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INVESTIGATIONS ON AIR QUALITY IN A SCHOOL

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Abstract
The high rate of children becoming ill during school periods as opposed to during school holidays has forced authorities associated with the educational system and labour medicine to carry out regular checks in schools and to assign hygienization tasks. Air quality reports, otherwise completely absent from schools, have been requested. Students have reportedly been confronted with headaches and drowsiness, particularly during the second half of their school day. This paper aims to determine the effects of the most important indoor microclimate indicators - namely classroom air temperature, relative humidity, and CO_2 content - on the students' productivity and their health. The study regarding microclimate monitoring in the Iosif Vulcan National College of Oradea,

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Romania, was carried out in the interval of March 2018-March 2019. The Trotek BZ 30 thermohygrometer was used to obtain measurements in classrooms, and the data on temperature, relative humidity, and CO_2 was then centralized and processed. Results show that the microclimate in various classrooms in the Iosif Vulcan National College of Oradea differs according to room type (computer science laboratory, library, classroom), time of day (during classes or after hours), and number of students.

Key words
Air Temperature, CO_2, Indoor Microclimate, Relative Air Humidity

AIMS AND BACKGROUND

The occasionally insufficient size of classrooms, relative to the number of their enrolled students, the various stored materials (such as the books in the library), the lack of adequate ventilation and air conditioning systems, and the computers used in the respective laboratory all play an important part in the indoor microclimate analysis. We have also taken into account the information yielded by other studies in the field, such as the one by Sonne (2006) that aimed to inform on the influence of indoor climate in United States schools and which states that "over half of the respondents (50.5%) indicated 'many' 'chronic' problems." A number of 22.5% of the study's subjects have responded that temperature is by far the most important factor influencing chronic health issues, followed by indoor air quality, humidity, and smell.

According to the studies carried out by Kenley and Seppänen (2006) the productivity of desk work without any physical effort is maximized at a temperature of 22°C. The productivity of desk activities tends to rise until a temperature of 21-22°C is reached, and to fall once the temperature is over 23-24°C. The results of the experiments conducted by Wyon and Wargockiin (2006) elementary schools in Denmark have shown that, by reducing temperature by 1°C from values of 24-25°C, there is an increase in the logics - and basic math - related productivity of students by approximately 2-4% when concentration and logical reasoning are then required. All of these have laid the foundations for the regarding of indoor air quality as a highly necessary contribution to indoor air quality control standards and for the taking of measures to maintain clean air and prevent its deterioration (Soto et al., 2009).

EXPERIMENTAL

The Iosif Vulcan National College is situated in the center of the city of Oradea, in a location consisting of two buildings: a main one for high-school students, and a secondary one for middle-school students (Figure 1). It accommodates a total of approximately 1,000 students on middle-school and high-school levels across 47 classrooms and laboratories. For the purposes of the current analysis, we

have selected two classrooms, one for high-schoolers and the other one for middle-schoolers, such that they would be differently placed within the school, on different floors and with different exposure to sunlight. In the selected classrooms we used the Trotek BZ30 to measure ambient temperature, relative air humidity, and CO_2 values. The device was placed in the middle of the classrooms so as it would record its data most accurately and without influence from external weather factors.

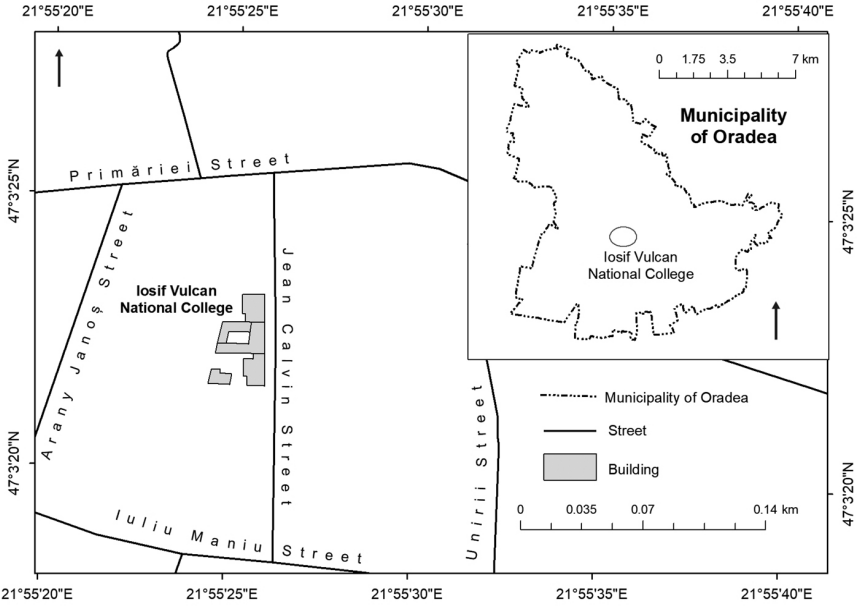

Figure 1
The locations of Iosif Vulcan National College of Oradea, Romania

Classroom 109 is on the first floor of the main building, its windows facing north, and has a surface of 55 m^2 and 26 students. Classroom 301 is on the third floor of the secondary building, its windows facing south, and has a surface of 55 m^2 and 30 students. Room 107 (the computer science lab) is on the first floor of the main building, its windows facing north, and has a surface of 55 m^2 and 33 computers. Room 5 (the school library) is on the ground floor of the main building, its windows facing north, and has a surface of 45 m^2 and 21,684 books.

Among studies on closed spaces, such as offices, hospitals, churches, and museums, school spaces hold a prominent position as students spend a large number of hours in their classrooms, of 5-6 hours a day. Assessment of the air quality inside the considered location was undertaken by checking whether airborne compound concentrations were within the limits established by regulations in force (Alves et al., 2013; Ilieş et al., 2018a). Compliance with health and

comfort directives is analysed in accordance with such standards as ISO 16814: 2008, SR EN ISO 7730: 2006, ASHRAE 55: 2004, etc. The volume of air breathed out by humans contains 4.4% CO_2. As carbon dioxide cannot be filtered or absorbed inside the rooms, the measuring of CO_2 concentration allows for the characterization of the condition of the indoor air. According to standards ASHRAE 62.1-2013 of the USA and EN-15251: 2012, EN-15241: 2011, EN-15242: 2009, and EN-13779: 2008 of Europe, the admitted indoor CO_2 concentration is 0.5%, although even with slighter concentrations there are cases of headaches and discomfort. Debits of fresh air per capita corresponding to an admitted indoor CO_2 concentration of 0.5% are used if the outdoor concentration is 0.04% for various metabolism values. Hence the necessity of indoor air quality control for closed spaces (De Gennaro et al., 2014; Ilieș et al., 2018b; Lee and Chang, 2000; Yang et al., 2015; Mainka et al., 2015). Just as in the case of outdoor air, it is necessary to adhere to standard norms for indoor microclimate and to certain values for temperature, humidity, CO_2, etc.

Studies on the effects of these parameters on human health are relatively few (Altintaş and Findik, 2016; Andrei and Băldean, 2018; Comșa, 2017; Demirel et al., 2014; Griffiths and Eftekhari, 2008). For thermal comfort inside a building it is recommended that temperatures should fall inside the interval of 19-22°C. From the hygiene norms proposed by Law 263 of July 19 2007, article 23, on the approval of hygiene norms for the protection, education, and instruction of children and youth, it is known that for adequate didactic activity in classrooms during the cold season, when heat sources are in use, temperatures must be of 18-20°C, with relative humidity of 20%-60%, and air speeds of 0.2-0.3 m/s. Temperature oscillations must not exceed 2°C during classes, while between hallways and classrooms the temperature differences must not exceed 3°C. Air temperature represents the most important climate factor with pathogenic effects as its value and variability determine physiological reactions that stimulate or, on the contrary, inhibit the human organism's capacity for effort and may furthermore be conducive to the development of pathogens9. If the temperature drops, the organism responds by both peripheral vasoconstriction with reduction of heat loss and by intensified thermogenesis, wherein the metabolism is increased to several times its normal value, and muscle tone is heightened – which is experienced as cold shivers. If temperatures reach 24-25°C, the organism will suffer when you go out in the cold. Similarly, when temperatures drop to 18-19°C there is the same risk of catching a cold. Humidity is the amount of water vapor in the air and it varies according to classroom temperature relative to the temperature outside. Classroom air humidity is particularly high during winter, when indoor temperature is high and outdoor temperature is low. Schools often have difficulties keeping relative indoor humidity within the optimal interval (30%-50%) to reduce allergies and irritations (ISO 7730: 2005). Legislation in force on hygiene norms for children (MO 1955/1995) prescribes that classrooms should keep humidity levels between 30% and 60% to negate the risk of mold

developing. And yet the potential relationship between classroom humidity and student health has not been explored, but the harmful effects of the lack of school ventilation are known. If there is insufficient air exchange, there are health threats to children sitting down in such spaces (decreased attention focus, worsened health, and aggravated allergic manifestations) (Almeida et al., 2011; Buonanno et al., 2012; Kalwasinska et al., 2012; Sofuoglu et al., 2011; Zwoździak et al., 2013). Also, humid classroom air increases the risk of mold developing (Indrie et al., 2019). Mold ruins the walls and gives an unpleasant smell to the entire room but is extremely dangerous for health as well (Comșa, 2015).

The processing and analysis of the data are based on the school measurements carried out within the rooms proposed for research during the monitored period. This data has granted the possibility of analyzing indoor microclimate conditions in classrooms in various areas of the school, depending on the chosen period, on the extent of sunlight exposure of the room, on the number of students and the surface of the classroom, and on the establishment of internal rules (airing classrooms during recess, acquiring flowers to oxygenate the classroom, emptying the trash cans and the desks at the end of school days, etc.) that would lead to keeping an optimal classroom climate. In those classrooms where mere airing could not ensure those conditions, air conditioning devices were installed, but issues regarding the timely changing of their filters have been reported (Grsic et al., 2014; Viegi et al., 2004).

On the same note, the microclimate in the companies, with shool workshops, producing knitwear, apparel and footwear is strongly vitiated by pollutants, toxic gases etc. In the production of knitwear and clothing there are flakes and excess CO_2, and in the production of footwear there are vapors of toluene and benzene, which endangers the health of the employees and practitioners, being required efficient ventilation installations and protective filters.

RESULTS AND DISCUSSION

For the interval of March 8-March 12, 2018, the analysis of CO_2 values (Figure 2) in classroom 109 shows that the higher values are reached during classes. On March 8 the following values were recorded: 2,929 ppm at 11:59 am; 2,914 ppm at 12:01 pm; and 3,137 ppm at 12:33 pm. On March 12, at 8:52 am the value was of 2,462 ppm. All values were thus over the maximum limit of 1,000 ppm, considered not to be dangerous to the health of children (Bornehag et al., 2001). The registered values go from the minimum value of 414 ppm on March 12 at 6:40 am, before the start of classes, to the maximum value of 3,137 ppm on March 8 at 12:33 pm, during classes. Based on the Figure 2 chart, it is evident that 80% of the values are less than or equal to 789 ppm, which is an optimal value only due to the long periods monitored after classes, when the students are not influenced.

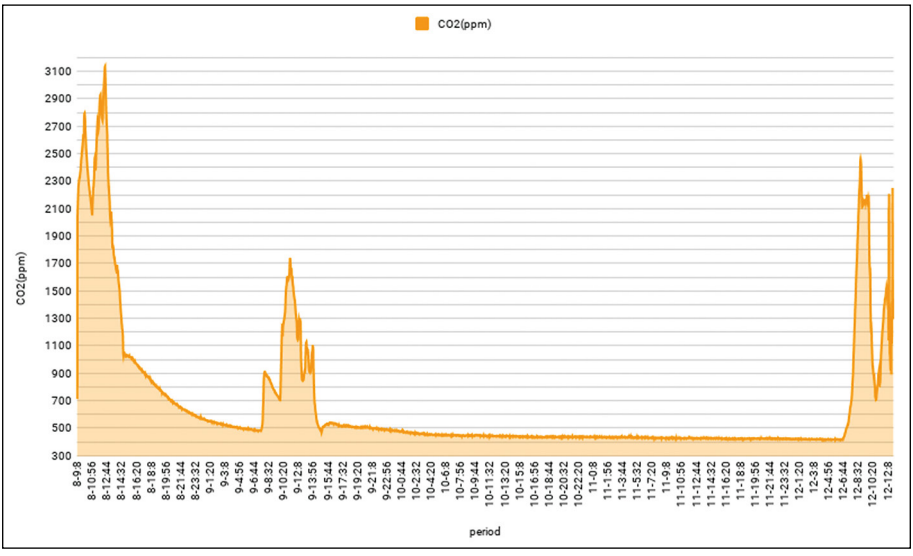

Figure 2
Chart of CO_2 values recorded in the interval March 8-March 12, 2018 in classroom 109

The recorded values for temperature vary from the minimum of 19.7°C obtained on the night of March 10, 2018 between 4:22 am and 4:31 am, to the maximum of 24.5°C obtained during daytime on March 12, 2018 at 12:25 pm. Based on the yielded data and the Figure 3 chart, it can be seen that 80% of values are less than or equal to 20.6°C, a value recommended by international standards for classrooms (ISO 7730, Law 263 of July 19, 2007). The recorded values for relative humidity vary from the minimum of 37.3% on March 10, 2018 in the interval of 10:44 am and 10:50 am, which is too low for an optimal climate, to the maximum of 59.9% on March 12 at 12:21 pm, which is in the optimal interval. Based on the recordings and the Fig. 3 chart it can be seen that 80% of values are less than or equal to 42.2%, which shows that the air is too dry and there is not enough airing done in the classroom.

During the interval of January 17-January 25, 2019 I took measurements in classroom 301, located in the secondary building (where middle-schoolers are housed), on the third floor and with 30 students.

Values recorded for CO_2 vary from the minimum of 342 ppm on January 18 at 3:26 pm to the maximum of 5,536 ppm on January 22 at 10:56 am. Based on the Figure 4 chart, it can be seen that 80% of values are less than or equal to 867 ppm. These values reveal that, during classes, CO_2 concentration is above the limits admitted as normal for indoor spaces (Bornehag et al., 2001). Average values inside the optimal interval, in accordance to SR EN ISO 7730:2006, are due to the fact that after classes the concentration of CO_2 drops greatly and remains low until students return to school.

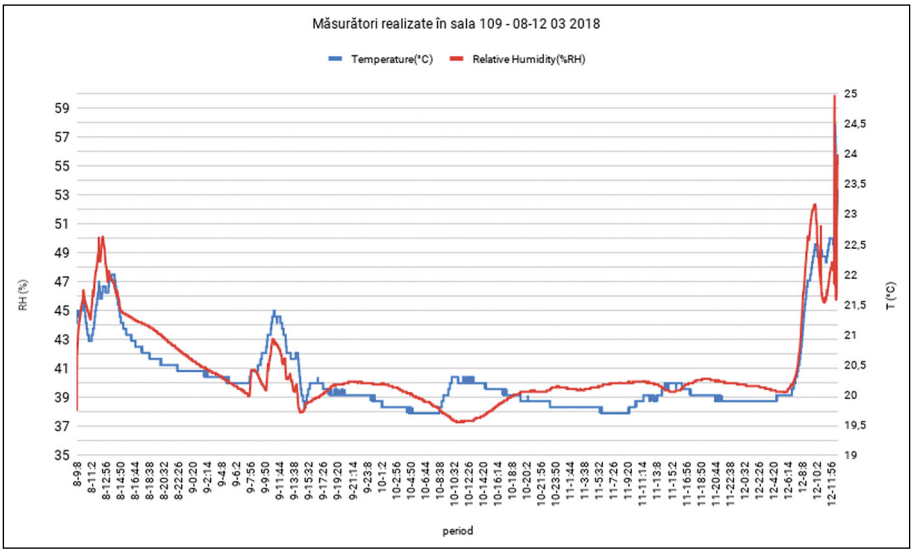

Figure 3
Values for temperature and relative humidity recorded in the interval March 8-March 12, 2018 in classroom 109

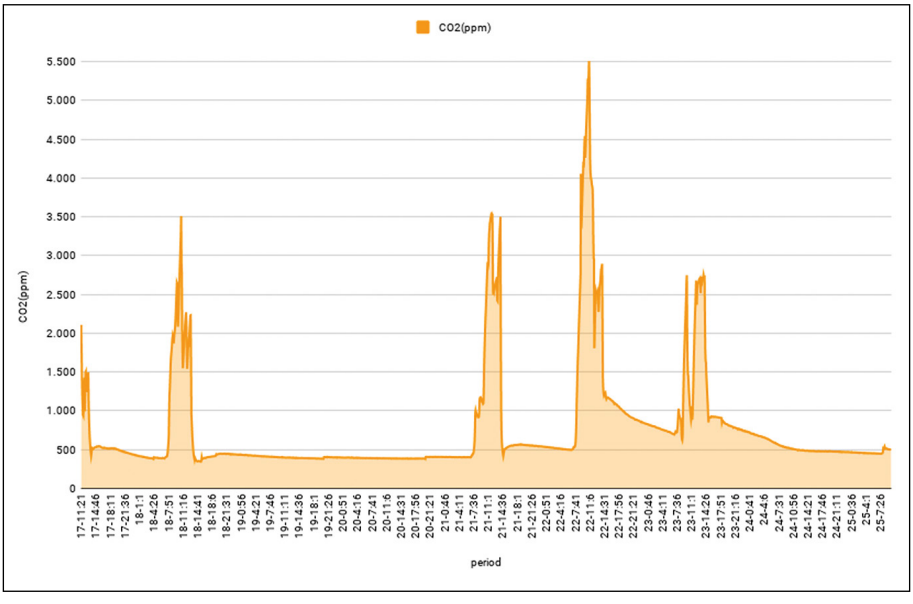

Figure 4
Chart of CO_2 values recorded in the interval January 17-January 25, 2019 in classroom 301

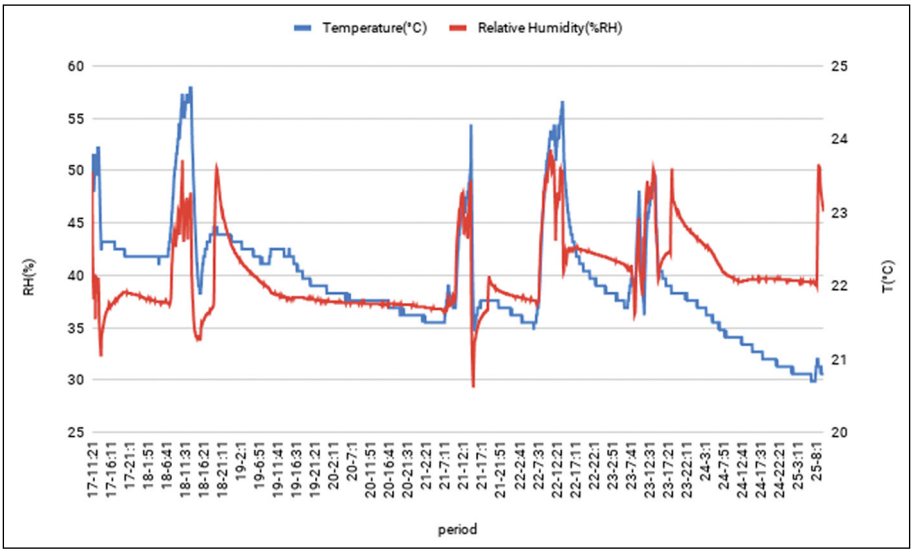

Figure 5
Values for temperature and relative humidity in the interval January 17-January 25, 2019 in classroom 301

Temperature varies between the minimum of 20.7°C on the morning of January 25, between 646 am and 6:56 am, and the maximum of 24.7°C on January 18, between 12:51 pm and 1:06 pm (Figure 5). The average value is of 21.9°C, which is within the interval recommended for classrooms by the temperature and humidity standard ASHRAE 55: 2004, while the maximum points are slightly above the admitted limits, but only briefly, which does not greatly influence the productivity of students. Temperature reaches maximum points at the end of the school day, when values were of 24.7°C on January 18, between 12:51 pm and 1:06 pm, and 24.5°C on January 22, between 1:56 pm and 2:01 pm. Relative humidity values vary between the minimum of 29.3%, recorded on January 21 at 2:46 pm, and the maximum of 52% on January 22 at 10:56 am. The average recorded value was of 39.3%. This is a very low value for an environment where children spend 6 h a day, according to Law 319/2006 on air quality for the protection of human health, which leads to the development of allergies and to the more sensitive children becoming ill. Relative humidity reached values above 51% on the morning of January 18 at 10:51 am, and 50% at 7:46 pm. On January 25 at 8:41 am it reached the value of 50% and the minimum value of 29% on January 21 at 2:46 pm (Figure 5).

We took measurements in room 107 (the computer science laboratory), fitted with 33 computers, during the interval of January 28-January 31, 2019.

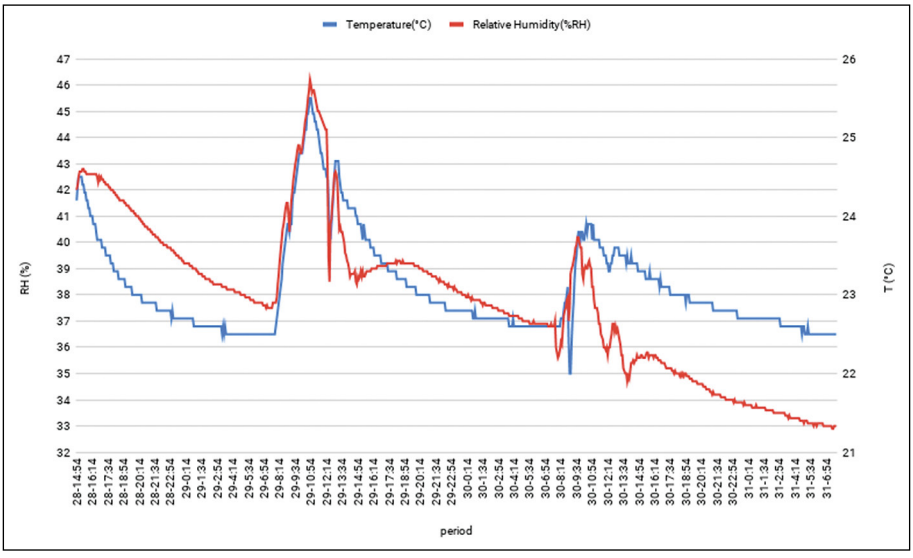

Figure 6
Values for temperature and relative humidity in the interval January 28-January 31, 2019 in the computer lab, room no. 107

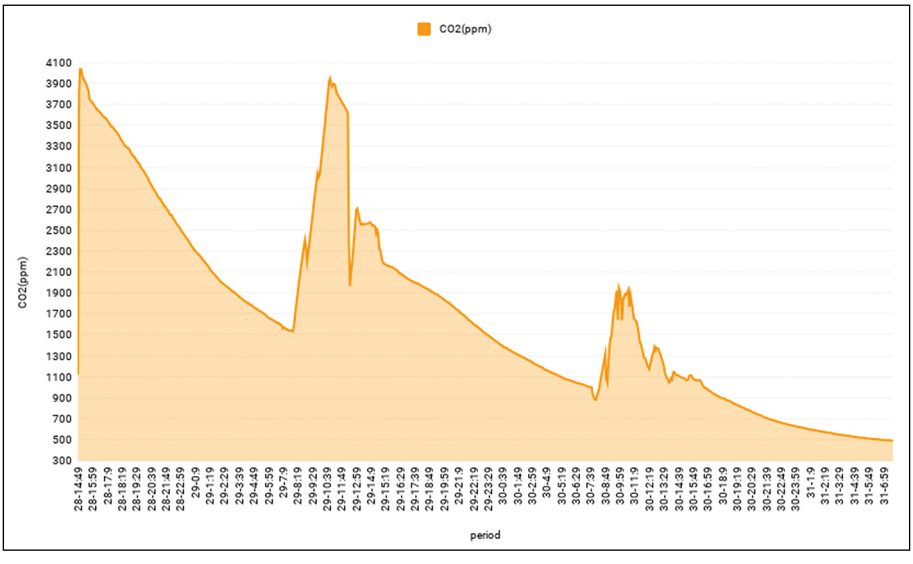

Figure 7
Chart of CO_2 values recorded in the interval January 28-January 31, 2019 in the computer lab, room no. 107

Values for temperature vary between the minimum of 22°C on January 30 between 8:59 am and 9:04 am and the maximum of 25.5°C on January 29 between 10:49 am and 10:54 am, the latter being a value over the limit admitted as optimal in a classroom. The average value is of 22.9°C, an optimal value, according to ASHRAE 55: 2004 and ASHRAE 62.1-2013, considering that heat is also emanated from the computers.

The values recorded for relative humidity vary between the minimum of 32% recorded on January 31 between 7:24 am and 7:29 am and the maximum of 46% on January 29 at 10:49 am. The average obtained value was 38%, which is too low for an optimal climate as recommended by ISO 7730: 2006 and has negative consequences on the students' general health.

CO_2 values vary between the minimum of 490 ppm, on January 31 at 7:39 am, and the maximum of 4,037 ppm, on January 28 between 2:59 pm and 3:04 pm. The average value was of 1,600 ppm, which is much over the limit of 1,000 ppm considered the maximum admitted limit, in accordance with ISO 7730: 2006. The highest values for CO_2 were 3,947 ppm on January 29 at 10:54 am; 3,896 ppm at 11:09 am; and 3,896 ppm at 11:14 am, all during classes. The lower values were 1,122 ppm on January 28 at 2:49 pm and 1,451 ppm on January 29 at 11:59 pm, both after classes. Based on the recordings and the chart in Figure 7, it is noticeable that 80% of values are less than or equal to 2,470 ppm.

On January 30 in room no. 107 the values during class intervals were very high, of 1,923 ppm at 9:44 am; of 1,950 ppm at 9:54 am; of 1,891 ppm at 10:24 am; and of 1,928 ppm at 10:39 am.

On January 31 in room 107 the CO_2 values varied between 490 ppm at 7:39 am and 625 ppm at 0:04 am. That day was a Saturday, and students were not in school, therefore they had no influence on CO_2 values.

Measurements were also taken between February 12-March 12, 2019, in room no. 5 (the school's library).

From the gathered data, according to Table 1, and based on the chart in Figure 8, it is clear that relative humidity values vary between the minimum of 22%, recorded on February 25, 2019 between 3:18 pm and 3:23 pm, and the maximum of 33.6%, recorded on February 22 at 1:38 pm. The average value is of 29%. These values are all below the minimum limit admitted as optimal for indoor climate qualitatively conducive to the librarian's work activity, as well as to the study activity of students frequenting the library, according to ASHRAE 62.1-2013. The recorded values for temperature vary between the minimum of 21.1°C on February 22, 2019, at 1:33 pm, and 25.1°C on February 10, 2019, between 10:43 am and 10:58 am. Most values are clustered around 23.8°C, hence they are values close to the upper optimal limit as suggested by Law 263 of July 19, 2007 (relative humidity 55%-65% and 10-24°C). The values obtained for CO_2 (Table 1) vary between the minimum of 385 ppm on March 11, at 10:28 am and 11:58 am, and the maximum

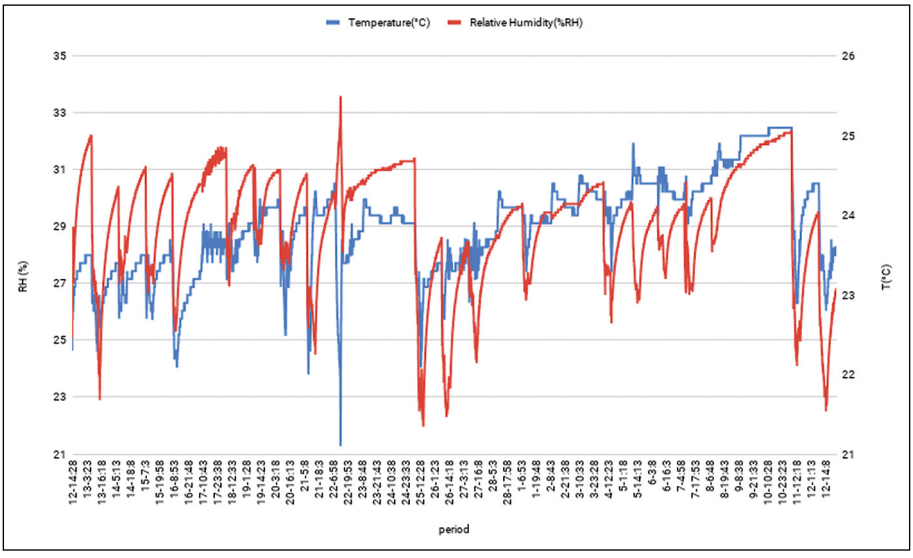

Figure 8
Values for temperature and relative humidity in the interval February 12 - March 12, 2019 in the school library (room no. 5)

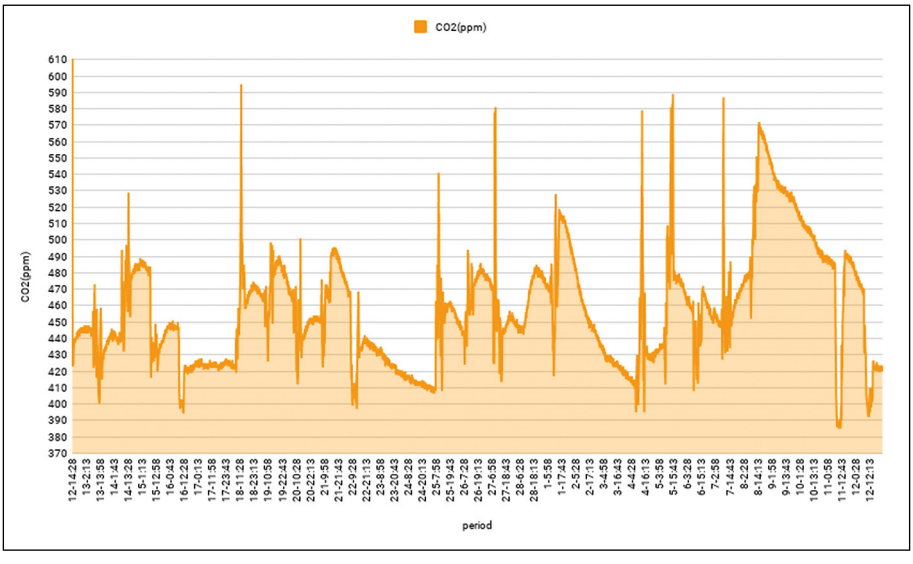

Figure 9
Chart of CO_2 values recorded in the interval February 12 - March 12, 2019 in the school library (room no. 5)

of 631 ppm on February 12 at 2:28 pm. The average value is of 452 ppm, which is a great value as per ISO 7730: 2006, and considering there is only one permanent human presence here, thus with little influence on CO_2 levels.

Table 1 Interpretation of the data in a comparative summary of the rooms

Room	Interval	Air temperature (°C)			Relative humidity (%)			CO_2 (ppm)	
		Min	Avg	max	min	avg	max	min	max
109	Mar. 8-12, 2018	19.7	20.3	24.5	37	40	59	414	678
301	Jan. 17-25, 2019	20.7	22	24.7	29	40	52	342	773
5	Feb.12-Mar.12, 2019	21.1	23.8	25.1	22	29	33	385	457
107	Jan. 28-31, 2019	22	23.1	25.5	30	37	46	490	1,711
Max. values	Mar. 2018-Mar. 2019	22	23.8	25.5	37	40	59	490	1,711
Min. values	Mar. 2018-Mar. 2019	19.7	20.3	24.5	22	29	33	342	678

Table 1 shows that the highest air temperature value, of 25.5°C, was recorded in the computer lab, whereas the lowest value, of 19.7°C, in room no. 109. The minimum value fits into the optimal interval as recommended by Law 263 of July 19, 2007, which is between 17°C and 24°C, but the maximum value exceeds that interval, as do the other recorded maxima.

Also from Table 1 it becomes clear that the maximum value for relative humidity, 59%, fits the interval recommended by Law 263 of July 19, 2007 (relative humidity of 55%-65% and 10-24°C) but the minimum value, 22%, is below the inferior limit, therefore it does not provide optimal conditions for school usage.

Concerning the values of CO_2 as presented in Table 1, we may conclude that the minimum, recorded in the library, of 342 ppm, fits the interval prescribed by the in-force norms (EN-15251: 2012, ISO 16814: 2008, ISO 7730: 2006, ASHRAE 62.1-2013) but the maximum, of 5,536 ppm, greatly exceeds the superior limit admitted as optimal.

CONCLUSIONS

The data obtained via measurements carried out on school grounds reveal that the classrooms do not exhibit optimal conditions, as not all monitored parameters take values within those recommended in the literature (SR EN ISO 7730: 2006, ASHRAE 55: 2004).

Taking into account that the productivity of the associated activities has the tendency to rise up to temperatures of 21-22°C and to drop as temperatures go over 23-24°C, the yielded data (featuring average temperatures of 23.8°C in the

library, 22.9°C in the computer lab, 21.9°C in classroom 301, and 20.6°C in classroom no. 109) leads us to conclude that temperature-wise conditions are at their upper limit, and thus not a significant hindrance to normal didactic activity; however, a 1°C reduction in temperature, particularly in the computer room, would prove beneficial for the development of the students' logical thinking.

There are state-sanctioned sanitation norms and standards for the organization and maintenance of general-purpose educational facilities, as well as for the execution of educational processes (GSanPin 5.5.2.008-01) according to student age, facility purpose, and climate zone. The normative intervals of such standards prescribe temperatures of 17-20°C for classrooms in schools and colleges, and of 16-18°C for libraries, while similarly prescribing 40%-60% as an interval for humidity. As such, conditions in the monitored rooms do not fit these limits (Ilieș et al., 2018c; Onet et al., 2019).

In what concerns relative air humidity, the average obtained values of 29.5% in the library, of 38% in the computer lab, of 39% in room 301, and of 42% in room no. 109 range within the normal limits, with only the library conditions falling slightly below the limit.

With the exception of the computer lab, where average values for CO_2 are over the limit, these values fall within normal limits (453 ppm in the library, 789 ppm in room 109, 867 ppm in room 301, and 1,600 ppm in the computer lab). However, they do not reflect optimal conditions being provided during classes (Griffiths and Eftekhari, 2008). During the time of day when students are normally in their classrooms, we recorded CO_2 values over the 1,000 ppm limit considered the maximum for admitted concentration in rooms – at a time when didactic activities are intensified and air flow lacking (EN-15251: 2012, ISO 16814: 2008, ISO 7730: 2006, ASHRAE 62.1-2013). Recorded maxima were of 3,137 ppm in room 109; 4,037 ppm in the computer lab; and 5,536 ppm in room no. 301. They prove that air quality is not conducive to educational activities, except for the library, where the maximum was of only 685 ppm.

To keep optimal ambient temperatures of 21-22°C and normal relative humidity of 30%-60% in classrooms, the following measures must be taken: air the classrooms for 10 min. after each class, which should also ensure the lowering of CO_2 levels; fit the rooms with various plants able to absorb the excess humidity, such as ivy, ferns, peace lilies (*Spathiphyllumspp.*), dwarf palms or pink quills (*Tillandsiaspp.*); reduce noise/dynamic pollution; uncover the windows, so as the natural light would enter the room; install air conditioning and use it in moderation, to reduce energy consumption; install a thermohygrometer; keep the rooms clean and selectively dispose of waste; use wall paints and solutions against dampness and moisture; buy a dehumidifier to provide high absorption of the ambient air moisture and to efficiently neutralize unpleasant odours in the classroom; open classroom doors to allow for air circulation.

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