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THE INFLUENCE OF A VENTILATION ON THE LEVEL OF CARBON DIOXIDE IN A CLASSROOM AT A HIGHER UNIVERSITY

WPŁYW WENTYLACJI NA POZIOM DITLENKU WĘGLA W POMIESZCZENIU UCZELNI WYŻSZEJ

Abstract: Carbon dioxide can affect on human mood and working conditions in closed area. Knowledge about the level of air pollutants concentration in the room, should be a guideline to design a properly working ventilation system. For years carbon dioxide, appearing during human breathing, was not taken into consideration as a factor determining the process of ventilation systems design. At present the assessment of air quality in closed rooms is performed on the basis of measurement of concentration of carbon dioxide metabolically produced by humans that can be referred to the so-called hygienic minimum, *eg* the upper limit of CO_2 concentration equal to 1000 ppm (0.1%).

Keywords: carbon dioxide, ventilation, concentration in the room

Introduction

Together with technological and industrial development taking place all over the world, the issues of carbon dioxide concentration in the air associated with human activities are discussed more and more frequently. Numerous scientists and politics share the opinion that the increase of average temperatures on Earth in relation to pre-industrial era is strictly associated with emitting of large amounts of carbon dioxide and other greenhouse gases into the atmosphere. Reducing the emission of these gases is considered the key step towards the assurance of stable natural environment.

The main sources of pollution in closed rooms are carbon dioxide, odor substances, biologically active particles, toxins emitted by materials: construction, decoration, as well as interior design elements [1].

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For many years carbon dioxide, appearing during human breathing, was not taken into consideration as a factor determining the process of ventilation systems design. Yet due to the increasing popularity of mechanical ventilation, more and more producers of ventilation equipment started equipping their centers in automatic control of ventilating air, depending on the concentration of carbon dioxide in a room [2].

The tasks of the efficiently working ventilation is the following [3]:

- Supply of appropriate amount of external air;
- Removal of smells emitted by humans;
- Dilution of pollutants coming from other internal sources;
- Reducing the content of water vapor in the interior air.

At present the assessment of air quality in closed rooms is performed on the basis of measurement of concentration of carbon dioxide metabolically produced by humans that can be referred to the so-called hygienic minimum, i.e. the upper limit of CO_2 concentration equal to 1000 ppm (0.1%). This value is denoted as Pettenkoffer number and recommended as acceptable both by CEN 1752 standard „Ventilation For Buildings - Design Criteria for Indoor Environment" [4] and by ASHRAE Standard 62-1989 „Ventilation for Acceptable Indoor Air Quality" [5].

The amount of exhaled carbon dioxide and other compounds emitted by people while breathing depends on psychomotor activity. Mental work associated with moderate effort results in the use of oxygen and emission of carbon dioxide. The functioning of brain requires particularly lots of energy, therefore the efficiency of thinking and creative effort is poorer in unfavorable conditions. Above 1000 ppm (*ie* 1939 mg/m^3) of carbon dioxide the quality of air in a room becomes unsatisfactory. In such conditions discomfort, reduction of work efficiency and somnolence increase [6].

In Poland information about maximum concentration of carbon dioxide is included in regulation on acceptable concentrations and intensity of harmful factors in the working place (Dz.U. Nr 217, entry 1833 [7]), in which, among others, the following terms were defined: the highest acceptable concentration - NDS (weighted average value of concentration; its influence on workers during 8-hour work per 24 hours, and for the average weekly working time, during the time of their professional activity should not cause negative changes in the workers' health if it appears in the working place for no longer than 15 minutes and not more frequently than twice within one shift at time interval of at least one hour) [7, 8].

Carbon dioxide in closed rooms

According to Kaiser [6] - the average concentration of CO_2 in the air exhaled by a human is 4.0-5.2%. It is estimated that during an inactive rest an adult exhales approx. 200 cm^3 of carbon dioxide per minute, which is 12 dm^3 per hour. Whereas during and intensive physical exercise or intensive mental and emotional tension the amount of exhaled CO_2 increases up to 4-6-times. Besides physical activity, also the external temperature indirectly influences the amount of CO_2 emission, because together with temperature increase also the frequency of breathing increases. Carbon dioxide is a colorless, odorless and tasteless gas lighter than the air, non-combustible and non-supporting gas combustion. In low concentration CO_2 does not prove toxic properties, whereas at higher concentration its harmful influence on the organism is observed. Physiological changes taking place in organism depend on the value of CO_2 concentration and can manifest themselves in the form of coughing, failing (at 2000 ppm), or metabolic stress and difficulties with breathing (at 15 000 ppm) [8].

Therefore, following Łubkowska and Kowalewski, it should be noted that in the rooms occupied by people the flow of air should not be lower than 20 m^3/h in case of adults and 15 m^3/h in case of kids. Whereas in air-conditioned and ventilated rooms with non-opening windows, the air volume flow of the ventilation air should be 30 m^3/h for each person in the room [9].

As far as the guidelines in standards are concerned there exists only one PN-EN 13779:2008 standard [10], in which it has been stated that: the quality of air supplied to the building meant for human stay should enable achieving proper quality of internal air, taking into consideration metabolism and type of human activity as well as technological conditions. They include information that for design of mechanical ventilation system, the level of carbon dioxide concentration in a room can be used. Depending on the quality of interior air four types of rooms have been determined (Table 1), and the quality of the interior air has been determined on the basis of the increase of concentration of carbon dioxide above the level of CO_2 in the air outside.

Table 1

Category of a room [10]

Category	**Description**	**Increase of CO_2 concentration above the CO_2 level in external air [ppm]**	
		Typical range	**Standard value**
WEW 1	High quality of interior air	≤400	350
WEW 2	Medium quality of interior air	400-600	500
WEW 3	Average quality of interior air	600-1000	800
WEW 4	Low quality of interior air	>1000	1200

The problems of the interior air quality, from the perspective of presence of carbon dioxide, are described in numerous publications. (*eg* [9, 11-18]), they mostly refer to buildings in which children and youths, not students, spend their time, hence further analysis of this type of rooms seems justified.

Unfortunately on the basis of accessible literature it can be concluded that for most of the examined rooms the obtained results were not compliant with recommendations and guidelines for closed rooms. According to Posniak et al [19] - the average concentration of carbon dioxide in most cases exceeded the level of 1800 mg/m^3, reaching the value of 7200 mg/m^3, and the above was caused by incorrectly designed or poorly working ventilation systems.

The research carried out by Polednik and Dudzinska [20] confirms the above. It can be concluded from the research that in spite of functioning of air-conditioning system in a selected classroom, the increase of the number of students resulted in higher emission of CO_2, and accordingly deterioration of the air quality in the classroom.

Characteristics of the examined object

The research on CO_2 concentration in a selected classroom of the Faculty of Civil Engineering, Architecture and Environmental Engineering of Lodz University of Technology was performed with the use of portable gas microchromatograph.

The microchromatograph VEGA-GC (Fig. 1) produced by an Italian company POLLUTION is a device enabling running analysis of gas pollution in field conditions. Thanks to the installation of two columns working subsequently in the measuring apparatus, during one measurement the analysis of a wide spectrum of gases can be performed. The used thermal-conductivity detector (TCD), enables analyzing the samples with the minimum concentration of 500 ppb in time from 6 to 300 seconds depending on the type of the examined gas.

a) b)

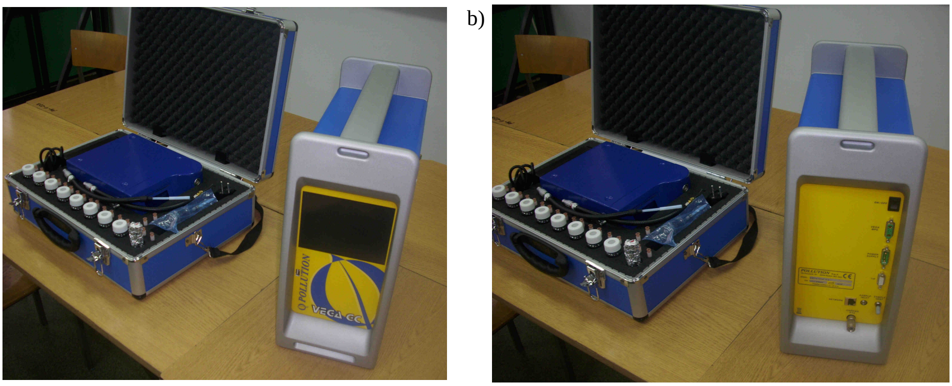

Fig. 1. The image of microchromatograph VEGA-GC and the system for introductory enrichment of a gas sample (a and b)

Technical data of the device [21]:

1. Power supply: adapter 110-220 V AC - 12/24 V DC; 2 nickel-metal-hydrogen batteries (NiMh).
2. Carrier gas: possibility of using helium, hydrogen, nitrogen or argon from an external source - gas cylinder. Required flow - 10 cm^3/min; possibility of using helium, hydrogen, nitrogen or argon from an external source - gas cylinder. Required flow - 10 cm^3/min.
3. Dimensions: 17 x 38 x 41 cm (width x height x depth).
4. Weight: 9 kilos without batteries; 13 kilos with two installed batteries.
5. User interface: color touch screen LCD with a diagonal of 6,5”.
6. Working conditions: operating humidity 0-95%; working temperature: 0-50ºC.
7. Characteristics of samples: temperature of sample 0-120ºC; sample pressure 50-200 kPa.
8. Working time: 60-300 s (depending on the number of analyzed substances).
9. Detector: thermo-conductive TCD.
10. Calibration: calibration every 6 months.
11. Minimum concentration: 500 ppb - solvent molecules.
12. Operation system: WINDOWS XP EMBEDDED.

Table 2 presents basic information on possibilities of measurements with the use of one of the columns used in VEGA GC by POLLUTION.

Table 2

A measurement column of microchromatograph VEGA-GC [21]

Name of column	Description	Exemplary gases
PPQ	Packed column, application: hydrocarbons containing carbon particles from C_1 to C_4.	N_2; N_2O; H_2O; CO_2; CH_4; acetylene; ethane; chloroethylene; ethanol; ethylene; propane; hydrogen sulfide and ammonia.

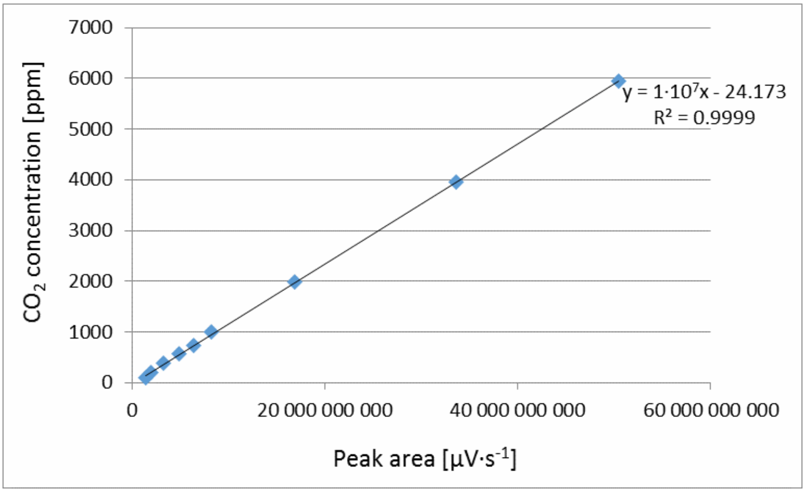

Fig. 2. Figure gauge for carbon dioxide

Measurements of carbon dioxide concentration have been made thanks to packed column PPQ installed in microchromatograph VEGA-GC. Each of the measurements in interior air was performed within the time interval of 90 seconds. The tests were performed with mechanical ventilation before and during a lecture for students. Thanks to these measurements it was possible to determine the times of appearance of levels of high carbon dioxide concentration and examine the influence of the number of people on the condition of air in a selected room, which can affect wellbeing and quality of work of persons staying in closed rooms.

CO_2 concentration in a selected room

In order to measure the level of pollution concentration one has to get acquainted with the methodology of measuring gas pollutions of the air (numerous publications can be found on the subject).

For the purpose of the analysis an aula located on the first floor, with the area of 97.8 m^2 and cubature of 390 m^3, was selected. In each of the cases the measurements were made in two measurement points: A1 and A2 (Figs. 3 and 4).

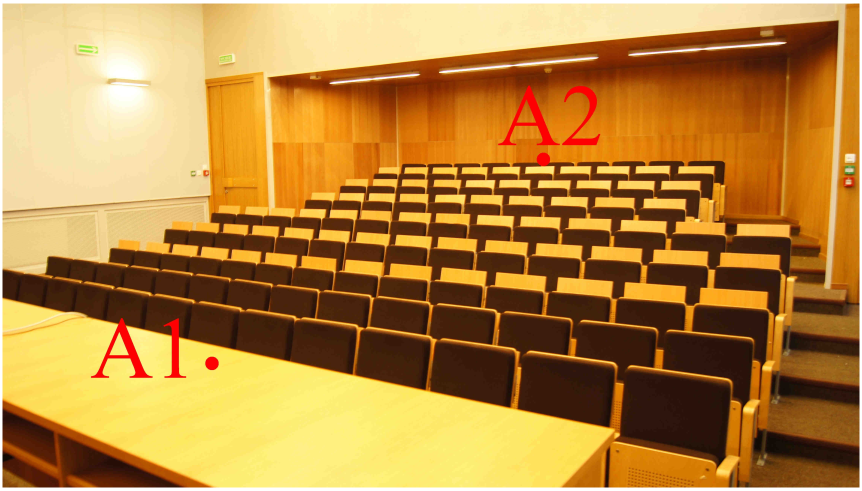

Fig. 3. Location of measurement points

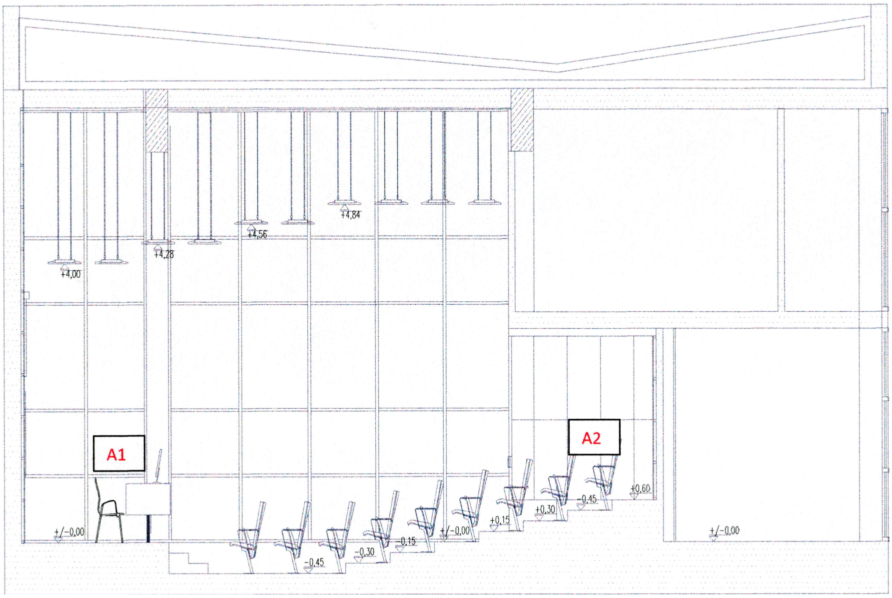

Fig. 4. Cross-section of the selected aula

In the first point the device was located opposite the seated students, on the 0.84 m high desk. In the second point the device was installed up the aula among the seated students, on the bench of 1.24 m of height. During the research with the mechanical ventilation switched on there were 84, 45 or 18 students in the room, including the teacher and the person taking measurements. The temperature in the classroom was initially around 21ºC, and by the end of the class increased to 23ºC. The time of measurement depended on the number of people present (due to high levels of CO_2 concentration), while the research was performed continuously, behind closed doors and windows all over the room. Next measurements were performed with mechanical ventilation switched on during a lecture for three variations of the number of attendants in the room: 102, 59 and 54 students, a lecturer and a person performing measurements. The temperature was initially around 20ºC, and by the end of the class it increased up to 22ºC. The class was run continuously, while the doors and the windows of the room were closed.

In the first variant the measurements were performed with the mechanical ventilation switched off. Initially the device was located in the measurement point A1. The level of CO_2 concentration with 84 people in the room after the first 4 minutes from starting the class was 4909.62 ppm. Then the values increased to reach after 31 minutes the level of 6449.30 ppm (due to the CO_2 level, the measurements were stopped), and it was caused by close proximity of persons remaining within the reach of the device, the number of people and the fact that the device was situated opposite the sitting students. During this series of measurements the students were taking very active part in the class. Next measurement series were performed for 45 and 18 people in the room. With 45 persons after 10 minutes from the beginning of the class the level of CO_2 concentration was 2281.99 ppm, and after around 45 minutes it was 3249.42 ppm. Whereas for 18 persons, after 10 minute stabilization periods the device indicated 632.77 ppm, and after 36 minutes - 86.6 ppm. The results of these measurements are presented in Figure 5.

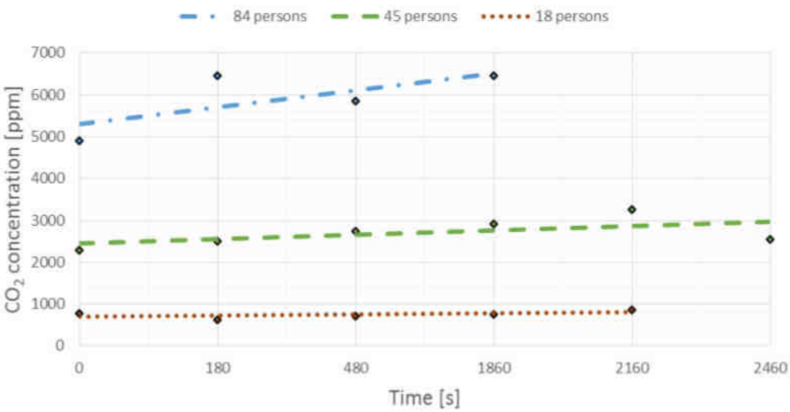

Fig. 5. Graph of changes in CO_2 concentration depending on the number of people staying in one room during lecture with mechanical ventilation switched on - measurement point A1

The next three series of measurements were also performed with mechanical ventilation switched off, only that in the measurement point A2. In the first measurement series, for 84 persons, the results of the measurements started to grow from 5697.43 to 6688.96 ppm after 33 minutes, and then, due to level of CO_2 concentration they were halted. In the next series of measurements, with 45 persons, they were within the range of 1711.63 and 2624.72 ppm after 35 minutes, whereas in the last series of measurements the values were between 801.88 and 1298.04 ppm after 33 minutes (Fig. 6).

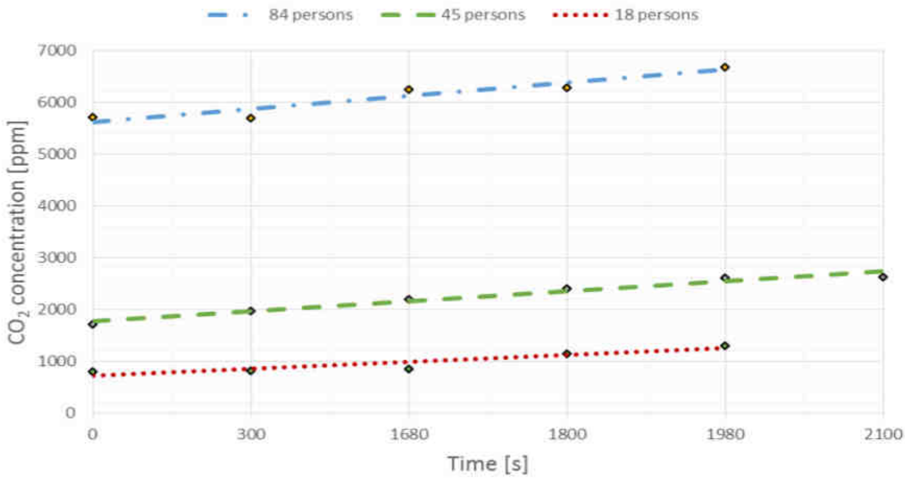

Fig. 6. The graph of changes in CO_2 concentration depending on the number of people staying in the room during lecture with mechanical ventilation switched off - measurement point A2

Next measurements in the classroom were performed already with mechanical ventilation switched on. In the measurements point A1 for 102 people the measurement device indicated 811.92 ppm, and after 90 minutes it was 1950.21 ppm. During the next series, first for 59 persons the CO_2 concentration increased during 90 minutes from 1242.69 to 1529.76 ppm, and after 15 minute break, for 54 persons, the values in the range from 1427.87 to 1552.45 ppm after 54 minutes (the differences in the values are most probably caused by a different group of persons as well as their number and the fact that classes in the examined room were performed with a little break between specific course - Fig. 7). The final measurement series were performed in the measurement point A2. The values for 102 persons oscillated after 88 minutes between 1095.15 and 1784.33 ppm. While for 59 persons the concentration of CO_2 increased in the analogical time from 1214.43 to 1601.50 ppm. After a 15-minute break, for 54 persons, and after 88 minutes the values were within the range of 1564.22 to 1603.69 ppm (Fig. 8).

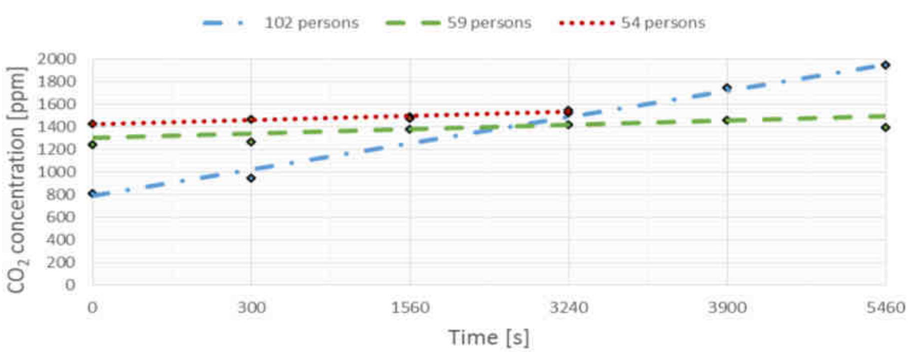

Fig. 7. Graph of changes in CO_2 concentration depending on the number of people staying in the room during classes with mechanical ventilation switched on - measurement point A1

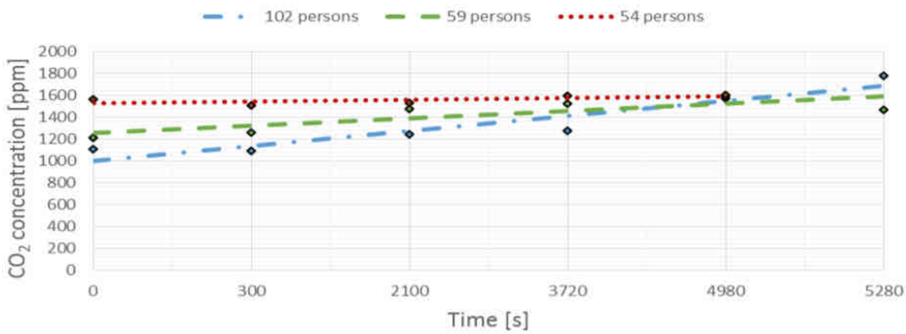

Fig. 8. Graph of changes in CO_2 concentration depending on the number of persons staying during a lecture in the class with mechanical ventilation switched on - measurement point A2

The last measurements were performed in the classroom with mechanical ventilation switched on, after one hour break and with no teaching activities. In the measurement point A1 the results of the measurements were approx. 780 ppm, and in the measurement point A2 approx. 805-810 ppm (Fig. 9).

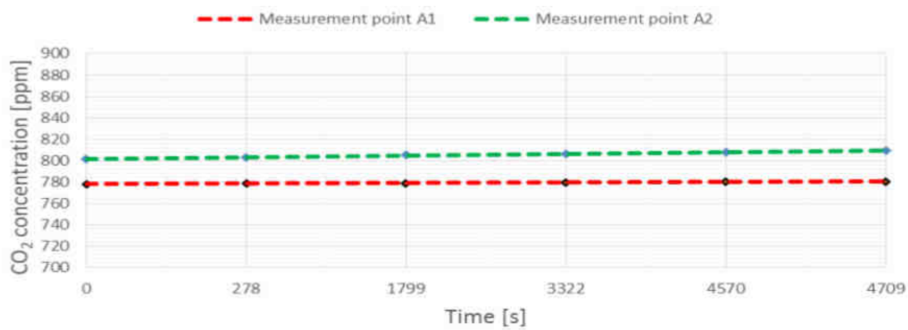

Fig. 9. Graph of changes in CO_2 concentration with no classes in the classroom with mechanical ventilation switched on, for the measurement points A1 and A2

Conclusions

The application of gas microchromatograph enabled detailed and quick measurements of the amount of carbon dioxide in selected rooms. The obtained results for CO_2 concentration confirmed the influence of human metabolism as well as the influence of ventilation (or of its lack) on the levels of the concentration in the rooms. Thanks to the research it was possible to observe the increase of the carbon dioxide quantity with time, and with considerably constant number of persons in the room. Such information can be useful not only in science and teaching, but also for designing ventilation systems in which the localization of the fresh air inlet as well as the distribution of inlets are the basic issue for the functioning of the whole system. As the variable of the number of people in the room or opening the door/window result in changes in carbon dioxide indications in the air, upon performing the measurements in the selected classroom, significant influence of the mechanical ventilation on the quality of the air was observed. The highest values were obtained for the mechanical ventilation switched off. They were several times higher than the acceptable values. Most probably it also resulted from the fact that during the series of measurements there were 84 persons in the room and the present students took very active part in the lecture. The teacher asked questions, and the students responded, answered at the whiteboard and solved problems.

To sum up, if the concentration of carbon dioxide in the classroom exceeds the maximum values acceptable for fulfillment of the minimum hygienic criterion, appropriate conditions of mental work are not assured to students, and in consequence the effort of the teachers is useless, and the students are not able to achieve such results as they would be capable of. Even a small increase in the level of carbon dioxide can result in headaches, conjunctival hyperemia and excessive perspiration or the feeling of anxiety. In extreme cases perception disorder may occur. Therefore, first of all an efficient and effective ventilation should be assured, whereas frequent airing of the rooms and introducing the forcibly circulating fresh air enables the reduction of the carbon dioxide level.

When interpreting the above results, it should be considered that renovation works were performed in the analyzed classroom last year, and freshly renovated rooms emit carbon dioxide from the walls. The phenomenon is associated with the maturation of the fresh plaster and other wall compounds. In consequence CO_2 is produced. For example in new dwelling rooms, for the first few years high concentration of carbon dioxide is observed, reaching even 2000 ppm in unaired rooms and around 800 ppm in aired rooms, even if people do not stay there [6].

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WPŁYW WENTYLACJI NA POZIOM DITLENKU WĘGLA W POMIESZCZENIU UCZELNI WYŻSZEJ

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Abstrakt: Ditlenek węgla może znacząco wpływać na samopoczucie oraz jakość pracy osób przebywających w pomieszczeniach zamkniętych. Znajomość poziomu koncentracji zanieczyszczeń powietrza w danym pomieszczeniu powinna być wytyczną do projektowania właściwie funkcjonującego systemu wentylacyjnego. Przez wiele lat ditlenek węgla, powstający w trakcie oddychania człowieka, nie był uwzględniany jako czynnik determinujący proces projektowania systemów wentylacyjnych. Obecnie ocenę jakości powietrza w pomieszczeniach zamkniętych wykonuje się w oparciu o pomiar stężenia ditlenku węgla wytwarzanego metabolicznie przez człowieka, który można odnieść do tzw. minimum higienicznego, czyli górnej granicy stężenia CO_2 równej 1000 ppm (0,1%).

Słowa kluczowe: ditlenek węgla, wentylacja, stężenia w pomieszczeniu