanje stijena u nadsloju iznad kanala čije su naslage ovdje debele u prosjeku svega 3-4 m. Pojedini skokovi temperature mogući su zbog dotjecanja toplije vode s površine (topla kiša i prokapnica koja se zagrijava procjeđivanjem kroz ugrijane stijene ljeti).

Ovisnost hoda srednje mjesečne temperature zraka o uvjetima na površini još je zornija ako se izmjerene vrijednosti usporede s vanjskim podacima klimatološke postaje Cres (Hs=5 m; Sl. 5). Korelacija je pozitivna i čvrsta (za razdoblje 1991.-2000. $r > 0{,}764$). Promjene temperature u spilji odraz su promjena na površini. Porast temperature zraka promatranog razdoblja u podzemlju je sporiji pa se javlja kašnjenje temperaturnog maksimuma u podzemlju za onim na površini.

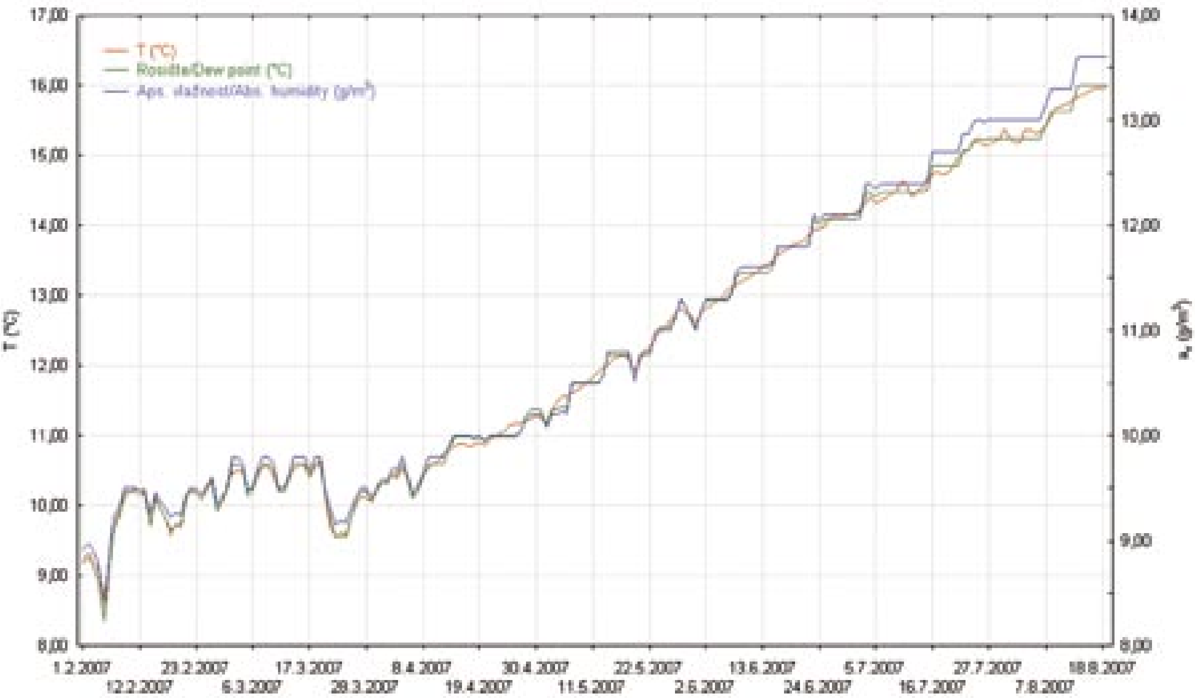
by the downward inclined passage, particularly during colder days when there was the input of comparatively dense and sinking cold air. For the purpose of tourist use, such passage "ventilation", although minimal, is considered to be a positive feature since it lessened an increase in temperature due to the lighting system and cave visitors.

Diurnal and mean monthly air temperature values at MT2 were lower than at MT1 until the second half of May. Afterwards their values rose above those recorded at MT1. The cause of this temperature trend, apart from the input of warm external air, is likely to be found in warming up of the overlying rock above the passage with average thick as little as 3-4 m. Individual temperature fluctuations are possible owing to the warm surface water input (warm rain and drip water that warms up during percolation through warmed up rock in summer).

The correlation of mean monthly air temperature trend and the surface conditions becomes clearer when the measured values are compared to the



Slika 8. Hod srednjih dnevnih temperatura zraka, rosišta i apsolutne vlažnosti MT1
Figure 8 MT1 mean diurnal air temperature, dew point and absolute humidity trend



Slika 9. Hod srednjih dnevnih temperatura zraka, rosišta i apsolutne vlažnosti MT2
Figure 9 MT2 mean diurnal air temperature, dew point and absolute humidity trend

Rosište

Rosište je temperatura pri kojoj nastupa kondenzacija vodene pare (Penzar, Penzar 1989). Ona se može postići tako da se uz nepromijenjenu količinu vodene pare zrak ohlađuje do zasićenja. U spiljama do kondenzacije dolazi zbog hlađenja toplijeg zraka u dodiru s hladnijim stijenama ili sedimentima na kojima se kao rezultat javlja spiljska rosa. Budući da je usko vezana uz vlažnost zraka, u spiljama gdje je vlažnost visoka temperatura rosišta je gotovo jednaka kao i temperatura zraka. Odstupanja od srednjih vrijednosti vrlo su mala (Tab. 2.). U spilji (dalje od zone vanjskih utjecaja u blizini ulaza) relativna vlažnost zraka je 96-100% pa su temperatura zraka i rosišta jednakih vrijednosti (Sl. 8. i 9.). Kondenzacija je primijećena na stijenama, tlu i sigama oko ulaza.

Relativna i apsolutna vlažnost zraka

U spilji su zabilježena vrlo mala kolebanja relativne vlažnosti zraka. Najmanje vrijednosti zabilježene su na MT2 početkom veljače kao najhladnijem mjesecu u nizu u kojem su bilježene i niže temperature zraka (Sl. 10.).

Vrijednosti vlažnosti zraka u spiljama vezane su uz hod temperature zraka, vlaženje stijena i sedimenata pritjecanjem vode, te iznosima izmjene energije između zraka, vode, stijena i sedimenata. S porastom temperature zrak može sadržavati više vlage, dok ohlađivanjem dolazi do kondenzacije. Apsolutna vlažnost raste s porastom temperature zraka.

external data from the climatological station on Cres (Hs=5 m; Fig. 5). Correlation is positive and solid (for the period 1991-2000 $r > 0.764$). Changes in the cave temperature reflected the surface changes. The increase in cave air temperature during the observed period was slower, in comparison to the surface values, and a delay of temperature maximum occurred.

Dew Point

Dew point is the temperature at which condensation of water vapour occurs (Penzar, Penzar 1989). Condensation in caves occurs as a result of cooling of warmer air that comes in touch with cooler rocks or sediments on which cave dew is formed. Since it is closely linked to the air humidity, in high humidity caves the dew point temperature approximated to the air temperature. Deviations from average values were slight (Tab. 2). In the cave (further from by the exterior conditions influenced zone near the entrance) relative air humidity was 96-100% resulting in equal value of air and dew point temperature (Fig. 8 and 9). Condensation was noticed on passage walls, soil and speleothems around the entrance.

Relative and absolute air humidity

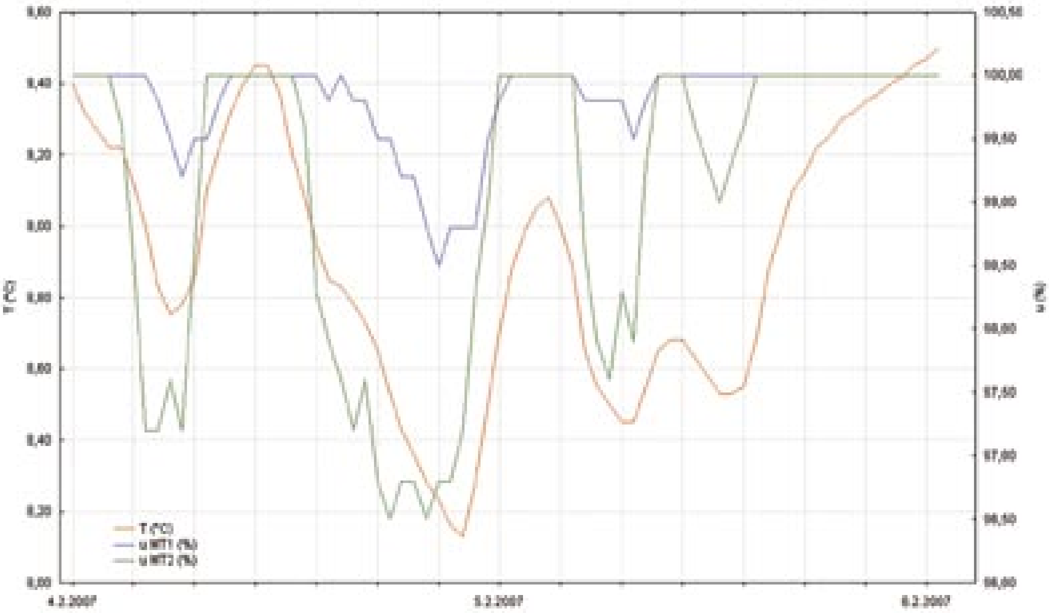
In the cave slight relative air humidity fluctuations have been recorded. The minimum values were recorded at MT2 in the beginning of February, the coldest month in a series, during which even lower air temperatures were recorded (Fig. 10).

The cave air humidity values correlate with the air temperature trend, rock and sediment moisture by means of percolating water inflow, and energy exchange values between air, water, rock and sediments. With an increase in temperature, air can contain more humidity, whereas its cooling results in condensation. Absolute air humidity rises with the increase in air temperature.

Tablica 2. Standardne devijacije (s) za temperaturu zraka (T), temperaturu rosišta (τ), apsolutnu (a_v) i relativnu (u) vlažnost zraka Spilje u Belejskoj komunadi

Table 2 Standard deviations (s) for air temperature (T), dew point temperature (τ), absolute (a_v) and relative (u) air humidity in the Cave in Belejska komunada

	MT1				MT2			
	T(°C)	τ (°C)	a_v (g/m³)	u (%)	T(°C)	τ (°C)	a_v (g/m³)	u (%)
s	0,64	0,67	0,47	0,05	2,06	2,06	1,41	0,19



Slika 10. Usporedba dnevnog hoda temperature i relativne vlažnosti zraka (u) MT1 i MT2 (4.-6. veljače 2007.)
Figure 10 The comparison of diurnal temperature trend with relative air humidity (u) MT1 and MT2 (4-6 February 2007)

Zaključak

Spilja u Belejskoj komunadi ima tipičnu spiljsku mikroklimu čije su značajke:

- niže vrijednosti temperature zraka te više vrijednosti relativne i apsolutne vlažnosti zraka nego na površini,
- visoka vlažnost zraka tijekom cijelog razdoblja (najčešće 99-100%),
- manje dnevne, mjesečne i sezonske oscilacije njihovih vrijednosti od onih na površini,
- oscilacije su najveće u blizini ulaza zbog pritjecanja hladnijeg zraka s površine zimi i toplijeg ljeti,
- s udaljavanjem od ulaza oscilacije se smanjuju,
- kašnjenje maksimuma temperature zraka u podzemlju za onima na površini,
- u kanalu je zabilježena pojava spiljske rose (pojačano u zoni ulaza).

Promatrano razdoblje 2007. godine na postaji Cres je bilo toplije od višegodišnjeg prosjeka (1991.-2000.) tako da su vjerojatno i spiljske temperature više nego što je njihov višegodišnji prosjek.

U spilji je dokazan utjecaj vjetra na snižavanje temperature zraka (bura u hladnijem dijelu godine). Glavnina zraka u spilju dolazi slobodnom

Conclusion

The Cave in Belejska Komunada has a typical cave microclimate with the following features:

- lower air temperature values and higher relative and absolute air humidity values than on surface,
- high air humidity during the entire period (in most cases 99-100%),
- smaller diurnal, monthly and seasonal oscillations from the surface ones,
- oscillations are greatest near the entrance due to the inflow of cooler air from the surface during winter and warmer air during summer,
- going further from the entrance, the oscillations are less pronounced,
- a delay in maximum cave air temperature in relation to the ones on the surface,
- in the passage the presence of cave dew was recorded (particularly in the entrance zone).

With respect to the surface air temperature, the observed 2007 period was above the average recorded in the 1991-2000 period, therefore it is likely that the cave temperatures reflected the same pattern.

Inside the cave the direct impact of wind on the decrease in air temperature has been proven (bora cirkulacijom kroz prostrani ulaz pa ju je važno osigurati i u slučaju turističkog iskorištavanja. Ljudi u spilji dovest će do porasta temperature zraka i pojačanog rošenja (te promjene drugih parametara) pa je bitno da se ulaz ne zatvara punim vratima koja će onemogućiti normalnu cirkulaciju zraka i provjetravanje spilje. To je važno i stoga što je spilja *niskog energetskog nivoa*[4] (HEATON, 1986) te je izuzetno osjetljiva na negativne antropogene utjecaje. Nepravilno gospodarenje spiljom može u kratkom vremenu dovesti do velikih promjena mikroklimatskih i drugih parametara za čije je vraćanje na prirodno stanje potrebno puno vremena.

Proučavanje uvjeta kondenzacije u krškom podzemlju i mjerenja iznosa kondenzacije zaslužuje veliku pozornost. Prema dosadašnjim spoznajama kondenzirana voda ima značajnu ulogu u okršavanju i speleogenezi (DUBLYANSKY, DUBLYANSKY, 2000). Ona korozivno djeluje na matičnu stijenu te ima utjecaja na oblikovanje raznih spiljskih denudacijskih mikroreljefnih oblika, ali i siga (npr. koraloidi). Spiljska rosa u kombinaciji s neadekvatnom rasvjetom može dovesti do pojave flore[5] na stijenama i sigama. Biokemijskim procesima i njihovom agresivnim produktima dolazi do intenzivnijeg nagrizanja površine. Osim toga, alge svojom pojavom narušavaju estetski doživljaj, naročito kada obraštaju sige. Negativne antropogene utjecaje koji se javljaju pri turističkom

[4] Podjela speleoloških pojava prema energentskim nivoima pomoćna je metoda u određivanju podnošljivog kapaciteta. Pogodna je za spilje u kojima nije obavljeno sustavno mjerenje geoekoloških parametara potrebnih za planiranje turističkog korištenja (Buzjak 2006 a). Energetski nivoi određeni su intenzitetom djelovanja prirodnih sila koje nakon turističkih posjeta (ili općenito antropogenih utjecaja) spilju vraćaju u njeno prirodno stanje. Do promjena dolazi izmjenom energije ili promjenama u nivoima energije. Speleološke pojave niskog energentskog nivoa najosjetljivije su na antropogene utjecaje zbog slabog djelovanja prirodnih sila. U njima najveći intenzitet među prirodnim procesima može biti npr. kapanje prokapnice koje nije dovoljno za vraćanje spiljskog prostora u prirodno stanje (kao npr. poplava kanala ili snažno strujanje zraka). Posjet tom tipu spilja može imati ozbiljne posljedice jer u kratkom vremenskom razdoblju može doći do izrazitih promjena fizičko-kemijskih parametara (temperature i vlažnosti zraka, koncentracije CO_2, unos spora i prašine i sl.) za čije je vraćanje na prirodno stanje zbog sporosti prirodnih procesa potrebno puno vremena.

[5] Njem. *Lampenflora*; najčešće alge i mahovine. Pod neadekvatnom rasvjetom misli se na obične žarulje i reflektore koji jako zagrijavaju zrak, stijene i sedimente te svojim svjetlosnim karakteristikama potiču razvoj flore. Alternativa je tzv. hladno svjetlo.

in the colder part of year). Given that the major amount of air gets in the cave via free circulation through the spacious entrance, it is necessary to make sure that this free air circulation is undisturbed in case of tourist usage. The presence of visitors inside the cave will result in an increased air temperature and intensified formation of cave dew (as well as changes in other parameters) so it is vital to leave the entrance ungated in order not to prevent normal air circulation and ventilation in the cave. Equally important is the fact that this is a *low energy level*[4] cave (HEATON, 1986), highly susceptible to negative antropogenous effects. Consequently, in a short time an unsuitable cave management could cause profound changes in microclimatic and other parameters whereas the efforts to restore them to their natural state would require quite a long time.

A research on condensation conditions in karst underground area and on the amount of condensation measured deserves to be taken seriously. According to our understanding so far, condensed water is an important factor during karstification and speleogenesis (DUBLYANSKY, DUBLYANSKY, 2000.). It corrodes the rock away and affects the formation of various cave denudated microrelief forms, including speleothems (e.g. coral-like formations). Cave dew combined with inadequate lighting may result in the growth of flora[5] on rocks and speleothems. Due to biochemical processes and resulting aggressive products, the

[4] Classification of speleological phenomena according to their energy levels is an auxiliary method used to determine a carrying capacity. It is suitable for caves in which no systematic measurement of the required geoecological parameters was conducted for the purpose of planning its tourist usage (BUZJAK, 2006A). Energy levels are determined by the intensity of natural processes that can restore a cave to its natural state after tourist visits (or antropogenous impact in general). The changes occur as a result of energy exchange or variations in energy levels. Speleological phenomena with a low energy level are the most sensitive to antropogenous impacts due to their feeble natural processes. Their strongest natural process intensity could be for example dripping of ground water which is insufficient to restore the cave environment to its natural state (e.g. passage flooding or strong air currents). A visit to that particular type of cave could have detrimental effects on the cave environment because in a quite short period of time dramatic alterations in physical and chemical parameters (air temperature and humidity, CO_2 level, spore and dust input etc.) may occur and the restoration to the original state, due to the slowness of natural processes involved, would take a long time.

[5] Germ. *Lampenflora*; mostly algae and mosses. The inadequate lighting refers to garden variety bulbs and spotlights which not only considerably warm up air, rocks and sediments but also allow flora to grow. Alternative is the "cold" light.

korištenju moguće je ublažiti kontinuiranim praćenjem mikroklimatskih parametara (osnovni su temperatura i vlažnost zraka), određivanjem turističkog kapaciteta spilje i njenih dijelova[6] te odabirom hladne rasvjete koja ne daje uvjete za razvoj flore.

Zahvala

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surface corrosion is intensified. In addition, the development of algae hinders the cave's aesthetic appeal, especially when found on speleothems. It is likely that the negative antropogenous impact due to the cave tourist usage could be minimized by means of continuous monitoring of microclimatical parameters (basic ones being air temperature and humidity), determining tourist capacity of the cave and its parts[6] and by opting for low-heat lights that do not support the plant development.

Acknowledgments

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[6] Turistički kapacitet spilje određen je gornjim brojem turista koji neće izazvati kritične promjene ekoloških parametara spilje (promjene fizičko-kemijskih svojstava zraka i vode), biološko onečišćenje, fizičko oštećenje i unošenje otpada (Buzjak, 2006a).

[6] The cave visitors capacity is the maximum number of visitors whose presence in a cave will not dramatically alter its ecological parameters (variations in physical and chemical characteristics of water and air), biological pollution, physical damage and rubbish dumping (Buzjak, 2006a).