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Original Article

Study of the correlation between indoor air quality in school buildings and children's health problems in Greece

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ABSTRACT

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Introduction: In recent years, air quality studies have focused on the indoor environments of school buildings, since children spend much of their daily time in the classrooms. Evidence indicates that indoor air pollutants can cause health problems to the vulnerable school population. The purpose of this study was to examine the correlation between air quality in school classrooms and students' health.

Methods: The study was conducted in sixty-one (61) classrooms of thirty-three (33) school buildings located in Central Athens within the Attica Region and in the Argolida Sector of the Peloponnese Region in Greece. Students' health in the selected school classrooms was evaluated using anonymous questionnaires completed by the students' parents. Indoor concentrations of chemical air pollutants in the selected classrooms such as carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen dioxide (NO_2), particulate matters (PM_{10}, $PM_{2.5}$), along with temperature (T) and relative humidity (RH), were monitored using the series 500 Portable Air Quality Monitor and used for statistical correlation analysis.

Results: The study showed that there was a statistically significant correlation between indoor CO_2 *($p=0.007$)* and students' performance, indoor VOCs *($p=0.023$)*, $PM_{2.5}$ *($p=0.008$)* and bronchitis, indoor $PM_{2.5}$ *($p=0.002$)* and asthma, indoor PM_{10} *($p=0.002$)*, $PM_{2.5}$ *($p=0.012$)* and migraines in students.

Conclusion: Indoor air pollution was related to students' health problems. Indoor air quality in school buildings is a critical environmental issue, and authorities must implement health policy strategies to minimize air pollutant concentrations in classrooms and protect student health.

Keywords: Health problems, Indoor air pollution, Public health, School children

Introduction

Epidemiological research indicates that indoor air quality is very important and can affect human health, as people spend approximately 90% of their time at home, at school or in educational buildings, or in the workplace.[1]

Outdoor air, building materials, equipment, and human activities may contribute to high indoor air pollution.[2] Over the last decade, studies have focused more on indoor environments because of the harmful effects on human health.[3]

Harmful air pollutants inside buildings include carbon dioxide (CO_2), carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen dioxide (NO_2), particulate matter (PM_{10}, $PM_{2.5}$), and others.[4] It has been reported that the degradation of indoor air quality in buildings can negatively affect human health by causing a wide range of diseases.[5-6] Indoor air quality in schools is critical because students are vulnerable and sensitive to air pollutants. For this reason, monitoring air quality in classrooms within school buildings is essential for protecting public health.[7]

Very few studies have been conducted in recent years regarding indoor air quality in school buildings, especially since the outbreak of the COVID-19 pandemic. The aims of this study were: a) to record the health problems of school children in classrooms of selected schools in the Central Sector of Athens within the Attica Region and in the Argolida Sector of the Peloponnese Region in Greece, b) to investigate the correlations between indoor air quality in school buildings and students' health problems. The findings of this study can help authorities address the critical issue of indoor air quality in school buildings and implement measures to improve student health and protect this vulnerable population.

Methods

The epidemiological environmental survey was carried out as a cross-sectional study from March 2022 to May 2023 in sixty-one (61) classrooms of thirty-three (33) school buildings located in the Central Sector of Athens within the Region of Attica and in the Argolida Sector within the Peloponnese Region in Greece. Some windows and doors were opened during the survey to optimize ventilation, in line with COVID-19 recommendations.

The school visits were conducted after 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). Air quality sampling was conducted in 1 to 3 classrooms per school during a single day, from 08:00 to 15:00. Air pollutants such as CO_2, CO, VOCs, NO_2, PM_{10}, $PM_{2.5}$, along with T and RH, were monitored at 1-minute intervals during one teaching hour per classroom using the series 500 Portable Air Quality Monitor (AeroQual), which enables by the calibrated sensors a real-time surveying of common air pollutants.

Health data regarding school-aged students were obtained using anonymous questionnaires completed at home by the students' parents. Specifically, the first author distributed 1,003 questionnaires in sealed envelopes to students for delivery to their parents. Afterward, they were returned to the school's Principal in sealed envelopes. The final step of the procedure was for the school Principal to return the completed questionnaires for each classroom to the first author.

The questionnaire comprised fifty-one (51) questions consisting of the following parts: a) demographic data (age, gender etc.) b) nutrition habits, c) child's health status and health problems such as hypertension, cardiovascular diseases, respiratory diseases including asthma and allergies, neurological disorders, migraines, sleep disorders, depression, skin irritations, children's performance and behavior, etc.) and d) data about socioeconomic status, attitude and parents' habits. The questionnaires were accompanied by a consent form for the parents.

Statistical correlations were conducted between the air pollutant concentrations recorded by the AeroQual series 500 Portable Air Quality Monitor inside selected classrooms and student health data to evaluate the relationship between indoor pollutants and students' health problems.

Statistical analysis was conducted using IBM SPSS Statistics (SPSS) for Windows, version 29.0.1.0. and MS Excel 2007. Data were validated for normality. Chi-squared test, Pearson's correlation coefficient, and cross-tabulation were used as statistical methods. Results were also validated using the nonparametric Mann-Whitney U test. The statistical significance level was set at 5% ($\alpha = 0.05$).

Results

Of the 1.003 questionnaires distributed, 503 were completed by students' parents/guardians (response rate: 50.14%) and returned in sealed envelopes to the first author. The completed questionnaires concerned 264 male and 239 female students (Figure 1). In addition, 363 children resided in and attended school in the area of Central Athens, while 140 resided in the area of Argolida. The ages of schoolchildren are summarized in Table 1. The majority of the children in the survey were 12 years old (23.5%).

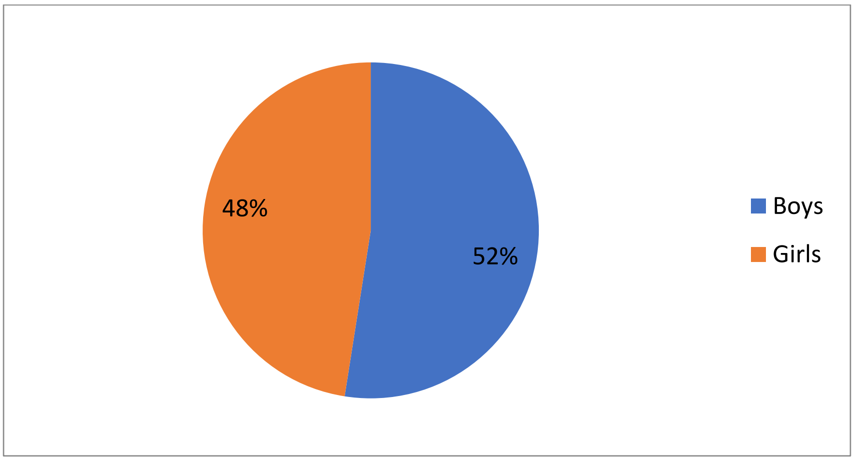

Figure 1: Students' sex in completed questionnaires

Table 1: Students' age in completed questionnaires

Age (years old)	Frequency (N)	%
7	52	10.3%
8	89	17.7%
9	16	3.2%
10	51	10.1%
11	112	22.3%
12	118	23.5%
13	33	6.6%
14	10	2.0%
15	22	4.4%

Most parents who completed the questionnaires had finished tertiary education (67.3%), 23.8% perceived indoor air of school buildings to be polluted, and 51.7% considered atmospheric pollution a major problem worldwide.

Statistical analysis of the questionnaires showed the following results regarding the health status and health problems of schoolchildren in the Central Athens and Argolida areas (Figure 2 and Table 2).

In Central Athens, within the Attica Region, 0.3% of students had hypertension, while no students had hypertension (0%) in the Argolida area within the Peloponnese Region.

Regarding the questionnaire results, 12.4% of students in the Athens area had allergies, while the percentage was lower in Argolida (2.9%).

Schoolchildren experienced bronchitis at a rate of 1.9%, while asthma at 3% in the Athens area. In the Argolida area, no cases of bronchitis or asthma were recorded among children.

23.4% of children in the school population in the Attica Region had difficulty concentrating, while 20.6% exhibited nervousness and hyperactivity. In contrast, children in the Argolida Region showed lower rates, with 8.6% of children experiencing concentration difficulties and 17.9% exhibiting nervousness and hyperactivity.

Regarding student performance, a decline was observed among 0.8% of students in the Attica Region, whereas no such deterioration was recorded in the Argolida Region. Student performance remained unchanged for 12.5% of the student population in the Attica Region, compared to 7.1% in the Argolida Region. Student performance improved for 86.7% of students in Central Athens, while a higher improvement rate of 92.9% was observed in the Argolida area. In the Attica Region, 1.4% of children exhibited neurological symptoms, such as convulsions (0.6%) and speech disorders (0.6%), while in the Argolida Region, no neurological symptoms were observed (0%) among children in the school population. 5% of children in the Athens area experienced migraines, compared to a significantly low rate of 0.7% in the Argolida area. 1.7% of the school population in the Central Sector of Athens showed symptoms of depression, while no children with symptoms of depression appeared in the Argolida Sector, according to the completed questionnaires. Sleep disorders were experienced by 0.8% of children in the school population in the Attica Region, whereas none were observed in the Peloponnese Region (0%). 10.7% of school children in the Attica Region had skin irritation, while in the Peloponnese Region the figure was 8.6%. The school children in both the Attica Region and the Peloponnese Region did not exhibit (0%) cardiovascular diseases or kidney problems, according to the completed questionnaires.

The correlation between students' health problems and concentrations of indoor air pollutants in classrooms where the cases occurred is shown in Table 3.

In the classrooms where children with allergy problems were present, the mean concentrations of indoor air pollutants were: 0.19 ppm CO, 792.93 ppm CO_2, 0.009 ppm NO_2, 11.84 ppm VOCs, 32.44 μg/m3 PM10, and 14.48 μg/m^3 $PM_{2.5}$. There was not a statistically significant correlation between indoor CO ($p=0.426$), CO_2 ($p=0.451$), NO_2 ($p=0.224$), VOCs (p=0.739), PM_{10} (p=0.270), $PM_{2.5}$ (p=0.756) and allergies in students.

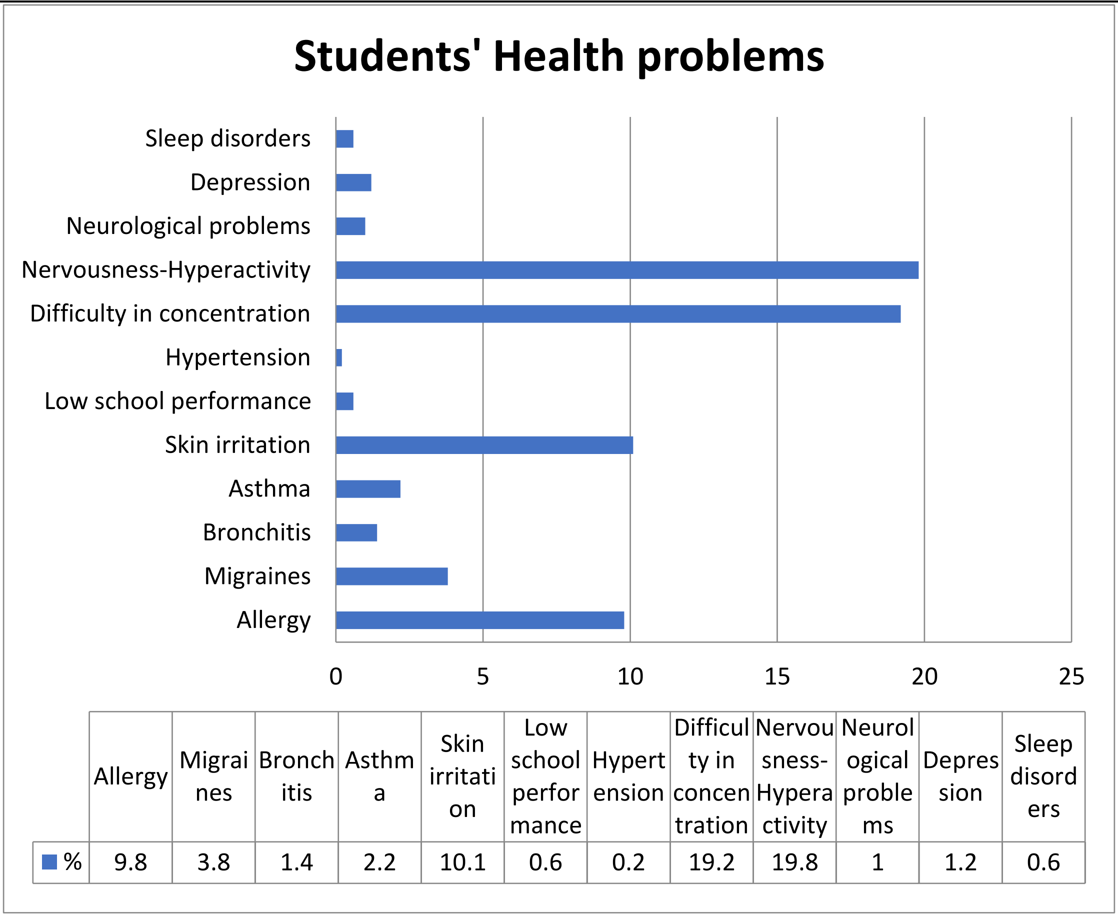

Figure 2: Reported health problems among students in the areas of Central Athens and in the Argolida

Table 2: Comparison of students' health problems between the area of Central Athens and the Argolida area

Students' Health problems	Central Athens (N)	Argolida (N)
Hypertension	1	0
Allergy	45	4
Bronchitis	7	0
Asthma	11	0
Difficulty in concentrating	84	12
Nervousness-hyperactivity	74	25
Problems with school performance	3	0
Neurological problems	5	0
Migraines	18	1
Depression	6	0
Sleep disorders	3	0
Skin irritation	39	12

Notes: *N= number of cases occurred

Bronchitis among students was observed in classrooms with mean concentrations of indoor air pollutants of 0.94 ppm CO, 792.28 ppm CO_2, 0.003 ppm NO_2, 17.01 ppm VOCs, 39.28 μg/m3 PM_{10}, and 19 μg/m³ $PM_{2.5}$. There was not a statistically significant correlation between indoor CO (p=0.053), CO_2 *(p=0.791)*, NO_2 *(p=0.725)*, PM_{10} *(p=0.091)* and bronchitis in students. There was a statistically significant correlation between indoor VOCs *(p=0.023)*, $PM_{2.5}$ *(p=0.008)* and bronchitis in students.

Asthma among students was observed in classrooms with mean concentrations of indoor air pollutants of 0.60 ppm CO, 762 ppm CO2, 0.005 ppm NO_2, 12.08 ppm VOCs, 37.90 μg/m3 PM_{10}, and 18.63 μg/m³ $PM_{2.5}$. There was not a statistically significant correlation between indoor CO (p=0.097), CO_2 *(p=0.772)*, NO_2 *(p=0.911)*, VOCs *(p=0.835)* and PM_{10} *(p=0.073)* and asthma in students. There was a statistically significant correlation between indoor $PM_{2.5}$ and asthma among students (p=0.002).

In classrooms where children with skin irritations were present, the mean concentrations of indoor air pollutants were: 0.19 ppm CO, 772.50 ppm CO_2, 0.005 ppm NO_2, 11.75 ppm VOCs, 30.24 μg/m3 PM10, and 14.14 μg/m³ $PM_{2.5}$. There was not a statistically significant correlation between indoor CO (*p=0.391*), CO_2 (*p=0.869*), NO_2 (*p=0.879*), VOCs (*p*=0.768), PM_{10} (*p*=0.915), $PM_{2.5}$ (*p*=0.802) and skin problems in students.

In the classrooms where students' performance was deteriorating, the indoor T and RH were 26.4°C and 49.8%, respectively. In addition, the mean CO_2 concentration was above 1000 ppm, specifically 1065.67 ppm. There was not a statistically significant correlation between indoor temperature (*p*=0.186), relative humidity (RH) (*p*=0.328) and students' performance. There was a statistically significant correlation between indoor CO_2 *(p=0.007)* and students' performance.

Table 3: Correlation between students' health problems and indoor air pollutants' concentration in classrooms where the cases occurred. Statistically significant correlations are indicated in bold

Students' Health Problems	CO (ppm)	CO_2 (ppm)	NO_2 (ppm)	VOCs (ppm)	PM_{10} (μg/m³)	$PM_{2.5}$ (μg/m³)
Allergy	0.19	792.93	0.009	11.84	32.44	14.48
	p= 0.426	*p=0.451*	*p=0.224*	*p=0.739*	*p=0.270*	*p=0.756*
Migraines	0.43	854.36	0.002	14.23	40.15	16.97
	p=0.100	*p=0.135*	*p=0.453*	*p=0.172*	***p=0.002***	***p=0.012***
Bronchitis	0.94	792.28	0.003	17.01	39.28	19.00
	p=0.053	*p=0.791*	*p=0.725*	***p=0.023***	*p=0.091*	***p=0.008***
Asthma	0.60	762.00	0.005	12.08	37.90	18.63
	p= 0.097	*p=0.772*	*p=0.911*	*p=0.835*	*p=0.073*	***p=0.002***
Skin irritation	0.19	772.50	0.005	11.75	30.24	14.14
	p=0.391	*p=0.869*	*p=0.879*	*p=0.768*	*p=0.915*	*p=0.802*
Low performance	0	1065.67	0.006	12.20	26.66	10.66
		p=0.007	*p=0.859*	*p=0.820*	*p=0.378*	*p=0.252*

Notes:* p<0.05 was statistically significant

Discussion

Epidemiological investigations demonstrate that indoor environments such as homes, workplaces, schools, educational institutions, etc. have a crucial effect on human health.[8] Children are mostly exposed to air pollutants, especially indoors at homes and schools.[9] The concentration of indoor air pollutants is influenced by the ambient air. A number of scientific studies have demonstrated a correlation between indoor and ambient air.[10-14] The concentration of indoor air pollutants may play a significant role on increasing the risk factor for students' health problems.[8] Evidence from previous studies indicates a correlation between the indoor concentration of air pollutants in the classrooms and the onset of health problems in students.[15-16]

In this study, due to government measures to protect the health and safety of students and teachers against COVID-19, some classroom windows and doors were opened during the sampling period. The sampling position within the classrooms was kept away from the ventilation channels to ensure accuracy. Air quality monitoring under these specific conditions provided a realistic representation of students' and staff's actual exposure to indoor air pollutants during natural ventilation in school buildings in Greece.

T and RH are key physical determinants of comfort in classroom indoor environments. For classroom comfort, the Technical Chamber of Greece recommends a maximum temperature of 26 °C and a relative humidity of 50%.[17]

Concentration of CO_2 is also an important indicator of air quality in school buildings, and high concentrations may diminish students' learning ability.[18] In this study, high concentration levels of CO_2 above 1000 ppm were normally recorded in overcrowded classrooms with inadequate natural ventilation. In the classrooms where students' performance was lower, the indoor T and RH were 26.4°C and 49.8%, respectively. Additionally, the mean concentration of CO_2 was 1065.67 ppm, and it was demonstrated that there was a statistically significant correlation between indoor CO_2 ($p=0.007$) and students' performance.

Indoor concentrations of CO normally originate from incomplete combustion of fuels or other organic substances and may affect nervous and cardiovascular system.[19] In this study in all classrooms where students with health problems were recorded, the indoor CO was below 35ppm, the recommended exposure limit (REL).[20]

NO_2 concentration levels in classrooms are often related with outdoor air.[21] Indoor NO_2 exposure can increase respiratory symptoms, allergies and skin irritation.[22-23] Evidence from previous studies indicates that high levels of indoor NO_2 concentrations in schools was associated with the prevalence of asthma and respiratory morbidity.[24-25] In this study the mean concentration of NO_2 inside the classrooms where students with health problems occurred ranged from 0.002ppm to 0.012ppm. There was not a statistically significant correlation between indoor NO_2 and respiratory problems and skin irritation in students.

Furthermore, VOCs are major indoor air pollutants that can harm students' health. The outdoor source of VOCs is ambient air, specifically traffic and industrial emissions.[26-28] According to previous investigations, the indoor sources of VOCs in classrooms include furnishings, building materials, school equipment, and students' activities.[29-30] There is evidence that VOCs concentrations above 6.64 ppm can increase the risk for serious health effects.[31] In this study, there was a statistically significant correlation between indoor VOCs ($p=0.023$) and bronchitis in students. The mean concentration of VOCs in the classrooms where students with bronchitis occurred was high and specifically 17.01 ppm.

Moreover, PM is a crucial indoor pollutant and can cause health problems such as respiratory problems, asthma, allergy, pulmonary diseases, and irritations.[32-33] Several studies have shown that the indoor concentrations of PM originate from outdoor sources (traffic, industries etc.) and indoor sources such as school activities and equipment.[34-36] In this study, asthma among students (2.2%) was recorded in classrooms with mean indoor PM10 and PM2.5 concentrations of 37.90 μg/m3 and 18.63 μg/m3, respectively. There was a statistically significant correlation between indoor $PM_{2.5}$ and asthma among students (p=0.002). Bronchitis (1.4%) among students was observed in classrooms with mean indoor PM_{10} and $PM_{2.5}$ concentrations of 39.28 μg/m^3 and 19 μg/m^3, respectively. There was a statistically significant correlation between indoor $PM_{2.5}$ and bronchitis *(p=0.008)*. Migraines (3.8%) occurred in classrooms where the mean concentration of indoor air pollutants for PM_{10} and $PM_{2.5}$ was 40.15 μg/m^3 and 16.97 μg/m^3 respectively. Additionally, there were statistically significant correlations between indoor PM_{10} (p=0.002) and $PM_{2.5}$ (p=0.012) and migraines among students.

Observed differences in cases, between regions, may underscore profound health inequalities. Quantifying these disparities through specialized indices, such as the Robin Hood Index (RHI), is essential for building a robust case for targeted public health interventions.[37]

The imperative for authorities to implement robust environmental health policy strategies is intrinsically linked to contemporary crisis management methodologies.[38] In the context of school environments, safeguarding student health necessitates the adoption of structured decision-making models by state actors, particularly when navigating public health emergencies or environmental degradation.

In addition, it is imperative to recognize that schools are also primary workplaces for educational personnel. The quality of the indoor environment is, therefore, a fundamental determinant of occupational health and safety (OHS) for teachers and administrative staff. Studies in this field must be conducted in such workplaces as are currently applied in healthcare organizations.[39]

Schools, as critical occupational environments, play a significant role in public health policy. The evidence suggests that structured decision-making models—informed by real-time monitoring of indoor air pollutants are no longer optional administrative tools but essential components of crisis management. Ultimately, aligning school infrastructure with rigorous workplace safety standards provides a dual benefit: it safeguards the physiological development of the student population while ensuring the long-term occupational and social well-being and productivity of the educational workforce.[40]

Present study has certain strength. This study was conducted in 33 school buildings and collected field and health data from 2 regions in Greece. This study is among the first conducted during the challenging period following the COVID-19 pandemic and addresses the relationship between indoor air quality in school buildings and children's health status. Nonetheless, this study has limitations as well. Health data were collected through questionnaires completed by students' parents, which may have introduced reporting bias. Confounding factors were mitigated through randomization and a focus on specific student age groups, which helped reduce selection bias. Despite the limitations, the study focuses on a significant public health issue, uses field data, and makes a valuable contribution by highlighting the importance of school environments for schoolchildren's health. Overall, these findings underscore the critical importance of maintaining high indoor air quality to safeguard student health and maximize academic performance.

Conclusion

Epidemiological studies indicate that exposure to indoor air pollutants in school buildings can lead to health problems among students. Many studies reported higher concentrations of air pollutants in school buildings than in other buildings.

This article presents a study about the indoor air quality in sixty-one (61) classrooms of thirty-three (33) school buildings located in the Central Sector of Athens within the Region of Attica and in the Argolida Sector within the Peloponnese Region in Greece and the correlation between indoor pollutants and health effects in students. This study showed a statistically significant correlation between: a) indoor CO_2 *(p=0.007)* and students' performance, b) indoor VOCs *(p=0.023)* and bronchitis in students, c) indoor $PM_{2.5}$ *(p=0.002)* and asthma in students, d) indoor $PM_{2.5}$ and bronchitis *(p=0.008)* in students, e) indoor PM_{10} *(p=0.002)*, $PM_{2.5}$ *(p=0.012)* and migraines in students.

Indoor air quality studies, particularly in critical workplaces such as schools, are essential in every country. Improving Indoor Air Quality (IAQ) in schools is a critical focus of recent environmental health research, especially following the global emphasis on ventilation, filtration and real-time monitoring of indoor pollutants in classrooms. Authorities can leverage the findings of these studies to effectively enhance the indoor environment of school buildings. Such improvements will ultimately protect and promote the health of both students and school staff.

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