



Development of novel assessments for indoor air quality monitoring and impact on children's health

Breathe Better, LEARN Better

POLICY RECOMMENDATIONS FOR INDOOR
AIRQUALITY IN SCHOOLS



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Introduction

Indoor air quality (IAQ) plays a significant role in health and wellbeing. This is particularly relevant for children, who often spend a large proportion of their time indoors either at home or at school. As many children will spend their daily lives in a school setting, it is important to consider the quality of the air that they breathe there. Studies have shown that poor indoor air quality can harm children's health and their cognitive development, so it is important to address the IAQ of schools.¹ As children are still developing and growing, poor air quality can result in complications that impact their lives not only immediately, but also later in life, including conditions such as asthma or impaired cognitive development.

School Cohorts in LEARN

LEARN's multi-country study evaluated the impact of air purification on primary school children across Belgium (Flanders), Denmark (Municipality of Aarhus), and Greece (Thessaloniki). By utilizing a single-blinded crossover design, the research included around 450 children from the 4th to 6th grades. All participants provided assent, and parental consent was obtained. Participants had sufficient language proficiency for completing the required assessments.

The study began with a baseline assessment where children's blood pressure was recorded, and two practice rounds of cognitive testing were performed to ensure familiarity with the tasks. Following each intervention phase involving the use of an air purifier (with or without filter), researchers collected a comprehensive battery of measurements, including clinical health indicators and cognitive performance tests. To further assess internal pollutant exposure, the Belgian and Danish sites collected urine samples, while the Belgian site also included blood sampling for a more detailed biological analysis.

Indoor air quality Measurement

In LEARN, indoor air quality was comprehensively evaluated in schools by measuring physical and chemical factors such as particles (e.g., PM_{2.5}, PM₁₀, and ultrafine particles (<100 nm)), volatile organic compounds (VOCs), aldehydes, and polycyclic aromatic hydrocarbons (PAHs), as well as microclimate parameters (e.g. temperature, CO₂, relative humidity). Combining continuous, real time sensors with active and passive air samplers to monitor the children-occupied classrooms allowed capture of exposure dynamics under a crossover study design (using a fully functional air purifier and a filterless simulated air purifier, respectively).

¹ <https://www.eea.europa.eu/en/analysis/publications/air-pollution-and-childrens-health>, <https://pmc.ncbi.nlm.nih.gov/articles/PMC7665158/>, <https://www.niehs.nih.gov/health/topics/agents/indoor-air>, Int. J. Environ. Res. Public Health 2022, 19(14), 8752; <https://doi.org/10.3390/ijerph19148752>

Monitoring these specific factors can provide policymakers and stakeholders with crucial evidence, as they reflect the indoor conditions in school environments across Europe and differentiate the impacts of inadequate ventilation (e.g., CO₂), indoor emissions (e.g., VOCs, aldehydes), and outdoor pollutant intrusion (e.g., PAHs). This comprehensive approach provides the data needed to develop targeted air remediation policies to protect children's health from poor indoor air quality in schools.

Technology Developed in LEARN

LEARN has developed new technology to aid the detection and on novel mediation strategies to improve air quality in schools.

The molecular specific detection of VOC pollutants is a critical aspect of air quality monitoring; gas toxicity varies significantly between individual VOCs. This is evidenced by the wide range of toxicity threshold concentration values. LEARN demonstrated for the first time the molecular specific and real time detection of a calibrated mixture of benzene, toluene, ethylbenzene and xylene (BTEX) VOCs using a novel technique coined as sample ionisation potential spectroscopy (SIPS). Unlike conventional photoionisation detection (PID) sensors, reporting total VOC concentrations and portable gas chromatography – mass spectrometry, SIPS offers real time and molecular selective detection. We demonstrated that SIPS can selectively detect BTEX compounds at threshold limit value–time-weighted average concentration levels in real time, without the use of bottled carrier gases and with immunity to confounding background signals from other VOCs. The SIPS sensor can be tuned to detect any VOC compound by adjusting the ionisation light wavelength to match the ionisation potential of the target VOC. Therefore, it is not limited to BTEX detection, paving the way for real time assessment of air toxicity. This achievement represents a significant advancement in the selective, real time monitoring of pollution caused by high molecular weight VOCs, which are traditionally assessed using PID technology.

Within the LEARN project, technology developments in air purifier placement simulation are enabling a shift from rule-of-thumb deployment to evidence-based placement recommendations. Airflow and particle transport can now be modelled using simulation approaches, increasingly calibrated with IAQ sensor data and ventilation layouts. This modelling of “what-if” scenarios, such as device location, operating modes, and changes in occupancy or room configuration, and translate the results into practical guidance that improves real-world clean-air impact.

In parallel, the LEARN project’s filter media and filter element innovation is advancing solutions that deliver higher filtration performance with lower energy demand and broader contaminant coverage. Media developments focus on high particle capture with minimal pressure drop (supporting quieter, more efficient operation), while hybrid concepts increasingly combine particulate filtration with molecular adsorption for odours and volatile organic compounds.

Recommendations

LEARN has shown that there is clear evidence of a relationship between poor indoor air quality, and children’s cognition and health. Improving indoor air quality in schools is beneficial for children’s diastolic blood pressure levels and their learning potential.

Implementing the recommendations made by LEARN will improve indoor air quality in schools preventing children from suffering the consequences of poor air quality. The recommendations are divided into four sections considering “Measuring IAQ”, “Designing Better School Environments”, “Changing Behaviours to improve IAQ”, and “Policy Measures to Improve IAQ”.

LEARN would direct all relevant stakeholders to consider implementing the recommendations.

Measuring Indoor Air Quality

To make it possible to better manage indoor air quality (IAQ), it is first necessary to be able to measure and accurately assess it. This allows for better decision making as to how to manage IAQ both daily and long-term and ensure that measures are taken in response to events that will have a negative influence on IAQ. Therefore, LEARN makes the following recommendations.

- The LEARN protocol should be used to better measure IAQ. In schools, we implemented a comprehensive monitoring strategy to assess the indoor and outdoor environment (Figure 1). We employed a multi-layered monitoring approach, combining passive and active sampling to track chemical pollutants. In addition, we used real time particle sensors to monitor particulate matter, UFPs, and black carbon. Microclimate monitors were also applied to track variables such as temperature and relative humidity. All these measures are designed to ensure the targeted implementation of our novel air remediation strategy.
- Schools should at the very least monitor outdoor pollutants (PM_{2.5}, PM₁₀) and local parameters (CO₂, temperature, and relative humidity) using existing data sources to determine whether special measures need to be taken to protect against poor outdoor air quality which will have an impact on IAQ.
- Schools, especially those in areas with historic poor air quality, should consider installing sensors or using portable sensors to measure IAQ. Data from such sensors can be used to aid decision making on managing IAQ and allow better reactions to incidences which would negatively impact air quality. New school buildings should have air sensors installed to allow better monitoring of IAQ.



Figure 1: Overview of indoor (classrooms) and outdoor sampling settings. (a) Placement of sampling devices inside the classroom and (b) at an outdoor location. (c) Detailed view of the devices.

Designing Better School Environments

When building new schools or refurbishing existing school buildings, the LEARN project reinforces that IAQ should be treated as a core design and operational requirement, alongside energy, comfort, and acoustics, because classroom IAQ outcomes depend on the combined performance of ventilation, filtration, room layout, and maintenance. In LEARN cohorts, portable air purifiers were evaluated as one of several possible filtration platforms, but they should be considered context-dependent: in new buildings and major refurbishments, the preferred solution is often a properly designed stationary Heating, Ventilation and Air Conditioning (HVAC) system or other fixed ventilation and filtration concepts that deliver consistent air exchange and controlled filtration.

- New school buildings using HVAC (or other fixed ventilation systems) should specify filtration performance explicitly (not just “a filter is installed”). LEARN-aligned specifications should require filter selection based on the local outdoor air challenges and the intended IAQ target, while ensuring low bypass leakage and acceptable pressure drop so that real airflow rates are maintained in operation.
- Filtration – whether via central HVAC, decentralised ventilation units or portable air purifiers – should be part of an overall IAQ management strategy, not a standalone measure. LEARN highlights the need for a clear operating model that includes: monitoring (e.g., carbon dioxide as a ventilation indicator, particulate matter where relevant, temperature/humidity), defined actions (HVAC setpoints, operating schedules, window strategies where used), and verification and maintenance (correct installation and sealing, planned filter change-out intervals, documentation). The effectiveness of any filter platform depends on “as-installed, as-operated” performance, not laboratory ratings alone.
- When planning new schools or refurbishments, air quality management should be treated as equally important as energy efficiency, and decisions should be made on

total performance rather than single-parameter optimization. LEARN supports designing for the best overall outcome across adequate fresh air supply/air change, effective filtration and separation for local pollutant loads, manageable energy impact (fan power driven by pollutant concentrations and airflow demand), acceptable noise levels for classrooms, and maintainability over the building lifecycle.

- Furniture, wall and floor coverings, and building materials can release pollutants such as volatile organic compounds (VOCs), aldehydes, polycyclic aromatic hydrocarbons (PAHs), and ultrafine particulate matter (UFPs). These emissions can contribute to indoor air pollution in schools, so they should be carefully considered when selecting and purchasing materials in building or refurbishing schools or in purchasing supplies for use in schools. Changing Behaviours to Improve IAQ.

Changing Behaviours to Improve IAQ

Whilst the school infrastructure can impact IAQ, it is possible to also suggest behavioural changes that can influence IAQ and help mitigate poor quality air. Alongside school staff, changing the behaviour of school students and parents is also important. Local decision makers, such as local authorities, can also put in place changes to behaviours that can have a positive impact on IAQ. There needs to be a holistic approach to improving air quality considering the local environment, local weather conditions and societal factors, as well as the physical structure of schools.

- Education about the importance of IAQ is important, both within schools and amongst parents, as well as within the local community, including local authorities and the neighbourhood around schools. From LEARN's results, it is clear that 36 % of schools never or rarely consider children's exposure to indoor air pollution, and that 43% are not or only slightly concerned about indoor air quality in schools. Positive messaging should be used to encourage behaviours that can enhance IAQ, such as better parking by switching off engines and limiting car usage in the immediate vicinity of schools, or by restricting practices such as the burning of waste on certain days when air quality is poor.
- Improving understanding of the influence of IAQ on cognitive behaviour and the education outcomes of children can be helpful in leading to behavioural changes. The LEARN suite of educational resources, and specifically the LEARN boardgame, can be useful in educating people about the importance of better IAQ for schools and children. By using these resources, people learn to identify main sources of indoor air quality pollution, their health impacts and which mitigation measures they can take to improve indoor air quality. (link to educational resources)
- In schools, appropriate staff (administrative, facilities, headteachers) should understand the impact of IAQ on the school environment and how to assess and make decisions based upon the local air quality conditions. There should be established protocols in schools to help decision making that can mitigate IAQ such as opening windows, using air purifiers and adjusting HVAC systems. LEARN studies have shown that participants prefer to be assisted by local authorities who can offer expertise and resources, relieving school staff from responsibilities. Local authorities should work with schools in their district to ensure that appropriate protocols are in place and used by the schools.

- Linked to the above recommendation, children should be made aware that they can alert their teacher or other appropriate school staff if they feel the indoor air quality is poor. Currently, only half of the children alert their teacher when the air quality in the classroom is poor.
- In terms of improving indoor air quality in schools, children would like to help in keeping the air fresh indoors. In LEARN, 90% of questioned children state that they want to help their teacher in this responsibility, e.g. in opening and closing windows for air ventilation during breaks.
- Schools should seek to mitigate the effects of poor outdoor air quality, as this will in turn have a negative impact on IAQ. Assessing the impact of local roads, and the placement of areas where smoking is permitted in relation to ventilation will help ensure that poor outdoor air quality does not impact IAQ.

Policy Measures to Improve IAQ

In the longer term, improving IAQ in schools will require policy measures to be introduced designed to make a positive contribution. Currently there is no overarching policy at the EU level addressing IAQ, although there have been recommendations and guidelines from the World Health Organisation on its importance. At an EU Member State level, some countries have put in place measures and policies around IAQ.

- Relevant policymakers at an EU, Member States and local government level should develop a more comprehensive and consistent approach to IAQ. A good introduction is provided in the IDEAL Cluster First Policy Brief.² From our results, it is clear that 81% of surveyed participants in Belgium, Denmark and Greece prefer simple and universal indoor air quality regulations, with the same basic standards for everyone (without targeted protection for vulnerable groups, such as children). Furthermore, 73% think that these rules and laws should be made mandatory, as this can speed up change.
- Policymakers should investigate the measurement of IAQ in schools. Whilst CO₂ is often measured as a proxy to understand IAQ, other measurements such as particles and VOCs are needed to understand the exact specifics of IAQ in school settings and as it is these that are affecting health.
- Policymakers responsible for schools, especially for the building of new schools or the refurbishment of existing schools, should ensure that IAQ is considered in their deliberations. Hereby, our surveyed participants prefer the full automation of indoor air quality management through technologies (65%), versus human control and agency.
- As children and other vulnerable groups spend time in other public spaces, policymakers should consider how to monitor and improve IAQ in other public spaces as well as in schools.
- Assessment methods and laboratories testing of IAQ need to be aligned with real-world conditions as much as possible. This requires the use of realistic experiments that can replicate human behaviour and also replicate the real environments being studied. Further research into IAQ should ensure that it replicates real-world conditions.

² <https://www.idealcluster.eu/wp-content/uploads/2024/10/FINAL-Policy-Brief-IDEAL-Cluster.pdf>

- Further research is needed to understand how to improve IAQ and policymakers should consider how this can be supported. There is a need for further studies at both a local and EU wide level on the following:
 - The need for IAQ policies at a local, national or EU level.
 - What pollutants and local conditions should be measured using available and cost-effective devices to allow schools to make decisions to improve IAQ.
 - How to ensure that planned schools or planned refurbishments to existing schools are treating air quality management as an important consideration.
 - What training is required at a school level to empower staff to make decisions around managing indoor air quality on a reactionary basis so that behaviours can be changed to mitigate the impact of poor local air quality.



LEARNing about the status of air quality in schools and its impact on the cognition of children is a major cornerstone in LEARN. For that, we want to overcome the barriers of the currently existing technologies and take a bold step towards developing and deploying novel sensors to detect the presence of potentially harmful air pollutants such as volatile organic compounds and fine and ultrafine particles.

The LEARN project measured and characterized indoor and outdoor air pollutants and evaluated the presence of biomarkers of exposure and their effect on children's cognition while trying to recapitulate those effects using *C.elegans* as a biosensor. Advanced human-based in vitro models of lung and skin coupled with a revolutionary multi-sensing device were used to investigate the mechanisms of toxicity in real time.

Novel remediation strategies to improve air quality and promote children's quality of life and life expectancy were developed by a team of environmental epidemiologists, toxicologists, air quality specialists, systems biology, engineers, and citizen/social scientists.

The scientific achievements of LEARN unlock significant technological potential in indoor air quality for decades to come, generating disruptive societal and economic impacts through a radical improvement in the quality of life of children in Europe.