15 years ESJ
Special edition

Indoor Air Quality in Selected School Buildings in the Central Sector of Athens at the Attica's Region and Potential Health Risks

Maria Anna Bikaki, Public Health Inspector–Economist, MSc., PhDc
Georgios Dounias, Professor
Georgios Farantos, Postdoc fellow
Olga Cavoura, Assistant Professor
Ioanna Damikouka, Assistant Professor
Lefkothea Evrenoglou, Associate Professor
Department of Public Health Policy, School of Public Health,
University of West Attica, Greece

Doi:10.19044/esj.2025.v21n37p54

Submitted: 20 May 2024
Accepted: 28 August 2024
Published: 15 January 2025

Cite As:
Bikaki M.A., Dounias G., Farantos G., Cavoura O., Damikouka I. & Evrenoglou L. (2025). *Indoor Air Quality in Selected School Buildings in the Central Sector of Athens at the Attica's Region and Potential Health Risks*. European Scientific Journal, ESJ, 21 (37), 54. https://doi.org/10.19044/esj.2025.v21n37p54

Abstract

Aims and Scope: Indoor air pollution is a significant environmental risk factor for health, particularly in schools, where students and teachers spend a considerable portion of their day (about 30%). As a result, they are more exposed to indoor pollution than outdoor air pollution. This paper focuses on investigating the indoor air quality (IAQ) in school buildings within the Central Sector of Athens, in the Attica Region, by recording physical parameters and concentration levels of indoor air pollutants related to comfort, health, and safety conditions within classrooms. The study also seeks to identify factors contributing to diminished air quality in classrooms and propose measures to improve indoor air quality in school buildings to protect public health. **Methods:** The indoor air quality research was conducted in forty-seven (47) classrooms across twenty-six (26) school buildings in the Central Sector of Athens, in the Attica Region, from March

2022 to May 2023. Air pollutants, including Carbon dioxide (CO_2), Carbon monoxide (CO), Volatile Organic Compounds (VOCs), Nitrogen dioxide (NO_2), and Particulate matters (PM_{10}, $PM_{2.5}$), along with physical parameters such as temperature (T) and relative humidity (RH), were monitored using the series 500 Portable Air Quality Monitor (AeroQual) during one teaching hour per day in each classroom. Some windows and doors were opened during sampling due to health and safety measures and recommendations for COVID-19 protection for students and teachers. **Findings:** The overall mean concentrations of the main parameters recorded inside the schools were 0.136 ppm for CO, 823.38 ppm for CO_2, 12.07 ppm for VOCs, 0.006 ppm for NO_2, 38.1 μg/m^3 for PM_{10}, and 15.4 μg/m^3 for $PM_{2.5}$. The mean recorded temperature was 24.52 ^oC, and the relative humidity was 45.78%. In this study, twenty- two (22) classrooms, representing 46.8% of the schools in the Attica Region, were found to have temperatures outside the comfort range for students. In all cases, indoor CO concentrations were lower than the recommended exposure limit (REL) of 35 ppm, as an 8-hour time-weighted average (TWA) set by the National Institute of Occupational Safety and Health (NIOSH). Eight (8) of the forty-seven classrooms in the Attica region (17%) had CO_2 concentrations exceeding 1000 ppm. VOCs exceeded the indoor limit value of 0.8 ppm in all schools (100%). There was a statistically significant difference between indoor and ambient air for CO, CO_2, and NO_2 (p<0.001), VOCs ($p=0.004$), and PM_{10} ($p=0.028$). **Conclusion:** The indoor air quality of the classrooms was influenced by outdoor air, the school's location, the number of windows opened during lessons, the number of students in the classroom, the activities conducted, the furnishings, and the school equipment. Lack of comfort conditions and exceeded limits of indoor air pollutants can lead to diminished IAQ, thereby posing harmful effects on students. Proper ventilation of classrooms during lessons and breaks is necessary for better air quality. Ventilation is one of the most important factors affecting indoor air quality, as it dilutes exposure to agents originating indoors.

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

Introduction

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

Indoor air pollution can be attributed to three main sources. The first source is ambient air, which brings outdoor pollution into buildings through openings like windows and doors. The second source is related to the furnishings, materials, and chemicals used indoors. The third source 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 (VOCs), Particulate Matter (PM), aerosols, biological pollutants, and others (Kumar et al., 2013) can lead to diminished IAQ and consequently harmful effects on human health.

Indoor air quality in schools is crucial, as students and teachers spend a significant portion of their day (about 30%) indoors, making them more exposed to indoor pollution than to ambient air pollution (Almeida et al., 2011).

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

The objectives of this study were: a) to determine the concentrations of physical parameters (temperature and relative humidity) and chemical pollutants (CO, CO_2, NO_2, VOCs, PM_{10}, $PM_{2.5}$) in classrooms of selected schools in the Central Sector of Athens, in the Attica Region, which are associated with potential health risks, and b) to compare the concentrations of air pollutants between the indoor and ambient air of these selected schools. The study also aimed to identify factors contributing to diminished air quality in classrooms and to propose measures for improving indoor air quality in school buildings to protect public health.

Methods

Athens is an area with high levels of air pollution due to industrial activities, transportation, and other anthropogenic factors. The research areas were selected to obtain comparative results regarding indoor and ambient air quality in school buildings.

The research was conducted in forty-seven (47) classrooms across twenty-six (26) school buildings in the Central Sector of Athens within the Region of Attica. The schools included in the research were primary schools (students aged 6-12 years) and lower secondary schools (students aged 13-15 years) located in the following urban areas of the Athens Central Sector: a) Athens, b) Zografou, c) Vyrona, d) Dafni - Ymittos, e) Ilioupoli, f) Nea Philadelphia – Chalkidona, and g) Kaisariani.

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

School visits were arranged in coordination with the Principal and in collaboration with the teachers.

Air quality sampling was conducted in 1 to 3 classrooms per school during a single day, from 08:00 to 15:00. The selection criteria for the classrooms included: a) the floor level, b) ventilation rate, and c) the number of students (classrooms size approximately 15-25 students).

Air pollutants such as Carbon dioxide (CO_2), Carbon monoxide (CO), Volatile Organic Compounds (VOCs), Nitrogen dioxide (NO_2), Particulate matter (PM_{10}, $PM_{2.5}$), along with physical parameters such as temperature (T) and relative humidity (RH), were monitored at 1-minute intervals using the series 500 Portable Air Quality Monitor (AeroQual), which enables real-time surveying of common air pollutants. Monitoring was conducted during one teaching hour per day in each classroom using the following sensors (Table 1):

- Carbon dioxide Detector 0-2000ppm (Type NDIR)
- Carbon monoxide Sensor 0-100ppm (Type GSE)
- Volatile Organic Compounds (VOCs) 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: range from -40^{o}C to 124 ^{o}C, Relative humidity: range from 0% to 100%)

The sampling position inside the classrooms was located opposite the whiteboard, in the middle of the classroom, at a height of about 1-1.5 m (breathing zone), avoiding areas exposed to direct sunlight, near the heating system (during winter), and ventilation channels. During the sampling, some windows and doors were opened due to health and safety measures and recommendations for COVID-19. For outdoor air quality measurements, the sampling position was near the school's central gate, 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 teaching hour and then summarized. Statistical analysis was performed using 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, and Pearsons' t-test was used to compare differences between two groups. Results were also validated using the nonparametric Mann-Whitney U test.

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

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 (VOCs)	Volatile Organic Compounds (VOCs) 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)

Results

The physical parameters of temperature (T) and relative humidity (RH) were monitored during one teaching hour in each classroom across selected schools. The mean indoor temperature was 24.52 °C, and relative humidity was 45.78%, while outdoor measurements recorded a mean temperature of 24.75 °C and relative humidity was 42.81%. Lower temperatures were recorded during winter, with the lowest indoor temperature being 17.30 °C, in an Athens school where no heating was used, and some windows were opened due to COVID-19 measures. Higher temperatures were recorded in May and June, with the highest temperature of 29.50 °C observed in an overcrowded classroom in the municipality of Vyronas, where the outdoor temperature was 31.10 °C, and the windows were only slightly opened. There was no statistically significant difference in 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 °C and 26 °C, with a relative humidity range of 45% and 50% (Santamouris et al., 2007). In this study, twenty-two (22) classrooms (46.8%) in the Attica Region were found to have no comfort conditions for students.

The mean concentration of CO in classrooms was recorded at 0.136 ppm. In all cases, indoor CO concentrations were below the 35 ppm recommended exposure limit (REL) by the National Institute for Occupational Safety and Health (NIOSH) as an 8-hour time-weighted average (TWA) (Environmental Protection Agency, 2024). The highest indoor CO concentration was 1.7 ppm in a school in the municipality of Vyronas, likely due to the use of an electric cooker by teachers to warm up the children’s lunch. The mean outdoor CO concentration was 0.742 ppm, higher than the mean indoor concentration, with the main source being traffic (Jones, 1999).

There was a statistically significant difference in CO levels between indoor and ambient air (p<0.001).

The mean indoor concentration of CO_2 was 823.38 ppm, with the highest concentration recorded at 1300 ppm in a classroom in the Athens municipality. This can be attributed to the fact that only one window was slightly opened while the classroom was overcrowded. CO_2 levels are more closely related to outdoor air intrusion and student respiration within the classrooms. The mean concentration of CO_2 in ambient air was recorded at 523.384 ppm, lower than indoor air concentrations. There was a statistically significant difference in CO_2 levels between indoor and ambient air (p<0.001). In this study, eight (8) classrooms (17%) in the Attica Region had CO_2 concentrations exceeding 1000 ppm.

The mean indoor concentration of VOCs was recorded at 12.07 ppm, with the highest concentration of 25 ppm observed in a classroom in the Athens municipality where students were using markers and glue during lesson activities. In addition, paints, wallpapers, furnishings, and the use of cleaning and disinfecting chemicals may have contributed to this high indoor concentration (Mendell et al., 2007). The mean concentration of VOCs in ambient air was recorded at 5.6 ppm, lower than indoor air concentrations. There was a statistically significant difference in VOCs between indoor and outdoor air (p=0.004). VOCs 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, with higher concentrations generally observed outdoors, as expected. The mean outdoor NO_2 concentration was 0.027 ppm, primarily attributed to traffic. There was a statistically significant difference in NO_2 levels between indoor and outdoor air (p<0.001). The highest indoor concentration of NO_2 was recorded at 0.020 ppm in a classroom at a school in the municipality of Vyronas. This can be attributed to the classroom's proximity to a busy road and a bus stop.

The mean concentration of PM_{10} indoors was 38.1 $\mu g/m^3$, while $PM_{2.5}$ was 15.4 $\mu g/m^3$. In contrast, the outdoor concentrations were 78.1 $\mu g/m^3$ for PM_{10} and 19.8 $\mu g/m^3$ for $PM_{2.5}$. The higher concentration of PM outdoors environment was associated with various sources, particularly motor vehicle emissions, dust from construction activities, re-suspension of road dust, and biomass burning. Indoor PM concentrations were influenced by factors such as the school's location, students' activities within the classroom, furnishings, and school equipment. There was a statistically significant difference in PM_{10} levels between indoor and outdoor environments (p=0.028), while the difference for $PM_{2.5}$ was not statistically significant ($p=0.053$). The highest indoor concentration of PM_{10} and $PM_{2.5}$ were 60 $\mu g/m^3$ and 23 $\mu g/m^3$, respectively, in a classroom at a school in the municipality of Athens. This was likely due to the classroom's proximity to a central roadway with heavy traffic and the use of a blackboard with chalk. The lowest indoor concentrations of PM_{10} and $PM_{2.5}$ was 9 μg/m^3 and 5 μg/m^3, respectively, in a library that was used for only two teaching hours each day.

Table 2 presents the indoor and outdoor concentration levels of physical parameters and air pollutants.

Table 2. Comparisons of concentration levels between indoor and ambient air pollutants and physical parameters. Statistically significant differences are indicated in bold

	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 (VOCs)	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*

Discussion

Several studies have found that concentrations of air pollutants in schools are higher than those in households and commercial buildings (Oeder et al., 2012). Temperature and relative humidity are crucial physical parameters for comfort conditions inside a classroom. Both indoor air temperature and relative humidity are affected by the number of students and the number of windows opened during class time. The present study showed that lower indoor temperatures were recorded when no heating was used and some windows were opened due to COVID-19 measures. Higher temperatures were recorded in overcrowded classrooms with inadequate ventilation, particularly during May and June when outdoor temperatures were also high. A total number of twenty-two (22) classrooms in the Attica Region had conditions that were not comfortable for students. Previous research has indicated that inadequate and often poor classroom air quality (CAQ) can increase the risk of respiratory illnesses and other health-related symptoms (Alves et al., 2013; Choo et al., 2015; Daisey et al., 2003). Global climate change intensifies the frequency, intensity, and duration of extreme heat events, which can lead to overheating in classrooms, resulting in thermal discomfort, reduced performance, and potential health risks (Jacklitsch et al., 2016).

Carbon monoxide (CO) exposure is an acute hazard because, CO is odorless, colorless and potentially lethal. Outdoors, CO primarily comes from traffic, while indoors, it can accumulate from sources such as electric cookers used in primary schools to warm children's lunch. Common effects of CO exposure include fatigue, headaches, confusion, and dizziness due to inadequate oxygen delivery to the brain (Kleinman, 2000).

CO_2 concentrations are typically high in school environments due to the reliance on natural ventilation systems for improving indoor air quality (Canha et al., 2016; Schibuola et al., 2018). Factors such as student's physical activity, window and door opening patterns, and ventilation performance can affect CO_2 levels in classrooms (Heeboll et al., 2018; Stabile et al., 2019; Kapalo et al., 2019). A maximum CO_2 concentration of 1000 ppm is recommended under normal conditions as an indication of hygienically sufficient air change. For workplaces, the United States Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH) have established a time-weighted average limit of 5000 ppm for airborne exposure during an 8-hour work shift in a 40-hour workweek (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2022; OSHA, 2024). This study found higher CO_2 concentrations (>1000 ppm) in overcrowded classrooms with inadequate ventilation. Mild CO_2 exposure can cause headaches and drowsiness, while higher concentrations can lead to rapid breathing, confusion, increased cardiac output, elevated blood pressure, and arrhythmias (Gall et al., 2016).

Volatile Organic Compounds (VOCs) are major indoor air pollutants that pose significant health risks to both children and adults. Primary sources of VOCs in schools include construction materials, furnishings (e.g., desks and shelves), glues, paints, cleaning chemicals, and carpets (Lee et al. 2006; Guo et al., 2004). The highest indoor VOCs concentration in this study was recorded in a classroom where students were using markers and glues. According to Molhave (1990), VOCs concentrations between 0.8 ppm and 6.64 ppm may cause headaches, while concentrations above 6.64 ppm can lead to more serious health effects, such as neurological problems.

The WHO Regional Office for Europe (2013) reported that concentrations of pollutants around roadways are influenced by both direct traffic emissions and background levels. $PM_{2.5}$ and ultrafine particles concentrations decrease by 50% within 100–150 m of a road, and levels of black smoke, $PM_{2.5}$, NO_2, and benzene return to background concentrations within this distance (WHO, 2013).

In this study, the measured NO_2 concentrations were generally higher outdoors than indoors, as expected. The primary source of NO_2 outdoors is traffic, while indoor concentrations of NO_2 in classrooms are largely due to the infiltration of outdoor air. The highest indoor concentration of NO_2 was recorded in a classroom located near a busy road and a bus stop. Currently, no standards have been established for Nitrogen oxides in indoor air. However, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and the U.S. Environmental Protection Agency (EPA) have set a National Ambient Air Quality standard of 0.053ppm as the average annual limit for NO_2 in outdoor air (EPA, 2024). Epidemiological surveys have shown an association between NO_2 concentrations in the air and increases in mortality and hospital admissions for respiratory diseases. Nitrogen dioxide can impair the lungs' defense against bacteria, making them more susceptible to infections and can also aggravate asthma (Barck et al., 2005).

Particulate matter (PM) pollution has been identified as a major source of indoor air pollution. Particulate pollutants originate from various sources, including chalk dust, students' activities, cleaning operations, and outdoor sources such as traffic and industrial emissions. The highest levels of PM_{10} and $PM_{2.5}$ were recorded in a classroom located near a central roadway with heavy traffic, consistent with findings from other studies conducted in schools near roadways (Branis et al., 2011; Mc Conell et al., 2010). In addition, this classroom used a blackboard with chalk, contributing to the indoor PM levels. The lowest indoor PM concentrations were recorded in a classroom that was only used for a few teaching hours each day. Epidemiological researches have shown that increased levels of PM can lead to an increased prevalence of acute and chronic health effects, including asthma, particularly among children (Mendell et al., 2005; Daisey et al., 2003). It is noteworthy to mention Directive 2008/50/EC of the European Parliament and council, dated 21 May 2008, on ambient air quality and cleaner air for Europe, which introduced additional $PM_{2.5}$ objectives aimed at reducing population exposure to fine particles. In addition, the EPA has set the primary (health-based) annual $PM_{2.5}$ standard at 9.0μg/m^3 to provide increased public health protection, in line with the available health science (EPA, 2024).

Scientific evidence on the health effects of indoor air pollution is rapidly developing. The new World Health Organization (WHO) guidelines provide levels for various air pollutants (WHO, 2021). Establishing guidelines for indoor air pollutants, conducting further environmental researches, and implementing health and safety are crucial for protecting public health.

Conclusions

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

The results showed the following:

- There was no statistically significant difference in temperature, relative humidity, and $PM_{2,5}$ between indoor and ambient air.
- A statistically significant difference was found between indoor and ambient air concentrations of CO, CO_2, VOCs, NO_2, and PM_{10}.

- Lower temperatures were recorded during winter, and higher temperatures were recorded during May and June. Both indoor air temperature and relative humidity were affected by the number of students and the number of windows opened during class time.
- The mean concentration of CO outdoors was higher than the mean indoor concentration. The primary source of CO outdoors is traffic, while indoors, the main source of CO is the use of electric cookers for warming children's lunches in primary schools.
- The mean concentration of CO_2 indoors was higher than in the ambient air. Indoor CO_2 levels in classrooms were influenced by the number of students and the number of windows opened.
- The mean concentration of VOCs in ambient air was lower than the indoor air concentration. Paints, glues, wallpapers, furnishings, and antiseptic liquids may contribute to the high indoor concentrations.
- NO_2 concentrations were generally higher outdoors than indoors, as expected. The main source of outdoor NO_2 is traffic, which also influences indoors concentration.
- Mean concentrations of PM_{10} and $PM_{2,5}$ were higher outdoors than indoors. Outdoor PM levels are related to various sources, particularly motor vehicle emissions, dust from construction activities, road dust re-suspension, and biomass burning. Indoor PM levels are influenced by the school's location, students' activities inside the classroom, furnishings, and school equipment.
- The indoor air quality (IAQ) in classrooms is influenced by ambient air, the school's location, the number of windows opened during lessons, the number of students in the classroom, activities, furnishings, and school equipment.
- Air pollutants in school classrooms can lead to diminished IAQ and may be responsible for sensory irritation, asthma, allergies, headaches, reduced school performance, and other potential health risks.

Proper ventilation of classrooms during lessons and breaks is necessary for better air quality. Ventilation is one of the most important factors affecting indoor air quality, as it dilutes exposure to indoors pollutants. A comparison of alternative control strategies suggests that adequate ventilation, filtration of incoming air, and controlling indoor sources are essential for reducing indoor exposures to acceptable levels (Hänninen et al., 2013). However, in some cases, ventilation may even become a source of contaminants if not designed or maintained properly (Zuraimi, 2010).

Declaration for Human Participants: The study was approved by the Research Ethics Committee of the University of West Attica (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 upon request by contacting the corresponding author. The data are not publicly available due to privacy restrictions.

Funding Statement: The authors did not obtain any funding for this research.

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