INDOOR AIR QUALITY ASSESSMENT (PILOT STUDY)

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Abstract

By being part of the public buildings with the highest usability ratio, educational establishments are bound by certain requirements on the construction, maintenance, control and especially the reduction of the risk factors associated with school environment and related to adolescents' health and physical development.

Air quality in school buildings and its role as a multicomponent risk factor, having a modulating effect on the health of students and teachers, has been the subject of an epidemiological study carried out in three comprehensive schools in the town of Haskovo. The study aimed at identifying the main air pollutants in the classrooms. Some physical, chemical and biological indicator parameters, such as air temperature, relative humidity, PM_{10}, $PM_{2.5}$, ozone, carbon monoxide, carbon dioxide, formaldehyde, nitrogen dioxide, volatile organic compounds, moisture and mold presence, have been analyzed.

It was found that a large percentage of the schoolchildren in the early school age (grades 1-4) occupied classrooms where carbon dioxide (90% of the classrooms) and fine particulate matter (50% of the classrooms) significantly exceeded the recommended concentrations for each. The remaining pollutants marked deviations from their respective standards only in isolated cases. The dynamics of the abovementioned pollutant levels measured in real time during classroom occupation as well as the air quality in the classrooms, defined by the microclimatic parameters and the presence of some chemical pollutants, were directly related to ventilation intensity, classroom occupancy, student activity, heating fuel type and building location.

The results of this study generally support the hypothesis of a relationship between air quality in classrooms, their occupancy and ventilation intensity.

Keywords: *indoor air quality (IAQ), schools, carbon dioxide (CO_2), fine particulate matter (PM)*

1. INTRODUCTION

Compromised air quality (ambient air/indoor air), associated with an increased incidence of hospitalizations [1], mortality [2, 3], cardiovascular and respiratory diseases, is classified as one of the serious preventable risk factors that are relevant to public health. In recent years, the attention of research teams has been drawn by indoor air quality where pollutant levels are often much higher than those in outdoor (ambient) air and people spend 70% to 90% of their time indoors (residential, work and/or public buildings) to which educational institutions also belong. School is an imperative; so the students are required to spend about a third of the day in the school environment without being able to change it by their own will. Poor air quality, alone or in combination with other risk factors in the school environment, occupied by about 20% of the total population, is a potential risk factor for the health and/or physical development of children, who are usually more sensitive to the impact of the living environment risk factors due to functional immaturity of a number of organs and systems.

Many epidemiological studies have found a link between exposure to indoor pollutants and a wide variety of health issues ranging from mild discomfort to the emergence of a disease in the short or long term, such as: initiation and aggravation of asthma in children [4, 5, 6, 7], increase in respiratory infections, allergies and exacerbation of existing chronic respiratory diseases, causing frequent absenteeism of schoolchildren and gaps in mastering educational material, thus negatively influencing students' attendance and performance, and staff work capacity [8, 9, 10], respectively.

As part of the public buildings with the highest usability ratio educational establishments are bound by certain requirements on the construction, maintenance, control and especially the reduction of the risk factors associated with learning environment and related to adolescents' health and physical development.

The limited school budgets and the lack of information on the undoubted role of school environment on adolescent health as well as the complexity and difficulty in identifying and quantifying the wide range of pollutants (risk factors) are not an incentive for managers to act on quality improvement of the environment [11], which is why regulatory mechanisms for indoor environment in school buildings have recently been developed and adopted in only few countries.

The present study **aims** to offer suitable mobile sampling and analytical equipment to identify and quantify the main air pollutants in the premises of school buildings, allowing real-time assessment of air quality in classrooms, ensuring adequate control and, if necessary, undertaking preventive measures to improve the environment.

2. MATERIALS AND METHODS

2.1. Study Design

A cross-sectional epidemiological study was conducted during the autumn/winter heating season (November-December) where information was collected on some of the main determinants of health, including the physical, chemical and biological factors influencing school and housing environment quality. The main criteria applied to the selection of the survey area were: a relatively low migration rate, relatively homogenous exposure to environmental pollutants (risk factors), equal opportunities for organized and affordable healthcare, education and other forms of public services within the populated place. The choice of the specific contingent of primary schoolchildren (grades 1-4, 7-11 years) for the subject of the study was consistent with the higher sensitivity of the child's organism to the impact of environmental risk factors due to the functional immaturity of a number of organs and systems.

The study was performed in three comprehensive schools in the town of Haskovo defined by a random selection procedure. The school principals were informed in advanced about the purpose and organization of the study, with an informed consent obtained from the parents of the schoolchildren of the selected educational establishments.

2.2. Air Quality Assessment Indicators in the School Environment – Classrooms

The air quality in the classrooms was assessed by the following groups of indicators:

- Indicators for some *physical parameters of the air in the premises* – air temperature and relative humidity;
- Indicators for the levels of certain *chemical* pollutants (PM_{10}, $PM_{2.5}$, ozone, carbon monoxide, carbon dioxide, formaldehyde, nitrogen dioxide, volatile organic compounds (benzene));
- Indicators for *biological* pollutants (presence of moisture and mold). The data about them were obtained through a questionnaire and an inspection of the school building for the presence of moisture and mold during the study.

2.3. Sampling and Analytical Equipment

At present, there is still no consensus among scientists on the most appropriate equipment and methods for analyzing specific pollutants in indoor environment. The main criteria which the choice of the sampling equipment in our study was based on were mobility and high sensitivity. Particulate matter levels (PM_{10} and $PM_{2.5}$) as well as CO_2, O_3 and CO levels were monitored through mobile devices for real-time measurement of their concentrations in the classrooms. The levels of the rest pollutants, such as formaldehyde, benzene, pinene, limonene, nitrogen dioxide, trichloroethylene and tetrachloroethylene, were assessed with passive sampling appliances (dosimeters), which due to their

small sizes, sufficient sensitivity, noiseless operation and no further emission of airborne harmful substances are considered suitable for quantitative assessment of pollutants in educational institutions [12, 13, 14, 15, 16, 17]. The technical specification and methods of analysis were in compliance with the WHO and European Commission methodological recommendations [18].

For quantitative measurement of the fine particles in the classrooms was used a portable EVM-3/3M device to directly measure the mass concentration of airborne dust based on a photometric principle. The apparatus was also equipped with a sampling device for quantitative collection of photometrically detected dust on a gravimetric filter. The levels of both aerosol fractions of particulate matters (PM_{10} or $PM_{2.5}$) were measured.

In the present study, the accuracy and sensitivity of the portable EVM-3 appliance was experimentally tested with the routine sampling devices "Casella Cyclone" and "Harvard Impactor" and no statistically significant difference in PM concentrations was observed in the results observed with the three devices.

Airborne ozone monitoring in the classrooms was conducted by an automatic gas analyzer, operating on the principle of non-dispersive UV spectrometry (also a portable EVM-3 device).

Carbon dioxide (CO_2), carbon monoxide (CO), air temperature and relative air humidity in the classrooms were quantitatively assessed with the portable instrument IAQ-CALC Indoor Air Quality Meter, model 7545. Airborne CO_2 concentrations were measured by a sensor, operating on a non-dispersive infrared principle, while CO concentrations – by a sensor based on an electrochemical principle.

Part of the gaseous pollutants, such as formaldehyde, benzene, pinene, limonene, nitrogen dioxide, trichloroethylene and tetrachloroethylene, were determined, as already mentioned above, by passive sampling devices (dosimeters) representing collectors in which the tested substance penetrates through a passive pathway and is retained by adsorption or chemical interaction [12, 15, 16, 20, 21]. The diffusion process takes place over a period of time, so the results obtained are integral for the entire study period (one school week). The positioning, the minimum sampling time as well as the conditions and the way of transportation and storage of the samples were consistent with the requirements of the manufacturer [22]. The identification and quantitative assessment of the tested substances, collected by the passive devices, requires that a subsequent analysis be performed, including a spectrophotometric analysis for nitrogen dioxide levels, a liquid chromatographic analysis for formaldehyde, a gas chromatographic analysis with flame-ionization detection for benzene, limonene, pinene and a gas chromatographic analysis with a mass selective detector to determine the levels of trichloroethylene and tetrachloroethylene, as well.

3. RESULTS

The indoor air quality was controlled in 12 classrooms (appointed for students 1 to 4 grade) distributed through the three schools included in the survey. The observation period covered one teaching week - from Monday to the end of Friday.

The measurements of the indoor air physical parameters proved moderate dynamics during the school day: air temperature ranged from 18 ° C to 21-22 ° C with relative humidity from 29 to 42%, which stands within the optimal recommended values for the parameters [23, 24]. The levels of the above mentioned parameters were significantly influenced by the building heating system and especially by the room ventilation, mostly executed by opening of windows (figure 1). The available additional artificial ventilation was not switched on during the survey.

The control of chemical risk factors, such as carbon dioxide (CO_2), benzene and fine particulate matter, revealed deviations from their regulated norms, while among the other investigated pollutants - carbon monoxide, nitrogen dioxide, formaldehyde, pinene, limonene, trichlorethylene and tetrachloroethylene, no high concentrations were recorded. The measured concentrations of chemical

risk factors were compared to their health standards for outdoor air [25] and the WHO recommendations (2010) [11].

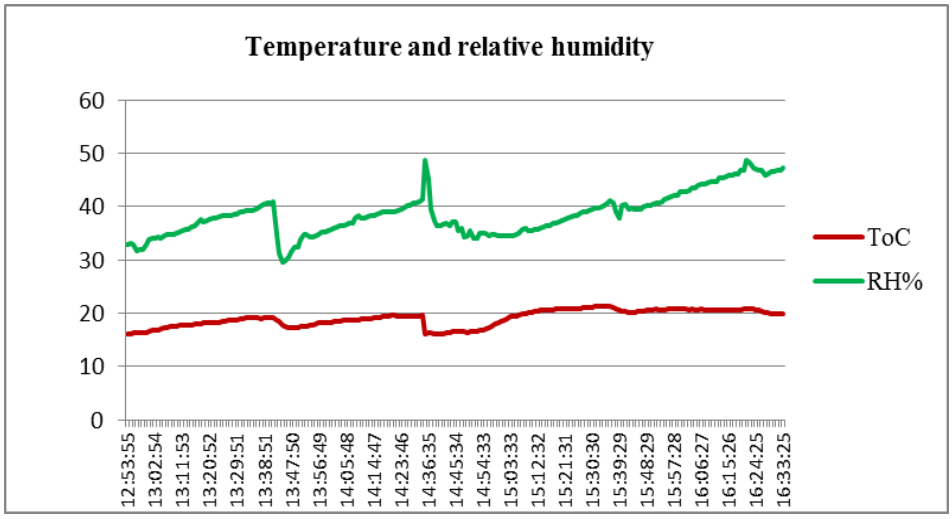


Fig. 1. Dynamics of air temperature and humidity in a classroom during a school day.

Highest school daytime dynamics was observed with the real-time controlled carbon dioxide values. Before the lessons (30 minutes before the first lesson), the CO_2 levelled between 470 and 600-700ppm and with the progression of the learning process the CO_2 gradually increased up to 2700ppm. The average daytime CO_2 for each classroom exceeded 1000 ppm (0,1 vol. %), and in some cases reached over 1500 ppm. (table 1). The variations in CO_2 concentrations were directly related to the intensity of room ventilation. During school breaks or unattended classroom periods, when the ventilation was improved by opening of windows and doors, CO_2 levels sharply decreased. With the beginning of the next lesson, CO_2 started a new rise to reach very high end-of-day values in some of the surveyed classrooms (figure 2). This fact illustrates that insufficient ventilation of the classrooms causes the compromised air quality in them, and on the other hand it is an indication for the main source of CO_2 presence in classrooms through the learning process (human respiration with exhaled CO_2). Only 8% of the students included in the survey had their lessons in classrooms with average CO_2 concentrations below 1000 ppm. Bulgaria has not enforced regulated health standards for CO_2 in educational establishments. For the survey purposes is used the 1000ppm standard, which is recommended by several international organizations [26, 27, 28].

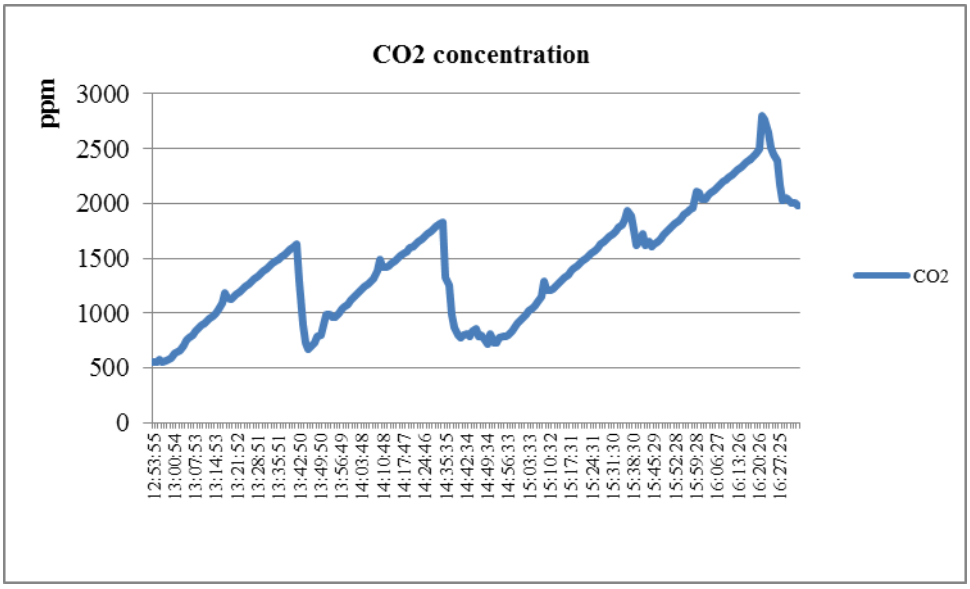


Fig. 2. Concentrations of carbon dioxide, presented as a real time measurement during a school day.

Classrooms	School 1	School 2	School 3
	CO_2 (ppm)	CO_2 (ppm)	CO_2 (ppm)
1	1178.58	1243.71	1565.28
2	1062.43	1414.63	1338.60
3	1185.55	1585.62	765.60
4	1087.95	1414.75	1324.05

Table 1. Carbon dioxide (average daily values)

Concentrations of benzene in individual classrooms, calculated for the observation period of one teaching week (Monday to Friday) and presented as an integral weekly average concentration, ranged from 2.5 to 43.6 μg/m^3. The average annual limit value for benzene in ambient air, regulated in Bulgaria, is 5 μg/m^3 [25].

In the three school buildings, sources of benzene in the classrooms were not established. The only possible source of benzene emissions were the heating boilers, associated with the building heating systems. The fuel used for heating is naphtha (in two of the schools) and natural gas (in the third school). Two of the classrooms with average benzene levels for the controlled period 43.6 μg/m^3 and 12.8 μg/m^3, are located next to intensive traffic highway.

Classrooms	School 1	School 2	School 3
	Benzene (μg/m^3)	Benzene (μg/m^3)	Benzene (μg/m^3)
1	2,72	43,58	8,50
2	2,46	12,81	8,34
3	3,17	5,06	6,00
4	3,63	5,93	9,53

Table 2. Benzene (average values for a teaching week – Monday to Friday)

The real-time measured and calculated as average values for the survey period (one school week) PM_{10} and $PM_{2,5}$, in half of the classrooms exceeded the national health standards.–Bulgaria has not enforced regulated limit values for fine particulate matter in indoor air, but only for atmospheric air, which are respectively: average twenty-four hour concentration for PM_{10} - 50 µg/m^3 and average annual concentration for $PM_{2,5}$ - 25 µg/m^3 [25]

Classrooms	School 1		School 2		School 3	
	PM_{10} (µg/m^3)	**$PM_{2,5}$ (µg/m^3)**	**PM_{10} (µg/m^3)**	**$PM_{2,5}$ (µg/m^3)**	**PM_{10} (µg/m^3)**	**$PM_{2,5}$ (µg/m^3)**
1	21.89	10.13	**110.78**	**59.78**	**54.29**	**31.14**
2	21.29	11.43	33.43	20.71	**58.75**	**39.25**
3	**61.86**	**30.86**	**56.33**	**25.0**	11.0	5.11
4	**52.33**	**26.83**	29.0	14.43	27.25	19.50

Table 3. Fine particulate matter (PM_{10} and $PM_{2,5}$) – average daily values

In the comparative analysis between the real-time levels of fine particulate matter in the classrooms and the average daily concentrations of PM_{10} (according to data from the air monitoring station of the Regional Environmental Inspectorate of Haskovo, selected for the days of the survey, there is no parallel dynamics between the PM_{10} concentrations in the outdoor and the indoor air. This fact implies that local sources of air pollution (heaters) and the human activities are more important for the air pollution in the classrooms. In this relation, additional measurements of fine particulate matter were made in some of the classrooms before the lessons begin. The concentrations of both PM_{10} and $PM_{2,5}$ were found to be lower at unattended periods, compared to periods of active lessons (not shown in tables).

4. DISCUSSION

This study is the first attempt in Bulgaria to identify and analyze the role of risk factors related to school indoor environment. It was found that indoor air quality, defined by microclimatic parameters (air temperature and humidity) as well as some chemical pollutants, depends mainly on the presence of local sources and human activity, including the functioning of the human body (breathing, sweating). The degree of influence on ambient air due to transfer is directly related to the type, intensity and rate of ventilation (duration and number of open classroom windows). It should be noted that due to the small number of surveyed schools as well as schoolchildren, the current data are only indicative and need confirmation in a larger study.

The schools involved in the study are situated in 2- to 3-storey buildings that were specially constructed for that purpose and partially or completely renovated in the past 5-10 years. Despite the improvements made, in 2 of the examined educational institutions there is still a need to renew the floor coverings and joinery, completely remove old leakages and find a solution to existing problems with moisture and mold as well as improve room aeration in all schools by increasing the time and number of open windows or through additional installation of mechanical fans in each classroom. It is advisable to fully switch to natural gas heating in all schools and rebuild as specialized study rooms those classrooms whose windows face the main road with intensive traffic so as to limit the time schoolchildren spend in them from 5-6 hours daily to 1 or 2 hours per week.

Almost 90% of the students involved occupy classrooms with CO_2 levels exceeding 1000ppm. Real-time measured CO_2 concentrations show such dynamics during classes that is directly dependent on the intensity of ventilation, classroom occupancy and student activity. The gradual rise in carbon dioxide levels is primarily associated with human metabolism in the absence of other sources of CO_2

emissions. Regardless of the more intense ventilation during school breaks, high levels of CO_2 indicate insufficient aeration of the learning areas. Our results confirm the high concentrations of CO_2 measured in dozens of Swedish schools, which the authors of the study explain with insufficient ventilation intensity and high occupancy (the number of schoolchildren in the classroom) [29, 30]. Other studies have found a link between elevated levels of carbon dioxide and deteriorating health status of students [31], increased absenteeism [32], increased incidence of infectious respiratory diseases [33] and complaints such as headache, dizziness, fatigue, impaired concentration and a sense of unpleasant smell in the room [34].

Approximately 50% of the surveyed schoolchildren in the city of Haskovo are exposed to fine particles in concentrations exceeding statutory health standards [25]. The PM_{10} and $PM_{2.5}$ levels in the classrooms in our study are not tangibly influenced by the levels of the same fractions in outdoor atmospheric air, but mainly by occupancy/human activity in the premises. In support of our observations are the results of Ligman et al. [35] who reported that the PM_{10} and $PM_{2.5}$ levels measured in several US educational establishments were higher than those measured in office buildings and showed no direct dependence on outdoor fine particle concentrations, while Janssen et al.[36] associated the elevated levels of particulate matter in the classroom with learning activities, particularly the use of chalk and physical activity of children.

The short study period and the small number of monitored schools, respectively children, are limitations in our study that may cause overestimation or underestimation of the observed dependencies. The pollutant monitoring in the classrooms has been conducted for 5 days only (one school week), which is insufficient to compare the established *weekly average* concentrations for some of the pollutants with the recommended or legally stipulated *annual average* levels for each of them. Such a comparison, interpretation of results and conclusions based on objective data from a sufficient number of measurements of the levels of risk factors require a study of a longer duration as well as repeated pollutant monitoring in the classrooms during the year (warm and cold season), inclusion of a larger number of children's and educational institutions and coverage of significantly more children.

5. CONCLUSION

In summary, the results of the present study, regardless of the limited number of examined institutions, generally support the hypothesis of a relationship between indoor air quality (classrooms), occupancy and ventilation intensity. Good air quality in schools is a critical component of a healthy school environment that stimulates educational process and influences productivity, comfort and health of students, teachers and other school staff, and should therefore be a public health priority requiring active preventive national policy to improve air quality in school, public and residential buildings.

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