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Study of Indoor Air Quality in School Buildings in the Argolida Sector of the Peloponnese Region in Greece and Potential Health Risks

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Abstract

Aims and Scope: Indoor air quality (IAQ) in schools is crucial, as students spend significant time in school environments in addition to their homes. Epidemiological researches have shown that indoor pollutants are linked to various health and respiratory issues. This paper focuses on investigating the indoor air quality (IAQ) in school buildings in the Argolida sector of the Peloponnese Region in Greece. **Methods:** The study was conducted in fourteen (14) classrooms across seven (7) school buildings in the Argolida Sector of the Peloponnese Region from March 2022 to May 2023. Physical parameters such as temperature (T) and relative humidity (RH), as well as air pollutants including Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOCs), and Particulate Matter (PM_{10}, $PM_{2.5}$) were monitored using the series 500 Portable Air Quality Monitor AeroQual. Measurements were taken for one teaching hour per day in each classroom. Due to governmental measures to protect public health from the spread of COVID-19, some windows and doors in the classrooms were opened during sampling. **Findings:** The mean temperature and relative humidity inside the classrooms were 22.12 ^{o}C and 50.87%, respectively. The overall mean concentrations of air pollutants recorded inside the schools were 691.35 ppm CO_2, 0.001 ppm NO_2, 9.97 ppm VOCs, 15.7μg/m^3 PM_{10}, and 11.4μg/m^3 $PM_{2.5}$. No indoor CO concentration (0 ppm) was detected in any of the classrooms. This study indicated the following: a) the indoor CO_2 concentration levels in the schools (100%) were below 1000 ppm, b) in five out of the fourteen classrooms (35.7%) within the school buildings, CO_2 concentration levels exceeded 700 ppm, and c) the indoor VOCs levels in the schools (100%) were above 0.8 ppm. Eight classrooms (57.1%) in Argolida's school buildings had no comfort conditions due to high relative humidity (RH > 50%). Statistically significant differences were found for temperature *($p= 0.001$)*, CO_2 *($p < 0.001$)*, NO_2 *($p=0.006$)*, and VOCs *($p=0.001$)* between indoor and ambient air. **Conclusion:** The air quality in school buildings in the Argolida sector was affected by the number of students in a classroom, the ventilation rate, and the school's equipment. The proximity of schools to central roads and construction activities also affected the concentration of indoor air pollutants. Indoor air pollution (IAP) can pose potential health risks. Developing monitoring systems for measuring indoor pollutants in schools, as well as strategies for controlling and improving IAQ, is essential for public health.

Keywords: Indoor air pollution, School buildings, Students, Argolida, Health risks

Introduction

Epidemiological research has shown that people spend most of their time indoors and are therefore more exposed to indoor air pollutants (Sousa et al., 2012a), whose concentrations are often higher than those in outdoor environments (Jones, 1999). Furthermore, indoor pollutants are associated with various health problems and respiratory symptoms (Saraga et al., 2011).

Investigating Indoor Air Quality (IAQ) in school buildings is crucial because children are more vulnerable to indoor air pollutants due to their not fully developed immune systems and lungs, greater inhaled breath rate per body mass, and the rapid growth of their tissues and organs (Branco et al., 2014b).

There is evidence of the increased prevalence of asthma and allergies over recent decades, particularly in developed countries, among children (WHO, 2007). It has been reported that more than a third of children in Europe have bronchial asthma or allergies (Asher et al., 1998). Indoor Air Quality issues can result in increased absences due to respiratory infections, allergic diseases from biological contaminants, or adverse reactions to chemicals used in schools. Students' performance decreases due to sickness or absence from school (Silverstein et al., 2001).

Indoor Air Quality (IAQ) is determined by a combination of air pollutants inside buildings, including Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOCs), Particulate Matter (PM), bacteria, and molds (Madureira et al., 2009, 2012). Diminished Indoor Air Quality (IAQ) in school buildings can lead to health problems for both students and teachers.

The Peloponnese Region is a geographic area in Southern Greece. It borders Western Greece to the north and Attica to the northeast. Argolida is a regional unit within the Peloponnese Region, located in the Eastern Peloponnese peninsula. It borders Corinthia to the north, Arcadia to the west and south, and Attica to the northeast. It is primarily a semi-mountainous area with a long coastline, though it also includes the very productive and densely populated lowland area of the Argolic Plain. According to the 2021 census, it had a population of 93.282 inhabitants and an area of 2.156 square kilometers. The capital of the prefecture is Nafplio, and its largest city is Argos.

This study extended previous scientific research on indoor air quality in school buildings in the Central Sector of Athens in the Attica Region (Bikaki et al., 2024) and focused on recording indoor physical parameters and chemical pollutants in classrooms in different school buildings in the Argolida Sector. The study aimed to assess comfort conditions, and potential health risks, and to compare the levels of air pollutants between indoor and ambient air in the selected schools within the Peloponnese Region.

Methods

The research was conducted in fourteen (14) classrooms across seven (7) school buildings in the municipalities of Nafplio and Argos-Mycenes, located in the Argolida Sector of the Peloponnese Region.

The scientific equipment, sampling positions, and criteria for selecting classrooms were consistent with those used in the study conducted in school buildings in the Central Sector of Athens in the Attica Region (Bikaki et al., 2024).

The study took place from March 2022 to May 2023. Air quality sampling was conducted in two (2) classrooms per school during a single day between 08:00 and 15:00. The selection criteria for the classrooms included: a) the floor number, b) the ventilation rate, and c) the number of students (classroom size: 15-25 students). Due to governmental measures to protect students' and teachers' health and safety against COVID-19, some windows and doors in the classrooms were opened during the sampling period.

The air pollutants Carbon dioxide (CO_2), Carbon monoxide (CO), Volatile Organic Compounds (VOCs), Nitrogen dioxide (NO_2), Particulate Matter (PM_{10}, $PM_{2.5}$), as well as 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. The appropriate sensors used were: i) Carbon dioxide Detector 0-2000 ppm (Type NDIR), ii) Carbon monoxide Sensor 0-100 ppm (Type GSE), iii) Volatile Organic Compounds (VOCs) Sensor 0-25 ppm (Type GSS), iv) Nitrogen dioxide (NO_2) Sensor 0-1 ppm (Type GSE), v) Particulate Matter PM_{10}/ $PM_{2.5}$ Sensor (Type Lazer Particle Counter), and vi) Temperature and Relative humidity Sensor (Temperature range: -40^{o}C to 124 ^{o}C; Relative humidity range: 0 to 100%). The sampling position inside the classrooms was opposite the whiteboard, in the middle of the room, at a height of about 1-1.5 m (breathing zone), avoiding places in direct sunlight, near the heating system (in winter), and ventilation channels. For 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 using the IBM Statistical Package for the Social Sciences (SPSS) for Windows, version 29.0.1.0. The statistical significance level was set at 5% (a=0.05). Data were checked for normality. Pearsons' t-test was used to compare differences between the two groups. Results were also validated using the nonparametric Mann-Whitney U test.

Results

Temperature (T) and relative humidity (RH) were monitored during one teaching hour in each classroom in school buildings in Argolida. The mean temperature and relative humidity indoors were 22.12 ^{o}C and 50.87%, respectively, while outdoors, they were 23.85 ^{o}C and 48.47% , respectively. The lowest indoor temperature was 21 ^{o}C in a classroom of a school in the Nafplio area. The highest indoor temperature was 24.3 ^{o}C in a school located in the Argos area, while the outdoor temperature was 24.2 ^{o}C. Due to safety measures against COVID-19, some windows were opened during the lessons. The highest relative humidity indoors was 59.4% in the same school in Argos area mentioned above. In this school, the classroom was overcrowded, and the windows were only slightly open. There was a statistically significant difference in temperature between indoor and outdoor air *($p=0.001$)*. However, there was no statistically significant difference in relative humidity between indoor and outdoor air *($p=0.070$)*. The recommended temperature for school buildings is between 19 ^{o}C and 26 ^{o}C, and the recommended range for relative humidity is between 45% and 50% (Santamouris et al., 2007). In this

study, eight (8) classrooms (57.1%) in Argolida's school buildings did not meet comfort conditions due to high levels of relative humidity (RH>50%).
No CO was detected indoors in any of the classrooms. The mean concentration of CO in the ambient air was 0.045 ppm. There was no statistically significant difference in CO levels between indoor and outdoor air (*p=0.165*).

The mean concentration of CO_2 indoors was recorded at 691.35 ppm. The highest concentration of CO_2 was recorded at 823 ppm inside an overcrowded classroom in the Nafplio area, where two windows were slightly opened. The mean concentration of CO_2 in the ambient air was recorded at 423.87 ppm, a lower level than indoors. There was a statistically significant difference in CO_2 levels between indoor and ambient air *($p<0.001$)*. This study indicated the following: a) the indoor concentration levels of CO_2 in the schools (100%) were below 1000 ppm, and b) five (5) classrooms (35.7%) in the school buildings had indoor concentration levels above 700 ppm.

The mean concentration of NO_2 indoors was recorded at 0.001 ppm. Concentration levels of NO_2 inside the classrooms were lower than outdoor levels. The highest concentration of NO_2 was recorded at 0.010 ppm inside a classroom in the Nafplio area. The mean concentration of NO_2 outdoors was recorded at 0.012ppm, with traffic in the Nafplio area being the main source. There was a statistically significant difference in NO_2 levels between indoor and outdoor air *($p=0.006$)*.

The mean concentration of VOCs was 9.97 ppm inside the classrooms. The highest concentration of VOCs was recorded at 19.01 ppm in a classroom in the Nafplio area. This classroom had been just cleaned during the break using detergents, which could have contributed to the high level of VOCs. The mean outdoor concentration level of VOCs was 3.58 ppm, which was lower than the indoor concentration. There was a statistically significant difference in VOCs levels between indoor and outdoor air *($p=0.001$)*. In this study, the indoor concentration levels of VOCs in all the selected schools (100%) were above 0.8ppm.

The mean concentrations of PM_{10} and $PM_{2.5}$ indoors were 15.7 μg/m^3 and 11.4 μg/m^3, respectively. The mean concentrations of PM_{10} and $PM_{2.5}$ outdoors were 20 μg/m^3 and 12.9 μg/m^3, respectively. The highest indoor concentrations of PM_{10} and $PM_{2.5}$ were recorded at 28 μg/m^3 and 18 μg/m^3, respectively, inside a classroom in the Nafplio area, where the teacher and students were writing with chalk on the blackboard during the lesson. In addition, this classroom was located near a central road with heavy traffic, and construction activities were taking place on the streets. The lowest indoor concentrations of PM_{10} and $PM_{2.5}$ were recorded at 7 μg/m^3 and 3 μg/m^3, respectively, inside a classroom in the Argos area. This can be explained by the fact that this school building was located in a field, far from central roads. There was no statistically significant difference in PM_{10} levels between indoor

and outdoor air *(p=0.436)*. There was also no statistically significant difference in $PM_{2,5}$ between indoor and outdoor air *(p=0.494)*.
The following table (Table 1) records the concentration levels of physical parameters and air pollutants inside the classrooms of the Argolida Sector.

Table 1. Concentration levels of indoor pollutants and physical parameters

	INDOOR LEVELS
Temperature (T)	22.12 ºC
Relative humidity (RH)	50.87%
Carbon dioxide (CO_2)	691.35 ppm
Carbon monoxide (CO)	0 ppm
Volatile Organic Compounds (VOCs)	9.97 ppm
Nitrogen dioxide (NO_2)	0.001 ppm
Particulate matter PM (PM_{10})	15.7μg/m^3
Particulate matter PM ($PM_{2,5}$)	11.4μg/m^3

In the following table (Table 2), the indoor and outdoor concentration levels of physical parameters and air pollutants in school buildings in the Argolida Sector, along with the statistically significant differences are recorded.

Table 2. Comparisons between indoor and outdoor concentration levels of physical parameters and air pollutants in school buildings in the Argolida Sector. Statistically significant differences are indicated in bold numbers

	Indoor Levels	**Outdoor Levels**	***p-value***
Temperature (T)	22.12 ºC	23.85 ºC	***0.001***
Relative humidity (RH)	50.87%	48.47%	*0.070*
Carbon dioxide (CO_2)	691.35 ppm	423.87 ppm	***<0.001***
Carbon monoxide (CO)	0 ppm	0.045ppm	*0.165*
Volatile Organic Compounds (VOCs)	9.97 ppm	3.58ppm	***0.001***
Nitrogen dioxide (NO_2)	0.001 ppm	0.012ppm	***0.006***
Particulate Matter (PM_{10})	15.7μg/m^3	20μg/m^3	*0.436*
Particulate Matter ($PM_{2.5}$)	11.4μg/m^3	12.9μg/m^3	*0.494*

Discussion

According to the Environmental Protection Agency (EPA, 2024), Indoor Air Quality (IAQ) refers to the air quality inside and around buildings as it relates to the health and comfort conditions of building occupants. Chemical agents, particulate matter, biological factors, and physical parameters in school buildings (indoor air pollution) can negatively impact the health of both students and teachers (Argunhan et al., 2018). Higher levels of indoor temperature and relative humidity were recorded in overcrowded classrooms with slightly opened windows. Eight (8) classrooms (57.1%) in the school buildings of Argolida did not meet comfort conditions due to high relative humidity levels (RH > 50%). Thermal conditions inside classrooms are crucial for students' health and are associated with physical parameters such as relative humidity and temperature (Fang et al., 2004).

Sources of Carbon monoxide (CO) include unvented kerosene heaters, gas space heaters, leaking chimneys, furnaces, gas water heaters, wood stoves, generators and other gas-powered equipment, and automobile exhaust (Donepudi et al., 2013). Carbon monoxide (CO) can be detected in the air of school buildings due to combustion processes, such as cooking or heating (WHO, 1999). It can also enter classrooms from the ambient air.

In this study, no CO was detected inside the school buildings in the Argolida Sector. Epidemiological research has shown that low concentrations of CO can affect cardiovascular and neurobehavioral functions, while high concentrations can lead to unconsciousness and death (Raub et al., 2000).

Indoor concentration levels of Carbon dioxide (CO_2) can be higher in classrooms with a large number of students and low ventilation rates. In this study, five (5) classrooms (35.7%) in the school buildings had indoor CO_2 concentration levels exceeding 700 ppm. A maximum CO_2 concentration of 1000 ppm is recommended under normal conditions as an indication of hygienically sufficient air change. Indoor CO_2 levels at 3000 ppm can increase headache intensity, sleepiness, fatigue, and concentration difficulty (Zhang et al., 2017).

Indoor Nitrogen dioxide (NO_2) concentration levels can be influenced by outdoor sources such as combustion processes and traffic. Concentrations inside the school buildings were recorded to be lower than outdoor levels. The highest concentration of NO_2 was recorded at a school located near the central road of Nafplio. Traffic in Nafplio, may contribute to both indoor and outdoor NO_2 concentration levels. Scientific research has established an association between NO_2 concentrations in the air and respiratory problems.

Volatile Organic Compounds (VOCs) are gases containing a variety of chemicals. Indoor sources primarily include human activities, cleaning products, and building materials. Higher indoor concentration levels were recorded in classrooms that had just been cleaned during the break using detergents. Headaches may occur when concentrations are between 0.8 ppm and 6.64 ppm, while more serious health effects may occur when the concentration exceeds 6.64 ppm (Molhave, 1990).

The various sources of Particulate Matter (PM) pollutants include indoor activities, school equipment such as chalks, cleaning procedures, outdoor traffic, and construction activities. The highest levels of PM_{10} and $PM_{2.5}$ were recorded inside a classroom in the Nafplio area while the teacher and students were writing with chalk on the blackboard during the lesson. In addition, this classroom was located near a central road with heavy traffic in Nafplio, where construction activities were also taking place. The lowest levels of PM_{10} and $PM_{2.5}$ were recorded inside a school building in the Argos area, which was located in a field far from central roads. PM is of particular health concern, especially for children because, when inhaled, it can affect cardiopulmonary function, leading to serious health effects (EPA, 2024).

Conclusions

This study showed a statistically significant difference in temperature, CO_2, NO_2, and VOCs between indoor and outdoor air. There was no statistically significant difference between indoor and outdoor air for relative humidity, CO, PM_{10}, and $PM_{2,5}$. Higher indoor temperatures and relative humidity were recorded in overcrowded classrooms with low ventilation rates. CO was not detected indoors in any of the classrooms. The mean concentration of CO_2 indoors was higher than the outdoor concentration. The large number of students in a classroom, the low ventilation rate, and the intrusion of CO_2 from the external environment may contribute to the indoor concentration levels. The mean concentration of NO_2 indoors was lower than the outdoor concentration. The location of schools near central roads with heavy traffic may influence the NO_2 concentration levels both indoors and outdoors. The mean concentration of VOCs indoors was higher than the mean outdoor concentration. Cleaning detergents, antiseptic liquids, markers, and paints may contribute to elevated indoor VOC levels. To reduce exposure to cleaning chemicals and disinfectants, cleaning in schools should ideally be conducted when the space is unoccupied, and should be completed at least five hours before students and teachers enter the classroom (Zarogianni et al., 2018). The mean levels of PM_{10} and $PM_{2.5}$ indoors were lower than the concentrations in the ambient air. Dust from chalk, the location of the school near streets with heavy traffic, and nearby construction activities may lead to higher indoor concentration levels. Indoor Air Pollution (IAP) is typically a complex mixture of particulate matter and various gaseous components, which can pose potential health risks. IAP composition depends on the sources, emission rates, and ventilation conditions (Hamanaka et al., 2018). It is crucial to identify the sources of indoor air pollution to control and reduce the concentration levels of air pollutants.

Declaration for Human Participants: Approval was granted 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).

Data Availability: The data supporting the findings of this study are available on request from the corresponding author. The data are not publicly available due to restrictions.

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