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WHITE PAPER

The Air Students **Breathe**

How indoor air quality influences health, learning performance, and educational outcomes in European schools.

A European perspective on CO_2, ventilation & healthy learning environments · 2026 Edition

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81%	**1,487**	**125**
of 2,444 classrooms exceed the 1,000 ppm CO_2 limit	ppm median CO_2 measured across all classrooms	peer-reviewed studies reviewed across Europe

The quality of indoor air directly affects the quality of learning

81% of classrooms exceed the recommended 1,000 ppm CO_2 concentration	**1,487** ppm median – nearly 50% above the recommended limit	**90M+** students attend European schools, 6–8 hours indoors daily

Indoor air quality (IAQ) is one of the most influential yet overlooked factors affecting educational environments. While schools invest heavily in teachers, technology, curriculum development, and learning facilities, the quality of the air students breathe often receives far less attention.

Research from across Europe demonstrates that poor indoor air quality is widespread in educational buildings. A 2024 systematic review covering 125 studies and 2,444 classrooms found that 81% of classrooms exceeded the recommended indoor CO_2 concentration of 1,000 ppm.[1] Elevated CO_2 is a reliable indicator of inadequate ventilation: when CO_2 is high, concentrations of airborne pollutants, allergens, particulate matter, and biological contaminants are typically elevated alongside it.

The implications extend beyond comfort. Poor indoor air quality has been linked to reduced concentration, increased fatigue, impaired decision-making, lower cognitive performance, and increased absenteeism. This white paper examines the state of indoor air quality in European schools, explores the impact of elevated CO_2 on health and learning outcomes, and presents evidence-based strategies – including fabric duct solutions – for creating healthier educational environments.

What this paper covers

A structured look at indoor air quality in European schools – from the scale of the problem and its measurable impact on health and learning, to the proven solutions and a practical path forward.

01 | The Invisible Factor in Educational Success

Across Europe, more than 90 million students attend pre-primary, primary, and secondary schools. Every school day, they spend six to eight hours inside classrooms – expected to concentrate, solve problems, absorb information, collaborate, and perform academically.

Educational success is influenced by many factors: teaching quality, curriculum design, technology, and student engagement. Yet one factor often remains largely invisible – the quality of the air students breathe. Unlike inadequate lighting or excessive noise, poor air quality cannot easily be seen, heard, or felt until its effects are already measurable. As Swegon Air Academy member Petra Vladykova has noted, this remains a real – but still invisible – problem.[2]

> **Indoor air quality should not be viewed solely as a building performance issue. It is fundamentally an educational issue.**

Students spend six to eight hours a day in classrooms like this one – making the air they breathe a constant, if invisible, part of how they learn.

02 | Why Indoor Air Quality Matters

Improving classroom air quality benefits the entire educational community – students, teachers, and the institutions responsible for both.

Student Health

- Respiratory irritation
- Allergy symptoms
- Asthma exacerbation
- Greater susceptibility to airborne infections
- General discomfort & fatigue

Student Performance

- Reduced concentration
- Lower attention levels
- Slower information processing
- Increased drowsiness
- Reduced cognitive performance

Teacher Wellbeing

- Headaches & fatigue
- Reduced concentration
- Voice strain
- Increased sick leave
- Lower workplace satisfaction

03 | Understanding Indoor Air Quality in Schools

Indoor air quality is determined by multiple interacting factors, each affecting occupant health and comfort. The three primary categories are CO_2 concentration, temperature and humidity, and airborne pollutants – including $PM_{2.5}$, PM_{10}, VOCs, and biological contaminants.

Why CO_2 is the key indicator

CO_2 is widely used as the primary indicator of ventilation effectiveness in occupied spaces. At the concentrations commonly found in classrooms – typically 1,000 to 3,000 ppm – CO_2 itself is not the direct cause of harm. Rather, elevated CO_2 is a reliable signal that ventilation is inadequate and that the broader indoor environment is deteriorating: allergens, fine particulates, VOCs, and biological contaminants accumulate alongside it.

This distinction matters. Improving ventilation to reduce CO_2 simultaneously addresses the full spectrum of indoor air contaminants. CO_2 monitoring is therefore the most practical and cost-effective tool for managing overall classroom air quality.

> **CO_2** A single, measurable proxy for the entire indoor air environment – when it falls, allergens, particulates and VOCs fall with it.

Indoor CO_2 levels & classroom conditions

CO_2 level	Health & cognitive effects
250–450 ppm	Normal outdoor air. Baseline reference.
450–1,000 ppm	Well-ventilated indoor air. Recommended maximum for classrooms across most EU member states.
1,000–2,500 ppm	Poorly ventilated air. Sick Building Syndrome symptoms emerge: fatigue, headaches, reduced concentration, impaired decision-making, increased absenteeism.
2,500–5,000 ppm	Severely polluted air. Measurably harmful to health. Significant cognitive impairment and airway irritation.
Above 5,000 ppm	Extreme risk. Severe physiological consequences including oxygen-deficiency effects. Dangerous for any sustained exposure.

04 | The European Air Quality Challenge

A growing body of research demonstrates that poor indoor air quality is widespread throughout European schools. The most comprehensive review to date analysed 125 studies covering 2,444 classrooms. The median CO_2 concentration was 1,487 ppm – nearly 50% above the recommended limit – with 81% of classrooms exceeding 1,000 ppm.[1]

Country	Key finding
Netherlands	80%+ of schools exceeded 1,200 ppm (Dutch recommended maximum) during classroom occupation.[3]
France	41% of schools had at least one classroom exceeding 1,700 ppm in 2023. Recommended norm: 800 ppm.[4]
Germany	CO_2 exceeded 1,000 ppm for 24% of total teaching time across 240+ classrooms, even with natural ventilation in use.[5]
Italy	54% of classrooms recorded mean CO_2 above 1,000 ppm despite teachers opening windows and doors.[6]
United Kingdom	Year-long study in five schools: peak of 5,966 ppm recorded; classrooms spent thousands of hours above the 1,500 ppm guideline.[7]
Lithuania	11 Vilnius schools: peak 5,152 ppm, average 1,660 ppm, 9 of 11 classrooms exceeding 2,000 ppm – measured in winter when window ventilation was impractical.[8]
Sweden ✓	90% of buildings use mechanical ventilation. CO_2, $PM_{2.5}$, PM_{10}, and formaldehyde concentrations consistently below guideline values in mechanically ventilated rooms.[9]

The pattern is unambiguous: every country studied that relies primarily on natural ventilation fails to maintain adequate air quality. Sweden – where mechanical ventilation is near-universal – demonstrates the problem is entirely solvable. The differentiating variable is not climate, geography, or national wealth. It is ventilation infrastructure.

05 | Lithuania: A Representative Northern European Example

Lithuania provides one of the most thoroughly documented national case studies of school air quality in Central and Eastern Europe. In 2018, the Lithuanian Passive House Association conducted CO_2 measurements in 11 Vilnius schools during winter – the season when natural ventilation is least viable and the problem most acute.

Peak CO_2 recorded – more than 5× the recommended limit	**5,152 ppm**
Classrooms exceeding 2,000 ppm	**9 of 11**
Average CO_2 across all classrooms	**1,660 ppm**
Permissible norm (legal standard)	**1,500 ppm**
Recommended norm	**1,000 ppm**
Outdoor temperature during testing (winter)	**−1°C to +6°C**

The winter context is significant. Outdoor temperatures of −1°C to +6°C represent the marginal zone in which teachers face a genuine trade-off between thermal comfort and ventilation. Opening windows at these temperatures rapidly chills the classroom, making sustained airing impractical during occupied hours. This cold-climate, sealed-building dynamic is shared across a large bloc of northern and eastern EU member states. The Lithuanian data is not an outlier.

06 | Why Natural Ventilation Cannot Solve the Problem

Most EU member states require classrooms to be ventilated through openable windows. In practice, four structural limitations make this consistently insufficient:

Thermal Conflict

Near-freezing winter temperatures across Central, Eastern and Northern Europe make sustained window ventilation physically impractical. Teachers rightly prioritise thermal comfort.

Insufficient Exchange Time

A 10-minute break cannot replace the CO_2 accumulated during a 45-minute lesson with 30 occupants. The physics of air diffusion do not permit adequate exchange in this timeframe.

Allergen Import

During pollen season, opening windows actively imports the outdoor allergens most harmful to children with respiratory conditions. Natural ventilation provides no filtration whatsoever.

No Control or Accountability

Natural ventilation depends on wind, temperature differentials and individual teacher behaviour. It is unpredictable, unmeasured, and produces no data against which compliance can be assessed.

07 | Health and Learning Consequences

7.1 – Sick Building Syndrome

Sick Building Syndrome (SBS) is a recognised condition associated with time spent in poorly ventilated or contaminated buildings. It is caused not by CO_2 itself, but by the broader accumulation of pollutants – biological contaminants, VOCs, fine particulate matter, and allergens – that occurs when ventilation is inadequate.

SBS typically becomes apparent at CO_2 concentrations above 1,000 ppm – the level exceeded by 81% of European classrooms. In schools, it presents as fatigue and drowsiness during lessons, headaches, eye and throat irritation, reduced capacity for reasoning and memory retention, and higher rates of illness-related absenteeism.

7.2 – Allergies, Asthma & Respiratory Disease

Children with allergies or asthma face a compounded problem in naturally ventilated schools: inadequate air exchange allows pollutant concentrations to build, while during pollen season open windows import the very allergens that trigger respiratory symptoms. These two effects reinforce each other, making naturally ventilated classrooms particularly harmful for allergic and asthmatic children.

10,000s

The SPINE network estimated that adequate ventilation in schools could prevent **tens of thousands of new cases of childhood asthma each year** across Europe.[10] This is a public health issue, not merely a comfort one.

7.3 – Academic Performance

Students in better-ventilated classrooms consistently achieve higher test scores, demonstrate improved attendance, and show better sustained concentration than those in poorly ventilated environments. The mechanism is physiological: inadequate ventilation reduces the brain's oxygen metabolism, impairing precisely the cognitive functions – concentration, reasoning, memory formation – that academic learning depends on.

> A child sitting in a 2,000 ppm classroom is physiologically disadvantaged in their ability to learn. Improving air quality is, in measurable terms, an educational intervention – not merely a building upgrade.

Fabric-based air distribution delivers uniform, low-velocity supply air across an entire space – controlled and measurable, regardless of season.

08 | Sweden: A Blueprint for Healthy Learning Environments

Sweden offers a compelling example of how policy and infrastructure can transform indoor environmental quality in schools. Approximately 90% of Swedish buildings are equipped with mechanical ventilation systems, providing controlled fresh-air supply throughout the year – regardless of outdoor temperature or pollen season.[11]

90% of Swedish buildings are equipped with mechanical ventilation – providing year-round, controlled fresh-air supply.

Studies in mechanically ventilated Swedish schools have consistently shown CO_2 below guideline values, reduced $PM_{2.5}$ and PM_{10}, reduced allergen exposure through HEPA filtration, and consistent indoor conditions regardless of season. A 2000 intervention study found pupils in schools with newly installed ventilation reported significantly fewer asthmatic symptoms.[12] A 2022 Gothenburg study of 45 classrooms found CO_2, formaldehyde, $PM_{2.5}$ and PM_{10} consistently lower in mechanically ventilated classrooms.[9]

> **Sweden's 90% mechanical ventilation rate is the result of a policy decision, not a geographic advantage. Every EU member state is capable of making the same choice.**

09 | Mechanical Ventilation as a Proven Solution

Mechanical ventilation provides controlled, predictable air exchange regardless of outdoor conditions: consistent fresh-air supply, controlled exchange rates, high-efficiency filtration, heat recovery, and improved comfort year-round. Modern demand-controlled ventilation (DCV) continuously adjusts airflow based on occupancy and measured CO_2, maintaining healthy conditions while optimising energy consumption.

Germany: decentralised mechanical ventilation in classrooms[5]

24% of teaching time above 1,000 ppm – natural ventilation

-54% exposure reduced

11% of teaching time above 1,000 ppm – mechanical ventilation

A 54% reduction in the time students were exposed to inadequate air quality – achieved without significant changes to the building fabric.

> **Mechanical ventilation transforms indoor air quality from a variable outcome into a measurable performance parameter.**

10 | Why Air Distribution Matters

Ventilation performance depends not only on how much air is supplied, but on how effectively it is distributed throughout the occupied space. Even a correctly sized system can fail if air distribution is poor – producing draughts, excessive noise, uneven temperatures, and air-stagnation zones.

Ventilation systems that create discomfort are frequently adjusted, restricted, or switched off by teachers – eliminating their benefits entirely. In schools, occupant comfort is not a secondary consideration. It determines whether the system is used at all.

11 | Optimising School Ventilation Through Fabric Air Distribution

Fabric-based air distribution systems offer several characteristics that align particularly well with the requirements of educational environments.

Draught-Free Air Delivery

Uniform low-velocity delivery through micro-perforations along the entire duct length eliminates the cold-blast effect of conventional ceiling outlets. Children stay comfortable; the system stays on.

Low Noise Operation

Fabric ducts operate at significantly lower sound pressure levels than metal ductwork and conventional diffusers – well suited to the acoustically sensitive environment of a classroom.

Hygienic Design

Unlike rigid metal ductwork, fabric ducts can be removed and machine-washed, eliminating the accumulation of dust, allergens and biological contaminants inside the system itself – especially relevant in buildings occupied by children.

Retrofit Flexibility

Lightweight construction and flexible installation simplify integration into existing school buildings, where traditional ductwork would present structural or logistical challenges.

Energy-Efficient Performance

Low-velocity delivery reduces fan energy requirements. Combined with demand-controlled ventilation and heat recovery, fabric duct systems are compatible with the energy targets of the EU Renovation Wave programme.

The system that stays on

The most effective ventilation system is ultimately the one that operates consistently – because occupants remain comfortable enough to leave it on.

12 | The Future of Healthy Learning Environments

Educational buildings are increasingly adopting health-focused design principles. Several developments are shaping the next generation of school environments:

- Continuous IAQ monitoring with real-time CO_2 dashboards visible to building managers and school administrators
- Smart building integration connecting ventilation performance with occupancy data and maintenance systems
- Healthy building certification schemes that formalise IAQ as a measurable, auditable performance indicator alongside energy and sustainability metrics
- Deep renovation programmes supported by EU Renovation Wave funding, in which ventilation upgrades are mandated as a condition of investment
- Policy convergence across EU member states towards enforceable 1,000 ppm CO_2 standards for educational buildings

The direction is clear: indoor air quality is moving from a background consideration to a primary design and operational objective. Schools that invest in ventilation infrastructure now will be ahead of both the regulatory curve and the health evidence.

13 | Recommendations

School Administrators

- Install classroom CO_2 monitoring
- Include IAQ in facility management programmes
- Evaluate ventilation performance regularly
- Prioritise retrofit of poorly ventilated buildings

Engineers & Consultants

- Design for health-based ventilation targets
- Prioritise occupant comfort alongside air quality
- Specify high-efficiency particulate filtration
- Consider air distribution effectiveness in system design

Policymakers

- Strengthen enforceable IAQ standards in schools
- Fund ventilation upgrades via renovation programmes
- Integrate IAQ as a condition of EU renovation funding
- Adopt Sweden's near-universal mechanical ventilation rate as a benchmark

14 | Conclusion

Every child deserves a classroom environment that supports learning rather than limits it.

The evidence from across Europe is clear. Poor indoor air quality remains widespread in educational buildings, and elevated CO_2 – as an indicator of broader ventilation failure – continues to affect the health and learning of millions of students every day. Yet Sweden demonstrates that this is not inevitable: with the right infrastructure and policy commitment, schools can maintain clean, filtered, comfortable air throughout the year.

The solutions already exist. By combining effective mechanical ventilation, high-efficiency filtration, intelligent control strategies, and well-designed fabric air distribution systems, schools can create healthier, more comfortable, and more productive learning environments.

> **Improving indoor air quality is not simply a building upgrade. It is an investment in health, educational performance, and future generations.**

Lightweight, machine-washable fabric ducts integrate easily into both new and existing school buildings.

FabricAir

FabricAir is a global provider of fabric-based air distribution solutions in educational facilities, healthcare buildings, sports venues, industrial facilities, and commercial spaces worldwide. Through collaboration with architects, engineers, contractors, and facility managers, FabricAir helps create indoor environments that prioritise comfort, health, and energy efficiency. Their solutions are installed in more than 120 countries and are engineered to deliver consistent, comfortable air distribution in every season.

fabricair.com

References

[1] Littlewood, J. "Indoor Air Quality in Naturally Ventilated Primary Schools: A Systematic Review of the Assessment & Impacts of CO_2 Levels." Buildings, 14(12), 4003. MDPI, 2024.

[2] Vladykova, P. / Swegon Air Academy. "Let Science Speak for Itself – Reflection on the Invisibility of a Problem with Indoor Air Quality in Schools." swegonairacademy.com, 2024.

[3] Bakó-Biró, Zs. et al. "A ventilation intervention study in classrooms to improve indoor air quality: the FRESH study." BMC Public Health, 14, 1184, 2014.

[4] Canha, N. et al. "Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France." Indoor Air, 26(3), 350–365, 2016.

[5] Schibuola, L. et al. "Assessing school ventilation strategies from the perspective of health, environment, and energy." Energy and Buildings. ScienceDirect, 2023.

[6] Stabile, L. et al. "Air change rates and infection risk in school environments: Monitoring naturally ventilated classrooms in a northern Italian urban context." Building and Environment. PMC, 2023.

[7] Evotech Air Quality. "Year-long study on CO_2 in classrooms highlights the need for better ventilation in schools." Air Quality News, 2022.

[8] Lietuvos mokyklų oro kokybės gerinimo projektas. Nacionalinė pasyvaus namo asociacija, 2022.

[9] Guo, H. et al. "Ventilation strategies and indoor air quality in Swedish primary school classrooms." Building and Environment, 2022.

[10] European Commission / SPINE Network. Schools Indoor Pollution & Health Observatory Network in Europe – Executive Summary of the Final Report. European Commission, 2014.

[11] Swegon Air Academy. "Breathe Better, Learn Better: How Ventilation Systems Keep Pollen Out in Schools in Sweden." swegonairacademy.com, 2025.

[12] Smedje, G. & Norbäck, D. "New Ventilation Systems at Select Schools in Sweden – Effects on Asthma and Exposure." Indoor Air, 10(3), 170–179, 2000.