SIE

IAQ IN INDIAN SCHOOLS

A TALE OF ELEVEN CITIES

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"Breathe Easy, Live Better: Unveiling the Secrets of Indoor Air Quality" is the key Mantra for all of us in future. Ignoring indoor air quality would have immense cost to the society. Almost two decades back, when this subject was still nascent even internationally, Prof Mukesh Khare initiated studies of indoors in India.

As we spend most of our time indoors, the quality of air we breathe plays a significant role in our health and wellbeing. Poor indoor air quality can lead to various health issues, from mild discomfort to serious diseases.

This report aims to educate and empower all the stakeholders associated with children's health who spend significant time in schools. By understanding the sources of pollution, implementing simple solutions, and adopting healthy habits, we can create a healthier and more comfortable living space. I would like to compliment the team which worked hard across multiple cities to bring together current research findings to all.

Let's breathe easy and live better! Fresh air is just the beginning. Healthy life is our goal. Let's work together to accomplish the goal of better health of children!!!!

Dr Rakesh Kumar
President, SIE

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OPERATIONAL DEFINITIONS AND ABBREVIATIONS

- **NV (Naturally Ventilated):** Classrooms relying on open windows/doors for airflow, with no mechanical support.
- **MV (Mechanically Ventilated):** Classrooms using HVAC and other air-conditioning systems for airflow, without natural openings.
- **HV (Hybrid Ventilated):** Classrooms combining natural ventilation with mechanical systems and filtration.
- **IAQ (Indoor Air Quality):** The condition of air inside classrooms, measured through pollutants such as particulates(PM_{10}, $PM_{2.5}$) and carbon dioxide (CO_2).
- **PM_{10} (Particulate Matter <10μm):** Coarse particles that can irritate the upper respiratory tract and eyes.
- **$PM_{2.5}$ (Particulate Matter <2.5μm):** Fine particles that penetrate deep into the lungs and can enter the bloodstream.
- **CO_2 (Carbon Dioxide):** A gas commonly used as an indicator of ventilation; levels above 1000 ppm suggest poor air exchange.
- **ppm (Parts per Million):** A unit for gas concentration (e.g., CO_2).
- **$\mu g/m^3$ (Micrograms per Cubic Meter):** A unit for particulate matter concentration.
- **WHO (World Health Organization):** Provides international health-based guidelines (e.g., $PM_{2.5}$ <15 $\mu g/m^3$ annual average, CO_2 <1000 ppm for comfort and safety).
- **ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers):** Sets standards for ventilation and indoor air quality.
- **Exposure Pathways:** How pollutants affect health–mainly inhalation, but also ingestion (dust on hands) and dermal contact.

1. INTRODUCTION

Indoor Air Quality (IAQ) is a critical determinant of the health, cognitive performance, and overall well-being of students and educators. Poor IAQ has been linked to ieased respiratory illnesses, absenteeism, reduced attention spans, and lower academic outcomes. In the context of Indian schools, where climatic diversity, building designs, and ventilation practices vary widely—understanding IAQ is essential for prioritizing effective interventions.
This report presents a consolidated analysis of field measurements from schools in Delhi & Gurugram, Gurgaon, Agra, and 8 cities in Maharashtra Cities region, representing distinct climatic and urban environments. By examining seasonal variations, architectural differences, and the influence of ventilation systems, the study provides an evidence-based view of IAQ dynamics in real-world classroom settings. The priority parameters for the present report were identified as Particulate matter (PM_{10} and $PM_{2.5}$) and carbon dioxide (CO_2), which were compared across selected cities to highlight exposure patterns, identify high-risk conditions, and suggest actionable solutions for creating healthier learning spaces in Indian schools.

2. IMPORTANCE OF INDOOR AIR QUALITY (IAQ) IN SCHOOLS

Indoor Air Quality (IAQ) is a crucial but often overlooked factor that directly affects the health, comfort, and learning ability of students and educators ability to teach. Children spend a large portion of their daytime inside classrooms, and as their lungs and immune systems are still developing, they are more vulnerable to pollutants than adults. Poor IAQ can lead to headaches, fatigue, allergies, asthma flare-ups, and ieased absenteeism.
Beyond health, IAQ also influences academic performance of students. Recent Studies in 2024-25 have shown that elevated carbon dioxide (CO_2) levels and exposure to fine particulate matter (PM_{10} and $PM_{2.5}$) can reduce concentration, slow information processing, and impair memory. In schools with inadequate ventilation, these effects can be significant, especially in regions where outdoor air pollution is already high.
Ensuring good IAQ in schools means creating healthier environments where students can focus, teachers can teach effectively, and the overall well-being of the school community is protected. It's not just an environmental issue – it's an educational and public health priority which needs attention of all the stakeholders.

3. OVERVIEW OF REPORT

Every breath a student takes in the classroom shapes their ability to learn, focus, and thrive. In Delhi, Gurugram, Agra and eight Maharastra cities(MMR), already saturated with outdoor pollution, the air inside classrooms tells a mixed story. Some are naturally ventilated but flooded with harmful particles like $PM_{2.5}$ and PM_{10}; others are sealed for protection but intensifies the accumulation of CO_2, affecting cognitive and physical health of students and staff. Proper interventions like hybrid ventilation (mechanical and natural) and high grade filtration offer a solution to make learning environments healthy and free from pollutants.

This report exposes these realities, not as distant statistics, but as urgent truths – to spark need to take action for clean and safe air in every educational institute, especially schools.

4. UNDERSTANDING INDOOR AIR QUALITY

4.1 $PM_{2.5}$, PM_{10}, CO_2 (Ventilation Surrogate)

Sources of $PM_{2.5}$ and PM_{10} include outdoor pollution (vehicular traffic, exhaust from buses idling near classrooms, emissions from industries, and dust from bare soil playgrounds) and indoor activities (chalk dust, cleaning procedures like brooming and dusting, art and craft activities).

CO_2 is a key indicator of ventilation adequacy – high levels suggest insufficient fresh air.

In classrooms, maintaining adequate ventilation and controlling particulate pollution is critical for healthy air.

4.2 Health Impacts of Poor Air Quality

- Children are more vulnerable due to developing lungs and higher air intake per body weight.
- Short-term effects include headaches, coughing, fatigue, and eye irritation.
- Long-term exposure ieases risks of asthma, allergies, and impaired lung development.
- High CO_2 levels reduce attention span, slow cognitive processing, and impair memory.
- Poor IAQ contributes to absenteeism and lower academic performance over time.

5. CURRENT NEWS, INSIGHTS, AND EXPERT OPINIONS

Global Media Insights

- **Closing classroom windows doesn't cut indoor pollution**

A UK study by Imperial College London (SAMHE project) monitored nearly 500 classrooms over a school year. It was found that around 80% of indoor $PM_{2.5}$ pollution came from outdoors, particularly on high-pollution days. Closing windows did not significantly reduce indoor pollution, though classrooms reported about 30% less pollution, providing some protection compared to outside air. Air filters only brought a ~29% reduction in particle levels, emphasizing that ventilation remains vital despite the risk of pollutant ingress.

- **Real-world study underscores indoor air hazards in schools**

A new collaboration between the American Lung Association and Carrier, focusing on a Minnesota charter school, found that indoor air in schools can be two to five times more polluted than outdoors. Poor IAQ has links to ieased asthma attacks, absenteeism, and reduced academic performance. The study calls clean indoor air "not a luxury—it's a necessity."

- **Rhode Island pushes legislation to improve school IAQ**

Rhode Island's House bill H5597 proposes state-level standards for IAQ, focusing on higher-grade HVAC filters (MERV-13) and regular inspections. Legislation (House Bill H5597) emphasize that better IAQ leads to improved learning, fewer sick days, and reduced transmission of illnesses like COVID-19 and flu.

Indian Media Insights

- **Indoor–outdoor concentrations of RSPM in classroom of a naturally ventilated school building**

A research study by Goyal & Khare (2009) monitored indoor–outdoor RSPM (PM_1, $PM_{2.5}$, and PM_{10}) in a naturally ventilated classroom near a busy roadway in Delhi, tracking pollutant concentrations hourly, daily, and seasonally alongside meteorological and traffic data. Results showed that RSPM levels exceeded permissible limits during all monitored periods, posing health risks to occupants. Indoor–outdoor ratios (I/O) for all particle sizes were greater than 1, indicating indoor air pollution sources, heavily influenced by classroom activities.

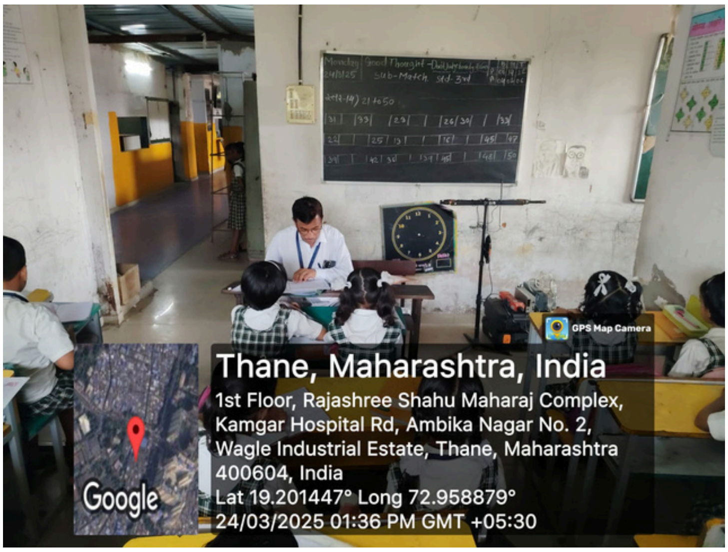
- **Impact of Classroom Ventilation on Concentration and Performance of Students**

A study carried out by Singh et al. in 2020 in Delhi schools assessed classroom ventilation by measuring CO_2 levels in air-conditioned (AC) and naturally ventilated (NV) buildings, using CO_2 as a key indicator of indoor air quality. AC schools frequently had CO_2 concentrations exceeding the recommended limit of 1,000 ppm, pointing to inadequate ventilation and potential health risks. The findings highlight concerns about ventilation, particularly in AC schools, and recommend further longitudinal research to clarify the effects of CO_2 on student performance.

- **School closures amid Delhi & Gurugram's smog crisis**

As smog reaches hazardous levels (AQI over 1,000), Delhi & Gurugram authorities shut schools and halted construction in November 2024. This drastic measure underscores how severe outdoor pollution directly disrupts academic routines and stresses the urgency for better indoor air strategies.

These stories collectively put a spotlight on IAQ challenges and interventions.



MONITORING SITES

6. DATA AND OBSERVATIONS

6.1 Methodology and Collaboration

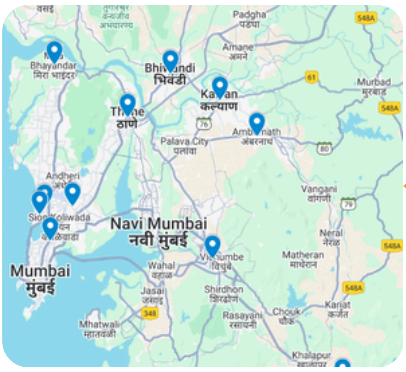
This project was jointly conducted by **Society for Indoor Environment (SIE), Techknowgreen Solutions Limited and YOGa Clean Air.**

- **Delhi & Gurugram:** A continuous real time monitoring was carried out using Kaiterra LE202 sensors, which was limited to single day intensive sampling during the critical period between November-January. The outdoor data was taken from Delhi and Gurugram Pollution Control Committee (DPCC) website.

- **Agra:** Dust samples from four Agra schools were collected across four seasons, dried, sieved (<63 µm), acid-digested, and analyzed for metals using ICP-OES. Pollution levels were evaluated using indices (Igeo, IPI, PLI, EF, PI) and source apportionment via correlation analysis and PCA. Health risks for children were assessed following USEPA methods for ingestion, inhalation, and dermal exposure pathways.

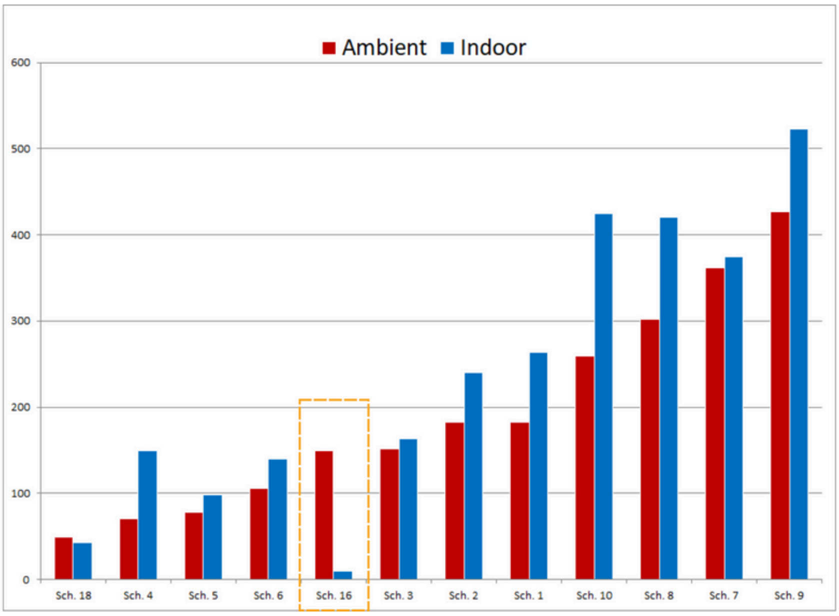
- **MMR:** Continuous real time monitoring was carried out for two seasons (Apr–Jun and Nov–Jan) using calibrated research grade instruments like Grimm, Testo and Tiger, with daily school-hours averages. Comparative analysis across Thane, Khopoli, Kalyan, Thane, Panvel Mira Bhayander, Ambernath, Bhiwandi, Dadar, Khar, Bandra, Thane, Kurla was also done to assess the pollution levels across these cities.

SITE LOCATIONS BY REGION



6.2 Comparative Analysis of Classroom Types

Naturally Ventilated (NV) Classrooms – Delhi & Gurugram



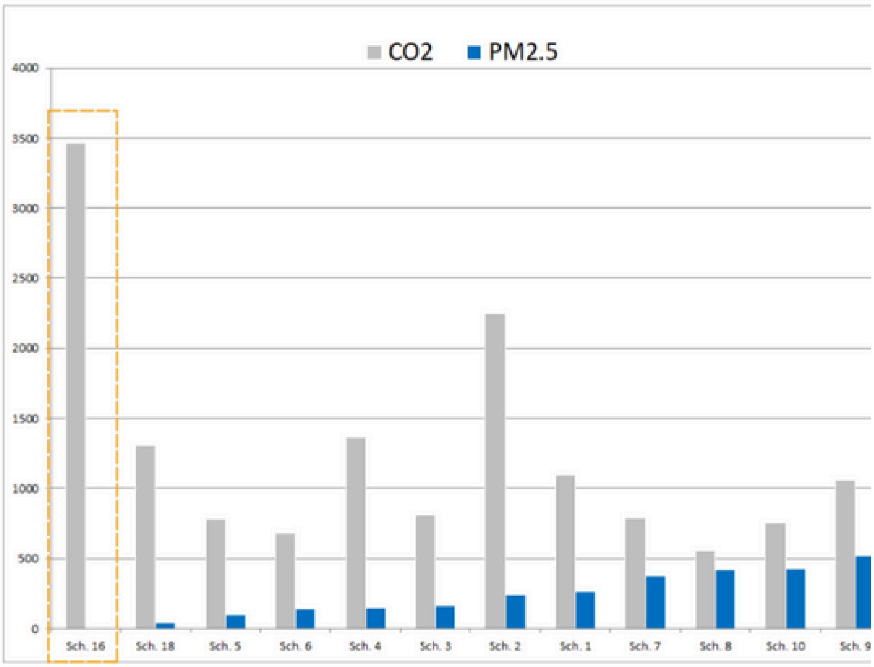
$PM_{2.5}$ trends at natural ventilated classes showed that indoor levels mirrored ambient levels.

There was **93% reduction in $PM_{2.5}$ levels when an intervention was implemented in one of the schools.**

$PM_{2.5}$ trends Indoor & Ambient across locations in Delhi & Gurugram

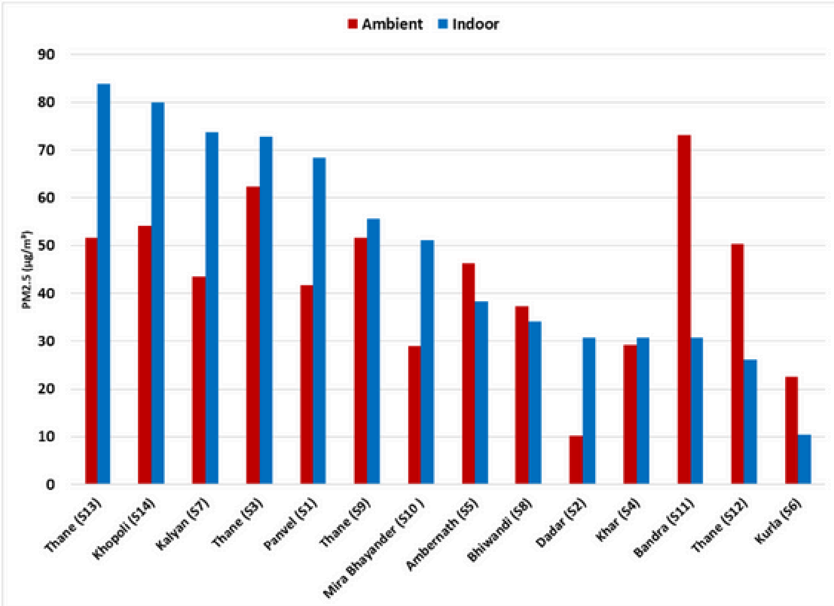
CO_2 levels in NV classrooms usually remain below 1200 ppm. However, since many classes were tested during winter when windows remained closed, CO_2 levels were observed higher in the classrooms.

In one of the schools, a reduction in $PM_{2.5}$ levels was observed because of appropriate interventions. However, CO_2 levels exceeded the usual levels due to a lack of ventilation in the classroom.



$PM_{2.5}$ & CO_2 trends across locations in the Delhi & Gurugram

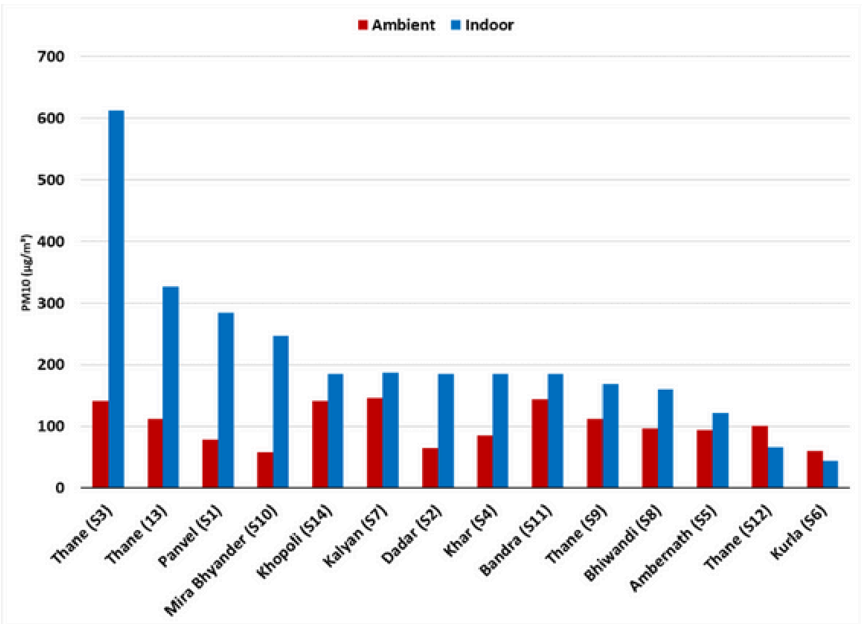
Naturally Ventilated Classrooms –Mumbai MMR



$PM_{2.5}$ trends in naturally ventilated classrooms showed that indoor concentrations either mirrored or exceeded ambient levels.

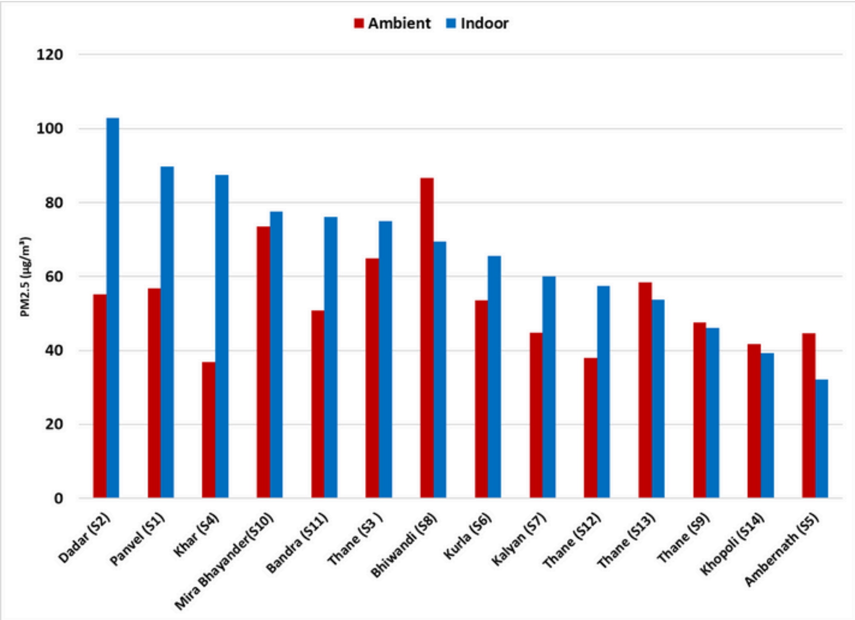
$PM_{2.5}$ trends across locations in the MMR during Apr-June period

PM_{10} trends in naturally ventilated classrooms showed that indoor concentrations exceeded ambient levels.



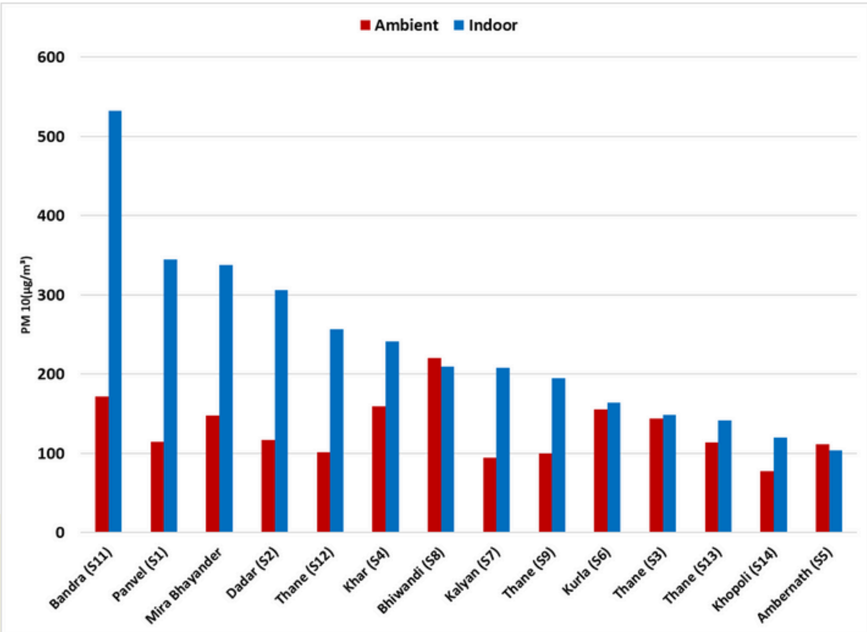
PM_{10} trends across locations in the MMR during Apr-June period

Naturally Ventilated Classrooms – MMR



$PM_{2.5}$ trends in naturally ventilated classrooms showed that indoor concentrations either mirrored or exceeded ambient levels.

$PM_{2.5}$ trends across locations in the MMR during Nov - Jan period

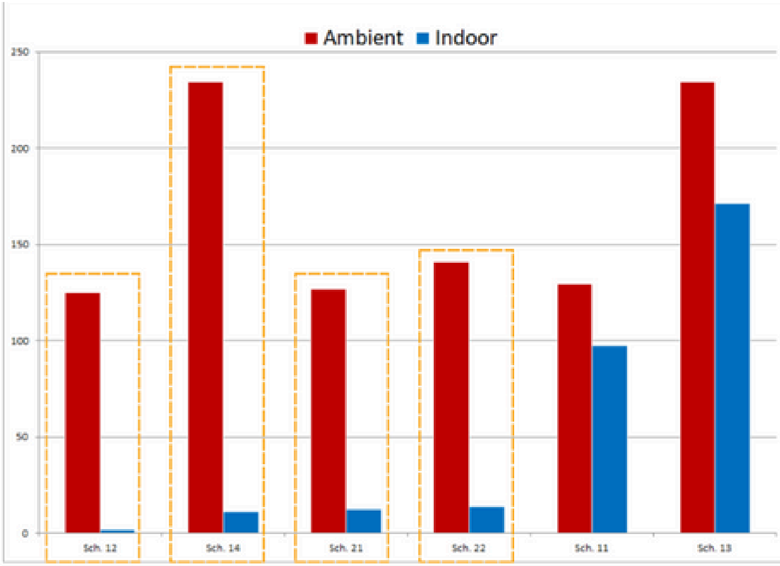


PM_{10} trends in naturally ventilated classrooms showed that indoor concentrations exceeded ambient levels.

PM_{10} trends across locations in the MMR during Nov - Jan period

- On an average, indoor PM_{10} levels exceeded ambient concentrations by 106%, with the highest readings observed in April–June due to dust infiltration.
- Seasonal variation was significant – for example, in Dadar, indoor $PM_{2.5}$ rose from about 40 µg/m³ (Apr–Jun) to 103 µg/m³ (Nov–Jan).
- Naturally ventilated classrooms showed no CO_2 accumulation, with levels consistently remaining below 700 ppm.

Mechanically Ventilated (MV) Classrooms – Delhi & Gurugram



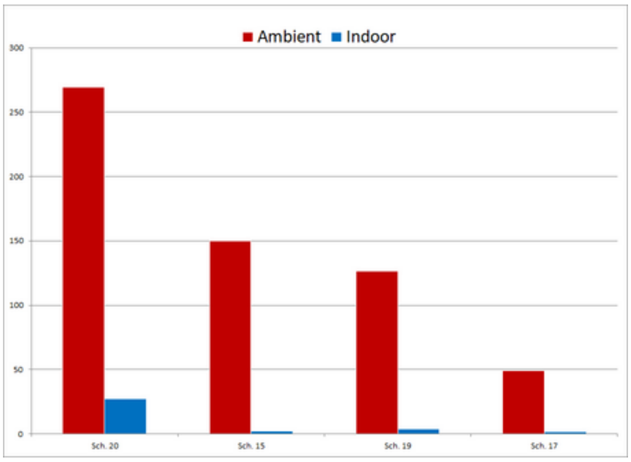
$PM_{2.5}$ trends in MV classrooms also reflect ambient levels, as the system brings in fresh air from the outside without fine filtration for $PM_{2.5}$ pollutants.

There is a **95% reduction in $PM_{2.5}$ levels when an mechanized filtration based intervention is implemented in such a classroom.**

Indoor & Ambient $PM_{2.5}$ trends across locations in the Delhi & Gurugram

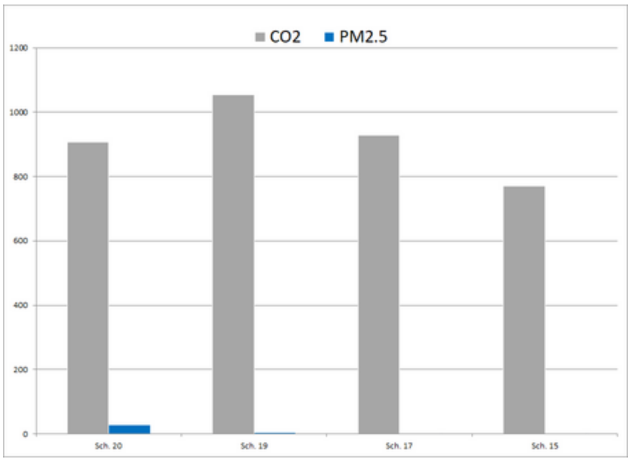
Hybrid Classrooms – Delhi & Gurugram

A naturally ventilated classroom with mechanized intervention



PM2.5 levels shown 99% reduction

Indoor & Ambient $PM_{2.5}$ trends in Delhi & Gurugram



CO_2 remained under 1200 ppm.

CO_2 & $PM_{2.5}$ trends in Delhi & Gurugram

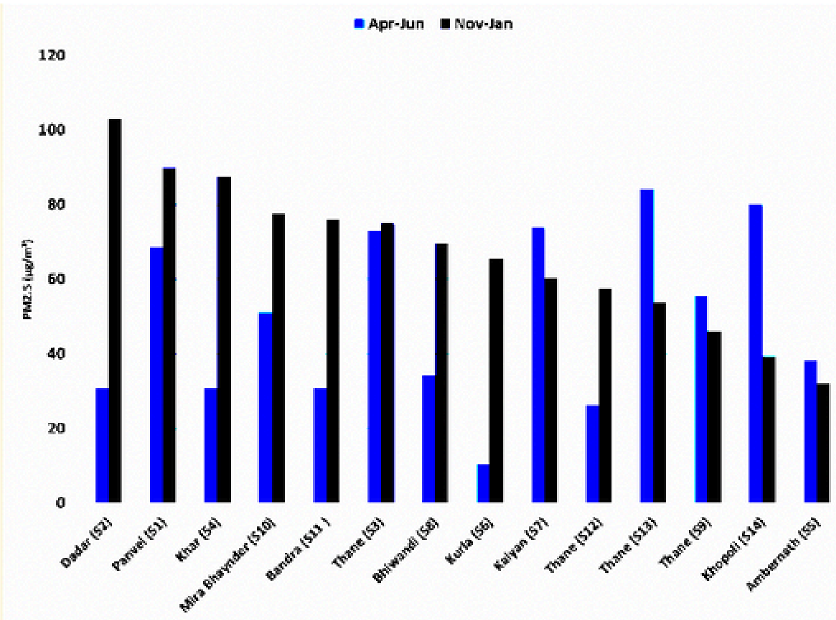
6.3 Seasonal & Regional Trends

6.3.1 Delhi & Gurugram :

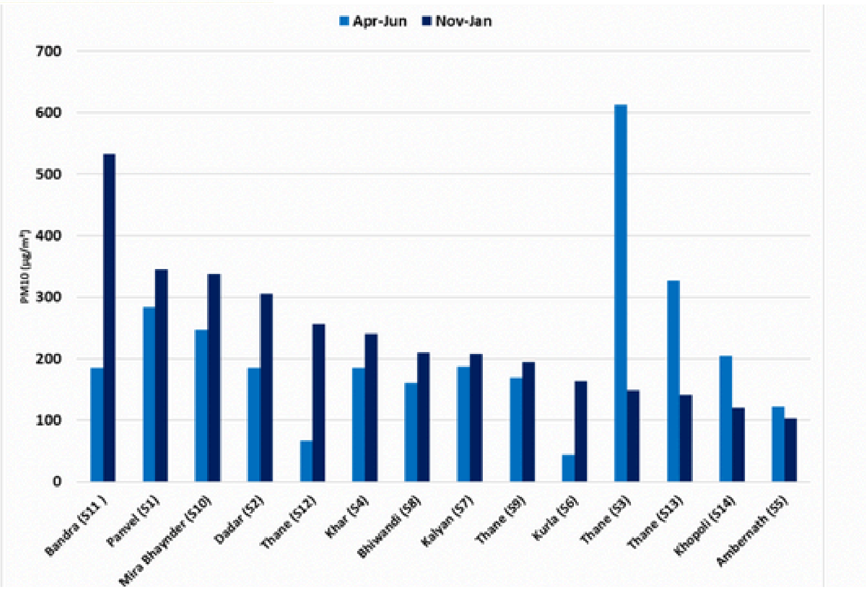
- Winter $PM_{2.5}$ levels were extreme, reaching up to 522 µg/m³ ± 5% indoors in NV classrooms.
- CO_2 spiked sharply when windows were kept closed.

6.3.2 MMR :

- Apr–Jun: Indoor $PM_{2.5}$ averaged ~49 µg/m³, PM_{10} ~220 µg/m³.
- Nov–Jan: Indoor $PM_{2.5}$ increased to ~66 µg/m³, PM_{10} to ~236 µg/m³.



$PM_{2.5}$ trends across locations in the MMR during Apr-June and Nov-Jan period



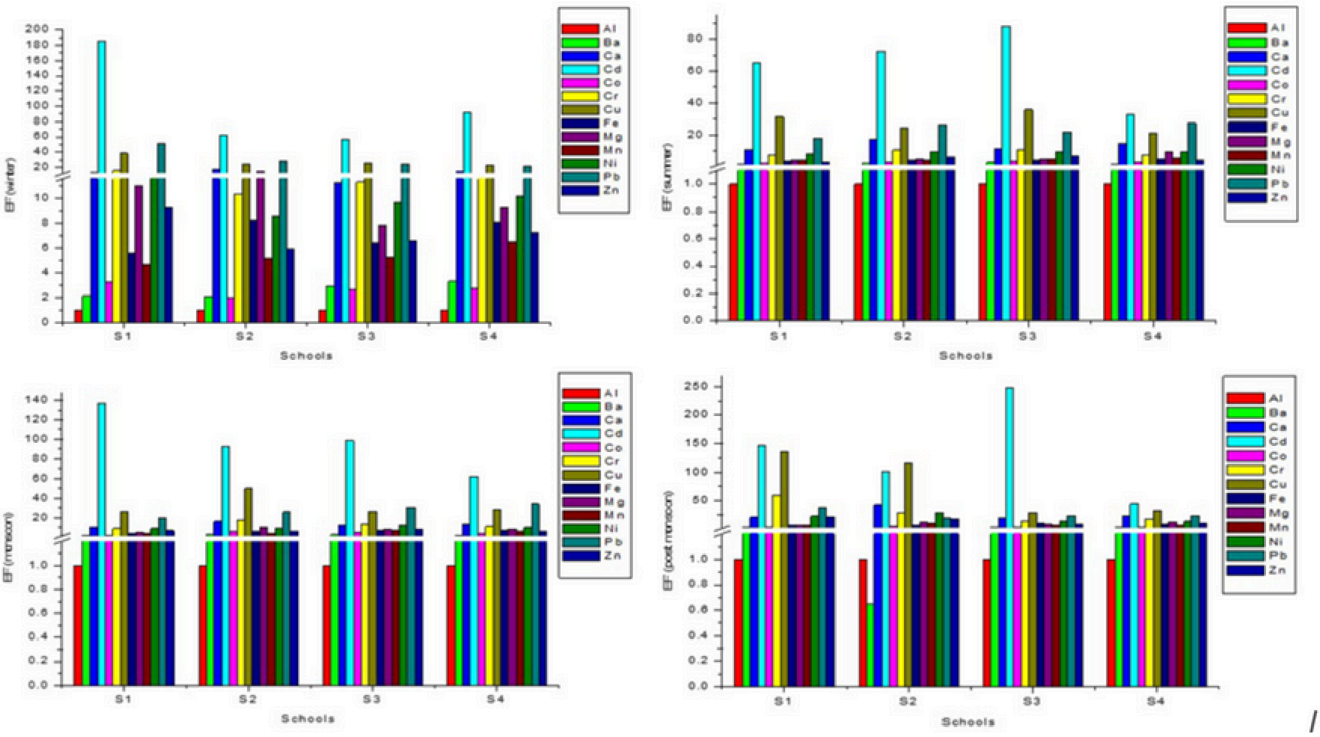
PM_{10} trends across locations in the MMR during Apr-June and Nov-Jan period

6.3.3 Agra - Heavy Metal Contamination in School Dust – Metal Profiling Matters

Particulate matter (PM) monitoring in schools often overlooks the toxic load carried by dust particles, particularly heavy metals that pose long-term health risks to children. A study of settled dust in urban and semi-urban schools in Agra found that lead (Pb), chromium (Cr), and cadmium (Cd) frequently permissible limits, with the highest levels recorded in the summer season due to dust re-suspension.

Analysis confirmed that traffic emissions, industrial activities, and construction were the main contributors, while metals like iron (Fe) and manganese (Mn) were largely due to natural origin. Although non-carcinogenic risks remained below thresholds, Pb and Cr posed carcinogenic risks at or above international safety benchmarks, mainly through ingestion and skin exposure.

These findings underline the need for schools to adopt integrated monitoring of both PM and heavy metals. Without metal profiling, indoor air toxicity is underestimated, limiting the effectiveness of mitigation measures.



Enrichment Factor (EF) of metals in school settled dust of Agra region during four seasons

7. KEY INSIGHTS FROM OBSERVATIONS

1. High Particulate Matter Across All Settings

- **$PM_{2.5}$ and PM_{10} levels consistently exceeded WHO guidelines** in Thane, Khopoli, Kalyan, Thane, Panvel Mira Bhayander, Ambernath, Bhiwandi, Dadar, Khar, Bandra, Thane, Kurla, Delhi & Gurugram, regardless of ventilation type.
- In **Delhi and Gurugram,** the NV classrooms in winter recorded very high particulate pollution, with $PM_{2.5}$ reaching upto **522 µg/m³** indoors.
- **MMR NV classrooms** often had *higher indoor than ambient* particulate levels, particularly in **Apr–Jun**, due to **dust infiltration**.

2. Seasonal Worsening in Nov-April

MMR:

- $PM_{2.5}$ rose from an average of **49 µg/m³ (Apr–Jun)** to **66 µg/m³ (Nov–Jan)** indoors.
- PM_{10} increased from ~**220 µg/m³** to **236 µg/m³** indoors.
- Biggest jumps observed in **Dadar** ($PM_{2.5}$ from ~31 to ~103 µg/m³) and **Bandra** (PM_{10} from 184.99 to 532.71 µg/m³) due to various construction activities and traffic.

Delhi & Gurugram: Winter spikes were even more pronounced, driven by **seasonal smog and reduced ventilation**.

3. Ventilation Trade-Offs

Naturally Ventilated Classrooms:

- Better CO_2 levels in maharashtra classrooms below 700 ppm, but poor PM control due to unfiltered outdoor air.
- In Delhi & Gurugram, similar observation of extreme PM with even CO_2 higher in some classrooms

Mechanically Ventilated Classrooms:

- Delhi & Gurugram MV classrooms with AC + filtration kept $PM_{2.5}$ low (<15 µg/m³), but CO_2 control depended heavily on outdoor(fresh) air intake.

4. Location-Specific Hot-spots

- **MMR high-risk zones: Bandra, Panvel, Dadar** – consistently reported high PM readings of both $PM_{2.5}$ and PM_{10}.
- **Delhi & Gurugram high-risk periods:** Delhi & Gurugram was a hot-spot during the Winter months, hence in NV classrooms – $PM_{2.5}$ was at critical levels.

This study assessed air quality across multiple cities, covering both government-funded and privately-funded schools. **NV** classrooms were found to be the most impacted, with high $PM_{2.5}$ exposure and elevated CO_2 levels resulting from limited ventilation at places. **MV** classrooms provided better CO_2 control through consistent airflow; however, they remained highly polluted in terms of $PM_{2.5}$.
Interventions in NV classrooms—such as the use of indoor air filters—successfully reduced $PM_{2.5}$ concentrations, but CO_2 levels rose beyond acceptable limits due to inadequate ventilation. In contrast, classrooms with **hybrid systems** or **MV Classroom** combined with filtration effectively maintained both $PM_{2.5}$ and CO_2 within safe ranges.

Notably, hybrid classrooms achieved a balance between ventilation and filtration, keeping air quality within WHO's recommended thresholds: $PM_{2.5}$ below 15 µg/m^3 and CO_2 under 1000 ppm. **These findings underscore the need for integrated solutions that ensure both clean air and adequate ventilation in learning environments.**

8. ACTION PLAN FOR STAKEHOLDERS

8.1 School Administrators

- Monitor and track indoor air quality (IAQ) regularly using reliable monitors in schools.
- Invest in effective solutions such as upgraded filtration, and well-designed ventilation systems.
- Allocate dedicated budgets for IAQ improvement, maintenance, and filter replacements in schools.
- Provide staff training on IAQ management, emergency response during pollution spikes, and preventive maintenance in schools.
- Avoid harmful cleaning agents that release volatile organic compounds (VOCs) into the air.

8.2 Teachers

- Maximize fresh air exchange during class breaks or low outdoor pollution periods in classrooms.
- Incorporate clean air awareness into lessons, encouraging students to understand and value good IAQ.
- Observe and report any recurring signs of discomfort among students, such as headaches, coughing, or fatigue.

8.3 Parents

- Advocate for healthy air in schools by engaging with administrators and participating in IAQ committees or forums.
- Maintain a low-pollution home environment by reducing indoor smoking, incense use, and other particulate sources.
- Empower and generate awareness in children to speak up if they experience discomfort in classrooms, fostering a proactive health culture.

9. COMMUNITY ENGAGEMENT ON SCHOOL AIR QUALITY PRACTICES

Do's	Don'ts
Ensure proper ventilation with openable windows and exhaust fans.	Avoidsealing windowsifno other ventilation is available.
Open windows when outdoor air quality is good to prevent CO_2 buildup.	Don't block air vents with furniture, posters, or curtains.
Install and operate exhaust fans at least 30 minutes before and after school hours.	Avoid overcrowding in class, as it reduces air circulation and increases CO_2 levels.
Regularly dust, sweep, and mop classrooms twice a day.	Avoid using strong chemical cleaners or aerosols that release toxic fumes.
Use low-VOC paints, cleaning agents, and furniture.	Avoid air fresheners or strongly scented products that emit VOCs.
Opt for hard flooring, which is easy to clean.	Avoid carpets, as they trap dust and allergens.
Use low-dust materials like whiteboards and dustless chalk.	Avoid materials that generate excessive dust, such as traditional chalkboards.
Educate staff and students on IAQ best practices.	Don't delay fixing ventilation.
Regularly service HVAC systems and replace filters as recommended.	Avoid air purifiers that generate ozone, which is harmful to health.
Install air quality sensors to monitor CO_2, particulate matter, and humidity.	Don't neglect air quality monitoring, as issues may go unnoticed.
Incorporate air-purifying indoor plants like spider plant, and golden pothos.	Don't overwater plants, as stagnant water can breed mosquitoes.
Cover playground soil with grass and sprinkle water to reduce dust.	Avoid vehicle idling near classrooms to prevent exhaust fumes from entering.
Create green barriers with trees or green walls to filter outdoor pollutants.	Don't burn dry leaves or solid waste; use sustainable waste management practices.

9. CALL FOR ACTION

- Improving indoor air quality (IAQ) in schools is not just a facility upgrade – it's an investment in the health, well-being, and academic success of future generations. Even simple, targeted interventions can transform classrooms into healthier, safer, and more productive learning spaces.
- Achieving this vision requires active collaboration between school administrators, teachers, and parents. By working together, we can create environments where every child can breathe clean air and thrive.
- We are committed to conducting deeper, data-driven studies to better understand IAQ conditions and identify the sources of pollutants across various school micro-environments. This knowledge will guide smarter, more impactful solutions – ensuring that clean air becomes a standard, not a privilege, in every classroom irrespective of rich or poor status of the community.

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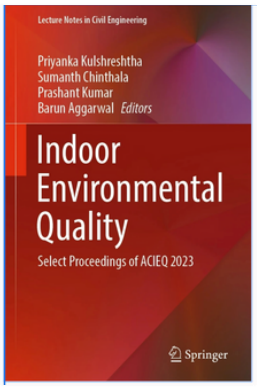
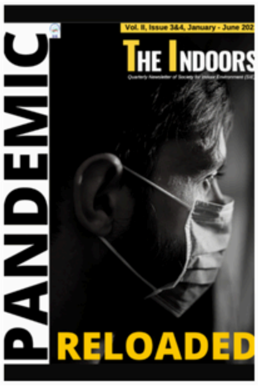
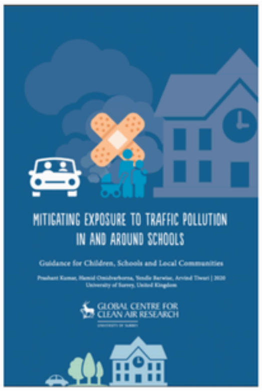
Publications





IEQ 2024 Compendium



Past Events

IEQ 2025 Event

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