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Indoor air quality in selected school buildings in the Central Sector of Athens at the Attica's Region and potential Health Risks

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Abstract

Aims and scope: Indoor air pollution is considered as an important environmental risk factor for health. Indoor air quality in schools is very important, as students and teachers spend most of their day (30%) indoors and consequently are more exposed to indoor pollution than outdoor air pollution. The present study has the aim to investigate the indoor air quality (IAQ) in school buildings in the Central Sector of Athens at the Attica's Region and record physical parameters and concentration levels of indoor air pollutants that are associated with comfort, health and safety conditions inside the classrooms. **Methods:** The indoor air quality research was conducted in forty-seven (47) classrooms in a total of twenty-six (26) school buildings in the Central Sector of Athens at the Attica's Region, during the period from March 2022 to May 2023. The air pollutants Carbon dioxide (CO_2), Carbon monoxide (CO), Volatile Organic Compounds (VOC's), Nitrogen dioxide (NO_2), Particulate matters PM (PM_{10}, $PM_{2.5}$) and physical parameters such as temperature (T) and relative humidity (RH) were monitored by the series 500 Portable Air Quality Monitor AeroQual, during (1) teaching hour per day in each classroom. During the samplings some windows and doors were opened, due to measures and recommendations for health and safety for students and teachers against COVID-19. **Findings:** The overall mean concentrations of the main parameters recorded inside the schools were 0,136 ppm CO, 823,38 ppm CO_2, 12,07 ppm VOC'S, 0,006 ppm NO_2, 38,1 μg/m^3 PM_{10} and 15,4 μg/m^3 $PM_{2.5}$. The mean recorder temperature was 24,52 ^oC, and relative humidity was 45,78%. In this study a total number of twenty- two (22) classrooms (46,8%) of schools at the Attica's Region had no comfort temperatures for students. In all cases indoor CO concentrations were below the 50 ppm, guideline set by WHO. Eight (8) of the forty-seven classrooms in the Region of Attica (17%) had a CO_2 concentration more than 1000ppm. VOC's exceeded the limit value of 0,8ppm indoors in all schools (100%). There was statistically difference for CO, CO_2, NO_2 (p<0,001), for VOC's ($p=0,004$) and for PM_{10} ($p=0,028$) between indoor and ambient air. **Conclusion:** The indoor air quality of the classrooms was influenced by the outdoor air, the location of school, the number of windows that were opened during the lesson, the number of students inside the classroom, the activities, furnishing and school equipment. No comfort conditions in classrooms and exceeded limits of indoor air pollutants can lead to diminished IAQ and thereby harmful effects on students. A well airing of the classrooms during the lessons and breaks is necessary for a better air quality. Ventilation is one of the most important factors affecting indoor air quality, diluting the exposure agents originating from indoors.

Keywords: Indoor air pollution, school buildings, students, concentration levels, health risks

Introduction

Indoor pollution is considered as a serious environmental risk factor for health, while most people spend an average of around 87% of their time indoors (Klepeis et al., 2001).

Indoor air pollution can be attributed to three main sources. One source is ambient air, while air pollution enters the interior of buildings through openings - windows and doors. A second source of indoor air pollution is related to the furnishing, materials and chemicals used indoors. A third source of indoor air pollution is anthropogenic activities (Jantunem et al., 2011).

According to the World Health Organization (WHO), indoor air pollution (IAP) is responsible for the deaths of 3.8 million people annually (World Health Organization, 2000). Air pollutants inside buildings including

Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen dioxide (NO_2) Volatile Organic Compounds (VOC's), Particulate Matter (PM), aerosol, biological pollutants and others (Kumar et al., 2013) can lead to diminished IAQ and thereby harmful effects on human health.

Indoor air quality in schools is very important, as students and teachers spend most of their day (30%) indoors and are consequently more exposed to indoor pollution than ambient air pollution (Almeida et al., 2011).

Some children are more sensitive than others to indoor air pollution, such as those with chronic respiratory diseases, particularly asthma, who are potentially at greater risk. In addition, children are more vulnerable to air pollutants due to their higher rates of breathing and their immune system (U.S. EPA 2012).

The objective of this study was: a) to determine the concentration of physical parameters (temperature and relative humidity) and chemical pollutants (CO, CO_2, NO_2, VOC's, PM_{10}, $PM_{2.5}$) in classrooms in selected schools in the Central Sector of Athens at the Attica's Region that are associated with potential health risks and b) to compare the concentrations of air pollutants between the indoor and ambient air of selected schools in the same Region.

Methods

Athens is an area with high level of air pollution due to the industries, transport and anthropogenic activities. The research areas were selected in this way in order to obtain comparative results in relation to indoor and ambient air quality in school buildings.

The research was conducted in forty-seven (47) classrooms from a total of twenty-six (26) school buildings in the Central Sector of Athens at the Region of Attica. The school buildings in which the research was carried out, are located in the following areas of the Athens Central Sector: a) Athens, b) Zografou c) Vyrona, d) Dafni - Ymittos, e) Ilioupoli, f) Philadelphia - Chalkidona and g) Kaisariani.

The study of the indoor air quality in the school buildings was conducted during the period from March 2022 to May 2023. The study has been approved by the Scientific and Ethical Committee of the University of the West Attica, School of Public Health (No 91717/22-10-2021) and by the Ministry of Education and Religion of Greece (No 156846/2-12-2021, 48986/3-5-2022, 26884/9-3-2023).

The visits in the schools were carried out after communication with the Principal and in collaboration with the teachers.

Air quality sampling was conducted from 1 to 3 classrooms for each school during a day from 08:00 to 15:00. The selection criteria of the classrooms were: a) the floor number, b) the ventilation rate, c) the number of students.

The air pollutants Carbon dioxide (CO_2), Carbon monoxide (CO), Volatile Organic Compounds (VOC's), Nitrogen dioxide (NO_2), Particulate matter PM (PM_{10}, $PM_{2.5}$), physical parameters such as temperature (T) and relative humidity (RH) were monitored (at interval time of 1 minute) with the series 500 Portable Air Quality Monitor AeroQual, which enables real-time surveying of common air pollutants, during (1) teaching hour a day in each classroom by the following sensors (table.1) :

- Carbon dioxide Detector 0-2000ppm (Type NDIR)
- Carbon monoxide Sensor 0-100ppm (Type GSE)
- Volatile Organic Compounds (VOC'S) Sensor 0-25ppm (Type GSS)
- Nitrogen dioxide (NO_2) Sensor 0-1ppm (Type GSE)
- Particulate Matter PM_{10}/ PM $_{2.5}$ Sensor (Type Lazer particle counter)
- Temperature and Relative humidity Sensor (Temperature: with range from -40°C to 124 °C, Relative humidity: with range from 0 το 100%)

The sampling position inside the classrooms was opposite to the white board, in the middle of the classroom at a height of about 1-1.5 m (breathing zone), avoiding places in the sun, nearby the heating system (in wintertime) and ventilation channels. During the samplings some windows and doors were opened, due to measures and recommendations for health and safety for students and teachers against COVID-19. For the outdoor air quality measurements, the sampling position was near the central gate of the school at the same height as the indoor sampling height.

In this study variables were continuously measured at 1-minute intervals in each classroom during one (1) teaching hour and then summarized. Statistical analysis was performed with IBM-SPSS Statistics 29.0.1.0 and MS Excel 2007. The level of statistical significance was set at 5% (a=0,05). Data were checked for normality. Pearsons' t-test was used to compare differences between two groups. Results were also validated using nonparametric Mann-Whitney U test.

AIR POLLUTANTS	**series 500 Portable Air Quality Monitor AeroQual SENSORS**
Temperature (T)	Temperature and Relative humidity Sensor (Temperature:-40°C to 124 °C)
Relative humidity (RH)	Temperature and Relative humidity Sensor (Relative humidity: 0 το 100%)
Carbon dioxide (CO_2)	Carbon dioxide Detector 0-2000ppm (Type NDIR)

Carbon monoxide (CO)	Carbon monoxide Sensor 0-100ppm (Type GSE)
Volatile Organic Compounds (VOC'S)	Volatile Organic Compounds (VOC'S) Sensor 0-25ppm (Type GSS)
Nitrogen dioxide (NO_2)	Nitrogen dioxide (NO_2) Sensor 0-1ppm (Type GSE)
Particulate matter PM (PM_{10}/$PM_{2,5}$)	Particulate Matter PM_{10}/ PM $_{2.5}$ Sensor (Type Lazer particle counter)

Table 1. Type of sensors of the series 500 Portable Air Quality Monitor AeroQual for the measurents of the air pollutants and physical parameters

Results

The physical parameters temperature (T) and relative humidity (RH) were monitored during one teaching hour in each classroom in selected schools. Mean of temperature and relative humidity indoors was 24,52 ^{o}C and 45,78% respectively, while outdoors was 24,75 ^{o}C and 42,81% respectively. Lower temperatures were recorded during winter time. The lowest indoor temperature value was 17,30 ^{o}C, in a school of the Athens municipality when no heating was used inside the classroom and some windows were opened due to measures against COVID-19. Higher temperatures were recorded during May and June. The highest temperature value was 29,50 ^{o}C in an overcrowded classroom of a school in the municipality of Byronas when the outdoor temperature was 31,10 ^{o}C and windows were slightly opened. There was not statistically difference for temperature (p=0,847) and relative humidity (p=0,108) between indoor and ambient air. According to the directives of the Technical Chamber of Greece, the recommended temperature for school buildings is between 19 ^{o}C and 26 ^{o}C and the range for relative humidity is between 45% and 50% (Santamouris et al., 2007). In this study a total number of twenty-two (22) classrooms (46,8%) of schools at the Attica's Region had no comfort conditions for students.

In this study, mean concentration of CO in classrooms was recorded at 0,136 ppm. In all cases indoor CO concentrations were below than 50 ppm, guideline set by WHO (WHO, 2000) for 30 min of time–weighted average exposure. The highest indoor CO concentration was 1,7 ppm in a school of Byronas municipality. This can be attributed to the fact that was a primary school, where teachers were using an electric cooker to warm up the children's lunch. The mean concentration of CO outdoors was 0,742 ppm and was higher than the mean indoor concentration. The main source for outdoor concentration of CO is traffic (Jones, 1999). There was statistically difference for CO between indoor and ambient air (*p*<0,001).

Mean indoor concentration of CO_2 was recorded at 823,38 ppm. The highest concentration of CO_2 was recorded at 1.300 ppm in a classroom of a school of Athens municipality. This can be explained by the fact that there was only one window slightly opened while the classroom was overcrowded. The concentration of CO_2 is more related to the intrusion of CO_2 from outdoor air and respiration of the students inside the classrooms. The mean concentration of CO_2 in ambient air was recorded 523,384 ppm lower level than the indoor air concentration. There was statistically difference for CO_2 between indoor and ambient air (*p*<0,001). In this study a total number of eight (8) classrooms (17%) of schools at the Attica's Region had concentration of CO_2 more than 1000 ppm.

Mean concentration of VOC's indoors was recorded 12,07 ppm. The highest concentration of VOC's was 25 ppm and was recorded in a classroom of a school in the municipality of Athens, where all students were using markers for drawing pictures and glues during lesson's activities. In addition, paints, wallpapers, furnishings, the use of cleaning and disinfecting chemicals may play role for this high indoor concentration (Mendell et al., 2007). The mean concentration of VOC's in ambient air was recorded at 5,6 ppm, lower level than the indoor air concentration. There was statistically difference for VOC's between indoor and outdoor air (*p*=0,004). VOC's exceeded the limit value of 0,8 ppm indoors in all schools (100%).

The mean concentration of NO_2 in the classrooms was 0,006 ppm. The measured NO_2 concentrations were generally observed to be higher outdoors than indoors as expected. Mean concentration of NO_2 outdoors was 0,027 ppm and the main source is traffic. There was a statistically difference for NO_2 between indoor and outdoor air (*p*<0,001). The highest indoor concentration of NO_2 was recorded at 0,020 ppm in a classroom of a school in the municipality of Byronas. This can be attributed to the fact that this class of the school was near to a busy road and at a bus stop.

Mean concentration of $PM_{10}/PM_{2.5}$ indoors was 38,1 μg/m^3 and 15,4 μg/m^3 respectively, while $PM_{10}/PM_{2.5}$ outdoor concentration was recorded respectively 78,1 μg/m^3 and 19,8 μg/m^3. The concentration of PM in the outdoor environment was related to various sources, particularly motor vehicle emissions, dust from construction activities, re-suspension of road dust and biomass burning. The concentration of PM indoors was related to the location of school, students' activities inside the classroom, furnishing and school equipment. There was a statistically difference for PM_{10} between indoor and outdoor environment (*p*=0.028), while there was not a statistically difference for $PM_{2,5}$ between indoor and outdoor environment (p=0,053). The highest indoor concentration of PM_{10} and $PM_{2.5}$ was 60 μg/m^3 and 23 μg/m^3 respectively in a classroom of a school in municipality of Athens. This can be explained by the fact that the classroom was located near a central roadway with a lot of traffic. In addition, in this classroom a blackboard with chalks was used as an equipment. The lowest indoor concentration of PM_{10} and $PM_{2.5}$ was 9 μg/m^3 and 5 μg/m^3 respectively in a classroom (library) that was only being used for two (2) teaching hours every day.

In the following table (table.2) are recorded the indoor and outdoor concentration levels of physical parameters and air pollutants.

	INDOOR LEVELS	**OUTDOOR LEVELS**	***P-value***
Temperature (T)	24,52°C	24,75 °C	*0,847*
Relative humidity (RH)	45,78%	42,81%	*0,108*
Carbon dioxide (CO_2)	823,38ppm	523,38ppm	***<0,001***
Carbon monoxide (CO)	0,136ppm	0,742ppm	***<0,001***
Volatile Organic Compounds (VOC'S)	12,07ppm	5,6ppm	***0,004***
Nitrogen dioxide (NO_2)	0,006ppm	0,027ppm	***<0,001***
Particulate matter PM (PM_{10})	38,1μg/m^3	78,1μg/m^3	***0,028***
Particulate matter PM ($PM_{2,5}$)	15,4μg/m^3	19,8μg/m^3	*0,053*

Table 2. Comparisons between concentration levels of indoor and ambient air pollutants and physical parameters. Statistically differences are marked with bold letters

Discussion

Temperature and relative humidity are very important physical parameters for the comfort conditions inside a classroom. Both the indoor air temperature and the relative humidity are affected by the number of students and by the number of windows opened during class time. The present study showed that lower indoor temperature values were recorded when no heating was used inside the classroom and some windows were opened due to measures against COVID-19. Higher temperature values were recorded in overcrowded classrooms of schools with inadequate ventilation rate. Higher temperatures were recorded during May and June, when in the same time the outdoor temperatures were high too. In this study a total number of twenty-two (22) classrooms of schools at the Attica's Region had no comfort conditions for students. Global climate change intensifies the frequency, intensity and duration of extreme heat events. These events may lead to overheating inside the school classrooms resulting in thermal discomfort, reduced performance and potential health risks (Jacklitsch et al., 2016).

CO exposure is an acute hazard because it is odorless, colorless and lethal. The source of CO outdoors is the traffic, while the main source for CO indoors is the ambient air. In this study the indoor source for CO in primary schools were the electric cookers were being used for warming up children's lunch. The most common effects of CO exposure are fatigue, headaches, confusion and dizziness due to inadequate oxygen deliver to the brain (Kleinman, 2000).

The CO_2 concentrations are high in most school environments since a natural ventilation system is used for improving indoor air quality (Canha et al., 2016; Schibuola et al., 2018). Pupil's physical activity, window and door opening patterns in the classrooms and ventilation performance can control the CO_2 levels in classrooms (Heeboll et al., 2018; Stabile et al., 2019; Kapalo et al., 2019). In this study higher concentration of CO_2 (>1000ppm) was recorded inside overcrowded classrooms with inadequate ventilation. Symptoms of mild CO_2 exposure may include headache and drowsiness and at higher concentration, rapid breathing, confusion, increased cardiac output, elevated blood pressure and increased arrhythmias may occur (Gall et al., 2016).

VOC pollutants are among the leading indoor air pollutants causing severe health issues for children and adults. Construction materials, furnishings such as desks and shelves, glues, paints, cleaning chemicals and carpets are primary VOC emission sources in schools (Lee et al. 2006; Guo et al. 2004). The highest indoor air concentration was recorded in this study in a classroom where all students were using markers for drawing pictures and glues during lesson's activities. According to Molhave (1990) when concentrations are between 0,8 ppm and 6,64 ppm occurrence of headaches may occur. When the concentration is greater than 6,64 ppm can cause more serious health effects such as neurological problems.

In this study, the measured NO_2 concentrations were generally observed to be higher outdoors than indoors as expected. The source of NO_2 outdoors is traffic. The indoor air concentration of NO_2 in the classrooms is more related to the intrusion of NO_2 from outdoor air. The highest indoor concentration of NO_2 was recorded in a classroom of a school that was near to a busy road and at a bus stop. Epidemiological surveys have shown that there is an association between NO_2 concentrations in the air and increases in mortality and hospital admissions for respiratory disease. Nitrogen dioxide can decrease the lungs defense against bacteria making them more susceptible to infections. It can also aggravate asthma. (Barck et al., 2005).

Many schools have identified particulate matter (PM) pollution as a major source of indoor pollution. Particulate pollutants come from various sources, including chalk dust, pupils' activities, cleaning operations and outdoor sources such as traffic and industrial emissions. The highest level of PM_{10} and $PM_{2.5}$ concentration was recorded in a classroom that was located near a central roadway with a lot of traffic, as the results were similar to other studies conducted in school located near roadways (Branis et al., 2011;

Mc Conell et al., 2010). In addition, in this classroom a blackboard with chalks was used as an equipment. The lowest indoor concentration of PM was recorded in a classroom that was only being used for few teaching hours every day. Epidemiological researches have shown that increased levels of PM may result in increased prevalence of acute and chronic health effects, including asthma, among children (Mendell et al., 2005; Daisey et al., 2003).

Conclusions

This study determined the concentration of physical parameters (temperature and relative humidity) and chemical pollutants (CO, CO_2, VOC's, NO_2, PM_{10}, $PM_{2.5}$) in forty-seven (47) classrooms in twenty-six (26) selected schools in the Central Sector of Athens at the Region of Attica during the period from March 2022 to May 2023.

The results showed the followings:

- There was not statistically difference for temperature, relative humidity and $PM_{2,5}$ between indoor and ambient air.
- There was statistically difference for CO, CO_2, VOC's, NO_2 and PM_{10} between indoor and ambient air.
- Lower temperatures were recorded during winter time and higher temperatures during May and June. Both the indoor air temperature and the relative humidity are affected by the number of students and by the number of windows opened during class time.
- Mean concentration of CO outdoors was higher than the mean indoor concentration. The source of CO outdoors is the traffic, while the main source for CO indoors is the electric cookers are being used for warming up children's lunch in Primary Schools.
- Mean concentration of CO_2 indoors was recorded higher than the ambient air. The concentration of indoor air in classrooms is influenced by the number of students and the number of opened windows.
- Mean concentration of VOC's in ambient air was recorded lower than the indoor air concentration. Paints, glues, wallpapers, furnishings, antiseptic liquids, may play role for high indoor concentration.
- The measured NO_2 concentrations were generally observed to be higher outdoors than indoors as expected. The main source of NO_2 outdoors is traffic and this fact also influence the concentration indoors.
- Mean concentrations of PM_{10} and $PM_{2,5}$ were recorded higher outdoors than indoors. The concentration of PM in the outdoor environment is related to various sources, particularly motor vehicle emissions, dust from construction activities, re-suspension of road dust and biomass burning. The concentration of PM indoors is related

to the location of school, students' activities inside the classroom, furnishing and school equipment.
- The indoor air quality in the classrooms is influenced by the ambient air, the location of school, the number of windows that are opened during the lesson, the number of students inside the classroom, the activities, furnishing and school equipment.
- Air pollutants inside the classrooms of schools can lead to diminished IAQ and may be responsible for sensory irritation, asthma, allergies, headaches, diminished school performance and for other potentional health risks.

A well airing of the classrooms during the lessons and breaks is necessary for a better air quality. Ventilation is one of the most important factors affecting indoor air quality, diluting the exposure agents originating from indoors. A comparison of the alternative control strategies showed that, adequate ventilation, filtration of the incoming air and controlling the indoor sources are necessary to reduce the indoor exposures to an acceptable level (Hänninen O, et al., 2013) although, in some cases, ventilation may even be source of contaminants if not designed or maintained properly (Zuraimi, 2010).

Human Studies: The study has been approved by the Scientific and Ethical Committee of the University of the West Attica, School of Public Health (No 91717/22-10-2021) and by the Ministry of Education and Religion of Greece (No 156846/2-12-2021, 48986/3-5-2022, 26884/9-3-2023).

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: The research data are available on request by contacting the corresponding author. The data are not publicy available due to privacy restrictions.

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