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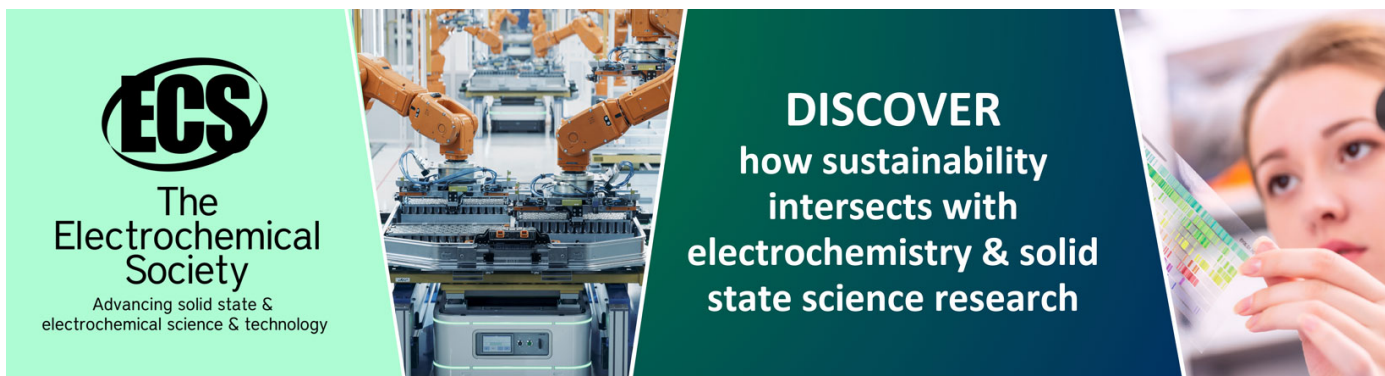
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Influence Of A Decentralized Ventilation System On The Indoor Air Quality Of A Primary School Classroom

T Catalina^{1,2*} and C Lungu¹

¹ Technical University of Civil Engineering Bucharest, România

² Faculty of Environmental Science and Engineering, Babes-Bolyai University, 30 Fântânele Street, RO-400294, Cluj-Napoca, România

tiberiu.catalina@gmail.com

Abstract. The indoor air quality is one of the main factors influencing the comfort in a building. This subject has already been covered by several studies in the case of adult's work environment. The research study is focused on the air quality in a primary school classroom and the children's sensation related to interior comfort. In this article we will present the results of the air quality experimentations when using a ventilation system. The classroom is equipped with a heat recovery unit. In order to perform CO₂, temperature and relative humidity (RH) measurements, we used ten portable measurement units. The sensors have been set in different spots of the classroom. The heat recovery ventilation unit had an important influence on the air quality when it was running. The observed result of this phenomenon was that the measures were homogeneously distributed in the classroom instead of being concentrated in different points. Moreover, it was found that with 17 m³/h/pers. the indoor CO₂ concentration can be dropped below 1000 ppm. The last part of the experimental study was based on a survey with different question regarding air quality, temperature and noise.

1. Introduction

Poor indoor air quality in indoor spaces is one of the major problems to be solved especially in refurbished buildings. If most of the recommendations are related to energy consumption issues about the true purpose of a building must not be forget: to provide a healthy and comfortable environment for the occupants [2]. The indoor air quality is one of the main factors influencing the comfort in a building. This subject has already been covered by many studies in the case of adult's work environment. Indoor air quality is a mix of parameters that can affect the health and comfort of the occupants [3]. Among the most studied pollutants it is mentioned the particulate matter concentration [4] determined PM₁₀ and PM_{2.5} in five elementary schools in Istanbul, Turkey and found that in four schools the maximum concentrations limits determined by the World Health Organization were exceeded considerably. Other authors have shown a direct relationship between poor academic performance of pupils and students and thermal comfort and indoor air quality in schools [5]. Clearly the solution for better air quality is the use of a mechanical ventilation system [6] but the main issue is foreseen for existing buildings where it is forbidden to do construction invasive modifications, or the costs are very high. The use of decentralized ventilation unit appear to be the only viable solution.



The question arises on what system, what are the performances, the costs, the installation problems, etc. [7] studied the indoor air quality in a classroom by measurements of CO₂ and radon while a cabinet type ventilation unit equipped with a heat recovery system was used the proper air quality. The reduction of radon concentration was found to be 15% compared to the same room non-ventilated. Thermal comfort was measured by [8] in two adjacent classrooms one with window air inlets (natural ventilation) while the second one with a mechanical ventilation with no heat recovery. Similar study was realized by [9] in a high school and it was found that after the renovation of the school the indoor radon/VOC concentration were higher than before. They concluded that during spring/autumn the introduction of fresh air without preheating it can alter the predicted mean vote index. This paper is focused on the measurements of CO₂ levels, as a key air quality indicator, in a primary school classroom and the children's sensation related to interior comfort. For good air quality the national norms IS recommends for IDA 1 (Indoor air quality 1) an air flow of 10 l/s (36 m³/h/pers.) but it is not clear if for children the same fresh air amount should be used. In this paper we have demonstrated that with 17 m³/h the indoor CO₂ levels will not overpass 1000 ppm for children under 13 years old. It was found in multiple papers than for schools retrofitted to nZEB standard issues of overheating during winter or poor air quality were reported [10].

2. Experimental method

The experimental study was conducted in Jose Marti school, located at 109A Boulevard Pache Protopopescu in Bucharest (GPS coordinates: latitude 44.439821 | Longitude 26.125606). This school is located on the edge of a small park near the boulevard. Consequently, it is not directly exposed to the pollution of the large circulation.

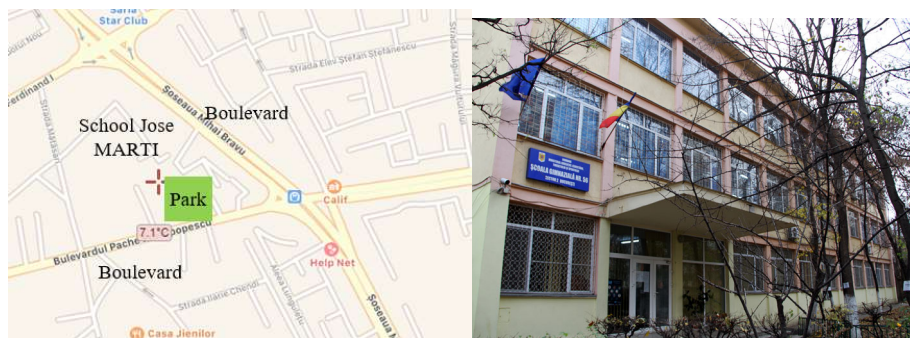


Figure 1. School position on the map. a) Jose Marti school main facade.

The studied classroom is situated on the first floor and its windows are oriented in the direction of the park. The indoor space is organized with a large teacher desk in the front of the room and three columns of six rows of pupils' desks are facing the one from the teacher. The room is sharing two masonry walls (the front and the back one) with neighbours' classrooms and one with the hallway on the right. The exterior wall is mostly composed of windows, and the class only entrance door is in front, near the teacher's desk between the classroom and the hallway. Until 1 p.m., the room is occupied by 30 children who are 10 to 11 years old, and in the afternoon, it hosts a class of 28 students whose age is between 12 and 13 years old. The day is divided into different periods of 50 minutes starting at 8 a.m. and spaced by breaks of 10 minutes. The last lesson finishes at around 5 or 6 p.m. On Thursday from 3 to 4 p.m. and on Friday from 8 to 9 a.m., the room is empty because the pupils go out for physical education sessions. During the course the corridor door remains closed. Air exchanges

between the classroom and the outside are limited to air infiltrations, or air currents due to the windows, when those are open. During the breaks the classroom door is opened so there is direct air flow between these two zones. In this classroom a decentralized ventilation unit was installed at ceiling level. The introduction/extraction of air is realized in the building façade, but no intrusive installation was needed as two window panels were removed.



Figure 2. Photo of the classroom. a) Position of the dataloggers and classroom dimensions.

The classroom HVAC system directly affects the indoor environment, and so the comfort perceived by the children. The classroom is equipped with a heat recovery unit with the following characteristics:

Table 1. Decentralized ventilation unit characteristics

Parameter		Parameter	
Max. air volume	1000 m ³ /h	Max. power consumption	480 W
Heat recovery factor	>90%	Energy efficiency category	IE3
Weight	130	Speed (t.p.m.)	3000
Voltage/frequency	230V/50/60Hz	IP rating	IP54

In order to perform CO₂, temperature and relative humidity (RH) measurements, we used ten K-33 portable ELG sensors from CO₂Meter with the following proprieties (CO₂ measurement: non-dispersive infrared (NDIR), Measurement range : 0 - 10 000 ppm, Accuracy : $\pm 30 \text{ ppm} \pm 3\%$ of measured value). 9 sensors were positioned on a 3 by 3 grid inside the classroom, and one outside the building as shown on Figure 2. In order to establish the impact of the heat recovery unit on the air quality of the classroom, it was decided to organize a three-day experimental campaign. On the first day, the CO₂, temperature and RH levels were measured in these 9 points from 8 a.m. to 5 p.m., with the ventilation heat recovery unit turned off. On the 2nd and 3rd day, the same recordings were made but with the heat recovery unit operating at respectively 25% (250 m³/h) and 35% (350 m³/h) of its capacity. In the morning of the 3rd day of the experimental campaign the pupils felt a general sickness around 11 a.m.: throat itching and red eyes. At this moment, the teacher took the decision to turn off the heat recovery unit for the rest of the morning. During the 2nd and the 3rd day of the experimental campaign, questionnaires were distributed to the students allowing us to know their opinion regarding to the air quality. During the experimental measurements the outdoor CO₂ values were recorded also and the values were found to be in the range 380-400 ppm.

3. Results

It can be seen from figure 3 that the CO₂ levels recorded for each points of the classroom spread over the whole day have interesting patterns. It can be noticed that during the first courses (50 minutes of class and 10 min break) we have a clear pattern of high CO₂ levels when the room is occupied and lower values during break time. This can be interpreted as an important increase (from 600 ppm to approximately 2800 ppm in 50 minutes), a decrease of approx. 500 ppm during the break, then a large raise of the CO₂ level again (+ 1000 ppm), and so on. A CO₂ meter was placed outside the classroom and recorded an uniform value of 400 ppm for the outdoor levels.

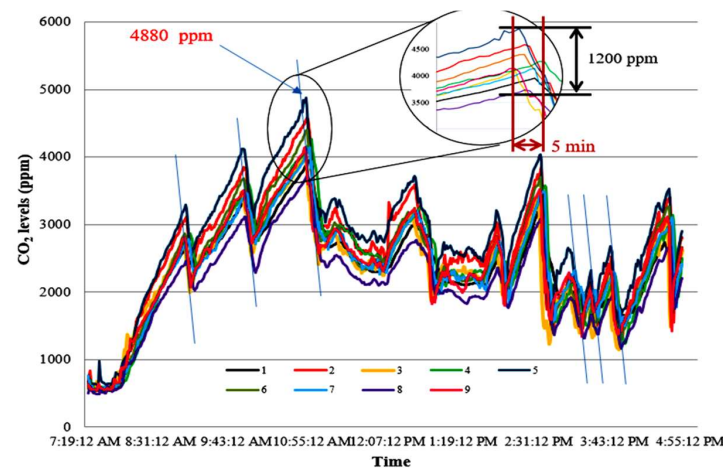


Figure 3. CO₂ levels for the 9 measurement points – 1st day no ventilation

After only three cycles, the CO₂ value reaches a peak concentration of 4800 ppm which is largely over the maximum admissible values. For the rest of the graph it is noticed that the measurements were perturbed by a partially opened window (between 11 a.m. and 1.30 p.m.). Another observation here is that we have large range between measurement points with values spread in a range of 1200 ppm. It is interesting to point out that in the middle of the classroom (point 5) has the highest level while the minimum values are those close to the corridor wall (point 8) and to the windows (point 1).

This difference can be explained by the absence of ventilation in the room, lack of homogeneity of the air, air infiltration next to windows or hallway door. The graphic exposed figure 4 is representing the evolutions of the CO₂ levels during the 2nd day when the heat recovery unit is functioning at 25% of its capacity, more exactly 250 m³/h (8.33 m³/h/student). To begin, it can be seen the very important fall of the levels around 3 p.m., due to the physical education course when the room was left empty. It can also be noticed that the heat recovery ventilation is smoothing the curves whose values are mostly found between 1600 ppm and 2150 ppm. Another observation is that the curves are more homogeneous. Compared to the 1st day levels the CO₂ concentrations have been divided by more than two with only 250 m³/h.

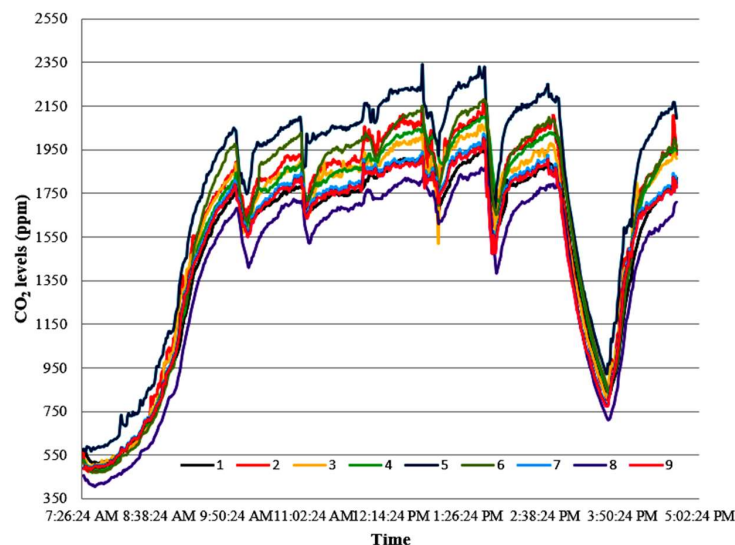


Figure 4. CO₂ levels for the 9 measurement points – 2nd day with ventilation (250 m³/h)

On the figure 5 are displayed the different CO₂ levels with the heat recovery working at 35% or 350 m³/h (11.2 m³/h/pers.). The very interesting shape of these curves is explained by the fact that the ventilation has been cut down for one hour and a half at 11.30 a.m. by the teacher because the pupils had eyes and throat irritations. After 12 p.m. to 14 p.m. the room was not occupied, and hallway door opened and thus explaining the large drop of CO₂ concentration. The values of the different measurement points are found to be in a smaller range of values (approx.. 600 ppm).

This also shows that the decentralized ventilation unit allowed better homogeneity of the indoor air despite the fact there is only one air inlet. The last very interesting thing we observe here is that we do not have the same concentrations between morning and afternoon classes. It was mentioned in the description that during morning time the age of pupils is 10-11 years old while in the afternoon 12-13-year-old maybe explaining this difference of 300 ppm (average value). In figure 5 the maximum level of 2801 ppm was reached because the system was turned off due to high sound pressure levels inside the room and the complaints of the teacher. Moreover, the relative humidity measurements showed values lower than 30%.

The questionnaire was filled out only by the student's from the afternoon classes (25 responses) and they found that the air quality is clearly better. The scale was from 1 to 10 and the first question was „How you found to be the air quality compared to the 1st day ?, where 10 it much fresher than yesterday. The average responses were situated 8.56/10 thus a proof that fresh was highly appreciated by the students. The noise level was also measured during the survey and the results demonstrated that noise at 250 m³/h is slight perceptible (2.4/10 where 0 is the same noise as 1st day) while for 350 m³/h is starting to be a problem (3.56/10). The air temperature sensation was similar for all three days thus a proof that the heat recovery unit did a good job and no air draft was reported. Even though the system was capable to introduce up to 1000 m³/h the experimental campaign was stopped as the noise level overpassed the required values in classrooms from 400 m³/h.

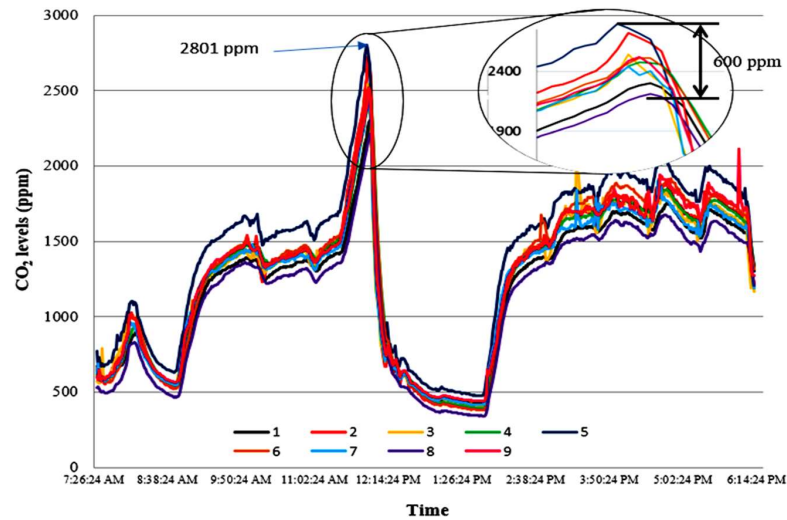


Figure 5. CO₂ levels for the 9 measurement points – 3rd day with ventilation (350 m³/h)

4. Conclusions

The first thing to notice is that when the users are in the classroom, the standard is never respected. Though, it was noticed that the use of a decentralized ventilation system can greatly reduce the CO₂ levels even for low ventilation air rates. The difference of concentrations inside the room in different points is huge can reach up to 1200 ppm. With the system working the air concentrations differences were reduced and the indoor air quality was more homogenous. Using a simple correlation (Figure 6) based on the realized measurements it can be stated that with around 17 m³/h/pers the CO₂ level will not overpass 1000 ppm. It must be mentioned that the data are valid for children with the age between 10 to 13 years and most probably the CO₂ levels would be higher for adults or children.

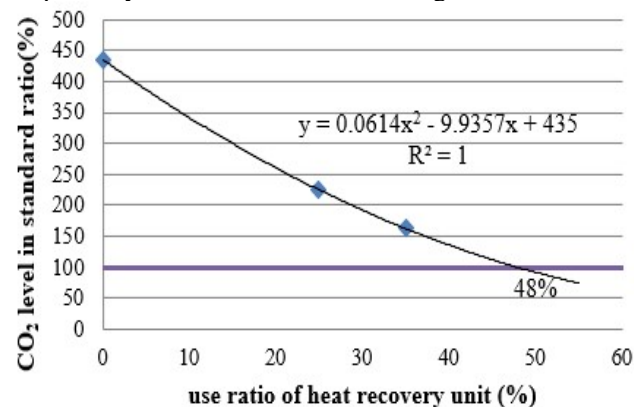


Figure 6. Impact of the heat recovery unit on the CO₂ level

The lack of a humidification system was among the problems that were encountered during the experimental campaign. Several times the occupants complained about eyes and throat irritations and the system was turned off. While the solution of placing the ventilation unit on the ceiling may appear

a good solution for space management inside the classroom it was found to be complicated and with high risk due to its weight (130 kg). The use of decentralized ventilation with ceiling units is still not an option to consider for existing schools. Moreover, with the unit inside a classroom the sound pressure level produced by the system may interfere seriously with the classroom activities.

5. Acknowledgement

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