Preliminary research on the thermo-hygrometric peculiarities of the Cacica salt mine microclimate

Dumitru MIHĂILĂ[1], Andrei-Emil BRICIU[1] and Luciana-Alexandra COSTAN (BRICIU)[1]*
[1] Ștefan cel Mare University, Suceava, Romania

* Correspondence to: Luciana-Alexandra COSTAN (BRICIU). E-mail: luciana.briciu@gmail.com.

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ABSTRACT: This study is based on the hourly thermo-hygrometric measurements carried out between July 2nd and December 14th, 2018 at three points in the Cacica Salt Mine and at two very close points between them outside the salt mine. iButton sensors were placed at -75 m (two sensors) and -41 m (one sensor) inside the salt mine and at an average altitude of 437 m outside the mine. We monitored for a period of 166 days (3984 hours) the inter-monthly, inter-diurnal and inter-hourly evolution of air temperature, relative humidity and THI bioclimatic index inside and outside the mine. Inside the salt mine, the microclimate is characterized by a relative thermo-hygric uniformity and a slight discomfort by cooling. The inter-hourly maximum amplitudes of the air temperature and relative humidity for all hours ranged, for all monitoring points inside the mine, between 0.4 and 2.1°C, respectively between 18.2 and 31%, while outside the mine the equivalent values were 41.9°C and 66%. The THI inter-hourly amplitudes ranged from 0.4°C to 1.5°C inside the mine, while outside the equivalent value was 39.1°C. The thermo-hygric uniformity of the salt mine microclimate is also evidenced by the standard deviation values of the hourly data which are very low into the mine (temperature: between 0.1 and 0.3°C; relative humidity: between 3.2 and 5.8%; THI: between 0.1 and 0.3°C) compared to the equivalent outside values (8.2°C, 11.4% and 7.9°C), respectively).

KEY WORDS: salt mine microclimate, low variability, slight discomfort by cooling.

1. Introduction

The benefits for human health of salt mines interior have long been known and discussed in various specialist papers (Știrbu et al., 2012). Speleotherapy and halotherapy are the cure elements that are offered by salt mines to the sick or tourists. The effects beneficial to the human

health of speleotherapy in salt mines are documented by numerous studies (Karakoca et al., 1995, Horowitz, 2010, Călin et al., 2012).

In Romania, there are numerous salt mines included in the tourist flow: Praid, Turda, Slănic Prahova, Târgu Ocna, Cacica, Ocnele Mari, Ocna Dejului. The total number of tourists in these salt mines was more than 900000 in 2009 and steadily increasing (Mihăilă, 2017). In fact, the number of tourists has reached such an extent that it changes the properties of the air in the mines, either directly through the sweat and warmth of the human body, or indirectly through the heat and contaminants generated by the means of transport inside the salt mines.

Simionca (2013) describes the models of valid climate therapy in some Romanian salt mines, including Cacica, necessary for them to function as underground sanatoriums (Mihăilă, 2017). Similar ideas are also expressed by Mirescu et al. (2012), who addresses the curative potential of Dej and Cacica salt mines in relation to the local therapeutic factors and the mine structure.

The purpose of this paper is to measure with high temporal resolution air parameters in Cacica salt mine and to show their evolution over a reasonably long period of time, identifying particularities and the related causes.

2. Study area

Cacica Salt Mine is located in the same name village, in the Solca-Cacica depression (Suceava County, Romania). Salt is exploited from this mine since the eighteenth century. The access galleries, like most of the halls, were manually dug and have a minimum width of 1 m / height of approx. 3 m (horizontal access paths). There are three vertical wells and three horizons of exploitation. The entrance of the mine is positioned at 432 m above sea level (a.s.l.); the chapel of St. Varvara in the mine is at 403 m a.s.l .; the horizon I, closed to exploitation, lies at 394 m a.s.l.; horizon II, also closed to exploitation, is located at 375 m a.s.l .; the third horizon, located at 360 m a.s.l., is the one in which the exploitation of salt continues. Today, the galleries and a number of large halls are open to the tourists: the Lake Hall, with an artificial salt lake accessible to the tourists (-41m below the topographic surface), the Dance Hall, where at the big celebrations were held, located at -44 m; the Sports Hall and the Recreation Hall, located at -75 m. The number of tourists is increasing, being higher than 73000 in 2012 (Maiorescu et al., 2014). According to the saline administrators (eng. Slevoacă), the number of tourists in the time interval 2.VII. - 14.XII. 2018 exceeded 54000 and, during 2018, it exceeded 105000.

The exploitation of salt is still done today at Horizon III, the exploitation method involving the kinetic dissolution of salt; brine is extracted from the underground and transported by pipeline to be recrystallized (the mine belongs to SALROM - the National Salt Society); the salt is commercially available as a table salt after adding the E536 (potassium ferrocyanide) anticaking agents. In the process of salt dissolving and brine extracting, petroleum products are used, which affect the air quality in the salt mine. Simionca (2011) reports studies showing that there is a high concentration of CO_2 in the Cacica mine (1100-1400 ppm), which is reduced after the mine ventilation (600 ppm); the same behaviour is indicated by the hydrocarbons detected in the mine's air, which reach 15.95 - 18.3 ppm during unventilated conditions. There is also a special smell in the Recreation Hall, which until recently served as a deposit for cheese barrels.

The therapeutic quality of the microclimate in the Cacica salt mine was demonstrated by numerous researches and measurements, which focused on the influence of bioclimatic, chemical, radioactive factors etc. on the human body. Studies by Ieţcu et al. (2012) demonstrated that the

physical, chemical, biological and radioactivity parameters allow for activities of salt mine therapy to be carried out inside Cacica mine. Some studies have focused on microclimate analysis and natural ionization of underground air, such as Enache and Bunescu (2012).

The tourist attractiveness of Cacica salt mine can be increased by surface land structures, but especially by the measures for the underground spaces. Maiorescu et al. (2012) proposed, in the modelling of the salt mine, the arrangement of a visitor center, parking platforms, a pavilion for an underground access lift for tourists, the arrangement of the underground access path, the refurbishment of the existing spaces with various endowments for tourists, a salt mine therapy section and so on.

3. Methods and data

Hourly air temperature and relative humidity measurements were performed at 5 points in the Cacica mine and its surroundings using iButton, DS1923-F5, logger sensors. The resolution of the measurements was 0.0625°C and 0.04% RH. The measurements were performed between July 1st and December 15th, 2018. Since measurements made with iButtons were performed both in months with daylight saving time and in months with standard time, all measurements were transformed in standard time. From the measurement period, only the days that were fully covered within the mentioned interval, i.e. days between July 2nd and December 14th, 2018, were retained for analysis.

The iButton instruments were placed in the mine at 2 different depths: -75 m relative to the topographic surface, two sensors (Sports and Recreation Hall); -41 m relative to the topographic surface, one sensor (Lake Hall). At 2 points outside the salt mine, a sensor was placed on the territory of the village of Cacica, near the salt mine (the 2 points are the edge of a deciduous forest – in the first half of the monitoring period - and the edge of an orchard - in the second half of the time interval); the average terrain elevation of the 2 points is 437 m a.s.l. (47°38'02.5"N 25°53'46.5"E – 445 m - observation point no. 1; 47°38'06.5"N 25°53'56.6"E – 428 m - observation point no. 2).

It is necessary to note the high declivity of the slope on which the sensor outside the saline was located and the relatively unfavourable exposure of the outside observation sites in relation to the solar radiation, which generated lower temperature values and higher relative humidity values than if these parameters would have been measured by a local and standard meteorological station.

On July 1st, 2018, in the time interval 11:20-13:00 (EEST), measurements of the atmospheric pressure variation in the mine were carried out at different depths. These measurements were performed with a TruBlue 275 Baro instrument at a 10 minutes time resolution.

The air temperature and relative humidity values were used to calculate the THI thermo-hygrometric index (unit of measure: °C, indicator of thermal and hygric stress or comfort of the human body); the calculus is based on the formula proposed by Kyle (1994):

THI={air temperature}-(0.55-0.0055*{air relative humidity})*({air temperature}-14.5).

Mihăilă et al. (2016) provide a correlation table between THI values and bioclimatic comfort or discomfort types; THI values between 15 and 20°C indicate bioclimatic comfort, while lower and higher values than those in this class express different degrees of bioclimatic discomfort caused by overcooling and, respectively, overheating.

4. Results and discussion

Our measurements showed that the relative humidity of the air has, from July to October, an opposite evolution inside the mine versus its exterior (Fig. 1). Between November and the first half of December, the evolutions of this parameter both in the exterior and interior spaces have the same pattern, with the outer/inner difference being large. The inter-monthly air temperature of the three monitoring points in the salt mine follows a known logical pattern, but it is possible to outline (if we have data for many years) a remanence in producing the annual thermal maximum (placed in August and not in July). Between July and December, the monthly average temperature fluctuated between 10.8°C and 8.8°C, while the relative humidity had monthly average values that fluctuated between 65.4% and 82.9% (Tab. 1).

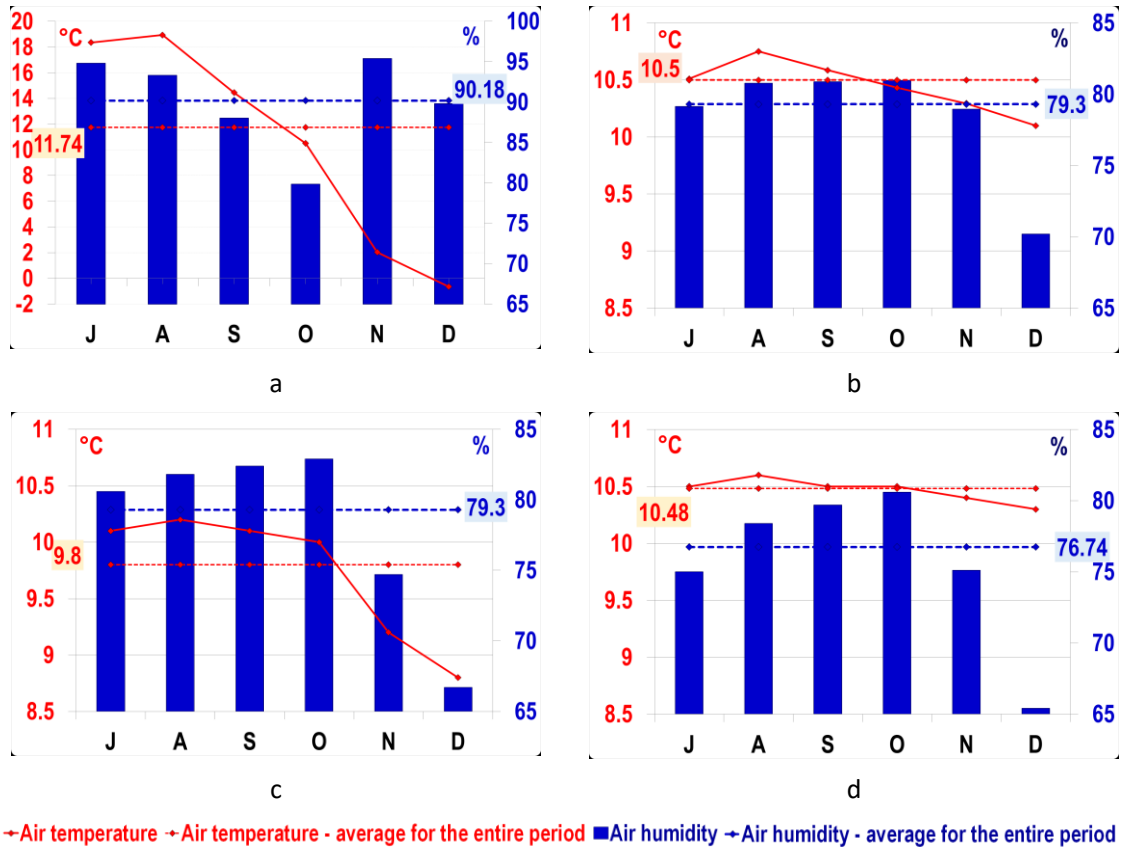

Figure 1 The inter-monthly evolution of air temperature and relative humidity compared to the averages of these parameters during July - December 2018: a. outside of the salt mine, b. Lake Hall, c. Sports Hall, d. Recreation Hall. This figure is available in colour online at www.georeview.ro.

Enache and Bunescu (2012) indicated the existence of a discomfort caused by cooling, caused in particular by the low temperatures in the Cacica salt mine (10.2 - 11.2°C); the relative air humidity measured by these authors had values of 66 - 71%. The same type of bioclimatic discomfort was observed by us after calculating the THI index, whose inter-monthly evolution is a relatively

uniform one (Tab. 2 and Fig. 2b, c, d). The greatest deviation of THI monthly average from the July-December period was calculated for the Sports Hall (Fig. 2c) and is caused by the more intense recreational activities of that place. However, the evolution of THI values in the Sports Hall (Fig. 2c) is much less variable than that of the index outside the salt mine (Fig. 2a).

Table 1 Average monthly values of air temperature (T) and relative humidity (RH) inside and outside Cacica salt mine.

	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)	T (°C)	RH (%)
	Exterior		Lake Hall		Sports Hall		Recreation Hall	
J	18.4	94.8	10.5	79.1	10.1	80.6	10.5	75
A	18.9	93.3	10.8	80.8	10.2	81.8	10.6	78.4
S	14.5	88.0	10.6	80.9	10.1	82.4	10.5	79.7
O	10.5	79.8	10.4	81.0	10	82.9	10.5	80.6
N	2.0	95.4	10.3	79.0	9.2	74.7	10.4	75.1
D	-0.6	89.8	10.1	70.2	8.8	66.7	10.3	65.4
Avg.	11.7	90.2	10.5	79.3	9.8	79.3	10.5	76.8

Table 2 Average monthly values of THI (°C) inside and outside Cacica salt mine.

	Exterior	Lake Hall	Sports Hall	Recreation Hall
J	18.2	11	10.6	11.1
A	18.8	11.1	10.7	11.0
S	14.4	11	10.6	11.0
O	10.6	10.9	10.4	10.9
N	2.2	10.8	10.0	11.0
D	0.1	10.8	9.8	11.1
Avg.	11.8	10.9	10.4	11.0

Moving the analysis at a higher level of detail, in the inter-diurnal profile, we discovered, in addition to the monotonous regime of the air temperature and relative humidity in July-October, a significantly higher variability of these two elements in November-December (Fig. 3).

The variations of the microclimatic parameters studied in the salt mine are low and have a very high „degree of independence" in relation to the outside environment during the warm period of the year. The cooler and moist air of the salt cannot be replaced by a warmer and drier air from the outside. In the cold period of the year, the "degree of independence" of the saline microclimate is slightly faded (Fig. 4).

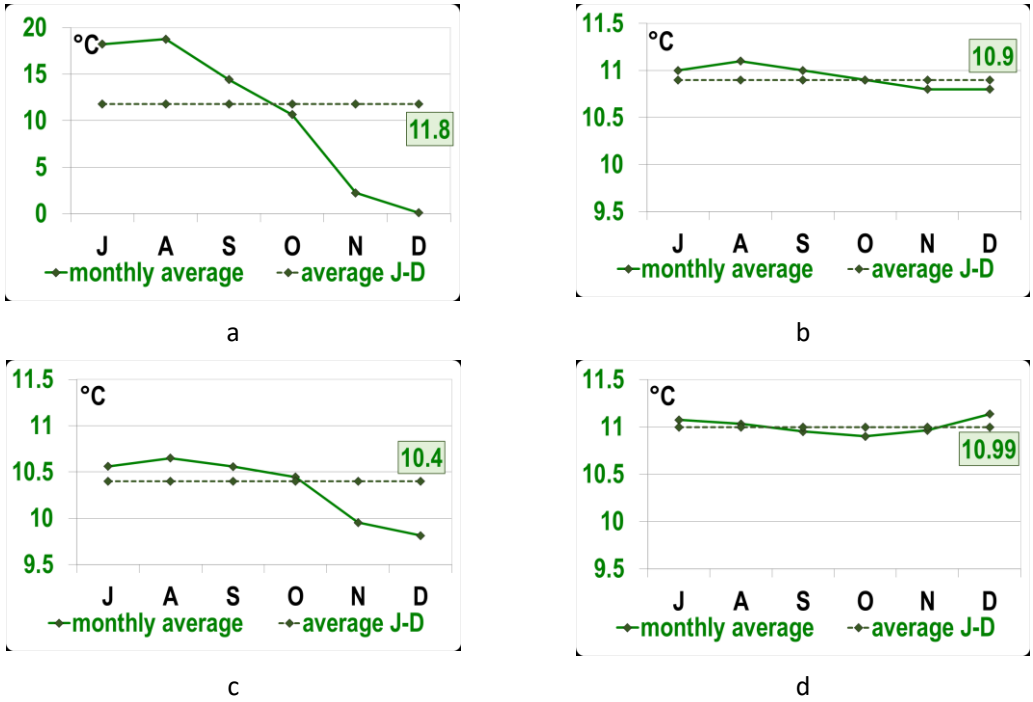

Figure 2 The inter-monthly evolution of THI compared to the average of this index during July - December 2018: a. outside of the salt mine, b. Lake Hall, c. Sports Hall, d. Recreation Hall. This figure is available in colour online at www.georeview.ro.

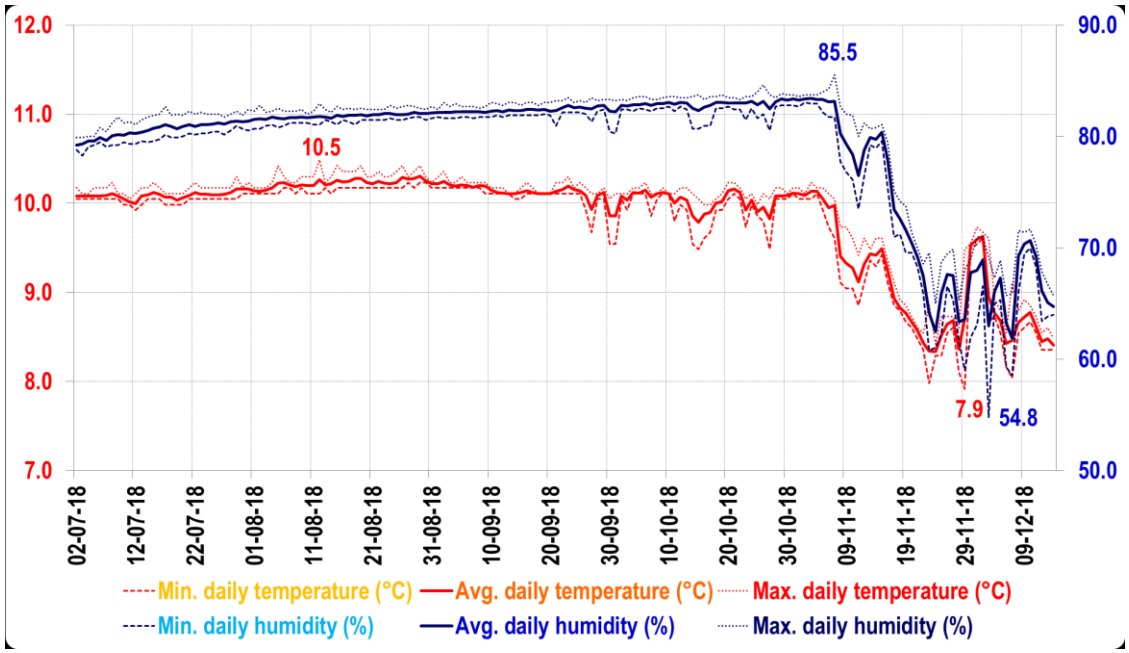

Figure 3 Inter-diurnal evolution of air temperature and relative humidity during July - December 2018 in Sports Hall (-75 m).

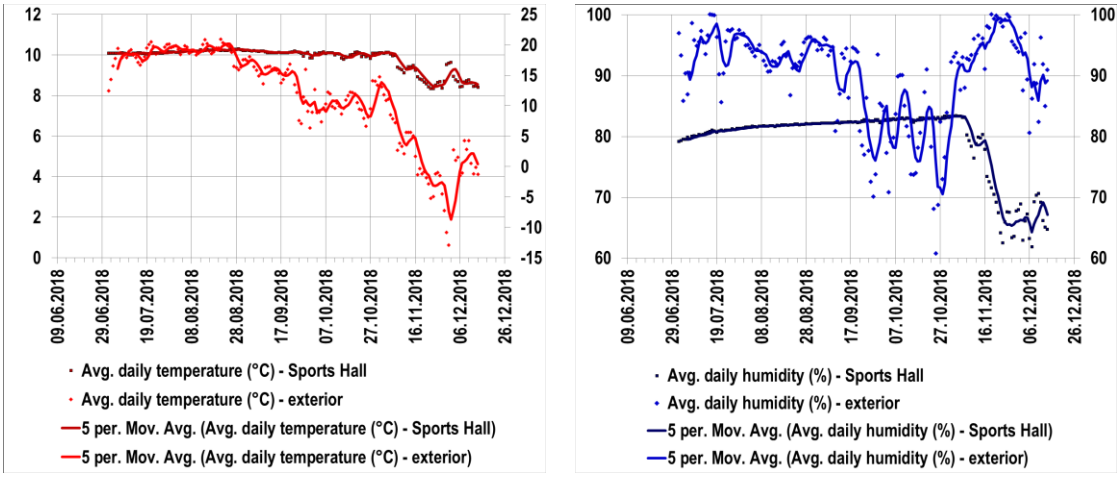

Figure 4 Correlative inter-diurnal evolution of air temperature (left) and relative humidity (right) inside and outside of Cacica salt mine (2.VII. - 14.XII. 2018).

During the cold season of the year, the cold and humid air outside of the salt mine falls inside it and is easily sedimented to the lower horizons of the mine. Salt mine air temperature drops slightly, but water vapours in the air are attracted to the walls, ceilings and access ways that are made of salt, so that the air in the saline becomes drier than normal.

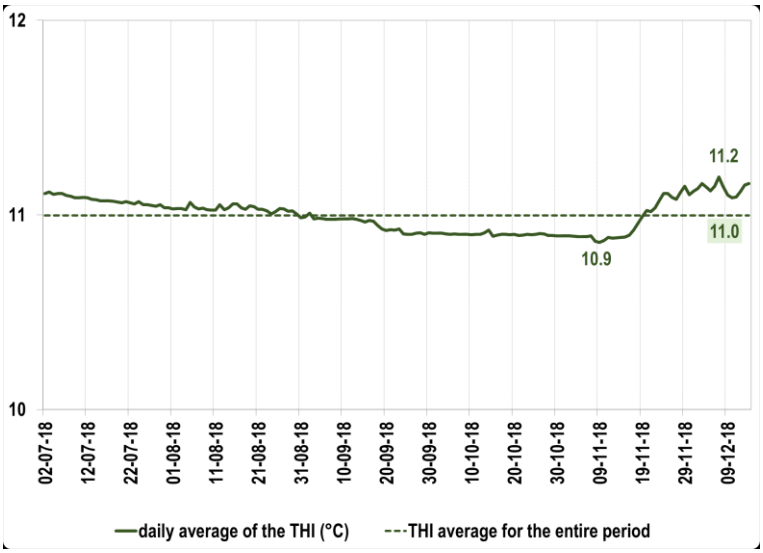

Figure 5 Inter-diurnal evolution of THI compared to the average of this index during July - December 2018 in Recreation Hall (-75 m).

The bioclimatic discomfort through cooling is a permanent one, although it is not very pronounced, having some limits easily tolerated by the human body (Fig. 5). This permanent sensation of coolness urges movement, helping the muscular and cardiovascular systems, burning excess calories and producing internal metabolic energy. The practice of sports (in the Sports Hall), the stairs trekking (going downward into the mine and climbing to the surface), combined judiciously with rest times (in the Recreation hall, Lake Hall, Dance Hall - where excellent musical auditions can be performed due to the special acoustics -, the chapel of St. Varvara) are beneficial procedures to the human body.

At the hourly detail, the evolution of the thermo-hygrometric complex of the analysed period was similar to that revealed by inter-diurnal analysis. The new analysis allows for detailing evolutions for different horizons of the salt mine (Figs. 6 and 7).

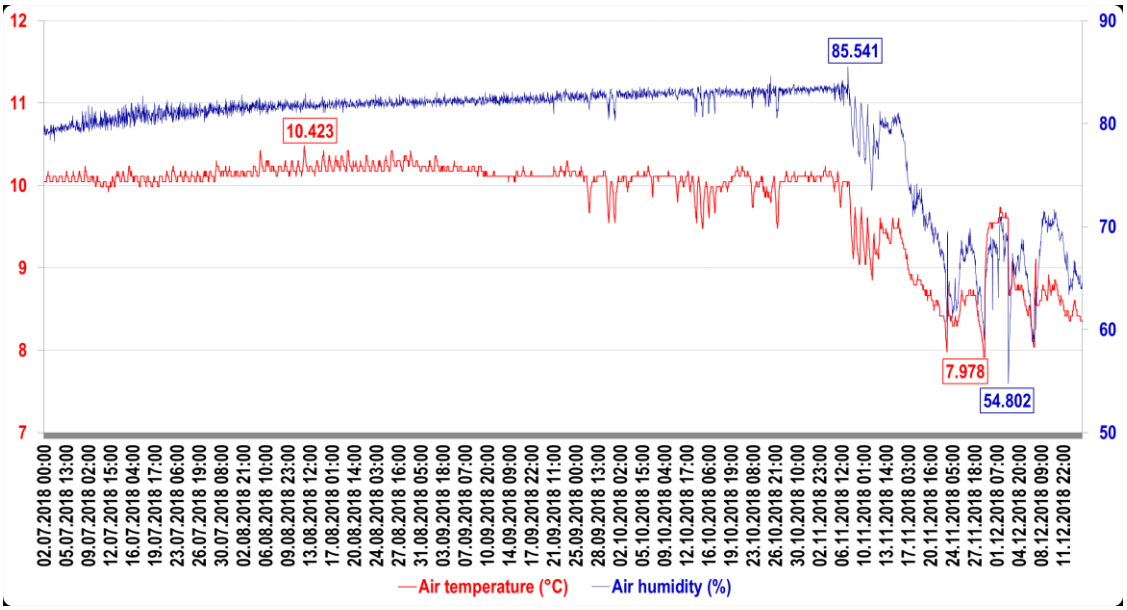

Figure 6 Inter-hourly evolution of air temperature and relative humidity in Sports Hall (-75 m).

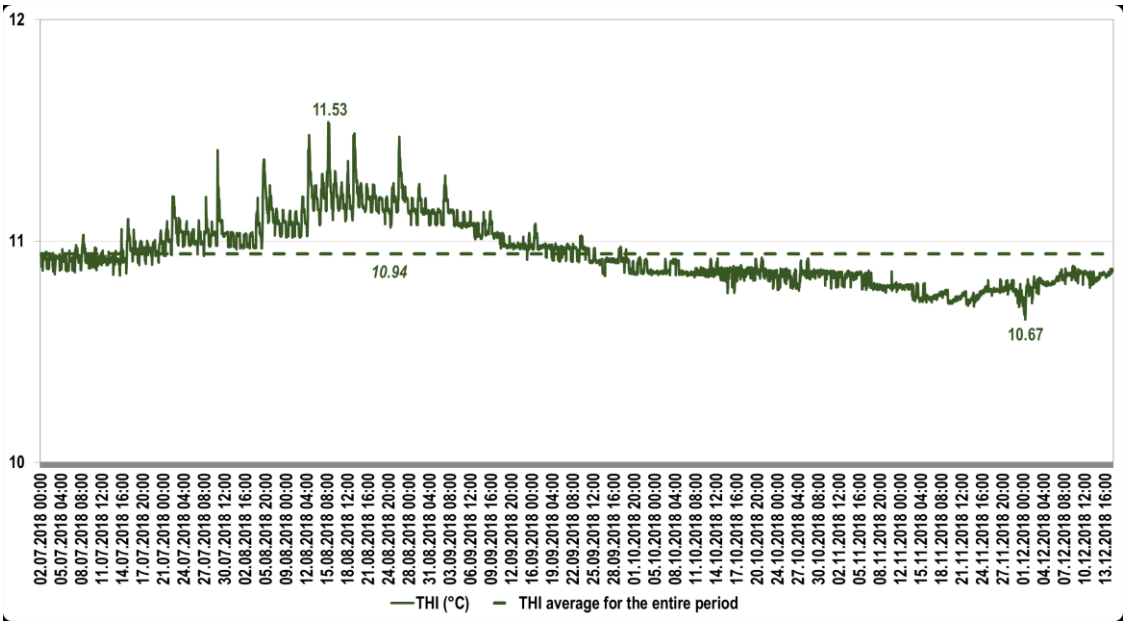

Figure 7 Inter-hourly evolution of THI compared to the average of this index during July - December 2018 in Lake Hall (-41 m).

The quasi-synchronous and directly proportional correlation temperature - relative humidity in the salt mine environment that is different from the outside environment (visible and amplified especially during the cold period of the year) is maintained by the high hygroscopic power of the salt walls that play a special role in the hygric balance of salt mine air.

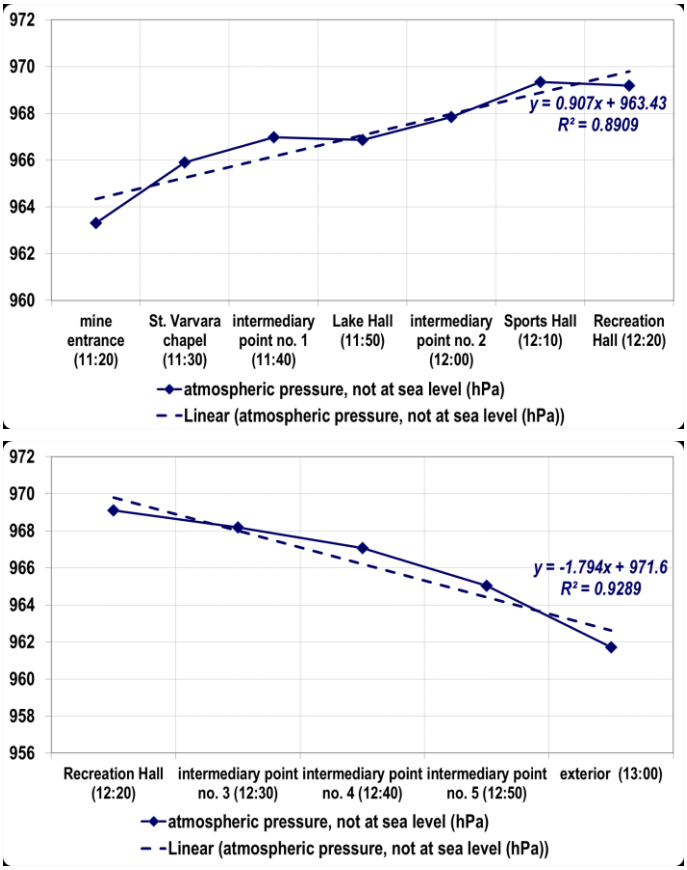

Figure 8 Atmospheric pressure at different levels in Cacica salt mine on July 1st, 2018.

In Cacica salt mine, as well as in the other salt mines, there is a slight hyperbarism (Ieţcu et al., 2012; Enache and Bunescu, 2012). These researchers showed that, at the lower horizons of the Cacica mine, the atmospheric pressure is higher with 8 - 9.3 hPa than the local pressure at the entrance of the mine.

According to our observations (which were only experimental and short-lasting) the baric superiority of the salt mine is maintained within the values of +6 - +7 hPa (Fig.8).

Higher atmospheric pressure is an important element in stimulating the cardiovascular system. The partial pressure of oxygen is also higher at the lower horizons of the salt mine and the human body can naturally benefit from better oxygenation.

5. Conclusions

Due to the special temperature and air humidity values and regimes in Cacica salt mine, the cool and relatively humid microclimate has tonic-stimulant features throughout the year.

Gradually dosed cures, sports in relation to medical recommendations, resting and relaxing breaks are procedures favouring the healthy peculiarities of the thermo-hygrometric complex of the salt mine. In conjunction with increasing air pressure, partial oxygen pressure, aerosols with a diverse chemical composition etc., all these specifics of salt mine microclimate are beneficial for enhancing the functioning of the muscular, circulatory and respiratory systems.

Cacica is thus registered with its natural factors of cure and balneary-climatic treatment among tourist resorts with a high tourist attractiveness. Still, the man has to value what nature has given him.

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