ESI Preprints **Not Peer-reviewed**

Study of indoor air quality in school buildings in Argolida's Sector at the Region of Peloponnese in Greece and potential Health Risks

Maria Anna Bikaki,
Public Health Inspector-Economist, MSc., PhD candidate
Georgios Dounias, Professor
Olga Cavoura, Assistant Professor
Georgios Farantos, Postdoc fellow
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/esipreprint.7.2024.p111

Approved: 05 July 2024
Posted: 08 July 2024

Cite As:
Bikaki, M. A., Dounias, G., Cavoura, O., Farantos, G., Damikouka, I., & Evrenoglou, L. (2024). *Study of indoor air quality in school buildings in Argolida's Sector at the Region of Peloponnese in Greece and potential Health Risks*. ESI Preprints.
https://doi.org/10.19044/esipreprint.7.2024.p111

Abstract

Aims and scope: Indoor air quality (IAQ) in schools is very important, as students spend more time in school environments besides home. Epidemiological researches have shown that indoor pollutants are associated with several health and respiratory problems. The aim of the present study was to investigate the indoor air quality (IAQ) in school buildings in the Argolida's Sector at the Region of Peloponnese in Greece. **Methods:** The study was conducted in fourteen (14) classrooms in a total of seven (7) school buildings in the Argolida's Sector at the Region of Peloponnese during March 2022 to May 2023. Physical parameters such as temperature (T) and relative humidity (RH) and air pollutants Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen dioxide (NO_2), Volatile Organic Compounds (VOC's), Particulate matters PM (PM_{10}, $PM_{2.5}$) were monitored by the series 500 Portable Air Quality Monitor AeroQual, during (1) teaching hour per day in each classroom. Due to governmental measures

to protect public health against the risk of further spread of COVID-19, some windows and doors in the classrooms were opened during the samplings. **Findings:** Mean temperature and relative humidity inside the classrooms was 22,12 ^{o}C and 50,87% respectively. The overall mean concentrations of air pollutants recorded inside the schools were 691,35ppm CO_2, 0,001ppm NO_2, 9,97ppm VOC'S, 15,7μg/m^3 PM_{10} and 11,4μg/m^3 $PM_{2.5}$. No indoor CO concentration (0 ppm) was detected in all classrooms. In this study: a) in all schools (100%) indoor concentration levels of CO_2 were below 1000ppm, b) in five (5) of fourteen (14) classrooms (35,7%) in the school buildings were detected concentration levels of CO_2 more than 700ppm. In all schools (100%) indoor concentration levels of VOC's were more than 0,8ppm. Eight (8) classrooms (57,1%) in Argolida's school buildings had no comfort conditions, due to the high levels of relative humidity (RH>50%). There was a statistically significant difference for temperature *(p=0,001),* CO_2 *(p<0,001), NO_2 (p=0,006)* and VOC's *(p=0,001)* between indoor and ambient air. **Conclusion:** The air quality in school buildings in the Argolida's Sector was affected by the number of students inside a classroom, the ventilation rate and school's equipment. The location of schools near central roads and construction activities played role on the concentration of indoor air pollutants. Indoor air pollution (IAP) can lead to potential health risks. The development of monitoring systems for measuring indoor pollutants in schools as well as strategies for control and enhancement of IAQ are considered essential for Public Health.

Keywords: Indoor air pollution, school buildings, students, Argolida, health risks

Introduction

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

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

There is evidence of the increased prevalence of asthma and allergies over the recent decades, especially in developed countries, among children (WHO,2007). It has been reported that more than a third of children in Europe has bronchial asthma or allergy (Asher et al., 1998).

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 (VOC's), Particulate Matter (PM), bacteria and molds (Madureira et al., 2009, 2012). Diminished Indoor Air Quality (IAQ) in school buildings can lead to health problems in students and teachers.

The Peloponnese Region is a geographic region in Southern Greece. It borders Western Greece to the north and Attica to the north-east. Argolida is a regional unit, that belongs administratively to the Peloponnese Region and geographically located in the Eastern Peloponnese peninsula. Borders to the north with Corinthia, to the west and south with Arcadia and to the northeast with Attica. It is mainly a semi-mountainous prefecture with a long coastline, however it includes the very productive and densely populated lowland area of the Argolic plain. In 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's city and its largest city is Argos (Wikipedia, 2024).

This study extended previous scientific research for indoor air quality in school buildings in the Central Sector of Athens at the Attica's Region (Bikaki et al, 2024) and focused on recording indoor physical parameters and chemical pollutants in classrooms in different school buildings in the Argolida's Sector that are associated with comfort conditions, potential health risks and comparing the levels of air pollutants between the indoor and ambient air of schools in the Region of Peloponnese.

Methods

The research was conducted in fourteen (14) classrooms from a total of seven (7) school buildings in the areas of municipality of Nafplio and municipality of Argos-Mycenes located in Argolida's Sector at the Region of Peloponnese.

The study was conducted from March 2022 to May 2023. Air quality sampling was conducted from two (2) classrooms for each school during a day from 08:00 to 15:00. Due to governmental measures for students' and teachers' health and safety against COVID-19, some windows and doors in the classrooms were opened during the samplings.

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 appropriate sensors. The scientific equipment, the sampling positions and the criteria for selecting classrooms were the same

with the study was conducted in school buildings in the Central Sector of Athens at the Attica's Region (Bikaki et al, 2024).

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 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 two groups. Results were also validated using nonparametric Mann-Whitney U test.

Results

Temperature (T) and relative humidity (RH) were monitored during one teaching hour in each classroom in school buildings of Argolida. Mean temperature and relative humidity indoors was 22,12 ^{o}C and 50,87% respectively, while outdoors was 23,85 ^{o}C and 48,47% respectively. The lowest indoor temperature was 21 ^{o}C in a classroom of a school in the area of Nafplio. The highest temperature indoors was 24,3 ^{o}C in a school located in the area of Argos, while the outdoor temperature was 24,2 ^{o}C. Due to the 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 the area of Argos as above. In this school the classroom was overcrowded and windows were slightly opened. There was a statistically significant difference for temperature between indoor air and outdoors *(p=0,001)*. There was not a statistically significant difference for relative humidity between indoor air and outdoors *(p=0,070)*. 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 eight (8) classrooms (57,1%) in Argolida's school buildings had no comfort conditions, due to the high levels of relative humidity (RH>50%).

There was not detected CO indoors in all the classrooms. Mean concentration of CO in the ambient air was 0,045ppm.There was not a statistically significant difference for CO between indoor and outdoor air (*p=0,165*).

Mean concentration of CO_2 was recorded at 691,35ppm indoors. The highest concentration of CO_2 was recorded at 823ppm inside an overcrowded classroom in the area of Nafplio, where two windows were slightly opened. Mean concentration of CO_2 in the ambient air was recorded at 423,87ppm, lower level than indoor air. There was a statistically significant difference for CO_2 between indoor and ambient air *(p<0,001)*. In this study: a) in all schools (100%) indoor concentration levels of CO_2 were below 1000ppm, b)

a total number of five (5) classrooms (35,7%) in the school buildings had indoor concentration levels more than 700ppm.

Mean concentration of NO_2 indoors was recorded at 0,001ppm. Concentration levels of NO_2 inside the classrooms were lower than the outdoor concentration levels. The highest concentration of NO_2 was recorded at 0,010ppm inside a classroom in the area of Nafplio. Mean concentration of NO_2 outdoors was recorded at 0,012ppm and the main source could be the traffic in the area of Nafplio. There was a statistically significant difference for NO_2 between indoor air and outdoors *(p=0,006)*.

The Mean concentration of VOC's was 9,97ppm inside the classrooms. The highest concentration of VOC's was recorded at 19,01ppm in a classroom in the area of Nafplio. This classroom had been just cleaned during the break by using detergents and this fact could have contributed to the high level of VOC's. The Mean outdoor concentration level of VOC's was 3,58ppm and was lower than the indoor concentration. There was a statistically significant difference for VOC's between indoor and outdoor air *(p=0,001)*. In this study in all schools (100%) indoor concentration levels of VOC's were more than 0,8ppm.

Mean concentrations of PM_{10}/$PM_{2.5}$ indoors was 15,7 μg/m^3 and 11,4 μg/m^3 respectively. Mean concentrations of PM_{10}/$PM_{2.5}$ outdoors was 20 μg/m^3 and 12,9 μg/m^3 respectively. The highest level of indoor concentration of PM_{10} and $PM_{2.5}$ was recorded at 28 μg/m^3 and 18 μg/m^3 respectively inside a classroom in the area of Nafplio, while teacher and students were writing with chalks on the blackboard during the lesson. In addition, this classroom was located near the central road with a lot of traffic in Nafplio and construction activities on the streets were taking place. The lowest level of PM_{10} and $PM_{2.5}$ indoors was recorded at 7 μg/m^3 and 3 μg/m^3 respectively inside a classroom in the area of Argos. This can be explained by the fact that this school building was located inside a field, far away from central roads. There was not a statistically significant difference for PM_{10} between indoor and outdoor air *(p=0,436)*. There was not a statistically significant difference for $PM_{2,5}$ between indoor air and outdoors *(p=0,494)*.

In the following table (table.1) the concentration levels of physical parameters and air pollutants inside the classrooms of Argolida's Sector are recorded.

	INDOOR LEVELS
Temperature (T)	22,12 ºC
Relative humidity (RH)	50,87%
Carbon dioxide (CO_2)	691,35ppm
Carbon monoxide (CO)	0 ppm
Volatile Organic Compounds (VOC'S)	9,97ppm
Nitrogen dioxide (NO_2)	0,001ppm
Particulate matter PM (PM_{10})	15,7μg/m^3
Particulate matter PM ($PM_{2,5}$)	11,4μg/m^3

Table 1. Concentration levels of indoor pollutants and physical parameters

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

	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)	691,35ppm	423,87ppm	***<0,001***
Carbon monoxide (CO)	0 ppm	0,045ppm	*0,165*
Volatile Organic Compounds (VOC'S)	9,97ppm	3,58ppm	***0,001***
Nitrogen dioxide (NO_2)	0,001ppm	0,012ppm	***0,006***
Particulate matter PM (PM_{10})	15,7μg/m^3	20μg/m^3	*0,436*
Particulate matter PM ($PM_{2,5}$)	11,4μg/m^3	12,9μg/m^3	*0,494*

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

Discussion

According to EPA (2024), Indoor Air Quality (IAQ) is the air quality inside and around buildings that is related with health and comfort conditions of building occupants. Chemical agents, particulate matters, biological factors and physical parameters in school buildings (indoor air pollution) can have negative effects on students' and teachers' health (Argunhan et al. 2018). Higher levels of indoor temperature and relative humidity were recorded at overcrowded classrooms with slightly opened windows. Eight (8) classrooms (57,1%) in the school buildings of Argolida had no comfort conditions, due to the high levels of relative humidity (RH>50%). Thermal conditions inside classrooms are very important for students' health and are associated with the physical parameters (relative humidity and temperature) (Fang et al. 2004).

Sources of CO include unvented kerosene heaters, gas space heaters, leaking chimneys, furnaces, gas water heaters, wood stoves, generators and

other gas-powered equipment, automobile exhaust (Donepudi, et al., 2013). Carbon monoxide (CO) can be detected in the air of the school buildings, due to combustion processes, such as cooking or heating (WHO, 1999). It can also enter inside the classrooms by the ambient air.

In this study no concentration of CO was detected inside the school buildings of Argolida's Sector. Epidemiological researches have shown that CO at low concentrations can affect cardiovascular and neurobehavioral functions and at 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 large number of students and low ventilation rate. In this study a total number of five (5) classrooms (35,7%) in the school buildings had indoor concentration levels of CO_2 more than 700ppm. According to ASHRAE standard, it is recommended that indoor concentration level of CO_2 is below 700ppm for avoiding health risks (ANSI/ASHRAE, 2013). Indoor concentration levels of CO_2 at 3000ppm increases headache intensity, sleepiness, fatigue and concentration difficulty (Zhang et al., 2017).

Indoor concentration levels of Nitrogen dioxide (NO_2) can be influenced by outdoor sources such as combustion processes and traffic. Concentrations inside the school buildings were recorded to be lower than the outdoor levels. The highest concentration of NO_2 was recorded at a school located near the central road of Nafplio. Traffic in the area of Nafplio, may play role on the indoor and outdoor concentration levels of NO_2. Scientific researches have approved that there is an association between NO_2 concentrations in the air and respiratory problems.

Volatile Organic Compounds (VOC's) are gases containing a variety of chemicals. Indoor sources are especially human activities, cleaning products, building materials. Higher indoor concentration levels are recorded in classrooms that have just been cleaned during the break by using detergents. Headaches may occur when concentrations are between 0,8 ppm and 6,64 ppm. More serious health effects may occur when the concentration is greater than 6,64 ppm (Molhave, 1990).

The various sources of PM pollutants are indoor activities, school equipment such as chalks, cleaning procedures, outdoor traffic, construction activities. The highest level of PM_{10} and $PM_{2.5}$ was recorded inside a classroom at the area of Nafplio, while teacher and students were writing with chalks on the blackboard during the lesson. In addition, this classroom was located near the central road with a lot of traffic in Nafplio and construction activities on the streets were taking place. The lowest level of PM_{10} and $PM_{2.5}$ was recorded inside a school building in the area of Argos that was located inside a field, far away from central roads. PM is of particular health concern to humans and children because, as it is sometimes

inhaled, it can affect cardiopulmonary function causing serious health effects (EPA,2024).

Conclusions

This study investigated air quality parameters in fourteen (14) classrooms in seven (7) selected schools in Argolida's Sector at the Region of Peloponnese.

This study showed that was a statistically significant difference for temperature, CO_2, NO_2 and VOC's, between indoor air and outdoors. There was not a statistically significant difference between relative humidity, CO, PM_{10} and $PM_{2,5}$ between indoor and outdoor air. Higher temperatures and relative humidity indoors were recorded inside overcrowded classrooms with low ventilation rate. There was not detected CO indoors in all the classrooms. Mean concentration of CO_2 indoors was higher than the outdoor concentration. The large number of students inside a classroom, the low ventilation rate and the intrusion of CO_2 from external environment may play role in the indoor concentration levels. Mean concentration of NO_2 indoors was lower than the outdoor concentration level. The location of schools near central roads with a lot of traffic may play role on the outdoor and indoor concentration levels of NO_2. The mean concentration of VOC's indoors was higher than the mean concentration outdoors. Cleaning detergents, antiseptic liquids, markers, paints, may contribute to high indoor concentration levels. Mean levels of PM_{10}/$PM_{2.5}$ indoors were lower than concentrations in the ambient air. Dust- chalks, the location of school near streets with a lot of traffic and near construction activities, may lead to higher concentration levels indoors. Indoor Air Pollution (IAP) is normally a complex mixture of particulate and various gaseous components and can lead to potential health risks. IAP compositions depend on sources, emission rates and ventilation conditions (Hamanaka et al., 2018). It is very important to determine the sources of indoor air pollution, in order to control and diminish the concentration levels of air pollutants.

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

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

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

Human Studies: Approval 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).

References:

1. Argunhan, Z., Avci, A.S.(2018). Statistical evaluation of indoor air quality parameters in classrooms of a university. Adv. Merteorol., 4391579.
2. Asher, M.I., Anderson, H.R., Stewart, A.W., Crane, J., Ait-Khaled, N., Anabwani, G., Anderson, H.R., Beasley, R., Bjorksten, B., Burr, M.L., Clayton, T.O., Ellwood, P., Keil, U., Lai, C.K.W., Mallol, J., Martinez, F.D., Mitchell, E.A., Montefort, S., Pearce, N., Robertson, C.F., Shah, J.R, Sibbald, B., Strachan, D.P., von Mutius, E., Weiland, S.K., Wiliams, H.C., ISAAC Steering Committee (1998). Worlwide variations in the prevalence of asthma symptoms: the International Study of Asthma and Allergies in Childhood (ISAAC). Eur. Respir.J. 12 (2). 315-335.
3. Bikaki, M. A., Dounias, G., Farantos, G., Cavoura, O., Damikouka, I., & Evrenoglou, L. (2024). 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, 29, 633.
4. Branco, P.T.B.S., Alvim-Ferraz, M.C.M., Martins, F.G., Sousa, S.I.V. (2014b). The microenvironmental modeling approach to assess children's exprosure to air pollution-a review. Environ. Res. 111, 485-491.
5. Donepudi R., Campagna AC. (2013). Respiratory Effects of Indoor Air Quality. In: Rippe J., ed. Lifestyle Medicine. Boca Raton, FL:CRC Press; 2013:709-718
6. EPA United States Environmental Protection Agency. Indoor Particulate Matter. Available online: https://www.epa.gov/indoor-air-quality-iaq/indoor-particulate-matter (accessed on 18 June 2024).
7. EPA United States Environmental Protection Agency. Introduction to Indoor Air Quality. Available online: https://www.epa.gov/indoor-air-quality-iaq (accessed on 18 June 2024).
8. Fang, L., Clausen, G., Fanger, P.O. (2004). Impact of temperature and humidity on the perception of indoor air quality. Indoor Air, 8, 80-90.
9. Hamanaka, R.B., Mutlu, G.M. (2018). Particulate matter air pollution: Effects on the cardiovascular system. Front. Endocrinol.2018, 9, 680.

10. International Programme on Chemical Safety (1999). Carbon Monoxide, World Health Organization: Geneva, Switzerland.
11. Jones, A.P. (1999). Indoor air quality and health. Atmos, Environ. 33, 4535-4564.
12. Madureira, J., Alvim-Ferraz, M.C.M, Rodrigues, S., Goncalves, C., Azevedo, M.C., Pinto, E., Mayan, O. (2009). Indoor air quality in schools and health symptoms among Portuguese teachers. Hum, Ecol. Risk Assess. 15 (1), 159-169.
13. Madureira, J., Paciencia, I., Oliveira Fernades, E. (2012). Levels and indoor-outdoor relationships of size-specific particulate matter in naturally ventilated Portuguese schools. J.Toxicol. Environ. Health A 75 (22-23), 1423-1436.
14. Molhave, L. (1990). Volatile Organic Compounds, indoor air quality and health. Indoor Air 1990:4:357-76.http://dx.doi.org/10.1111/j.1600-0668.1991.00001.x.
15. Raub, J.A., Mathieu-Nolf, M., Hampson, N.B., Thom, S.R. (2000). Carbon monoxide poisoning-A public health perspective. Toxicology, 145, 1-14.
16. Santamouris, M., Michalakou, G., Patarias, P., Gaitani, N., Sfakianaki, K., Papagralstra, M.(2007). Using Intelligent clustering techniques to classify the energy performance of school buildings. Energy Build 2007;39:45-51. http://dx.doi.org/10.1016/j.enbuild.2006.04.018
17. Saraga, D., Pateraki, S., Papadopoulos, A., Vasilakos, CH., Maggos, Th. (2011). Studying the indoor air quality in three non-residential environments of different use: a museum, a printer industry and an office. Build. Environ. 46, 2333-2341.
18. Sousa, S.I., Ferraz, C., Alvim-Ferraz, M.C., Vaz, L.G., Marques, A.J., Martins, F.G. (2012a). Indoor air pollution on nurseries and primary schools:impact on childhood asthma-study protocol, BMC Public Health 12, 435.
19. Wikipedia: https://en.wikipedia.org/wiki/Argolis (accessed on 16 June 2024)
20. World Health Organization (2007). Global Surveillance, Prevention and Control of Chronic Pespiratory Diseases-a Comprehensive Approach, Geneva.
21. Zhang, X., Wargocki, P., Lian, Z., Thyregold, C. (2017). Effects of exposure to carbon dioxide and bioeffluents on perceived air quality, self assessed acute health symptoms and cognitive performance. Indoor Air, 27, 47-64.