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THE STUDY OF CO_2 CONCENTRATION IN A CLASSROOM DURING THE COVID-19 SAFETY MEASURES

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Abstract. The COVID-19 crisis has affected the process of how the study procedures are organized at schools in Latvia. Three different options were available for the school to choose from. However, most schools have opted for option A which states that the classes are organized face-to-face but various safety measures must be ensured. Each class or group is equated to a closed set where there are no distance requirements. In turn, the distance between the classes must be observed. This means that students stay in the same class all day and are accompanied by teachers of the respective classes. This can lead to improper ventilation as for most of the schools in Latvia it is organized through the opening of windows. To test this, measurements of CO_2 concentration were done in a classroom Secondary School in Daugavpils. The results showed that the CO_2 concentration was very high and often reached and exceeded the maximum measuring capacity of the device - 4000 ppm. It indicates that following the special safety procedures cause a negative effect on IAQ as the classrooms are not properly ventilated. This can lead to a drop in the performance of pupils as well as stimulate the transmission of other infectious diseases. Further measurements are necessary to gather data from different schools and best practices must be found.

1 Introduction

In total at the start of the year 2019, there were 707 educational institutions in Latvia. In them, around 214 thousand pupils were studying, according to the information of the Ministry of Education and Science. Of all these schools a small number have undergone deep renovation not just adding external insulation but also implementing central mechanical ventilation systems. Some of the existing studies [1], [2] mentions the benefits of renovation works which rises thermal comfort. At the same time, this can cause a risk of condensation on windows if no ventilation is present as 52% of respondents have indicated condensation on windows after the renovation work.

This lack of modern ventilation systems in schools means that most of the students are still having classes in buildings where the ventilation is only ensured by natural ventilation. According to the study [3], the main causes of indoor air pollution are insufficient and inadequate ventilation rates, emissions from cleaning products, and the chemicals emitted by building materials or furnishings.

This can be especially problematic during the COVID-19 crisis when the study process is ongoing but with special safety measures. In Latvia, the schools had three different options for how to operate to choose from. Most of the schools have opted for the option when the classes are organized face-to-face but various safety measures must be ensured. Each class or group is equated to a closed set where there are no distance requirements. In turn, the distance between the classes must be observed. This means that students stay in the same class all day and are accompanied by teachers of the respective classes. According to the rules, the movement in school was restricted to minimize the contact between pupils. They were allowed to go to the hall to provide class ventilation, but students often preferred to stay in classes even during breaks.

According to various guidance's [4]–[7] on how to operate schools during the COVID-19 they all have in common the general principles: Increase outdoor air ventilation but do not open doors to common halls if there are students, decrease occupancy in areas where outdoor ventilation cannot be increased; increase central air filtration or use portable high-efficiency particulate air (HEPA) filters. However, in many cases, these guidelines cannot be implemented and therefore could potentially cause the risk of bad IAQ, as the only possible ventilation is through openable windows. While the outside air temperature during the winter period is very low the ventilation period shortens as the indoor temperature rapidly drops and the classroom is under-ventilated.

The most common way of expressing adequate ventilation rate is through CO_2 concentration. It is directly linked to the room characteristics, the number of persons present, outdoor air quality, and ventilation rate. The CO_2 concentration of 1000 ppm is often stated as a typical threshold level for good IAQ [8]. If it gets higher than this can cause poisoning and have been shown to affect the human thinking process. At the same

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time, no indicator clearly distinguishes the threshold between quality air and low-quality air, as individual people may feel comfortable in different conditions of fresh air volume and composition depending on their physiology, emotional state, clothing, activity, the temperature of the environment, etc.

Even before the COVID-19 crisis a lot of studies had indicated that there are problems with indoor air quality and thermal comfort in schools over the whole world [9]–[11]. In many of the studied schools, the CO_2 levels have exceeded even 2500 ppm [12]. For example, an existing study [13] presents the results on CO_2 concentration measurements in classrooms in different countries like Germany, Portugal, Spain, France Scotland, and others. The minimum indoor CO_2 concentration observed was 351 ppm (in Portugal) while the maximum was 6000 ppm (in the UK). Most of the observed schools were found to have natural ventilation which could not provide enough fresh air during the day. At the same time, some of the schools with mechanical ventilation also had increased CO_2 levels. This was explained by the lack of regulation of ventilation systems. The study concluded that CO_2 levels in classrooms are affected by ventilation types. and that ventilation efficiency can be assessed by measuring the level of CO_2 in the room. Measurements of CO_2 concentrations in several schools were also performed in 2018 in Australia. The study [14] shows how the CO_2 concentration changes dynamically during the lesson and that the CO_2 concentration in the classroom can increase from 400 to 2800 ppm in one and a half hours, which can be detrimental to the health of students. In Sweden [15], indoor air quality in newly built energy-efficient schools with mechanical ventilation was studied. In 60 rooms out of 61 (4 schools), the CO_2 concentration was found to correspond to air quality Categories 1 or 2. In a different study [16] it was suggested that correct commissioning of a ventilation system and use of VAV valves, can significantly increase the IAQ and thermal comfort.

Studies performed in Latvian education institutions [17], [18] have also shown that the indoor environment is critical in many classrooms. In 2015, the World Health Organization produced a document entitled "School environment: policies and current status" to draw the attention of school administration to indoor air quality [19]. In the year 2015/2016 WHO study "Indoor Air Quality in Schools" was conducted in Latvian schools. 14 schools participated in the study. A total of 42 classes were measured. Based on the results, 28 classes (67%) were found to violate the limit for carbon dioxide concentration. 26 of all 42 classes had natural ventilation. The WHO study found that the amount of fresh air supplied over a given period depends on the volume of the room, the number of people and the nature of the work to be done [19], [20].

A lot of schools use natural ventilation worldwide, but it is not reliable as well as can cause high heat losses. Even in the relatively warm climate of Italy, two studies [21], [22] indicate that the extra energy consumption by natural ventilation can increase up to 36% of the overall energy need for space heating of the classroom. It was concluded that mechanical ventilation is the best way to reduce air pollution and is cost-effective in terms of energy savings, as well as properly regulated mechanical ventilation is capable of ensuring that CO_2 concentrations do not exceed 1000 ppm. A study [23] shows that ventilation with a heat recovery efficiency of at least 80% should be installed for schools in a cold climate. The payback period of such investment can be calculated according to methods provided in the studies [24], [25].

For schools with natural ventilation, a study [26] recommends installing a CO_2 concentration sensor in their classrooms to inform the teacher about the violation of the CO_2 concentration and the need to ventilate the room. However, a wide study [27] of schools located in a Mediterranean area with natural ventilation system showed that there is no direct relationship been between the airtightness of the envelope and the internal concentration of CO_2. This indicates that there is a significant influence from other factors affecting the quality of the indoor environment, including class schedules and the opening and closing of windows and doors. Besides, the measured CO_2 concentration exceeded the 1000 ppm threshold even when the windows were open, with CO_2 concentration falling below 1000 ppm in only 28% of case studies with open windows and 17% of the total case studies.

Another aspect of the CO_2 concentration is its influence on mental performance and ability to concentrate. This is of high importance in a school environment where the pupils need to pay constant attention. It has been proven that IAQ has a direct effect on the working capacity of students and thus impacts academic performance [28], [29]. Some studies [30] show that ill-advised energy conservation measures can reduce children's performance of schoolwork by as much as 30%. This is a significant problem since students due to their age can be more susceptible to long-term health damage caused by poor IAQ in school buildings. Experiments carried out at the Lawrence Berkeley National Laboratory found out that a relationship between CO_2 levels in the air and human thinking ability can be demonstrated [31]. The tests were performed at a CO_2 concentration of 600, 1000, and 2500 ppm. In a recent study [32] it was found that as the CO_2 concentration in the classroom increases, the performance test results decrease. Also, some studies [33] indicate that the increase in CO_2 concentration can lead to lower attendance levels. The cause is not directly the CO_2 concentration, but it can serve as an indicator of bad IAQ which can cause more illnesses between the pupils [34], [35].

2 Materials and Methods

The study was conducted during two week period in mid-September of 2020 at Secondary School in Daugavpils, Latvia. During the measurement period, the outside air temperature was 7-15°C at 8:00 (school starting time) and 12-22°C at 15:40 (latest finishing time). The school heating system was not operated at that moment.

The school building was originally built in the 1950s but has been renovated in 2010. The building walls are made of bricks which now have an additional external insulation layer. The ventilation during the renovation has not been improved and still is only natural with openable windows and with the local exhaust in bathrooms. The school is located in the center part of the city, near a highway and railroad. The outdoor CO_2 concentration measured during the study was 480 ppm.

The area of the designated study room is about 28 m^2, height is 3.5 m. The study room has 2 windows and 1 door. The room has 16 student seats and a teacher workstation. The set-up of the measurements can be seen in Figure 1. There were 13-14 students during the lessons, so about 2 m^2/person was provided, which corresponds to Republic of Latvia Cabinet Regulation No. 610 requirements.

Figure 1. Picture of ongoing measurements in the classroom.

The measurements of CO_2 concentration together with temperature and relative humidity were logged with an EXTECH SD800 logger. The respective measurement ranges are for CO_2 - 0 to 4,000ppm; for Temperature - 0 to 50°C; for Humidity - 10 to 90% RH.

The data was logged with 30-second increments. Measurements were made during all teaching hours, including breaks. The school day varied depending on the class schedule from 8:00 to 15:40. Based on the recommendations the logger was placed about 1 meter from the wall and 1-1.5 m from the floor. No direct sunlight was allowed on the data recorder and it was placed away from the windows.

Along with the measurements, a questionary was given to the pupils. The questionnaire contained four questions: "Evaluate the overall microclimate in the classroom", "Do you feel a sensation of overheating?", "Do you feel tired, have difficulty concentrating?", "Do you experience a headache?". The questionary was organized digitally and had multiple choice answers. For the question of microclimate evaluation pupils had to evaluate it on a scale of 1 to 5, where 1 means very bad and 5 excellent. For questions about concentration and overheating possible answers were – "yes" (1), "a little" (0.5), or "no" (0). While the question about headaches could be answered with "yes" (1) or "no" (0). Afterward, the data was converted to numerical format.

These questions were asked at the end of each class and anonymously answered by all present pupils (17 – 18 years old) and a teacher. The number of respondents changed in the range from 2 to 14 (sometimes not all students answered the questionnaire as they forgot), with an average of almost 9 and mode of 8. In total the questionnaires were performed 40 times, from which 4 were at the start of the day before the classes have been started. The total number of the analyzed answer was 346.

3 Results and Discussion

The measurements (see Table 1) show that the CO_2 concentration in the classroom significantly exceeds the generally accepted norms of 1000 ppm. The data analysis for the whole week shows that the average CO_2 concentration is about 2380 ppm, while the absolute maximum is 4424 ppm, which is higher than the measurement range of the logger. This indicated that the real max value could be even higher.

Table 1. Average CO_2 concentration for each measured class.

Class nr.	Date						
	15.09	17.09	18.09	21.09	22.09	23.09	24.09
	CO_2 concentration, ppm						
1.	-	1131	-	1280	-	1271	-
2.	1746	1294	-	2625	2320	2169	1137
3.	1963	1919	-	3776	3697	3271	1862
4.	2410	1827	-	3111	3614	3599	-
5.	2516	1798	1411	2771	2562	2357	-
6.	1990	1542	2252	-	3039	-	-
7.	2094	-	2687	-	2461	-	-
8.	-	-	2328	-	3903	-	-
9.	-	-	1458	-	-	-	-

The maximum CO_2 concentration usually is observed at the 3rd – 4th classes. This might be explained by shorter breaks in the morning as the break length between the first and second class is 10 minutes, while the rest are 15 minutes.

Figure 2 shows the number of times the average CO_2 concentration over the class time has been in a defined range. It reveals that there is a significant problem of underventilation which can cause negative effects on pupil's health and performance.

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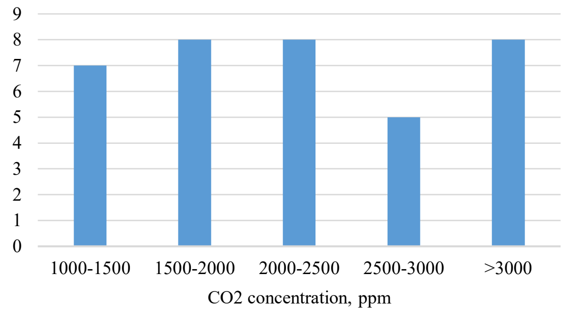

Figure 2. Number of classes with ranged average CO_2 concentration during the measurement period**.**

Figure 3 and Figure 4 shows detailed results on how the CO_2 changes during two separate days. The results indicate that the CO_2 concentration (blue line) consistently is above 1500 and reaches 2500 ppm. Even during the brakes, the CO_2 concentration decreases only slightly and does not reach outside value. This means that the break period is too small and does not provide enough time for ventilation. During the 10-minute break, the CO_2 concentration decreases by roughly 1000 ppm, but as the starting value is already so high it is not enough. The temperature (red line) significantly increased during the day even without heating.

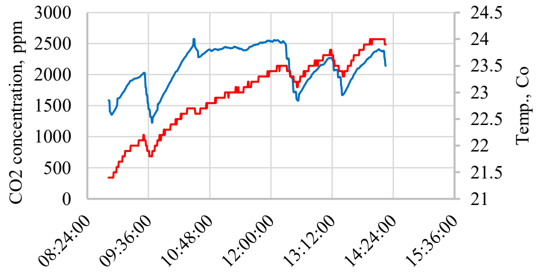

Figure 3. CO_2 and temperature in the classroom on 15.09.2020.

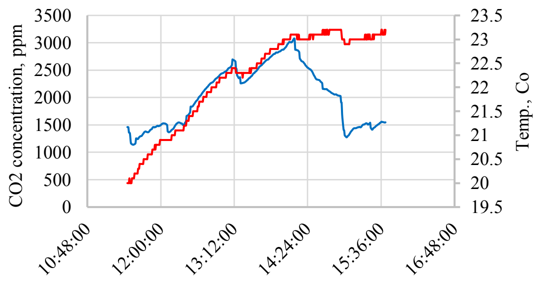

Figure 4. CO_2 and temperature in the classroom on 18.09.2020.

To analyze the relationship between the CO_2 concentration and how the pupils feel the analysis of questionnaires was performed. The average values of questionnaire answers, CO_2 concentration, and indoor temperature were calculated for each class, so a total of 40 samples were analyzed.

The results are shown in Figure 5 and Figure 6. They show that there is a noticeable relation, however, it is very week. The absolute values of the correlation coefficients *r* are in the range (0.36; 0.57). The overall sensation evaluation microclimate decreases with the rise of CO_2. At the same time, it must be noted that the CO_2 is above recommended values all the time, therefore the results can be influenced as the persons adapt to the bad IAQ conditions.

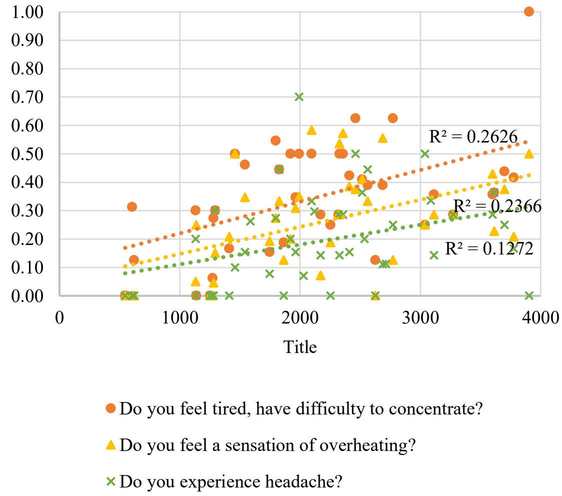

Figure 5. Evaluation of personal comfort and health depending on CO_2 concentration ($p<0,05$).

It could be expected that the exceedingly high CO_2 concentration would lead to a high number of persons with headaches, however, the data does not show this. There are no noticeable relations between the increase in CO_2 and pupils with headaches. However, such a result could also be in a case when there is already a high number of persons with headaches and a further increase in CO_2 concentration cannot affect this. From all of the answers, it can be seen that in almost 20% of cases pupils mentioned that they experience headaches. This is a relatively high number and could indicate that the IAQ is not good.

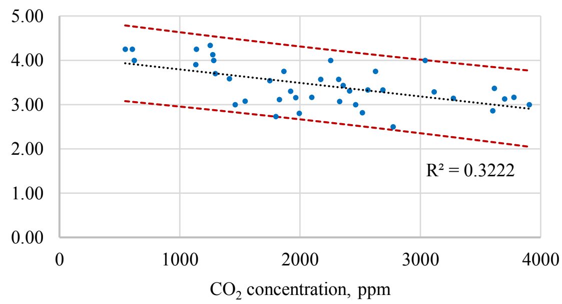

Figure 6. Evaluation of the overall microclimate in the classroom depending on CO_2 concentration ($p<0,001$). Samples, regression line, and confidence interval (95%).

Measurements of average indoor temperatures are shown in Table 2. The average overall period was 22°C, with a minimal value of 18.5°C and a maximal 24°C. Average relative humidity was very high - around 63%, with a minimum of 42% and a maximum of 74%. The median value was 64.2%.

Table 2. Average indoor temperature for each measured class.

Class nr.	Date						
	15.09	17.09	18.09	21.09	22.09	23.09	24.09
	Indoor temperature,°C						
1.	-	21.1	-	18.7	-	19.1	-
2.	21.8	21.4	-	19.8	20.5	20.4	19.9
3.	22.4	22.3	-	20.9	21.5	21.9	20.6
4.	22.9	22.7	-	21.3	22.0	22.4	-
5.	23.3	23.1	20.7	21.3	22.4	22.9	-
6.	23.5	23.2	21.9	-	22.9	-	-
7.	23.7	-	22.7	-	22.2	-	-
8.	-	-	23.1	-	22.7	-	-
9.	-	-	23.0	-	-	-	-

The questionary results were also compared to the measured indoor temperature to see if there is any relevance. Figure 7 and Figure 8 show the obtained results. Across all questions, they indicate a stronger relation to the indoor air temperature than to CO_2 concentration. The absolute values of the correlation coefficients *r* are in the range (0.61; 0.81). Especially strong relation is between the measured temperature and the feeling of overheating, which was expected as these factors are directly linked. At the same time, the results show that at the highest of average class temperatures – 23.7°C, the average vote for overheating was 1.17. Up until 22.5°C, the estimation of thermal comfort from pupils can be considered as good with an average vote of 0.8.

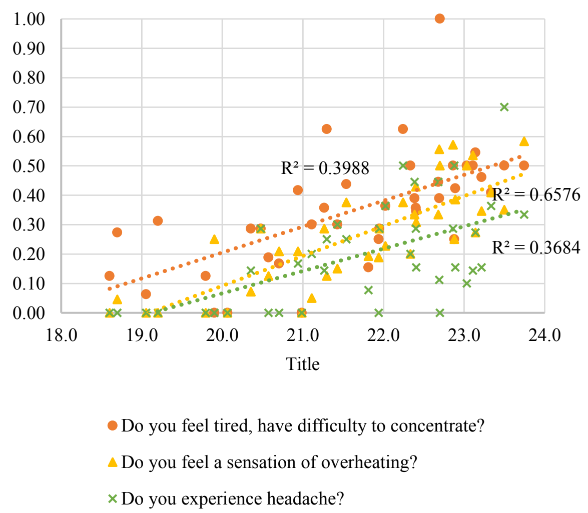

Figure 7. Evaluation of personal comfort and health depending on indoor temperature (p<0,001).

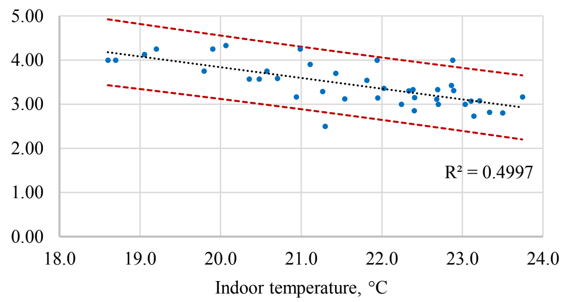

Figure 8. Evaluation of the overall microclimate in the classroom depending on indoor temperature (p<0,001). Samples, regression line, and confidence interval (95%).

The average evaluation of the overall microclimate before 11:20 (20 samples) were 3.58 but after that time (20 samples) 3.30, that corresponds to the fact that during the second half of the day the indoor temperature was higher, but also indicate that the overall pupil's tiredness might also influence the answers.

By the time the paper was finished, the epidemiological situation in Latvia got worse. This caused more strict safety measures which included fully distant schooling. This means that at a given moment this research is not actual. However, it is expected that when things start to get better the schools will return to face-to-face classes and for the first period will still operate under special measures. Therefore, this research could be relevant in the nearest future.

The Latvian Ministry of Education and Science has shown an interest in the field and is in search of possible solutions. The solution must be easily implemented, without a need for complicated design projects and influence on building constructions, possibly decentralized for each classroom and with low costs. As one potential would be an installation of dedicated mechanical ventilation units with heat recovery which serve separate classrooms.

4 Conclusions

The CO_2 concentration during the learning process at Secondary School was much higher than recommended – with an average of about 2380 ppm and the absolute maximum of 4424 ppm. This might be explained by lack of mechanical ventilation and additional epidemiological rules, so students stayed in the classroom even during the breaks and in such a way interfere with sufficient natural ventilation. This means that in future such situation should be avoided and either longer breaks or fewer persons in class should be ensured.

The high measured CO2 concentration indicated the lack of air exchange and therefore can increase the risk of disease spreading. Numerous publications and guidelines stress that increased ventilation must be ensured to decrease the potential virus concentration in rooms.

There is a noticeable relation between students' well-being and CO_2 concentration however it is very week. A stronger relation is established between students' well-being and indoor temperature. With increasing classrooms' CO_2 concentration and temperature, evaluation of overall microclimate in the classroom is decreasing.

To improve the study, observations of CO_2 concentrations in other classrooms and other schools should be made. Further development of the study can be performed by measuring CO_2 concentration in other schools with different ventilation types.

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