Electronic Journal of General Medicine
2025, 22(2), em632
e-ISSN: 2516-3507
https://www.ejgm.co.uk/

MODESTUM

Review Article

OPEN ACCESS

Quality of indoor air in educational institutions and adverse public health in Europe: A scoping review

Ioannis Pantelis Adamopoulos [1,2*], Niki Fotios Syrou [3], Maad Mijwil [4], Pramila Thapa [5], Guma Ali [6], Lóránt Dénes Dávid [7,8,9]

[1] Department of Environmental Hygiene and Public Health Inspections, Hellenic Republic Region of Attica, Athens, GREECE
[2] Department of Public Health Policy, Sector of Occupational & Environmental Health, School of Public Health, University of West Attica, Athens, GREECE
[3] Department of Physical Education and Sport Science, University of Thessaly, Karies, Trikala, GREECE
[4] College of Administration and Economics, Al-Iraqia University, Baghdad, IRAQ
[5] Life Skills Education Institute Pvt. Ltd., Kathmandu, NEPAL
[6] Department of Computer and Information Science, Faculty of Technoscience, Muni University, Arua, UGANDA
[7] Department of Tourism and Hospitality, Faculty of Economics and Business, John von Neumann University, Kecskemét, HUNGARY
[8] Department of Sustainable Tourism, Institute of Rural Development and Sustainable Economy, Hungarian University of Agriculture and Life Sciences, Gödöllő, HUNGARY
[9] Savaria Department of Business Economics, Savaria University Centre, Faculty of Social Sciences, Eötvös Loránd University; Szombathely, HUNGARY
***Corresponding Author:** adamopoul@gmail.com

Citation: Adamopoulos IP, Syrou NF, Mijwil M, Thapa P, Ali G, Dávid LD. Quality of indoor air in educational institutions and adverse public health in Europe: A scoping review. Electron J Gen Med. 2025;22(2):em632. https://doi.org/10.29333/ejgm/15962

ARTICLE INFO

Received: 18 Dec. 2024

Accepted: 31 Jan. 2025

ABSTRACT

Indoor air quality (IAQ) at educational institutions has emerged as an important public health issue, affecting the health and cognitive performance of school-aged children, students, and faculty alike. This scoping review study seeks to investigate and synthesize current literature on the factors influencing the current state of research on IAQ in educational institutions and its implications for public health. The methodology of this study is the scoping review with the guidelines of preferred reporting items for extension reviews. The technique thoroughly investigated peer-reviewed journals, international organizations, government reports, and case studies on IAQ in educational contexts. Using keywords such as IAQ; educational institutions; public health; Europe, and “adverse health outcomes,” the study’s inclusion and exclusion criteria, as well as the criteria use of quality assessments. The results show that poor IAQ is linked to various public health problems, including respiratory issues and cognitive impairments, especially among vulnerable groups like children and teachers. Inadequate ventilation, volatile organic compounds, mold growth, and external contaminants are all common causes of poor IAQ. Monitoring and management measures are required to improve IAQ in Educational Institutions, encouraging students’ health and academic performance. Policy implications are also important for interdisciplinary approaches addressing this public health concern.

Keywords: educational institutions, public health, Europe, indoor air quality, health outcomes

INTRODUCTION

Assessing indoor air quality (IAQ) in educational institutions is one of the most effective preventive measures to avoid adverse public health effects. It is crucial to prioritize the well-being of individuals within these educational settings, as indoor air pollution has emerged as one of the top five environmental risks to public health worldwide [1]. In recent years, the concern over poor IAQ has grown significantly in Europe, with alarming consequences for the health of its population [2]. Prosecutable cases of indoor air pollution endanger physical health and have profound implications for emotional well-being and behavioral patterns [3, 4]. It is particularly distressing that IAQ issues disproportionately affect vulnerable groups, such as children, pregnant staff, and individuals already grappling with pre-existing health conditions [3, 5]. The impact of IAQ extends beyond these immediate health concerns and permeates into other critical aspects of life [6]. Moreover, the influence of IAQ on the learning and achievement levels of individuals and laboratory animals cannot be overlooked [7]. The educational environment is a hotspot for community infections and chronic exposure to environmental hazards [8]. Hence, it becomes imperative to comprehensively comprehend the direct consequences of IAQ on students’ health, educational capabilities, and occupational performance of the dedicated educational staff. Understanding the adverse implications of IAQ on individual learning highlights the urgency in addressing this issue and emphasizes the need for proactive measures to mitigate its effects [9]. The quality of the air that we breathe indoors, especially in educational institutions, does matter tremendously and directly affects the health and well-being of students and staff, making it crucial to prioritize and improve [10]. Poor air quality within schools can negatively affect the health of the upper respiratory system, cognitive functions, and absenteeism rates [11]. The significant impact air quality has on the well-being of individuals is evident in the data, as schools with lower air quality often experience higher sick leave rates compared to those with better air quality [12]. Unhealthy buildings pose a considerable threat to teachers and students, who spend most of their time inside these structures, thus becoming highly susceptible to physical and psychological factors that can intensify stress levels [13, 14]. The detrimental consequences of poor IAQ can manifest in various ways, affecting the physical health and mental well-being of those within and striving for optimal IAQ to create a conducive environment that fosters learning, growth, and overall vitality [15, 16]. Focus on IAQ extends physical, chemical, and biological pollutants, although these are undoubtedly crucial factors, on specific IAQ components, including but not limited to allergens, cultures, parasitic diseases, unsafe environmental viruses, toxic fungi, volatile organic compounds (VOCs), bacteria, formaldehyde, endotoxins, carbon monoxide (CO), and microscopic fungi [17]. It is equally important to consider room factors contributing to IAQ, such as hydrothermal information and humidity information, among others [18]. Several recent research studies have pointed out that IAQ plays a vital role in the environment in which individuals live, is perceived as indicative of good or bad air quality and denotes positive or negative environmental influences on the population's quality of life and health [10, 19, 20]. IAQ is crucial for health, especially in educational settings. High occupancy rates and varying ventilation standards in European institutions can exacerbate IAQ issues, affecting respiratory, allergies, and cognitive impairments [21]. Throughout Europe, several factors contribute to indoor air pollution in educational buildings, which may result in an imbalance of IAQ relative to outdoor air, negatively impacting students' and educators' health and quality of life [22]. It is appropriate to provide the students with a good classroom environment where the IAQ meets comfort requirements and students' performance is optimal [23, 24]. The scope of this study is to implement effective strategies to enhance IAQ, minimize the constraints imposed on schooling, and unlock the full potential of every student. It is evident that the detrimental effects of IAQ permeate every aspect of educational institutions, encompassing all staff members within educational institutions; adopting preferential actions is the key to safeguarding the health, well-being, and future success of communities. This comprehensive scoping review study aims to provide extensive information and compelling evidence in response to the following key questions. It is vital to highlight that IAQ encompasses a wide range of effects, and despite extensive research and studies, consequences and associations with numerous health problems have to be fully identified. This study aims to identify pollutants affecting IAQ in educational institutions, their health implications, current policies for improvement, and gaps in existing literature for future innovative research.

MATERIALS AND METHODS

Study Design

This scoping review employs the Joanna Briggs Institute (JBI) methodology. It aligns with the guidelines of preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews (PRISMA-ScR) [25]. It actively examines existing literature on IAQ in European educational institutions and its links to adverse public health outcomes.

Information Sources

The search strategy queried electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar, covering studies from their inception to January 2025. The researchers reviewed the references cited in eligible articles to ensure comprehensive coverage and identify missed studies. They manually searched key journals and conference proceedings and accessed gray literature, including reports from government and health organizations, through Google Scholar and institutional repositories.

Search Strategy

Collaborating with an experienced librarian, the researchers developed a comprehensive search strategy. They searched multiple databases, including PubMed, Scopus, Web of Science, and Google Scholar, covering their records from inception to January 2025 and utilized the following search terms: "Indoor air quality" OR "IAQ" AND "Educational institutions" OR "schools" OR "universities" AND "Public health" OR "health outcomes" OR "respiratory health" OR "cognitive impairment" AND "Europe". The researchers combined search terms using the Boolean operators AND and OR and applied filters for publication date and language. The researchers identified grey literature by searching Google Scholar, institutional websites, and European public health agencies. Additionally, they manually screened the reference lists of the included articles to find more relevant studies.

Eligibility Criteria

The eligibility criteria for the scoping review include the following.

Inclusion criteria

The researchers included peer-reviewed studies, reports, and grey literature that met the following criteria:

- Research studies conducted in European educational institutions, e.g., schools, colleges, and universities.
- Research on IAQ parameters, including particulate matter (PM), VOCs, carbon dioxide (CO_2), CO, nitrogen dioxide (NO_2), ozone (O_3), and microbial contaminants.
- Research studies that assessed the health impacts of IAQ on occupants, specifically students and staff.
- Research studies examining health outcomes such as respiratory illnesses, allergies, cognitive impairments, or other adverse public health effects.
- Research studies published in peer-reviewed journals, conference proceedings, and reports and guidelines for international and national organizations.
- The researchers included original research articles, reviews, observational studies (such as cross-sectional, cohort, and case-control), and experimental studies.
- Research studies written in English or with available English translations.
- Research studies were published between January 2020 and January 2025.

Exclusion criteria

The exclusion criteria included:

- Studies conducted outside Europe.
- Research studies written in non-English languages.

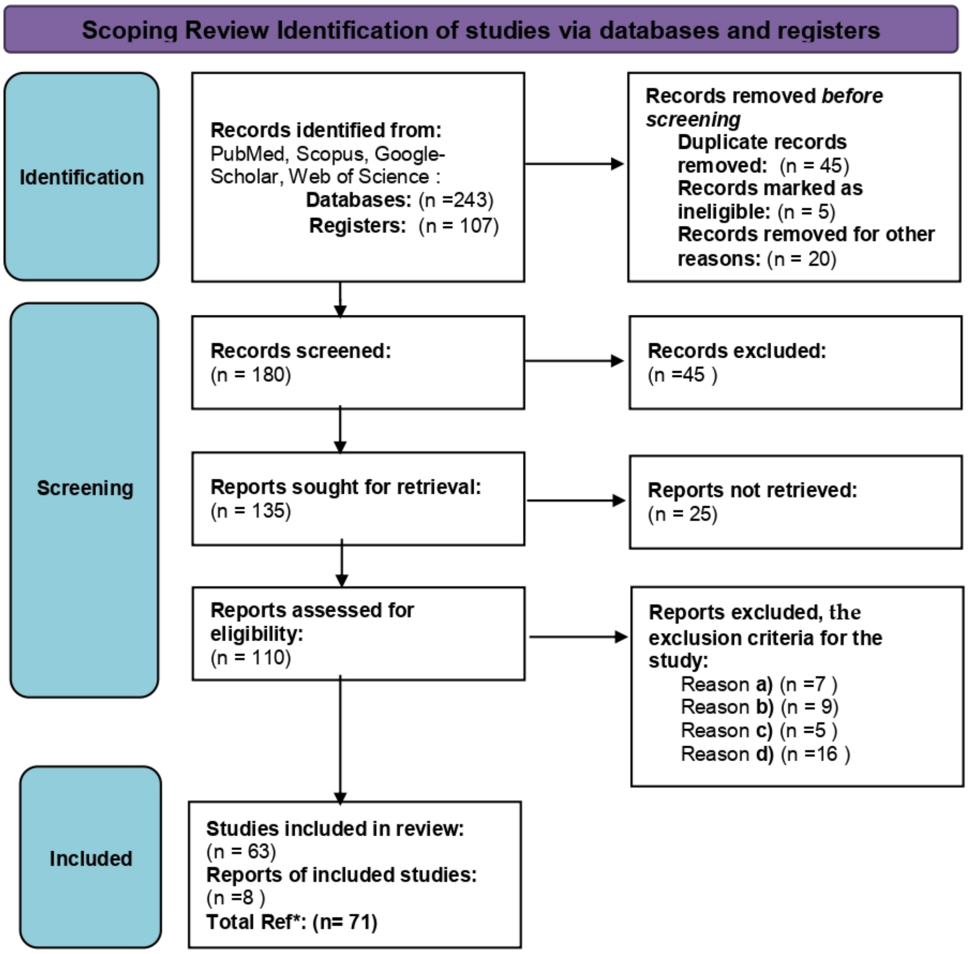

Figure 1. Flow chart diagram of the study PRISMA-ScR (Source: Authors' own elaboration)

- Grey literature, such as policy briefs, conference abstracts, and dissertations, were excluded.
- Research studies that did not provide specific data on IAQ or health outcomes.

Data Screening and Selection

Four reviewers independently screened titles and abstracts to identify potentially relevant studies, and they retrieved full-text articles for studies that met the eligibility criteria. Any reviewer discrepancies were resolved through discussion or by consulting a fifth reviewer. The study selection process follows the PRISMA-ScR guidelines for scoping reviews, and the researchers documented it using a PRISMA-ScR flow diagram, as shown in **Figure 1**, to illustrate the study's flow. The researchers imported all retrieved articles into Mendeley Desktop 1.19.8 for reference management and removed any duplicates.

Data Extraction

The researchers developed and piloted a standardized data extraction form to ensure consistency. The form collects data across six key areas: study characteristics, including authors, publication year, country, and design; population details, such as sample size, age group, and educational setting; IAQ parameters, covering pollutant types, measurement methods, and reported levels; health outcomes, with details on health effects and assessment methods; interventions, when applicable, describing IAQ improvement measures; and key findings and limitations. Four reviewers independently extracted and cross-verified the data for accuracy.

Quality Assessment

Although scoping reviews typically do not require quality appraisal, the researchers assessed the methodological rigor of the included studies using adapted tools from JBI and the Cochrane Collaboration. They classified studies as high, medium, or low quality based on methodology clarity, sample size, representativeness, statistical analysis, and relevance to the research question. This quality assessment did not exclude any studies but offered context for the findings. The researchers evaluated the quality of observational studies using the Newcastle-Ottawa scale, intervention studies with the Cochrane risk of bias tool, and cross-sectional studies with a modified JBI critical appraisal checklist version.

Data Analysis and Synthesis

The researchers performed a descriptive synthesis to summarize the findings from the included studies by grouping IAQ parameters and health outcomes thematically. They tabulated the results, summarizing quantitative data with descriptive statistics and synthesizing qualitative data narratively. They categorized IAQ data by pollutant type and concentration ranges across the studies while grouping health impacts into respiratory, cognitive, and other outcomes. Additionally, they examined trends across countries and educational settings.

Ethical Considerations

Since this study reviewed existing literature, it did not require ethical approval. However, the researchers adhered to ethical guidelines to ensure the accuracy and transparency of the reporting.

Limitations

Publication bias, language restrictions, and the variability in IAQ measurement methods and health outcome assessments limited the review. By using standardized methodologies and prioritizing underrepresented regions, researchers can address these challenges and enhance the reliability of their findings.

RESULTS

Due to the many people they accommodate daily, educational institutions are considered public buildings, and the level of indoor pollutants has important public health implications. Under this subsection, this study has adverse health effects from exposure to them. In light of modern society's concern for physical and cognitive development to ensure prosperity, it becomes crucial for the health of school-age children, students, teachers, and staff of all educational institutions to correlate IAQ with the public health and well-being of specific populations. Poor IAQ can cause regular cases of "sick building syndrome" and increase the incidence of upper respiratory tract infections, allergies, asthma in children, building-related diseases, and even death from long-term exposure to large amounts of pollutants [26]. Children are more vulnerable because they can remove pollutants from their bodies less easily than adults [27, 28]. Another mechanism of indoor irritants on health is their potential effect on the brain, which may interfere with cognitive function or even promote the development of neurological diseases, leading to negative consequences in their education [29]. Regarding PM concentrations, all chemical and physical hazards, including environment-associated risks [30], provided the categorization of measures and averages above from recent literature [31-34].

Table 1 indicates the measurement ranges for the five air quality categories for specific pollutants, the averaging times for each pollutant, the air quality standard average measures from the global organization government, and non-government regulations and guidelines.

The current regulatory approaches to IAQ were conducted, which are multi-faceted across Europe. The investigation considered twenty countries, including all of the member states of the European Union. The conclusion was that legislation in IAQ is fragmented and sometimes lacks proper application and enforcement. Furthermore, limited financial and human resources, including those in educational buildings, often serve as significant barriers to effectively managing IAQ. In educational institutions and for public health services evolving with inspections, IAQ limits have been established not only for tobacco and CO_2 but also for several other air pollutants, such as NO_2, PM_{10}, $PM_{2.5}$, benzene, heavy metals, radon, and Aspergillus fumigatus, and also consider the difficult circumstances of the period during COVID-19 Pandemic [7, 35-43]. Poor IAQ can lead to significant health and economic burdens. Estimates suggest that each allergen may cost between 0.01 and 22 billion Euros. These costs highlight the economic impact of allergens on public health [12, 44]. Studies have linked many asthma-related hospitalizations to environmental factors, showing a direct correlation between healthcare costs and lost productivity [25]. This trend suggests a potentially significant economic impact [1]. To reduce these costs and prevent the onset of IAQ-related health problems, it is important to raise awareness among the population about monitoring environmental parameters and taking precautions not to exceed the pollution threshold value [26].

IAQ Issues in Educational Institutions

a. **Improved ventilation:** *Reduce pollutant levels, improve IAQ, implement mechanical ventilation systems, and promote physical air circulation.*

b. **Regular monitoring:** *Implementing specific IAQ assessments, identifying and mitigating potential hazards, and applying air quality tests to monitor levels of CO_2, PM, VOCs, etc.*

Table 1. Measurement ranges for air quality categories, average times, targets, distinguishing fair, and poor categories

Air pollutants	Average time	Units	Guidelines	Good	Fair	Poor	Very poor	Extremely poor
O_3	0-7 hours	ppm	0.100/0.065	< 0.067 /< 0.043	0.100/0.043	0.150/0.097	0.200/0.130	0.201/ 0.131
NO_2	0-7 hours	ppm	0.080/9.000	< 0.053 /< 6.000	0.053 / 9.0	0.081/13.500	0.121/18.000	0.161/18.100
Sulfur-dioxide	0-1 hours	ppm	0.100	< 0.067	0.067 /0.100	0.101/0.150	0.151-0.200	0.201
https://www.qld.gov.au/environment/management/monitoring/air/air-monitoring/measuring/samplers - pm10PM < 10 µm	0 /23 hours	µg/m3	100/50	< 50/< 25	100/25	100.1-50.1	600-300	300.1-600.1
PM.2.5 < 2.5 µm	0/23 hour	µg/m3	50/25	< 25.0/ < 12.5	12.5 - 50	50.1-100.0	300-150	300.1-150.1
TSP	0/23 hours	µg/m3	250/80	< 125/< 40	125 - 250/40-80	500.0/80.1	1,500.0/160.1	1,500.1/480.1
Visibility	1 hour	Mm-1	235	< 118	118 - 235	236-470	471-1,410	1,411-1,610

c. **Education and training:** *Training educational institution staff on indoor pollutants and best practices for maintaining IAQ management.*

d. **Policy development:** *Governments should establish clear policies, guidelines, and standards for IAQ.*

e. **Community engagement:** *Engaging the community in discussions about IAQ is a collaborative approach to improving educational institutions' environments.*

DISCUSSION

All studies and research findings of varying methodologies, IAQ indicators, monitoring periods, education system stages, classroom occupancy ages, and geographic locations highlight the underlying relationships between IAQ, health, and academic performance [10, 18, 45]. A few studies examining the health impacts of IAQ interventions in schools included follow-up data on health effects and highlighted improved academic achievement [9, 10, 46]. The limitations of the findings are that they are not easily scalable across Europe due to the role of numerous confounding local [8] and school-based factors that are not controlled in observational studies [47, 48]. Results can vary from one school to another, and the data from several studies were characterized by considerable variability [49]. Improved IAQ did not improve health or academic outcomes in the intervention studies [50]. It should be noted that case studies of individual schools were valuable in providing a rich [51], in-depth understanding of the approaches and practices used at a local level and provided recommendations for IAQ interventions based on stakeholders' and practitioners' experiences in the field of IAQ management [52]. Over the last two decades, there has been growing research into concrete issues facing IAQ in schools and associated health concerns, with this subfield even having its conference series [31].

Much of this research has been conducted in North America, Australia, Scandinavia, and Central Europe [10, 53], but there is a good representation of some other Western European countries [19]. The questions addressed range from the health outcomes associated with exposure to specific pollutants and cumulative exposure indices to the physical environmental conditions associated with air quality [53, 54], such as outdoor air exchange rates and the variation of indoor CO_2 concentrations [55]. The vast studies used a mixture of data collection and modeling to assess the air quality [56].

Educational facilities can be places where diverse pollutants and other factors will have a significant impact on IAQ; school-aged children and the staff working within them can be susceptible to some of the harmful effects [18, 26, 57], such as respiratory health symptoms and performance decrement, both potential health outcome factors of ambient concentration [58]. Focus on IAQ within educational institutions, such as schools, colleges, and universities, and review studies that present results only from these environments or most have taken place in North America and Europe [46, 59]. The relevant investigated air quality assessment components, as well as closed environments, such as offices, kindergartens, and civil service buildings, have not been included in the Discussion section of this study. Although most recognized as a problem that predominantly affects students, the poor quality of indoor air can broadly impact society beyond the impact of an educational institution [60]. Long-term exposure to indoor pollutants can raise the chance of acquiring health problems, aggravating pre-existing illnesses, and creating productivity losses [61]. Exposure to chemicals is detrimental to human health, and most acute allergy symptoms are caused by microbiological organisms found inside. Research-portals links provide poor IAQ to the study development of chronic illnesses and an increase in the occurrence of respiratory diseases. Finally, extreme weather events and climate crises increase negative public health issues [61, 62].

Assessing IAQ in European educational institutions is essential for protecting students' and staff's health and well-being. Although comprehensive, up-to-date indexes covering all European countries are scarce, numerous studies and initiatives have offered valuable insights into IAQ in specific regions. The distribution of the European countries' indexes on IAQ in educational institutions in countries that provide statistics and results are folowing:

In **Greece, Athens** conducted a study in Athens central sector, assessing IAQ in 47 classrooms across 26 schools from March 2022 to May 2023. They measured pollutants such as CO_2, CO, VOCs, NO_2, and PM (PM_{10} and $PM_{2.5}$). The study found that 17% of classrooms had CO_2 levels exceeding 1,000 ppm, and all schools had VOC concentrations above the 0.8 ppm indoor limit. The results stress the urgent need to improve ventilation and manage air quality in Greek schools [63].

In **Croatia**, the Croatian Academic Research Network partnered with Smart Sense to improve IAQ in more than 400 schools. As part of the "e-Schools" initiative, the project involved installing sensees IAQ Sensors to monitor CO_2 levels, temperature, and humidity continuously. By collecting real-time data, the initiative aimed to foster healthier learning environments and enhance student performance by providing actionable insights on air quality[64].

In **England UK, London** researchers assessed IAQ in a higher education building in the UK, focusing on CO_2, NO_2, $PM_{2.5}$, and SARS-CoV-2 levels. They explored various strategies to enhance IAQ, such as increasing ventilation, utilizing background ventilation, improving airflow through open doors, and using HEPA air purifiers. The results emphasized the critical role of background ventilation and open doors in lowering CO_2 concentrations and demonstrated the effectiveness of air purifiers in reducing particle and biological contaminants[65].

In **Scotland, the UK** conducted a study examining how environmental variables and thermal sensation influenced students' perceptions of IAQ in naturally ventilated primary schools. The study revealed that students' air sensation ratings were more strongly linked to CO_2 levels than operative temperatures during non-heating seasons. It was also found that keeping CO_2 levels below 1,000 ppm and maintaining operative temperatures within students' thermal comfort range could enhance their IAQ perceptions by 43% [66].

In **Spain** the Polytechnic University of Catalonia launched the Qaire project to monitor and optimize IAQ across its campus. Using the Dexma Platform, the project centralized data from various sensors to enable real-time CO_2 levels and other environmental factors monitoring. This initiative aimed to enhance IAQ and energy management, creating a healthier environment for students and staff [67].

In **Finland**, a Finnish study examined IAQ in six comprehensive school buildings, comparing schools with IAQ complaints to those without. The research revealed higher concentrations of airborne cultivable microbes and specific fungal strains in schools with reported IAQ issues. The study highlighted that undetected or unresolved moisture or mold problems could contribute to these IAQ concerns [68].

Finally, an important issue to refer to is the Air pollution from African dust is negatively correlated with climate change because of its important impact in trapping heat in the atmosphere and generating heat-related illnesses, cardiovascular disorders, and respiratory ailments [69]. Associated with health risks from extreme weather events of the climate crisis [62], and climate change and adverse public health impacts on human health [70], an important role correlated with the health of the students and employees is stress management in educational institutions [71].

Limitations of the Study and Future Research

The implications of inadequate IAQ in educational institutions go beyond individual health outcomes. Poor IAQ can raise healthcare costs, impair productivity, and lower academic achievement, ultimately affecting society. Addressing IAQ in schools is vital for protecting kids' and staff's health and well-being. Numerous gaps exist due to the rising quantity of research on IAQ in educational institutions. More longitudinal studies are required to examine the long-term health impacts of low IAQ on children. Furthermore, research on the efficacy of various strategies to promote IAQ in educational institutions and schools is scarce. Future research should concentrate on producing evidence-based guidelines for schools to implement to improve IAQ and preserve student health.

CONCLUSIONS

This study offered an overview of ongoing concerns with IAQ in European educational institutions. The review indicates that many European children, students, and staff at educational institutions are exposed to inferior IAQ in buildings, and various health consequences are associated with the detrimental influence on academic performance. Even while some restrictions and recommendations are in place, they may not protect this population's health, particularly for air contaminants with co-toxicity effects. The present study and recommendations for interior air quality are based on European standards, with outdoor input most typically utilized to establish criteria for indoor air policies. A new set of IAQ indices and a new European air quality monitoring foundation are required to evaluate health parameters and improve teaching quality. Furthermore, policymakers encourage European member countries to take an integrated approach to nationwide cross-sectoral strategies that address health, education, and pollution. Harmonized research across Europe, in addition to utilizing research infrastructure and open data in information technology to provide a comprehensive solution for IAQ in educational institutions, regaining regulation from harmful indoor settings that require the public health's citizens' protection.

Author contributions: IPA, NFS, MM, PT, GA, & LDD: writing–original draft preparation; **IPA, NFS, MM, GA, & LDD:** writing–review and editing; **IPA, NFS, MM, & GA:** formal analysis and data curation; **IPA, NFS, & MM:** software; **IPA, NFS, & PT:** resources; **IPA, NFS, & GA:** visualization; **IPA, NFS, & LDD:** methodology and investigation; **IPA & NFS:** conceptualization; **IPA, PT, & GA:** validation; & **IPA:** supervision, project administration, and funding acquisition. All authors have agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that ethical approval of the research was carried out in accordance with the rules and current bioethics legislation, all the conditions and specifications of the national and European Union legislation for the protection of personal data as well as in accordance with the instructions of the quality assurance and the study was carried out according to the Declaration of Helsinki.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

1. Van Tran V, Park D, Lee Y-C. Indoor air pollution, related human diseases, and recent trends in the control and improvement of indoor air quality. Int J Environ Res Public Health. 2020;17(8):2927. https://doi.org/10.3390/ijerph17082927 PMid:32340311 PMCid:PMC7215772
2. González-Martín J, Kraakman NJR, Pérez C, Lebrero R, Muñoz R. A state-of-the-art review on indoor air pollution and strategies for indoor air pollution control. Chemosphere. 2021;262:128376. https://doi.org/10.1016/j.chemosphere.2020.128376 PMid:33182138
3. Yue X, Ma NL, Sonne C, et al. Mitigation of indoor air pollution: A review of recent advances in adsorption materials and catalytic oxidation. J Hazard Mater. 2021;405:124138. https://doi.org/10.1016/j.jhazmat.2020.124138 PMid:33092884
4. Manisalidis I, Stavropoulou E, Stavropoulos A, Bezirtzoglou E. Environmental and health impacts of air pollution: A review. Front Public Health. 2020;8:14. https://doi.org/10.3389/fpubh.2020.00014 PMid:32154200 PMCid: PMC7044178
5. Naclerio R, Ansotegui IJ, Bousquet J, et al. International expert consensus on the management of allergic rhinitis (AR) aggravated by air pollutants: Impact of air pollution on patients with AR: Current knowledge and future strategies. World Allergy Organ J. 2020;13(3):100106. https://doi.org/10.1016/j.waojou.2020.100106 PMid:32256939 PMCid: PMC7132263
6. Anjum MS, Ali SM, Subhani MA, et al. An emerged challenge of air pollution and ever-increasing particulate matter in Pakistan; a critical review. J Hazard Mater. 2021;402: 123943. https://doi.org/10.1016/j.jhazmat.2020.123943 PMid:33254830
7. Vasiljevic T, Harner T. Bisphenol A and its analogues in outdoor and indoor air: Properties, sources and global levels. Sci Total Environ. 2021;789:148013. https://doi.org/10.1016/j.scitotenv.2021.148013 PMid:34323825
8. Dimitroulopoulou S, Dudzińska MR, Gunnarsen L, et al. Indoor air quality guidelines from across the world: An appraisal considering energy saving, health, productivity, and comfort. Environ Int. 2023;178:108127. https://doi.org/10.1016/j.envint.2023.108127 PMid:37544267
9. Sridharan S, Kumar M, Singh L, Bolan NS, Saha M. Microplastics as an emerging source of particulate air pollution: A critical review. J Hazard Mater. 2021;418: 126245. https://doi.org/10.1016/j.jhazmat.2021.126245 PMid:34111744

10. Sadrizadeh S, Yao R, Yuan F, et al. Indoor air quality and health in schools: A critical review for developing the roadmap for the future school environment. J Build Eng. 2022;57:104908. https://doi.org/10.1016/j.jobe.2022.104908
11. Wargocki P, Porras-Salazar JA, Contreras-Espinoza S, Bahnfleth W. The relationships between classroom air quality and children's performance in school. Build Environ. 2020;173:106749. https://doi.org/10.1016/j.buildenv.2020.106749
12. Awada M, Becerik-Gerber B, Hoque S, et al. Ten questions concerning occupant health in buildings during normal operations and extreme events including the COVID-19 pandemic. Build Environ. 2021;188:107480. https://doi.org/10.1016/j.buildenv.2020.107480 PMid:36570375 PMCid:PMC9759512
13. Aguilar-Gomez S, Dwyer H, Graff Zivin J, Neidell M. This is air: The "nonhealth" effects of air pollution. Annu Rev Resour Econ. 2022;14(1):403-25. https://doi.org/10.1146/annurev-resource-111820-021816
14. Maung TZ, Bishop JE, Holt E, Turner AM, Pfrang C. Indoor air pollution and the health of vulnerable groups: A systematic review focused on particulate matter (PM), volatile organic compounds (VOCs) and their effects on children and people with pre-existing lung disease. Int J Environ Res Public Health. 2022;19(14):8752. https://doi.org/10.3390/ijerph19148752 PMid:35886604 PMCid:PMC9316830
15. Baloch RM, Maesano CN, Christoffersen J, et al. Indoor air pollution, physical and comfort parameters related to schoolchildren's health: Data from the European SINPHONIE study. Sci Total Environ. 2020;739:139870. https://doi.org/10.1016/j.scitotenv.2020.139870 PMid:32544681
16. Brumberg HL, Karr CJ, Council on Environmental Health. Ambient air pollution: Health hazards to children. Pediatrics. 2021;147(6):e2021051484.
17. UK Air. Short-term effects of air pollution on health. UK Air; 2024. Available at: https://uk-air.defra.gov.uk/air-pollution/effects?view=short-term (Accessed: 17 December 2024).
18. Astuti RDP. Poor indoor air quality impacts in industrial and non-industrial workplace to human health: The recent trends and control strategies. In: Health effects of indoor air pollution. Cambridge (MA): Academic Press; 2024. p. 101-37. https://doi.org/10.1016/B978-0-443-16090-5.00001-5
19. Rosário Filho NA, Urrutia-Pereira M, D'Amato G, et al. Air pollution and indoor settings. World Allergy Organ J. 2021;14(1):100499. https://doi.org/10.1016/j.waojou.2020.100499 PMid:33510831 PMCid:PMC7806792
20. Pulimeno M, Piscitelli P, Colazzo S, Colao A, Miani A. Indoor air quality at school and students' performance: Recommendations of the UNESCO Chair on Health Education and Sustainable Development & the Italian Society of Environmental Medicine (SIMA). Health Promot Perspect. 2020;10(3):169-74. https://doi.org/10.34172/hpp.2020.29 PMid:32802752 PMCid:PMC7420173
21. Kumar P, Singh AB, Arora T, Singh S, Singh R. Critical review on emerging health effects associated with the indoor air quality and its sustainable management. Sci Total Environ. 2023;872:162163. https://doi.org/10.1016/j.scitotenv.2023.162163 PMid:36781134
22. Szabados M, Csákó Z, Kotlík B, et al. Indoor air quality and the associated health risk in primary school buildings in Central Europe–The InAirQ study. Indoor Air. 2021;31(4):989-1003. https://doi.org/10.1111/ina.12802 PMid:33615561
23. Abhijith KV, Kukadia V, Kumar P. Investigation of air pollution mitigation measures, ventilation, and indoor air quality at three schools in London. Atmos Environ. 2022;289:119303. https://doi.org/10.1016/j.atmosenv.2022.119303
24. Raju S, Siddharthan T, McCormack MC. Indoor air pollution and respiratory health. Clin Chest Med. 2020;41(4):825-43. https://doi.org/10.1016/j.ccm.2020.08.014 PMid:33153698 PMCid:PMC7665158
25. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. https://doi.org/10.1136/bmj.n71 PMid:33782057 PMCid:PMC8005924
26. WHO. Considerations for school-related public health measures in the context of COVID-19. World health Organization; 2020. Available at: https://www.who.int/publications/i/item/considerations-for-school-related-public-health-measures-in-the-context-of-covid-19 (Accessed: 17 December 2024).
27. Loaiza-Ceballos MC, Marin-Palma D, Zapata W, Hernandez JC. Viral respiratory infections and air pollutants. Air Qual Atmos Health. 2022;15:105-14. https://doi.org/10.1007/s11869-021-01088-6 PMid:34539932 PMCid:PMC8441953
28. Domingo JL, Rovira J. Effects of air pollutants on the transmission and severity of respiratory viral infections. Environ Res. 2020;187:109650. https://doi.org/10.1016/j.envres.2020.109650 PMid:32416357 PMCid:PMC7211639
29. Ali MU, Yu Y, Yousaf B, et al. Health impacts of indoor air pollution from household solid fuel on children and women. J Hazard Mater. 2021;416:126127. https://doi.org/10.1016/j.jhazmat.2021.126127 PMid:34492921
30. Domínguez-Amarillo S, Fernández-Agüera J, Cesteros-García S, González-Lezcano RA. Bad air can also kill: Residential indoor air quality and pollutant exposure risk during the COVID-19 crisis. Int J Environ Res Public Health. 2020;17(19):7183. https://doi.org/10.3390/ijerph17197183 PMid:33008116 PMCid:PMC7578999
31. Cilluffo G, Ferrante G, Fasola S, et al. Association between asthma control and exposure to greenness and other outdoor and indoor environmental factors: A longitudinal study on a cohort of asthmatic children. Int J Environ Res Public Health. 2022;19(1):512. https://doi.org/10.3390/ijerph19010512 PMid:35010773 PMCid:PMC8744738
32. Ielpo P, Mangia C, de Gennaro G, et al. Air quality assessment of a school in an industrialized area of southern Italy. ApplSci. 2021;11(19):8870. https://doi.org/10.3390/app11198870
33. Lucialli P, Marinello S, Pollini E, et al. Indoor and outdoor concentrations of benzene, toluene, ethylbenzene and xylene in some Italian schools evaluation of areas with different air pollution. Atmos Pollut Res. 2020;11(11):1998-2010. https://doi.org/10.1016/j.apr.2020.08.007
34. Zammit C, Bilocca D, Ruggieri S, et al. Association between the concentration and the elemental composition of outdoor PM2. 5 and respiratory diseases in schoolchildren: A multicenter study in the mediterranean area. Atmos. 2020;11(12):1290. https://doi.org/10.3390/atmos11121290

35. Langiano E, Ferrara M, Falese L, et al. Assessment of indoor air quality in school facilities: An educational experience of pathways for transversal skills and orientation (PCTO). Sustainability. 2024;16(15):6612. https://doi.org/10.3390/su16156612
36. Ortiz M, Itard L, Bluyssen PM. Indoor environmental quality related risk factors with energy-efficient retrofitting of housing: A literature review. Energy Build. 2020;221:110102. https://doi.org/10.1016/j.enbuild.2020.110102
37. Kumar P, Kausar MA, Singh AB, Singh R. Biological contaminants in the indoor air environment and their impacts on human health. Air Qual Atmos Health. 2021;14(11):1723-36. https://doi.org/10.1007/s11869-021-00978-z PMid:34394766 PMCid:PMC8346343
38. Elsaid AM, Ahmed MS. Indoor air quality strategies for air-conditioning and ventilation systems with the spread of the global coronavirus (COVID-19) epidemic: Improvements and recommendations. Environ Res. 2021;199:111314. https://doi.org/10.1016/j.envres.2021.111314 PMid:34048748 PMCid:PMC8146370
39. Torres-Agullo A, Karanasiou A, Moreno T, Lacorte S. Overview on the occurrence of microplastics in air and implications from the use of face masks during the COVID-19 pandemic. Sci Total Environ. 2021;800:149555. https://doi.org/10.1016/j.scitotenv.2021.149555 PMid:34426330 PMCid:PMC8520475
40. Halios CH, Landeg-Cox C, Lowther SD, Middleton A, Marczylo T, Dimitroulopoulou S. Chemicals in European residences–Part I: A review of emissions, concentrations and health effects of volatile organic compounds (VOCs). Sci Total Environ. 2022;839:156201. https://doi.org/10.1016/j.scitotenv.2022.156201 PMid:35623519
41. Chojer H, Branco PT, Martins FG, Alvim-Ferraz MC, Sousa SI. Development of low-cost indoor air quality monitoring devices: Recent advancements. Sci Total Environ. 2020;727:138385. https://doi.org/10.1016/j.scitotenv.2020.138385 PMid:32498203
42. Adamopoulos IP, Syrou NF, Lamnisos D, Boustras G. Cross-sectional nationwide study in occupational safety & health: Inspection of job risks context, burn out syndrome and job satisfaction of public health Inspectors in the period of the COVID-19 pandemic in Greece. Saf Sci. 2023;158:1-10. https://doi.org/10.1016/j.ssci.2022.105960
43. Adamopoulos IP, Lamnisos D, Syrou NF, Boustras G. Public health and work safety pilot study: Inspection of job risks, burn out syndrome and job satisfaction of public health inspectors in Greece. Saf Sci. 2022;147:105592. https://doi.org/10.1016/j.ssci.2021.105592
44. Squizzato R, da Silva I, Moreira CA, et al. Indoor and outdoor airborne particles concentrations and their relations with respiratory symptoms in volunteers from the education sector. Rev Bras Geogr Fís. 2022;15(2):670-81. https://doi.org/10.26848/rbgf.v15.2.p670-681
45. Marchetti P, Miotti J, Locatelli F, et al. Long-term residential exposure to air pollution and risk of chronic respiratory diseases in Italy: The BIGEPI study. Sci Total Environ 2023;884:163802. https://doi.org/10.1016/j.scitotenv.2023.163802 PMid:37127163
46. Giusti L, Mammarella S, Salza A, et al. Predictors of academic performance during the COVID-19 outbreak: Impact of distance education on mental health, social cognition and memory abilities in an Italian university student sample. BMC Psychol. 2021;9(1):142. https://doi.org/10.1186/s40359-021-00649-9 PMid:34526153 PMCid:PMC8441245
47. Settimo G, Manigrasso M, Avino P. Indoor air quality: A focus on the European legislation and state-of-the-art research in Italy. Atmos. 2020;11(4):370. https://doi.org/10.3390/atmos11040370
48. Young BN, Benka-Coker WO, Weller ZD, Oliver S, Schaeffer JW, Magzamen S. How does absenteeism impact the link between school's indoor environmental quality and student performance? Build Environ. 2021;203:108053. https://doi.org/10.1016/j.buildenv.2021.108053
49. Korsavi SS, Montazami A, Mumovic D. Indoor air quality (IAQ) in naturally-ventilated primary schools in the UK: Occupant-related factors. Build Environ. 2020;180:106992. https://doi.org/10.1016/j.buildenv.2020.106992
50. Jia L-R, Han J, Chen X, Li Q-Y, Lee C-C, Fung Y-H. Interaction between thermal comfort, indoor air quality and ventilation energy consumption of educational buildings: A comprehensive review. Build. 2021; 11(12):591. https://doi.org/10.3390/buildings11120591
51. Wu X, Nethery RC, Sabath MB, Braun D et al. Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study. medRxiv. 2020;2020.04.05.20054502. https://doi.org/10.1289/isee.2020.virtual.O-OS-638
52. Ma N, Aviv D, Guo H, Braham WW. Measuring the right factors: A review of variables and models for thermal comfort and indoor air quality. Renew Sustain Energy Rev. 2021;135:110436. https://doi.org/10.1016/j.rser.2020.110436
53. Azuma K, Yanagi U, Kagi N, Kim H, Ogata M, Hayashi M. Environmental factors involved in SARS-CoV-2 transmission: Effect and role of indoor environmental quality in the strategy for COVID-19 infection control. Environ Health Prev Med. 2020;25:66. https://doi.org/10.1186/s12199-020-00904-2 PMid:33143660 PMCid:PMC7607900
54. Turner MC, Andersen ZJ, Baccarelli A, et al. Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. CA Cancer J Clin. 2020;70(6):460-79. https://doi.org/10.3322/caac.21632 PMid:32964460 PMCid:PMC7904962
55. Morawska L, Allen J, Bahnfleth W, et al. A paradigm shift to combat indoor respiratory infection. Science. 2021;372(6543):689-91. https://doi.org/10.1126/science.abg2025 PMid:33986171
56. Vardoulakis S, Giagloglou E, Steinle S, et al. Indoor exposure to selected air pollutants in the home environment: A systematic review. Int J Environ Res Public Health. 2020;17(23):8972. https://doi.org/10.3390/ijerph17238972 PMid:33276576 PMCid:PMC7729884
57. Becerra JA, Lizana J, Gil M, Barrios-Padura A, Blondeau P, Chacartegui R. Identification of potential indoor air pollutants in schools. J Clean Prod. 2020;242:118420. https://doi.org/10.1016/j.jclepro.2019.118420

58. Charres I, Lucarelli F, Feliciano M, Furst L, Alves C. Seasonal variations of size-classified aerosol-bound elements in school environments and risk factors for the prevalence of atopic diseases among pupils. Build Environ. 2024;265: 111949. https://doi.org/10.1016/j.buildenv.2024.111949
59. Strak M, Weinmayr G, Rodopoulou S, et al. Long term exposure to low level air pollution and mortality in eight European cohorts within the ELAPSE project: Pooled analysis. BMJ. 2021;374:n1904.
60. O'Dell K, Hornbrook RS, Permar W, et al. Hazardous air pollutants in fresh and aged western US wildfire smoke and implications for long-term exposure. Environ Sci Technol. 2020;54(19):11838-47. https://doi.org/10.1021/acs.est.0c04497 PMid:32857515
61. Ali N, Islam F. The effects of air pollution on COVID-19 infection and mortality–A review on recent evidence. Front Public Health. 2020;8:580057. https://doi.org/10.3389/fpubh.2020.580057 PMid:33324598 PMCid:PMC7725793
62. Adamopoulos IP, Frantzana A, Syrou NF. Climate crises associated with epidemiological, environmental, and ecosystem effects of a storm: Flooding, landslides, and damage to urban and rural areas (extreme weather events of storm Daniel in Thessaly Greece). Med Sci Forum. 2024;25(1):7. https://doi.org/10.3390/msf2024025007
63. Bikaki MA, Dounias G, Farantos G, Cavoura O, Damikouka I, Evrenoglou L. Indoor air quality in selected school buildings in the Central Sector of Athens at the Attica's Region and potential health risks. Eur Sci J. 2024;21(37): 633-45. https://doi.org/10.19044/esj.2025.v21n37p54
64. Prpić J. Transforming Croatian schools with indoor air quality monitoring. MySensees; 2024. Available at: https://mysensees.com/case-studies/transforming-croatian-schools-with-indoor-air-quality-monitoring/?utm_source=chatgpt.com (Accessed: 17 December 2024).
65. Abbaspour A, Bahadori-Jahromi A, Amirkhani S, et al. Multi-zonal analysis of indoor air quality in a higher educational building in the UK. Sustainability. 2023;15(16):12118. https://doi.org/10.3390/su151612118
66. Korsavi SS, Montazami A, Mumovic D. Perceived indoor air quality in naturally ventilated primary schools in the UK: Impact of environmental variables and thermal sensation. Indoor Air. 2020;31(2):480-501. https://doi.org/10.1111/ina.12740 PMid:32893905
67. Vornanen-Winqvist C, Järvi K, Andersson MA, et al. Exposure to indoor air contaminants in school buildings with and without reported indoor air quality problems. Environ Int. 2020;141:105781. https://doi.org/10.1016/j.envint.2020.105781 PMid:32417615
68. Papilloud L. Indoor air quality management in universities Spacewell Energy (Dexma); 2023. Available at: https://www.dexma.com/blog-en/indoor-air-quality-management-in-universities-case-study/?utm_source=chatgpt.com (Accessed: 17 December 2024).
69. Adamopoulos IP, Syrou NF. Climate change, air pollution, African dust impacts on public health and sustainability in Europe. Eur J Public Health. 2024;34(Supplement_3):ckae144.1374. https://doi.org/10.1093/eurpub/ckae144.1374 PMCid:PMC11517644
70. Adamopoulos IP, Frantzana A, Adamopoulou J, Syrou NF. Climate change and adverse public health impacts on human health and water resources. Environ Sci Proc. 2023;26(1):178. https://doi.org/10.3390/environsciproc2023026178
71. Khan AJJ, Yar S, Fayyaz S, Adamopoulos I, Syrou NF, Jahangir A. From pressure to performance, and health risks control: Occupational stress management and employee engagement in higher education. Preprints. 2024;2024121329. https://doi.org/10.20944/preprints202412.1329.v1